Title:

NEOGENE EVOLUTION OF ISOLATED CARBONATE PLATFORMS IN THE SOUTHERN MOZAMBIQUE CHANNEL (SW INDIAN OCEAN) - IMPACT OF TECTONIC AND REJUVENATED VOLCANISM

Authors: Courgeon, S.[1,2], Jorry, S.J.[2], Jouet, G.[2], Camoin, G.[1], BouDagher-Fadel, M.K.[3], Bachèlery, P.[4], Caline, B.[5], Boichard, R.[5], Révillon., S.[6], Thomas, Y.[1], Thereau E.[1], Guérin, C.[1],

[1]Aix-Marseille Université, CNRS, IRD, CEREGE UM34, 13545 Aix-en-Provence, France

[2]IFREMER, Institut Carnot Edrome, Unité Géosciences Marines, 29280 Plouzané, France

[3]University College London, Earth Science, 2 Taviton St, London WC1H 0BT, UK

[4]Laboratoire Magmas et Volcans, Observatoire de Physique du Globe de Clermont-Ferrand, 6 avenue Blaise Pascal, 63178 Aubière, France

[5]TOTAL Exploration and Production, CSTJF, Avenue Larribau, 64000 Pau, France

[6]SEDISOR/UMR 6538, Laboratoire Domaines Océaniques, IUEM, 29280 Plouzané, France

[7]Department of Earth Science, Rice University, Houston, Texas 77005, USA

*Corresponding author: simon.courgeon@gmail.com

Abstract

The southern central Mozambique Channel is characterized by a 100km-long volcanic ridge hosting two guyots (Hall and Jaguar banks) and a modern atoll (Bassas da India) fringed by a broad terrace. Dredge sampling and geophysical acquisitions carried out during recent oceanographic cruises (PTOLEMEE, PAMELA-MOZ1, PAMELA-MOZ4) revealed that those flat-top seamounts correspond to karstified and drowned shallow-water carbonate platforms widely covered by volcanic morphologies and material. Microfacies and well-constrained datings indicate that those carbonate platforms, characterized by fauna assemblages dominated by corals, larger benthic foraminifera, red and *Halimeda* algaes, developed in tropical settings during Miocene times. End of carbonate production and shallow-water platforms drowning is recorded by the deposition of outer neritic limestones during Pliocene. Overall, this drowning episode seems associated to (1) rejuvenated volcanic activity typified by the establishment of wide submarine lava flow complex and (2) extensional tectonic responsible for well-developed normal fault network dividing the flat-top seamounts into distinct structural blocks. Explosive volcanic activity also took place into carbonate platforms and was responsible for crater(s) formation and deposition of tuff layers including carbonate fragments. During Late Neogene, shallow-water carbonate production resumed in colonizing highest topographies inherited from tectonic deformation and volcanic production. Latest carbonate development phases ultimately lead to the formation of Bassas da India atoll. The geological history of South Mozambique Channels isolated carbonate platforms represents a new case illustrating the major impact of active tectonic and volcanism on long-term (millions years) evolution of carbonate platforms. This research is co-funded by TOTAL and IFREMER as part of the PAMELA (Passive Margin Exploration Laboratories) scientific project.

1. Introduction

Understanding the processes controlling the long-term (millions to tens of millions year) evolution of shallow-water carbonate platforms represents a major scientific question and has been the subject of numerous studies during the last decades. Onset, growth and demise of tropical carbonate platforms are controlled by numerous parameters essentially including: (1) biota and skeletal grain production, (2) eustatism, (3) tectonics and volcanism and (4), environmental conditions, especially⎯climate, oceanography and clastic/nutrient input. However, active debates remain on respective impacts of these factors and on possible interplays.

Development of shallow-water carbonate platforms in active tectonic settings are frequently marked by various interactions with structural deformation and volcanic activity (e.g. Fernandez-Mendiola and Garci-Mondejar, 2003). Faulting and differential tectonic movements are often involved in carbonate platform segmentation and in diachronous developments, subaerial exposures or drownings (e.g. Wilson, 2000; Bachtel et al., 2004, Ruiz-Ortiz et al., 2004; Lehrmann et al., 2007; Meunier et al., 2014; Courgeon et al., 2016a). Sensitive to light and temperature, shallow-water carbonate systems commonly settle or backstep on topographic high inherited from tectonic activity (e.g. Lü et al., 2013, Wu et al., 2014). Smothering carbonate biota and increasing water turbidity, volcanic eruptions and associated material are sometimes invoked to explain shallow-water carbonate platform terminations (e.g. Wilson, 2000). However, shallow-water carbonate producers can also adapt to volcanic settings, modifying their shape and morphology to accommodate high volcaniclastic influx (Wilson and Lokier, 2002) or colonizing volcanic reliefs in subsequent transgressive settings (e.g. lava deltas, Puga-Bernabéu et al., 2016). Isolated carbonate platforms and reefs settled on volcanic edifices can be affected by –faulting and rejuvenated volcanism (e.g.

Bergsen, 1995; Staudiguel and Clague, 2010). For instance, during its Aptiean-Albian evolution, the MIT guyot shallow-water carbonate platform underwent major explosive eruptions which produced a large amount of ejecta and intermixed carbonate and volcanic clasts (Martin et al., 2004). Despite these devastating events, carbonate sedimentation subsequently resumed before final drowning during latest Lower Cretaceous (Ogg., 1995).

Throughout the Neogene, widespread and numerous (sub)tropical isolated shallow-water carbonate platforms flourished in the Indo-Pacific realm. During this period, global shallow-water carbonate factory was dominated by red algaes and corals but also, while they were not as prolific as during Eocene and Oligocene, by larger benthic foraminifera (LBF; Pomar and Hallock, 2008). In SE Asia, Late Cenozoic shallow-water carbonate platforms and reefs extensively developed in active tectonic settings and their evolutions were highly influenced by structural movements (Bachtel et al., 2004; Sattler et al., 2009, Wu et al., 2014). On the Marion Plateau (NE Australia, Eberli et al., 2010), along northwest shelf of Australia (Saqab and Bourget., 2016) or in the Maldives Archipelago (Belopolsky and Droxler, 2004; Betzler et al., 2009; Lüdmann et al., 2013), Neogene evolutions of isolated carbonate platforms and build-ups were primarily controlled by eustatic sea-level fluctuations and major changes in climate and oceanography. In the Pacific Ocean, despite common periods of sub-aerial exposure, numerous Miocene shallow-water carbonate platforms have kept on developing until present-day to form modern pacific atolls (e.g. Midway Atoll, Major and Matthews., 1983; Enewetak and Bikini Atolls, Lincoln and Schlanger., 1991; Mururoa Atoll, Aissaoui and Kirschvink, 1991, Buigues, 1997). Presently, no case study relates Neogene evolution of isolated shallow-water carbonate platforms marked by active tectonic and rejuvenated activity of volcanic substratum.

In the southern central part of the Mozambique Channel, a 100 km long volcanic ridge hosts both drowned shallow-water carbonate platforms (Hall and Jaguar banks) and a modern

atoll (Bassas da India) fringed by a broad carbonate terrace (Courgeon et al., 2016b). The submerged isolated carbonate platforms, dated Neogene, are marked by well-developed faults networks and widespread volcanic morphologies that suggest important geodynamic activity and complex interactions during their evolution (Courgeon et al., 2016b). Based on multi-resolution seismic data set, high resolution bathymetry DEMs, submarine videos and dredge samples, this study aims at: (1) detailing modern Bassas da India atoll geomorphology, (2) describing architecture, age and nature of drowned carbonate platforms, (3) illustrating interaction between carbonate production and tectonic/volcanic activity, and (4) Proposing a model for differential evolutions, discussing drowning causes and inheritance for modern atoll growth.

2. Geological Settings

The Mozambique channel is a broad triangular seaway located between the Madagascar continental slope to the east and the Mozambique continental slope to the west (Fig. 1A). Its formation results from break-up of West (South America and Africa) and East (Madagascar, India and Australia) Gondwana in the Middle Jurassic (e.g. Gaina et al., 2013). This rifting period was accompanied by the relative motion of Madagascar- with respect to Africa (~ 165-120 Ma) trough a major transform fault presently represented by a 1200 km long bathymetric high called the Davie Ridge (DR, e.g. Bassias, 1992; Coffin and Rabinowitz, 1987, Fig. 1A). During Late Cretaceous, Marion hotspot activity and break-up between Madasgcar and India were marked by important onshore volcanism (e.g. Storey et al., 1995;- Torsvik et al., 2000) but also, potentially, by offshore volcanism north of Madagascar (Courgeon et al., 2016b). During the late Cenozoic, the MC Channel was marked by renewed geodynamic activity associated, for instance, with volcanism at the Comores archipelago (Michon et al., 2016) and in the south MC (Courgeon et al., 2016b), and with extensional deformation along the Davie

Ridge (Courgeon et al., 2016b). Timing, location and nature of these tectonic episodes suggest they are linked to development and propagation of East African rift system (Salman and Abdula, 1995; Chorowicz, 2005; Kusky et al., 2010; Mc Gregor, 2015; Courgeon et al., 2016b, Michon et al., 2016).

Nowadays, the MC hosts several isolated carbonate platforms called the "Iles Eparses" (Fig. 1B). These shallow-water platforms are characterized by typical tropical neritic carbonate production dominated by corals, benthic foraminifera, green algae and mollusks (Battistini, 1976, Jorry et al., 2016, Prat et al., 2016). The Iles Eparses isolated carbonate platforms are characterized by asymmetrical geomorphologies polarized by dominant winds, and evolved under different hydrodynamics settings locally responsible for sand dunes development and migration (Prat et al., 2016). Emerging platform areas are typified by karstified fossil reefs dated from the last interglacial (Guillaume et al., 2012; Jorry et al., 2016). On the Glorieuses Archipelago, carbonate platform flank exhibits successive submerged terraces interpreted as resulting from last deglacial sea-level rise (Jorry et al., 2016).

The south central part of the Mozambique channel is characterized by a seamount chain consisting of two guyots, the Hall and Jaguar banks, and of the atoll of Bassas da India characterized by a 12 km wide submarine terrace (Fig. 1B). The submerged flat-top edifices, lying at hundreds of meters water depth (-800m to -120m), correspond to drowned Neogene shallow-water carbonate platforms that probably colonized volcanic reliefs during Early Miocene (Courgeon et al., 2016b). These tropical carbonate platforms, characterized by successive terraces levels, are marked by well-developed normal faults (Fig. 1B) and their tops are covered by volcanic reliefs and material. Long-term evolution of these Neogene carbonate platforms, including drowning episodes, was seemingly influenced by tectonic an volcanic activity in connection with EARS development (Courgeon et al., 2016b). However architecture of these carbonate platforms is unknown and timing and processes involved in interaction with

tectonic and volcanism remain obscure. Moreover, Jaguar Bank remains undated and no model has been proposed to explain differential evolutions and final growth and Bassas da India modern atoll.

3. Material and methods

This work is mainly based on geophysical and geological data acquired during the 2014 PTOLEMEE and PAMELA-MOZ1 cruises onboard the RV *L'Atalante* and during the 2015 PAMELA-MOZ4 cruise on board the RV *Pourquoi pas ?*. These cruises were carried out as part of the PAMELA (Passive Margin Exploration Laboratory) research project. Geological interpretations presented in this study result from the combined analysis of (1) Multi-resolution seismic profiles, (2) bathymetry DEMs and associated slope maps, (3) Dredged rock samples, and (4) underwater videos.

Seismic data set was collected using the seismic acquisition system SEAL HR 5.2 P18. For conventional seismic (CRUISE-SRxxx), data were acquired using a 24 traces and 600m streamer with a 12.5m inter-trace interval. Conventional seismic processing consists of stacking and migration at constant velocity. For high-resolution seismic (CRUISE-HRxxx), data were acquired using 72 traces and 930m streamer with a 6.25 inter-trace interval. For HR seismic, processing was conducted, when possible, using velocities analysis. Locally, seismic data used in this study suffers from low penetration and disturbed signal induced by direct contact on the seafloor between seawater and rocky seabed. Seismic stratigraphy has been conducted using coupled analysis of both, HR and conventional, seismic data sets. Conventional seismic was mainly used to understand general architecture of studied guyots whereas HR seismic was studied in order to details superficial formations and to better asses geological process involved in their later evolutions.

Bathymetric data were acquired with Kongsberg EM122 and –Kongsberg EM 710 multibeam systems. Data were processed using CARAIBES^{TM} v4.2 software and were gridded into 20m, 10m and 5m resolution DEMs (WGS84). Geomorphological and morphometric analysis were carried out with ArcGIS^{TM} v10.3 using customized Mercator projections. Underwater videos and pictures were conducted with the SCAMPI camera system (IFREMER) and were used to better constrain submarine geomorphologies. To interpret Bassas da India atoll geomorphology we used laser bathymetry and topography (LiDAR, 2009 and 2011, Litto3D program) coupled with satellite imagery (2009, GoogleEarth, DigitalGlobe).

Rock samples were collected using rock (CRUISE-DRxx-sample), Niwa (CRUISE-DNxx-sample) and Warren (CRUISE-DWxx-sample) dredges. The petrographic analysis combines hand sample and thin section observations. The interpretation of carbonate depositional environments relies on faunic assemblages and depositional textures and was supplemented by diagenetic observations in order to evidence reworking, alteration and potential emersion periods. Dating of carbonate samples is based on (1) planktonic and larger benthic foraminifera biostratigraphy (BouDagher-Fadel, 2008, 2013, 2015; Supplementary 1) and (2) strontium isotopic stratigraphy (SIS; McArthur, 2012; Supplementary 2); for details on dating methods, see Courgeon et al., 2016b. Ages of younger carbonate samples have been estimated by radiocarbon dating (Libbey, 1952).

4. Results

4.1. Geomorphology of Bassas da India atoll

Bassas da India corresponds to a roughly circular atoll about 10km in diameter (Fig. 2B). Its NE margin is characterized by a large embayment probably inherited from past episodes of seamount flank collapses (Courgeon et al., 2016b). Its reef rim, enclosing a shallow lagoon (<10m water depth), can be divided into three morphological classes (Fig. 2A): (1) the *reef front*, gently deeping seaward in the wave breaking zone; (2) the *reef crest*, corresponding to the most elevated topography of the modern atoll and marked by the highest reefal density on satellite imagery (Fig. 2C); and (3), the *back reef*, localized just behind the reef crest and typified by more scattered reefal constructions and by sandy material. The transition between reef an lagoon is characterized by a well-developed, cambered and light belt interpreted as the *sand apron*. Bassas da India reef rim is much larger on southern margin (up to 1km) than along northern one (<300m) whereas inverse relationships are observed for back-reef domain and sand apron (Fig. 2A). Overall, these differential developments attribute to Bassas da India geomorphology a clear asymmetry between southern margin and northern margin. Along northern marin, reef crest is intersected by channel systems interpreted as *tidal fairways* allowing tidal water exchanges between lagoon and open sea (Fig. 2A & 2C). In parallel, in the northern sector of the atoll, sand apron and back reef domains are locally marked by positive, lobate and elongated morphologies, bright on satellite imagery and interpreted as sand *shoals/dunes* systems. The latter are typified by well-developed crests exhibiting typical sinusoidal shapes. Bassas da India lagoon (and locally sand apron) is punctuated by numerous isolated reefal constructions corresponding to *patch reefs* and *pinnacles* (Fig. 2A). Finally, below the reef front, the overall steep flank marked by spurs and grooves features correspond to the *fore-reef* domain. While bathymetry coverage is not complete between atoll rim and deeper bathymetry DEM (Fig. 2A), Bassas da India atoll southeastern slope is typified by a narrow terrace morphology lying at 120m water depth.

4.2. Seismic stratigraphy and sea-floor geomorphology

<u>4.2.1.Seismic stratigraphy</u>

Seismic profiles realized along the Hall Bank, the Jaguar Bank and Bassas da India terrace (Fig. 3, 4 & 5) are characterized by two major seismic facies (SF1 and SF2) and by a minor one (SF3) restricted to Bassas da India. While their respective resolutions involved differences (e.g. penetration), both conventional (Fig. 3) and high resolution (Fig. 4 & 5) seismic data sets are typified by these three seismic facies. The first seismic facies (SF1) is overall characterized by low to moderate amplitudes, semi-continuous to discontinuous reflections and by chaotic to wavy internal configurations (Fig. 3-5). Locally, SF1 is marked by horizontal and oblique more continuous reflections that respectively form aggrading (e.g. Fig. 3A) and prograding (e.g. Fig. 3B) patterns. This seismic facies, dominating studied profiles, is rapidly attenuated in depth where seismic reflections are lost and locally replaced by homogeneous chaotic facies sometimes marked by sub-horizontal blurry horizons that most likely correspond to seismic artifacts (e.g. Fig. 3A). While observable thickness of SF1 is sometimes very low, as for instance along high-resolution seismic profiles (Fig. 4A), it can reach up to 200ms on conventional seismic data set (Fig. 3C). The second seismic facies (SF2) is characterized by moderate to high amplitude, semi-continuous to discontinuous reflections (Fig. 3-5). It is typified by various geometries including, horizontal, oblique and chaotic reflections. SF2 is observed in the most superficial part of the seismic profiles and seems to cover deeper SF1 reflections (Fig. 3-5). Along some platforms edges (Fig. 3A & 3B), SF2 high-amplitude and oblique reflections form seaward prograding wedges. Vertical thickness of SF2 ranges from less than 10ms up to 200ms (Fig. 3A & 4A). The third seismic facies (SF3) is only observed at Bassas da India (Fig. 3C & 5). SF3 is characterized by low to moderate amplitudes and continuous to chaotic reflections. Overall, SF3 seems to cover and fill reliefs formed by SF1 and SF2, however, high amplitudes reflections and continuous SF2 reflections are locally

inter-bedded (Fig. 5). Finally, top of Bassas da India terrace is partly covered by undulating geometries associated to SF3 and that can reach up to 20ms high (Fig. 3C & 5).

SF1 and SF2 are separated by an irregular seismic unconformity, U1 (Fig. 3-5). While sometimes U1 is marked by a relatively continuous peak (Fig. 3B, 4C & 4D), it is also frequently only typified by reflections terminations and abrupt seismic facies change (e.g. Fig. 3A, 4A & 4B). U1 is mainly marked by onlaps of SF2 reflections (Fig. 3A, 3C, 4A & 4B) but is also characterized by toplaps (Fig. 3B & 4C), dowlaps (Fig. 4B) or concordance (Fig. 4D). U1 is typified by a very rugged topographies that locally stresses well-developed depressions (Fig 3-5). These depressions, 100m to 1500m wide, can reach more than 200ms in depth (e.g. Fig. 3A & 4A). Locally, depression bottom is not clear on seismic profiles and U1 cannot be continued at their base (Fig. 3A, 3C & 5). They are mostly filled by high-amplitude onlapping SF2 reflections but also exhibits complex geometries marked by downlaps. Along Bassas da India terrace, the main depression is marked at this bottom by high amplitude SF2 reflections but is also filled by SF3 reflections (Fig. 5C & 5). While most pits observed on seismic data seem entirely filled, on the Hall bank, one depression looks only partly filled and forms along the seafloor a flat-bottom negative topography (Fig. 3A). Otherwise, seafloor is frequently marked by SF2 reflection toplaps indicating post-deposition erosion (e.g. Fig. 3A, 4A & 4D).

Northeast of the volcanic ridge, basinal sedimentary layers are marked by well-developed normal faults that frequently reach the seafloor (Fig. 6A). Along the Jaguar Bank, normal faults undercut the overall flat-top seamount in distinct tilted panels typified by vertical offsets up to 100ms (Fig. 1, 3B & 7B). While the Hall Bank structure does not seem to be affected by major tectonic deformation (Fig. 1, 3A & 7A), Bassas da India southern terrace is marked by various normal faults inducing collapsing structures along its south eastern margin (Fig. 1, 3C, 5 & 7C). Observed along seismic profiles as well as on the seafloor on bathymetry DEMs of the study area (Fig. 1-7; Courgeon et al., 2016b), these normal faults form a clear SW-

NE extensional deformation network (Fig. 6B) responsible for major vertical offsets along South MC seamounts and platforms.

4.2.2. Surface geomorphology and seismic interpretations

South MC drowned carbonate platforms are partly covered by rugged and positive morphologies corresponding to volcanic material (Fig. 7; Courgeon et al., 2016b). On the Jaguar Bank (Fig. 7B), for instance, smooth surface of the drowned carbonate platform is covered by fingered and flowing features interpreted as lava flows and exhibiting well preserved lava channel and levees morphologies (Fig. 8A). Underwater pictures collected along these morphologies confirm direct contact between rough and dark volcanic rocks (Fig 8C & 8D) marked by typical polygonal fracturing network (see Yamagishi, 1991) and, bright and flat carbonate slabs (Fig. 8B). Volcanic reliefs are locally marked by elongate channel-shapes depressions (Fig. 7B) that seemingly correspond to lava channels and/or tubes (e.g. Fornari, 1986). Geomorphology of south MC flat-top seamounts suggests that SF1 corresponds to carbonate platform deposits and that SF2 corresponds to volcanic material. Typified by overall low amplitudes and chaotic to wavy reflections (Fig. 3-5), SF1 presents typical characteristics of carbonate platform deposits (e.g. Bachtel et al., 2004; Burgess et al., 2013). Overlying SF1, SF2 is characterized by higher amplitudes and locally parallel reflections (Fig. 3-5) that would thus correspond to volcanic deposits and lava flows observed on tops of drowned carbonate platforms (Fig. 7 & 8). The seismic unconformity U1 is interpreted as the contact between volcanic material and underlying carbonate deposits. Undulating geometries observed along seismic profile of Bassas da India (Fig. 3C & 5) are associated in surface geomorphologies to thin and elongate positive morphologies (Fig. 7C) interpreted as sand ridge system partly covering volcanic reliefs. Nature of SF3 reflections remain elusive, they might correspond to carbonate sediments, volcanic material or mixed deposits.

The interpretation of SF1 as carbonate platform deposits suggest that topographic irregularities and depressions observed along U1 (Fig. 3-5) could correspond to karstic features, implying periods of subaerial exposure. Inherited reliefs were subsequently filled and covered by volcanic material (SF2). Otherwise, the Hall Bank top is typified by a 1300m wide, circular and flat-bottom depression which is 40m deep compared to the surrounding sea-floor (Fig. 9A). This depression is discontinuous in subsurface, forming a partially filled conic feature whose base cannot be observed (Fig. 3A). Its bottom is characterized by a central pit and by concentric positive ridges (Fig. 9A) associated to very dark outcrops interpreted as volcanic rocks (Fig. 9D). These observations might imply that this depression results more from explosive volcanic activity. In parallel, smaller and superficial closed to semi-enclosed depressions are also observed on tops of the Hall Bank (Fig. 7A). Finally, summits of flat-top seamounts are typified by extensive pebbles fields (Fig. 9B & 9C) suggesting, in concordance with seismic data set (SF2 toplaps), erosion events after volcanic production.

The summit of the Jaguar Bank (Southern extremity, Fig. 10A) is marked by rounded, overall flat and smooth morphology that seems to be sited on faulted and rugged antecedent volcanic reliefs. Culminating at 117m water depth, this 2km-wide morphological feature present typical characteristics of a carbonate build-up. Along Bassas da India Southern flank, the wide drowned carbonate platform covered by volcanic products and bounded by major normal faults, is typified toward modern atoll by successive rounded and flat-top morphologies interpreted as subsequent carbonate terraces (Fig. 7C; Courgeon et al., 2016b).

4.3. Dredge samples analysis

4.3.1. Carbonate platform flanks

On the southwestern flank of the Hall Bank (DR18, see location on Fig. 1B), two rock samples have been recovered. MOZ1-DR18-01 (Fig. 11A) correspond to a skeletal packstone

typified by large (several millimeters wide) corals fragments often coated by red algae and encrusting foraminifera layers. Also marked by abundant LBF (e.g. *Lepidocyclina* sp., *Cycloclypeus* sp.), MOZ1-DR18-01 has been dated Burdigalian (Tab. 1; by both SIS (16.29 +/- 0.10 Ma) and foraminifera biostratigraphy (N8a, 17 - 15.9 Ma). MOZ1-DR18-02 corresponds to a grainstone dominated by robust LBF (mainly Miogypsinids, Fig. 11B) and marked by abundant *Halimeda* sp. fragments. SIS and foraminifera assemblages indicate a Langhian age (Tab. 1). Rock sample collected along the southern flank of the Jaguar Bank (MOZ4-DR05-01, see location on Fig. 1B & 10A) corresponds to skeletal packstone also marked by wide encrusted corals grains (Fig. Xx), *Halimeda* sp., LBF (e.g. *Katacycloclypeus* sp., *Lepidocyclina* sp., *Sphaerogypsina* sp., Fig. Xx) and red algae (Fig. 11C & 11D). While slight differences are observed, both dating methods indicate that MOZ4-DR05-01 is Middle to Serravallian to Tortonian in age (Tab. 1). Two rock samples have been collected along Bassas da India southeastern flanks (MOZ1-DR20, see location on Fig. 1B & 7C). MOZ1-DR20-01 (Fig. 11E) corresponds to a skeletal packstone marked by abundant planktonic foraminifera, coral fragments ghosts, numerous mollusks (e.g. gastropods) and, occasionally, volcanic clasts. While biostratigraphic interval associated to DR20-01 foraminifera assemblage is quite vague (i.e. Miocene - Pliocene, Tab. 1), SIS gives a Tortonian age (8.48 +/- 0.49 Ma). Moldic porosity observed in MOZ1-DR20-01 is often typified by geopetal infilling made of crystalline and silty sediments without skeletal particules (Fig. 11F). These features are called crystal silts (or vadose silts) and typically results from freshwater vadose diagenesis during periods of subaerial exposure (e.g. Dunham, 1969; Flügel, 1982). MOZ1-DR20-01 is also typified by reworked *Miogypsina* LBF that are characteristic of Early to Middle Miocene in age (BouDagher-Fadel, 20123). The second rock sample collected along Bassas da India southeastern flank (MOZ1-DR20-02, Fig. 11G) corresponds to a skeletal packstone dated Messinian by both SIS and biostratigraphy (Tab. 1).

4.3.2. Carbonate platforms tops

In the NE domain of the Hall Bank top, dredge MOZ1-DW05 (see location on Fig. 1b & 7A) has collected a wide diversity of both volcanic and carbonate rock samples in the form of pebbles (Fig. 9B & 9C). These pebbles are very frequently coated by thin (<10 mm) and dark Fe-Mn crusts (Fig. 9C, Courgeon et al., 2016b). MOZ1-DW05-C1 correspond to a dolomitized, coral-rich and perforated limestone reworked into a packstone of planktonic foraminifera (Fig. 12A). While dolomitized limestone remains undated, SIS and foraminifera biostratigraphy indicate that subsequent packstone is Early Pliocene in age (Tab. 1). MOZ1-DW05-C2 consists of a –packstone of planktonic foraminifera included into a dark rock including heterogeneous mineral and carbonate fragments and interpreted as a tuff (Fig. 12B). The packstone is dated Pleistocene by both SIS and biostratigagraphy (Tab. 1). The latter includes dark volcanic clasts and is typified by laminated bright crusts network that correspond to phosphatization features. MOZ1-DW05-10 mainly consists of heterogeneous, vesicular, bright and angular fragments that correspond to coarse ashes and lapillis (Fig. 12E). Some volcanoclasts are fringed by thin (<0.1 mm) dark layers (Fig. Xx); they are called armored lapillis. In parallel, this volcanic tuff consists of brownish and rounded clasts including carbonate skeletal grains (e.g. red algae and Echinoids, Fig. 12E) and interpreted as carbonate fragments. On the Western area of the Jaguar Bank, dredge operations (MOZ4-DN02-02, See location on Fig. 1B & 7B) have collected heterogeneous limestone samples. MOZ4-DN02-02c (Fig. 12D) corresponds to dolomitized grainstone reworked into a wackestone of planktonic foraminifera. The grainstone consists of abundant red algaes, Halimeda sp., corals and LBF and is characterized by Miogypsina forms indicating an early to Middle Miocene age. Infilling porosity, the wackestone is dated Pliocene (Tab. 1). MOZ4-DN02-02c is finally typified by circular, beige to brownish intersecting features associated with a radial internal structure, spheroidal aggregates and by a central cavity (Fig. 12D). They are interpreted as *Microcodium*

fossil, -such structures corresponds to biologically controlled calcification pattern that typically develop in subaerial environments (e.g. Košir, 2004; Kabanov et al., 2008). MOZ4-DN02-02d (Fig. 12C) corresponds to a skeletal packstone dominated by planktonic foraminifera and including large and reworked coral and algal fragments. Dated Pliocene, this packstone is also marked by brownish alteration features and beige layered crusts (Fig. 12D) corresponding to phosphatization products. Along southern part of Bassas da India southern terrace, dredge operations (MOZ4-DR08, see location on Fig. 1B & 7C) have collected a massive piece of dark microlitic rock (Fig. 12F) corresponding to an altered bloc of lava flow. Associated fracture network is filled first by a wackestone of planktonic foraminifera (MOZ4-DR08-01b, Fig. 12F) dated Early Pliocene (Tab. 1). This first filling is intersected by new fractures filled by a phosphatized packstone of planktonic foraminifera typified by numerous *Halimeda* plates and red algae fragments (MOZ4-DR08-01a , Fig. 12G). Although differences are observed between SIS and biostratigraphy datings (400 kyr gap between SIS and biozone younger boundary, Tab.1), they suggest that MOZ4-DR08_02a is Pleistocene in age.

Finally, dredge operation carried on along the carbonate build-up morphology on the summit of the Hall bank (MOZ4-DR06, see location in Fig. 1B & 10A) has collected well-preserved limestone samples including coral boundstone and *Halimeda* sp grainstones (Fig. Xx). $_{14}$C dating realized on coral and *Halimeda* sp. samples give 13-8 ka ages (Latest Pleistocene - Holocene)

5. Discussion

5.1. Development of Miocene shallow-water carbonate platforms

Previous work– (Courgeon et al., 2016b) supplemented by multi-resolution seismic profiles as well as extended high resolution bathymetry DEMs and new dredge rock samples show that flat-top and flooded seamounts of the southern MC correspond to drowned carbonate platforms. These carbonate platforms are characterized by various terrace levels and abrupt margins frequently incised by large collapsing scares (Fig. 1; Courgeon et al., 2016b). Their distinct overall geomorphologies (size and shape, Fig. 1) are most likely inherited from volcanic edifice geometry during initial colonization by shallow-water carbonate producers (Fig. 13). While seismic dataset locally illustrate thick carbonate sedimentary layers (until 200ms TWT, Bassas da India, Fig. 3C), basal contact with volcanic substratum cannot be observed. Carbonate deposit exhibit both aggrading and prograding configurations (Fig. 3) reflecting typical phases and patterns of carbonate platform development. Overall chaotic and discontinuous aspects of SF1 seismic reflections are characteristics of shallow-water carbonate platform deposits, the latter being often associated with bio-constructions (e.g. reef, Wu et al., 2009) and karstic features resulting from periods of subaerial exposures (e.g. Betzler et al., 2015). Well-developed progradations (SF1, Fig. 3B) on the northern margin of the Jaguar Bank suggest asymmetric carbonate platform growth that could result from southern dominant winds as presently observed at Bassas da India (Fig. 2A; Jorry et al., 2016).

Dredging operation carried along the flanks of the Hall and Jaguar banks and Bassas da India southern terrace (MOZ1-DR18, MOZ4-DR05 & MOZ1-DR20, see location on Fig. 1) have collected skeletal packstones and grainstones broadly dominated by photozoan carbonate grains (i.e. corals, red and green algae, LBF and encrusting foraminifera; Fig. 11 & Tab. 1). Well-constrained datings that combine both foraminifera biostratigraphy and SIS show that shallow-water carbonate platform deposits are Miocene (Tab. 1). Benthic foraminifera LBF fauna is dominated by Miogypsinids miogypsinids (e.g. *Miogypsina*, e.g. Fig. 11B), Nummulitids (e.g. *Cycloclypeus*, *Katacycloclypeus*, *Operculina*; e.g. Fig. 11D),

~~Lepidocyclinids~~ lepidocyclinids (*Lepidocyclina*), Amphisteginids (e.g. *Amphistegina*, Fig. 11G) and various encrusting foraminifera. These assemblages are characteristics of warm and shallow-water environments (BouDagher-Fadel, 2008). LBF frequently present robust forms (e.g. Fig. 11B & 11D) indicating high energy environments (e.g. Hallock and Glenn, 1986, Beavington-Penney and Racey, 2004). Abundance of large hermatypic coral fragments coated by red algae and encrusting foraminifera (e.g. Fig. 11A & 11C) could suggest occurrence of coral reefs. However, lack of clear rim morphologies along seismic profiles (Fig. 3) tend to suggest isolated bioherms and patch reefs more than barrier reefs. Studied Miocene carbonate platforms are also marked by widespread *Halimeda* green algae debris (e.g. Fig. 11B). Halimeda-rich carbonate deposits are commonly found from early Cenozoic up to present-day along tropical reef systems (e.g. Flugel., 1988; Reuter et al., 2012). During Late Miocene in the Mediterranean province, several studies have for instance reported well-developed Halimeda bioherms along shallow-water carbonate platforms slopes (e.g. Bossellini et al, 2001) as well as Halimeda segmented reefs (Bragga et al., 1996,).

Skeletal carbonate assemblages similar to those found in the Southern MC (Tab. 1) have been commonly described in the Indo-Pacific realm during Miocene as, for instance, in the Queensland Plateau (Australia, Betzler and Chaproniere, 1993), in Sarawak (Malaysia, Mihaljevic et al., 2014), in Sulawesi (Indonesia, BouDagher-Fadel., 2002) or in the South China Sea (Sattler et al., 2004). Overall, biotic assemblages of Miocene isolated carbonate platforms typically reflect photo-autotrophic carbonate production system of tropical shallow-water factory (e.g. "T factory", Schlager, 2003). Geomorphological, seismic and petrographic studies suggest that South MC Miocene carbonate platforms corresponded to flat-topped and shallow-water open platforms (sensu Pomar et al., 2012) associated, at least temporarily, with isolated reef complexes. However, relative scarcity as well as large stratigraphic interval of dredge samples collected along studied Miocene platforms prevent detailed depositional model

reconstruction. Moreover, Miocene times were marked by major climatic fluctuations (e.g. Zachos et al., 2001) frequently invoked as responsible for important changes in carbonate platform geometry and production type (e.g. Brachert et al., 1996; Betzler et al., 2012).

5.2. Demise and karstification of Miocene carbonate platforms

Limestone samples collected on tops of drowned Miocene carbonate platforms and terraces are composed of various packstones and wackestones dominated by planktonic foraminifera and frequently including large reworked shallow-water carbonate grains (e.g. coral, red algae, LBF; Fig. 12A, 12C & 12D). Characteristics of pelagic-dominated and outer-neritic carbonate environments, these deposits are typically deposited during and\or after the drowning of the shallow-water carbonate platforms below the photic zone. SIS and bio-stratigraphy analysis indicate they are Early Pliocene to Pleistocene in age (Tab.1).While most of the time, reworked shallow-water assemblages cannot be dated, on the Jaguar Bank (MOZ4-DN02-02c, Fig. 12D), occurrence of *Miogypsina* spp. LBF indicate an Early to Middle Miocene age (BouDagher-Fadel and Price, 2013). Moreover, reworked skeletal components are similar to those observed in Miocene limestones collected along carbonate platforms flanks (e.g. LBF, Coral, Red algae; Fig. 11; Tab. 1). These reworked assemblages are locally marked by extensive dolomitization (Fig. 12A & 12D) but its origin remain obscure. Overall, dating and petrographic analysis carried out on limestone samples collected along flank and tops of drowned carbonate platforms and terraces suggest that end of shallow-water carbonate sedimentation and drowning occurred in the Late Miocene - Early Pliocene time span.

In addition, limestone collected on top of drowned carbonate platforms and terraces are typified by encrusting Fe-Mn mineralization (Fig. 9C, Courgeon et al., 2016b) and widespread phosphatization figures (Fig. 12B, 12C & 12G). These features are characteristic of hardgrounds that typically develop during long periods of non deposition within marine

environment (e.g. Murdmaa et al., 1995; Mangini et al., 1987). Along south MC isolated carbonate platform, and commonly in carbonate depositional sequences, hardgrounds mark then end of shallow-water carbonate sedimentation and form drowning unconformities (e.g. Schlager, 1989; Godet, 2013). Along Cretaceous Pacific guyots, drowning unconformities capping shallow-water carbonate deposits are frequently covered by convex upward and pelagic caps (e.g. Van Waasbergen and Winterer, 1993; Wilson et al., 1998). In the South MC, drowned carbonate platforms do not exhibit cap morphologies and terminal pelagic sedimentation seems very restricted (abundance of reworked shallow-water carbonate grains, Fig. 12). This lack could be explained by the relative young age of south MC guyots and/or by strong currents along their tops preventing accumulation of pelagic sediments. Otherwise, drowned carbonate platforms are widely covered by volcanic material.

In parallel, along seismic profiles, tops of isolated carbonate platforms are marked by a rough surface (U1) punctuated by well-developed and various depressions (Fig. 3-5). These depressions, filled by volcanic material, are locally associated to SF1 erosional reflections terminations (Fig. 3A & 4A) suggesting a post-depositional origin. While volcanic processes can locally be discussed (see section 5.3.), such features are commonly interpreted along shallow-water carbonate platforms as karstic formations (e.g. Van Waaserbgen and Winterer, 1993; Betzler et al., 2015). In parallel, Tortonian packstone collected along Bassas da India southern flank (MOZ1-DR20-01, Fig. 11E) and Pliocene wackestone recovered on the Jaguar bank top (MOZ4-DN02-02c, Fig. 12D) are respectively marked by vadose silts and *Micrcocodium* structures that typically indicate periods of sub-aerial exposures. Overall, roughs karstic reliefs and depressions along U1 as well as meteoric diagenetic features on carbonate samples evidence episodes of subaerial exposure of South MC isolated carbonate platforms during their terminal evolutions.

  5.3. Rejuvenated volcanic activity an tectonic deformation: nature and timing

Drowned Miocene carbonate platforms and terraces of the Southern MC are marked by an extensive volcanic cover (e.g. Fig. 3, 7 & 10; Courgeon et al.,2016b) indicating rejuvenated activity along volcanic edifices acting as substratum for shallow-water carbonate sedimentation. Overall, rugged reliefs observed along guyots tops present morphological characteristics of submarine effusive systems. Rough aspect of the sea-floor on bathymetric DEMs (Fig. 7) reflect typical texture of submarine lava flow morphologies (McClinton and White., 2015). The western realm of the Jaguar Bank is typified by lobate lava flow complexes (see. Gregg and Fink., 1995) that flow and accumulate directly on carbonate platform top (Fig. 8A). On the Hall Bank, volcanic morphologies that seemingly entirely cover carbonate platform, present low reliefs, domed and very rugged morphologies (Fig. 7A) interpreted as inflated lava lobes. Such volcanic reliefs typically develop onto very low slopes during subaqueous basaltic eruptions (see Deschamps et al., 2014). Associated to high-amplitude reflection on seismic profiles, volcanic flows and material filled karstic depressions and can form thick (up to 100ms, Hall Bank, Fig. 3A) prograding wedges along platform margins that present geometrical similarities with lava deltas (e.g. Wright et al., 2012). While no intersecting volcanic features are observed trough carbonate platforms along seismic profiles, probably due to seismic resolution, magmatic material most likely rose and reached the surface trough injection networks (Fig. 13). Shallow and rounded depressions observed along volcanic reliefs on top of the Hall Bank (Fig. 7A) probably results from collapsing events associated to deposition and cooling of volcanic material (e.g. Halliday, 2007; Chadwick et al., 2013). Seismic and geomorphological interpretations are confirmed by submarine pictures (Fig. 8, Courgeon et al., 2016b) and dredging operation that collected various lava flow fragments on top of the Hall Bank (MOZ1-DW05, see location on Fig. 1 & 7A) and a massive lava bloc on top of Bassas da India terrace (MOZ4-DR08, see location on Fig. 1 & 7C). Fractures network

affecting this lava bloc is filled by Zanclean wackestone (3.65 Ma, Early Pliocene, Fig. 12F) suggesting a prior, Late Miocene to Early Pliocene effusive volcanic activity.

Pebbles collected on top of the Hall Bank (i.e. MOZ1-DW05, Fig. 9C) also include volcanic tuffs (e.g. MOZ1-DW05-10, Fig. 12E). These tuff are characterized by coated "armored" lapillis (or accretionnary lapilis, Fig. Xx) that typically result from violent explosive eruptions implying contact between surface or shallow phreatic waters and magma (e.g. Houghton et al., 2015). In addition, volcano-clastic formations also frequently include carbonate fragments (Fig. 12B & 12E) indicating that explosive activity took place in contact with a pre-existing carbonate platform (Fig. 13). Similar volcano-clastic deposits associated with phreatomagmatic magmatic eruptions through carbonate platforms have been reported in the depositionial sequence of the Oman Exotics carbonate platform (Trias, Basile and Chauvet, 2009) and at the MIT Guyot in the West Pacific (Early Cretaceous, Martin et al., 2004). In all cases, this type of eruptions imply well-developed explosive volcanic feature into the pre-existing carbonate platform. It is here proposed, that the large circular depression observed on top of the Hall Bank (Fig.7A & 9A) and whose bottom is not observed on the seismic profil (Fig. 3A) correspond to a phreatomagmatic crater. Conic shape, rounded surface morphology and flat-top bottom represent, moreover, common characteristics of such volcanic explosive features (e.g. Maars-diatreme volcanoes, White and Ross, 2011). No tuff ring (or tuff cone) morphology is presently observed on the sea-floor (Fig. 7A & 9A), it was most likely not deposited or eroded and reworked into abundant pebbles observed and collected on top of the Hall Bank (Fig. 9B).In parallel, volcanoclastic deposits locally include Pleistocene packstone fragments indicating explosive volcanic activity until recent times (Fig. 12B & 13; Tab. 1). Finally, the large and heterogeneously filled depression observed on Bassas da India southern terrace (Fig. 3C & 5) could also result from explosive volcanic activity.

In parallel, south MC seamounts are affected by a dense normal fault network structuring the drowned carbonate platforms in various panels and blocks (Fig. 1, 3B, 3C, 5, 7, 10 & 13; Courgeon et al., 2016b). The different platforms are not affected to the same degree by faulting. While at the Jaguar Bank extensional deformation is responsible for titled panel and horst and graben structures (Fig. 3B, 7B, 10 & 13), at Bassas da India faulting induced successive collapsing structures along its southern flanks (Fig. 3C, 5, 7C & 13). The large terrace morphology of Bassas da India is bounded by two prominent faults escarpments (Fig. 7C) that most likely form a single major fault responsible for the downward shift of this block along Bassas da India southern flank (Fig. 13). At the opposite, the Hall Bank is only typified by rare faults (Fig. 1) that do not seem to affect its structure. Normal faults network frequently intersects lava flow geomorphologies (i.e. Jaguar Bank, Fig. 7B), suggesting that tectonic deformation continued after effusive volcanic activity (until Early Pleistocene ?). As described along other carbonate platforms (e.g. Fernandez-Mendiola and Garci-Mondejar, 2003), faults and associated weakness zones potentially acted as pathways for magmatic material rise during volcanic eruptions. Seismic profiles and bathymetry DEMs show that these faults belongs to SW-NE corridor of extensional deformation continuous on the adjacent basinal deposits (Fig. 6B) and that probably extends regionally. Overall, density of faults and high offsets suggest major and complex vertical movements into this deformation corridor during Late Neogene (Fig. 13). For instance, evidence of subaerial exposure (Microcodium, Fig. 12D) trough limestones samples collected along the Jaguar Bank top (MOZ4-DN02, approx. 550m of water depth, see location on Fig. 7B) suggest minimum subsidence values of 180m.Myr^{-1} from Early Pliocene onwards. More regional studies (Courgeon et al., 2016b) tend to show that tectonic deformation and rejuvenated volcanism as well as initial volcanism responsible for original seamounts edification are associated to development and propagation of the East African Rift System from Late Oligocene onwards (e.g. McGregor, 2015)

5.4. Resumption of shallow-water carbonate production and modern atoll edification

During Late Neogene, at the Jaguar Bank summit, shallow-water carbonate producers colonized a horst structure and form a rounded and small (<2km wide) carbonate build-up that presently culminates at 117m of water depth (Fig. 10A & 13). Dating of coral boundstones and *Halimeda* grainstones collected on top of this edifice (Fig. 10B) suggest that the latter was drowned during terminal Pleistocene - early Holocene (13-8 ka), i.e. during last deglacial sea-level rise (e.g. Clark et al., 2009). Along Bassas da India southern flank, several terrace morphologies are sited on volcanic reliefs capping drowned Miocene carbonate Platforms (Fig. 7C). The first terrace, 250m deep, is interpreted as a part of a Late Pliocene-Pleistocene carbonate platform that collapsed with Bassas da India southern flank along a major normal fault (Fig. 13). Pleistocene carbonate deposits (MOZ4-DR08-01a, Fig. 12G; Tab. 1), filling fractures in lava bloc collected on top of Miocene drowned carbonate terrace and marked by abundant shallow-water skeletal components, could correspond to exports of this carbonate platform. Overhead, another terrace morphology is observed at 120m deep (Fig. 2A, 7C & 13A). This flat-top morphology could correspond to Pleistocene carbonate terrace marking a backstepping episode during atoll growth (e.g. Webster et al., 2009). However, standing at 120m of water depth (i.e. sea-level during last glacial maximum, 17-23 ka; e.g. Clark et al., 2009), this morphology could correspond to an erosional notch induced by wave action or to small reef developing along platform slope during LGM lowstand (e.g. Camoin et al., 2001). Finally, ultimate carbonate growth phase that lead to Bassas da India atoll edification was seemingly limited to highest topographies inherited from extensive tectonic (Fig. 13). Nowadays, Bassas da India southern carbonate terraces are partly covered by sandy deposits forming well-developed ridges (Fig. 3C, 5 & 7C). These sedimentary bodies are most likely fed by material resulting from erosion and skeletal production of modern atoll (Fig. 13) and trapped during their export toward adjacent basin on wide and flat terraces tops.

While Darwin's subsidence-driven model (1842) has been widely accepted to explain origin of bucket structure of modern atolls, more recent study show that these sedimentary edifices result more from (1) biotic self-organization of reef builders (Schlager and Purkis, 2013) and, (2) from Late Neogene high amplitude sea-level fluctuations responsible for alternate phases of reef growth along atoll rim during highstands and dissolution of lagoonal sediments during lowstands (e.g. Toomey et al., 2016). Seemingly settled on a Pliocene-Pleistocene carbonate platform (Fig. 13), Bassas da India modern atoll is also likely associated to topographic inheritance from past history of underlying carbonate platform and reefs. Otherwise, the wide notch along its northeastern edge is inherited from a major failure of seamount flank (Fig. 2A, Courgeon et al., 2016b). Although narrow tidal fairways locally cross the reef along leeward margin, shallow lagoon of Bassas da India is completely enclosed and is marked by well-developed reef perimeters sand aprons (Fig. 2A). As observed along various modern atolls (Purdy and Gischler., 2005), trapping of carbonate sediments and progradation of sands aprons towards atoll center could lead, by terms, to complete filling of the lagoon. Finally, modern geomorphology of Bassas da India atoll is marked a clear asymmetry between northern and southern margins. The overgrowth of southern reef rim and the concentration of sand bodies (i.e. shoals and dunes) and tidal fairways on the northern domain (Fig. 2A) typically reflect windward-leeward polarity caused by southern dominant wind and associated swell. These interpretations are consistent with annual wind statistics on Europa Island, located 120 kilometers SW of Bassas da India (Fig. 1A) and dominated by southern winds (Jorry et al., 2016).

5.5. Controls on differential evolutions and drowning

South MC and shallow-water drowned carbonate platforms and terraces are directly covered by extensive effusive volcanic morphologies and material. Moreover, dating of carbonate deposits that infill fracture network affecting lava block (MOZ4-DR08-01, Bassas da

India, Tab. 1, Fig. 12F) suggests that volcanic activity occurred, at least at Bassas da India, during Early Pliocene times. Volcanic activity appears thus, overall, to be contemporary with drowning of isolated carbonate platform (i.e. late Miocene - Early Pliocene), suggesting that rejuvenated volcanism is involved in shallow-water carbonate platform demise. Evidences of Pleistocene explosive eruptions have also been observed on top of the Hall Bank. Volcanic eruptions can physically smothered shallow-water carbonate producers trough lava flows and deposition of ash layers. Otherwise, volcanic ash components tend to enhance surface-water productivity and nutrient input, reducing sun-ligh penetration and promoting heterotrophic organisms development at the expense of autotrophic reef builders (e.g. Houk, 2011).While volcanic activity is overall detrimental to shallow-water carbonate producers (e.g. Wilson, 2000; Houk, 2011), shallow-water carbonate producer frequently demonstrate the ability to adapt. For instance, In Indonesia, reef communities recover promptly (i.e. 5 years) after effusive eruption by colonizing lava flow (Tomascik et al., 1996). Rejuvenated volcanism was coupled with sustained extensional tectonic deformation responsible for major collapse structures and high offset normal fault development along south MC isolated carbonate platforms (Fig. 13). This NW-SE trend regional deformation was seemingly involved in drowning of Miocene shallow-water carbonate platforms. Outpacing carbonate accumulation rates, rapid increase of accommodation provoked by tectonic subsidence is frequently implied in drowning of shallow-water carbonate platforms evolving in active tectonic settings (e.g. Wilson 2000, Wu et al., 2014). Overall, our result suggest that drowning of Miocene shallow-water carbonate platforms of the southern MC was primarily triggered by volcanic activity and tectonic deformation.

The three different carbonate platforms most likely appear and start to develop during the same period, i.e. during the Late Oligocene - to Early Miocene when their volcanic substratum reach the photic zone (Fig. 13). However, there is a apparent SW-NE chronostratigraphic gradient between the Hall Bank where Burdigalian and Langhian

limestones have been recovered, the Jaguar Bank marked by Serravalian sample and finally Bassas da India terrace where Late Miocene (Tortonian and Messinian) have been collected (Tab. 1, Fig. 13). This trend could suggest diachronous drownings that could be linked to differential tectonic (e.g. subsidence rates) and volcanic activity between the three distinct carbonate platforms. However, depth uncertainties related to dredge operations, numerous and various carbonate terraces (Fig. 1; Courgeon et al., 2016b) as well as extensive faulting requires caution on the interpretation of diachronous evolutions. During Late Neogene, shallow-water carbonate production resumed along highest reliefs inherited from tectonic deformation and volcanic production (Fig. 13). At Bassas da India, modern atoll is sited on the footwall of the major normal fault affecting the seamount. On the Jaguar Bank, the ultimate carbonate build-up settled along a narrow horst, its drowning during last deglacial sea-level rise was probably caused by rapid accommodation creation. The absence of renewed shallow-water carbonate production at the Hall Bank (Fig. 13) could be explained by the lack of tectonically raised reliefs and/or to high subsidence rates preventing shallow-water carbonate producers from re-colonizing the seamount during Late Neogene. Structural control on location and growth of shallow-water carbonate build-ups and platforms is very common in active tectonic settings (e.g. Wilson, 2000; Lü et al., 2013; Wu et al., 2014).

In parallel, Neogene times were marked by major climatic (e.g. Zachos et al., 2001) and eustatic (e.g. Miller et al., 2005) fluctuations that frequently impacted evolution of shallow-water carbonate systems. During the Late Miocene - Early Pliocene time span, global cooling, oceanographic reorganization and intensification of the Asian monsoon were responsible for various drowning events along isolated shallow-water carbonate platforms systems of the Indo Pacific Realm (e.g. Maldives, Betzler et al., 2009; Marion Plateau, Eberli et al., 2010). Deteriorating production and accumulation abilities of shallow-water carbonate systems, inimical environmental conditions were thus potentially implied in drowning of Miocene

shallow-water carbonate platforms of the southern MC. Superimposed on tectonic vertical motions, high amplitude and high frequency changes of the global sea-level during Neogene (Miller et al., 2005) were most likely responsible for periods of sub-aerial exposures and for associated erosion and karstification processes on tops of south MC carbonate platforms. Long-term emersion periods are otherwise frequently observed before drowning of shallow-water carbonate platforms (e.g. Schlager, 1998).

6. Conclusion

The main results of this study can be summarized as follow:

(1) Carbonate platform of the southern Mozambique Channel appeared and developed in shallow-water and tropical settings during the Miocene. They were characterized by classic fauna assemblages dominated by corals, red algae, LBF and *Halimeda*. End of shallow-water carbonate production and drowning of these carbonate platforms occurred during Late Miocene - Pliocene times and was recorded by the deposition of pelagic carbonates and by hardgrounds formation on their summits.

(2) From Late Miocene - Early Pliocene, carbonate platforms underwent rejuvenated activity of their volcanic substratum. Volcanic material directly covered antecedent carbonate platform and filled associated karstic depressions. This volcanism was accompanied by extensional tectonic deformation that structured the isolated platforms in distinct panels and blocks. It is proposed that this geodynamic phase is the main trigger of Miocene carbonate platform drowning.

(3) During Late Neogene (Late Pliocene-Pleistocene), shallow-water carbonate production resumed along topographic high inherited from volcanic production and tectonic structuration. While locally, carbonate build-up where subsequently drowned during last

deglacial sea-level rise, carbonate growth ultimately lead at Bassas da India to the edification of a modern atoll.

The evolution of South Mozambique Channels isolated carbonate platforms represents a new case illustrating the major impact of active tectonic and volcanism on long-term (millions years) isolated carbonate production. However, chronostragraphic framework and carbonate depositional system associated these isolated platforms remain poorly constrained. Henceforth, drilling operation have to be considered to validate first hypothesis on long-term evolution of these carbonate platforms and to discuss respective environmental impact.

References

Aïssaoui, D.M., Kirschvink, J.L., 1991. Atoll magnetostratigraphy: calibration of their eustatic records. Terra Nova 3, 35-40.

Bachtel, S.L., Kissling, R.D.,Martono, D., Rahardjanto, S.P., Dunn, P.A., MacDonald, B.A., 2004. Seismic Stratigraphic Evolution of the Miocene-Pliocene Segitiga Platform, East Natuna Sea, Indonesia: The Origin, Growth, and Demise of an Isolated Carbonate Platform, In: G. Eberli, J.L. Massaferro and J.F.R. Sarg (Eds.), Seismic Imaging of Carbonate Reservoirs and Systems. AAPG Memoir 81, 309-328.

Bard, E., Hamelin, B., Arnold, M., Montaggioni, L.F., Cabioch, G., Faure, G., and Rougerie, F., 1996. Deglacial sea level record from Tahiti corals and the timing of global meltwater discharge. Nature 382, 241–244

Basile, C., Chauvet, F., 2009. Hydromagmatic eruption during the buildup of a Triassic carbonate platform (Oman Exotics): Eruptive style and associated deformations. Journal of Volcanology and Geothermal Research 183, 84-96.

Bassias, Y., 1992. Petrological and geochemical investigation of rocks from the Davie Fracture Zone (Mozambique Channel) and some tectonic implications. Journal of African Earth Sciences 15, 321–339.
Coffin, M. F., Rabinowitz, P. D., 1987. Reconstruction of Madagascar and Africa: evidence from the Davies Fracture Zone and Western Somali Basin. Journal of Geophysical Research 92, 9385-9406.

Battistini R., Gayet J., Jouannic C., Labracherie M., Peypouquet J.P., Pujol C., Pujos-Lamy A., Turon J.L. (1976) Etude des sédiments et de la microfaune des îles Glorieuses (Canal du Mozambique). Cah. ORSTOM Ser. Géol. 2, 147-171.

Beavington-Penney, S. J., Racey, A., 2004. Ecology of extant nummulitids and other larger benthic foraminifera: applications in palaeoenvironmental analysis. Earth-Science Reviews 67, 219-265.

Belopolsky, A.V., Droxler, A.W., 2004. Seismic expressions and interpretations of carbonate sequences: The Maldives carbonate platform, equatorial Indian Ocean. American Association of Petroleum Geologists Studies in Geology 49, 46 p.

Bergersen, D.D., 1995. Physiography and architecture of Marshall Islands guyots drilled during leg 144: geophysical constraints on platform development. in Haggerty, J.A., Premoli Silva, I., Rack, F., and McNutt, M.K. (Eds.), 1995 Proceedings of the Ocean Drilling Program, Scientific Results 144, 561-583.

Betzler, C., Chaproniere, G.C.H., 1993. Paleogene and Neogene larger foraminifers from the Queensland Plateau: biostratigr phy and environmental significance. Proceedinds of Ocean Drilling Programs, Scientific results 133, p 51-66.

Betzler, C., Fürstenau, J., Lüdmann, T., Hübscher, C., Lindhorst, S., Paul, A., Reijmer., J.J.G., Droxler, A. W., 2012. Sea-level and ocean-current control on carbonate-platform growth, Maldives, Indian Ocean. Basin Research 25, 172-196.

Betzler, C., Hübscher C., Lindhorst, S., Reijmer, J.J.G., Römer, M., Droxler, A.W., Fürstenau, J., Lüdmann, T., 2009. Monsoon-induced partial carbonate platform drowning (Maldives, Indian Ocean). Geology 39, 867-870.

Betzler, C., Lindhorst, S., Lüdmann, T., Weiss, B., Wunsch, M., & Braga, J. C., 2015. The leaking bucket of a Maldives atoll: Implications for the understanding of carbonate platform drowning. Marine Geology 366, 16-33.

BouDagher-Fadel, M. K., 2002. The stratigraphical relationship between planktonic and larger benthic foraminifera in Middle Miocene to Lower Pliocene carbonate facies of Sulawesi, Indonesia. Micropaleontology 48, 153-176.

BouDagher-Fadel, M.K., 2008. Evolution and Geological Significance of Larger Benthic Foraminifera. Developments in Palaeontology and Stratigraphy 21, 1-548.

BouDagher-Fadel, M.K., 2013. Diagnostic First and Last Occurrences of Mesozoic and Cenozoic Planktonic Foraminifera. Professional Papers Series, 1-4.

BouDagher-Fadel, M.K., Price, G.D., 2013. The phylogenetic and palaeogeographic evolution of the miogypsinids larger benthic foraminifera. Journal of the Geological Society of London 170, 185-208.

BouDagher-Fadel, M.K., 2015. Biostratigraphic and Geological Significance of Planktonic Foraminifera, London, UCL Press, 298 p.

Bosellini, F. R., Russo, A., Vescogni, A., 2001. Messinian reef-building assemblages of the Salento Peninsula (southern Italy): palaeobathymetric and palaeoclimatic significance. Palaeogeography, Palaeoclimatology, Palaeoecology 175, 7-26.

Brachert, T. C., Betzler, C., Braga, J. C., & Martin, J. M., 1996. Record of climatic change in neritic carbonates: turnover in biogenic associations and depositional modes (Late Miocene, southern Spain). Geologische Rundschau 85, 327-337.

Braga, J. C., Martín, J. M., & Riding, R., 1996. Internal structure of segment reefs: Halimeda algal mounds in the Mediterranean Miocene. Geology 24, 35-38.

Buigues, D., 1997, Geology and hydrogeology of Mururoa and Fangataufa, French Polynesia. In: Vacher, H.L., Quinn, T.M. (Eds.), Geology and Hydrogeology of Carbonate Islands. Elsevier, Amsterdam, 433-451.

Burgess, P. M., P. Winefield, M. Minzoni, and C. Elders, 2013, Methods for identification of isolated carbonate build-ups from seismic reflection data: AAPG Bulletin 97, 1071–1098, doi:10.1306/12051212011.

Camoin, G.F., Arnaud-Vanneau, A., Bergersen, D.D., Enos, P., Ebren, P., 1998. Development and demise of mid-oceanic carbonate platforms, WodejabatoGuyot (NW Pacific). International Association of Sedimentologists Special Publication 25, 39-67.

Camoin, G. F., Ebren, P., Eisenhauer, A., Bard, E., Faure, G., 2001. A 300 000-yr coral reef record of sea level changes, Mururoa atoll (Tuamotu archipelago, French Polynesia). Palaeogeography, Palaeoclimatology, Palaeoecology 175, 325-341.

Chadwick Jr., W.W., Clague, D.A., Embley, R.W., Perfit, M.R., Butterfield, D.A., Caress, D.W., Paduan, J.B., Martin, J.F., Sasnett, P., Merle, S.G., Bobbitt, A.M., 2013. The 1998 eruption of Axial Seamount: New insight on submarine lava flow emplacement from high-resolution mapping. Geochemistry, Geophysics, Geosystems 14, 3939-3968.

Chorowicz, J., 2005. The East African rift system. Journal of African Earth Sciences 43, 379-410.

Clark, P. U., Dyke, A. S., Shakun, J. D., Carlson, A. E., Clark, J., Wohlfarth, B., Mitrovica, J.X., Hostetler, S.W., McCabe, A. M., 2009. The last glacial maximum. Science 325, 710-714.

Coffin, M. F., Rabinowitz, P. D., 1987. Reconstruction of Madagascar and Africa: evidence from the Davies Fracture Zone and Western Somali Basin. Journal of Geophysical Research 92, 9385-9406

Courgeon, S., Bourget., J., Jorry, S.J., 2016a. The Malita intra-shelf basin (Bonaparte Basin, NW Australia) – A Plio-Quaternary analogue for ancient epireic carbonate settings. AAPG Bulletin 100, 565-595.

Courgeon, S., Jorry, S.J., Camoin, G.F., BouDagher-Fadel, M.K., Jouet, G., Révillon, S., Bachèlery, P., Pelleter, E., Borgomano, J., Poli, E., Droxler, A.W., 2016b. Growth and demise of Cenozoic isolated carbonate platforms: New insights from the Mozambique Channel seamounts (SW Indian Ocean). Marine Geology 380, 90-105.

Darwin, C., 1842. The structure and distribution of coral reefs

Deschamps, A., Grigné, C., Le Saout, M., Soule, S. A., Allemand, P., Vliet-Lanoe, V.,Floc'h, F., 2014. Morphology and dynamics of inflated subaqueous basaltic lava flows. Geochemistry, Geophysics, Geosystems 15, 2128-2150.

Dunham, R.J., 1969. Early vadose silt in Townsend mound (reef), New Mexico. In: Depositional Environments in carbonate rocks. (Ed. G. M. Friedman). Spec. Publs. Soc. econ. Paleonr. Miner., Tulsa, 14, 139-181.

Eberli, G.P., Anselmetti, F.S., Isern, A.R. & Delius, H., 2010. Timing of changes in sea-level and currents along Miocene Platforms on the Marion Plateau, Australia. In: Cenozoic Carbonate Systems of Australia (Ed. by Morgan W.A., George A.D., Harris P.M., J.A. Kupecz & J.F. Sarg), SEPM Spec. Publ. 95, 219–242. SEPM, Tulsa, OK.

Fernandez-Mendiola, P.A., Garcia-Mondejar, J., 2003. Carbonate platform growth influenced by contemporaneous basaltic intrusions (Albian of Larrano, Spain). Sedimentology 50, 961-978

Flügel, E., 1982. Case Histories. In *Microfacies Analysis of Limestones* (pp. 556-580). Springer Berlin Heidelberg.

Flügel, E., 1988. Halimeda: paleontological record and palaeoenvironmental significance. *Coral Reefs 6*, 123-130.

Flügel, E., 2004. Microfacies of carbonate rocks. Springer, Berlin, Germany, 976 pp.

Fornari, D.J., 1986. Submarine lava tubes and channels. Bulletin of Volcanology 48. 291-298.

Gaina, C., Torsvok, T.H., Hinsbergen, D.J.J., Medvedev, S., Werner, S.C., Labails, C., 2013. The African Plate: A history of aceanic crust accretion and subduction since the Jurassic. Tectonophydics 604, 4-25.

Godet, A., 2013. Drowning unconformities: palaeoenvironmental significance and involvement of global processes. Sedimentary Geology 293, 45-66.

Guillaume, M.M.M., Reyss, J.-L., Pirazzoli, P.A., Bruggemann, J.H., 2013. Tectonic stability since the last interglacial offsets the Glorieuses Islands from the nearby Comoros archipelago. Coral Reefs 32, 719-726.

Halliday, W.R., 2007. Pseudokarst in the 21st century. Journal of Cave and Karst studies 69. 103-113.

Hallock, P., Glenn, E.C., 1986. Larger Foraminifera: A Tool for Paleoenvironmental Analysis of Cenozoic Carboate Depositional Facies. Palaios 1, 55-64.

Houghton, B. F., White, J. D., & Van Eaton, A., 2015. Phreatomagmatic and related eruption styles , in: Sigurdsson, H., Houghton, B., McNutt, S.R., Rymer, H., Stix, J., (Eds.), The Encyclopedia of Volcanoes, Second Edition, Elsevier, USA, 537-552.

Houk, P., 2011. Volcanic Disturbances and Coral Reefs. In *Encyclopedia of Modern Coral Reefs*, Springer Netherlands. pp. 1138-1140

Jorry, S.J., Camoin, G.F., Jouet, G., Le Roy, P., Vella, C., Courgeon, S., Prat, S., Paumard, V., Boulle, J., Caline, B. and Borgomano., J., 2016. Modern sediments and Pleistocene reefs from isolated carbonate platforms (Iles Eparses, SW Indian Ocean): A preliminary study. ActaOecologica 72, 129-143.

Kabanov, P., Anadón, P., & Krumbein, W. E., 2008. Microcodium: an extensive review and a proposed non-rhizogenic biologically induced origin for its formation. Sedimentary geology *205*, 79-99.

Košir, A., 2004. Microcodium revisited: root calcification products of terrestrial plants on carbonate-rich substrates. Journal of Sedimentary Research 74, 845-857.

Lehrmann, D.J., Donghong, P., Enos, P., Minzoni, M., Ellwood, B.B., Orchard, M.J., Jiyan, Z., Jiayong, W., Dillett, P., Koenig, J., Steffen, K., Druke, D., Druke, J., Kessel, B., Newkirk, T., 2007. Impact of differential tectonic subsidence on isolated carbonate-platform evolution: Triassic of the Nanpanjiang Basin, south China. Americain Association of Petroleum Geologist Bulletin 91, 287-320.
Libbey, W. F., 1952. Radiocarbon dating. University of Chicago Press.

Lincoln, J.M., Schlanger, S.O., 1991. Atoll Stratigraphy as a Record of Sea Level Change: Problems and Prospects. Journal of Geophysical Research 96, 6727 - 6752.

Lüdmann, T., Kalvelage, C., Betzler, C., Fürstenau, J., Hübscher C., 2013. The Maldives, a giant isolated carbonate platform dominated by bottom currents. Marine and Petroleum Geology 43, 326–340.

Lü, C., Wu, S., Yao, Y., Fulthorpe, C.S., 2013. Development and controlling factors of Miocene carbonate platform in the Nam Con Son Basin, southwestern South China Sea. Marine and Petroleum Geology 45, 55-68.

Major, R.P., Matthews, R.K., 1983. Isotopic composition of bank margin carbonates on Midway Atoll: Amplitude constraint on post-early Miocene eustasy. Geology 11, 335-338.

Mangini, A., Halbach, P., Puteanus, D., Segl, M., 1987. Chemistry and growth history of central Pacific Mn crusts and their economic importance, Marine Minerals, 205-220.

Martin, U., Breitkreuz, C., Egenhoff, S., Enos, P., Jansa, L., 2004. Shallow-marine phreatomagmatique eruptions through a semi-solidified carbonate platform (ODP Leg 144, site 878, Early Cretaceous, MIT Guyot, West Pacific). Marine Geology 204, 251-272.

McArthur, J. M., Howarth,R. J. et al., 2012. Chapter 7 - Strontium Isotope Stratigraphy. The Geologic Time Scale 2012, Boston, Elsevier, 127-144.

McClinton, J. T., & White, S. M. (2015). Emplacement of submarine lava flow fields: A geomorphological model from the Niños eruption at the Galápagos Spreading Center. Geochemistry, Geophysics, Geosystems 16, 899-911.

McGregor, D., 2015. History of the development of the East African Rift System: A series of interpreted maps through time. Journal of African Earth Sciences 101, 232-252.

Menier, D., Pierson, B., Chalabi, A., Ting, K.K., Pubellier, M., 2014. Morphological indicators of structural control, relative sea-level fluctuations and platform drowning on present-day and Miocene carbonate platforms. Marine and Petroleum Geology 58, 776-788.

Michon, L., 2016. The volcanism of the Comoros Archipelago integrated at a regional Scale, in: Bachèlery, P., Lénat, J.-F., Di Muro, A., Michon, L. . (Eds.), Active volcanoes of the Soutwest Indian Ocean. Springer-Verlag, the Netherlands 333-344.

Mihaljević, M., Renema, W., Welsh, K., Pandolfi, J. M., 2014. Eocene–Miocene shallow-water carbonate platforms and increased habitat diversity in Sarawak, Malaysia. Palaios 29, 378-391.

Miller, K.G., Kominz, M.A., Browning, J.V., Wright, J.D., Mountain, G.S., Katz, M.E., Sugarman, P.J., Cramer, B.S., Christie-Blick, N., Pekar, S.F., 2005. The phanerozoic record of global sea-level change. Science 310, 1293-1298.

Murdmaa, I., Nemliher, J., Bogdanova, O., Gorshkov, A., Kallaste, T., Vasilyeva, V., 1995. Ferromanganese and phosphatic hardgrounds on the western pacific guyots drilled during legs 143 and 1441. In Proceedings of the Ocean Drilling Program - Scientific results 144. 419-428

Ogg, J.G., Camoi, G.F., Arnaud Vanneau, A., 1995. LimalokGuyot: depositional history of the carbonate platform from downhole logs at site 871 (lagoon), in: Haggerty, J.A., Premoli Silva, I., Rack, F., and McNutt, M.K. (Eds.), Proceedings of the Ocean Drilling Program, Scientific Result 144, 233-253.

Prat S., Jorry S.J., Jouet G., Camoin G.F., Vella C., Le Roy P., Caline B., Boichard R., Pastol Y. (2016) Geomorphology and sedimentology of a modern isolated carbonate platform: The glorieuses archipelago, SW Indian Ocean. Marine Geology, in press

Purdy, E. G., Gischler, E., 2005. The transient nature of the empty bucket model of reef sedimentation. Sedimentary Geology 175, 35-47.

Pomar, L., Bassant, P., Brandano, M., Ruchonnet, C., Janson, X., 2012. Impact of carbonate producing biota on platform architecture: insights from Miocene examples of the Mediterranean region. Earth-Science Reviews, 113, 186-211.

Pomar, L., Hallock, P., 2008. Carbonate factories: A conundrum in sedimentary geology. Earth-Science Reviews 87, 134-169.

Puga-Bernabéu, A., Webster, J.M., Braga, J.C., Clague, D.A., Dutton, A., Eggins, S., Fallon, S., Jacobsen, G., Paduan, J.B., Potts, D.C., 2016. Morphology and evolution of drowned carbonate terraces during the last two interglacial cycles, off Hilo, NE Hawaii. Marine Geology 371, 57-81.

Reuter, M., Piller, W. E., Richoz, S., 2012. The dispersal of Halimeda in northern hemisphere mid-latitudes: Palaeobiogeographical insights. Perspectives in Plant Ecology, Evolution and Systematics 14, 303-309.

Ruiz-Ortiz, P.A., Bosence, D.W.J., Rey, J., Nieto, L.M., Castro, J.M., Molina, J.M., 2004. Tectonic control of facies architecture, sequence stratigraphy and drowning of a Lisassic carbonate platform (Betic Cordillera, Southern Spain). Basin Research 16, 235-257.

Saqab, M.M., Bourget, J., 2016. Seismic geomorphology and evolution of early-mid Miocene isolated carbonate build-ups in the Timor Sea, North West Shelf of Australia. Marine Geology 379, 224-245.

Salman, G., Abdula, I., 1995. Development of the Mozambique and Ruvuma sedimentary basins, offshore Mozambique, Sedimentary Geology 96, 7-41.

Sattler, U., Zampetti, V., Schlager, W., & Immenhauser, A., 2004. Late leaching under deep burial conditions: a case study from the Miocene Zhujiang Carbonate Reservoir, South China Sea. Marine and Petroleum Geology 21, 977-992.

Sattler, U., Immenhauser, A., Schlager, W., Zampetti, V., 2009. Drowning history of a Miocene carbonate platform (Zhujiang Formation, South China Sea). Sedimentary Geology 219, 318-331.

Schlager, W., 1989. Drowning unconformities on carbonate platforms. in Controls on Carbonate Platformand Basin Development, SEPM Special Publications 44.
Schlager, W., 1998. Exposure, drowning and Sequence Boundaries on Carbonate platforms, in Reefs and Carbonate Platforms in the Pacific and Indian Oceans, Camoin, G.F., Davies, P.J. (Eds.), Special Pulications of Internationnal Association of Sedimentologists 25, 3-21.

Schlager, W., 2003. Benthic carbonate factories of the Phanerozoic. International Journal of Earth Sciences 92, 445-464.

Schlager, W., Purkis, S. J., 2013. Bucket structure in carbonate accumulations of the Maldive, Chagos and Laccadive archipelagos. International Journal of Earth Sciences 102, 2225-2238.

Staudigel, H., Clague, D.A., 2010. The geological history of deep-sea volcanoes: Biosphere, hydrosphere, and lithosphere interactions. Oceanography 23, 58–71.

Storey, M., Mahoney, J.J., Saunders, D., Dunca, R.A., Kelley, S.P., Coffin, M.F., 1995. Timing of hot spot-related volcanism and the breakup of Madagascar and India. Science 267, 852

Toomey, M. R., Ashton, A. D., Raymo, M. E., Perron, J. T., 2016. Late Cenozoic sea level and the rise of modern rimmed atolls. Palaeogeography, Palaeoclimatology, Palaeoecology 451, 73-83.

Tomascik, T., Van Woesik, R., Mah, A. J., 1996. Rapid coral colonization of a recent lava flow following a volcanic eruption, Banda Islands, Indonesia. Coral Reefs 15, 169-175.

Torsvik, T. H., Tucker, R. D., Ashwal, L. D., Carter, L. M., Jamtveit, B., Vidyadharan, K. T., & Venkataramana, P., 2000. Late Cretaceous India–Madagascar fit and timing of break-up related magmatism. Terra Nova *12*, 220-224

Van Waasbergen, R. J., Winterer, E. L.,1993. Summit geomorphology of western Pacific guyots. The Mesozoic Pacific: Geology, Tectonics, and Volcanism, 335-366.

Webster, J. M., Braga, J. C., Clague, D. A., Gallup, C., Hein, J. R., Potts, D. C., Renema, W., Riding, R., Riker-Coleman, K., Silver, E., Wallace, L. M., 2009. Coral reef evolution on rapidly subsiding margins. Global and Planetary Change 66, 129-148.

White, J. D., Ross, P. S., 2011. Maar-diatreme volcanoes: a review. Journal of Volcanology and Geothermal Research 20, 1-29.

Wilson, P.A., Jenkyns, H.C., Elderfield, H., Larson, R.L., 1998. The paradox of drowned carbonate platforms and the origin of Cretaceous Pacific guyots. Nature 392, 889- 894.

Wilson, M.E.J., 2000. Tectonic and volcanic influences on the development and Diachronous termination of a Tertiary tropical carbonate platform. Journal of Sedimentary Research 70, 310-324.

Wilson, M.E.J., Lokier, S.W., 2002. Siliclastic and volcaniclastic influences on equatorial carbonates: insights from the Neogene of Indonesia. Sedimentology 49, v.583-601.

Wright, K. A., Davies, R. J., Jerram, D. A., Morris, J., Fletcher, R., 2012. Application of seismic and sequence stratigraphic concepts to a lava-fed delta system in the Faroe-Shetland Basin, UK and Faroes. Basin Research 24, 91-106.

Wu, S., Yang, Z., Wang, D., Lü, F., Lüdmann, T., Fulthorpe, C.S., Wang, B., 2014. Architecture, development and geological control of the Xisha carbonate platforms, northwestern South China Sea. Marine geology 350, 71-83.

Wu, S., Yuan, S., Zhang, G., Ma, Y., Mi, L., Xu, N., 2009. Seismic characteristics of a reef carbonate reservoir and implications for hydrocarbon exploration in deepwater of the Qiongdongnan Basin, northern South China Sea. Marine and Petroleum Geology 26, 817-823.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., & Billups, K., 2001. Trends, rhythms, and aberrations in global climate 65 Ma to present. Science, 292, 686-693.

Acknowledgments

Captions

Figure 1: (A) Physiography of the Mozambique Channel (GEBCO 2014, 100m resolution). Green squares correspond to Eparses Islands. Ba. means Bassas da India. Eu. means Europa. Glo. means Glorieuses. Black dashed line correspond to the Davie ridge. Study Area is indicated by a black rectangle. (2) Bathymetry DEM (20m resolution) of the study area. White lines correspond to fault lineaments. Red lines and lettering correspond to seismic profiles shown in Figure 3. Dark blue rectangles locate geomorphological close-ups presented in Figure 7. Yellow and blacks stars and lettering indicate the approximate location of dredge operations.

Figure 2: (A) Geomorphological interpretation of Bassas da India atoll. Resolution of bathymetry DEM illustrating seamount flanks is 10m. (B) Topographic/bathymetric DEM of Bassas da India Atoll (LIDAR dataset, 1m resolution). Black rectangle indicate the location of the satellite image presented in Figure 2C. (C) Satellite image and associated interpretation of the northwest domain of Bassas da India atoll.

Figure 3: Conventional seismic profiles and associated interpretations. (A) MOZ4-SR198 (Hall Bank, see location on Figures 1 & 7A). (A) PTOLEMEE-SR68 (Jaguar Bank, see location on

Figures 1 & 7B). (C) (A) PTOLEMEE-SR65 (Bassas da India, see location on Figures 1 & 7C). Pink arrows correspond to seismic reflections terminations. Red lines correspond to faults. Green line corresponds to the seafloor. Pink lines in (B) correspond to seismic artefact. Art. means seismic artefact.

Figure 4: High Resolution seismic profiles and associated interpretations. (A) PTOLEMEE-HR52 (Hall Bank, see location on figure 7A). (B) PTOLEMEE-HR56 (Hall Bank, see location on figure 7A). (C) PTOLEMEE-HR53 (Hall Bank, see location on figure 7A). (C) PTOLEMEE-HR32 (Jaguar Bank, see location on figure 7D). Pink arrows correspond to seismic reflections terminations. Red dashed lines correspond to faults. Green line corresponds to the seafloor

Figure 5: PTOLEMEE-HR59, High resolution seismic profile and associated interpretation. See Location on Figure 7C. Red lines correspond to faults. Green line corresponds to the seafloor. pink arrows correspond to seismic reflections terminations.

Figure 6: (A) PTOLEMEE-SR106, conventional seismic profile (See location on figure 6B). Black lines correspond to faults. Green line corresponds to the approximate boundary between the volcanic ridges and adjacent deposits. (B) Slope map (20m resolution) of the study area extended towards NE. Red lines represent the SW-NE normal fault networks affecting the seamounts and the adjacent basinal deposits.

Figure 7: High resolution (10m) bathymetry DEMs. (A) Hall Bank, (B) Jaguar Bank and (C) Bassas da India. See location in Figure 1. Black lines and lettering correspond to seismic profiles. Pink lines and lettering correspond to location of dredge operations. Red lines correspond to fault escarpments. Dashed red lines correspond faults inferred both from bathymetry DEMS and seismic lines. White rectangles correspond to geomorphological close-ups presented in Figures 8A & 9A.

Figure 8: (A) Very high resolution (5m) bathymetry DEM illustrating a loba lava flow complex on top of the Jaguar Bank (sea location in Figure 7B. Red squares and lettering correspond to location of submarines pictures presented in Figure 8B, 8C & 8D. Submarine pictures of the sea floor. (B) Bright and flat rocky outcrops interpreted as carbonate slabs. (C) & (D) fractured, rugged and very dark outcrops interpreted as lobate lava flows.

Figure 9: (A) Very high resolution (5m) bathymetry DEM illustrating a rounded and flat-top depression on top of the Hall Bank. This morphology is interpreted as a phreatomagmatic crater (see details in the text). Red squares and lettering correspond to location of submarine pictures presented in Figure 9B & 9D. (B) Submarine picture of a pebble field. (C) Pebbles encrusted by FE-MN crusts and collected in the NE sector of the Hall Bank (MOZ1-DW05, See location on Figure 7A). (D) Submarine picture of a very dark outcrop interpreted as volcanic.

Figure 10: (A) High resolution (10m) bathymetry DEM illustrating the geomorphology of the Jaguar Bank summit (See location in Figure 1). White dashed lines correspond to fault escarpments. Pink lines and lettering correspond to location of dredge operation. (B) *Halimeda* (Ha) grainstone and Coral (Co) boundstone collected along carbonate build-up morphology (MOZ4-DR06).

Figure 11: Thin sections micrographs of rock samples collected along carbonate platform flanks (See dredge location on Figures 1, 7 & 10).(A) MOZ01-DR18-01: Skeletal Packstone with large encrusted corals (B) MOZ04-DR18-02: Skeletal grainstone of LBF and Halimeda sp. (C, D) MOZ04-DR05-01: Skeletal packstone of LBF and Halimeda with large encrusted corals. (E) MOZ01-DR20-01: Skeletal packstone, close up (F) illustrates moldic porosity geopetally infilled by crystaline silty sediments (crystal silts). (G) MOZ1-DR20-02: Skeletal Packstone. RA: red algae; Co: coral; EF: encrusting foraminifera; Ga: Gastropods; Br: Bryozoans; VF: Volcanic fragment; Te: Textularidae; LBF: large benthic foraminifera; Cy:

Cycloclypeus; Lp: *Lepidocyclina*; Mio: *Miogypsina*; Ka: *Katacycloclypeus*; Op: *Operculina*; Am: *Amphistegina*; Sp: *Sphaerogypsina*.

Figure 12: Thin sections micrographs of rock samples collected along carbonate platform tops (See dredge location on Figures 1, 7 & 10). (A) MOZ01-DW05-C1: Packstone of planktonic foraminifera including dolomitized coral-rich limestone. Perf.: perforation features. (B) MOZ01-DW05-C2c: Phosphatized packstone of planktonic foraminifera including volcanic clasts and covered by tuff. Volcanoclastic deposits include carbonate fragments (blue arrows). (C) MOZ04-DN02-02d: Phosphatized packstone of planktonic foraminifera including large reworked coralgal fragments. In (B, C), white arrows indicate brownish and beige concretions and crusts that correspond to phosphatization features. (D) Dolomitized grainstone reworked into wackestone of planktonik foraminifera. Beige to brownish circular features are interpreted as *Microcodium* (Mc) structures (see details in the text). (E) MOZ01-DW05-10: Volcanic tuff including armored lappilis (AL, red arrows indicate dark layers coating lappilis, see details in the text) and large carbonate fragment (white rectangle and associated close-up). (F) Fractured and altered lava infilled first by wackestone of planktonic foraminifera (MOZ4-DR08-01b). A second fracturation network is infilled by phospahtized packstone of planktonic foraminifera (G, MOZ04-DR08-01a) marked by abundant shallow-water carbonate grains. Co: coral; Bi: Bivalve; RA: red algae; Am: *Amphistegina*; Mio: *Miogypsina*; Ha: *Halimeda*; Mi: Milliolids.

Figure 13: (A) Simplified hypothetical schema of South Mozambique channel isolated carbonate platforms architectures. (B) Simplified hypothetical schemas of Neogene evolution of south Mozambique Channels isolated carbonate platforms. Not to scale.

Table 1: Synthesis of dating and microfacies analysis.