Jörn mit herzlichen Grüßen
WChr Dullo

Project: Du 129/6 „Morphologie und sedimentäre Entwicklung der tiefen Vorriffhänge der Comoren im Vergleich mit dem Roten Meer und der Karibik", Project Leader: W.-Chr. Dullo (Kiel)

Sealevel Changes and Evolution of the Foreslopes of the Comoro Islands: Direct Observations from Submersible

Wolf-Christian Dullo, Gilbert F. Camoin, Dierk Blomeier, Anton Eisenhauer & Bernard A. Thomassin

Area of Study: Comoro Island, Western Indian Ocean
Environment: Foreslope, forereef
Stratigraphy: Holocene, Pleistocene
Organisms: Calcareous algae, scleractinians
Depositional Setting: Foreslope
Constructive Processes: Coralgal framework
Destructive Processes: Gravitative block gliding
Preservation: superb
Research Topic: Modern reefs, sealevel changes, foreslope facies

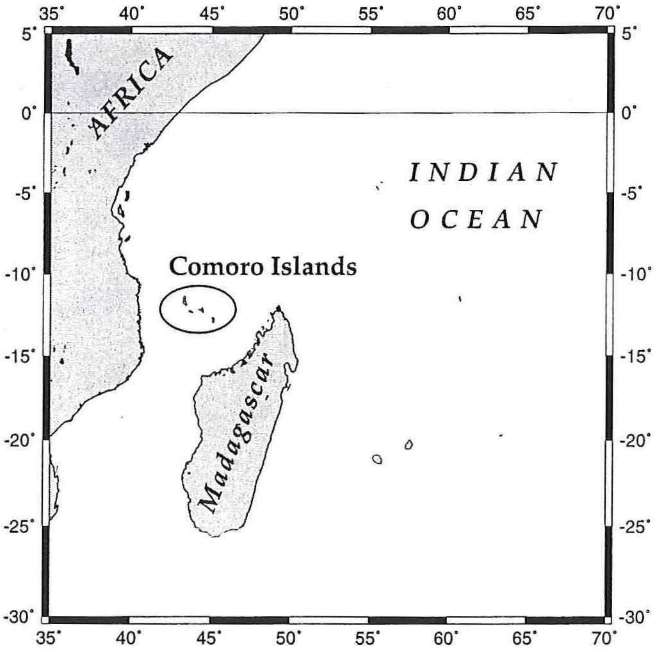

Fig. 1: Locality map of the Comoro Islands.

Abstract

Mayotte foreslopes exhibit a distinct pattern in the overall morphology, starting in the deep with an unlithified sedimentary wedge and slope, followed upwards by a cemented slope, and finally by a steep, almost vertical wall. On top of the wall, drowned reefs occur. Dated corals may reveal the history of sealevel changes indicating reef growth during isotope stage 3 (50-26 kyrs BP) at a present-day water depth that is deeper than 80 m and also has developed a coeval reef talus facies. A maximum sealevel drop of 150 m occurred during the last glacial maximum followed between 22-18 kyrs BP. This lowering of sealevel is documented by karst features such as small caves and corroded and jagged surfaces. The phase of deglaciation is recorded by two give-up reef levels at 100 m/90 m water depth and 65 m/55 m water depth which we may relate to the Bølling (14 kyrs BP) and post Younger Dryas (11.5 kyrs BP) meltwater pulses, known from the deep-sea record.

1 Introduction

Reefs are recorders of environmental changes (MONTAGGIONI & MACINTYRE 1991). Following earlier studies using bathymetric profiles, bottom cameras, and dredges (e.g. MACINTYRE 1972), the invention of small submersibles has triggered the in situ investigation of foreslopes. The sites that have been visited by submersibles for geological purposes are still small in number, although the first deep diving expeditions date back to the early seventies. The majority of geological investigations concentrated on the Caribbean (GRAMMER & GINSBURG 1992 cum lit.), while few studies are known from the Pacific reef province (LAMBERT & ROUX 1991 cum lit.). Equivalent data for the Indian Ocean are limited to the Red Sea (BRACHERT & DULLO 1991 cum lit.).

The Comoro Islands make up an island chain located in the northern end of the Mozambique channel between Madagascar and Africa (Fig. 1, 2). The four main islands of this archipelago, Grande Comore, Moheli, Anjouan, and Mayotte, are nearly aligned along a NW-SE axis. The isolated main volcanic complexes vary greatly in age and cover a time span that ranges from the Miocene and Pliocene to the most recent eruption in 1977 (KRAFFT 1982). The variation in age, increasing southeastwards from Mayotte to Grande Comore, is also reflected by the varying coastal morphology, including the development of living coral reefs, the general weathering of the volcanic rocks, and the general elevation of the islands above sealevel (GUILCHER 1971).

The hydrographic regime around the Comoros is controlled by the Southern Equator Current and the Mozambique Current, which themselves are governed by the biannual change of the monsoon winds (EHNY 1987). However, all these oceanwide changes do not affect the counter-clockwise direction of the local currents around the Comoros throughout the whole year, because they are mainly driven by the Southern Equatorial Current. Sea surface tempera-

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Göttinger Arb. Geol. Paläont., **Sb2**, 19-22, Göttingen

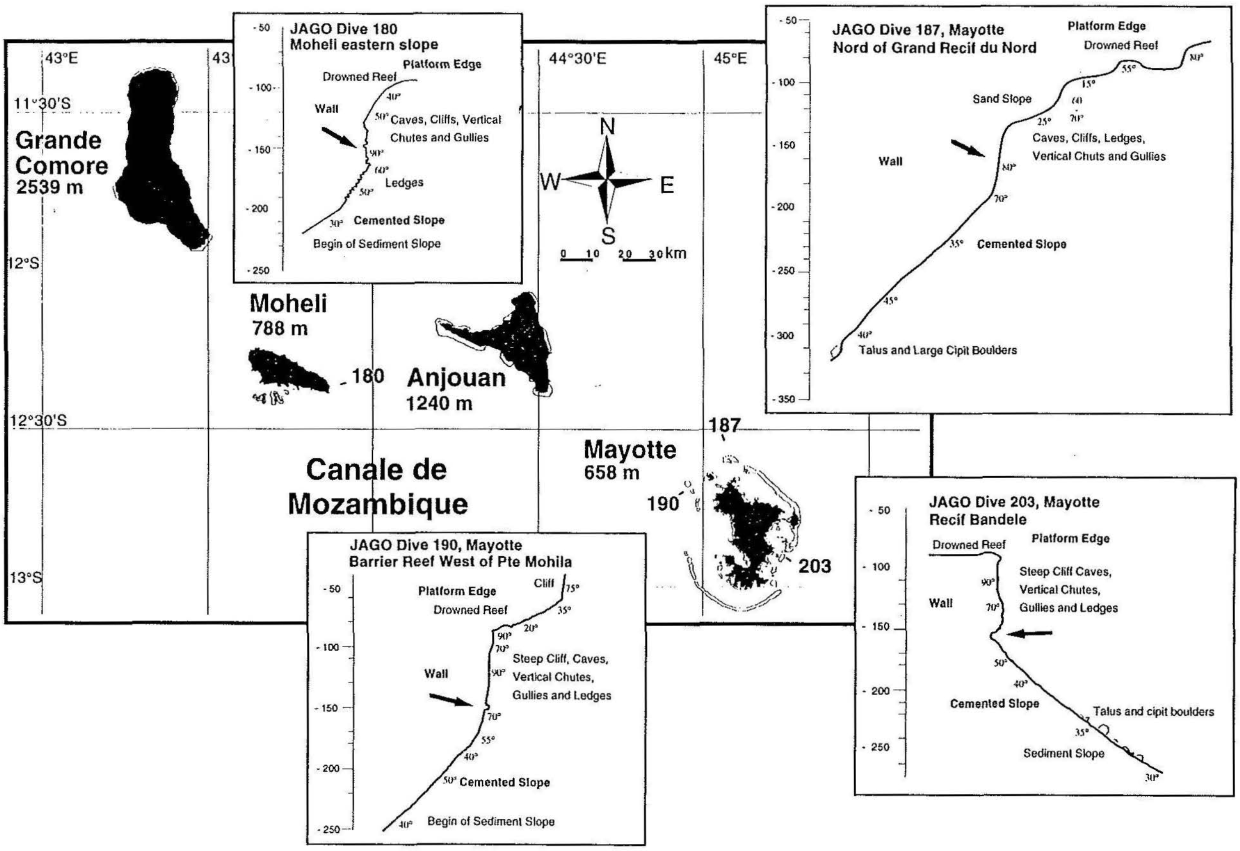

Fig. 2: Locality map, showing the Comoro Islands and selected foreslope morphologies of the different dive sites. They all are drawn in the same size without any vertical exaggeration.

ture does not decrease below 24°C and its annual average is around 28°C (Pitton et al. 1981). The prevailing swell is from the SE and on the southern and windward margins of the island. This long-period swell could still be felt in the submersible down to 90 m-100 m deep!

2 Material and Methods

A total of 35 dives were performed around the islands using the two-man submersible JAGO. JAGO has a diving limit of 400 m and was operated from the surface vessel DEEP SALVAGE I. The bathymetry of the diving sites was first checked by simple echo sounding on an analog recorder. The inclination of the slope was measured using a simple clinometer. The depth was continuously recorded with a fathometer. Sedimentological and biological information was mapped on these simple profiles. In addition, we recorded simultaneously the water temperature and the light penetration into the shallower parts. Furthermore, we documented each change in slope geometry and facies on video tape and slides.

A simple but heavy duty chisel was mounted to the keel to collect hard rock samples. By ramming the sub at full speed, we were able to recover samples that weigh up to 5 kg, even from the well-cemented slopes and the drowned reefs. Therefore, we were able to obtain coral material and sedimentological information on the older reef rocks without using explosives. The corals we sampled fall into two groups: The first one represents in situ specimens, which show no signs of transport and fracturing and still display a framework fabric. The second one comprises coral debris, exhibiting fractures. Dated specimens from the latter group can not provide any hint for ancient sealevel, however, these dates provide information about the timing of reef growth and talus sedimentation.

3 Results

The foreslopes of the islands Mayotte and Moheli are characterized by a general morphology (Fig. 2) that displays striking similarities to other coral reef foreslopes in the world. We can distinguish three major morphological and sedimentary units which comprise a deeper sediment slope, a shallower cemented slope, and a wall or steep cliff (Grammer & Ginsburg 1992). In addition, we observed drowned reefs as a distinct feature on the foreslopes at 90 m and 60 m of water depth, respectively.

The deepest part of the sediment slope below 300 m depth is characterized by silty to muddy carbonates. Upslope, grain size changes abruptly from silt to sand and even gravel around 250 m depth. The sediment consists of a mixture of recent unconsolidated material and reworked carbonates characterized by corroded surfaces and distinctive colors (i.e. white versus gray, respectively). Accumulations of huge blocks occur on top of the sediment slope, up to several cubic meters in size. We observed them in 14 dives concentrated along the eastern and southwestern margins of the barrier reefs, which are the site most hit by cyclones. These blocks do not display any distinctive arrangement according to depth. They provide a hard substrate for various benthic organisms on a sediment slope where unlithified material prevails.

Upslope, around 200 m of water depth, the sediment slope grades into the cemented slope composed of well-cemented grainstones with shallow-water derived biota; reworked shallow-water corals include *Acropora*, *Porites*, and

Goniopora. The inclination of the cemented slope is predominantly around 60° with a minimum inclination of 40°. The surface of the cemented slope corresponds to a submarine hardground as indicated by the occurrence of multiple generations of borings.

A sharp increase in inclination occurs between 190 m and 160 m depth, where the cemented slope steepens and forms an almost vertical wall (75° to 90°) as a prominent part of the cemented slope. This wall is a typical feature of most of the investigated slope sites of the island. The surface of the wall is covered by irregularly arranged ledges which may protrude up to half a meter from the wall.

There are two karst systems within the bathymetric range of the cemented slope and the wall. Their occurrence is limited to distinct levels. The first level is located between 150 m and 155 m water depth and consists of small solution caves smaller than 3 m. These caves may continue up to 2 m horizontally into the wall or the cemented slope. Furthermore, the surface of the wall exhibits small-scale solution features, like karren and kamenitza morphologies. A thin coralgal veneer has started to grow over the karst features in a few sites. In situ shallow-water scleractinians (*Acropora*) derived from the initial framework of this coralgal facies at 152 m water depth were dated 18.4 ±0.5 kyrs BP and 16.1 ±0.5 kyrs TIMS at 160 m.

The second karst horizon occurs between 120 m and 125 m water depth, where we have found caves more than 3 m deep and wide. Furthermore, karst channels and solution pipes may connect different caves, which we could prove by chasing fish from one to another. The surface of carbonates exhibits karren and kamenitza features as well.

The wall is composed of *Halimeda* grainstones and packstones or skeletal grainstones and rudstones. They represent a reef talus facies forming the rocks of the wall or of the cemented slope. Therefore, corals only occur as fragments. Ages obtained from these cemented reef talus sediments range between 37.4 ±0.8 to 27.6 ±0.9 kyrs BP. Although we did not see unequivocal internal bedding during all our dives, we could observe a clear indication of an inclined internal bedding in dive 197.

The upper part of the wall around 110 m and 105 m of present water depth is reef rock as well. We obtained only two ages of 55.6 ±2.1 and 33.6 ±1.1 kyrs BP which provide a hint for the time of reef growth. As these reef rocks form the uppermost part of the wall, we assume that they correspond to the talus facies described above, which occurs bathymetrically deeper comprising the lower part of the wall and the cemented slope.

On top of the wall, drowned reefs are found concentrated bathymetrically between 100 m and 90 m. In contrast to the coralgal veneers recovered from the cemented slope and the wall, they form small mounds, elevated by up to 3 m in comparison to the surrounding sediment. Some convincing examples exist, where the ancient growth morphology of the constituting shallow-water scleractinians is still seen below the intense encrustation of mainly coralline algae. One in situ shallow-water coral (*Porites*) was dated at 13.6 ±0.4 kyrs BP TIMS. Two other corals were dated at 10.1 ±0.2 kyrs BP (*Cyphastrea*) and at 2.9 ±0.3 kyrs BP (*Leptoseris*). They probably represent the transition from shallower to deeper environments as the latter is still living in this depth.

In a few dives, we recognized a second level of drowned reefs between 65 m and 55 m, already covered by a veneer of living platy scleractinians. The base of these coralgal associations is composed of shallow water corals such as branching *Pocillopora* and *Acropora*, although recorded as small pieces. Bathymetrically shallower terrace steps have not been included in this survey due to severe swell conditions.

4 Discussion

The oldest samples we could date to be derived from the uppermost part of the wall having an age of 55.6 ±2.1 and 33.6 ±1.1 kyrs BP, respectively. Associated with this reef facies is a reef talus comprising the deeper part of the wall and the cemented slope. According to published sealevel curves comprising the last 130,000 yrs (e.g. BARD et al. 1990), there is a prominent sealevel lowstand oscillating around 80 m deep during late isotope stage 3. During that time, shallow-water reefs developed together with their associated talus facies on the present-day deeper forereef and may have contributed to the overall morphology of this prominent terrace (Fig. 2).

The overall morphology of the wall, mainly related to intense erosion with the formation of reef outrunners (GRAMMER and GINSBURG 1992), even known in the fossil record as cipit boulders and subsequent karstification, was created during a rapid lowering of sealevel starting around 26 kyrs BP (Fig. 2) and approaching the last glacial maximum (LGM). As sealevel fall stopped around 22 kyrs BP, the karstification processes bathymetrically moved down to 150 m of present water depth, creating small caves, karren and kamenitza features. After most parts of the karst had been formed and sealevel might had started to rise slowly at the end of the LGM, scleractinians started to grow on the cemented slope. This is in good agreement with the dates of 17 ±1 kyrs BP obtained by VEEH & VEEVERS (1970) on corals (*Galaxea clavus* (DANA)) 175 m deep in the Middle Great Barrier Reef.

The rapid sealevel rise recorded during the last deglaciation, averaging 10 mm/yr (FAIRBANKS 1989), interrupted sediment transport off the wall and created new space for accommodation as soon as the wall was flooded. During this interruption, hardgrounds and laminar micritic crusts were formed and lithified. The results from BRACHERT & DULLO (1991) demonstrate that this type of hard ground and laminar micrite was formed under conditions of rapidly rising sealevel. During this rapid sealevel rise, the surface of the starved cemented slope would correspond to a diastem, thus, recording a typical drowning unconformity as reported by GRAMMER & GINSBURG (1992). This is verified by textural evidence (i.e. boring) indicating that the surface of the slope is a submarine hardground.

The build-ups located on top of the deeper forereef terrace at 90 m/100 m water depth, represent a coralgal succession, frequently beginning with shallow-water stony corals and ending in an encrustation by a *Leptoseris* framework. This indicates a classical drowning event. According to our present knowledge, the process of deglaciation is marked by pulses of meltwater input. They are recorded both in deep sea sediments (BERGER 1990) and in drilled coral reefs (FAIRBANKS 1989, BARD et al. 1990).

As soon as the rate of sealevel rise decreased around 6 kyrs BP (COLONNA 1994), potential space for the accumulation of reef-derived sediments became more and more limited. Therefore, carbonate sediments have to be exported into deep-water environments. Since then, the unlithified sedimentary wedge has started to accumulate at the base of the cemented slope.

5 Conclusions

- Shallow-water reefs grew between 80 m and 90 m of present water depth during late isotope stage 3 (50-26 kyrs BP) comprising the uppermost part of the wall and probably forming the prominent terrace at that depth. Related talus sediments occur deeper within the lower part of the wall or of the cemented slope.

- Maximum lowering of sealevel due to LGM conditions led to karstification and dissolution features down to 150 m water depth. A thin shallow-water coral veneer started to grow almost at the end of the LGM recorded as in situ fabrics as well as bioclasts within coeval talus sediments.
- Rapidly rising sealevel after the onset of deglaciation soon flooded the top of the wall and created new space for sediment accommodation. Therefore, sediment transport off the wall was interrupted leading to the formation of hardgrounds on the ledges due to sediment starvation.
- Coeavally reefs started to grow on top of the wall at 100 m and 90 m water depth forming small-scale mounds 3 m high. They are covered now by a deep-water coral community. These reefs were presumably drowned due to the Bølling melt water pulse (14 kyrs BP). Shallower reef mounds presently at 65 m/55 m may have drowned due the melt water pulse of the Younger Dryas (11.5 kyrs BP).

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