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Differential Vertical Crustal Movements Deduced from Late Holocene Coral-Rich Conglomerates: Farquhar and St. Joseph Atolls (Seychelles, Western Indian Ocean)

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ABSTRACT

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Petrological analysis and radiometric dating of samples collected from coral-rich conglomerates in two remote Seychelles atolls suggest differential emergence (1.2 m in Farquhar, 0.8 m in St. Joseph) since the almost simultaneous deposition of the conglomerate material, about one thousand years ago. This confirms that tectonically the Seychelles area was relatively unstable during late Quaternary times, as already suggested by a previous study.

ADDITIONAL INDEX WORDS: *Coral reef, petrological analysis, atoll, Seychelles, Indian Ocean, sea level, vertical movements.*

INTRODUCTION

In January and February 1986, under the auspices of Project IGCP-200 "Sea level correlation and applications," an international expedition, aboard the R/V *Professor Shtokman* of the Institute of Oceanology of the Academy of Sciences of the USSR, was devoted to palaeogeographic and geomorphological investigations in shelf and coastal areas of the western Indian Ocean (Kaplin *et al.*, 1986). This gave an opportunity for a short visit to a few small oceanic islands, remote and difficult to access.

In this paper a comparison is made between results obtained in Farquhar (10°11′S, 51°07′E) and in St. Joseph (5°25′S, 53°20′E) Islands, suggesting the occurrence of slight differential crustal movements during the late Holocene.

GEOLOGICAL SETTING AND PREVIOUS WORK

The geodynamic history and the geologic and tectonic settings of this area of the western Indian Ocean have been outlined by RABINOVITZ *et al.* (1983), BRAINTHWAITE (1984) and MART (1988). In the Amirante Arc, only coral atolls and sand cays are exposed today and no igneous rocks are known (BAKER, 1963). Between the Amirante Islands (Seychelles) and Madagascar, small marine plateaux, the origin of which is not clear, rise from depths of over 2000 m. They bear Farquhar and a few other small islands (Providence, St. Pierre, *etc.*) (Figure 1). Farquhar Atoll consists of a small number of coral sand islands located near the northeast rim of a slightly submerged bank, 9 to 21 km wide, and is located about halfway between Cape Amber, the north point of Madagascar, and the Amirante Trench. It was discovered by Joâo de Nova in 1504 and renamed in 1824 after Sir R. Farquhar, Governor of Mauritius (Lionnet, 1970). In 1905 it was visited by the Percy Sladen Trust Expedition. Geomorphological information on the atoll has been provided mainly by GARDINER and COOPER (1907), GARDINER (1936), BAKER (1963), and especially by STODDART and POORE (1970), BAT-

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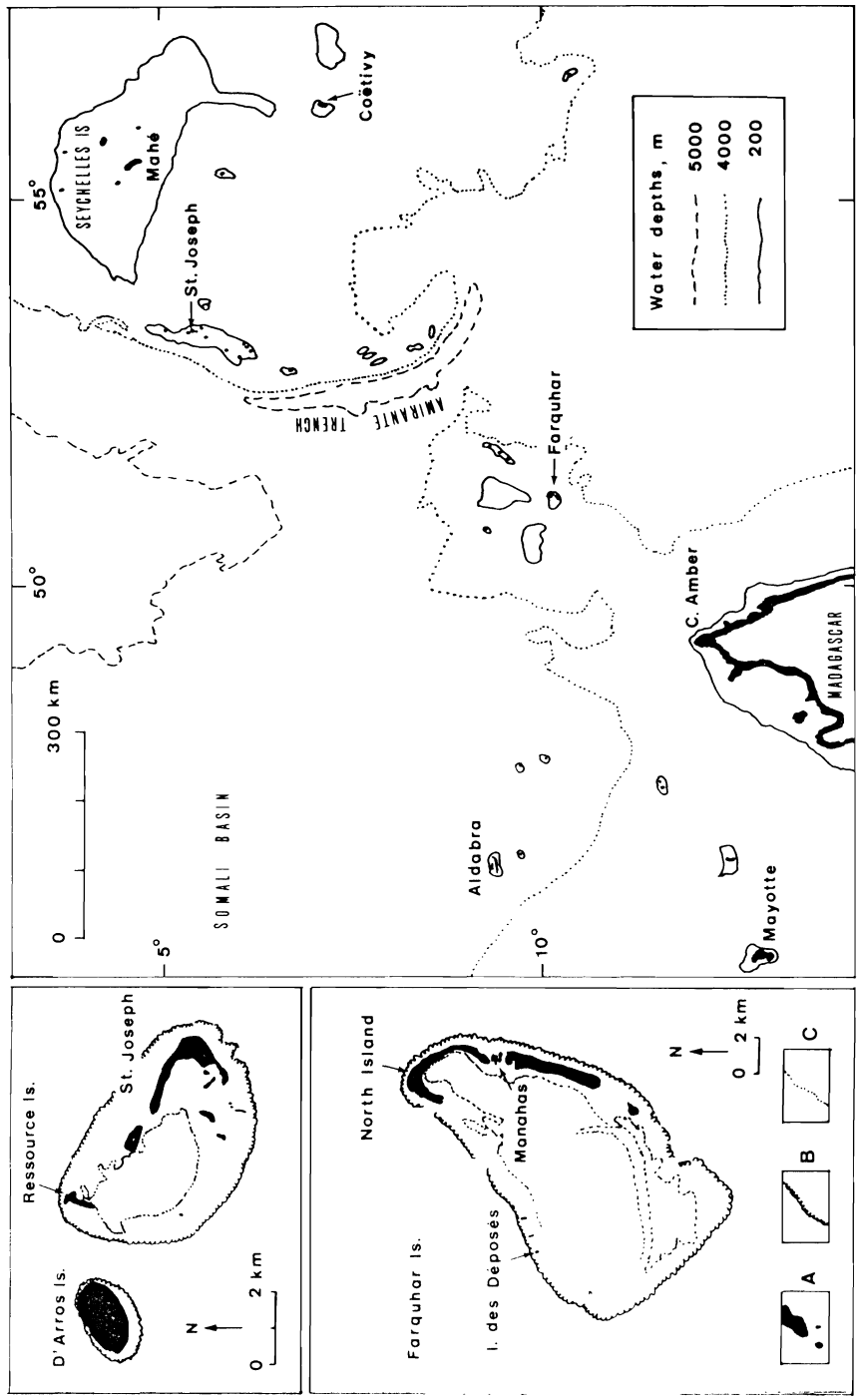
SEYCHELLES IS
Mahé
St. Joseph
Coëtivy
AMIRANTE TRENCH
Farquhar
C. Amber
MADAGASCAR
Aldabra
Mayotte
SOMALI BASIN
55°
50°
5°
10°
0 300 km
Water depths, m
5000
4000
200
Ressource Is.
St. Joseph
D'Arros Is.
N
0 2 km
North Island
Manahas
I. des Deposés
Farquhar Is.
A
B
C

TISTINI (1977) and BATTISTINI and JOUANNIC (1979).

Evidence of emergence in Farquhar has been reported by GARDINER (1936) from the northwestern part of the atoll, where isolated masses of rock on the outer sides of the surrounding reef and on small islets (Ile du Milieu, Ile des Lapins, Ile des Déposés), sparsely scattered with small encrusting corals, are interpreted (p. 432) as remnants "of an almost or quite continuous reef that stood up for 10 feet or more above the water level and formerly surrounded the whole bank." STODDART and POORE (1970), though they did not visit these islets, estimate that "they may be storm-cast reef-blocks." BATTISTINI (1977) and BATTISTINI and JOUANNIC (1979) describe these rocky masses as compact limestone, including large coral heads, some of which are in growth position, and recemented coralline breccias. On the small islets they are capped with storm ramparts and vegetation. Two coral samples, collected from this compact limestone on the Ile des Déposés at the highest tide level, were dated 3100 ± 700 (Th/U) and 3640 ± 100 (^{14}C) yr BP respectively. A third sample, collected 0.5 m higher than the highest tide level, was dated 4900 ± 600 yr BP. This would indicate, according to BATTISTINI and JOUANNIC (1979), a former sea-level stand about 2 m above present.

In the eastern part of Farquhar Atoll, indications of recent emergence are less elevated. They consist of slightly emerged beachrocks and conglomerates around the northern part of North Island and especially in the Manaha Islands, where the surface of conglomerate flagstones stands about 0.5 m above high water level (STODDART and POORE, 1970). This surface could correspond, according to BATTISTINI and JOUANNIC (1979), to a former sea-level stand a little over one metre higher than at present, *i.e.*, about one metre lower than in the northwest part of the atoll. As noted by STODDART and POORE (1970), there is a clear similarity between the conglomerates and shallow channels around the Manaha Islands and the *hoa* in the Tuamotu Islands (South Pacific).

St. Joseph is an atoll, 4 to 6 km in diameter, located on the east side of the Amirante Bank, which is situated near the western tip of the Seychelles Bank, on the east side of the Amirante Trench. Geomorphological information is extremely scarce and fragmentary in the Amirantes. From St. Joseph, ecology and geomorphology observations have been reported by STODDART and COE (1979). *Hoa*-like features have been described in St. Joseph by BAKER (1963, p. 54) as follows: "The reef has a well developed outer ramp on all sides except the west.... There are openings in the reef margin but no deep passes communicating with the lagoon, which spills its water at tide changes through a number of narrow channels."

Figure 1 (*facing page*). Location map. (A) emerged land; (B) outer reef margin; (C) lagoon reef margin.

METHODS

According to the method used by MONTAGGIONI and PIRAZZOLI (1984) in coral reef areas of the South Pacific, especially near the Tuamotu *hoa*, relative sea-level drops can generally be determined from petrological analysis of exposed skeletal conglomerates. This is obtained by sampling the conglomerates on vertical sections, at several levels between the present-day low-tide level and the upper part of the outcrops, and identifying by petrological analysis the possible diagenetic boundary between two different marine environments of cementation (phreatic and vadose) for the first generation of intergranular cements. In the absence of moating phenomena, this boundary is considered to be related to the former mean low-tide level at the time of cementation. The difference in elevation between this boundary and the present-day mean low tide level is regarded as corresponding to the relative sea-level change which has occurred since the early lithification of the rubbly deposit concerned. Radiocarbon dating of aragonitic coral fragments, sampled from the deposit near the boundary level, will provide useful indications of the maximum age of the former sea level.

This method, which has been applied successfully to atolls and barrier reefs of French Polynesia (for detailed references, see PIRAZZOLI and MONTAGGIONI, 1988), is used here for the first time on Indian Ocean reef material.

Measurements of altitude have been referred to the tide levels predicted by the Admiralty Tide Tables at D'Arros Island (for St. Joseph) and at Farquhar, with reference to Zanzibar. However, no tide gauge is in operation now in either of the two atolls. Possible deviations of meteorological origin from the tide levels pre-

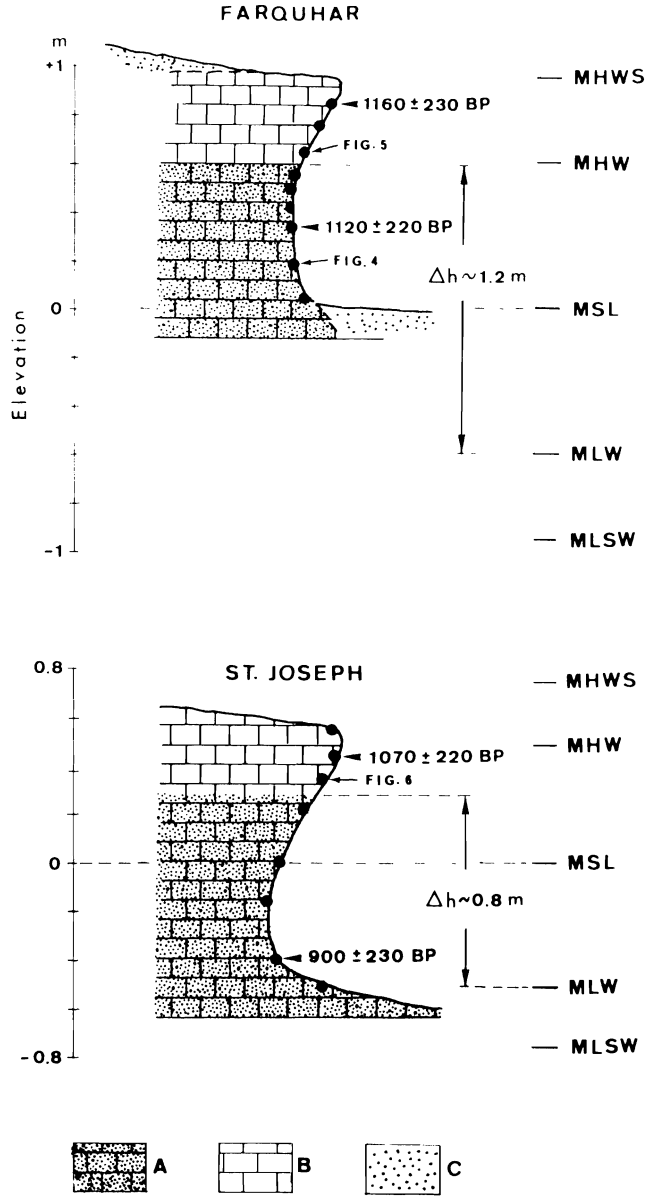

Figure 2. Position of the samples analysed in Farquhar and St. Joseph, in relation to the former marine environments of cementation and of the present tide levels. (A) zone of former marine phreatic environment; (B) zone of former marine vadose environment; (C) recent sand deposits.

dicted during the field work could not be checked. Nevertheless, it seems unlikely that such deviations, if they existed, could have been of the same order as the differences in level measured between the two islands.

RESULTS

In spite of the brevity of our visit, which prevented us from carrying out systematic geomorphological surveys, and particularly unfavourable meteorological conditions in Far-

Figure 3. Sampling of the Manahas conglomerate in Farquhar Atoll (photo P.A. Pirazzoli).

quhar, which made it impossible to reach the islets dated by BATTISTINI and JOUANNIC (1979), detailed observation and sampling could be carried out on conglomerate sections at Farquhar and at St. Joseph.

At Farquhar, nine samples have been collected from a single vertical profile of a conglomerate formation developed on the northernmost side of the Manahas (Figures 2 and 3), and then analyzed. The samples consist of calcirudite rich in foraminifers, coral and coralline algal particles. Their vertical position on the profile is indicated in Figure 2 in relation to the present mean sea level (MSL).

The lower four samples, up to +0.4 m, show only one generation of cements, with a dense, structureless micrite matrix, typical of the marine phreatic zone (Figure 4). The next two samples, between +0.45 and +0.55 m, exhibit two successive generations of cements: (1) a dense, structureless micrite matrix; and (2) the lateral development of micrite crystals in a "grain-contact" attitude, or thin rims of aragonite fibres with truncated crystal ends. Here cementation has occurred twice, within the marine phreatic, then in the marine vadose zone.

Above +0.6 m, samples show diagenetic fea-

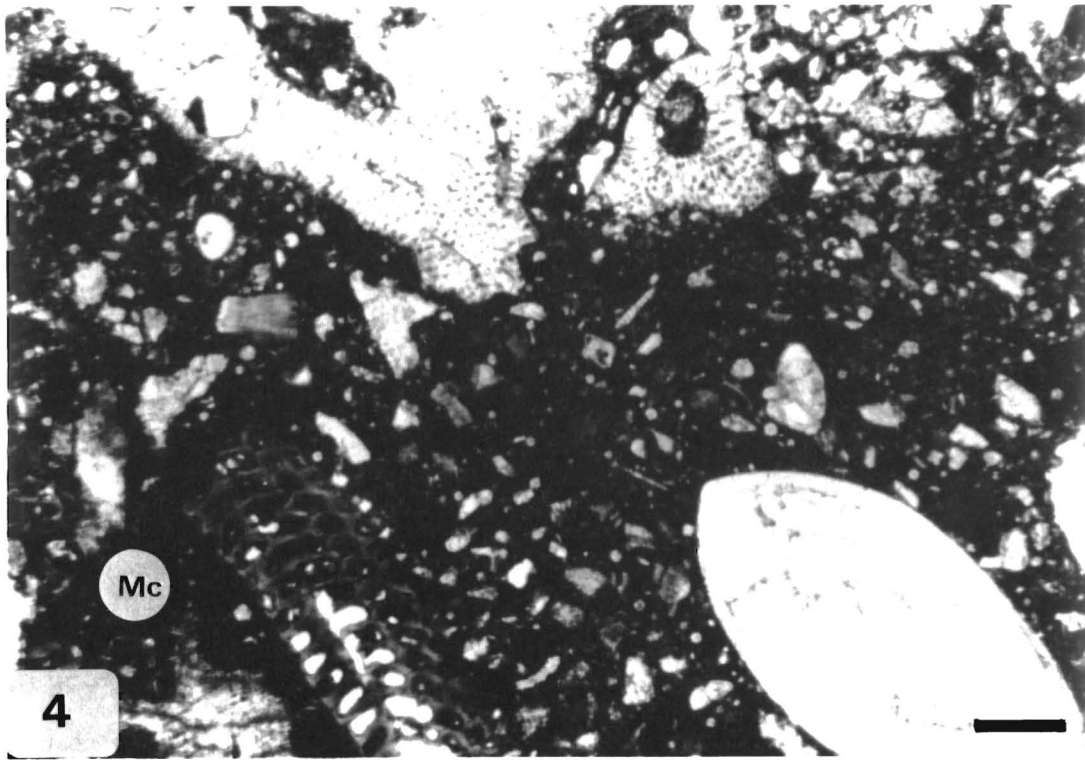

Figure 4. Typical marine phreatic cement-matrix infilling, from the lower sequence of exposed onglomerates in Farquhar Atoll (sample 6FA2, situated at about +0.2 m above present MSL): occurrence of a dense, structureless micrite matrix (Mc), completely infilling all the interparticular pore spaces available. (Scale = 250 μm).

tures typical of the marine vadose zone only: one or several successive generations of cements in a grain-contact attitude, fibrous rims with truncated crystal ends in the form of meniscus and/or local microstalactites or dripstones (Figure 5). Porosity, which is usually less than 25–30% in the lower six samples, increases to 30–40% in the upper three.

The boundary between the two former environments of cementation (phreatic and vadose) for the first generation of intergranular cements, can be situated between 0.55 and 0.60 m above the present MSL in the Manahas conglomerates and the relative sea-level drop since early lithification can be estimated at about 1.2 m. Two coral samples, collected at about +0.3 m and +0.85 m (in relation to MSL) have been dated 1120 ± 220 yr BP (MGU-1094) and 1160 ± 230 yr BP (MGU-1092), respectively.

At St. Joseph, eight samples have been collected from a conglomerate exposure near Resource Islet and analyzed (Figure 2). The lower five samples, up to about +0.25 m, are typified by very poorly sorted, mainly silt-supported material (wackstone, wackstone-packstone), one single generation of dense micritic matrices and low residual porosity (10–25%). The three upper samples, above +0.35 m, are characterized by less poorly sorted, silt- to grain-supported material (packstone, packstone-grainstone), two generations of cements both exhibiting typical non-phreatic features (grain-contact, bridge-contact and/or microstalactites) (Figure 6) and high residual porosity (30–50%).

The boundary between the former marine phreatic and vadose zones should be localized between 0.25 and 0.35 m above the present MSL in the St. Joseph's conglomerate and the relative sea-level drop since early lithification can

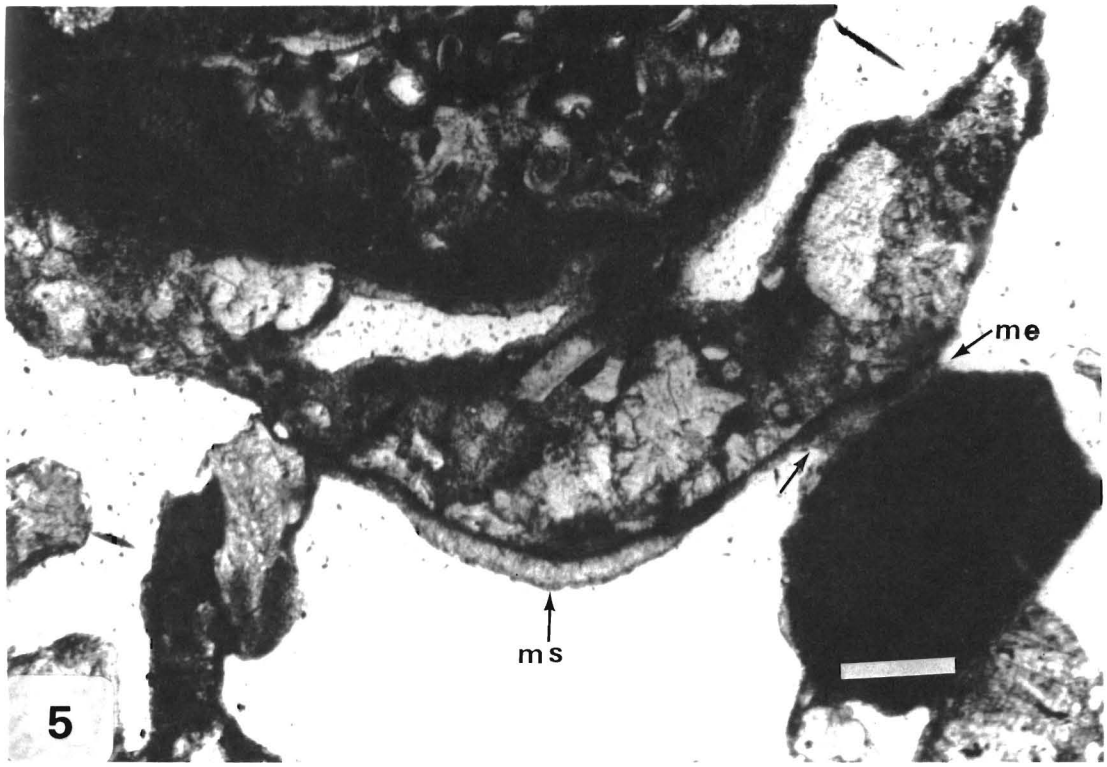

Figure 5. Typical marine vadose cements from the upper sequence of exposed conglomerates in Farquhar Atoll (sample 6FA7, situated at about +0.65 m above present MSL): occurrence of cement rims in a pendant (microstalactitic) attitude (ms) and in the form of meniscus (me). Note the remaining high residual porosity. (Scale = 100 μm).

be estimated at about 0.8 m. Two coral samples, collected at about −0.4 m and at +0.45 m (in relation to MSL), have been dated 900 ± 230 yr BP (MGU-1101) and 1070 ± 220 yr BP (MGU-1097), respectively.

DISCUSSION AND CONCLUSION

The radiocarbon ages obtained from the coral conglomerates of Farquhar and St. Joseph are very near to each other and statistically indiscernible. This suggests that the skeletal debris forming the conglomerates was deposited on the reef flat of the two atolls at about the same time, ca. one thousand years ago, during a short period of increased storminess, or during a major tropical cyclone or tsunami. The mean low water level at that time corresponds to the boundary between the former marine phreatic and vadose zones identified in the conglomerates. Since that time, differential vertical crustal movements have occurred, making emergence in Farquhar greater than in St. Joseph and in other Seychelles Islands. According to the data provided by BATTISTINI and JOUANNIC (1979), this emergence trend is at least 4000 years old in Farquhar.

Eustatic fluctuations may have contributed to the relative sea-level changes observed in this part of the Indian Ocean. BADYUKOV *et al.* (1986), in particular, mention the possibility of a small sea-level drop around 1000–500 yr BP in this area. It is worth noting, however, that indications of Holocene emergence are conspicuously absent not only throughout the granitic islands of the Seychelles (STODDART, 1984; MONTAGGIONI and HOANG, 1988), but also in isolated atolls such as Coëtivy (KAPLIN and PIRAZZOLI, 1989). In contrast, elevated coral formations dating from the last interglacial period have been reported from several granitic

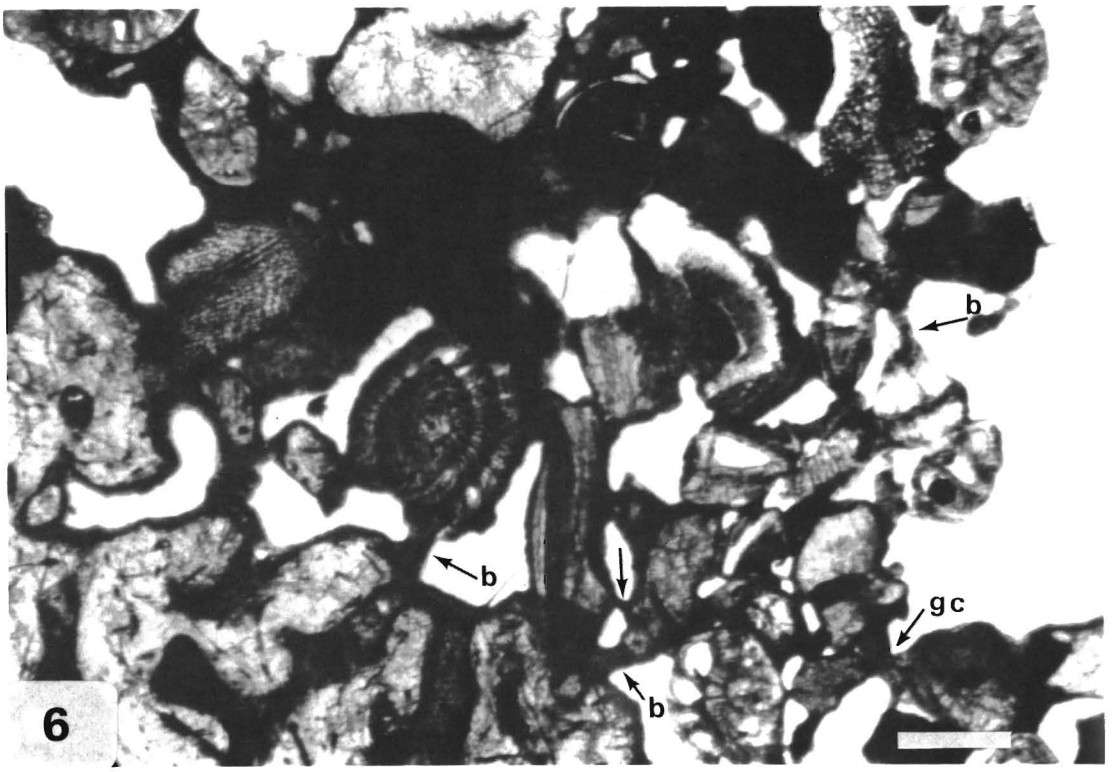

Figure 6. Typical marine vadose matrices from the upper sequence of exposed rubbly deposits on St. Joseph Atoll (sample RS 1.50, collected at +0.45 m above present MSL): occurrence of scattered patches of dense micrite matrix, laterally changing into thin rims in a grain-contact attitude (gc) or in the form of bridges between adjacent grains (b). (Scale = 100 μm).

islands (VEEH, 1966; MONTAGGIONI and HOANG, 1988), but are completely absent from atolls such as Farquhar, St. Joseph or Coëtivy. This tends to confirm the conclusion reached by MONTAGGIONI and HOANG (1988) of relative tectonic instability in the Seychelles area in late Quaternary times, with local movements presumably caused by either hydroisostatic or thermal processes and changing from place to place.

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LITERATURE CITED

BADYUKOV, D.D.; DEMIDENKO, Y.L.; KAPLIN, P.A. and NIKOLAEV, S.D., 1986. Geomorphology and late Pleistocene development of the Seychelles and Amirante shoal-banks (in Russian with English abstract). *Okeanologija*, 26(2), 273–281.

BAKER, B.H., 1963. Geology and mineral resources of the Seychelles archipelago. *Geological Survey Kenya, Memoir n°* 3, 140p.

BATTISTINI, R., 1977. Un atoll à morphologie énigmatique: Farquhar (Seychelles). *Bull. Assoc. Géogr. Franç.*, 444, 195–204.

BATTISTINI, R. and JOUANNIC, C., 1979. Recherches sur la géomorphologie de l'atoll Farquhar (Archipel des Seychelles). *Atoll Research Bulletin,* 230, 1–20.

BRAINTHWAITE, C.J.R., 1984. Geology of the Seychelles. *In*: D.R. Stoddart, (Ed.), *Biogeography and Ecology of the Seychelles Islands*. Junk, The Hague: pp. 17–38.

GARDINER, J.S., 1936. The reefs of the western Indian Ocean. I. Chagos archipelago; II. The Mascarene region. *Trans. Linnean Society London,* 19, 391–436.

GARDINER, J.S. and COOPER, C.F., 1907. Description of the Expedition (Percy Sladen Expedition to the Indian Ocean in 1905). Transactions Linnean Society London (Zoology), 2, 12, 1–55, 111–175.

KAPLIN, P.A. and PIRAZZOLI, P.A., 1989. A geomorphological reconnaissance of Coëtivy Atoll (Seychelles, Indian Ocean). *Atoll Research Bulletin,* 319, 1–8.

KAPLIN, P.A.; PIRAZZOLI, P.A.; PAVLIDES, Y.; MEDVEDEV, V.S. and BADENKOV, Y., 1986. Sea level and environmental changes in shelf areas of the western Indian Ocean. *Journal of Coastal Research*, 2(3), 363–367.

LIONNET, J.F.G., 1970. Names of islands. *Atoll Research Bulletin*, 136, 221–224.

MART, Y., 1988. The tectonic setting of the Seychelles, Mascarene and Amirante plateaus in the western equatorial Indian Ocean. *Marine Geology*, 79, 261–274.

MONTAGGIONI, L.F. and HOANG, C.T., 1988. The last interglacial high sea level in the granitic Seychelles, Indian Ocean. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 64, 79–91.

MONTAGGIONI, L.F. and PIRAZZOLI, P.A., 1984. The significance of exposed coral conglomerates from French Polynesia (Pacific Ocean) as indicators of recent relative sea-level changes. *Coral Reefs*, 3, 29–42.

PIRAZZOLI, P.A. and MONTAGGIONI, L.F., 1988. Holocene sea level changes in French Polynesia. *Palaeogeography,Palaeoclimatology,Palaeoecology*, 68, 153–175.

RABINOWITZ, P.D.; COFFIN, M.F. and FALVEY, D., 1983. The separation of Madagascar and Africa. *Science*, 220, 67–69.

STODDART, D.R., 1970. Coral islands of the western Indian Ocean. *Atoll Research Bulletin*, 136, 1–5.

STODDART, D.R., 1971. Environment and history in Indian Ocean reef morphology. *Symposia Zoological Society London*, 28, 3–38.

STODDART, D.R., 1984. Coral reefs of the Seychelles and adjacent regions. *In:* D.R. Stoddart (Ed.), *Biogeography and Ecology of the Seychelles Islands.* Junk, The Hague: pp. 63–81.

STODDART, D.R., and COE, M.J., 1979. Geography and ecology of St. Joseph Atoll. *Atoll Research Bulletin*, 223, 27–42.

STODDART, D.R. and POORE, M.E.D., 1970. Geography and ecology of Farquhar Atoll. *Atoll Research Bulletin*, 136, 7–26.

VEEH, H.H., 1966. $^{230}Th/^{238}U$ and $^{234}U/^{238}U$ ages of Pleistocene high sea level. *Journal Geophysical Research*, 71, 3379–3386.

□ RESUMEN □

Los análisis petrológicos asi como las dataciones radiométricas efectuadas a las muestras de coral tomadas en dos atolones de Seychelles, sugieren una emergencia diferencial (1.2 m en Farquhar, 0.8 en St. Joseph) dado que la deposición del material se realizó simultáneamente hace unos mil años. Esto confirma que tectónicamente el área de Seychelles fue relativamente inestable durante el último periodo del Cuaternario, como se ha sugerido en estudios anteriores.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ RÉSUMÉ □

L'analyse pétrographique et la datation radiométrique d'échantillons prélevés de conglomérats récifaux en deux atolls éloignés des îles Seychelles indiquent une différence dans l'émersion (1,2 m à Farquhar, 0,8 m à Saint-Joseph) depuis le dépôt presque simultané des matériaux des conglomérats, il y a environ mille ans. Ceci confirme la relative instabilité tectonique de la région des Seychelles à la fin du Quaternaire, qui avait été déjà suggérée par une étude antérieure.

□ ZUSAMMENFASSUNG □

Petrographische Analysen und radiometrische Datierungen von Proben, welche aus korallenreichen Konglomeraten von 2 abseits liegenden Seychellen-Atollen geborgen wurden, weisen auf unter-schiedliche Hebung (1,2 m in Farquhar, 0,8 m in St. Joseph) seit gleichzeitiger Ablagerung der Konglomerate vor ca. 1000 Jahren hin. Das bestätigt, daß das Seychellen-Gebiet im Spätquartär relativ instabil war, wie bereits frühere Studien angedeutet haben.—*Dieter Kelletat, Essen/FRG.*