

Jens Zinke · John J. G. Reijmer · Marco Taviani ·
Wolf-Christian Dullo · Bernard Thomassin

Facies and faunal assemblage changes in response to the Holocene transgression in the Lagoon of Mayotte (Comoro Archipelago, SW Indian Ocean)

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Abstract This paper documents the facies change in response to the Holocene transgression within five sediment cores taken in the lagoon of Mayotte, which contain a Type-1 depositional sequence (lowstand, transgressive and highstand deposits underlain by an erosive sequence boundary). Quantitative compositional analysis and visual examination of the bioclasts were used to document the facies changes. The distribution of the skeletal and non-skeletal grains in the lagoon of Mayotte is clearly controlled by (1) the rate and amplitude of the Holocene sea-level rise, (2) the pre-Holocene basement topography and (3) the growth-potential of the barrier reef during sea-level rise, and the changes in bathymetry and continuity during this period. The sequence boundary consists of the glacial karst surface. The change-over from the glacial lowstand is marked by the occurrence of mangrove deposits. Terrigenous and/or mixed terrigenous-carbonate muds to sandy muds with a mollusc or mollusc-ostracod assemblage dominate the transgressive deposits. Mixed carbonate-siliciclastic or carbonate sand to gravel with a

mollusc-foraminifer or mollusc-coral-foraminifer assemblage characterize the early highstand deposits on the inner lagoonal plains. The early highstand deposits in the outer lagoonal plains consist of carbonate muds with a mollusc-foraminifer assemblage. Late highstand deposits consist of terrigenous muds in the nearshore bays, mixed terrigenous-carbonate sandy muds to sands with a mollusc-foraminifer assemblage on the inner lagoonal plains and mixed muds with a mollusc-foraminifer assemblage on the outer deep lagoonal plains. The present development stage of the individual lagoons comprises semi-enclosed to open lagoons with fair or good water exchange with the open ocean.

Keywords Lagoonal communities · Quantitative compositional analysis · Systems tracts · Sea-level changes · Comoro Archipelago · Holocene

Introduction

The volcanic island of Mayotte belongs to the Comoro archipelago, which is situated in the SW Indian Ocean in the mid-northern area of the Mozambique Channel (Fig. 1). The island of Mayotte is surrounded by an almost continuous barrier reef system, which encircles a large lagoon, 1,500 km² and up to 80 m deep. The Holocene barrier reef sequence is up to 20 m thick and rests on an older reefal framework of Pleistocene age (Camoin et al. 1997).

After an extended period of subaerial exposure during the preceding glacial, barrier reef growth started again at 9.2 kyr B.P. (Camoin et al. 1997; Zinke et al. 2003a). Recolonisation of the lagoon floor was controlled by (1) the rate and amplitude of sea-level rise in combination with (2) changes in hydrodynamic parameters within the shallow-water areas, (3) light penetration and (4) water turbidity within the water column, (5) nutrient supply, but also (6) by the pre-Holocene substrate conditions (Zinke et al. 2001, 2003a, 2003b). At present, the water exchange between the lagoon and the open ocean is determined by the bathymetry and continuity of the barrier reef, which

J. Zinke (✉) · W.-C. Dullo
IFM-GEOMAR, Leibniz-Institut für Meereswissenschaften,
Wischofstrasse 1-3, Kiel, 24148, Germany
e-mail: zinj@geo.vu.nl

M. Taviani
Istituto di Scienze Marine, Sez. Geologia Marina,
Consiglio Nazionale delle Ricerche,
Via Gobetti 101, 40129 Bologna, Italy

B. Thomassin
Centre d'Océanologie de Marseille,
Station marine d'Endoume,
Chemin de la batterie des Lions, 13007 Marseille, France

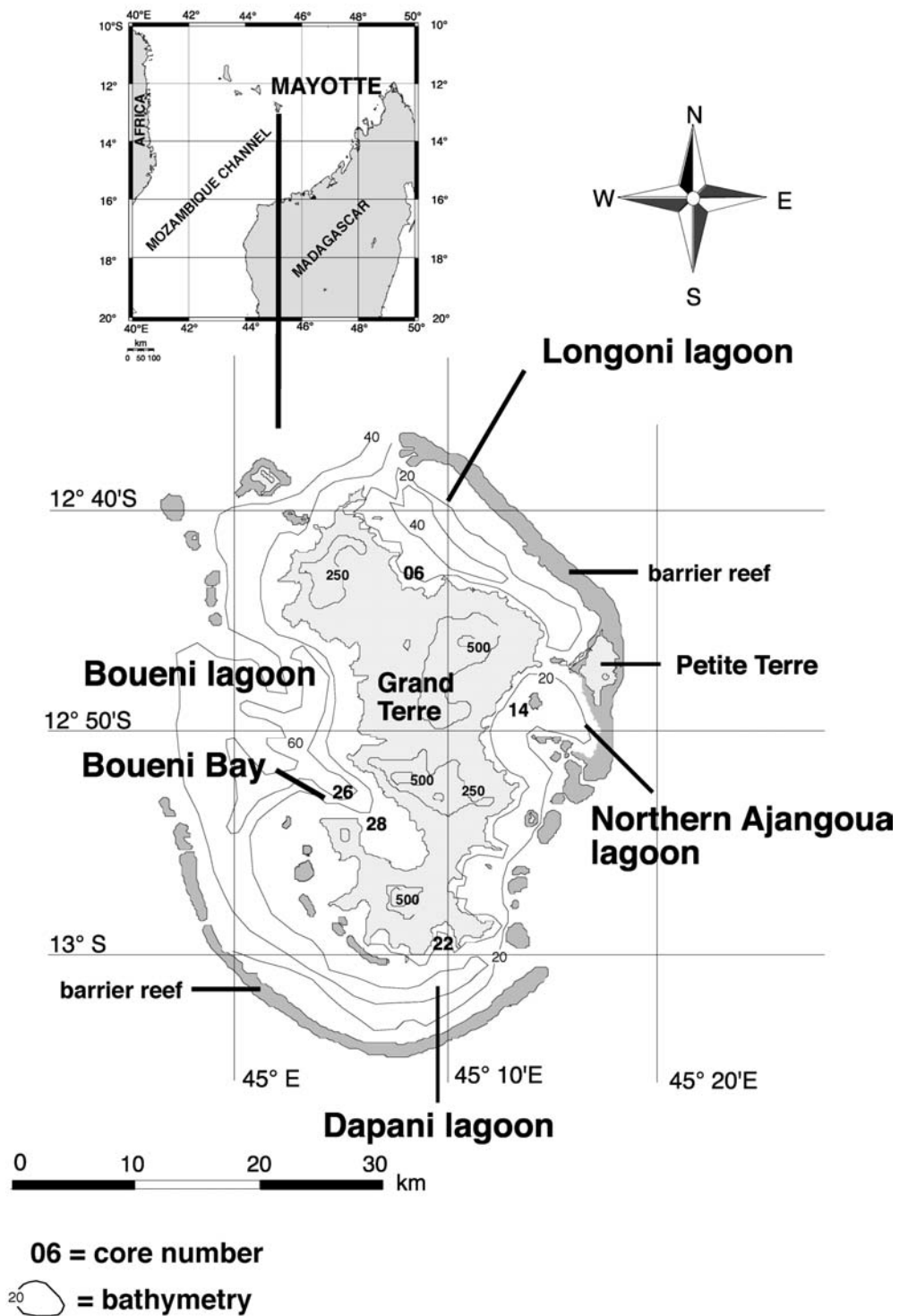
Present address:

J. Zinke, Vrije Universiteit Amsterdam, FALW,
De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands

Present address:

J. J. G. Reijmer, Université de Provence (Aix-Marseille I),
Centre de Sédimentologie-Paléontologie FRE, CNRS 2761
"Géologie des Systèmes Carbonatés",
3, place Victor Hugo, Case 67, 13331 Marseille Cédex 3, France

Fig. 1 Locality map of the island of Mayotte located in the northern area of the Mozambique Channel. The locations of the studied cores are indicated (after Zinke et al. 2003b)



was determined by pre-Holocene topography and the growth potential of the reef. During the Holocene transgression the lagoon changed into an increasingly enclosed sedimentary basin. This change over affected the distribution of the benthic and pelagic biogenic community. Paulay (1990) divided the reef and lagoonal development during the Holocene transgression into four successive, contiguous stages:

Stage 1: rapid flooding and submergence of Pleistocene reefs;

Stage 2: keep-up or catch-up of reefs to sea level forming a barrier to the surrounding ocean, but still with water exchange;

Stage 3: largely closed communication between lagoon and surrounding ocean; and

Stage 4: dying lagoon, where conditions became unfavourable for normal marine life. The habitat formation and the faunal development are tightly linked to these development stages.

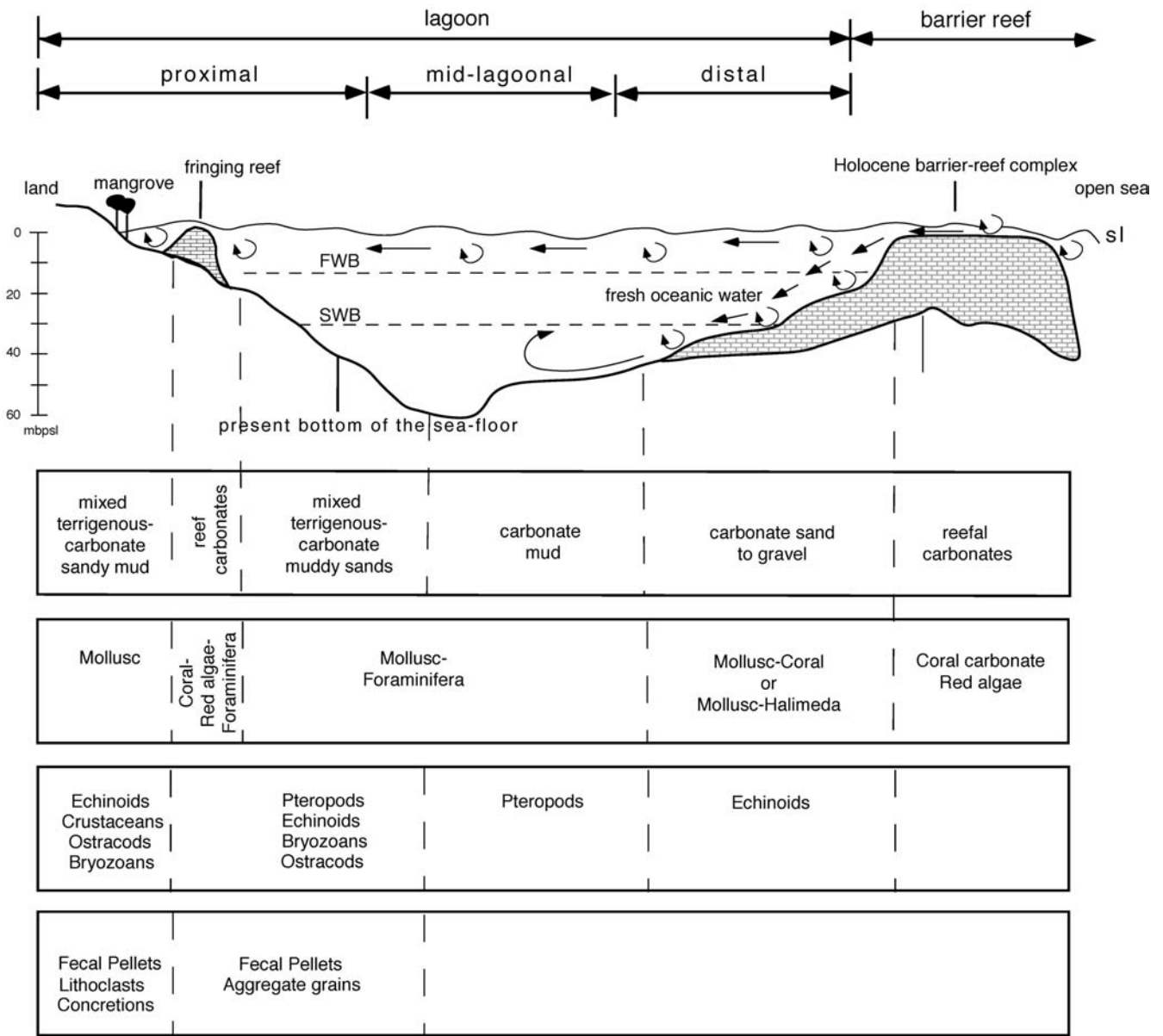


Fig. 2 Idealized section through the lagoon/reef system from Mayotte showing the relationship between physiography and sediment constitution (from Zinke et al. 2003b). Sediment texture,

major skeletal grains, minor skeletal grains and non-skeletal grains for individual facies realms are indicated

This study documents the faunal changes in response with respect to the Holocene transgression based on the study of five sediment cores taken from the lagoon of Mayotte. We will infer the development stages of different areas within the lagoon of Mayotte throughout the Holocene based on changes of the faunal assemblages and the sedimentary habitat as shown in the individual cores.

Previous studies

Quantitative bioclastic analysis of skeletal and non-skeletal grains, grain-size distribution and texture from Recent reefal and lagoonal environments of Mayotte were described in detail in several descriptive studies (Masse et

al. 1989; Thomassin et al. 1989; Kouyoumontzakis et al. 1991). Five main sedimentary facies were recognized (Fig. 2): (1) coral-mollusc facies on the outer barrier reef slope, (2) coral-calcareous red algae facies on reef flats, (3) mollusc-coral and/or (4) mollusc-*Halimeda* facies on the lagoonal floor with coral build-ups or the lagoonal plains with single coral colonies, and (5) mollusc-foraminifer facies on lagoonal plains. Molluscs dominate muddy substrates because of the trophic regime related to terrigenous input from the hinterland (Masse et al. 1989). The bioclastic assemblage and the granulometry shows that the bulk of the sandy fraction only showed minor transport (Masse et al. 1989). The mud fraction content in the bulk sediment was the major environmental discrimination factor of the individual facies realms (Masse et al.

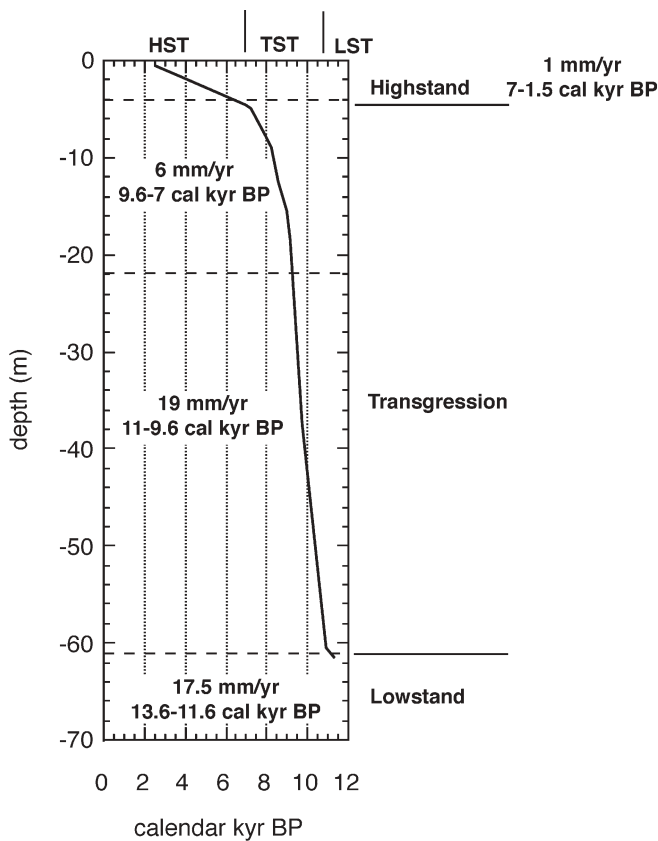


Fig. 3 Reconstructed sea-level curve on the basis of examination of in-situ samples from the fore-slopes of the barrier reef, a barrier reef core, four fringing reef cores and four sediment cores from the lagoon of Mayotte (after Zinke et al. 2003a). Average rates of sea-level rise are indicated for specific time intervals. *LST* lowstand systems tract, *TST* transgressive systems tract, *HST* highstand systems tract

1989). The foraminifer assemblages found not only characterize specific granulometric variations but also differ between terrigenous and carbonate-dominated environments (Kouyoumoumtzakakis 1989; Kouyoumoumtzakakis et al. 1991). The Recent ostracod assemblage, described by Babinot and Kouyoumoumtzakakis (1995), encompasses thirtynine species from thirtyfive genera. They predominantly comprise Cytheracea and Bairdiacea with less common Cypridacea. The Recent bivalve fauna was described by Maggiorani-Charpentier and Maggiorani (1989) and Gout et al. (1989).

A brief summary of the bioclastic composition of Holocene sediments within the lagoon of Mayotte, based on two sediment cores from the northeastern and southwestern lagoon, was given by Thomassin et al. (1991). Elmoutaki (1991) and Elmoutaki et al. (1992) studied the palynological association in one Holocene sediment core from the southwestern lagoon as well as several Recent sediment surface samples from all lagoonal areas. The sedimentary response to the Holocene transgression, including sequence stratigraphic, geochemical, and grain-size analysis, was recently described by Zinke (2000) and Zinke et al. (2000, 2001, 2003b). The sea-level curve for

Mayotte island is well documented (Colonna et al. 1996; Camoin et al. 1997, 2004; Dullo et al. 1998; Zinke et al. 2003a) and is based on the analysis of coral samples collected from the foreslopes using a submersible and by cores drilled into the eastern Pamandzi barrier reef and the the lagoonal deposits (Fig. 3).

Materials and methods

Core sites were selected along seismic profiles. Sediment cores were taken with a Kullenberg type piston corer of 8 m length using drain pipes as liners. After recovery, the sediment surface was marked on the core tubes to record compaction effects during storage and transport. Core recovery was almost 100%. The cores were cooled during ship and land transport. The cores were cut with a standard saw at the IFM-GEOMAR in Kiel (Germany). One half was reserved for sampling while the other half was archived. All cores halves were stored at 10°C in the IFM-GEOMAR core repository.

Subsamples were taken on one half every 10 cm in the core. Bulk sediment samples were wet-sieved and split into a coarse (>63 μm) and a mud fraction (<63 μm). The weighed coarse fraction was further divided into subfractions through dry-sieving; very fine sand (63–125 μm), fine sand (125–250 μm), medium sand (250–500 μm), coarse sand (500–1,000 μm) and very coarse sand to gravel (>1,000 μm). Each subfraction was weighed and stored in preweighed glass vials.

The subfractions of the coarse fraction (0.125– >1 mm) were divided into representative sub-samples with a microsplitting device. These subsamples were evenly spread out on a sample tray for counting. For each sub-sample of each subfraction, 500 grains were counted using a binocular microscope. Absolute weight-percentages of components in bulk sediment were calculated by multiplying the relative percentages of components with the weight-percentages of the coarse fraction (0.125– >1 mm). This procedure eliminates the dilution effect produced by the terrigenous sediment, fine-fraction input.

Sixteen sedimentary constituents have been identified and the non-identifiable components were grouped separately. In addition, thin-sections of all facies types were made to identify problematic carbonate grains:

- major skeletal grains: mollusc shells and fragments (benthic bivalves and gastropods, pteropods etc.), foraminiferans (Rotalida, Miliolida, Textulariida), echinoid spines and plates, crustacean fragments, ostracod shells and coral fragments;
- minor skeletal grains: bryozoan fragments, ophiurid ossicles, alcyonarian and sponge spicules and worm tubes.
- non-skeletal grains: lithoclasts, ferrallitic concretions, pellets, aggregate grains and plant remains;

The detailed quantitative compositional analysis was carried out on three sediment cores that cover the typical Holocene facies succession in the inner and outer lagoon: two cores from the southwestern Bouéni lagoon (MAY.KL.89026 and MAY.KL.89028) and one from the southern Dapani lagoon (MAY.KL.89022) (Figs. 4, 5, 6, Fig. 7). The varying composition is described for lowstand, transgressive, early highstand and late highstand deposits and their indicative facies. Two cores, MAY.KL.89006 (NE-Longoni lagoon; Fig. 8a) and MAY.KL.89014 (E-Ajangoua lagoon; Fig. 8b), were only visually examined for their distribution of skeletal and non-skeletal grains.

The lithologic description of the sediments follows Masse et al. (1989). The terms carbonate or terrigenous define the dominant source of the muddy sediments.

To establish a chronological framework of the postglacial sedimentation processes within the lagoon, organic matter or carbonate fossils were sampled at specific levels within the individual cores for conventional and AMS- ^{14}C -datings (Table 1). The radiocarbon

ages are calculated with the 5568 years half-life. The radiocarbon ages were all converted to calendar years before present (1950 A.D.) using the program CALIB 4.3 (Stuiver et al. 1998). Marine samples were calibrated with the marine calibration curve, where a standard reservoir age correction of 400 years is included (MARINE.98; Stuiver et al. 1998). The organic samples were calibrated with the dendrochronological calibration curve (INTCAL.98; Stuiver et al. 1998).

Results

The standard postglacial to Holocene facies succession starts with a basal ferralitic soil, which is followed by mangrove peat, terrigenous mud, mixed terrigenous-carbonate sandy muds, carbonate mud or sandy mud (Fig. 4a–e). In the nearshore bays sedimentation terminates with mixed terrigenous-carbonate mud to sandy mud, and terrigenous mud (Fig. 4e, f), partly due to anthropogenic influences.

Ferralitic soil

Overlying the basaltic bedrock or last interglacial lagoon sediments, a few meter thick soils are developed, which consist of dark to reddish brown clay (cores MAY.KL.89022, MAY.KL.89026, MAY.KL.89028; Figs. 4a, c, 5, 6, 7). No macrofauna was found in these soils. The soil top terminates at 12 kyr B.P. in the deep

channels and at about 9.7 kyr B.P. in the nearshore areas (Figs. 5–7).

Dark organic clay and mangrove peat

Meter thick dark organic clays (cores MAY.KL.89026) with plant and root remains overlie the ferralitic soils in the deeper channels and date between 12 and 11.2 kyr B.P. (Elmoutaki et al. 1992; Zinke et al. 2003a, 2003b). The clays are progressively replaced by peat containing pneumatophores of *Rhizophora* mangrove trees. The mangroves flourished between 11.2 and 10.8 kyr B.P. (core MAY.KL.89026). The pollen assemblage in the mangrove peat points to dense deciduous forests reflecting high transport rates of terrestrial material into the lagoon in a humid climate (Elmoutaki et al. 1992).

Terrigenous mud to sandy mud with a mollusc assemblage

The terrigenous mud to sandy mud overlying the mangrove peats and organic clays is observed in core MAY.KL.89028 between 9.8 and 9.5 kyr cal B.P. (Fig. 4b). Ferralitic concretions and lithoclasts are frequently observed (Figs. 4a (top) and 5). Large molluscs, associated with either marine (*Anadara* sp., cardiiids, *Saccostrea* sp., *Sheldonella lateralis*, *Septifer bilocularis*,

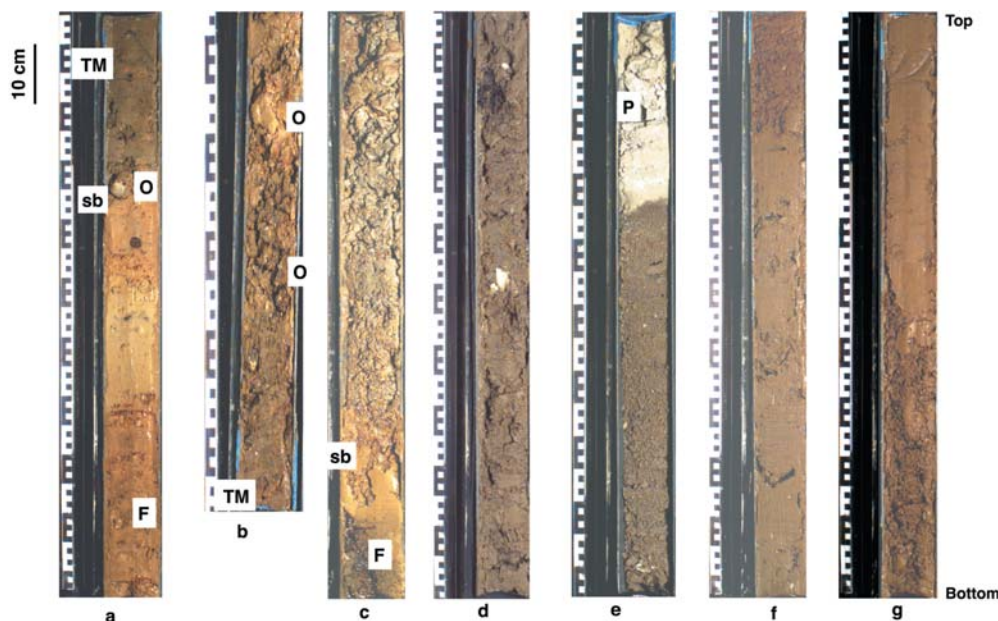


Fig. 4 Selected photographs of vibrocores; scale in cm. **a** Terrigenous mud (TM) on top of ferralitic soil (F) in core MAY.KL.89028, 2.5–2.3 m depth in core (O Oyster, sb sequence boundary). **b** Mixed terrigenous-carbonate mud to sandy mud on top of terrigenous mud in (TM) core MAY.KL.89028, 2–2.5 m depth in core (O Oyster). **c** Carbonate sand to gravel on top of ferralitic soil (F) in core MAY.KL.89022, 2–3 m depth in core (sb

sequence boundary). **d** Carbonate muddy sand in core MAY.KL.89028, 1–2 m depth in core. **e** Mixed terrigenous-carbonate mud of the early highstand systems tract in core MAY.KL.89006, 5.15–5.75 m depth in core (volcanic pumice (P), 4.85–5.15 m). **f** Mixed terrigenous mud in core MAY.KL.89014, 1–2 m depth in core. **g** Terrigenous mud in core MAY.KL.89022, 0–1 m in core

core MAY.KL.89028

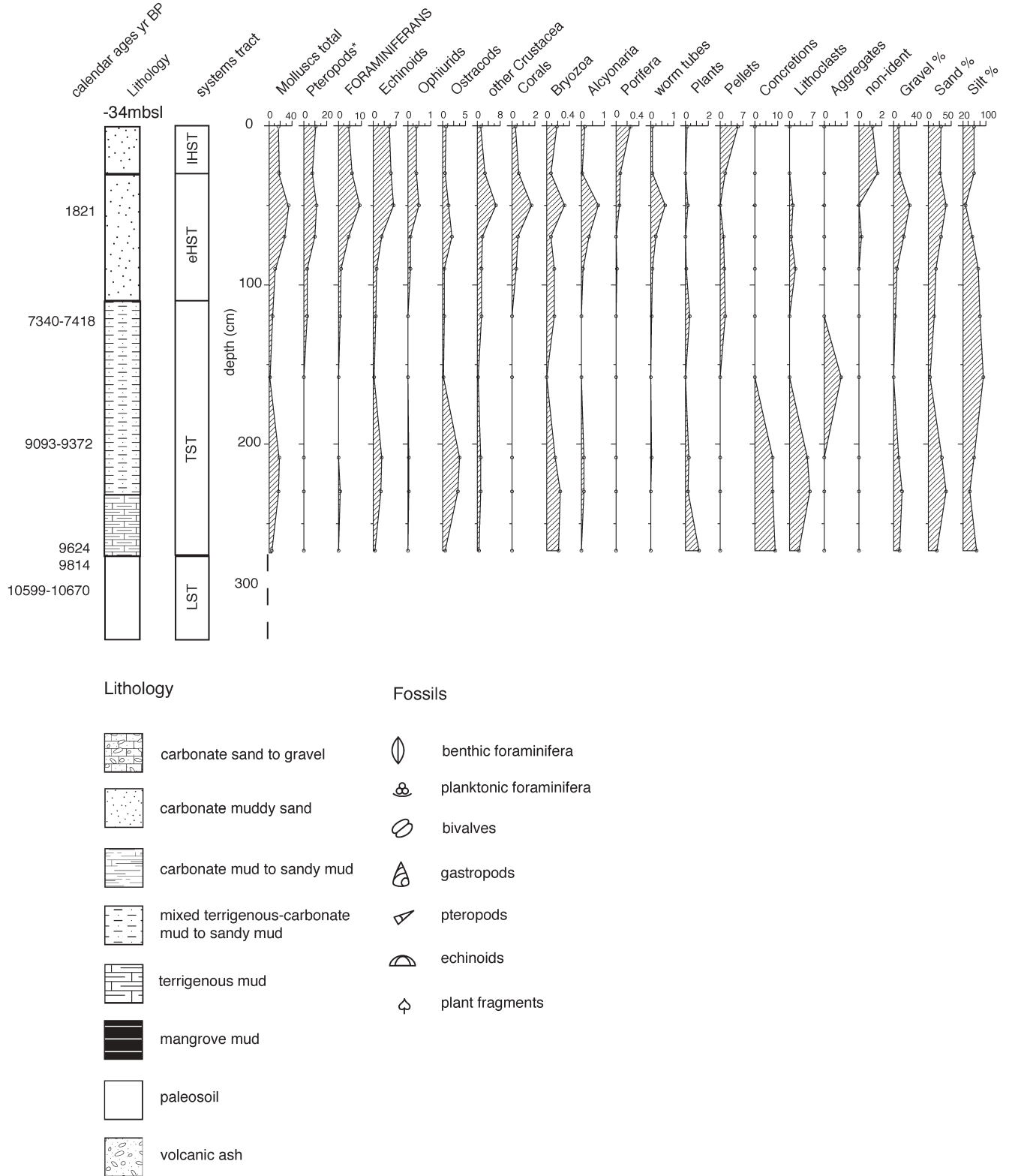


Fig. 5 Results of component analysis for core MAY.KL.89028 from the proximal SW-Bouéni lagoon. Values are reported as absolute weight-percentages of the bulk sediment. *TST* transgressive systems

tract, *eHST* early highstand systems tract, *IHST* late highstand systems tract. The lithology is indicated in the legend

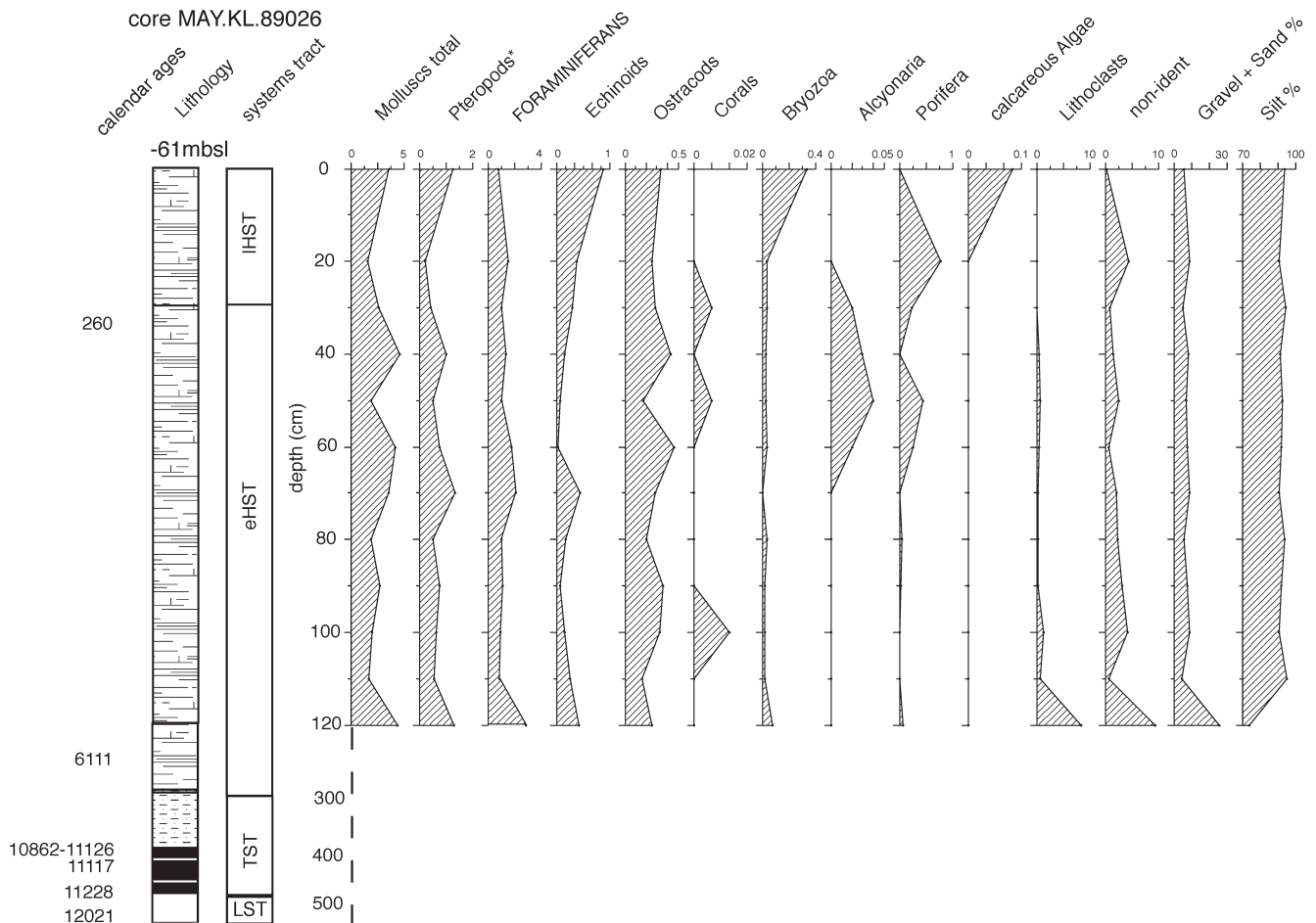


Fig. 6 Results of component analysis for core MAY.KL.89026 from the mid-lagoonal SW-Bouéni lagoon. Values are reported as absolute weight-percentages of the bulk sediment. *eHST* early high-

stand systems tract, *IHST* late highstand systems tract. See Fig. 4 for legend

Chama sp., “*Tellina*” sp., solecurtid sp., veneraceans) or mangrove environments (*Cerithium* sp., oysters), occur in concentrated amounts (Thomassin et al. 1991; Figs. 4a (top) and b and 5; Annex 1). Gastropods are mostly cerithiaceans (*Cerithium nesioticum*, *Finella pupoides*, *Cerithidium* sp., *Scaliola* sp.) other discopods (*Vitrinella* sp.), and cephalaspidean opisthobranchs (*Ringicula* sp., *Chrysallida* sp.; Annex 1). Ostracods, echinoids and crustaceans show higher percentages (Figs. 5 and 6). The ostracod assemblage indicates a nearshore littoral environment in very shallow water (Babinot, personal communication). Foraminifera are rare (Annex 1).

Mixed terrigenous-carbonate mud to sandy mud with a mollusc assemblage

Mixed terrigenous-carbonate muds to sandy muds are observed in cores MAY.KL.89026 and MAY.KL.89028 (Figs. 4b, 5 and 6). They cover a time period between 9.5 and 8.5 kyr cal B.P. in the nearshore bays (core MAY.KL.89028, Fig. 4b) and 11 and 7.5 kyr cal B.P. in the deep lagoonal plains (core MAY.KL.89026, Fig. 6).

Locally, the mixed terrigenous-carbonate facies is absent probably due to marine erosion (core MAY.KL.89022, Figs. 4c and 7). Ferralitic concretions and lithoclasts are nearly absent in the mixed terrigenous-carbonate mud to sandy mud, while pellets and aggregate grains become more abundant at specific levels (Figs. 5 and 7). The aggregate grains consist of small bioclasts (<0.063 mm) that are stuck together with mud-“lumps/clasts” and plant remains. Molluscs are the dominant skeletal component. At the same time a remarkable increase in the percentage of benthic gastropods can be observed over bivalves (*Nucula* sp., arcids, “*Tellina*” sp., veneraceans) with skeletal assemblages dominated by small cerithiaceans (mainly *Finella pupoides*), other discopods (“*Vitrinella*” sp.), ptenoglossids (*Epitonium* sp., *Eulima* sp.), cephalaspidean opisthobranchs (*Ringicula* sp., *Retusa* sp., *Cylichna* sp., *Acteocina* sp.) and minor amounts of juvenile shells belonging to columbellids and conids (core MAY.KL.89028, Fig. 5). The first occurrence of holoplanktic input is marked by the appearance of thecosomatous pteropods (*Creseis acicula*) at 1.60 m-core depth in core MAY.KL.89028 with an approximate age of 8.5 kyr B.P. (Figs. 4d and 5). Foraminifera also appear,

core MAY.KL.89022

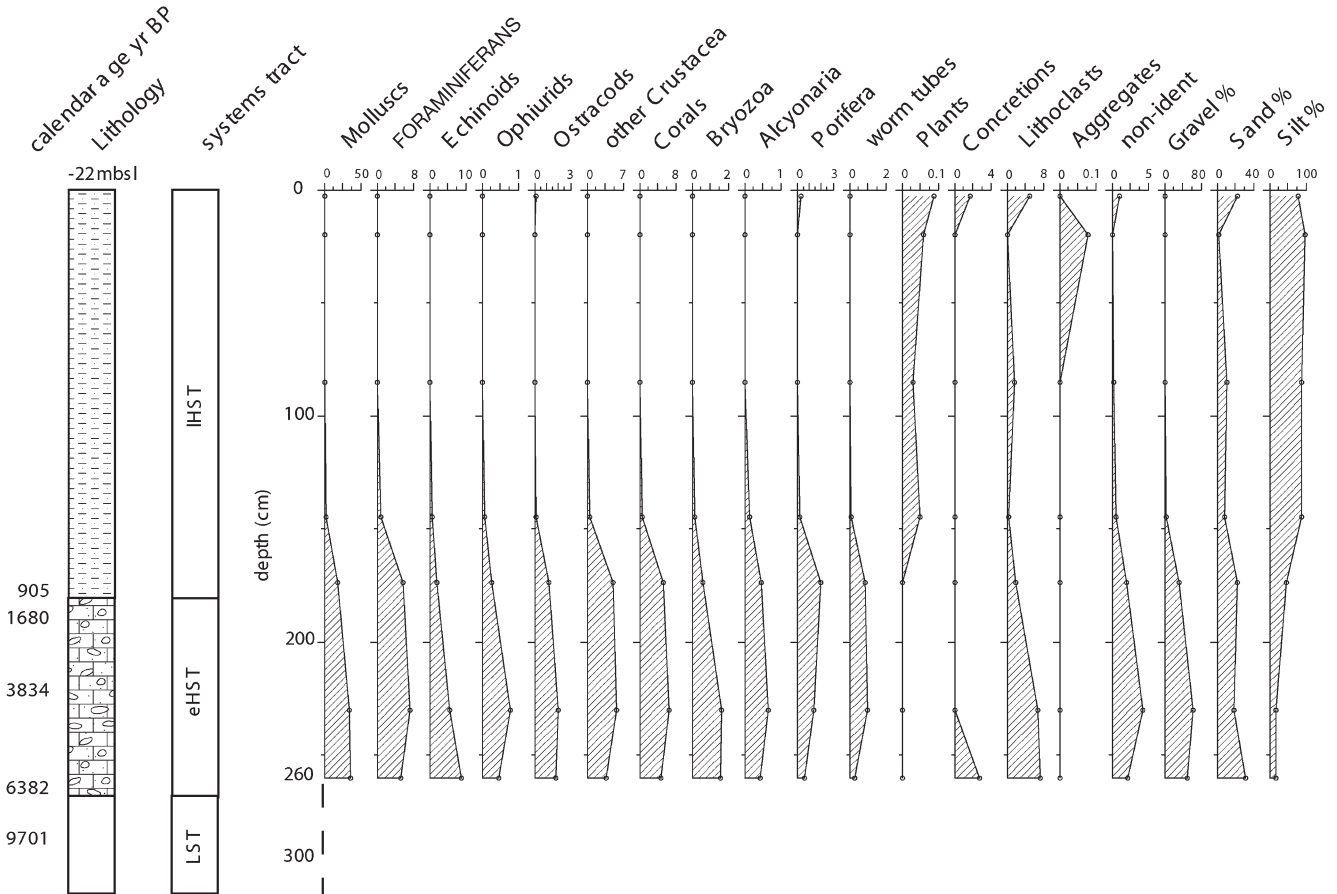


Fig. 7 Results of component analysis for core MAY.KL.89022 from the proximal S-Dapani lagoon. Values are reported as absolute weight-percentages of the bulk sediment. *eHST* early highstand

systems tract, *IHST* late highstand systems tract. See Fig. 5 for legend

however with very low abundance, with a dominance of Rotaliida (A 1). The occurrence of both planktonic foraminiferans and pteropods suggests an enhanced water exchange between the lagoon and the surrounding ocean. At the boundary from the transgressive to the early highstand deposits (1.1–1.2 m in core MAY.KL.89208, Fig. 5), which is the time of maximum flooding, pteropods became the dominant skeletal component. Echinoids, crustaceans and ostracods are also present (Fig. 5). The diverse ostracod assemblage suggests a normal marine environment in a sheltered lagoonal position (Babinot, personal communication).

bivalves (*Nucula* sp., *Barbatia* sp., pectinids, *Hyotissa* sp., *Tellina* sp., *Pitar* sp., veneraceans), gastropods (*Finella pupoides*, *Cerithium nesioticum*, *Cerithium* sp., *Eulima* sp., *Odostomia* sp., *Retusa* sp., *Cylichna* sp.) and pteropods, are the most abundant skeletal component with a clear dominance of thecosomatous pteropods (*Creseis acicula*). Foraminifera are the second major component and echinoids are also common (Fig. 6).

Carbonate mud to sandy mud
with a mollusc-foraminiferan assemblage

Carbonate muddy sand
with a mollusc-foraminiferan assemblage

Carbonate muds to sandy muds overlying the mixed terrigenous-carbonate muds are well preserved in core MAY.KL.89026 from the deep lagoonal plain and also occur in the eastern Ajangoua lagoonal plains (Fig. 6; Zinke et al. 2003b). This facies prevails only in the deep lagoonal plains for the last 7.5 kyr. Molluscs consisting of

The carbonate muddy sands are well preserved in core MAY.KL.89028 and cover the time interval between 7.4 kyr cal B.P. to the present (Fig. 5). This facies type occurs in the nearshore slopes with low terrigenous input at intermediate depths (25–40 m). Molluscs and foraminiferans are the dominant skeletal grains (Figs. 5 and Fig. 9d–f). Thecosomatous pteropods (*Creseis acicula*) and small bivalves (*Sheldonella lateralis*, *Striarca symmetrica*, *Chama* sp., *Bellucina* sp., “*Tellina*” sp., *Gafrarium* sp., veneraceans, *Cardiomya* cf. *alcocki*)

Table 1 List of radiocarbon dates obtained for the sediment cores from the lagoon of Mayotte (from Zinke et al. 2003b). The radiocarbon ages were converted into calendar ages with the calibration program Calib 4.3. (data sets INTCAL.98 and MARINE.98) after Stuiver et al. (1998)

Sample number	Depth in core (m)	Material	¹⁴ C-ag yr B.P.	Cal age yr B.P.	Delta ¹³ C ^a	pMC ^b
MAY.KL.89006, water depth: 31 m, 12°42'45"S, 45°08'40"E						
KIA5207	0.26	Organic	310±20	315	-24.68±0.16	96.23±0.28
KIA5208	0.63	Organic	710±0	663	-26.34±0.14	91.54±0.30
KIA5209	2.17	Organic	3640±30	3945	-31.29±0.14	63.53±0.22
KIA5210	2.97	Bivalve	4960±30	5295	-0.95±0.20	53.95±0.22
KIA5211	5.71	Gastropod	6370±40	6810	-1.31±0.17	45.26±0.21
MAY.KL.89014, water depth: 34 m, 12°49'00"S, 45°13'04"E						
KIA5212	0.65	Bivalve	2590±30	2293	-0.14±0.18	72.46±0.28
KI4328	1.06	Oyster	2870±55	2689	1.35	n.d
KI4329	1.41–1.44	Oyster	3780±50	3695	2.03	n.d
KIA5213	3.52	Oyster	4260±30	4381	3.00±0.09	58.86±0.22
KIA5214	4.22	Gastropod	6040±40	6444	-0.61±0.15	47.14±0.25
KI4330	5.18–5.23	Oyster	5520±65	5900	1.62	n.d
MAY.KL.89022, water depth: 26 m, 12°58'80"S, 45°09'08"E						
KIA5903	1.84	Gastropod	1345±35	905	2.14±0.15	84.56±0.36
KIA5904	1.94	Bivalve	2090±35	1680	1.82±0.29	77.08±0.34
KI4386#	2.30	Bivalve	3880±50	3834	2.62	n.d
KIA5905	2.60	Coral	5965±50	6382	2.60±0.18	47.59±0.30
KIA11560	2.80	Organic	8737 ±43	9701	-28.17±0.10	33.70±0.18
MAY.KL.89026, water depth: 56 m, 12°52'35"S, 45°05'25"E						
LGQ597*	0.20–0.30	Bivalve	350±280	350	n.d	n.d
LGQ598*	1.70–1.80	Bivalve	5700±970	6111	n.d	n.d
LGQ599*	3.55–3.62	Bivalve	10190±190	10862–11126	n.d	n.d
LGQ600*	3.65–3.70	Organic	9650±190	11117	n.d	n.d
LGQ601*	4.45–4.49	Organic	9860 ±210	11228	n.d	n.d
LGQ602*	5.20–5.50	Organic	10270±410	12021	n.d	n.d
MAY.KL.89028, water depth: 37 m, 12°54'00"S, 45°06'18"E						
KIA5204	0.50	Organic	1870±30	1821	-29.66±0.17	79.24±0.25
KIA5205	1.13	Organic	6460±30	7340–7418	-28.96±0.15	44.74±0.19
KI4331	2.04	Oyster	8750±70	9093–9372	1.03	
KIA8739	2.73	Coral	9020±100	9624	-4.68±0.14	32.55±0.41
KI4332	2.75	Oyster	9150±95	9814	0.98	
KIA5206	2.97	Organic	9420±40	10599–10670	-28.10±0.08	30.94±0.16

The calibrated ages are given as the midpoint of 1σ range ± half width of this range in calibrated years. True age of sample between these extremes for 2σ probability

KI samples conventional-dated at the Leibniz Laboratory (Kiel, Germany)

KIA samples AMS-dated at the Leibniz Laboratory (Kiel, Germany)

An Asterisk and the sign LGQ indicates samples dated with the conventional ¹⁴C-method at the Gif-sur-Yvette laboratory (France)

^a Please note that for the AMS dates δ¹³C includes the fractionation occurring in the sample preparation as well as in the AMS measurement and therefore are less significant for the original sample as compared to the conventional technique

^b Corrected "pMC" indicates the fraction of modern (1950) carbon corrected for fractionation using the ¹³C measurement

n.d. not determined

dominate over benthic gastropods (*Finella pupoides*, *Diala* sp.; Fig. 9d–f). The latter reaching the highest percentages throughout the core. Foraminifera and ostracods become more diverse (Annex 1). Crustaceans, echinoids and coral fragments are also common (Fig. 5).

Carbonate sand to gravel with a mollusc-foraminiferan-coral assemblage

This facies type is preserved in core MAY.KL.89022 and occurs at steep nearshore slopes with strong longshore currents (Fig. 4c (top 60 cm) and 7). Lithoclasts show relatively high percentages (7%) at the lithologic boundary at 2.6 m in core MAY.KL.89022 at which level also ferrallitic concretions are present (Fig. 4c (bottom) and 7). Mollusc assemblages are very diverse and well preserved showing the dominance of gastropods and bivalves over

scaphopod shells (Annex 1). The gravelly bioclastic section at 2.60–2.70 m is enriched by epifaunal (*Arca* sp., *Acar plicata*, *Chama* sp., *Cardita* sp., oysters) and infaunal (*Nucula* sp., *Vasticardium* sp.) bivalves, predatory (*Natica* sp., *Gyrineum pusillum*, *Chicoreus* sp., *Nassarius* sp., *Vexillum* sp., *Cylichna* sp.) and suspensivore (*Turritella* sp.) gastropods (Fig. 9g, h; Annex 1). The gastropod component is dominated by small cerithioideans (*Finella pupoides*, *Cerithidium perparvulum*, *C. diplax*, *Diala semistriata*, *Scaliola* sp., *Styliferina goniochila*), other discopods (*Turritella* sp., *Cerithium* sp., *Microliotia* sp., *Caecum* spp., "Vitrinella" sp., capulid sp., vermetid sp., *Natica* sp.; Fig. 9g; Annex 1), vetigastropods (*Diodora* sp.), ptenoglossans (*Cerithiopsis* sp., triphorid sp., *Epitonium* sp., *Eulima* sp.), neogastropods (*Chicoreus* sp., *Nassarius* sp., *Gibberula* sp.), heterostrophs (orbitestellid sp., and the pyramidellids *Odostomia* sp., *Turbonilla* sp., *Odetta* sp., *Chrysallida* sp., *Hervieria*

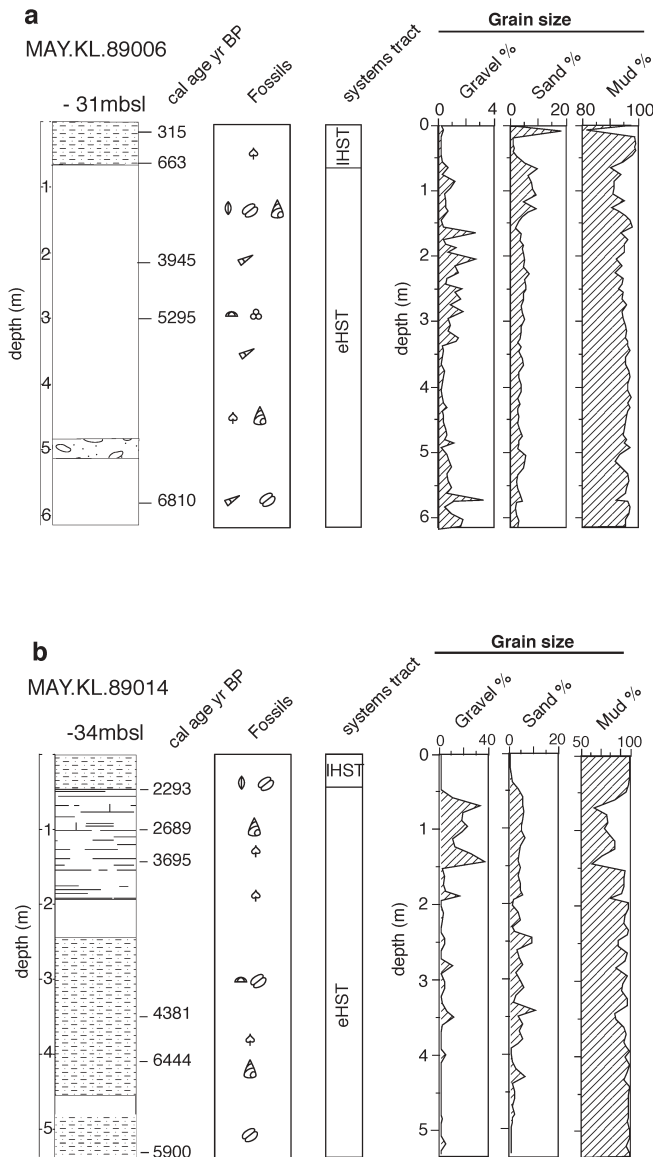


Fig. 8 Results of the visual inspection of the skeletal and non-skeletal composition of **a** the core MAY.KL.89006 from Longoni lagoon and **b** core MAY.KL.89014 from the N-Ajangoua lagoon. The textural composition of the cores is also indicated. *eHST* early highstand systems tract, *IHST* late highstand systems tract. See Fig. 5 for legend

gleriella, *Gurmatia pulchrior*) and cephalaspidean opisthobranchians (*Ringicula* sp., *Retusa* sp., *Cylichna* sp., *Tornatina* sp.). Bivalves include both infaunal and epifaunal forms such as protobranchs (*Nucula* sp.), pteriomorphs (*Arca* sp., *Acar plicata*, *Sheldonella lateralis*, *Septifer bilocularis* and oysters), heterodonts (*Pillucina* sp., *Bellucina* sp., and veneraceans) and scaphopods (*Dentalium* sp., *Fustiaria* sp.). Thecosomatous pteropods (*Creseis acicula*) are less abundant. Echinoids, bryozoans, ostracods, serpulid polychaete tubes, coralline algae, foraminiferans, crustaceans and corals are common (Figs. 7, 9g, h). The Foraminifera assemblage is typical for a sandy nearshore environment (Kouyoumouzkakis,

personal communication; Annex 1). The ostracod assemblage indicates a normal marine environment (Babinot personal communication).

Mixed terrigenous-carbonate mud to sandy mud with a mollusc assemblage

This facies type is present in nearshore bays with significant terrigenous input over the last 7 kyr in cores KL.89006 and KL.89014 (Figs. 4e and f, 9a–c).

The bioclastic assemblage consists mostly of molluscs, echinoids, ostracods and foraminiferans. Molluscs are the most dominant skeletal grains throughout the early highstand deposits (Annex 1). Bivalves (veneraceans) and gastropods show equal percentages and are mostly concentrated in the fine to medium sands (Fig. 9a, b). The gastropods are very diverse and exquisitely preserved; the assemblages are dominated by small cerithiaceans (*Finella pupoides*) together with *Nassarius* sp. and *Cylichna* sp. (Fig. 9a, b). An enormous amount of holoplanktic (globigerinds and thecosomatous pteropods *Creseis acicula*) and meroplanktic organisms (triphorid larval stage) mixed with small cerithiaceans (*Finella pupoides*, *Diala* sp.), *Cerithium* sp., “*Vitrinella*” sp., *Natica* sp., *Eulima* sp., *Chrysallida* sp., *Cylichna* sp., *Acteocina* sp.; and few bivalves (veneraceans) characterize the significant open marine input (Fig. 9a, c). Foraminifera are restricted to a small number of species (mainly *Bolivina*) and occur only in the fine to very fine sand fraction (Fig. 8, Annex 1). Crustacean fragments, echinoid fragments and spines, and ostracod shells are abundant. Pellets and aggregate grains are frequently observed.

Fig. 9 Selected photographs of skeletal grains in four sediment cores. **a** MAY.KL.89014, 1 m in core, 250–500 μ m, pteropod-gastropod assemblage; bioclasts include whole and fragmented shells of thecosomatous pteropods (*Creseis acicula* = CR) and benthic gastropods (cerithioids = CE), *Turritella* sp. (TU), echinoid spines (EC), and bivalve fragments (BI); bar = 1 mm; **b** MAY.KL.89014, 3.82 m in core, 250–500 μ m, cerithioids (CE), *Creseis acicula* (CR), echinoids (EC), other small bivalves (BI), scale bar as in **a**; **c** MAY.KL.89006, 1.80 m in core, 250–500 μ m, mostly veneraceans (Ve), *Finella pupoides* (Fi), worm tubes (Wo), serpulid fragments (Se), echinoids (Ec) and decapod crustacean fragments (De), scale as in **b**; **d** MAY.KL.89028, 5 cm in core, >1 mm, coarse bivalve-rich assemblage; pectinid (PE), arcid (*Arca* = AR), chamid (*Chama* = CH), veneracean (VE) and other bivalves; bar = 1 mm; **e** MAY.KL.89028, 50 cm in core, 250–500 μ m, ostracod-gastropod-bivalve facies; bioclasts include various species of ostracods (OS), cerithioids (CE) and other gastropods (GA), and small bivalves (BI); bar = 0.5 mm; **f** MAY.KL.89028, 50 cm in core, >1 mm, bivalve-rich assemblage; whole and fragmented shells of arcid (AR), lucinid (LU), veneracean (VE) and cuspidariid (*Cardiomya* = CU) bivalves; bar = 1 mm; **g** MAY.KL.89022, 230 cm, >1 mm, coarse bioclastic hash composed by whole and fragmented bivalves (BI), gastropods (*Nassarius* = GA), serpulid polychaete tubes (SE), scleractinian corals (CO), bryozoans (BR), coralline algae (AL) etc.; bar = 1 cm; **h** MAY.KL.89022, 230 cm, >1 mm, bryozoans (Br), bivalve *Arca* sp. (Ac), gastropod *Natica* sp. (Nt), echinoid fragments (Ec) and other bivalves, scale bar = 1 cm

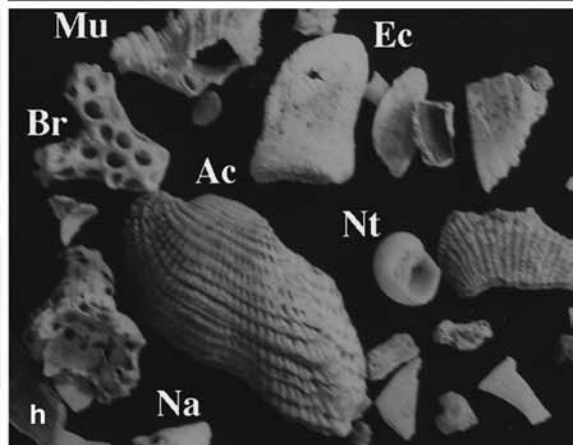
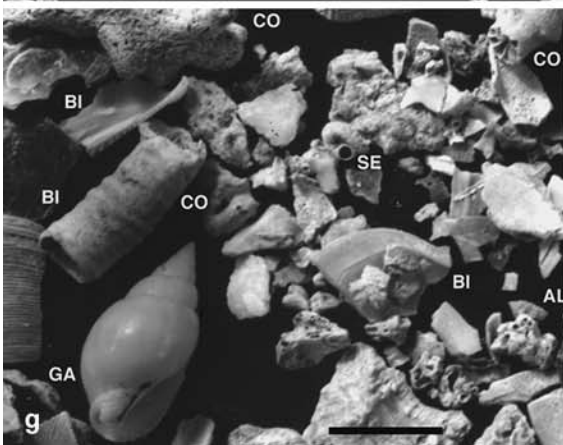
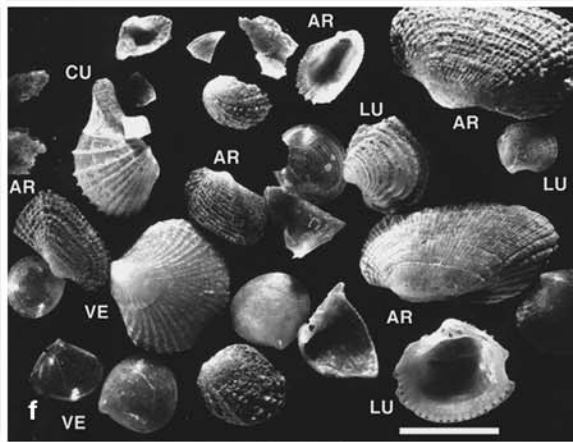
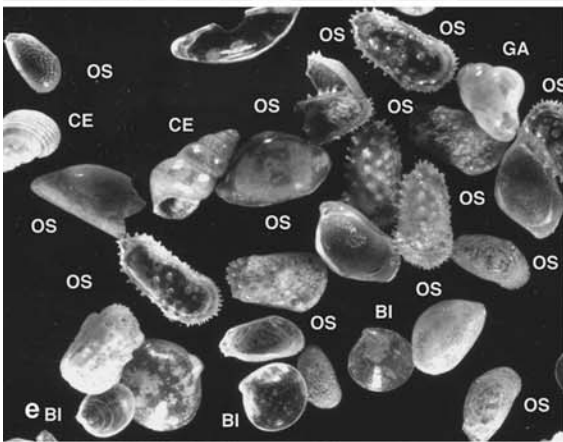
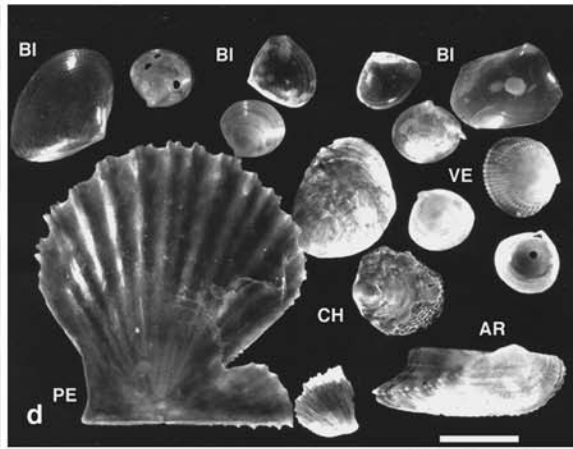
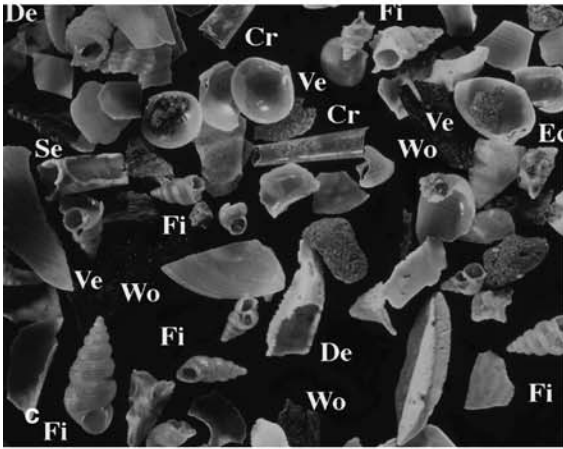
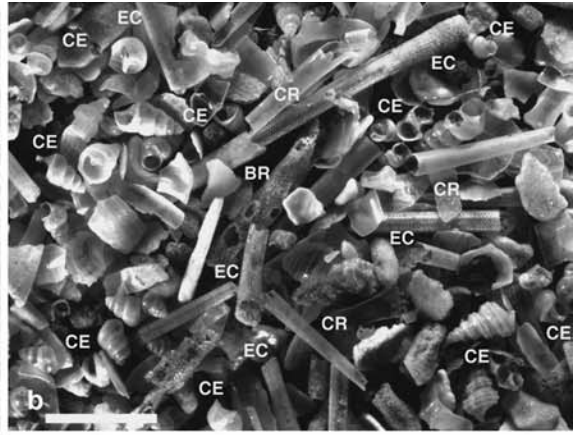
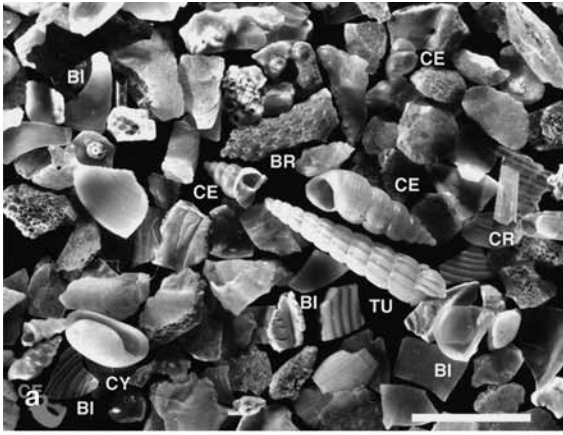
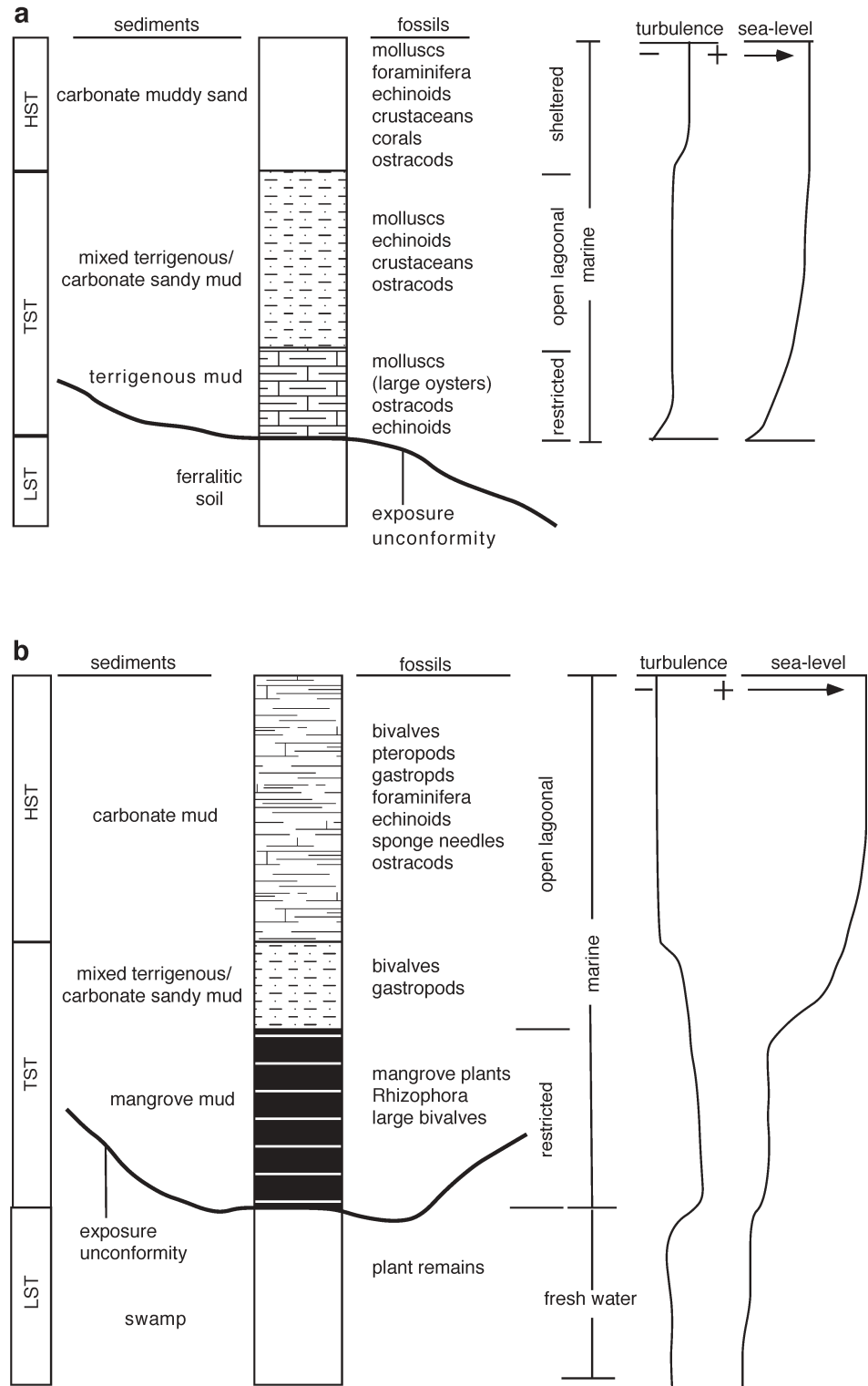


Fig. 10 Schematic facies evolution and sediment texture of Holocene sediments in the lagoon of Mayotte in relation to sea-level change and energy patterns in **a** proximal lagoonal setting, **b** mid-lagoonal depression. *LST* lowstand systems tract, *TST* transgressive systems tract, *HST* highstand systems tract. See Fig. 5 for legend



Terrigenous mud

Terrigenous muds overlying carbonate muds to sandy muds or carbonate sands occur in the nearshore bays with high terrigenous input at intermediate depths (20 m; Figs. 4g and 7). While the amount of counted individuals

of molluscs decreased, the amount of foraminiferans increased in these intervals (A 1). The foraminiferan and ostracod assemblages are typical for a littoral muddy environment with marine influence (Babinot and Kouyoumtzakis, personal communication).

Discussion

The deepest parts of the large lagoon surrounding Mayotte island were flooded around 11.6 kyr B.P. through the karstic passages cut into the Pleistocene barrier reef during the glacial lowstand (Zinke 2000; Zinke et al. 2003a, 2003b) (Fig. 3). During the interval from 11.6 to 11 kyr B.P. mangroves developed in the outer lagoon (core MAY.KL.89026) indicating a short stillstand period or at least a reduced rise in sea level (Fig. 9b). Mangroves are excellent sea-level indicators, since they mark the uppermost level of the intertidal flat at about ± 0.5 m on Mayotte. The deposition of mangroves at the transgressive base is also observed during the flooding of other Holocene lagoons, shelves and carbonate platforms, like the Bahamas (Newell et al. 1959), Belize (Shinn et al. 1982), Bermuda (Kuhn 1984), South Florida (Scholl, 1964; Dodd and Siemers 1971) and the Great Barrier Reef shelf (Larcombe and Carter 1998).

A rapid sea-level rise at 11 kyr B.P., probably related to the so-called meltwater pulse 1B (Fairbanks 1989) recorded in drowned reefs on Mayotte (Dullo et al. 1998; Zinke et al. 2003a) (Fig. 3), drowned the mangrove forest. The faunal association changed completely to a mollusc dominated terrigenous facies (Fig. 9b). Continued rise in sea level caused a further retreat of the shoreline, the terrigenous influence diminished in the outer lagoon and the inner lagoon with its smooth morphology became flooded. A terrigenous facies rich in non-skeletal grains derived from reworking of the underlying paleosoils with dominantly molluscs and characterises the transgressive systems tract (TST) in the inner lagoon (Fig. 9b). At the same time a mixed terrigenous-carbonate facies with molluscs developed in the outer lagoon (Fig. 9a). Suspension feeding molluscs favour such a transitional environment in which fine organic particulate nutrients derived from the hinterland are transported into the lagoon and partly stay in suspension (Masse et al. 1989). This high terrigenous input resulted in a very restricted biogenic assemblage, but with an increased number of individuals of each specific species (TST in cores MAY.KL.89026 and MAY.KL.89028; late high stand systems tract (HST) in core MAY.KL.89022).

Kuhn (1984) documented a similar Holocene TST faunal succession in the proximal and middle North-lagoon of the Bermuda Islands. The dominance of suspension feeders, like molluscs, echinoderms, bryozoans and ostracods, in transgressive deposits with high terrigenous input and thus nutrient concentrations also has been documented in numerous fossil sedimentary systems (Belperio and Searle 1988; Hallock and Schlager 1986; Harris et al. 1990; Crevello 1991; Blomeier and Reijmer 1999; Hillgärtner 1999; Strasser et al. 1999).

The flooding of the Pleistocene barrier reef top occurred at about 8.6 kyr B.P., which is indicated by an abrupt increase in pelagic skeletal grains (pteropods, pelagic foraminifera) and high calcium carbonate contents of the sediments in both cores within the Bouéni lagoon at this datum level (Figs. 5 and 6). Thus, the

exchange of the Bouéni lagoon with the open ocean was at a maximum since this time. Wave action toward the coastline was probably higher and intensified the resuspension and redistribution of the nearshore sediments and paleosoils. This resulted in a high input of terrigenous muds into the inner lagoon, which favoured a mollusc-ostracod assemblage (Fig. 9a). In contrast, a carbonate dominated, mollusc-foraminiferan facies developed in the outer lagoon (Fig. 9b). The outer lagoon most likely was protected from wave action by the barrier reefs and only received a restricted terrigenous input because of its significant depth and distance to the terrigenous source, respectively.

Barrier reef growth started at about 9.6 kyr B.P. at a depth of about 22 m bpsl, as shown in the reef core PMI-7 from the eastern Ajangoua lagoon (Camoïn et al. 1997). The lag time between flooding of the substrate and the onset of Holocene reef growth was probably very short and the reefs kept up with sea-level rise, as shown by their keep-up growth pattern. The barrier reef accreted very rapidly between 9.6–7.5 kyr B.P. and created a barrier that reduced the exchange between the open ocean and the lagoon. Hence, this keep-up phase of the barrier reef growth forms part of the TST. This is also observed in other studies of Holocene reef growth, like in One Tree Reef from the Southern Great Barrier Reef offshore NE-Australia (Marshall and Davies 1982; Davies and Hopley 1983), the Morley core from the Houtman Abrolhos Islands, offshore W-Australia (Eisenhauer et al. 1993) and on Tahiti in the central Pacific (Cabioch et al. 1999).

After the decline in sea-level rise after 7 kyr B.P., the barrier reef growth pattern changed from dominantly vertical to lateral accretion. The closure of the lagoon became complete at places where the conditions for reef growth were at an optimum, like in the NE-, E- and S-lagoon. Following the classification of Paulay (1990), these lagoons are in a stage II state with reduced water exchange between lagoon and ocean through passages. Within these lagoons, a muddy environment dominated by molluscs (terrigenous province) and mollusc-foraminiferans (carbonate province) characterises the early and late HST in the inner or deeper lagoonal plains, respectively (Fig. 9a, b). The formation of the fringing reefs that are confined to the inner lagoons commenced during that time (Zinke 2000; Zinke et al. 2003a). They formed a topographic barrier towards the inner lagoonal bays reducing energy conditions behind it. The fringing reefs expanded to a zone with high carbonate productivity in which significant amounts of bioclasts are produced. These were exported into neighbouring depositional areas, as soon as production (vertical growth) outpaced the available accommodation space. This pattern is typical for modern and ancient reefal settings (Marshall and Davies 1982; Davies et al. 1989; Kuhn 1984; Harris et al. 1990; Eisenhauer et al. 1993; Peerdeman and Davies 1993). As a result the depositional facies in the proximity of the fringing reefs showed a complete facies change over from terrigenous to carbonate dominated sediment deposition

(early HST in core 89022 and 89028, fringing reef cores in Zinke et al. 2003a) (Figs. 5 and 7). The outer lagoons, in close proximity to the barrier reef and the large passages, are dominated by a sandy environment with a coral-mollusc-foraminifera assemblage (Figs. 5 and 9b).

The NW- and SW-lagoons are still in an open lagoonal stage. At these sites the barrier reef remains submerged even during low tide, which results in continuous water exchange with the surrounding ocean. Therefore, high quantities of pelagic organisms (pteropods, pelagic foraminiferans) occur within the highstand deposits of the inner lagoonal plains (Figs. 5, 6 and 9). The outer lagoonal areas show sandy bottoms with single coral build-ups and frequent coral reef patches, probably as a result of good water circulation. The high quantity of carbonate muds in the deep lagoonal valley fills probably result from high carbonate production in these outer sandy bottom and coral reef areas, which can be transported over greater distances (HST in core 89026, Fig. 6). Intercalation of sand- to gravel-sized bioclasts or lithoclasts into deep lagoonal sediments is confined to high-energy events, e.g. severe storms. Applying the classification of Paulay (1990), these lagoons are in a stable stage II state with permanently sufficient water exchange between the lagoon and the open ocean.

This study showed that the distribution of skeletal and non-skeletal grains in the lagoon of Mayotte is mainly controlled by the rate and amplitude of the Holocene sea-level rise. The pre-Holocene topography in combination with the growth-potential, bathymetry and continuity of the barrier reef had a large effect on the hydrodynamic regime within the sedimentary environments. The fast accretion of the barrier reef during sea-level rise (TST) protected the shallow and deep subtidal lagoons and reduced the transport potential of bioclasts and prevented their distribution throughout the lagoon and surrounding environments. Thus, the faunal composition of the shallow and deep lagoonal deposits during the highstand in sea level is mainly controlled by autochthonous sediment production and single sediment distribution events like storms.

The results of this study confirm faunal changes during a sea-level rise observed in present-day and fossil mixed terrigenous-carbonate lagoons and/or rimmed carbonate platforms (Kuhn 1984; Gardulski et al. 1986; Belperio and Searle 1988; Crevello 1991; Peerdeman and Davies 1993; Blomeier and Reijmer 1999; Hillgärtner 1999; Strasser et al. 1999; Gischler 2003). An almost similar facies succession in response to the Holocene sea-level rise, like for the proximal- and mid-lagoonal settings within the lagoon of Mayotte, is found in the North-lagoon of Bermuda (Kuhn 1984).

Conclusions

The distribution of the skeletal and non-skeletal grains in the lagoon of Mayotte is clearly controlled by the rate

and amplitude of the Holocene sea-level rise, the pre-Holocene topography and the growth-potential, bathymetry and continuity of the barrier reef. The combination of these parameters had a large effect on the hydrodynamic regime within the lagoon, and thus on the transport and redistribution potential of bioclasts. The bioclast composition and the granulometry of the deep lagoonal sediments from the Mayotte lagoon indicate mostly an in situ origin of the sandy fraction or deposition in the vicinity of the production areas. The transgressive, highstand and late highstand deposits could be discriminated by their skeletal and non-skeletal grains. Non-skeletal grains are concentrated in the transgressive and late highstand deposits, skeletal grains reach their maximum portion during the early highstand. The skeletal grains show substrate preferences, like molluscs being the only important biota in mixed facies with significant terrigenous input. Terrigenous and/or mixed terrigenous-carbonate muds to sandy muds with a mollusc or molluscs-ostracod assemblage dominate the transgressive deposits. Mixed or carbonate muddy sands to sands with a mollusc-foraminifera or mollusc-coral-foraminifera assemblage characterize the early highstand deposits of the inner lagoonal plains. The early highstand deposits of the outer lagoonal plains consist of carbonate muds with a mollusc-foraminiferan assemblage. Late highstand deposits consist of terrigenous muds in the nearshore bays, mixed terrigenous-carbonate sandy muds to muddy sands with a mollusc-foraminiferan assemblage on the inner lagoonal plains and mixed terrigenous-carbonate muds with a mollusc-foraminiferan assemblage on the outer deep lagoonal plains. The lagoons surrounding the mainland of Mayotte are in a stage with sufficient water exchange between lagoon and ocean in the SW-, W- and NW-lagoons and reduced circulation in the NE-, E- and S lagoons.

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Annex 1: List of identified bivalves, gastropods and foraminiferans for selected levels within the core. Core number, depth in core, systems tract and calibrated calendar ages are indicated (Zinke et al. 2001, 2003b)

Core MAY.KL	Depth in core (m)	Systems tract	Bivalves	Gastropods	Foraminifera	Age kyr B.P.
89006	0–6.2	HST	Veneracean spp.	<i>Finella pupoides</i> <i>Diala</i> sp. <i>Cerithium nesoticum</i> <i>Cerithium</i> sp. <i>Vitrinella</i> sp. Strombus labiosus <i>Natica</i> sp. <i>Eulima</i> sp. <i>Nassarius</i> sp. <i>Chrysallida</i> sp. <i>Acteocina</i> sp. <i>Cylichna</i> sp. <i>Creseis acicula</i> <i>Diacria</i> sp.	Buliminida: <i>Bolivina</i> sp.	6.8–present
89014	4.9–5.1 0–0.4 2.4–4.6 4.9–5.4	Volcanic pumice IHST eHST	<i>Nucula</i> sp. <i>Barbatia</i> sp. Pectinid sp. “Oysters” <i>Hyothissa</i> sp. <i>Tellina</i> sp. <i>Pitar</i> sp. Veneracean spp.	<i>Finella pupoides</i> <i>Cerithium nesoticum</i> <i>Cerithium</i> sp. <i>Eulima</i> sp. <i>Nassarius</i> sp. <i>Odostomia</i> sp. <i>Cylichna</i> sp. <i>Retusa</i> sp. <i>Creseis acicula</i>	Buliminida: <i>Bolivina</i> sp.	~6 2.3–present 5.9–4
89022	1.9–2.4 4.6–4.9 1.3–1.6	Volcanic pumice IHST			Rotaliida: <i>Rotalia</i> sp. <i>Operculina</i> sp. <i>Amphistegina</i> sp. <i>Heterostegina</i> sp. <i>Marginopora</i> sp. <i>Eponides</i> sp. <i>Discorbis</i> sp. Miliolida: <i>Triloculina</i> sp. <i>Quinqueloculina</i> sp. <i>Spiroloculina</i> sp. Textulariida: <i>Textularia</i> sp.	~4 ~6 0.9–1.3
	1.6–1.8	IHST		<i>Creseis acicula</i>	Rotaliida: <i>Amphistegina</i> sp. <i>Heterostegina</i> sp. <i>Eponides</i> sp. <i>Discorbis</i> sp. Miliolida: <i>Triloculina</i> sp. <i>Quinqueloculina</i> sp. <i>Sorites discoides</i> <i>Haverina</i> sp. Textulariida: <i>Textularia</i> sp. Buliminida: <i>Bolivina</i> sp.	1.3–1.7
	1.8–2.6	eHST	<i>Nucula</i> sp. <i>Arca</i> sp. <i>Acar plicata</i> <i>Sheldonella lateralis</i> <i>Septifer bilocularis</i> Oysters <i>Chama</i> sp. <i>Cardita</i> sp. <i>Vasticardium</i> sp. <i>Pillucina</i> sp. <i>Bellucina</i> sp. Veneracean spp. Scaphopods: <i>Dentalium</i> sp.	<i>Diodora</i> sp. <i>Diala semistriata</i> <i>Finella pupoides</i> <i>Scaliola</i> sp. <i>Styliferina goniochila</i> <i>Cerithium diplax</i> <i>Cerithium perparvulum</i> <i>Cerithium</i> sp. <i>Turritella</i> sp. <i>Microliotia</i> sp. <i>Vitrinella</i> sp. <i>Lucidesta</i> sp. <i>Caecum</i> sp. Capulid sp. Vermetid sp.	Buliminida: <i>Bolivina</i> sp. Rotaliida: <i>Amphistegina</i> sp. <i>Heterolepa</i> sp. <i>Elphidium</i> sp. Miliolida: <i>Quinqueloculina</i> sp.	1.7–6.4

Core MAY.KL	Depth in core (m)	Systems tract	Bivalves	Gastropods	Foraminifera	Age kyr B.P.	
			<i>Fustiaria</i> sp.	<i>Natica</i> sp. Triphorid sp. <i>Cerithiopsis</i> sp. <i>Epitonium</i> sp. <i>Eulima</i> sp. <i>Gyrineum pusillum</i> <i>Chicoreus</i> sp. <i>Nassarius</i> sp. <i>Vexillum</i> sp. <i>Gibberula</i> sp. Orbistelliid sp. <i>Odostomia</i> sp. <i>Turbonilla</i> sp. <i>Odetta</i> sp. <i>Chrysallida</i> sp. <i>Hervieria gliriella</i> <i>Gurmatia pulchrior</i> <i>Cylichna</i> sp. <i>Retusa</i> sp. <i>Ringicula</i> sp. Cephalaspidean sp. <i>Retusa</i> sp. <i>Cylichna</i> sp. <i>Tornatina</i> sp. <i>Nassarius</i> sp. <i>Diacria</i> sp. <i>Cerithium</i> sp.			
89026	2.2–2.9	TST					
	2.9–3.6	TST	<i>Anadara</i> sp. <i>Saccostrea</i> sp. Cardiid sp.			10.7–8.9	
89028	0–0.3	IHST	<i>Sheldonella lateralis</i> Arcid sp. <i>Chlamys</i> sp. <i>Chama</i> sp. <i>Diplodonta</i> sp. <i>Tellina</i> sp. Veneracean spp.	<i>Diala</i> sp. <i>Finella pupoides</i> <i>Scaliola</i> sp. <i>Chrysallida</i> sp. <i>Ebala</i> sp.	Rotaliida: <i>Operculina</i> sp. <i>Nummulites cumingii</i> <i>Calcarina hispida</i> <i>Planorbulinella</i> <i>larvata</i> Globigerinoida: <i>Globigerinoides ruber</i> <i>Globigerina</i> sp. Miliolida: <i>Quinqueloculina ag-</i> <i>glutinas</i> <i>Triloculina trigonula</i> <i>Spiroloculina</i> sp.	1–present	
	0.3–0.7	eHST	<i>Sheldonella lateralis</i> <i>Striarca symmetrica</i> <i>Chama</i> sp. <i>Bellucina</i> sp. <i>Tellina</i> sp. <i>Gafrarium</i> sp. <i>Cardiomya</i> cf. <i>alcocki</i>	<i>Diala</i> sp. <i>Finella pupoides</i> <i>Creseis acicula</i>	Rotaliida: <i>Operculina</i> sp. <i>Nummulites cumingii</i> <i>Amphistegina</i> <i>madagascarensis</i> <i>Eponides repandus</i> <i>Rotalia laprillosa</i> <i>Rosalina</i> sp. <i>Elphidium</i> sp. <i>Doscorbis</i> sp. <i>Heterolepa</i> sp. Globigerinida: <i>Globigerinoides ruber</i> Miliolida: <i>Spiroloculina</i> sp. <i>Quinqueloculina</i> <i>berthelotiana</i> <i>Quinqueloculina</i> <i>agglutinas</i> <i>Quinqueloculina</i> <i>distorqueata</i> <i>Pyrgo</i> sp. <i>Amphisorus</i> sp. Textulariida: <i>Textularia</i> sp.	5.3–1	

Core MAY.KL	Depth in core (m)	Systems tract	Bivalves	Gastropods	Foraminifera	Age kyr B.P.
	0.7–1.1	eHST	<i>Barbatia foliata</i> <i>Acar plicata</i> <i>Sheldonella lateralis</i> <i>Striarca symmetrica</i> <i>Lopha cristagalli</i> <i>Chama</i> sp. <i>Bellucina</i> sp. <i>Pillucina</i> sp. <i>Diplodonta</i> sp. <i>Tellina</i> sp. <i>Cardomya</i> cf. <i>alcoki</i>	<i>Finella pupoides</i> <i>Diala</i> sp. <i>Cerithium</i> sp. Rissoid sp. <i>Vitrinella</i> sp. <i>Natica</i> sp. <i>Dentimargo</i> sp. <i>Megastomia</i> sp. <i>Odetta</i> sp. <i>Acteocina</i> sp. <i>Creseis acicula</i>	Rotaliida: <i>Cibicides</i> sp. <i>Eponides</i> sp. <i>Rotalia</i> sp. <i>Elphidium</i> sp. <i>Cancris</i> sp. <i>Heterolepa</i> sp. Globigerinida: <i>Globigerinoides ruber</i> Buliminida: <i>Bolivina</i> sp. <i>Reussella</i> sp. Lagenida: <i>Amphicoryna</i> sp. Miliolida: <i>Quinqueloculina</i> <i>distorqueata</i> <i>Triloculina trigonula</i> Textulariida: <i>Textularia</i> sp. Rotaliida: <i>Rotalia laprillosa</i> <i>Elphidium</i> sp. <i>Nummulites cumingii</i> <i>Eponides repandus</i> <i>Gavelinopsis</i> sp. Globigerinida: <i>Globigerinoides ruber</i> <i>Globigerinoides</i> <i>sacculifer</i> <i>Globigerina</i> sp. Miliolida: <i>Spiroloculina</i> sp.	5.3–7
	1.1–2	TST	<i>Nucula</i> sp. Arcid sp. <i>Tellina</i> sp. Veneracean spp.	<i>Finella pupoides</i> <i>Vitrinella</i> sp. <i>Epitonium</i> sp. <i>Eulima</i> sp. Columbellid sp. Conid sp. <i>Cyclina</i> sp. <i>Retusa</i> sp. <i>Acteocina</i> sp. <i>Ringicula</i> sp. Cephalaspidean sp.	<i>Rotalia</i> sp. <i>Rotalia laprillosa</i> <i>Elphidium</i> sp. <i>Nummulites cumingii</i> <i>Eponides repandus</i> <i>Gavelinopsis</i> sp. Globigerinida: <i>Globigerinoides ruber</i> <i>Globigerinoides</i> <i>sacculifer</i> <i>Globigerina</i> sp. Miliolida: <i>Spiroloculina</i> sp.	7–9.3
	2–2.7	TST	<i>Sheldonella lateralis</i> <i>Septifer bilocularis</i> “Oysters” <i>Chama</i> sp. <i>Tellina</i> sp. Solecurtid sp. Veneracean spp.	<i>Finella pupoides</i> <i>Scaliola</i> sp. <i>Cerithium nesioticum</i> <i>Cerithium</i> sp. <i>Vitrinella</i> sp. <i>Chrysallida</i> sp. <i>Ringicula</i> sp. Cephalaspidean sp.	Rotaliida: <i>Nummulites cumingii</i> Miliolida: <i>Spiroloculina</i> sp.	9.3–9.8

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