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Bajocian and Bathonian ostracods and depositional environments in Madagascar (Morondava Basin and southern Majunga Basin)

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WOLFGANG METTE and MARKUS GEIGER

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Abstract. Micropalaeontological investigations in the southern part of the Morondava Basin and the southernmost part of the Majunga Basin have yielded Bajocian and mid-upper Bathonian ostracod assemblages which comprise a total of 16 species. Whereas the most abundant species, *Fastigatocythere malgachica* (GREKOFF) has been previously described from the Bajocian of the Morondava Basin by GREKOFF (1963), the genus *Paradoxorhyncha*, represented by *P. australiense* (CHAPMAN) and the new species *P. malgachica*, are documented from Madagascar for the first time. The geographical distribution of this genus, which has been previously reported from Western Australia and South America, suggests that it migrated along the southern shores of Gondwana during Bajocian times. Except for *P. australiense*, which is known from the lower Bajocian of Western Australia, and *Striatojonesia striata* (TRIEBEL & BARTENSTEIN), which is widely distributed in both the Lower and Middle Jurassic of Europe and the Bajocian of North Africa and the Near East, no other species of the faunas presented in this paper is known from regions outside Madagascar. On the basis of sedimentological and palaeoecological criteria, the Bajocian faunas can be assigned to marginal marine environments which were subject to salinity variations, and the Bathonian faunas to normal marine near-shore environments with high water turbulence.

■ *Ostracods, Bajocian, Bathonian, taxonomy, facies, Madagascar*

Zusammenfassung: Mikropaläontologische Untersuchungen in jurassischen Schichtfolgen des südlichen Morondava Beckens (Südwest Madagaskar) lieferten Ostrakodenfaunen aus dem Bajoc und mittleren-oberen Bathon, die insgesamt 16 Arten umfassen. Während die häufigste Art *Fastigatocythere malgachica* (GREKOFF) bereits von GREKOFF (1963) aus dem Bajoc des Morondava Beckens beschrieben worden war, ist die Gattung *Paradoxorhyncha*, vertreten durch die Arten *P. australiense* (CHAPMAN) und die neue Art *P. malgachica*, erstmals aus Madagaskar nachgewiesen. Die geographische Verbreitung von *Paradoxorhyncha*, die ursprünglich von Westaustralien beschrieben und später auch aus Südamerika bekannt gemacht wurde, spricht dafür, dass sich diese Gattung im Bajoc entlang des Südrandes von Gondwana ausbreitete. Während *P. australiense* und *Striatojonesia striata* (TRIEBEL & BARTENSTEIN) im Unter- und Mitteljura Europas und im Bajoc Nordafrikas und des Nahen Osten weit verbreitet sind, wurden die übrigen hier beschriebenen Arten bisher nicht außerhalb von Madagaskar nachgewiesen. Sedimentologischen und palökologischen Kriterien zufolge stammen die Faunen des Bajoc aus randlich marinen Milieus mit Salinitätsschwankungen und die Faunen des Bathon aus normalmarinen küstennahen und stark turbulenten Flachwasserbereichen.

■ *Ostrakoden, Bajoc, Bathon, Taxonomie, Fazies, Madagaskar*

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Contents

Introduction

Jurassic ostracods from Madagascar were documented for the first time by the extensive pioneering work of GREKOFF (1963), which has been supplemented by the stratigraphical and micropalaeontological investigations of RAFARA (1990). Subsequent palaeobiogeographical studies have shown these assemblages to belong to an endemic fauna called the South Gondwana Fauna, which was distributed across East Africa, Madagascar and India, as well as Australia and South America (DINGLE 1988). However, the above mentioned studies were confined to the Majunga Basin and faunas older than Bathonian had not previously been described from the Majunga Basin. Consequently, the early evolution of the South Gondwana Fauna in the Lower and Middle Jurassic is little known because of the paucity of the fossil record, the inaccessibility of fossil horizons and insufficient research. Biostratigraphical and micropalaeontological research in south-west Madagascar, which was concerned with the development of the Morondava Basin and related tectonic processes (LUGER et al. 1994, DINA 1996, this paper), yielded a number of Bajocian and mid-upper Bathonian ostracod assemblages (Fig.5) including a new species. These findings show that further research may yield additional important fossil data which can assist in our understanding of the early evolution and palaeobiogeography of the South Gondwana Fauna.

Lithostratigraphy, facies and ostracod faunas

The Bajocian marine sediments of the Morondava Basin were deposited during the first extensive marine transgression of the Proto-Indian Ocean, onto interconnected rift basins which were filled with mainly continental deposits of Permian to Lower Jurassic age and correlate with the southern African Karroo megasequence. The Bajocian-Bathonian sedimentary sequences are interpreted as post-rift strata of the Gondwana Breakup Rift (GEIGER et al., in press).

The ostracod taxa presented in this paper were obtained from three sections in the Bajocian and mid-upper Bathonian of the southern Morondava Basin (Analamanga, Sakaraha and Anjeba sections - Fig.1) and one section in the southernmost part of the Majunga Basin (Beronono section). Since the Analamanga and Sakaraha sections (road cut 5 km west of Sakaraha) are very similar with respect to lithofacies and fossil content and the sedimentary successions are stratigraphically equivalent, only the former section is described herein.

Analamanga section

At the Analamanga section (Fig. 2), located approximately 10 km north of Sakaraha (S 22°51,738', E 044°32.950'), a Bajocian sedimentary succession with a thickness of approximately 50 m is exposed. The sequence begins with a transgressive oolitic limestone, which unconformably overlies fluvial siliciclastics of presumed Aalenian age. The lower and middle parts of the succession comprise intercalated mudstones, marls, siltstones, well-sorted sandstones and limestones. The sandstones and limestones are partly oolitic and rich in shells of bivalves and/or gastropods. Low angle crossbedding, ripple marks and flute casts in the sandstones are indicative of a shallow marine intertidal environment. The ooliths in the basal section indicate brief episodes of outer lagoonal shoal/barrier environments during transgressions. These transgressions may have reached even further inland since open marine conditions occur sporadically. The upper part of the section consists of fossiliferous oolitic limestones, which are interpreted as a coastal oolite barrier. The carbonate-cemented sandstones of the Bajocian sedimentary successions in the Morondava Basin have been interpreted as perideltaic deposits

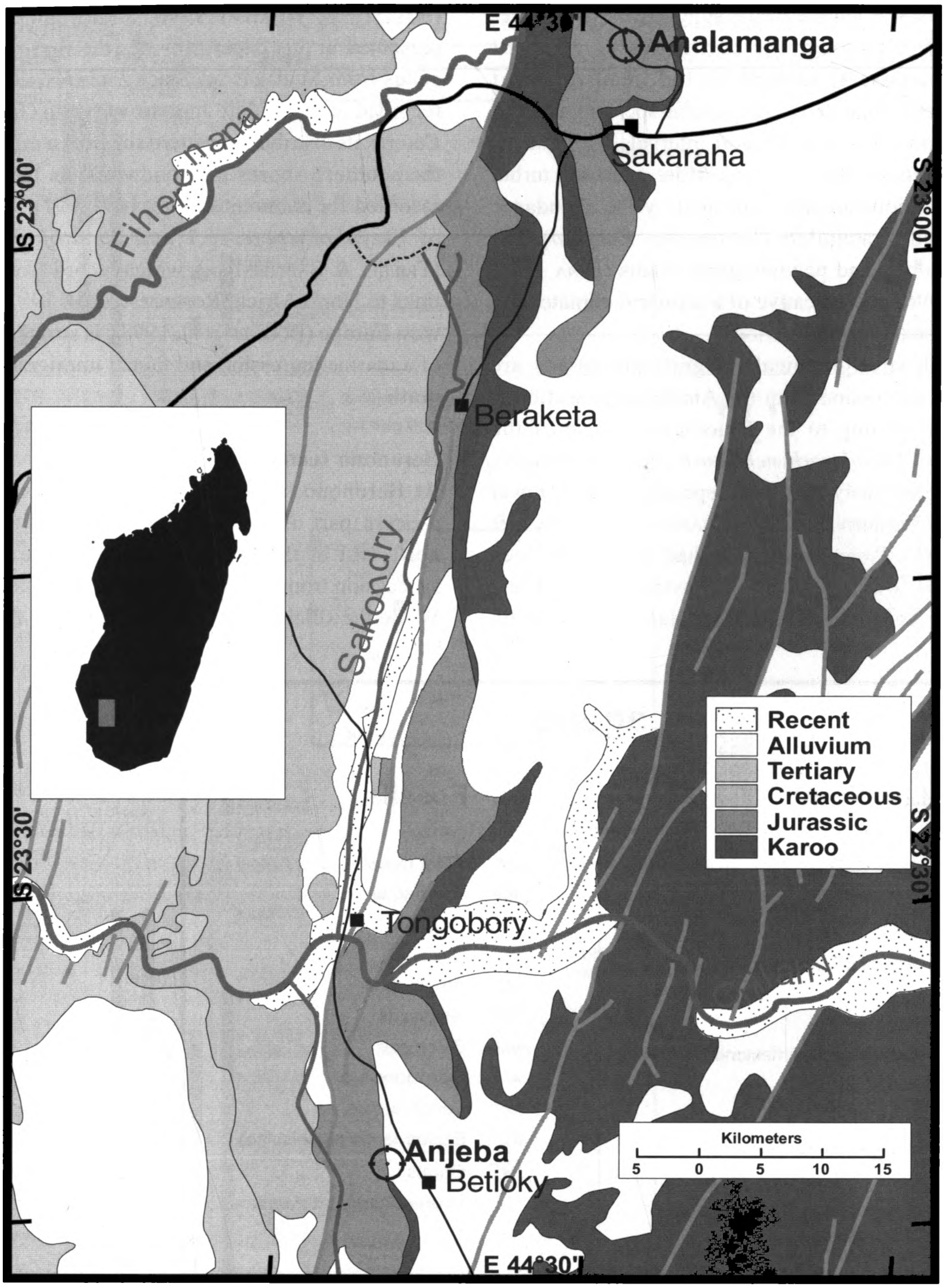


Fig.1: Geological map with location of study area and sites of sections.

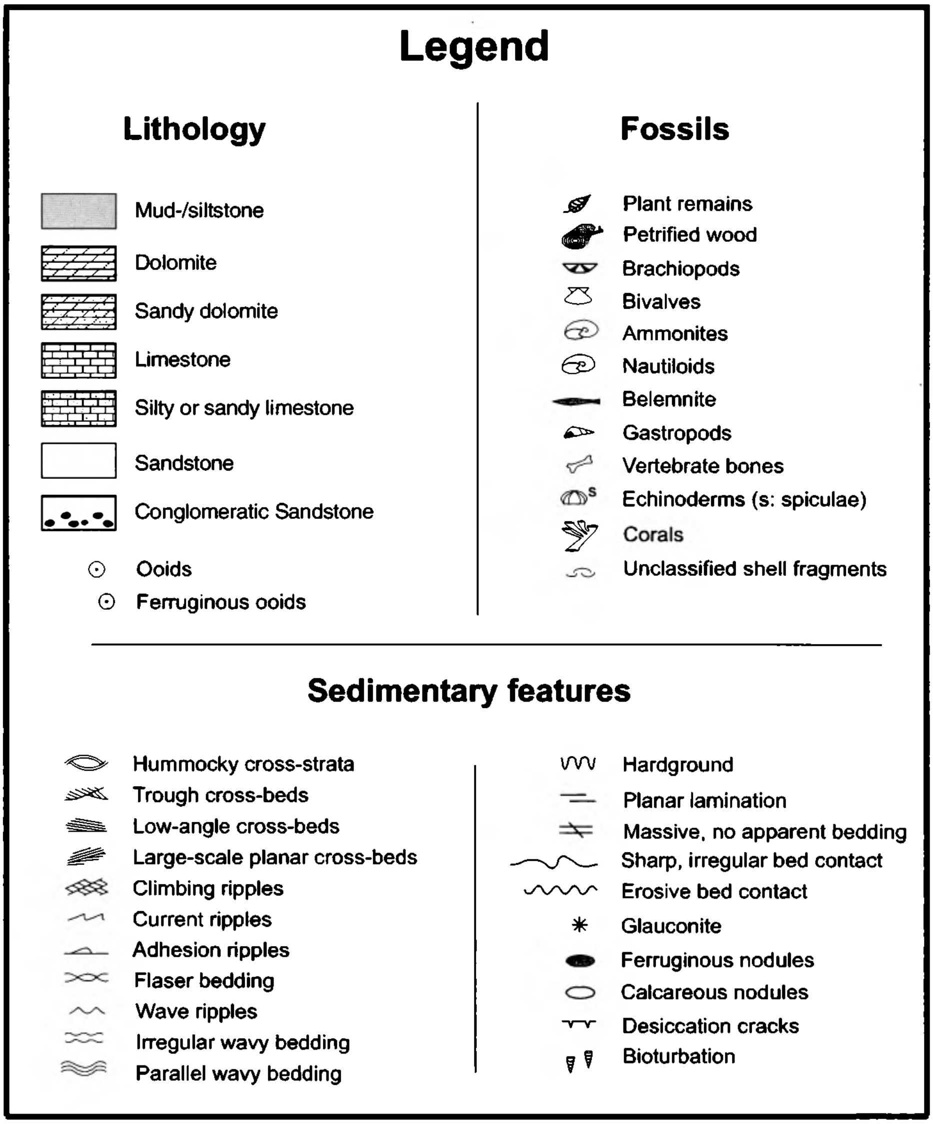
(MONTENAT et al. 1996). This assumption is, however, not supported by the sedimentology and facies of the Analamanga and Sakaraha sections.

The ostracod faunas from the Analamanga section are of relatively low taxonomical and ecological diversity (Fig.5). The dominant taxon of most faunas is *Fastigatocythere malgachica* (GREKOFF), followed by *Paradoxorhyncha malgachica* n.sp and *Ektyphocythere* sp.1. Foraminifera are rare but most of the ostracod faunas are associated with fragments of echinoids, asteroids and ophiorids, and monotypic assemblages of gastropods and bivalves. The low diversity of the microfaunas and the occurrence of *Darwinula,* as well as the high abundance of monotypic mollusc assemblages with *Pronoella* and *Trancredia* (det. FÜRSICH, Würzburg), indicate brackish conditions. Abundant plant remains and wood fragments are also indicative of a near-coastal lagoonal environment. Relatively good preservation of the thin-shelled *F. malgachica* is suggestive of low water turbulence. However, the *insitu* preservation of hermatypic corals, as well as the occurrence of dasycladacean algae (*Cylindroporella* sp.) and asteroid moulds, shows that at least short intervals with normal marine conditions also occurred. More open and turbid marine conditions are also indicated by the abundance of nodosariid foraminifera (*Lenticulina, Palmula*). The clay mineralogy and palynological results (DINA 1996, UHMANN 1996) are indicative of a semiarid climate with short (seasonal?) humid periods.

Although stratigraphically significant fossils are absent, the succession from the Analamanga section is assumed to belong to the Bajocian because of the occurrence of *Paradoxorhyncha australiense* (CHAPMAN), which has previously only been reported from the lower Bajocian of Western Australia (CHAPMAN 1904, MALZ & OERTLI 1993). *Paradoxorhyncha* had previously been found in the lower Bajocian of Western Australia and the upper Aalenian-lower Bajocian of Argentina (BALLENT & WHATLEY 1996, 2000), and the material presented in this paper provides the first record of this genus from Madagascar. Since *Paradoxorhyncha* is not recorded in the Middle Jurassic of North Gondwana and Europe, its distribution pattern suggests a migration along the southern shores of Gondwana, as has also been recorded for ammonites (RICCARDI 1991). The presence of *Ektyphocythere* sp.1 and *Striatojonesia striata* (TRIEBEL & BARTENSTEIN), which record biogeographical links to North Africa (ROSENFELD et al. 1987) and south-west Europe (BOOMER et al. 1998), is strongly suggestive of a marine ingression and faunal immigration from the north.

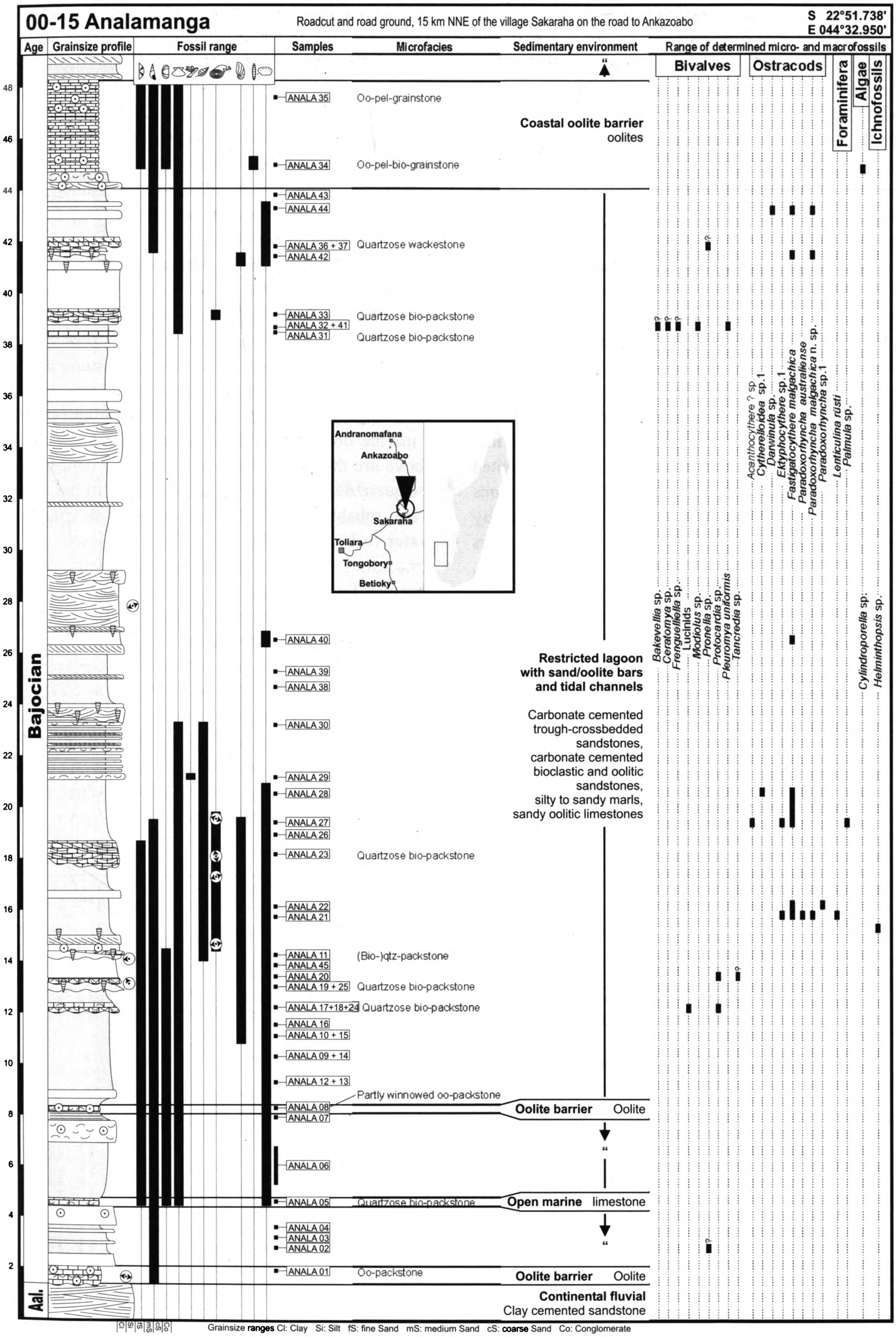
Beronono section

At Beronono, a small village in the extreme south-western part of the Majunga Basin and about 40 km north-east of the town of Kandreho, the sedimentary succession from the Toarcian to the Bajocian is exposed. While the siliciclastic Toarcian (dated by the ammonite



next page:

Fig.2: Analamanga section (lithostratigraphy, sedimentary structures, fossil occurrences, depositional environments).


00-15 Analamanga
Roadcut and road ground, 15 km NNE of the village Sakaraha on the road to Ankazoabo
S 22°51.738'
E 044°32.950'
Age
Grainsize profile
Fossil range
Samples
Microfacies
Sedimentary environment
Range of determined micro- and macrofossils
Bivalves
Ostracods
Foraminifera
Algae
Ichnofossils
Bajocian
Aal.
ANALA 35
Oo-pel-grainstone
Coastal oolite barrier
oolites
ANALA 34
Oo-pel-bio-grainstone
ANALA 43
ANALA 44
ANALA 36 + 37
Quartzose wackestone
ANALA 42
ANALA 33
Quartzose bio-packstone
ANALA 32 + 41
ANALA 31
Quartzose bio-packstone
ANALA 40
ANALA 39
ANALA 38
ANALA 30
ANALA 29
ANALA 28
ANALA 27
ANALA 26
ANALA 23
Quartzose bio-packstone
ANALA 22
ANALA 21
ANALA 11
(Bio-)qtz-packstone
ANALA 45
ANALA 20
ANALA 19 + 25
Quartzose bio-packstone
ANALA 17+18+24
Quartzose bio-packstone
ANALA 16
ANALA 10 + 15
ANALA 09 + 14
ANALA 12 + 13
Partly winnowed oo-packstone
ANALA 08
ANALA 07
ANALA 06
ANALA 05
Quartzose bio-packstone
ANALA 04
ANALA 03
ANALA 02
ANALA 01
Oo-packstone
Restricted lagoon
with sand/oolite bars
and tidal channels
Carbonate cemented
trough-crossbedded
sandstones,
carbonate cemented
bioclastic and oolitic
sandstones,
silty to sandy marls,
sandy oolitic limestones
Oolite barrier Oolite
Open marine limestone
Oolite barrier Oolite
Continental fluvial
Clay cemented sandstone
Andranomafana
Ankazoabo
Sakaraha
Toliara
Tongobory
Betioky
Bakevellia sp.
Ceratomya sp.
Frenguelliella sp.
Lucinids
Modiolus sp.
Pronella sp.
Protocardia sp.
Pleuromya uniformis
Tancredia sp.
Acanthocythere ? sp.
Cytherelloidea sp.1
Darwinula sp.
Ektyphocythere sp.1
Fastigatocythere malgachica
Paradoxorhyncha australiense
Paradoxorhyncha malgachica n. sp.
Paradoxorhyncha sp.1
Lenticulina rüsti
Palmula sp.
Cylindroporella sp.
Helminthopsis sp.
Cl Si fS mS cS Co
Grainsize ranges Cl: Clay Si: Silt fS: fine Sand mS: medium Sand cS: coarse Sand Co: Conglomerate

Bouleiceras) and Aalenian deposits did not yield any microfossils, a few ostracods were recovered from the overlying Bajocian strata in the Beronono section (Fig. 3). The Bajocian succession in the Beronono section is 26 m thick and consists of a lower unit dominated by fine to medium-grained siliciclastics, and a calcereous upper unit with thin intercalations of mudstones and siltstones. A two m thick bed of bioturbated sandstone at the base of the section, with abundant vertebrate bones, bivalve shells and erosive sedimentary structures is interpreted as a transgressive beach deposit. The overlying succession of grey to black mudstones/ siltstones and quartzose limestones are, in places, rich in poorly preserved, dis-articulated bivalve shells which were either concentrated by wave action in a coastal environment or by increased current velocity during storm events in a shallow sub-littoral milieu. Due to the low species diversity of the ostracod assemblages, it is furthermore supposed that the succession was deposited in a restricted marine environment, although deviations from the normal salinity are not indicated by palaeontological data. The ostracod fauna (Fig. 5), is similarly to the faunas from the Analamanga section, strongly dominated by *Fastigatocythere malgachica* (GREKOFF) and accompanied by rare agglutinated foraminifera and fragments of echinoids and ophiorids. The only age-indicative species is *Striatojonesia striata* (TRIEBEL & BARTENSTEIN) suggesting a Bajocian age for the Beronono section. The micritic limestones and intercalated dark-grey to black mudstones/siltstones in the upper part of the section are bioturbated but did not yield any macro- or microfauna, possibly due to a lack of oxygen at the sediment surface.

Anjeba section

The mid-upper Bathonian Anjeba section (Fig.4), located about 5 km west of Betioky in the southern Morondava Basin (S 23°42.090', E 044°20.607'), differs markedly from the Anamalanga section both in lithofacies and fossil content. The Anjeba succession is a 12 m thick transgressive unit that consists of sandstones with large-scale trough cross-bedding at the base, overlain by oolitic limestones and dolomites and coarse-grained to conglomeratic sandstones. The sandstones are intercalated with calcareous siltstones. A fossiliferous quartzose oolitic limestone and a bed of detrital limestone with an *insitu* fauna of bivalves and hermatypic corals make up the top of the section. The lithology and sedimentary structures of the basal sandstone suggest deposition in a high energy coastal environment, while the overlying oolitic carbonates probably originated from a marine oolite shoal. The coarse-grained sandstones above are thought to represent shoreface deposits and the quartzose oolitic limestones at the top of the section were probably also derived from oolite shoals under high water turbulence. The fauna from the lower oolitic limestones comprises bivalves, gastropods, benthic foraminifera (*Valvulina, Mesoendothyra croatica, Ammobaculites*) and dasycladacean algae (*Terquemella, Heteroporella, Cylindroporella, Neomeris*), indicating a well-lit shallow lagoonal environment, similar to the present day Red Sea /Arabian Gulf (MURRAY 1991). The ostracods from the middle part of the section (Fig. 5) are dominated by *Fabanella* ? sp.1 and the thick-shelled *Oligocythereis pertusa* GREKOFF, which are poorly preserved, probably due to abrasion in a high energy regime. The macrofossil content of the upper oolitic

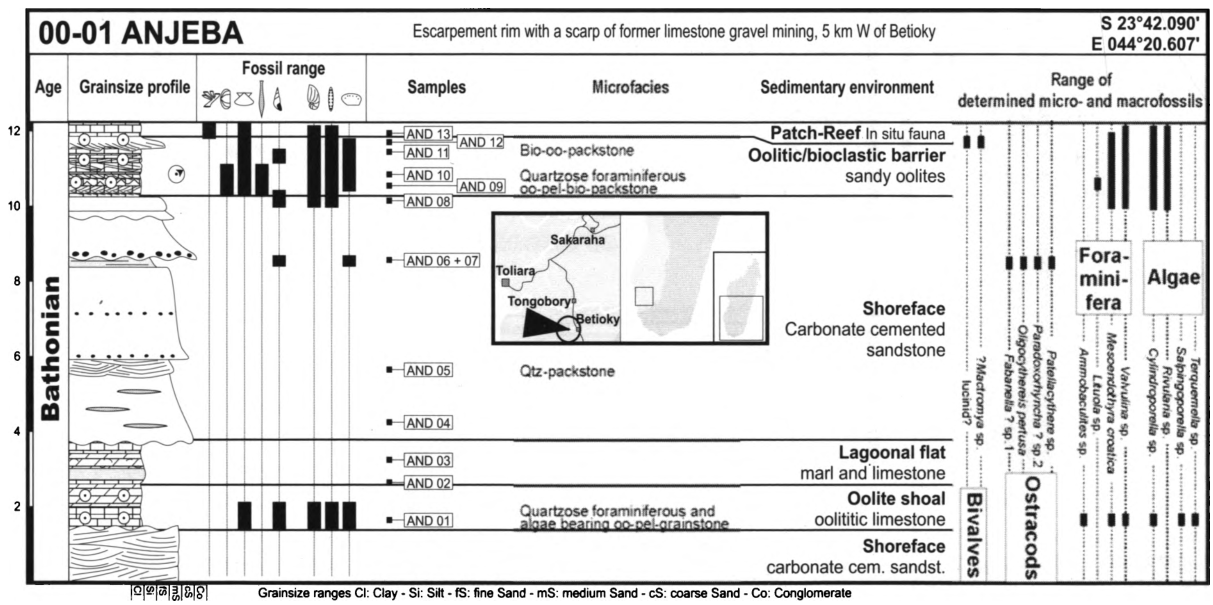
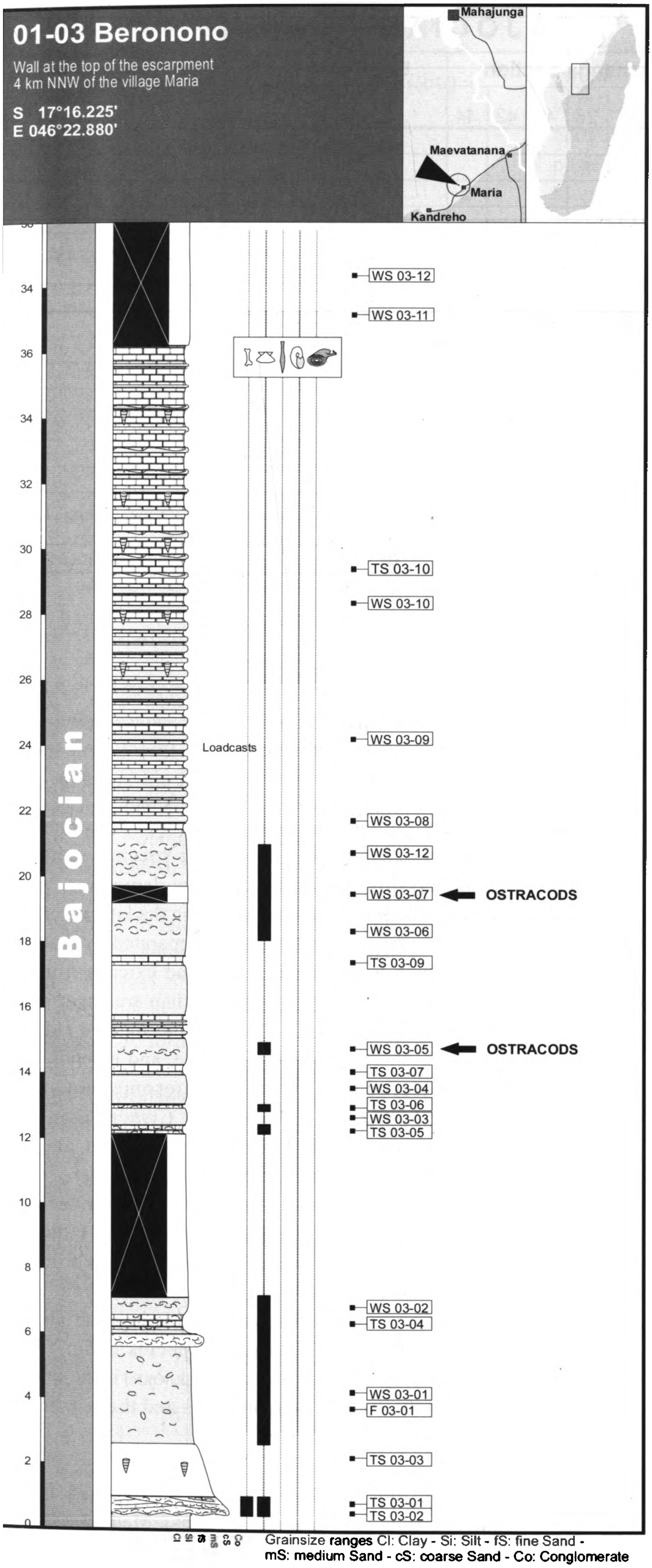


Fig.3: Beronono section (lithostratigraphy, sedimentary structures, fossil occurrences, depositional environments).



limestones (echinoids, bivalves, belemnites, gastropods) is indicative of open marine conditions and normal salinity. A continuation of the transgression and normal marine conditions are reflected by the autochthonous coral and bivalve meadow at the top of the section.

The ostracod fauna is suggested to be of middle or late Bathonian age because of the presence of *O. pertusa* GREKOFF, which so far has only been recorded from the mid-upper Bathonian of the Majunga Basin (GREKOFF 1963).

Sections, samples and material

At the Analamanga section 36 microfossil samples were collected, of which 7 samples (samples 21, 22, 27, 28, 40, 42, 43), yielded rich ostracod assemblages with 8 species which have been analysed taxonomically. At the Anjeba section 10 microfossil samples were collected, of which 1 sample (sample 7) contained a microfauna, with 6 ostracod species. Two ostracod faunas of low diversity (samples 5, 7), which are similar to the material from the Analamanga section, have been found at the Beronono section in the southernmost part of the Majunga Basin. The ostracods are stored at the Institute of Geology and Palaeontology at Innsbruck University and the ostracod catalogue numbers refer to Me 2001.

Fig.4: Anjeba section (Lithostratigraphy, sedimentary structures, fossil occurrences).

	BAJOCIAN								Middle-Upper Bathonian
sections:	Analamanga Section							Beronono section	Anjeba Section
samples:	21	22	27	28	40	42	44	5, 7	7
Acanthocythere ? sp.			X						
Cytherelloidea sp.1				X					
Darwinula sp.							X		
Ektyphocythere sp.1	X		O					X	
Ektyphocythere ? sp.									X
Fabanella ? sp.1									●
Fabanella ? sp.2									X
Fastigatocythere malgachica	●	O	●	O	●	O	O	●	
Fastigatocythere sp.								X	
Oligocythereis pertusa Grekoff									O
Paradoxorhyncha australiense	X								
Paradoxorhyncha malgachica n.sp.	X					O	●		
Paradoxorhyncha sp.1		X							
Paradoxorhyncha ? sp.2									X
Patellacythere sp.									X
Striatojonesia striata								X	

X = rare (less than 5% of specimens) O = abundant (5-50% of specimens) ● = dominant (more than 50% of specimens)

Fig.5: Stratigraphical range and relative abundance of ostracods.

Systematic Palaeontology

WOLFGANG METTE

The following abbreviations have been used: c= carapace, lv = left valve, rv = right valve, L = length, H = height, W= width.

Order **Podocopida** MÜLLER 1894

Suborder **Platycopina** SARS 1866

Family **Cytherellidae** SARS 1866

Genus *Cytherelloidea* ALEXANDER 1929

Type species. *Cytherelloidea williamsoniana* (JONES 1849)

Cytherelloidea sp. 1

Pl. 4, Figs. 7-9

Dimensions (mm).			L	H
Female	M1/10	c	0.70	0.36
	M9/15	c	0.68	0.32
Male	M1/15	lv	0.60	0.30

Material. 3 carapaces and 5 valves.

Remarks. The species resembles *Cytherelloidea* sp. D DEPECHE 1987 from the upper Bathonian and lower Callovian of Saudi Arabia (DEPECHE et\al. 1987) in carapace outline and fine reticulation. In contrast to *Cytherelloidea* sp. D, the present specimens have a mediodorsal-posterodorsal carapace depression and a posterio-medioventral depression on the lateral surface. The two carapace depressions are separated by a median ridge which is sinuous in males and extends from the posterodorsal area to the anteromedian area over 3/4 of the carapace length. On females the median ridge is relatively short, crescentic in shape, and extends from the posterodorsal to the anteromedian area. *Cytherelloidea* sp.1 differs from *Cytherellidea ipis* GREKOFF in the reticulate ornamentation and the occurrence of a sinuous median ridge. *Cytherelloidea* sp. A KHOSLA, JAKHAR & MOHAMMED has a similar ridge pattern but, in contrast to the species from India, the median ridge on the present species extends from the posterodosal margin to the anteromedian area. Furthermore, the specimens from Madagascar show a fine reticulation. The present species differs from *Cytherelloidea refecta* (JONES & SHERBORN) in the sinuous shape of the median ridge in males and the reticulation of the entire lateral surface.

Distribution. Bajocian of the Morondava Basin (Analamanga and Sakaraha sections), Madagascar.

Suborder **Podocopina** SARS 1866

Superfamily **Cytheracea** BAIRD 1850

Family **Cytheridae** BAIRD 1850

Genus *Fabanella* MARTIN 1961

Type species. *Fabanella prima* MARTIN 1961

Fabanella ? sp.1

Pl. 3, Fig. 10; Pl. 4, Figs. 1-2

Dimensions (mm).			L	H
Female	M6/16	c	0.84	0.42
	M6/17	c	0.86	0.44
	M6/38	c	0.88	0.46
	M6/18	c	0.88	0.48
Male	M6/19	c	0.96	0.44
	M6/39	c	0.88	0.40
	M6/40	c	0.88	0.37

Material. 58 carapaces and 1 valve.

Remarks. The species is tentatively assigned to the genus *Fabanella* because of the similar carapace outline in lateral and dorsal views. Internal features are not accessible and the lateral surface is poorly preserved. The presumed female specimens are similar to the male specimens of *Fabanella sarda* MALZ from the Bajocian-lower Bathonian of Sardinia (MALZ et al.1985) and the upper Bajocian-lower Bathonian of southern Tunisia (METTE 1995) in lateral outline. The present species is more broadly rounded at the posterior margin and has no anterodorsal oblique sulcus like *F. sarda*. The presumed males have a much more elongate outline than the males of *F. sarda*. The present species differs from *Fabanella bathonica* (OERTLI) in the weak concavity of the central dorsal margin, the absence of an anterodorsal sulcus and the more elongate outline of the presumed males. In addition, the posterodorsal margin is longer and less steeply inclined towards the posterior end.

Distribution. Middle - upper Bathonian of the Morondava Basin (Anjeba section), Madagascar.

Fabanella ? sp.2

Pl. 4, Fig. 3

Dimensions (mm).		L	H
M6/41	c	0.58	0.32

Material. 2 carapaces.

Remarks. *Fabanella* sp. 2 differs from *Fabanella* ? sp.1 in the longer and straight dorsal margin and the symmetrically rounded posterior end of the rv. In contrast to *F. bathonica* from the Bathonian of Europe, the dorsal margin of the present species is not inclined towards the posterior, and the posterior end is more symmetrically rounded. The species differs also from *F. sarda* in its evenly convex posterior margin.

Distribution. Middle – upper Bathonian of the Morondava Basin (Anjeba section), Madagascar.

Family **Cytheruridae** MÜLLER 1894

Subfamily **Cytherurinae** MÜLLER 1894

Genus *Paradoxorhyncha* CHAPMAN 1904

Type species. *Paradoxorhyncha foveolata* CHAPMAN 1904

Remarks. The systematic position of the genus *Paradoxorhyncha* has been the subject of controversial discussions. MALZ & OERTLI (1993) assigned the genus to the Progonocytherinae because of the hinge structure and the similarities in carapace shape and ornamentation to *Majungaella* (p.126). MALZ & OERTLI interpreted the hinge of *Paradoxorhyncha* as an „intermediate type between the (more primitive) lophodont hinge and the (more advanced) entomodont hinge“ and suggested that the genus is an „early offshoot of the *Majungaella* lineage“. Its assignment to the Progonocytherinae was later rejected by BALLENT & WHATLEY (1996) because, according to their published amendments to the definition of that family , the Progonocytheridae and Progonocytherinae should exclude all taxa without an entomodont hinge. According to BALLENT & WHATLEY (1996), both the external features of the carapace and the hinge structure suggest that the genus is better placed in the Cytheruridae.

Paradoxorhyncha malgachica n.sp.

Pl. 2, Figs. 2-10

Derivation of name. Reference to its occurrence in Madagascar.

Holotype. Female carapace, M1/13, pl.2, fig. 3.

Type locality. Analamanga section (road cutting), on the road between the villages of Sakaraha and Ankazoabo, 15 km NNE of Sakaraha, SW Madagascar (S 22°51.738′ / E 044° 32.950′).

Type horizon. Calcareous marl, about 15 m above the transgressive base of the Bajocian, which is marked by an oolitic limestone bed of 1 m thickness, and about 1 m below a claystone-siltstone with petrified wood.

Paratypes. 48 valves and carapaces of males and females.

Occurrence. Analamanga section, samples 21, 42, 44, Bajocian, SW Madagascar.

Dimensions (mm).			L	H
Female	M1/22	lv	0.50	0.29
Holotype	M1/13	c	0.48	0.32
	M1/25	lv	0.46	0.30
	M1/43	rv	0.48	0.32
	M1/27	rv	0.46	0.32
	M1/29	rv	0.40	0.24
	M1/31	rv	0.44	0.29
	M1/28	rv	0.46	0.31
	M1/44	rv	0.47	0.31
	M1/45	rv	0.48	0.33
Male	M1/34	c	0.72	0.36

Material. 49 valves and carapaces.

Diagnosis. A species of *Paradoxorhyncha* with a distinct reversed overlap on the dorsal margin and a dense, fine, punctate ornamentation of the lateral surface. Sexual dimorphism is very distinct: the female right valves are dorsally strongly arched and sub-triangular and the males are very elongate and sub-rectangular in lateral view.

Description. The carapace outline is sub-ovate (females) or elongate sub-rectangular (males) in lateral view and sub-ovate to lens-shaped in dorsal view. The greatest carapace length is at mid-height, the greatest height at mid-length (females) or just before mid-length (males), and the greatest width at mid-length. The anterior margin is broadly rounded and distinctly infracurved. The dorsal margin of the lv is straight or slightly convex and gently inclined towards the posterior margin. The dorsal margin of the rv is broadly rounded and distinctly arched at mid-length (females), or angled in front of mid-length with a straight anterodorsal and posterodorsal slope (males). The posterior margin of the lv is relatively broad and symmetrically rounded. In the rv, the posterior margin is narrowly rounded and indistinctly pointed at 1/3 of its height. The ventral margin is straight and merges gradually into the ascending and broadly convex posteroventral margin. The carapace displays a ventrolateral tumidity, which overhangs the ventral margin. The anterior marginal zone is laterally compressed. Along the dorsal margin there is a strong reversed overlap of the rv over the lv. The lateral surface is densely covered by relatively small puncta and is additionally ornamented by the openings of the normal pores. In many specimens a variable number of normal pores are filled with sediment or diagenetic calcite. In some specimens there is a more or less distinct ventrolateral keel along the ventrolateral carapace tumidity. Sexual dimorphism is very prominent: the males are much more elongate than the females in lateral and dorsal views.

Internal features. The hinge of the rv consists of a relatively long and smooth median groove and smooth, narrow, elongate terminal teeth. The dorsal margin strongly overreaches the median hinge element. The hinge of the lv consists of complementary elements; the terminal elements are smooth, narrow, elongate sockets and the median element is a smooth hinge bar. The inner margin and the line of concrescence coincide and the inner lamella is narrow. The central muscle scars consist of 4 sub-vertically arranged adductor scars, a crescentic antennal and a sub-ovate mandibular scar in front. Radial pore canals are not preserved.

Discussion. *Paradoxorhyncha* ? sp. from the Bajocian of Australia (MALZ & OERTLI 1993) is very similar to *P. malgachica* in the outline of the lv and has a similar type of ornamentation. It is, therefore, probably closely related to *P. malgachica*. However, in contrast to *Paradoxorhyncha* ? sp. the specimens from Madagascar do not show a crenulation of the terminal hinge elements. *P. malgachica* is also similar in carapace outline, size and ornamentation to *Paradoxorhyncha* ? *australiense* (CHAPMAN) from the lower Bajocian of Australia. The latter species also has a fine punctate ornamentation. The

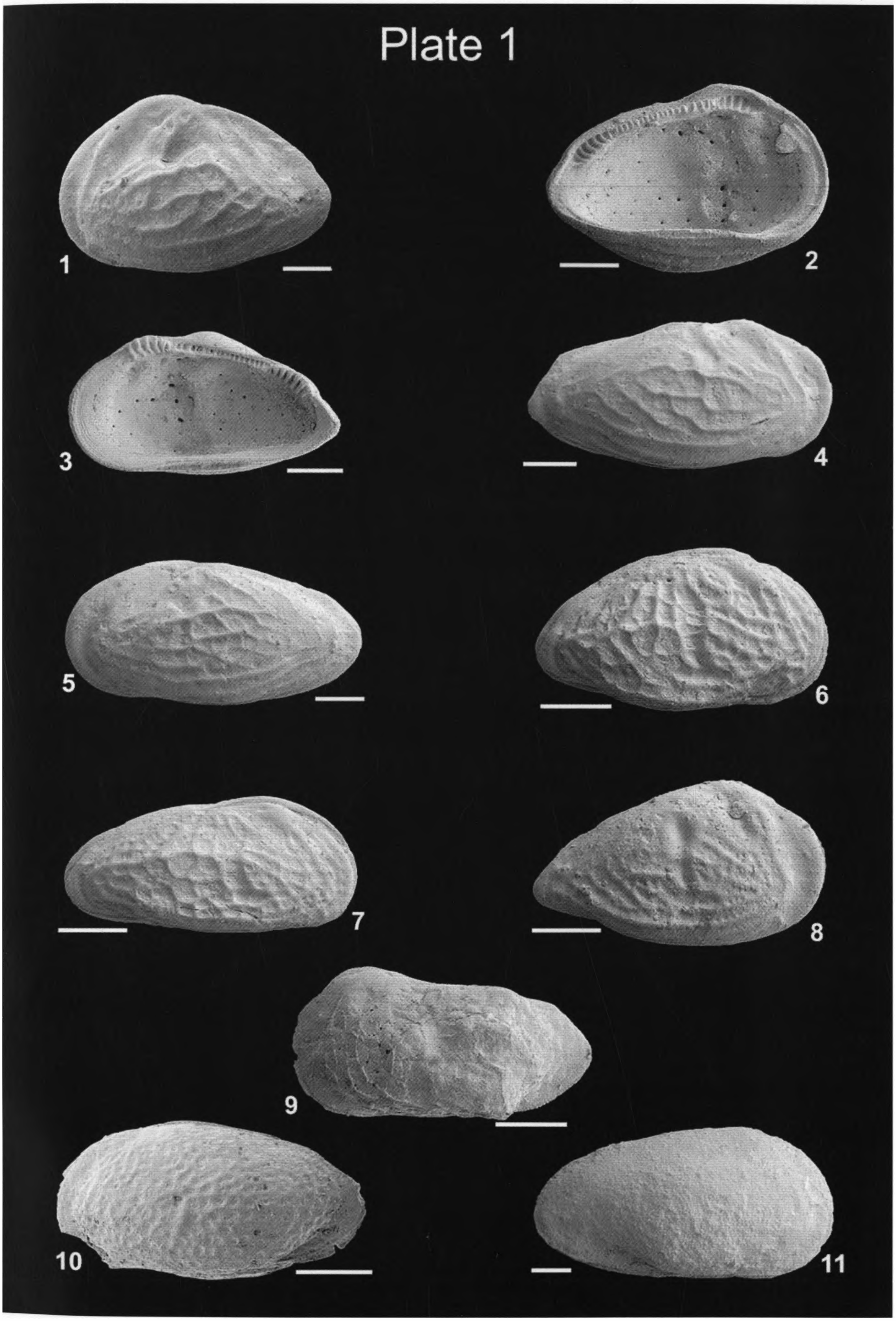
EXPLANATION OF PLATE 1

Figs. 1-8. *Fastigatocythere* (*Fastigatocythere*) *malgachica* (GREKOFF, 1963).
1-3. Sample 21, Analamanga section, Bajocian. 1. Female, left valve, M1/1. 2. Female, right valve, internal view, M1/3. 3. Female, left valve, internal view, M1/6. 4-8. Sakaraha section, Bajocian. 4. Male, right valve, M9/1, sample 4. 5. Male, left valve, M9/2, sample 4. 6. Juvenile with sexual dimorphism (female), right valve (of carapace), M9/8, sample 1. 7. Juvenile with sexual dimorphism (male), right valve (of carapace), M9/7, sample 1. 8. Juvenile, right valve, M9/12, sample 1.
Fig. 9. *Acanthocythere* ? sp., left valve, M1/20, sample 27, Analamanga section, Bajocian.

Fig.10. *Paradoxorhyncha* sp.1, left valve (of carapace), M1/8, sample 21, Analamanga section, Bajocian.

Fig.11. *Paradoxorhyncha* ? sp.2, male, right valve (of carapace), M6/26, sample 07, Anjeba section, middle-upper Bathonian.

Scale bar 100 μm.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puncta in the central part of the lateral surface are slightly larger than the pits in the peripheral areas and the marginal zones are smooth. In contrast to the species from Australia, the present species shows a very regular and fine punctate ornamentation of the complete lateral surface, a distinct reversed overlap along the dorsal margin, and a more strongly arched dorsal margin on the female rv which distinctly overreaches the median hinge element. Furthermore, the present species differs from *Paradoxorhyncha neuquenensis* (BALLENT) and *Paradoxorhyncha jurassica* (CHAPMAN) in the regular punctate ornamentation of the complete lateral surface, the more convex dorsal margin and the distinct reversed overlap. *P. malgachica* differs from *Paradoxorhyncha foveolata* CHAPMAN) from the lower Bajocian of Australia in the sub-triangular carapace outline of the females, the fine punctate ornamentation and the stronger reversed overlap.

Distribution. *P. malgachica* is recorded from the Bajocian of the Morondava Basin (Analamanga section), Madagascar.

Paradoxorhyncha australiense (CHAPMAN)

Pl. 2, Fig. 1

1904 *Cytheropteron australiense* sp. nov. – CHAPMAN: p. 203, pl. 23, figs. 7, 7a,b.
1956 *Cytheropteron australiense* CHAPMAN – KELLETT & GILL : p. 125.
1978 *Cytheropteron australiense* CHAPMAN – DE DECKKER in : DE DECKKER & JONES: p. 56.
1993 *Paradoxorhyncha ? australiense* (CHAPMAN 1904) – MALZ & OERTLI: p. 127, figs. 1.2, 5.33, 6.40, 43-48.

Dimensions (mm).	L	H
Male M1/14 c	0.57	0.26

Material. 1 carapace.

Remarks. The present specimen coincides with the males of *P. australiense* in carapace outline, size and ornamentation. The most similar species is *Paradoxorhyncha neuquenensis* (BALLENT). *P. australiense* differs from *P. neuquenensis* (BALLENT), from the upper Aalenian-lower Bajocian of Argentina, in its larger size, the more symmetrically rounded anterior margin on the males and the more distinctly bow-shaped ventrolateral carapace tumidity. In the latter feature, *P. australiense* also differs from *Paradoxorhyncha jurassica* (CHAPMAN).

Distribution. *P. australiense* has been recorded from the lower Bajocian of Australia (CHAPMAN 1904, MALZ & OERTLI 1993) and occurs in the Bajocian of the Morondava Basin (Analamanga section), Madagascar.

Paradoxorhyncha sp.1

Pl. 1, Fig. 10

Dimensions (mm).	L	H
M1/8 c	0.40	0.22

Material. 1 carapace.

Remarks. *Paradoxorhyncha* sp.1 has a similar outline and surface reticulation to *Paradoxorhyncha foveolata* CHAPMAN but it is much smaller than the latter species. It is improbable that the present carapace is a juvenile of the latter species because the juveniles of *P. foveolata* CHAPMAN have a much finer ornamentation and a more elongate outline than the present specimen.

Distribution. Bajocian of the Morondava Basin (Analamanga section), Madagascar.

Paradoxorhyncha ? sp. 2

Pl. 1, Fig. 11

Dimensions (mm).	L	H
Male M6/42 c	0.62	0.32
M6/26 c	0.74	0.38

Material. 6 carapaces.

Remarks. The species is represented by a few carapaces. Because of the lack of internal features, it is questionable

EXPLANATION OF PLATE 2

Fig. 1. *Paradoxorhyncha australiense* (CHAPMAN,), left valve (of carapace), M1/14, sample 21, Analamanga section, Bajocian.

Figs. 2-10. *Paradoxorhyncha malgachica* n.sp., Analamanga section, Bajocian. 2. Female, left valve, paratype, M1/18 , sample 27. 3. Female, left valve (of carapace), holotype, M1/13, sample 21. 4. Female, right valve, paratype, M1/26 , sample 42. 5. Female, right valve, paratype, internal view, M1/24, sample 42. 6. Female, right valve, paratype, M1/29, sample 42. 7. Female, left valve (of carapace), paratype, M1/35, sample 44. 8. Female, right valve, paratype, M1/36, sample 42. 9. Male, left valve (of carapace), paratype, M1/38 , sample 44. 10. Male, left valve (of carapace), paratype, M1/34, sample 44.
Scale bar 100 µm.


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whether the present specimens belong to *Paradoxorhyncha*. In lateral and dorsal view the males are elongate to sub-ovate and the females are sub-triangular to sub-ovate. The carapace outline is somewhat similar to *Paradoxorhyncha australiense* (CHAPMAN) from the Bajocian of Australia, but the present material differs from the Australian species in the less distinct mid-ventrolateral carapace tumidity and in the narrowly rounded posterior margin. Details of the surface ornamentation are not preserved.

Distribution. Middle – upper Bathonian of the Morondava Basin (Anjeba section), Madagascar.

Family **Bythocytheridae** SARS 1926

Genus *Striatojonesia* SCHORNIKOV 1990

Type species. *Striatojonesia striata* (TRIEBEL & BARTENSTEIN 1938)

Striatojonesia striata (TRIEBEL & BARTENSTEIN 1938)

Pl. 3, Fig. 9

Dimensions (mm).		L	H
M8/15	lv	0.52	0.28
M8/17	lv	0.53	0.26
M8/16	rv	0.54	0.28

Material. 5 valves and 1 carapace.

Remarks. The species has a relatively long stratigraphical range and a wide geographical distribution. It has been reported from the Pliensbachian-Middle Bathonian of central and western Europe (England Germany, France, Spain), and the Bajocian of North Africa (Morocco, Egypt) and Jordan (reference list in ANDREU, QAJOUN & CUBAYNES 1995). The present material, which is from the Bajocian of the southernmost Majunga Basin (Beronono section) is the first published record of *Striatojonesia striata* from the South Gondwana region (Africa, South America, India, Australia, Madagascar). It has also been reported by DINA (1996) as *Monoceratina striata* from the Bajocian of the Morondava Basin (Sakaraha section).

Family **Progonocytheridae** SYLVESTER-BRADLEY 1948

Subfamily **Progonocytherinae** SYLVESTER-BRADLEY

Genus *Fastigatocythere*

Remarks. According to the original definition (WIENHOLZ 1967) the genus *Fastigatocythere* is characterized by the entomodont hinge, inverted chevron-type (triangular or sub-triangular) ridge pattern, distinct anterodorsal sulcus and 7-9 anterior marginal pore canals. The definition of *Fastigatocythere* was later amended (WHATLEY & BALLENT 1996) by extending both the variability of the hinge structure and the range in the number of marginal pore canals. According to the amended definition, the genera which show the typical ornamentation of a sub-triangular ridge pattern, a lobodont hinge and/or up to 14 anterior pore canals (*Amicytheridea, Glyptogatocythere, Zerqacythere*) are also incorporated into the genus. Because of the differences in the hinge structure and number of radial pore canals *Fastigatocythere* (*sensu* WIENHOLZ 1967) and the latter genera are, however, regarded herein as subgenera of *Fastigatocythere* (*sensu* WHATLEY & BALLENT 1996).

Subgenus *Fastigatocythere* (WIENHOLZ 1967)

Type species. *Fastigatocythere rugosa* WIENHOLZ 1967

EXPLANATION OF PLATE 3

Figs. 1-5. *Ektyphocythere* sp.1. 1-2. Sample 1, Sakaraha section, Bajocian. 1. Female, left valve, M10/2. 2. Male, left valve, internal view, M10/1. 3-5. Sample 07, Beronono section, southern Majunga Basin, Bajocian. 3. Female, left valve (of carapace), M8/13. 4. Female, right valve (of carapace), M8/12. 5. Male, left valve (of carapace), M8/14.

Fig. 6. *Ektyphocythere* ? sp., right valve (of carapace), M6/20, sample 07, Anjeba section, middle-upper Bathonian.

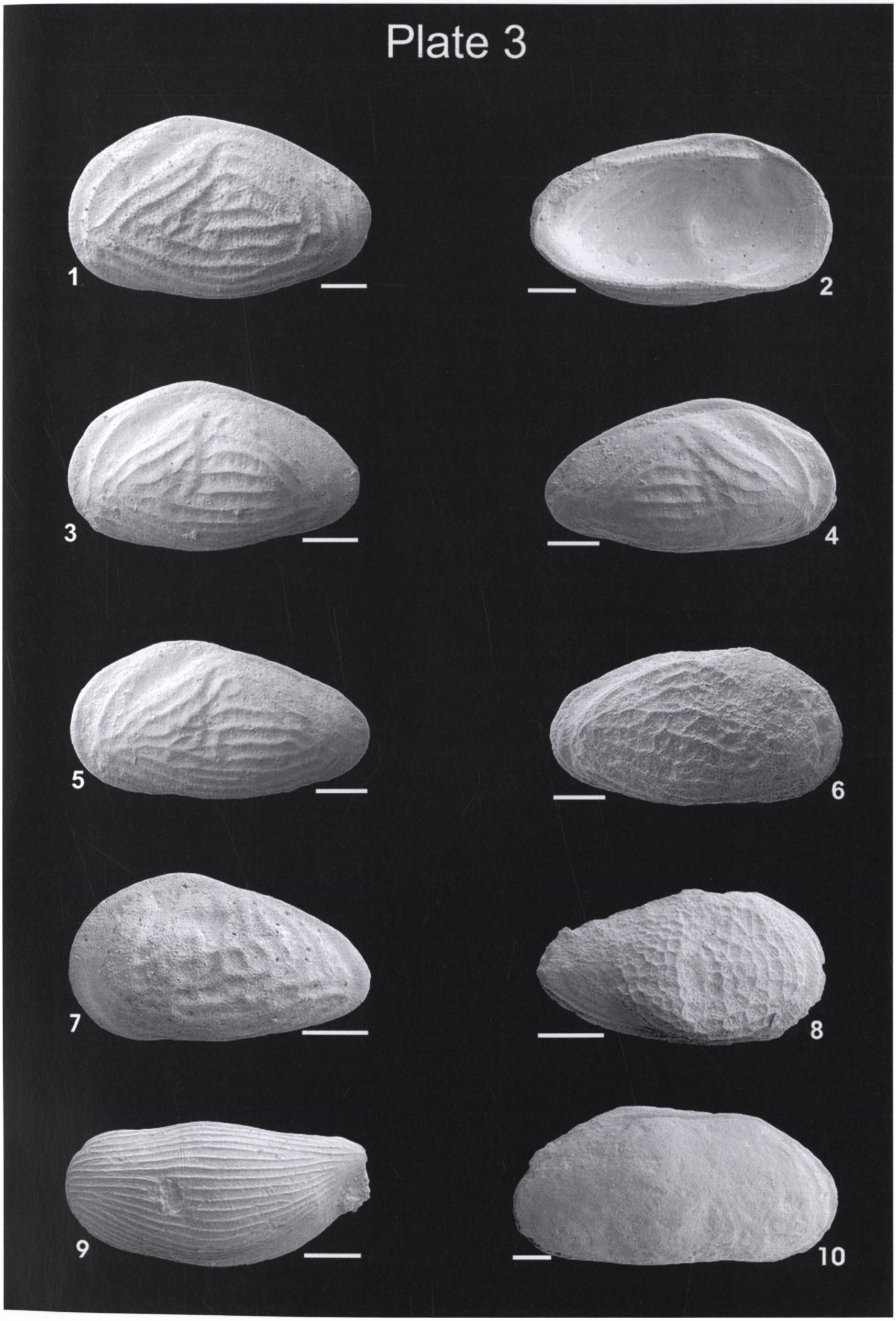
Fig. 7. *Fastigatocythere* sp., left valve, M8/18, sample 02, Beronono section, southern Majunga Basin, Bajocian.

Fig. 8. *Patellacythere* sp., right valve (of carapace), M6/24, sample 07, Anjeba section, middle-upper Bathonian.

Fig. 9. *Striatojonesia striata* (TRIEBEL & BARTENSTEIN 1938), left valve, M8/17, sample 07, Beronono section, southern Majunga Basin, Bajocian.

Fig. 10. *Fabanella* ? sp. 1, right valve (of carapace), M6/16, sample 07, Anjeba section, middle-upper Bathonian.

Scale bar 100 μm.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Fastigatocythere (*Fastigatocythere*) *malgachica* (GREKOFF 1963)

Pl. 1, Figs. 1-8

V 1963 *Progonocythere juglandica malgachica* n. subsp. – GREKOFF: p. 1731-1732, pl. 3, figs. 56-62, pl. 8, fig. 216.
? 1997 *Habocythere malgachica* (GREKOFF) - KHOSLA et al.: p. 18, pl. 4, figs. 2-6.

Dimensions (mm).			L	H	W
Female	M1/46	lv	0.47	0.31	
	M1/47	lv	0.53	0.35	
	M1/48	lv	0.54	0.35	
	M1/49	lv	0.46	0.30	
	M1/4	c	0.50		0.30
	M1/50	c	0.50	0.34	
	M1/3	rv	0.48	0.28	
	M1/6	rv	0.48	0.26	
Male	M1/1	lv	0.52	0.33	
	M1/2	lv	0.53	0.32	
	M1/51	lv	0.51	0.30	
	M1/52	lv	0.50	0.28	
	M1/53	lv	0.48	0.29	
	M9/1	rv	0.56	0.28	

Material. About 200 valves and carapaces.

Remarks. The specimens which are the subject of this study are assigned to *Fastigatocythere* (*Fastigatocythere*) because of the type of ornamentation (sub-triangular ridge pattern), carapace shape, and entomodont hinge. There are 7 to 8 anterior marginal pore canals, which are straight, simple and widely spaced. Within the central muscle scar field are 4 sub-vertical adductor scars and ovate antennal and mandibular scars. The hinge is entomodont with a coarsely denticulate median hinge bar in the lv. The anterior 4 denticles of the median hinge bar are slightly larger than the posterior ones. The anterior tooth is subdivided into 6 lobes and the posterior tooth into 7 lobes. The anterior socket has 5 loculi and the posterior socket 6 loculi. Sexual dimorphism is strongly developed. The males have an elongate, ovate outline while the females are shorter and are sub-triangular. In contrast to the adult specimens, the valves of the juveniles show a distinct median vertical sulcus extending beyond mid-height. This vertical sulcus is visible on the inner side of the juvenile valve as a long vertical ridge. On the lateral surface of the adults, two oblique sulci occur in the dorsomedian and anterodorsal area. The vertical sulcus which occurs on the juveniles is also visible on the inner side of the adult valve, but not on the outer side. On the specimens of the last juvenile stage (A-1) the lateral surface is completely covered by a distinct inter-costal reticulation, whereas in adult specimens the ornamentation is dominated by longitudinal ribs and the reticulation is reduced to the central part of the lateral surface. Furthermore, the A-1 juvenile specimens exhibit precocious sexual dimorphism which is less distinct than the sexual dimorphism of the adult.

The present species has previously been recorded from the Bajocian of the Morondava Basin by GREKOFF (1963). The specimens which were described as *Habocythere malgachica* (GREKOFF) from the Callovian of India (KHOSLA et al. 1997), are similar to the present species. Whether or not it is conspecific with *F. malgachica* is questionable because it has a lobodont rather than an entomodont hinge structure.

Distribution. *F. malgachica* occurs in the Bajocian of the southern Morondava Basin and the southernmost Majunga Basin (Beronono section). It was first described from the Sakaraha section, near the town Sakaraha, by GREKOFF (1963) and later by DINA (1996). The present material was obtained from the Analamanga and Sakaraha sections. A questionable occurrence of this species was also reported by GREKOFF from the upper Bathonian of the Majunga Basin. *Habocythere malgachica* (GREKOFF) which is either conspecific or closely related to to *F. malgachica* has been recorded from the Callovian Chari Formation (*Progonocythere laeviscula* Zone) of India (KHOSLA et al. 1997).

Genus *Acanthocythere* SYLVESTER-BRADLEY

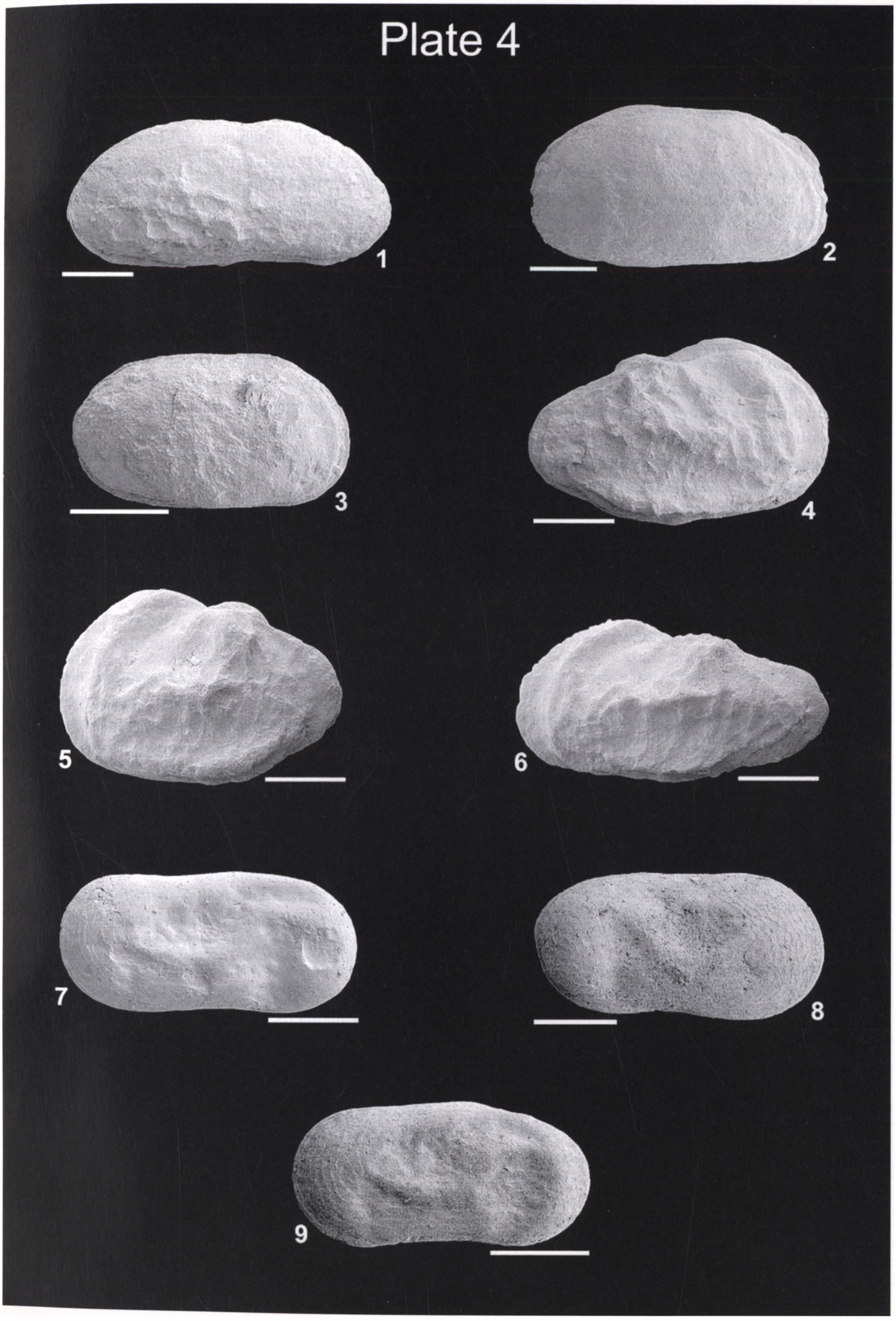
Type species *Cythere sphaerulata* JONES & SHERBORN 1888

EXPLANATION OF PLATE 4

Figs. 1-6. Sample 07, Anjeba section, middle-upper Bathonian. 1-2. *Fabanella* ? sp.1. 1. Male, right valve (of carapace), M6/19. 2. Female, right valve (of carapace), M6/18. 3. *Fabanella* ? sp.2, right valve (of carapace), M6/23. 4-6. *Oligocythereis pertusa* GREKOFF. 4. Female, right valve (of carapace), M6/29. 5. Female, left valve (of carapace), M6/30. 6. Male, left valve (of carapace), M6/33.

Figs. 7-9. *Cytherelloidea* sp.1, 7. Female, left valve (of carapace), M9/15, sample 01, Sakaraha section, Bajocian. 8. Female, right valve (of carapace), M1/10, sample 21, Analamanga section. 9. Male, left valve, M1/15, sample 27, Analamanga section.

Scale bar 200 µm.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Acanthocythere ? sp.

Pl. 1, Fig. 9

Dimensions (mm).		L	H
M1/19	rv	0.46	0.24
M1/20	lv	0.41	0.23

Material. 2 valves.

Remarks. Due to the poor preservation the present species is left in open nomenclature. The ornamentation strongly suggests a close relationship to *Acanthocythere*. The lateral surface is covered with small pores which are arranged in an irregular polygonal network. The polygonal fields are also covered by very fine pores. In the anterior quarter of the lateral surface 3 delicate ribs occur, running parallel to the anterior margin. The ventral part of the posterior margin shows a fine crenulation. The posterior part of the valves is also ornamented by a broad posterodorsal ridge which rises above the posterodorsal margin and another posteroventral ridge which projects over the posteroventral margin. A broad and shallow eye node occurs on the anterodorsal angle. Internal features not seen.

Distribution. *Acanthocythere* ? sp. occurs in the Bajocian (Analamanga section) of the Morondava Basin, Madagascar.

Family **Protocytheridae** LUBIMOVA 1955

Subfamily **Kirtonellinae** BATE 1963

Genus *Ektyphocythere* BATE 1963

Type species. *Ektyphocythere triangula* (BRANDT 1961)

Ektyphocythere sp. 1

PL. 3, Figs. 1-5

? 1998 *Ektyphocythere mediodepressa* sp. nov. – BOOMER, AINSWORTH & EXTON: p. 11-12, fig. 8, figs. 1-8.
? 1987 *Ektyphocythere bucki* (Bizon) – ROSENFELD, GERRY & HONIGSTEIN: p. 261, pl. 1, figs. 9- 11.

Dimensions (mm).		L	H
M1/11	rv	0.61	0.30
M1/54	rv	0.64	0.31
M1/16	lv	0.59	0.35
M1/55	lv	0.65	0.34

Material. 3 carapaces and 7 valves.

Remarks. The hinge of the present species is antimerodont. On the anterior margin about 6 to 8 simple and straight radial pore canals have been observed. The species is probably closely related to *Ektyphocythere mediodepressa* BOOMER, AINSWORTH & EXTON from the upper Toarcian of Portugal (BOOMER et al. 1998). It has the same outline in lateral view and the same type of ornamentation. The vertically aligned elements of ribbing on the vertical sulcus do not occur on the present specimens but this difference could be the result of poor preservation or intraspecific variability. Furthermore, in contrast to *E. mediodepressa*, the ridge pattern in the central part of the lateral surface of the present material looks more regular, and on the rv the dorsal ridges do not overreach the dorsal margin as distinctly as they do on the species from Portugal. The specimens described as *Ektyphocythere bucki* (BIZON) from the Toarcian of Egypt (ROSENFELD et al. 1987), and as *Ektyphocythere dierallaensis* from the Bajocian of Jordan (BASHA 1980) also have a very similar outline in lateral view and a similar ornamentation to both *E. mediodepressa* and the material from Madagascar. *Ektyphocythere* sp.1 is, therefore, suggested to be either conspecific with, or a close descendant of, the above mentioned taxa from the Toarcian of Portugal and Egypt.

With regard to carapace outline and ornamentation, the species also resembles ostracod taxa from the Toarcian of western Europe, which have been considered by ANDREU et al. (1995) to belong to *Ernstella bucki/ rugosa*. According to ANDREU et al. the latter species shows a great intraspecific variability in ornamentation and can be differentiated into the morphs A-E. With respect to ornamentation, the specimens from Madagascar are most similar to the morph D. ANDREU et al. (1995) assigned the following species to *Ernstella bucki/rugosa*: *Ektyphocythere bucki* (BIZON) which occurs in the Toarcian of Europe and Israel, and in the Bajocian of Jordan, and the species *Ektyphocythere intrepida* (BATE & COLEMAN), *Ektyphocythere rugosa* (BIZON), *Praeschuleridea pseudokinkelinella* (BATE & COLEMAN) which are recorded from the Toarcian of Europe. The present specimens are most similar to *E. bucki* and *E. intrepida*. In contrast to *E. intrepida*, the present specimens are smaller and have a sub-central vertical sulcus. *Ektyphocythere* sp.1 differs from *E. bucki* in its more distinctly pointed posterior margin and larger size. However, the similarity in ornamentation points to a close relationship between the present material and *E. bucki*. *Ektyphocythere australis* BALLENT from the early Bajocian of Argentina is also similar to the presented material in both ornamentation and outline. The material from Madagascar differs from *E. australis* in the greater number of ribs on the lateral and ventrolateral surface and the less convex posteroventral margin. From the great similarity in outline and ornamentation *E. australis* is presumably a descendant of *E. bizoni* AINSWORTH from the Toarcian-Aalenian of Western Europe.

Distribution. *Ektyphocythere* sp.1 has been found in the Bajocian of the Morondava Basin (Analamanga and Sakaraha sections) and in the Bajocian of the southernmost part of the Majunga Basin (Beronono section), Madagascar.

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