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THE MID-JURASSIC MARINE TRANSGRESSION IN EAST AFRICA: NEW DATA ON THE DEPOSITIONAL ENVIRONMENT AND AGE OF THE LOWER KAMBE FORMATION (AALENIAN TO BAJOCIAN) IN THE MOMBASA AREA (S.E. KENYA)

MAURIZIO CHIOCCHINI [1], MILVIO FAZZUOLI [2] & VIVIANA REALE [2]

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Abstract. The Lower Kambe Formation crops out from Mombasa towards the northeast, along the coastal area of Kenya; it was deposited during the first phases of the Middle Jurassic marine transgression. The lithology of the Lower Kambe Fm. varies passing from the southern areas towards the north: near Mombasa, this formation consists of an alternance of calcareous and marly intervals; the marly levels become thinner and tend to disappear towards the north, where the succession becomes entirely calcareous and shows features of a carbonate platform.

According to field observations, in the Mwachi River area near Mombasa, four lithological units crop out, that we consider as informal members, namely from bottom: (a) Calcarenitic member (Cam), well bedded calcarenites and some conglomerates; (b) Lower Shaly member (LSm), marly shales with marly limestone beds; (c) Conglomeratic member (Cgm), alternance of calcarenitic beds and levels of conglomerates; (d) Upper Shaly member (USm), marly shales and siltstones with thin beds of calcilutites and quartz sandstones.

The sedimentological features of the Cam point to a shoreline environment, possibly shoreface; those of the LSm to a mid/outer ramp; the onset of tectonically active slopes is evidenced by the occurrence of gravity flow structures in the fine-grained sediments. At the top of LSm a marked shallowing of the deposition environment occurred. The Cgm was deposited on a inner ramp, where polymictic coarse deposits (arenaceous, shaly and carbonate clasts) indicating a strong erosion of the coastal areas, were intercalated to the wave-winnowed calcarenites; also the calcarenitic upper portion of the Cgm was deposited on an high energy inner ramp depositional environment. Upwards, a deepening occurred, as the fine sediments of the USm point to a mid/outer ramp. The age of the Lower Kambe Formation has been determined by several Authors on the basis of ammonites; in this work calcareous nannofossils stratigraphy is provided. The age given by ammonites is Bajocian; the calcareous nannofossil assemblage, found in various localities along the Mwachi River, indicates an Aalenian – Bajocian p.p. age. The discrepancy is possibly due to a complex geological situation (faults?) in the localities with ammonites.

Riassunto. La "Lower Kambe Formation" affiora nell'area costiera del Kenya. Questa formazione si è deposta durante le prime fasi della trasgressione marina del Giurassico Medio. La litologia della Lower Kambe Formation varia da sud verso nord-est: presso Mombasa sono presenti alternanze di livelli calcarei e livelli marnosi; verso nord-est i livelli marnosi si assottigliano fino a scomparire e la successione diventa interamente calcarea e mostra caratteristiche di sedimentazione carbonatica di piattaforma. Nell'area del Mwachi River, presso Mombasa, sono state riconosciute quattro unità litologiche che sono state considerate come membri informali; a partire dal basso sono: (a) Calcarenitic member (Cam), calcareniti con livelli conglomeratici alla base; (b) Lower Shaly member (LSm), argilliti marnose con strati di calcari marnosi; (c) Conglomeratic member (Cgm), alternanza di pacchi di strati calcarenitici e di livelli di conglomerati poligenici; (d) Upper Shaly member (USm): argilliti marnose con sottili strati di calcilutiti e di quarzoareniti.

Le caratteristiche sedimentologiche del Cam sono indicative di un ambiente costiero, di spiaggia sommersa; quelle del LSm sono riferibili ad un ambiente di rampa intermedia/esterna; la formazione di scarpate di origine tettonica è suggerita da strutture deformative nei sedimenti fini. Al tetto del LSm ha avuto luogo una marcata diminuzione di profondità. Nel Cgm si sono avute dapprima condizioni di rampa interna con la presenza di corpi di conglomerati poligenici (con clasti di arenarie, siltiti, carbonati del substrato e frammenti di coralli), indicanti una forte erosione delle aree costiere. Anche la porzione superiore, calcarenitica, del Cgm è indicativa di condizioni di alta energia in una rampa interna. Successivamente si è verificato un marcato approfondimento ed i sedimenti prevalentemente fini dell'USm sono indicativi di una rampa intermedia/esterna. La Lower Kambe Formation è stata datata da altri Autori con ammoniti e nel presente lavoro, in località diverse, con nannofossili calcarei. Le datazioni mediante ammoniti hanno indicato un'età Bajociana, mentre lo studio delle associa-

1 Dipartimento di Scienze della Terra, Università di Camerino, Viale Gentile III da Varano, 62032 Camerino, Italy. E-mail: maurizio.chiocchini@unicam.it.

2 Dipartimento di Scienze della Terra, Università di Firenze,Via La Pira, 4, 50121 Firenze, Italy. E-mail: milvio@dicea.unifi.it; vreale@geo.unifi.it

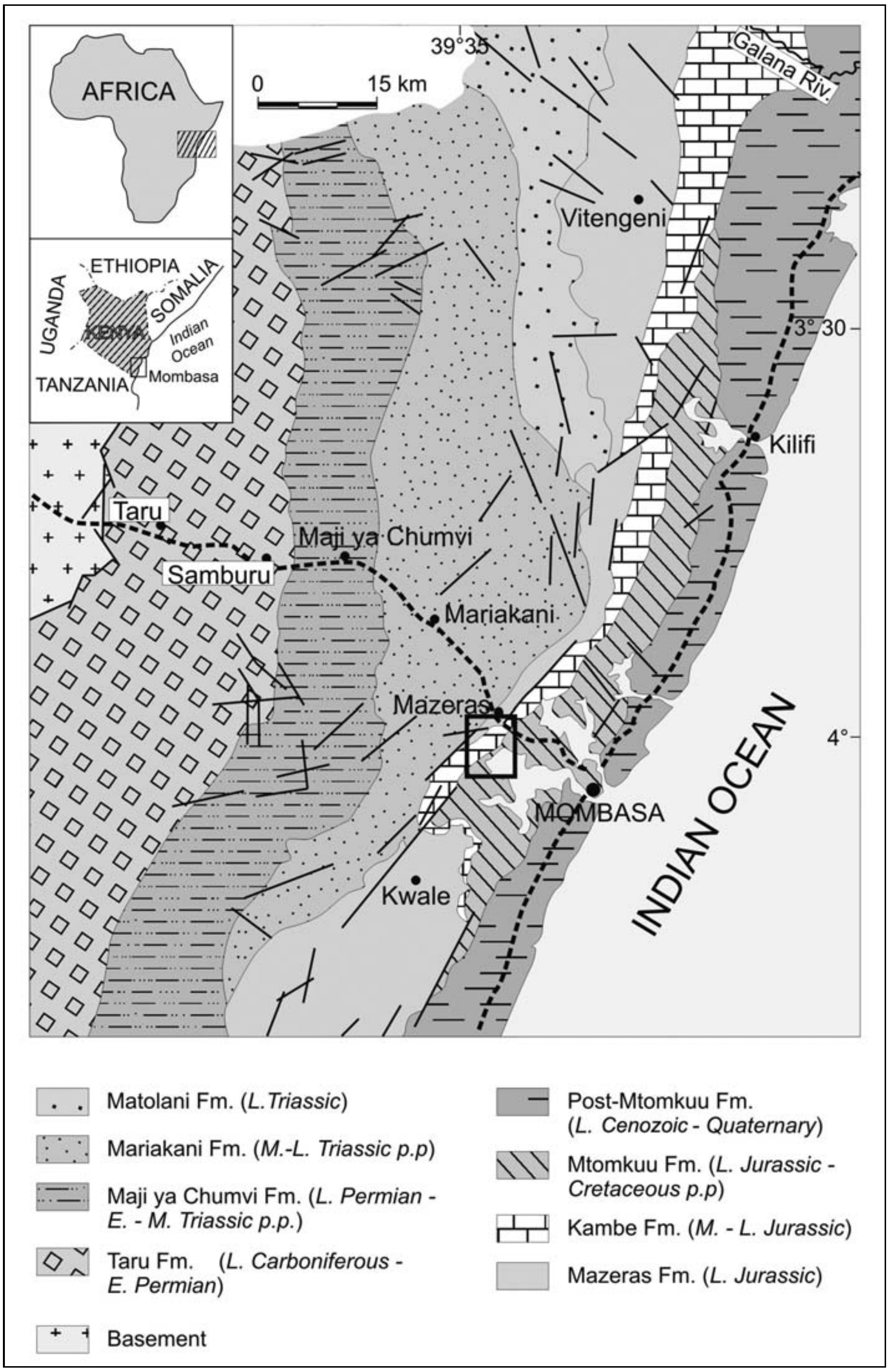


Fig. 1 - Simplified geological Map of the Mombasa-Kilifi area (SE Kenya), after Rais Assa (1988), modified. Framed area south of Mazeras in Fig. 2.

zioni a nannofossili calcarei indica un'età Aaleniana per il LSm e per la base dell'USm, Bajociana p.p. per il resto dell'USm. Queste discrepanze temporali sono molto probabilmente dovute ad una situazione geologica complessa, cioè alla presenza di faglie non riconosciute nelle località con ammoniti.

Introduction

During the Jurassic, the inception of marine sedimentation in different regions of East Africa, generally above continental clastic sediments, represents a problem centered on the exact time(s) of the marine encroachment, the sedimentary facies due to the encroachment, the tectono-sedimentary context and the role played by eustatism. After the basic work of Arkell (1956), who formerly discussed the timing of the marine transgression at a regional scale on the basis of the analysis of the biostratigraphic data available, this problem has been not addressed in detail. In fact, even if several lithostratigraphic data are nowadays available through outcrop sections or oil wells (Kamen Kaye 1978, 1982; Mbede 1987; Rais Assa 1988; Nyagah 1995) regarding the region including Kenya, Tanzania and Madagascar, the biostratigraphic data are generally not much detailed. According to Arkell (1956), some restricted areas of Central Arabia up to East Africa (northeast Somalia, northeast Kenya, Madagascar) were affected by an early transgression, that occurred during the Early Toarcian and was dated by ammonites characteristic of the Indo-Malagasy region *(Bouleiceras).* A further transgression in the Middle Jurassic spread over a large part of Southern Arabia, Ethiopia, Eritrea, Somalia, Kenya, Tanzania and Madagascar. Arkell (1956) described the fauna of this second transgression as characterized by brachiopods and pelecypods *(Eligmus rollandi* and *Gryphaea costellata)* and regarded the transgression in general as Late Bathonian. The coastal areas of Kenya (in particular near Mombasa) and of Tanzania were considered by Arkell (1956) of particular interest because of the occurrence of earliest Bathonian and Bajocian assemblages in the oldest marine sediments. Recent studies and some new data concerning the fossil record in northeast Somalia (Luger et al. 1990; Mette 1993), southwest Somalia (Canuti et al. 1983; Ali Kassim et al. 1987; Buscaglione et al. 1993; Chiocchini et al. 2002), coastal Kenya and Tanzania (Westermann 1975; Kapilima 1984; Galacz 1990) provide new informations about the age of the oldest record of Jurassic marine sediments in East Africa. According to these new data, the timing of the transgression in different areas (Kamen Kaye 1978, 1982; Rais Assa 1988; Bosellini 1989b) is sometimes different from the timing proposed by Arkell (1956) (i.e. Bajocian instead of Bathonian).

The aim of this paper is to illustrate the geological and paleontological results of a research carried out on the Lower Kambe Formation (Middle Jurassic) near Mombasa (coastal Kenya). In particular we aim to describe the lithostratigraphy of the succession in the Mwachi River area, in order to trace the sedimentary evolution that involved the formation of the Kambe carbonate platform and the demise of part of it, and to give new biostratigraphical data about the early phases of marine transgression in this sector of East Africa.

Geological setting

The Kambe Limestone (sensu Caswell 1953, 1956) crops out, as a 120 Km elongated strip (Fig. 1), along the coastal area of Kenya from near Mombasa towards the north-east. The outcrops are narrow to the South, where some SW-NE trending faults are present, and become wider to the North, in proximity of the Galana (or Sabaki) River (Fig. 1). The Kambe Limestone of the Kenya coastal area is represented mainly by carbonate facies (Caswell 1953, 1956); only in the Mombasa area, the occurrence of clay and marly levels has been reported (McKinnon Wood 1938; Weyr 1938; Arkell 1956; Westermann 1975). According to Caswell (1953, 1956), from Mazeras to the north (Fig. 1), the lithological succession becomes entirely calcareous, showing features of a carbonate platform. The thickness of the formation increases northwards, passing from 150 to 600 m.

To the northwest of Mombasa, close to the confluence of the Duruma and Mwachi rivers, calcareous levels bearing brachiopods, bivalves, gastropods and corals are interbedded with clayey and marly levels bearing pelagic fauna (thin-shelled pelecypods and ammonites). These latter levels have been named "Mwachi Shales" by McKinnon Wood (1938), "*Posidonia* Shales" by Weyr (1938), "Lower *Posidonia* Shales with Limestone" and "Upper *Posidonia* Beds with thin Limestones" by Westermann (1975). The presence in these sediments of ammonites indicating a Bajocian and/or Bathonian age has been reported by Spath (1920, 1930, 1927-33), McKinnon Wood (1930, 1938), Westermann (1975) and Galacz (1990).

According to Westermann (1975), in the Mwachi section, on the left (northern) side of the river, the "Kambe Limestone Series" unconformably overlies the Mazeras Sandstones and it consists of four mappable

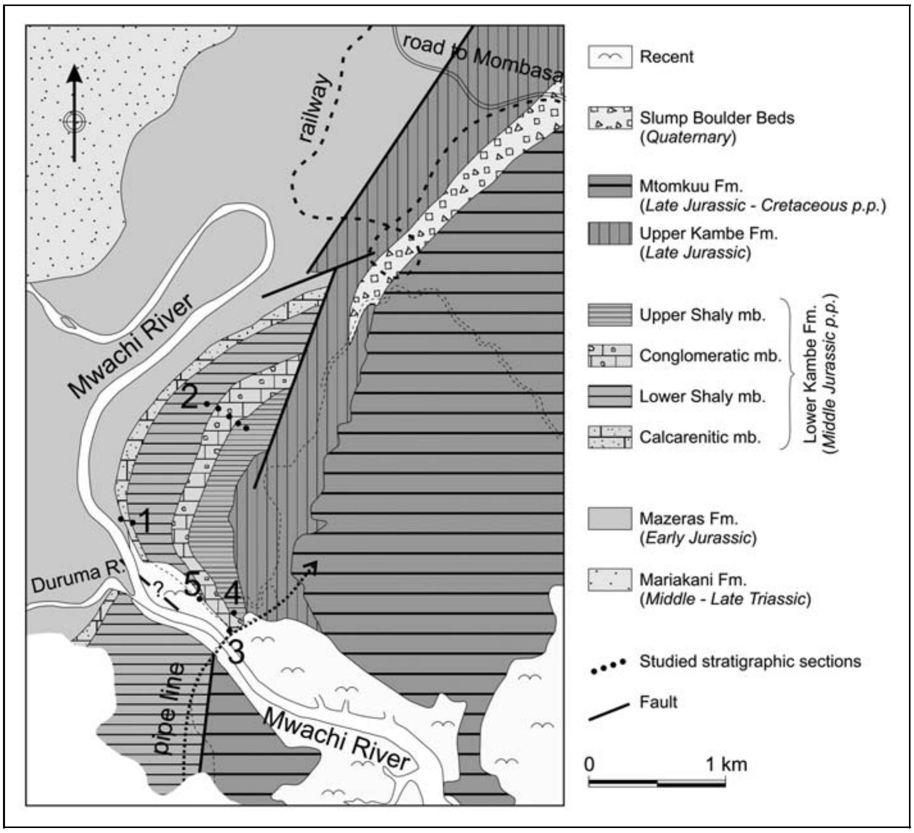


Fig. 2 - Geological sketch map of the area at the confluence between the Mwachi and Duruma Rivers, after Westermann (1975), modified. 1, 2 – stratigraphic sections studied by the Authors; 3 – fossil locality M76 (G550) cited by Westermann (1975); 4,5 – fossil localities MR1 and MR2 cited by Galacz (1990).

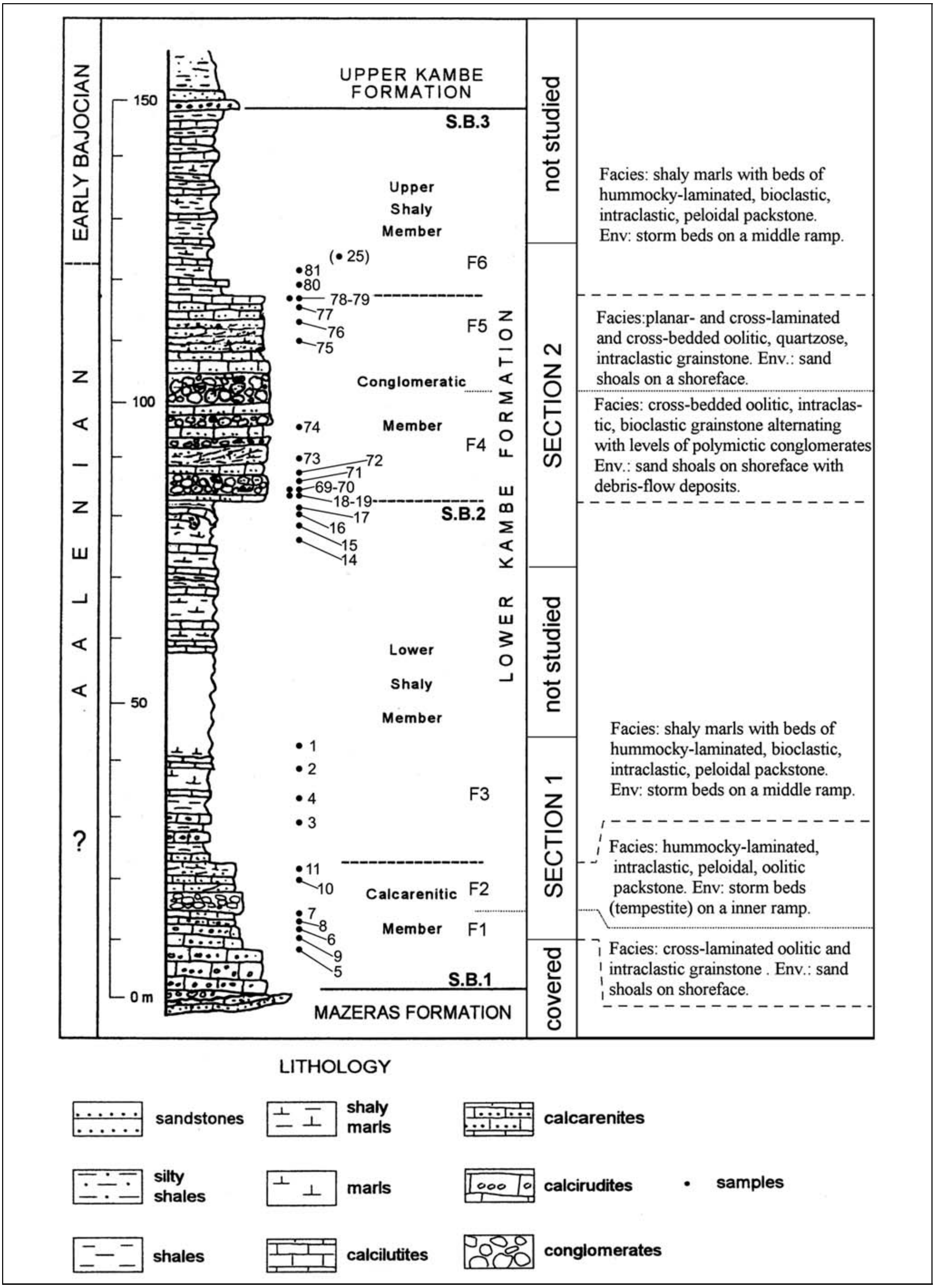


Fig. 3 - Stratigraphic log of the Lower Kambe Formation at the Mwachi River section. After Westermann (1975) modified; formational names mostly according to Rais Assa (1988). F1-6 – (litho)facies; S.B. 1-3 – Sequence Boundaries.

units, from the bottom: 1) Pisolitic and Oolitic Limestones with Basal Conglomerate – thickness: 30 m; 2) Lower *Posidonia* Shales with Limestone – thickness: 65 m; 3) Massive Coral Limestone – thickness: 12 m; 4) Upper *Posidonia* Beds with thin limestones interbedded – thickness: 43 m. The Kambe Limestone Series of Westermann (1975) has been renamed "Lower Kambe Formation" (LKF) by Rais Assa (1988); this formation is unconformably overlain by the "Upper Kambe Formation" (UKF). In the present paper we follow the Rais Assa (1988) nomenclature.

Lithostratigraphy

The geological sketch map of the area by Thomas, reported in Westermann (1975), formed the base for the field work. Observations on the four units quoted and mapped by Westermann (1975) and sample collections were made in the Mwachi River area by M. Fazzuoli, during the revision of Ph. D. Thesis of Dr. Maina Gichaba (Gichaba 1996). Two stratigraphic sections were measured and sampled: a lower section (1 in Fig. 2), including the calcareous unit 1) of Westermann (1975) and the lowermost portion of the shaly unit 2), occurs close to the alluvial plain on the right side of the Mwachi River, about half a Km north of the confluence with the Duruma River and about 1.2 Km northwest of the Mombasa pipeline bridge (Fig. 2). The upper section (2 in Fig. 2), is located about 1 Km to the northeast, at about 110 m above sea level, in a quarry called Quarry Mazeras A, which provided rock material for the ground of the Mombasa airport. The top of the shaly unit 2), the calcareous unit 3) and the base of the shaly unit 4) are well exposed in the quarry. The sample n. 25 has been collected in a quarry about 10 km to the NNE, where the transition between the unit 3) and the unit 4) is exposed. The shaly levels are generally poorly exposed outside the quarries, due to weathering and vegetation. It is worth noticing that the fossil localities with ammonites, quoted by Westermann (1975) and Galacz (1990), occur close to the pipeline bridge (3 and 4-5 in Fig. 2).

In the Mwachi area, according to our field observations, four lithological units occur (Fig. 3), that we consider as informal members of the Lower Kambe Formation (according to Rais Aissa 1988), namely from the bottom: 1) Calcarenitic member (Cam); 2) Lower Shaly member (LSm); 3) Conglomeratic member (Cgm); 4) Upper Shaly member (USm).

Calcarenitic member

Lithology - According to Westermann (1975), some meters of conglomeratic beds are present at the base of this member. Unfortunately, during our field work it was not possible to observe these beds in the studied section, as its base is covered by Recent fluvial sediments and soil. Upwards, (Fig. 3) the succession consists of:

– 6 m of 20-40 cm thick beds of grainstones with intraclasts, ooids (often with quartz grains as nucleous), quartz grains, peloids and bioclasts (Pl. 1A). Sedimentary structures are common, as low-angle cross-stratification, planar- and cross-laminations. These beds alternate with 10-20 cm thick beds, constituted by finer-grained peloidal, bioclastic and quartz grainstones and packstones and with mm-thick shaly beds. The beds are arranged in a coarsening and thickening up sequence.

– 1 m thick conglomeratic bed, constituted by angular to sub-rounded, mm- to cm- sized calcareous lithoclasts and subordinately of mm-sized quartz grains, with a slightly normally graded structure (Fig. 4). The texture of the lithoclasts consists of rudstones with large oncoids, intraclasts, ooids, bioclasts and quartz grains (Pl. 1B)

– about 4 m of 10-40 cm thick beds of intraclastic, peloidal, oolitic and bioclastic grainstones, with hor-

Fig. 4 - Calcarenitic member: hummocky cross bedded calcarenites and a conglomeratic bed, consisting of cm- and mm-sized clasts of limestones and subordinately of quartz grains.

	AALENIAN																						EARLY BAJOCIAN		
	Calcarenitic member							Lower Shaly member			Conglomeratic member														Upper Shaly. mb
	5	9	6	8	7	10	11	3	4	2	13	15	16	18	68	69	70	71	72	73	74	75	76	78	80
Valvulinidae	•	•	•	•	•	•	•	•		•	•	•	•		•	•	•				•		R	•	
Nodosariidae		•																							
Verneulina sp.	•	•	•	•		•	•																		
Pseudocyclammina sp.																					?	?			
Siphovalvulina variabilis Septfontaine		•			•		•																		
aff. *Protopeneroplis* n. sp.		•																							
Codiacean Algae				•	•																				
Ammobaculites sp.				•			•																•		
Glomospira sp.	•																								
Ophtalmidium sp.	•					•	?						•		•	•	•				?				
aff. *Acrulammina* sp.													•												
Trocholina sp.																								•	
und. arenac. foraminifers																		•		•					
"filaments"						•	•		•	•		•	•												•
radiolarians												•													
echinoderms	•	•	•		•	•	•	•	•		•	•			•	R	R		•	R	R	•	R	•	R
gastropods				•	•						•			•						•	•		•	•	
pelecypods														•		•	•	R	•	R					
Anthozoa																	•								

Fig. 5 - Table of microfossil distribution - R (rare);? (uncertain).

izontal and hummocky cross stratification, alternating with cm-thick shaly levels;

– about 2 m of 5-30 cm thick beds of intraclastic, peloidal, oolitic and bioclastic grainstones with hummocky cross stratification, and of peloidal, quartz and bioclastic wackestones and grainstones. The limestone beds, that become thinner upwards, alternate with cm- to dm-thick shaly beds. Close to the top of the interval, cm-thick bioclastic (with "filaments"), peloidal and quartz wackestones are also present. The transition from the Calcarenitic member to the overlying Lower Shaly member is sharp.

Fossil assemblage - In this and in the following paragraphs dealing with fossil assemblages, we will not present the calcareous nannofossil data, that will be shown in the Biostratigraphy chapter. The fossil content of the Calcarenitic member consists of benthic foraminifers (*Siphovalvulina variabilis* Septfontaine, aff. *Protopeneroplis* n.sp., *Verneulina* sp., Valvulinidae, Nodosariidae), pelecypods, echinoderms, gastropods and Codiacean Algae (Fig. 5)

Depositional environment - The sedimentological features of the mostly calcareous lower interval of the Calcarenitic member point to a shoreline environment, possibly shoreface, within an inner ramp setting (sensu Burchette & Wright 1992), in which carbonate sands were deposited by storm events on a muddy sea bed near or slightly below the wave base. The features of the upper interval are indicative of a deepening trend under the fair weather wave base and of a transition from the inner ramp to the middle ramp.

Events - The sedimentary evolution of the Calcarenitic member marks the onset of the marine transgression above the siliciclastic sediments of the Karoo continental basins.

Lower Shaly member

Lithology - Only the lower portion of the member, about 15m thick, is exposed in the stratigraphic section n.1. It consists of metric beds of dark-grey marls and calcareous marls, with scattered dark grey, up to 10 cm thick calcilutite beds, and fine calcarenitic, up to 10 cm thick beds with plane-parallel laminations and hummocky cross stratifications (storm beds). The textures of the coarser-grained beds are packstones with quartz grains, bioclasts, intraclasts, peloids and rare ooids; the textures of the fine-grained beds include mudstone-wackestone with silt-sized quartz grains, peloids and bioclasts.

The middle portion of this member, (about 50 m thick, according to Westermann 1975) is covered by scree.

The upper portion (4 m) cropping out at the base of the stratigraphic section n. 2 (Mazeras Quarry A), is

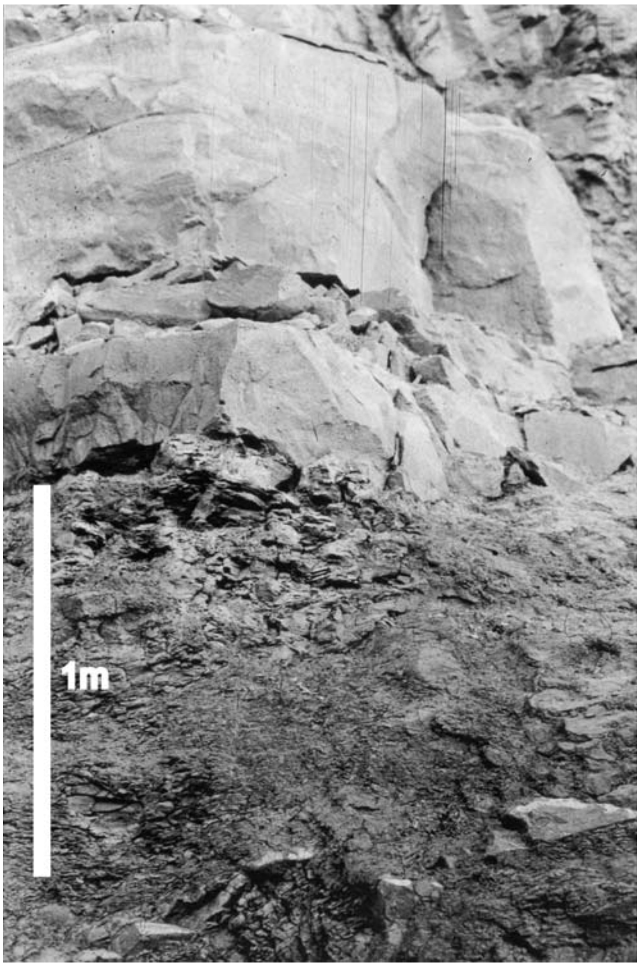


Fig. 6 - Abrupt transition between the top shaly marls of the Lower Shaly member and the basal calcareous beds of the Conglomeratic member. Some marly limestone beds are deformed by slumpings; the vergence of the reverse fold is toward the East.

represented by dark grey shales more or less marly, including cm-thick beds of dark grey marly calcilutites and cm-thick, lenticular levels of calcirudites (Fig. 6). The calcilutites consist of wackestone with peloids, silt-sized quartz grains, intraclasts and bioclasts; the calcirudite level consists of rudstone with intraclasts, ooids and quartz grains. The calcareous beds are either deformed by boudinage structures or show plastic deformations (Fig. 6). The transition from the shales to the overlying limestone of the Conglomeratic member is sharp and shows a slight but clear angular unconformity.

Fossil assemblage - The microfossil content of the Lower Shaly member is rather scarce and consists of "filaments", rare Valvulinidae, echinoderms and radiolarians (Fig. 5).

Depositional environment - The Lower Shaly member represents a further step in the deepening trend. As evidenced by the scattered and rather fine storm beds within more or less bioturbated shales and shaly marls, the lower portion of this member was deposited on the distal part of a middle ramp, near the storm wave base.

Events - In the middle/outer ramp with fine-grained sedimentation, the occurrence of storm layers deformed by slumps, and also of slump structures within the shales and the marly shales, indicates that the slope of the ramp increased and that soft sediment began to slide. The reverse folds and slumping structures have N-S axes; the vergence of the reverse fold is toward East and indicates that the slope steep increased toward the present Indian Ocean. (Fig. 2). The rapid increase in steepness in a previous low-gradient slope ramp (< 1° according to Ahr 1973), seems to suggest a superimposed tectonic control.

Conglomeratic member

Lithology - The Cgm can be subdivided into three portions.

The lower portion (26 m thick) is represented by calcarenitic beds, including calciruditic lenses, alternating with meter-thick conglomeratic beds. The calcarenitic beds, 10-50 cm thick and organized in sets of 2 m up to 4.50 m thickness, consist of large scale laminated planar cross-bedded, well sorted grainstones with ooids, abundant quartz grains, intraclasts, lumps, oncoids and bioclasts (benthic foraminifers).

Four conglomeratic beds, 2 to 4.40 m thick, are present: the conglomerates consist of mm- to dm-sized clasts and of a sand-size to clay-size matrix. The conglomerates are generally neither sorted nor graded; the fabric may vary horizontally: it is somewhere clast-supported and only a scarce matrix, constituted by sand-size calcareous grains or by shaly marls, is present. Elsewhere the fabric is matrix-supported and the clasts are scattered within finer grains. The matrix is a rudstone/grainstone and packstone with ooids, oncoids, intraclasts, bioclasts and abundant quartz grains (Pl. 1E); locally the matrix may also consist of grey-greenish marls. The conglomerates are polymictic, with subangular to subrounded clasts: the coarser clasts consist mostly of calcareous lithoclasts (oolitic-intraclastic-lithoclastic grainstone, oolitic-oncoidal grainstones/packstone, coral boundstone, bioclastic and intraclastic wackestone, mudstone and coarsely cristalline limestones). Other lithoclasts are siliciclastic and consist of yellowish and whitish quartz sandstones and siltstones, greenish marls, and yellowish laminated pelites.

The middle portion of the Cgm (14 m thick) consists of grey and yellowish, 10 to 40 cm -thick beds of grainstone with ooids, abundant quartz grains, intraclasts, lumps, oncoids and bioclasts (Pl. 1F). The beds are planar- and cross-laminated and low angle cross-stratified; they are stacked in m- thick sets (Fig. 7); small

Fig. 7 - Upper portion of the Conglomeratic member, consisting of dms-thick beds of well laminated, low angle cross-stratified, well sorted calcarenites.

conglomeratic lenses are included within fine-grained beds. The bedding planes correspond either to amalgamation surfaces or to stylolithes or mm- thick levels of grey shales.

The uppermost portion of the Cgm (about 3.5 m thick), consists of beds organized in a thinning and fining-up sequence (Fig. 7). Cm- to dm- thick beds of planar cross-laminated oolitic and quartzose grainstone alternate with wackestone beds, rare hummocky-laminated quartzose sandstone beds (Pl. 1G) and shaly levels, that show a thickening upward trend.

At the top of this portion, the transition to the overlying unit is transitional and it occurs in about 1 meter thickness (Fig. 7).

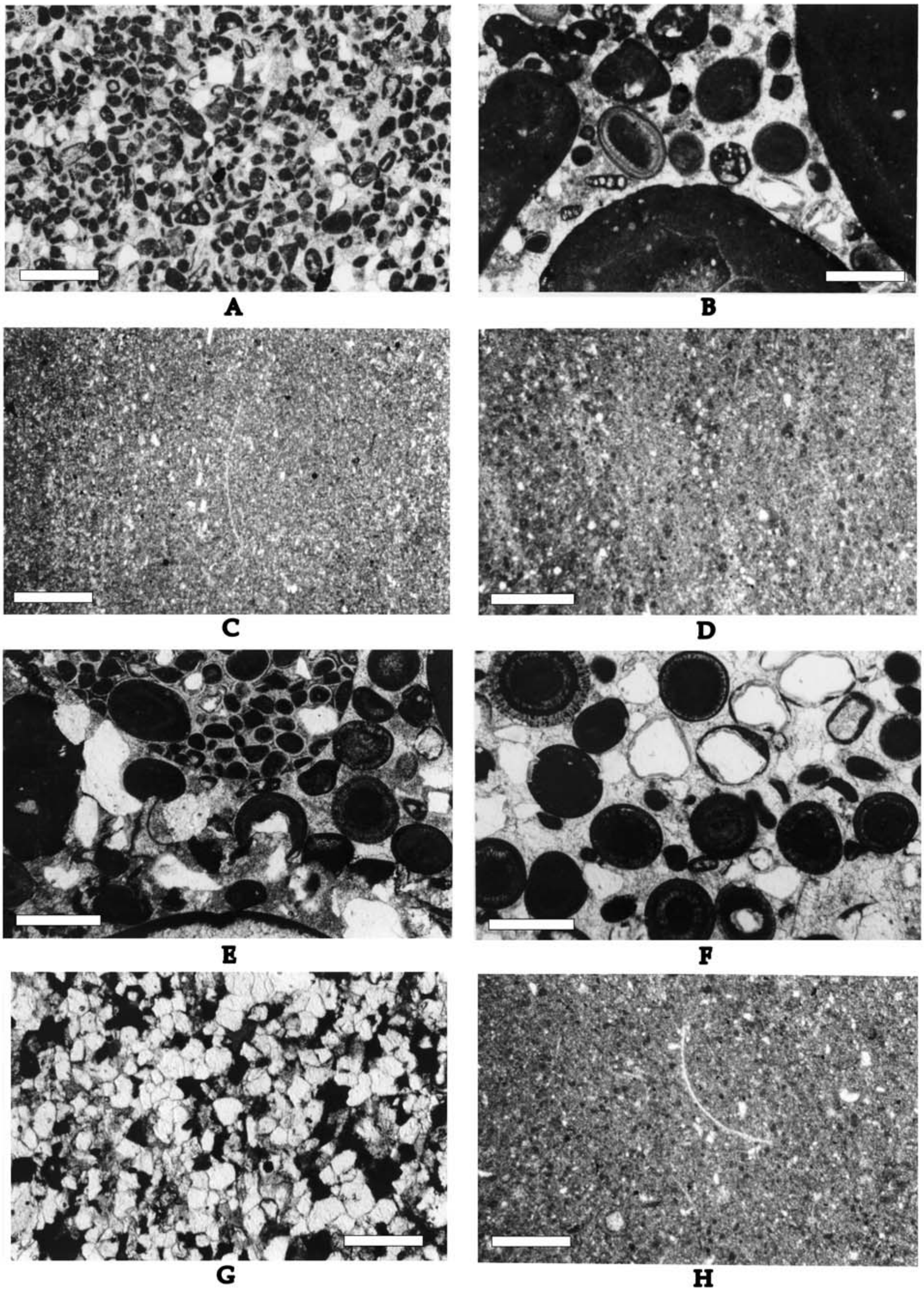
Fossil assemblage - The fossil content is represented mainly by abundant coral fragments, by echinoderms, gastropods, pelecypods, anthozoans and by benthic foraminifers (Valvulinidae, *Ammobaculites* sp., *Glomospira* sp., *Ophtalmidium* sp. aff. *Acrulammina, Trocholina* sp.); only in the finer-grained beds of the upper portion some "filaments" are present (Fig. 5).

Depositional environment - The sharp transition between the Lower Shaly member and the Conglomeratic member is related to an abrupt shallowing of the sedimentation environment, that from distal and storm-influenced became proximal and wave-dominated: a submarine shoals system sensu Ward et al. (1985) developed. Some debris flows took place (possibly as catastrophic events) within this high energy, shallow water environment. The limited area of observation does not permit to constrain whether the source of the coarse material was of local extent or it was derived from an extended escarpment (apron). In any case, the polymictic composition and the lack of any sorting or grading of clasts in the conglomeratic beds indicate an active erosion of a thick sedimentary succession constituted by the basal Cam of the LKF and by different formations of the underlying siliciclastic Karoo substrate and a rapid deposition in this shallow water environment. The shoreface environment persisted also after the end of the catastrophic events, but later on a deepening occurred and the sedimentary features of the top portion are indicative of sedimentation below the fair weather wave base, on a mid-ramp.

Events - The abrupt shallowing of the sedimentation environment, as well as the active erosion of a thick sedimentary succession constituted by the formations of the sedimentary substrate, was possibly due either to an eustatic fall or to a tectonic activity or both (Bosellini et al. 1999). In the case of an eustatic fall, a more regular transition to shallower facies and a sedimentary arrangement in upwards shoaling sequences would be expected, in analogy with coeval sequences in Eritrea (Danakil Alps: Sagri et al. 1998) and Ethiopia

PLATE 1

Microfacies of the Lower Kambe Formation, parallel nicols, bar = 1mm: A) Bioclastic, oolitic, quartzose fine grainstone with foraminifers (Calcarenitic member, 95K5); B) Oncoidal, oolitic, bioclastic, quartzose rudstone with foraminifers, gastropods, echinoderms (Calcarenitic member, 95K7); C) partly recrystallized, silty, very fine packstone with "filaments" (Lower Shaly member, 95K4); D) silty wackestone with "filaments" and prob. radiolarians (Lower Shaly member, 95K15); E) Oncoidal, oolitic, bioclastic, quartzose, lithoclastic rudstone (Conglomeratic member, 95K70); F) oolitic, quartzose, bioclastic grainstone; abundant ooids with quartz nuclei (Conglomeratic member, 95K76); G) Quartzose sandstone (top of the Conglomeratic member, 95K77); H) silty wackestone with "filaments" (Upper Shaly member, 95K80).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(Mekele: Martire et al. 1998); moreover, during the upper Aalenian an eustatic rise has been detected (Haq et al. 1987). We suggest, in agreement with Bosellini (1989a), that extensional or more probably transcurrent or trans-tensional tectonics triggered the debris flows deposition in this shallow water environment. Later on, a transgressive trend followed and a deepening of the sedimentary environment occurred.

Upper Shaly member

Lithology - This unit has been observed only in its lower portion, exposed for a thickness of about 4 m on the top of the Mazeras Quarry 2; other samples of the same level, identified in the official geological map of the Kilifi-Mazeras area (Caswell 1956) and by fields observations, have been collected about 10 km to the NNE at Kambe, in a quarry of the Athi River Mining Co. The observed basal interval of the USM mainly consists of grey silty shales, more or less marly, that include 5-10 cm thick, storm-related beds of dark-grey mudstones and bioclastic, quartz-rich wackestone (Pl. 1H), and of cross- and hummocky-laminated oolitic and quartzose grainstone and quartz sandstones (Fig. 8). According to Westermann (1975), the remaining portion is about 30 m thick and consists mainly of siltstones and shales; in the studied area, this portion is covered by scree and soil.

Fossil assemblage - The fossil content of the lower part of the Upper Shaly Member consists of rare echinoderms, foraminifers (Valvulinidae) and “filaments” (Fig. 5).

Depositional environment - The occurrence of thin and generally fine-grained storm beds within the pelagic fine-grained sediments indicates an outer ramp environment, well below fair weather wave base.

Events - The relative sea-level rise of the early Bajocian (Haq et al. 1987) gave origin to a decrease of the carbonate input and to an increase in the siliciclastic input, both in the fine-grained fraction and in the coarser-grained storm beds; the backstepping of the shoreline due to the same transgression originated a marked grain size decrease (Fig. 3).

Sedimentary evolution and sequence stratigraphy

All the above described sedimentary features point to a depositional environment of the LKF characterized by light gradients of the sea bottom and by relatively shallow water depth, i.e. a homoclinal ramp (sensu Read 1985). The tectonic setting was a coastal basin related to the genesis of the proto-Indian Ocean (Rais Assa 1988). According to Reeves et al. (1987) a paleo-triple junction developed in eastern Kenya during the Jurassic, with two branches, corresponding to the Mombasa and the Somali coasts respectively, that developed into a part of the Indian Ocean. The third arm (Lamu embayment and its development to the North-East, Anza Trough) aborted during the Cretaceous; a northern extension of the Lamu embayment was also represented by the Mandera-Lugh Basin (Bosellini 1986).

The LKF was probably deposited as a relatively narrow carbonate platform close to the junction with the Lamu embayment, corresponding and parallel to the southern directed arm (Mombasa and Tanzania coast). This latter originated by the southward motion of Madagascar along the Davie Fracture Zone (Bunce & Molnar 1977; Segoufin & Patriat 1981); this has been considered as a right-lateral sheared (transcurrent-type) continental margin (Bosellini 1986). The deformations in the outer ramp pelagic sediments of the Lower Shaly member originated by tectonically active slopes steepening eastwards, i.e. towards the (future) Indian

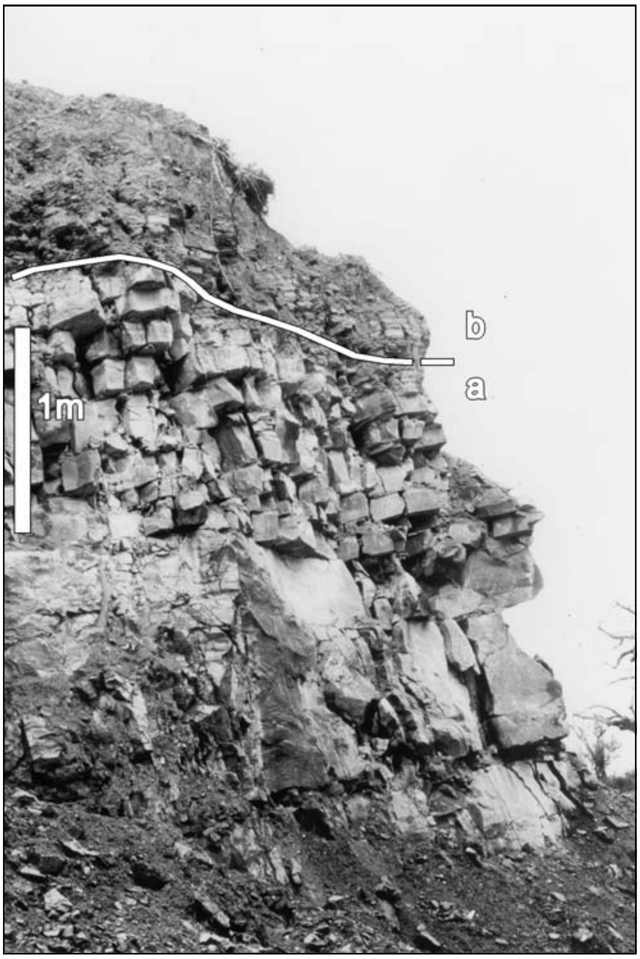


Fig. 8 - Transition between the topmost calcareous beds of the Conglomeratic member (a) and the basal silty and calcareous marly beds of the Upper Shaly member (b).

Ocean. This fault-controlled deepening gave origin to an intraplatform basin that had a sedimentary analogue in the Tanga Limestone basin of northern Tanzania (about 140 km to the south; Kapilima 1984). It is worth noticing that in the Mandera-Lugh Basin (Barbieri 1968; Canuti et al. 1980; Angelucci et al. 1983; Buscaglione et al. 1993), that is considered as a part of an oblique-rifted extensional continental margin (Bosellini 1986), the transition from shallow water formations to deeper water formations of the same Middle-Upper Jurassic sedimentary cycle does not indicate evidence of important tectonic dislocations. This fact may support the hypothesis of transcurrent-type tectonics in the Kambe basin. Also, the polymictic debris flow deposits of the Cgm, indicate strong erosion (and possibly active tectonics) of the western emerged and coastal areas, constituted by a thick sedimentary succession (basal calcareous levels of the LKF and of the underlying sandstones of the Mazeras and older formations of the Karoo Group; see Fig. 2).

The sedimentary evolution of the LKF seems to be framed into two depositional sequences. The unconformity surface between the Cam and the underlying continental Mazeras Formation (Caswell 1953; Rais Assa 1980) corresponds to the basal Sequence Boundary. The lower depositional sequence includes the Cam and the LSm. The sedimentological features of the Cam indicate a shoreline environment in an inner ramp setting that deepened upwards to a mid- ramp; the deposition environment of the overlying LSm is referred to a mid ramp evolving to an outer ramp. As general trend, we can envisage a Transgressive System Tract. The shallowing of deposition environment between the LSm and the Cgm occurs as a sharp facies dislocation sensu Myers & Milton (1996) (i.e. as abrupt transition) and therefore may corresponds to a Sequence Boundary. As, according to Haq et al. (1987), in the upper part of the Aalenian an eustatic rise took place, therefore the origin of this abrupt shallowing may be mainly tectonic.

The upper Depositional Sequence includes the Cgm, that may correspond to the Lowstand Wedge System Tract and to a part of the Transgressive System Tract, and the USm (at least the small studied portion), that is also related to the Transgressive System Tract.

Biostratigraphy

Previous dating

Near the examined locality abundant fossils have been found in the past by several Authors. A small fossil collection, sampled by Prof. Gregory in different localities has been described by Spath (1920). Other fossils were collected by Mrs. McKinnon Wood along the Mombasa Pipe Line (McKinnon Wood 1930). The fossil assemblages include brachiopods, pelecypods and ammonites, but the stratigraphic control was poor or missing as a portion of fauna was found in boulders. In 1930, Mrs. McKinnon Wood collected a new fossil collection and later on she published the results of this sampling in McKinnon Wood (1938). In this paper, the brachiopods suggest a Late Aalenian to Bajocian, whilst the ammonites indicate the Bajocian. According to the analysis of Westermann (1975), most of those fossils were found in limestone boulders or were erroneously referred to stratigraphically higher levels. Nevertheless, Westermann (1975) found a correspondence among samples M25, M76 and G550 of the McKinnon Wood's and Gregory's collections and the sample W3b, collected by himself at the base of the Upper *Posidonia* Shales (Fig. 2), containing *Calliphylloceras* cf. *disputabile*, which he dated as Middle-Late Bajocian. Towards the South, in sample M21, ammonites of the Lower *Posidonia* Shales indicate an Early Bajocian. Therefore, according to Westermann (1975, p. 33), it is possible that the "Pisolitic and Oolitic Limestones with Basal Conglomerate are either of very early Bajocian or perhaps even of Aalenian age" and that the Kambe Limestone at the Mwachi River "approximately comprises the entire Bajocian (s.s.)". Galacz (1990) sampled two ammonite levels close to the pipeline bridge, on the right side of the Mwachi River, at two localities corresponding to sites G550 and M76 of previous collections (Fig. 2): MR-2 at the top of the "Lower *Posidonia* Shales", just below the base of the "Massive (Coral) Limestone" and MR-1 about 15-20 m above the top of the "Massive (Coral) Limestone", within the "Upper *Posidonia* Shales". According to Galacz (1990, p. 202), "the age of the Kambe Limestone Series around Mombasa is Bajocian, Humphresianum to Garantiana Zone".

Microfossils

The microfossil assemblages (Fig. 5) are always very scarce and generally not very significant; they do not allow to attribute a precise age to the studied samples.

Calcareous nannofossils

Methods - Standard techniques for smear slide preparation were employed (Hay 1965; Monechi & Thierstein 1985). The calcareous nannofossil analysis was performed by optical light microscope at a magnification of 1500 x. The total and relative nannofossil abundances are given in Fig. 9, the semiquantitative analyses are based on observations of at least 360 fields of view corresponding to about 5.5 mm^2.

Biostratigraphic results - Calcareous nannofossils are generally rare to abundant and moderately preserved (Fig. 9). In particular, the assemblages are domi-

AALENIAN						BAJOCIAN	AGE
Lower Shaly member			Upper Shaly member				LITHOSTRATIGRAPHY
95 K 1	95 K 14	95 K 17	95 K 79	95 K 80	95 K 81	95 K 25	SAMPLES
F	C	C	F	R	A	R	ABUNDANCE
M	M	M	M	P	M	P	PRESERVATION
VR	R		R				*Axopodorhabdus cylindratus*
					R		*Biscutum* cfr. *B. grandis*
R	R	R	R		F		*Biscutum intermedium*
F		F	R		F		*Biscutum novum*
VR	F				R		*Bussonius prinsii*
R							*Carinolithus superbus*
R	F	R			R		*Crepidolithus crassus*
	R	R					*Crepidolithus sp.*
	VR			R	F		*Discorhabdus criotus*
F	F	F	F	R			*Discorhabdus ignotus*
F	F	F			C		*Discorhabdus striatus*
		R					*Ethmorhabdus gallicus*
R	F		R		F		*Hexalithus magharensis*
F	F	F	F		C		*Lotharingius crucicentralis*
		R			R		*Lotharingius hauffii*
		R			R	cfr.	*Lotharingius sigillatus*
F	F	R	R		F		*Lotharingius velatus*
VR	VR	R					*Parhabdolithus liasicus*
VR		F	R				*Tubirhabdus patulus*
R		R	R		R		*Retacapsa incompta*
F	C	R	R	R	C		*Schizosphaerella spp.*
VR	VR						*Similiscutum cruciulus*
	VR	R			R		*Triscutum sullivanii*
					R		*Triscutum tiziense*
R	R	F	R		F	R	*Watznaueria contracta*
					VR		*Watznaueria colacicchii*
R					R	VR	*Watznaueria fossacincta*

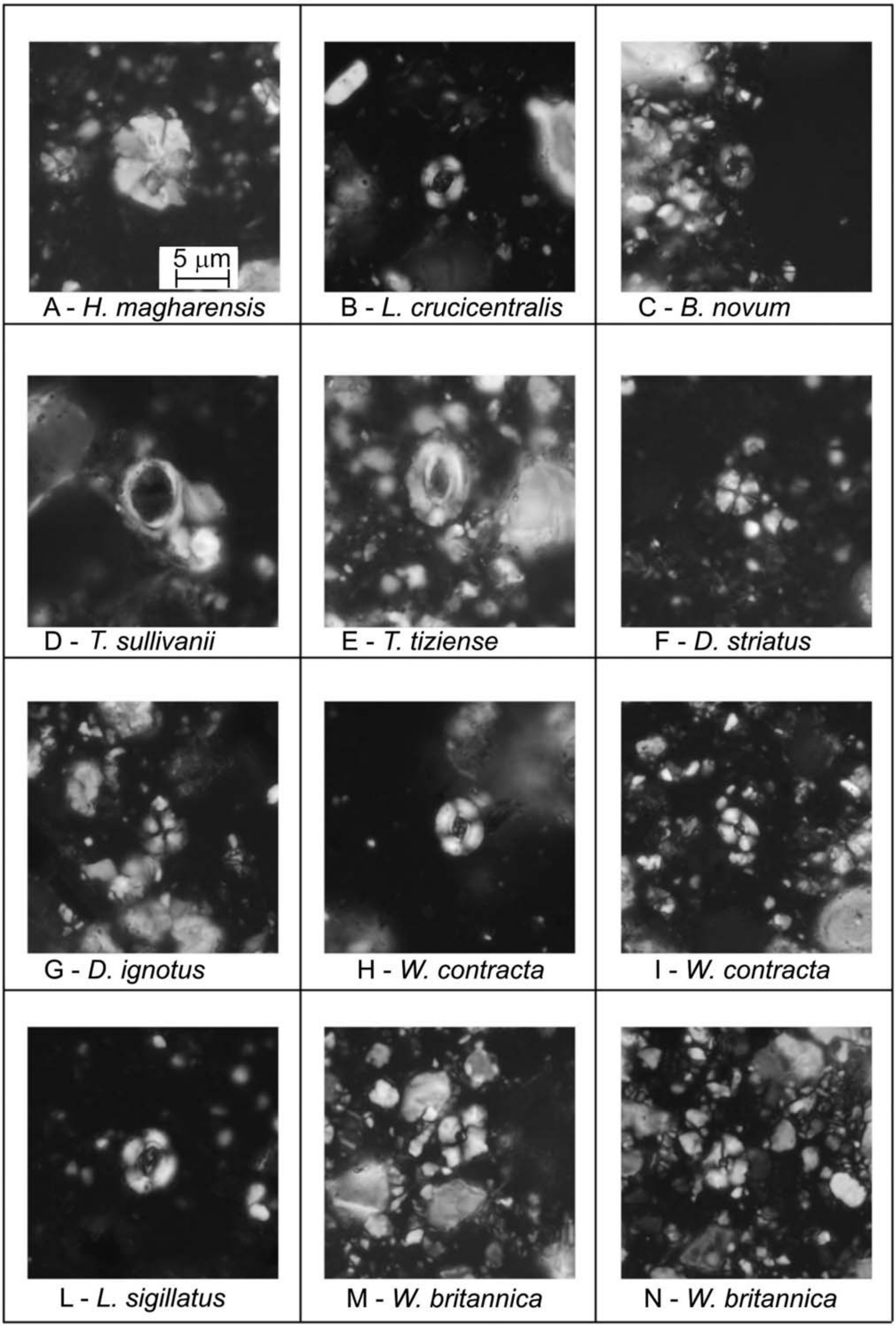
Fig. 9 - Calcareous nannofossil range chart of the Lower Kambe Formation. Legend: Preservation: M (Medium, moderate etching and/or overgrowth,); P (Poor, strong dissolution and/or overgrowth). Total Abundance: A (Abundant), more than 10 specimens in 1 field of view; C (Common), 10-1 specimens in1 field of view; F (Few), 1-0,1 specimen in 1 field of view; R (Rare), 0,1-0,01 specimen in 1 field of view; VR (Very Rare), <0,01 specimen in 1 field of view. Species Abundance: A (Abundant), more than 1 specimen in 1 field of view; C (Common), 1 specimen in 1-10 fields of view; F (Few), 1 specimen in 10-30 field of view; R (Rare), 1 specimen in 30-50 fields of view; VR (Very Rare), 1 specimen in more than 50 fields of view.

nated by *Lotharingius crucicentralis, L. velatus, Discorhabdus ignotus, D. striatus, Biscutum novum, B. intermedium, Watznaueria contracta,* and *Schizosphaerella* spp. Few or rare *L. hauffii, L. sigillatus, Tubirhabdus patulus, Hexalithus magharensis, Retacapsa incompta, Triscutum sullivanii, T. tiziense, Watznaueria fossacincta*, *Ethmorhabus gallicus, Carinolithus superbus,* and *Crepidolithus crassus* are also found in the assemblages.

The presence of *H. magharensis* and *W. contracta* in the lowermost sample collected, allow us to refer the deposition of the Lower Shaly member to the Aalenian. These species are quite common in Tethyan assemblages and their First Occurrences have been calibrated by ammonites as to *Opalinum* Zone, in different areas (de Kaenel et. al. 1996, cum biblio; Bown & Cooper 1998; Mattioli & Erba 1999, cum biblio). The occurrence of *H. magharensis* is particulary important because the distribution of this taxon seems to be restricted to the Tethyan and Pacific Realm and it has never been recorded in the Boreal realm (Bown & Cooper 1998). It is important to note that the occurrence of *Similiscutum cruciulus* in the lowest samples is among the youngest occurrence of this species. In fact the LO of *S. cruciulus* is reported in Morocco at the Domerian /Toarcian boundary and in the lower Toarcian in Portugal (de Kaenel et al. 1996). The biostratigraphic range of this species is not yet well constrained, but recent studies confirm the occurrence of *S. cruciulus* in the Aalenian according to this work (Early Bajocian in Mattioli & Erba 1999). Concerning the age of the Upper Shaly member, the LO of *Bussonius prinsii* confirms an Aalenian age; in fact, this event is reported in the Opalinum Zone in Portugal and Switzerland by de Kaenel et al. (1996) and in the *Murchisonae* Zone in the Boreal realm by Bown & Cooper (1988). Moreover, several marly samples have been collected in a quarry about 10 km to the NNE of the previous outcrop, where the top of the Cgm and the base of the USm crop out. These samples are stratigraphically correlatable

PLATE 2

Calcareous nannofossils of the Lower Kambe Formation. All light micrographs crossed nicols. A) *H. magharensis* (Lower Shaly Member, 95K14, Aalenian); B) *L. crucicentralis* (Lower Shaly Member, 95K14, Aalenian; C) *B. novum* (Upper Shaly Member, 95K81, Aalenian); D) *T. sullivanii* (Lower Shaly Member, 95K17, Aalenian); E) *T. tiziense* (Upper Shaly Member, 95K81, Aalenian); F) *D. striatus* (Lower Shaly Member, 95K14, Aalenian); G) *D. ignotus* (Lower Shaly Member, 95K14, Aalenian); H) *W. contracta* (Lower Shaly Member, 95K14, Aalenian); I) *W. contracta* (Lower Shaly Member, 95K17, Aalenian); L) *L. sigillatus* (Lower Shaly Member, 95K17, Aalenian); M) *W. britannica* (Upper Shaly Membe, 95K25, Early Bajocian); N) *W. britannica* (Upper Shaly Member, 95K25, Early Bajocian).


5 µm
A - H. magharensis
B - L. crucicentralis
C - B. novum
D - T. sullivanii
E - T. tiziense
F - D. striatus
G - D. ignotus
H - W. contracta
I - W. contracta
L - L. sigillatus
M - W. britannica
N - W. britannica

with the highest samples collected in the Mwachi River. In the uppermost one (95K 25), the occurrence of *Watznaueria britannica* and the absence of *W. manivitae* (species very resistant to dissolution and generally very abundant in the early Bajocian Tethyan assemblages) allow us to refer this sample to the uppermost Aalenian or to the base of Bajocian (Mattioli & Erba 1999, cum biblio).

Comparison with previous age assignments - An Aalenian age for the LSm is well documented by the calcareous nannofossils assemblage and by the absence of *W. britannica*, that appears only in the uppermost sample (Fig. 9). However, these nannofossil data disagree with the relatively recent and well established age determinations given by ammonites (Westermann 1975; Galacz 1990) that document a Bajocian age for the same interval of the LSm. Considering that the samples of Westermann and Galacz came from different localities, rather far from our sampling sites (cf. Fig. 2), and that Galacz (1990, p. 201) evaluated a thickness of the "Massive (Coral) Limestone" (= Cgm) of about 10 m (instead of 34 m), we hypothesize that the geological situation of the Mwachi River area could be more complex (i.e. presence of not detected faults) than the sketch map reported in Westermann (1975). We tentatively suggest that the contact between the (inferred) LSm with sample SM-2 and the overlying "Massive (Coral) Limestone" (Galacz 1990) is tectonic and not stratigraphic, and therefore that both the samples with ammonites probably come from the USm.

Conclusions

This study of the stratigraphic succession of the Lower Kambe Formation provides information about the sedimentary and structural evolution in the coastal Kenya area during the Aalenian and a part of the Bajocian. According to field and laboratory observations, the main results are the following:

- The sedimentation of the whole Lower Kambe Formation occurred on a homoclinal ramp.
- The depositional environment of the Cam and the LSm evolved from an inner ramp to an outer ramp.
- The gravity deformations in the topmost fine-grained sediments of the LSm indicate a tectonic phase, possibly of transcurrent- (or transtensive-) type.
- At the top of the LSm a marked and abrupt shallowing occurred, probably of tectonic origin.
- The CgM was deposited on a inner ramp.
- The conglomeratic beds of the Cgm, with clasts originated by a strong erosion of the neighbouring substratum, are debris-flow deposits emplaced by catastrophic events.
- The USm was deposited on an mid/outer ramp.
- The biostratigraphic data provided by calcareous nannofossils indicate that the marine transgression in the studied area began during the Aalenian or possibly earlier, according to the Aalenian age of the Lower Shaly member.
- There is a discrepancy with the recent biostratigraphic data provided by ammonites (Westermann 1975; Galacz 1990) that suggested a Bajocian age to the LSm and USm. To explain this discrepancy, we can suppose that the geological situation of the sites where the ammonites were sampled was more complex (i.e., with not detectable faults) with respect to the sketch map presented in Westermann (1975) and that both ammonite samples (Galacz 1990) came only from the Upper Shaly member, dated as late Aalenian-early Bajocian using nannofossils biostratigraphy.

Appendix 1

Index of quoted calcareous nannofossil species

Genus *Axopodorhabus* Wind & Wise in Wise & Wind, 1977
*Axopodorhabdus cylindratus (*Noël, 1965), Wind & Wise in Wise & Wind, 1977

Genus *Biscutum* Black in Black & Barnes, 1959
Biscutum grandis Bown, 1987
Biscutum intermedium Bown, 1987
Biscutum novum (Goy, 1979) Bown, 1987

Genus *Bussonius* Goy, 1979
Bussonius prinsii (Noël, 1973) Goy, 1979

Genus *Carinolithus* Prins in Grun et al., 1974) Bown, 1987
Carinolithus superbus (Deflandre, 1954) Prins in Grun et al., 1974

Genus *Crepidolithus* Noël, 1965
Crepidolithus crassus Rood, Hay & Barnard, 1973

Genus *Discorhabdus* Noël, 1965
Discorhabdus criotus Bown, 1987
Discorhabdus ignotus (Gorka, 1957) Perch-Nielsen, 1968
Discorhabdus striatus Moshkovitz & Ehrlich, 1976

Genus *Ethmorhabus* Noël,1965
Ethmorhabus gallicus Noël, 1965

Genus *Lotharingius* Noël,1973 emend. Goy, 1979
Lotharingius crucicentralis (Medd, 1971) Grun & Zweili, 1980
Lotharingius hauffii Grun & Zweili in Grun et al., 1974
Lotharingius sigillatus (Stradner, 1961) Prins in Grun et al., 1974
Lotharingius velatus Bown & Cooper, 1989

Genus *Parhabdolithus* Deflandre, 1952
Parhabdolithus liasicus Deflandre, 1952

Genus *Podorhabdus* Noël, 1965
Podorhabdus grassei Noël,1965

Genus *Retacapsa* Black, 1971
Retacapsa incompta Bown & Cooper,1989

Genus *Similiscutum* de Kaenel & Bergen, 1993
Similiscutum cruciulus de Kaenel & Bergen, 1993

Genus *Triscutum* Dockerill,1987
Triscutum sullivanii de Kaenel & Bergen, 1993
Triscutum tiziense de Kaenel & Bergen, 1993

Genus *Watznaueria* Reinhardt, 1964
Watznaueria britannica (Stradner, 1963) Reinhardt, 1964
Watznaueria colacicchi Mattioli & Reale in Mattioli, 1995
Watznaueria contracta (Bown & Cooper, 1989) Cobianchi, Erba & Pirini Radrizzani, 1992
Watznaueria fossacincta (Black, 1971) Bown in Bown & Cooper, 1989
Watznaueria manivitae Bukry, 1973

Incertae Sedis
Genus *Hexalithus* Gardet, 1995
Hexalithus magharensis Moshkovitz & Ehrlich, 1976

Genus *Schizosphaerella* Deflandre & Dangeard, 1938
Schizosphaerella punctulata Deflandre & Dangeard, 1938

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