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PALEOENVIRONMENTAL ANALYSIS AND CYCLICITY OF THE MUSTAHIL FORMATION (CRETACEOUS OF CENTRAL SOMALIA)

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Riassunto. La Formazione di Mustahil è un'unità marnoso-calcarea di età cretacica, la cui serie tipo affiora nella Valle di Fafan (Ogaden, Africa orientale). Viene qui descritta una sezione, misurata a Bur Bitthale nei pressi di Belet Uen (Somalia Centrale).

La successione, datata Aptiano superiore - Albiano inferiore-medio in base alla presenza di *Orbitolina texana* e *Orbitolina subconcava*, consiste in due sequenze *thickening-coarsening upward* ben sviluppate, dove sono state riconosciute quattro diverse facies. Il tetto di entrambe le sequenze è costituito da un *reef cap* a Rudiste, dominato da *Eoradiolites lyratus.* Questi cicli vengono interpretati come parasequenze *shoaling upward*, che rappresentano il risultato di due regressioni deposizionali prodotte dalla progradazione di ampi sistemi carbonatici di acqua bassa sull'adiacente rampa e piattaforma profonda.

Abstract. The Cretaceous Mustahil Formation is a marlstone-limestone unit, outcropping typically in the Fafan Valley of Ogaden (eastern Africa). A Mustahil section, measured at Bur Bitthale near Belet Uen (Central Somalia), is here described. The succession, dated as Late Aptian to Early-Middle Albian age on the basis of good faunal evidence (*Orbitolina texana* and *Orbitolina subconcava*), consists of two well developed thickening-coarsening sequences, where four different facies have been recognized. The cap of both sequences is represented by a rudistid framework dominated by *Eoradiolites lyratus.* We interpret these cycles as shoaling up parasequences, which are the result of two depositional regressions produced by the progradation of broad shallow-water carbonate systems over the adjacent ramp and deep shelf.

Introduction.

The Mustahil Formation is a Cretaceous unit of eastern Africa, described and formally defined by Tavani (1948). It outcrops typically in the Fafan Valley of Ogaden, with the type section exposed near the village of Mustahil, and along the Shebeli river, from Kallafo as far as Mahaddei Uen. According to Tavani (1948, pp. 67-68), this unit is

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represented by "a succession of more or less marly limestones overlain by a complex of massive organogenous limestones, generally rich in *Orbitolinae*".

The aim of this paper is to describe a Mustahil section measured at Bur Bitthale, near Belet Uen (Central Somalia), where the succession is clearly organized into several thickening-coarsening upward cycles. Paleontology as well as facies analysis make it possible to interpret these cycles as shoaling up parasequences (Van Wagoner et al., 1988), produced by relative sea-level fluctuations, where sudden flooding episodes, documented by ammonite-bearing shales, are in turn followed by gradual depositional regressions culminating with rudistid and coral reef caps. The basal flooding episode, which is synchronous with major transgressions observed in widely separated regions such as the Gulf Coast and southeastern Arabia (Scott et al., 1988), is likely to represent an Aptian eustatic sea level rise.

Geologic and stratigraphic setting.

The Mustahil Formation outcrops in the southwestern part of the Mudugh Basin and extends for more than 200 km along a NW-SE trending narrow belt, more or less parallel to the Shebeli river valley. This outcrop belt widens out to reach a width of 25 km in the Fafan Valley of Ogaden (Fig. 1).

The Mudugh Basin is a main structural feature of the Somali continental margin, formed in Jurassic time as an oblique-rifted basin during the separation of Madagascar from Africa (Bosellini, 1986, 1989). The basin is infilled mainly with Jurassic-Cretaceous successions, thickening toward the Indian Ocean and accompanied by shelf-to-basin facies changes.

The Mustahil Formation, about 200 m thick (Barbieri et al., 1979), is a very fossiliferous marlstone-limestone unit, with rudistid and coral buildups, directly overlying the Main Gypsum, a several hundred meter thick anhydrite-dolomite succession of Neocomian-Early Aptian age. The Mustahil starts with a 50 m thick member of marl and shale, rich in Aptian ammonites including *Cheloniceras rude* Tavani and *Parahoplites* cf. *weissi* Neumayer (Tavani, 1948; Barbieri et al., 1979). This basal flooding event corresponds to the Aptian transgression observed all over central and northern Somalia (Bosellini, 1989). Upward, the Mustahil Fm. passes transitionally into the Fer Fer and Belet Uen Formations of Cenomanian-Turonian age (Barbieri et al., 1979).

Shallowing upward cycles (at least three cycles, 30-80 m thick each), consisting of a basal shale followed by marl, marly limestone, and culminating with rudistid and coral reef caps, characterize the whole Mustahil Formation.

Tavani (1942, 1948) and Barbieri et al. (1979) suggest an Aptian- Albian age for the marls and marly limestones of the lower cycle, on the basis of the occurrence of *Paleorbitolina lenticularis* (Blumenbach) and *Neithea morrisi* (Pictet & Renevier); they assign instead a Cenomanian age to the rudistid limestones (reef cap) of the first cycle and to the entire second cycle, owing to the occurrence of *Eoradiolites lyratus* Conrad, *Chon-*

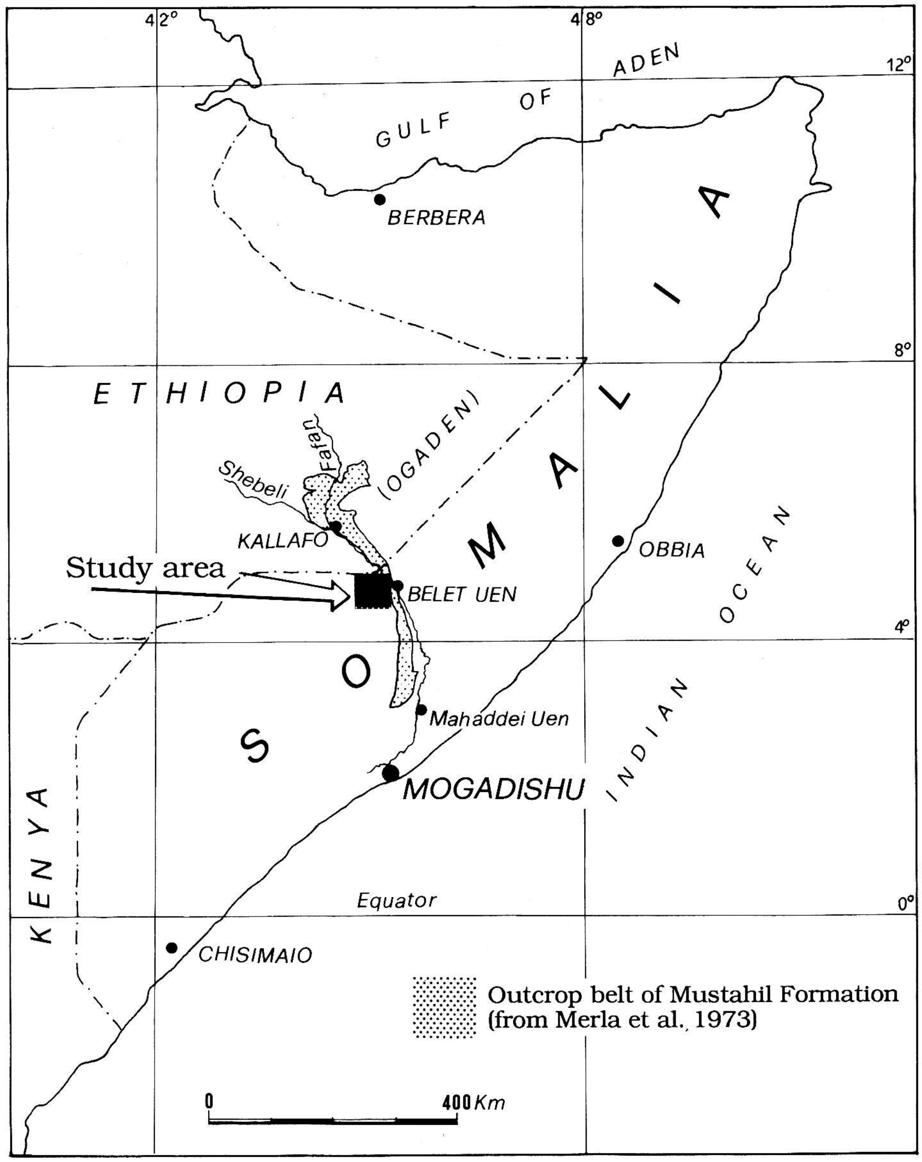

Fig. 1 - Index map and location of the study area.

drodonta joannae (Choffat) in the rudistid limestones, and of *Orbitolina trochus* (Fritsch) and *Orbitolina scutum* (Fritsch) in the marls and marly limestones of the second cycle.

According to the above quoted authors, at Bur Makadhuuf, 5 km NW of Bugda Akable, the Albian age of the marly limestones directly overlying the Main Gypsum, is documented by the presence of *Hibolites semicanaliculatum* (de Blainville), *Douvilleiceras* *spinosum* Tavani, *Douvilleiceras monile* (Sowerby), *Terebratulina gracilis* (Cloth) and *Exogyra canaliculata* (Sowerby) (Tavani, 1942; Barbieri et al., 1979). Gibson and Percival (1965) suggest an indefinite Albian age for the Mustahil Formation for the presence of *Orbitolina scutum* (Fritsch) and *Orbitolina paronai* Prever. Prestat (1970) suggests an Early Albian age for the Mustahil Formation on the basis of the occurrence of *Lithocodium aggregatum* Elliott, *Cuneolina laurenti* Sartoni & Crescenti, *Colomiella mexicana* Bonet, *Colomiella recta* Bonet and *Coskinolina sunnilandensis* Maync.

Our study of the *Orbitolinae* occurring at Bur Bitthale, 6-7 m from the base (sample 3) up to the marls underlying the reef cap of the second cycle (sample 10), suggests a Late Aptian to Early-Middle Albian age for the whole succession. In fact, the occurrence of *Orbitolina texana* (Roemer) in the samples BB3, BB6, BB7, BB8 and BB9a allows us to assign a Late Aptian age to these sediments, whereas the entire second cycle, starting from the basal marls, is of Early-Middle Albian age owing to the occurrence of *Orbitolina subconcava* (Leymerie).

Facies and cycles of the Mustahil Formation.

As stated above, the Mustahil Formation is clearly organized into several thickening-coarsening upward cycles.

At Bur Bitthale, 11 km southwest of Belet Uen, where a detailed section has been sampled and measured, two cycles, respectively 31 and 30 m thick, are distinctly outcropping (Fig. 2, 3); both these cycles culminate with a rudistid reef cap. At Damaralays instead, about 2.5 km northwest of Bur Bitthale, where the section is about 76 m thick and can be grossly subdivided into two parts, only the upper cycle is present. The lower part (about 41 m thick) consists of marly limestones rich in *Orbitolinae*, the upper one (about 35 m thick) of a reefal facies with rudists at the base and corals in the upper two thirds (Barbieri et al., 1979).

Two thick cycles, with a comprehensive thickness of 120 m, can be also inferred from the description of Barbieri et al. (1979) at Bur Tilal, 13 km northwest of Belet Uen. There, the two reef caps are 20-25 m thick each, while the basal marl units, directly overlying the Main Gypsum, are 50 m thick in the lower cycle and about 30 m in the upper one.

At Bur Bitthale, the following four different facies can be recognized (Fig. 2); they appear to be stratigraphically ordered giving rise to two well developed cycles. All four facies occur in the lower cycle, while only the last three are present in the upper one.

Facies A: clays and marly clays bearing rare ammonites.

Facies B: marls and marly limestones rich in *Orbitolinae*, irregular echinoids and molluscs; several bioclastic breccias occur throughout this part of the section.

Facies C: bioclastic rudstone with *Orbitolinae* and rudistid fragments.

Facies D: biohermal limestone (rudistid framework).

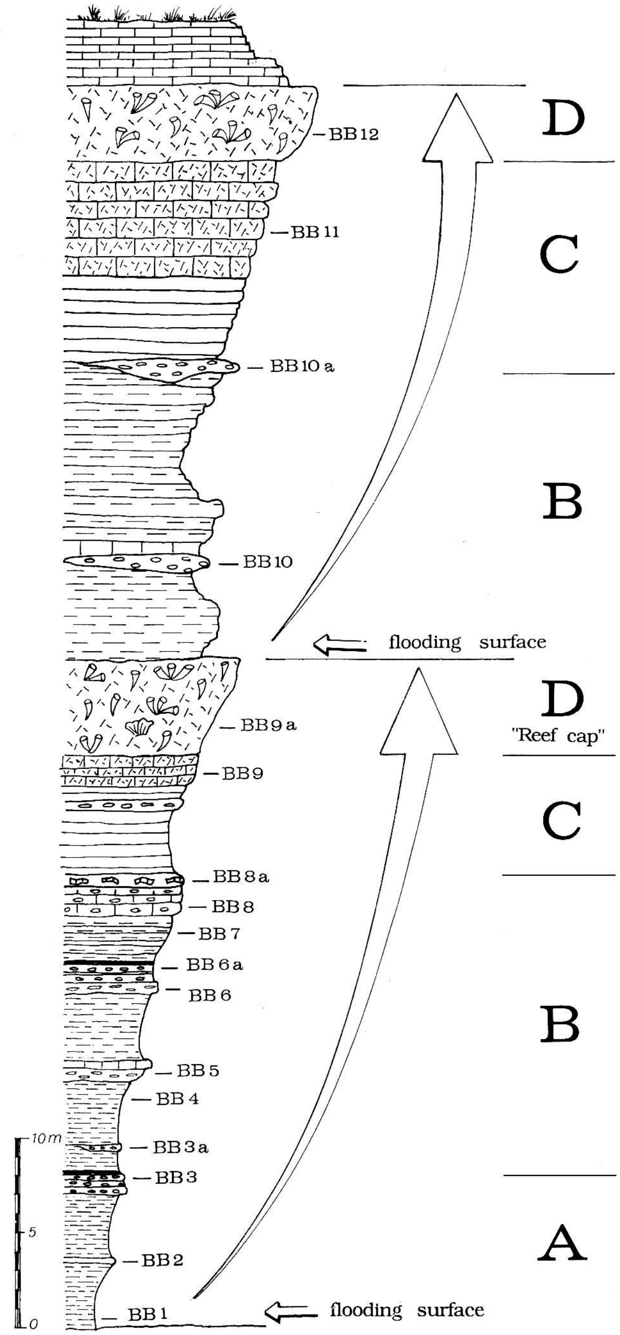

Fig. 2 - Measured section showing the two shallowing up parasequences of Aptian to Early Albian age (Bur Bitthale, Belet Uen, Central Somalia).

Facies A.

Facies A occurs only at the base of the first cycle, and is represented by greenish clays, finely laminated and fissile. The fossil content is given by ammonites (*Cheloniceras rude* Tavani and *Parahoplites* cf. *weissi* Neumayer), rare planktonic foraminifers (*Hedbergella* ?), calcispheres and ostracods. Upward, there is a gradual increase in the lime content and marlstones prevail. In the measured section, this facies is 7 m thick.

Based on the composition, texture and biota, Facies A is interpreted as a deep shelf deposit, a very distal and deep ramp beyond the reach both of storm waves and gravity-displaced supplies.

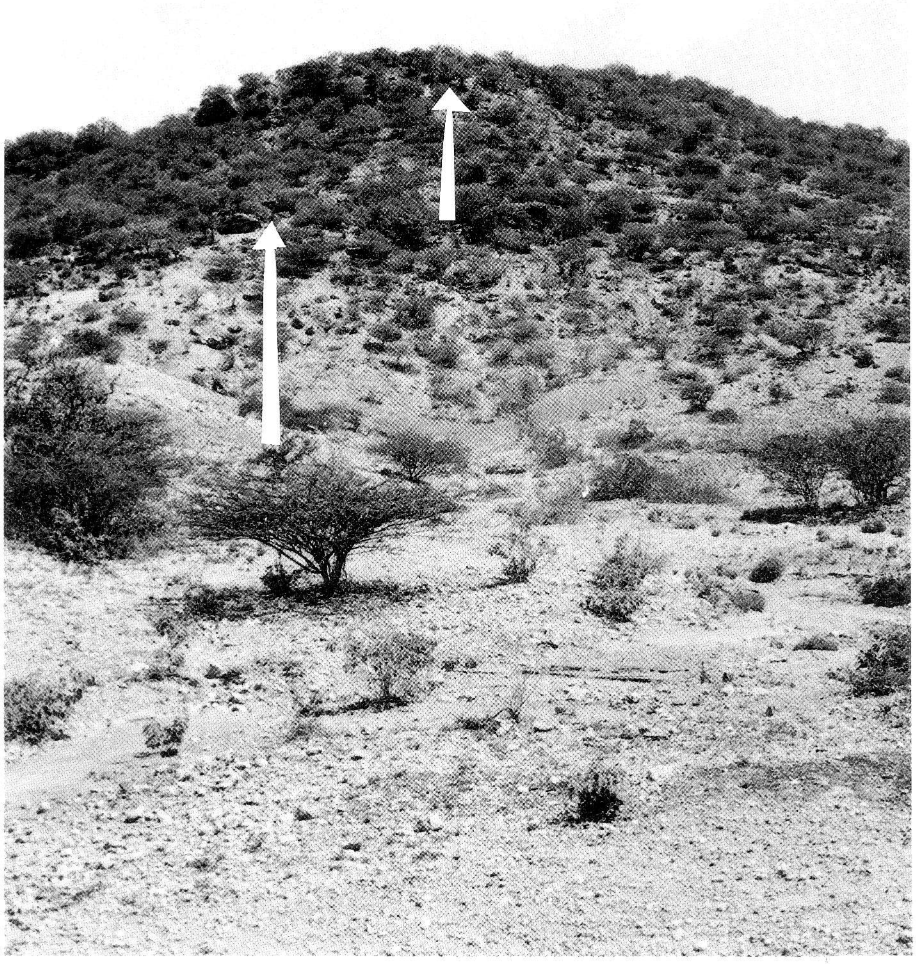

Fig. 3 - The measured section at Bur Bitthale: the two cycles are indicated by arrows.

Facies B.

Facies B is characterized by marlstone and limestone which upward become richer in siliciclastic and bioclastic components. Toward the top, the rock consists of poorly sorted calcarenites rich in *Orbitolinae*, echinoid fragments, rudists, colonial and solitary corals, siliceous sponges, pelecypods and other molluscs.

This part of the section starts with a very lenticular and massive limestone bed bearing small rudistid fragments, *Orbitolinae* (*O. texana*), irregular echinoids, pelecypods, gastropods and numerous solitary, azooxanthellate, non epithecate corals. Among the pelecypods *Neithea* (*Neitheops*) *quinquecostata* (Sowerby), *Neithea* (*Neitheops*) *morrisi* (Pictet & Renevier) and *Atreta melleni* Stephenson are very abundant, while among the gastropods *Tylostoma globosum* Sharpe is present. The corals are represented by numerous specimens of *Peplosmilia* sp., with a large basal attachment and commonly encrusted by small vermetids and *Atreta melleni.* Similar bioclastic and coquinoid beds, rich in *Orbitolinae* and other shallow-water organisms, occur throughout and characterize this facies. Based on the bed thickness (30-80 cm), and absence of grading and of erosional base, we interpret them as debris-flow deposits on a distal fore-reef ramp. However a storm-layer origin can not be totally ruled out.

At the base of the marly part of the section, many flat *Orbitolinae* occur. Upward, the marls become gradually more calcareous and conic *Orbitolinae* are more abundant.

Fig. 4 - Facies B: marlstone rich in *Orbitolinae.*

Irregular echinoids such as *Astropygaulus trigonopygus* Checchia-Rispoli and *Somalechinus gibbosus* Checchia-Rispoli are also abundant throughout this facies. Thin sections (BB5 and BB7) show that the sediment is a mudstone-wackestone with scattered *Orbitolinae*, mostly flat or subconical and without any coating, rare textulariids, other benthic foraminifera, small globigerinids, rare ostracods and pelecypod fragments (Fig. 4).

It is interesting to point out that the upper surfaces of the bioclastic deposits are coated by a ferruginous, reddish crust, suggesting long exposure to oxygenated waters and formation of hardgrounds, then colonized by solitary, azooxanthellate, epithecate and non epithecate corals, all characterized by a more or less wide basal attachment and mostly encrusted by irregularly arranged vermetids and *Atreta melleni.* The observed species are *Acrosmilia* cf. *fromentali* d'Orbigny, *Peplosmilia* sp., *Epistreptophyllum* sp., *Calamophyllia* sp. They are associated with small subglobose colonies with rather wide basal attachment areas of *Cyathophora steinmanni* Fromentel, which are also encrusted by vermetids and *Atreta melleni.* Generally these corals are adapted to hard substrates. Other fossils include rare siliceous sponges (*Syphonia pyriformis* Goldfuss), irregular and regular echinoids (*Heterodiadema lybicum* Decor), rudistid and pelecypod fragments. Texturally (BB6), the rock is a packstone-wackestone rich in intraclasts and bioclasts in association with fragments of rudists, pelecypods, textulariids, planktonic foraminifera (*Hedbergella*), ostracods and *Orbitolinae. Orbitolinae* are mostly conical and coated by a thick rim of encrusted organisms. Also some intraclasts are coated by this kind of rim.

Facies C.

Facies C is represented by packstone and grainstone rich in *Orbitolinae*, molluscs and fragments of rudists and other shallow-water organisms (Fig. 5).

This facies starts with sheet and foliaceous colonial corals which colonized the hard substratum represented by the last bioclastic unit of the underlying facies.

The species observed include *Felixogyra vaughani* Prever, *Felixogyra deangelisi* Prever, *Microsolena* aff. *distefanoi* (Prever). *Felixogyra vaughani* occurs as lamellar colony, the top of which is colonized by vermetids and bryozoa. *Felixogyra deangelisi* and *Microsolena* aff. *distefanoi* are foliaceous colonies with small basal attachment areas, and encrusted by vermetids and *Atreta melleni* on their lower surfaces, documenting clearly that these flat colonies did not lay on the sea-bottom. *Orbitolinae*, which are mostly conical, are very abundant and generally uniformly distributed; patchy, irregular concentrations are rare and probably related to storm deposition. The clastic components consist of rudistid fragments, benthic foraminifera, molluscs, etc.

This facies can be interpreted as a deposit accumulated on a proximal fore-reef ramp.

Facies D.

Facies D is a typical biohermal facies consisting mainly of radiolitids; it constitutes the cap of the cycles (Fig. 6). The prevailing species is *Eoradiolites lyratus* Conrad, associated with very rare caprinids (*Caprina* sp. and *Policonites africanus* Tavani), fragments of rudists and other molluscs, echinoids and *Orbitolinae.* Corals seem to be absent or rare. *Eoradiolites lyratus* shows an "elevator"-like shape (Skelton, 1979) forming "packed bouquets or bushes". Young individuals show frequently a spirogyrate juvenile attachment stage, and attach on the top of adult individuals. These bouquets, consisting of many individuals which are superimposed upon each other up to 3-4 times, can reach a height of more than 1 meter and a width of 50-60 cm. Inter-and intra-framework sediment is represented either by bioclastic packstone and wackestone ("packed biomicrite") or coarse bioclastic grainstone. Packed biomicrite occurs among and within the rudists, and consists of skeletal fragments whose sizes vary from some centimeters to few microns. In the last case, it may be difficult to distinguish them from the matrix. A substantial enrichment in *Chondrodonta joannae* (Choffat) and ostracods is observed in the upper part of this facies interval.

The Mustahil rudistid-dominated frameworks show the following characteristics:

Fig. 5 - Facies C: rudstone with rudistid fragments.

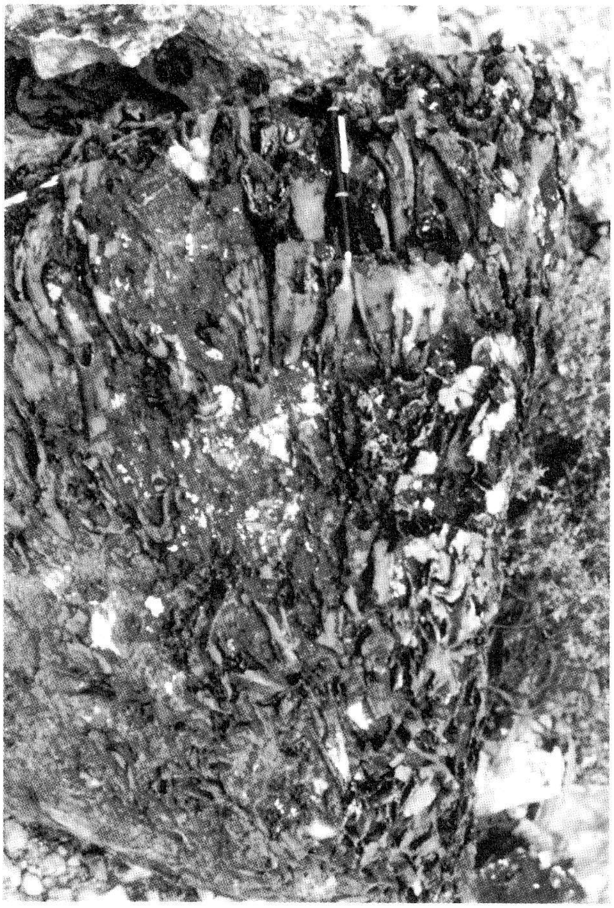

Fig. 6 - Facies D: clusters of *Eoradiolites lyratus* Conrad in life position.

1) Compared to coral-algal-dominated reef ecosystems, rudistid frameworks show a markedly low species diversity, consisting of only one or few bioconstructors;

2) The rudistid framework is loosely constructed, not being bound by corals, encrusting algae, bryozoa, or sponges. Mostly the buildups are bafflestones; the degree of pseudocoloniality (i.e., clustering or packing) and lateral interlocking or co-cementation among rudists controlled their success in building elevated and resistant frameworks.

3) The framework sizes of the two Mustahil reef caps are limited: these structures, generally interbedded with storm-derived bioclastic sediments, may reach a thickness of 5-6 m;

4) All samples of *Eoradiolites lyratus* are completely without epi-and endobionts. Kauffman and Johnson (1988) suggest some explanations about the absence of epi-and endobionts on some rudistid shells (especially radiolitids):

- a possible anti-fouling chemistry in the periostracum of rudistid shells discouraged settling of epi-and endobionts, and other competitors;
- the aspect of rudistid shell structure (high porosity) does not favour larval settling, especially of endobionts (see also Skelton, 1979);
- an active physical role of a large extrudable mantle on some rudists (especially radiolitids);
- a possible secretion by the rudistid mantle of an anti-fouling chemical halo.

Skelton (1979), instead suggests that this absence is related to the type of aggregation in bush-or-platform like clusters reducing the exposure of individuals to attack by borers, epibionts and predators.

Depositional dynamics and the origin of cycles.

The two shoaling up cycles observed in the Mustahil Formation of Central Somalia are the result of two depositional regressions which followed major flooding episodes of the shelf. These depositional regressions were produced by the progradation of broad shallow-water carbonate systems, colonized by marginal coral and rudistid reefs, over the adjacent ramp and deep shelf. The four facies previously described represent four distinct depositional belts arranged along the fore-reef slope connecting the platform to the deep shelf (Fig. 7).

In terms of sequence stratigraphy (Vail et al., 1977; Haq et al., 1987), the two cycles may be described as parasequences (Van Wagoner et al., 1988) bounded by marine-flooding surfaces (Fig. 8). They constitute a parasequence set which belongs to the lower part of the Gira supersequence of Aptian to Maastrichtian age (Bosellini, 1989). The Mustahil Formation lies directly on the Main Gypsum and its basal contact, with ammonite-bearing clays and marlstones, represents the transgressive surface of the sequence.

The boundary between the Main Gypsum and the Mustahil Formation represents also a dramatic deepening and change in water mass conditions on the shelf, an event registered at the same time (Late Aptian) in widely separated regions such as the Gulf Coast and southeastern Arabia.

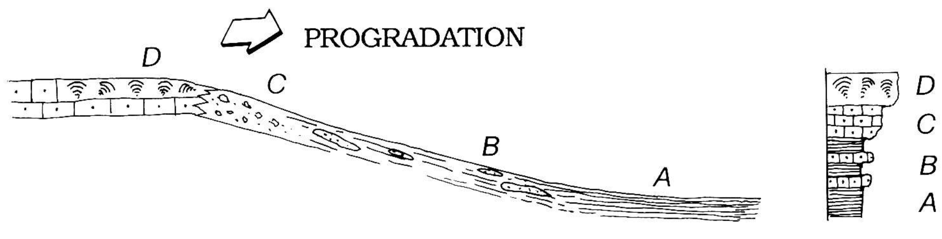

Fig. 7 - The Cretaceous modal cycles of Central Somalia are the result of depositional regressions produced by the progradation of broad shallow-water carbonate systems, colonized by marginal corals and rudistid reefs, over the adjacent ramps and deep shelf.

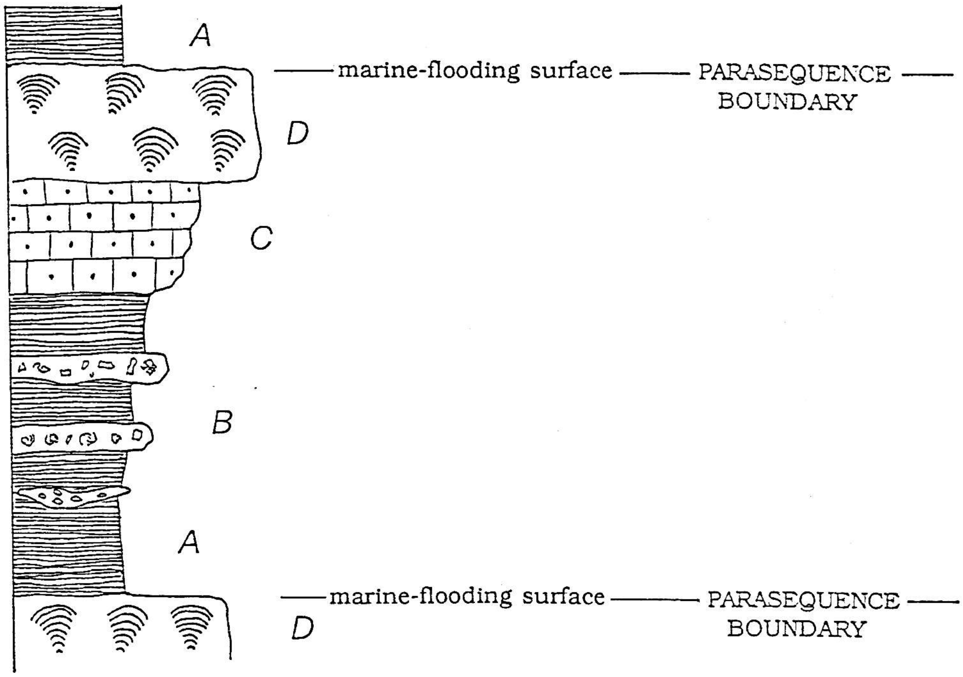

Fig. 8 - The modal cycle of the Aptian-Albian succession of Central Somalia. It is a shoaling up parasequence, capped by rudistid-coral reef units.

According to Scott et al. (1988), the intra-Aptian rise began about 115.8 Ma and in many places is represented by a sharp lithologic change, by submarine hardgrounds, or by onlap; deep-water deposition resumed from 115.2 to 113.9 Ma. As this event of relative sea-level rise is synchronous in the Gulf Coast basin, the southeastern Arabian platform and central Somalia shelf, it may represent a major eustatic sea-level rise.

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