Sedimentation, diagenesis and syntectonic erosion of Upper Cretaceous rudist mounds in central Tunisia

M.H. NEGRA*, B.H. PURSER† and A. M'RABET‡

*Faculté des Sciences de Tunis, Département de Géologie, Laboratoire de Sédimentologie et Bassins Sédimentaires, Campus Universitaire, 1020 Tunis-Belvédère, Tunisia; and †Université de Paris-Sud, Centre d'Orsay, Laboratoire de Pétrologie Sédimentaire, Batiment 504, 91405 Orsay Cedex, France ‡ETAP, 27 bis, avenue Khéreddine Pacha, 1002-Tunis, Tunisia

ABSTRACT

The Upper Cretaceous carbonates of central Tunisia include lensoid mounds composed essentially of micrite locally rich in rudist and corals. Although these organisms can be closely packed and contribute actively to the creation of bioherms, the majority (70–80%) are scattered in micritic mounds. Their debris forms graded sequences indicating a hydrodynamic accretion. Three types of mud-mound are recognized: type 1, essentially a wackestone, contains debris of rudists, corals, echinoderms, associated peloids and scarce calcispheres. Type 2 is a composite mud-mound comprising a type 1 mud-mound directly overlain by a type 3 bioherm. Type 3 is a muddy, bioconstructed rudist-coral bioherm in which interrudist spaces are filled with fine (wackestone) sediment rich in rudist–coral and echinoderm debris.

Conglomerates containing blocks reworked from the rudist carbonates are volumetrically important. They clearly indicate significant Late Cretaceous lithification and erosion. Within the mounds, early diagenesis is expressed by neogenic microspar and by interlocking or coalescing nanofabrics which characterize the upper part of type 1 micritic mounds or certain reworked pebbles. It is clear that early lithification is responsible, at least in part, for the rigidity of the mounds expressed by steep margins. Erosion of the lithified mounds is related to tectonic instability, notably during the Campanian. Micrites rich in planktonic microfaunas intercalated between rudist mounds suggest that mounds formed below wave base, possibly on an open marine slope. The fact that organic activity is not the major factor responsible for their construction will be demonstrated in this paper

INTRODUCTION

Upper Cretaceous carbonates include both shallow-marine, rudist-bearing micrites and deeper, argillaceous limestones rich in planktonic forams, both facies outcropping in the numerous anticlines of central and southern Tunisia. Rudist and coral-bearing carbonates of Campanian and Maastrichtian age are particularly well exposed along the southern flanks of Jebel el Kebir and at Jebel Serraguida (Fig. 1) where they include a series of lenticular bodies averaging 30 m in thickness and 250 m in width. These carbonates are of particular interest not only because of their oil reservoir potential but also because of their unique sedimentary attributes.

In common with many mounds in the geological record including the Inner Dinarides of Yugoslavia (Polsak, 1981), Provence limestones in France (Masse & Philip, 1981), the Valles Platform in Mexico (Enos, 1986), the Priolo Formation in Sicily (Camoin, 1983; Tronchetti & Camoin, 1986), the Akros massif in Greece (Philip and Mermighis, 1989), the Dinant Synclinorium in Belgium (Boulvaïn & Coen-Aubert, 1989) and Pyrenean basins (Scott et al. 1990), the Tunisian examples are composed mainly of carbonate muds; rudists, although locally abundant, are generally dispersed, many mounds being devoid of unbroken rudists and corals. Field study indicates that these lenticu-
Fig. 1. Simplified geological map of Campanian–Maastrichtian outcrops in central Tunisia, showing the location of the two areas studied.
lar bodies (type 1 mud-mounds), statistically the most common, although populated by rudists and corals, were not produced only by organic processes. They do not correspond to bioherms but nevertheless consist of fine-grained sediment and appear to have been wave-resistant. Their rigidity is due mainly to an early lithification, indicated by the presence of thick (20 m) conglomerates whose constituent blocks, up to 3 m in diameter, contain rudists and other elements identical to those within the adjacent mounds.

The principal aim of this contribution is to demonstrate the multiple factors determining the nature and evolution of these carbonate mounds at Jebel el Kebar. These will be compared subsequently with other rudist mounds in central Tunisia, notably at Jebel Serraguia. Finally, the authors evaluate the relative importance of biological, hydrodynamic, diagenetic and erosional processes, the latter seemingly related to contemporaneous tectonic instability, in determining the origin of the rudist mounds in central Tunisia.

Stratigraphic and tectonic setting

The Late Cretaceous of central Tunisia comprises several hundred metres of carbonates and deeper marine marls (Fig. 2). A marked break at the top of Cenomanian deposits (Zebag Formation, also locally rich in rudists) is overlain by a shallowing-upward sequence, about 100 m in thickness, comprising marls (Annaba Formation) overlain by shallow-marine carbonates partly rich in rudists and exhibiting hard grounds (Bireno Formation, lower-middle Turonian in age; see Robaszynski et al., 1990; Camoin, this volume). The latter are also overlain by shallowing-upward sequences, about 300 m thick, comprising marls and carbonates (Aleg Formation, middle Turonian–lower Campanian). This Aleg Formation is also topped by an erosional surface marked by local conglomerates, upon which are developed the upper Campanian–Maastrichtian rudist facies of the Merfeg Formation (Khessibi, 1978). These massively bedded Merfeg carbonates (discussed in this contribution) grade laterally into deeper marine limestones of the Abiod Formation (Burollet, 1956). Clearly, the Merfeg–Abiod transition reflects a marked lateral variation in Senonian bathymetry whose slopes are confirmed both by the presence of numerous slumps and other resedimentation phenomena characteristic of the Abiod basinal limestones.

The Mesozoic sediments of central Tunisia, including the platform carbonates of the Merfeg Formation, have been folded during the Miopliocene. Most anticlines, including Jebel el Kebar, are asymmetric, the south flank being slightly overturned. These subvertical dips favour the topographic expression of the numerous mounds, although tending to limit the extent to which their three-dimensional geometry can be determined. The existence of a varied Cretaceous bathymetry, together with frequent resedimentation phenomena, suggests Cretaceous tectonic instability. This may possibly have been related to the presence of underlying Triassic evaporites. The outcrop evidence of Triassic material is clear in adjacent anticlines but not in Jebel el Kebar. The upper Cretaceous instability is considered to be a major factor in the formation of the Campanian–Maastrichtian rudist-bearing mounds (Negra et al., 1987).

BIOTIC COMMUNITIES AND SEDIMENTARY ATTRIBUTES OF THE RUDIST MOUNDS AT JEBEL EL KEBAR

Three major, intimately related, sedimentary facies have been identified: (i) massive micritic carbonates (Fig. 3b, e), locally rich in rudists; (ii) laminated argillaceous planktonic foraminiferal micrites (Fig. 3d), lithologically similar to the Abiod Formation; and (iii) carbonate conglomerates (Fig. 3c), generally stacked against the carbonate mounds, comprising micritic and rudist-bearing elements, clear evidence of contemporaneous lithification of the adjacent mounds.

Aleg marls

Marls forming the top of Aleg Formation constituting the substrate for mud-mounds are rich in planktonic and benthonic foraminifera. However, within these marls, the proportion of planktonic foraminifera relative to benthonic foraminifera changes laterally. In the Rous el Kebar area (on the SE flank of the anticline, Fig. 3), planktonic foraminifera (mainly Globotruncanita stuartiformis and Rosita fornicata) attain 70% of total foraminifera present (Bismuth, oral communication). Benthonic foraminifera (mainly Dorothyia, Gavellinella, Gyroidinoides, Gaudryina), ostracods (Cytherella) and debris of Inoceramus and echinoderms constitute
<table>
<thead>
<tr>
<th>Age</th>
<th>Formations</th>
<th>Lateral change</th>
<th>Water depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maastrichtian</td>
<td>Abiod</td>
<td>Abiod – Merfa – Berda</td>
<td></td>
</tr>
<tr>
<td>Campanian</td>
<td>Merfa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santonian</td>
<td>Aleg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coniacian</td>
<td>Douleb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle – Turonian</td>
<td>Bireno</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower – Middle</td>
<td>Annaba</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turonian</td>
<td>Zebag</td>
<td>Bahloul</td>
<td></td>
</tr>
<tr>
<td>Cenomanian</td>
<td>Zebag</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vriconian</td>
<td>Fahdene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aptian</td>
<td>Serdj</td>
<td>Orbata</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. Synthetic log of the Upper Cretaceous series in central Tunisia.

30%. Towards the SSW (in the periclinal area, Fig. 3), the proportion of planktonic foraminifera decreases, and does not exceed 30%; these marls are dominated by benthonic foraminifera, ostracodes and debris of echinoids, crinoids, *Inoceramus* and brachiopods. Benthonic foraminifera are mainly *Dorothia oxycona*, *Gyroidinoides*, *Lenticulina*, *Gavelinella* and *Anomalinaeides*. Ostracods are mainly *Trachyleberidea genitzi*, *Berdya*, *Cytherella*. Planktonic foraminifera are mainly *Globotruncanita stuartiformis*, *Rosita fonnicata*, *Globotruncan* *bulloides*, *Globotruncana linneiana*, *Globotruncana lapparenti*. The relative abundance of benthic foraminifera, ostracodes and bioclastic debris indicates a shallowing towards the south-west prior to the deposition of the overlying mounds.

**The Merfa mud-mound facies**

The rudist mounds of the Merfa Formation directly overlie open marine marls and argillaceous limestones of the Aleg Formation (Burollet, 1956). The contact between the two formations is an obvious lithological discontinuity marked by a ferruginous crust. It is locally conglomeratic, pebbles and enveloping matrix containing both planktonic and benthonic foraminifera. This intraformational conglomerate indicates local early lithification followed by erosion of the upper part of the Aleg Formation before rudist mound formation.
Fig. 3. Maps and section of the Jebel el Kebar anticline showing the geometry and distribution of rudist mounds and related facies: (a) Aleg marl Formation; (b), (c) & (f) three rudist-colonized horizons all within the Merfeg Formation (b, mud-mounds; e & f, biostromal horizons); (c) conglomerates piled against mounds; (d), (g) laminated planktonic foraminiferal argillaceous micrites, overlying mounds; (h) Miocene clays and silts of Beglia and Segui Formations.
Morphology

Only the first rudist member (Fig. 3b) of the Mergel Formation is lenticular, the two other rudist members (Fig. 3e) being biostomal (10–15 m). The first member comprises a series of rudist lenses (Fig. 3b) laterally separated by conglomeratic deposits (Fig. 3c) and overlain by thin-beded argillaceous limestones (Fig. 3d).

The base of each mound is generally flat but can be locally concave; the top of the mound is markedly convex. According to sedimentary structures and constitution, several types of mud-mound are distinguished, each having its particular morphology (Fig. 4).

Mud-mounds sensu stricto (type 1) and composite mud-mounds (type 2) are asymmetric; they have a thickness in the range 11–30 m and a lateral extent attaining 500 m. The thickness/extent ratio (about 1/20) indicates a lateral accretion of mud. In addition, statistically, the north-eastern flank of each mound is clearly steeper (40° at least). Their three-dimensional form is not easy to establish, but in two examples appears to be irregular and slightly elongated to the north.

Muddy, rudist bioherms (type 3), in contrast, are generally subsymmetric, being less than 15 m in thickness and having a lateral extent of 40–50 m. The thickness/lateral extent ratio (about 1/3) associated with steep slopes indicates 'rapid' vertical

Fig. 4. Schematic geometry and composition of the three types of mud-mound: (1) type 1 mud-mounds sensu stricto; (2) type 2 composite mud-mounds; (3) type 3 muddy rudist bioherms. (a) Aleg marl Formation; (b) mud-mounds; (b') rudist bioherms; (c) conglomerates piled against mounds; (d) laminated planktonic foraminiferal argillaceous micrites, overlying mounds; (e) biostromal horizon; (f) erosional surface; (g) contemporaneous fracture; (k) lateral accretion sets; (l) burrows; (r) rudists (mainly hippuritids); (p) corals.

**Biotic components**

Rudists (see Figs 5 & 6). Taxonomy and orientation change according to type of mound. In type 3 rudist bioherms, rudists are mainly hippuritids (Hippurites colliciatus Woodward, Vaccinites bracensis Sladice-Trifunovic) and some caprinids and radiolitids (Pironaea cf. corrugata (Woodward), Pironaea cf. timacensis Milovanovic, Sabinia sp.; Negra & Philip, 1987). Vaccinites attains lengths of 60 cm. In the lower parts of certain bioherms, rudists may be intimately linked in vertical growth position; interrudist spaces are filled with fine (wackestone) sediment rich in rudist-coral and echinoderm debris. In type 2 composite mounds, rudists (mainly hippuritids) are scattered and have no preferential orientation. The overlying, bioconstructed limestone includes Vaccinites and Hippurites (about 90%), Rajkia, Pseudopolyconites and Joufia (about 10%) are joined and fossilized in inclined growth position, their ventral cavities being oriented towards the south-west. In the upper part of the biocreation, the more diversified hippuritids, radiolitids and caprinids are associated with hermatypic corals. Rudists are commonly bored and disintegrate to form debris. The boring organisms are not identified, however, floating sponges and lamellibranchs are present in the rudist mounds; biogenic micrite (not identified here by SEM because of the frequent modification of micritic grains by diagenesis) can originate by disintegration of radiolitid rudists (Philip et al., 1978).

The inclined growth position of hippuritids within the type 2 composite mud-mounds indicates a sedimentary slope of the mound. The preferential orientation of rudist ventral cavities towards the south-west suggests nutrient supply via currents from this direction.

**Corals.** Although contributing to mound construction, massive colonial corals alone never constitute buildups. However, they may become relatively abundant at the top of certain bioconstructed mounds. Like rudists, they frequently disintegrate to form various grades of bioclastic debris.

**Other organisms.** Frequently associated with rudists, the most common are echinoids (mainly Plesiaster, Negra, 1984) which are generally fragmented. All organisms occur in a micritic or bioclastic matrix.

On the whole, the most common mud-mounds at Jebel el Kebar (type 2 composite mud-mounds, Fig. 3) comprise two biotic successions. A lower bioconstructed level, about 10 m in thickness, is characterized by the predominance of rudists relative to corals. Rudists are mainly hippuritids which constitute about 90% of the bioconstruction. An upper bioconstructed level, about 15 m in thickness, includes rudists and massive colonial corals in a subequal proportion. Rudists are more diversified: Joufia and Sabinia are associated with hippuritids which are predominant (about 90% of the rudists).

**Sedimentary components**

The majority of rudist mounds are composed essentially of micrite and microsparite in which float rudists and corals. These micrites do not exhibit traces of algal mats or cyanobacterial features but exhibit cross-bedding, notably in their lower parts. The cross-bedded strata are gently inclined (5–10°) and form a lens within the type 1 mud-mound. They are locally preserved by early dolomitization and silicification, but are generally modified or totally destroyed by intense burrowing mainly by Ophiomorpha (Fig. 5C) and by recent caliche-type weathering. These oblique, seemingly lensoid, strata are probably extensive. In addition, horizontal laminations with graded bedding occur locally.

A typical rudist mound at Jebel el Kebar (Fig. 3) exhibits several textures. The basal 40 m consists of packstones containing rudist, coral and echinoderm debris. The cross-bedded carbonates are fine, well-sorted bioclastic grainstones. They are overlain by a wackestone containing rudist, coral and echinoderm debris, calcispheres and peloids. Under SEM, this wackestone corresponds to ‘loosely packed interlocking’ structure of anhedral to subhedral ‘nanograins’ whose diagenetic attributes are discussed in a following paragraph.

**Environment of deposition**

**Vertically.** A faunal succession (Flügel, 1981) occurs within the mounds at Jebel el Kebar. Rudists are the most common organisms and although occasionally present throughout, they construct only the upper part of certain mounds. They seem to be adapted to
the mound environment. Corals, in contrast, become relatively abundant only in the upper part of the mound where they are associated with diversified rudists; within this relatively shallower environment, palaeoecological conditions seem to have been more favourable: colonial corals are developed, rudists are more diversified. However, the absence of levels constructed exclusively by corals is probably due to global environmental stress (Scott et al., 1990).

**Laterally.** The rudist–coral communities pass into more diversified rudist–coral communities towards the south-west where Pironea may appear. In addition, mounds are built (from base to top) by somewhat larger rudists (mainly Vaccinites) in vertical growth position, associated, in subequal proportion, with massive colonial corals. This lateral change concerning rudist–coral communities coincides with changes in foraminiferal associations in the underlying marls; towards the south-west these...
marls contain a relatively high proportion of bioclastic debris, bentonic foraminifera and ostracodes. All these changes suggest shoaling conditions towards the south-west. Thus, the south-west part of Jebel el Kebar may correspond to a bathymetric high in which rudist-coral buildups were developed in a high-energy environment. The south-east part may reflect relatively deeper slope environments in which non-bioconstructed (type 1) and composite (type 2) mud-mounds developed.

Laminated argillaceous planktonic foraminiferal micrites

Relation to mound facies

Mound complexes in central Tunisia comprise a repetition of rudist mounds and bedded, argillaceous pelagic micrites. The rudist mounds are overlain by centimetric bedded argillaceous limestones which pinch out over the convex top of each mound (Fig. 4). Contact with the mound is generally smooth, sharp and locally subvertical, indicating that the mound was lithified early. Penetration of pelagic muds into fissures or other voids in mounds is never observed.

Nature and composition of micrite

Bedded micrites contain 20–25% of smectite and kaolinite. Their faunas are dominated by planktonic (Globotruncanana, Globigerinelloides; Fig. 6E) and bentonic foraminifera (textulariidae, lagenidae), coccoliths (Fig. 6F), some calcispheres and rare echinoderm debris. Under SEM, bedded argillaceous micrites are different from mound micrites; coccoliths and their debris (Fig. 6F), the main constituents of bedded argillaceous micrites, are absent in rudist mounds. In addition, 'neogenic' microspar, frequent in rudist mounds, is poorly developed or absent in bedded argillaceous micrites.

At Jebel el Kebar, bedding changes from the south to the north; micrite beds are generally centimetric at the southern flank but become thicker (30 cm) and more massive to the north.

Environment of deposition

Following lithification and erosion of the rudist mounds, the bedded, argillaceous micrites were deposited in a deeper (below wave base), more open marine environment which, nevertheless, was closely related to the mounds; repetitions of mounds and planktonic argillaceous micrite are a characteristic feature of these complexes.

At Jebel el Kebar, laminated argillaceous micrites are less well developed on the north-west flank (only one intercalation; at least two intercalations on the south-east), and the Merfeg Formation is clearly thicker in the south-east (135 m) than in the north-west (50 m), suggesting that the south-east was a more open marine environment than the north-west.

Conglomerates (Fig. 7)

Relation to mound facies

Conglomerates, although occurring locally below the mounds, are generally situated laterally to them; there is always a clear break between conglomerates and mound sediments (erosional surface, Fig. 4). The conglomerates are not a simple lateral extension of mounds, i.e. talus deposits, but are piled against a pre-existing, subvertical mound surface: they are not derived directly from adjacent mounds but have formed further upslope. They are particularly well exposed at Bir ech Chegaiga and Roué el Kebar (Fig. 8), where they attain 20 m in thickness and about 100 m in lateral extent. At Jebel el Kebar, conglomerates constitute about 25% of the first member of the Merfeg Formation, while mound carbonates form 75%.

Composition and textures of conglomerates

Conglomerates contain pebbles and metric-sized boulders (Fig. 7A) floating in a micritic matrix rich in planktonic, bentonic foraminifera and calcispheres. Blocks and pebbles are slightly rounded. Blocks are micritic or rich in rudists and corals. They exhibit at least three types of texture: (i) pack-grainstones containing rudist, coral and echinoderm debris cemented by isopachous, layered microspar (Fig. 8D); (ii) wackestones-packstones containing calcispheres and echinoderm debris; and (iii) wackestone-packstone textures containing planktonic and bentonic foraminifera, similar to that of their supporting matrix. However, the majority of pebbles are micritic, with a composition similar to that of the micrite composing the mounds, but having a different diagenetic nanofabric—generally interlocking to coalescing with much 'neogenic' microspar (Fig. 8F).
Fig. 6. Petrographic fabrics of micrites comprising mounds and conglomerates. (A) Irregular spar cement in conglomerate pebble. (B) SEM photo showing interlocking fabric of micrite grains (1) partly surrounded with microspar cement (2) in conglomerate pebble. (C) SEM photo showing microspar crystal (1) englobing micrite grains (arrows) in type 1 mud-mound. (D) SEM photo showing micrite grain (1) enclosed in microspar (2), top of type 1 mud-mound. (E) Photomicrograph of typical pelagic micrite (laminated argillaceous planktonic foraminiferal micrite) overlying the rudist mounds. (F) SEM photo showing porous coccolith debris in pelagic micrites.
At Rous el Kebar valley, there exist three conglomeratic bodies separated by laminated argillaceous limestones. Each conglomeratic unit is characterized by an erosional base locally exhibiting bounce casts and groove casts, with a predominantly east-west direction. Some flute casts at the base of the first conglomeratic unit are indicative of turbulent flow to the east and south-east.

Sorting in the conglomeratic units is very poor to absent. Metric-sized blocks, which are always associated with millimetric pebbles, are localized preferentially within the basal 10 m. However, graded
Fig. 8. Diagenetic transformations of rudist debris and nanofabrics of conglomerates. (A) Perforated rudist debris in mound facies. 1, irregular boring; white arrow, enveloping micritic layer; black arrow, 'linear' micritic layer in an intraparticular position. (B) Neomorphosed and micritized debris. (C) Conglomerate block composed of debris cemented with microspar, floating in pelagic micrite. (D) Details of conglomerate block showing microspar cement which can be within partly dissolved rudist debris (1) or intergranular (2) between bioclastic debris. (E) SEM photo of pelagic matrix of conglomerates, showing anhedral to subhedral micritic grains (1), scarce spar crystals (2) and partially preserved intergranular porosity (3). (F) SEM photo of micrite of conglomerate block whose coalescent nanofabric (especially, 'amoeboid' crystals, 1) contrasts with that of the matrix (compare E).

bedding is not obvious. Both blocks and pebbles form grain-supported textures and always include muddy matrix, suggesting mud flow. Conglomerates are topped by planar-laminated micrites which are often affected by reverse microfaults with millimetric throws. This
planar-laminated level and the overlying marls may correspond to ‘d’ and ‘e’ terms of the Bouma Sequence; these debris-flow deposits, overlain by turbiditic sequences, may constitute fluxuturbidites (Slaczka & Thompson, 1981; Negra, 1989).

**Dynamics**

The association of different lithologies such as micrite, bioclastic, rudist framestone, etc., indicates mixing and not simple collapse of adjacent mounds. Furthermore, frequent striations at the base of the conglomerate beds (Rous el Kebar) confirm lateral movement on a slope. This slope, as deduced from groove marks and flute casts, was inclined towards the east and south-east.

Movement was sporadic and sudden. At Rous el Kebar, where three rudist units pass abruptly into three conglomerate discharges separated by laminated planktonic foraminiferal argillaceous micrites, the irregular surface marking the base of the conglomerates erodes laminated argillaceous micrites. Clearly, there is not a simple, regular, in situ erosion of mounds; conglomerates probably have been deposited on, or at the base of, a slope, against the mounds. Together with the planktonic nature of the argillaceous micrite facies, this would suggest that the mounds were formed well below wave base, possibly on an open marine slope. The sporadic nature of conglomeratic sedimentation, and the absence of structures indicative of waves, suggest that this erosion was due to tectonic instability.

**Lateral variation of three facies units at Jebel el Kebar**

As already noted, mounds comprising the first member of the Merfeg Formation, are subdivided into three types. Mud-mounds sensu stricto (type 1) are asymmetric with floating or lacking rudists. Composite mud-mounds (type 2) are asymmetric and comprise a type 1 mud-mound capped by a rudist blanket. Muddy, rudist bioherms (type 3) are subsymmetric and are constructed by rudists and corals.

Type 1 mud-mounds and type 2 composite mud-mounds are situated on the south flank; they frequently exhibit current structures such as cross-bedding, indicating that sedimentation was periodically above wave base. Type 3 rudist bioherms, in contrast, are concentrated at the southwest end of Jebel el Kebar (Fig. 3). They do not exhibit current structure; in addition, rudists are relatively large and are generally well preserved.

Laminated planktonic foraminiferal argillaceous micrites (Abiod facies) are best developed on the south-east flank where they are intercalated between rudist units; they become very lenticular in the periclinal area (to the west) and more massive on the north-west flank. These lateral variations confirm open marine and possibly deeper conditions to the east and south-east.

Conglomerates are well developed on the south-east flank (especially at Rous el Kebar) and the periclinal area (in which blocks are smaller) but, in contrast, are thinly developed on the north-west flank. They suggest that rudist mounds are more exposed to erosion on the south-east flank where tectonic instability was probably more active.

The combination of lateral sedimentary variation expressed by the three different facies and localization of current structures, indicates open marine and possibly deeper conditions to the E and SE of Jebel el Kebar. On a larger scale, toward the south, Campanian–Maastrichtian sedimentation comprises bioclastic carbonates (Berda Formation) exhibiting birdseyes and/or mud-cracks affecting shallow-marine deposits (Abdallah, 1987). To the north and east, in contrast, regional sedimentation was relatively deep (Abiod facies).

**DIAGENESIS OF MOUNDS**

Microsparitization is the main diagenetic process affecting mounds (Fig. 6). Subhedral crystals of microspar and spar are precipitated within micritic, bioclastic and bioconstructed limestones (Negra, 1984; Negra & Loreau, 1988). The frequency of microsparitization is intimately related to the initial texture (microspar is relatively frequent in bioconstructed limestones) and to the degree of lithification (M’Rabet et al., 1986). Abundant in the upper part of certain mounds (Negra, 1986; Loreau & Negra, 1987), it has two origins: cementation (M’Rabet et al., 1986) and neomorphism (Folk, 1965; Bathurst, 1975; Negra, 1986; Loreau & Negra, 1987). As already noted, it is, at least partly, the product of early lithification demonstrated by the frequency of intraformational conglomerates (Negra, 1984). These conglomerates, which separate adjacent mounds, are formed of reworked rudist limestones. In some pebbles, rudist, coral and echinoderm debris are cemented by an isopachous-
layered microspar (Fig. 7B); pebbles and blocks float within an open marine matrix rich in planktonic foraminifera.

Micrite diagenesis has been studied by comparing the micrite constituting mounds with that in the laminated argillaceous muds sealing the rudist mound-conglomerate complex. The puncitic, loosely packed, interlocking and coalescing nanofabrics characterizing these various facies (Fig. 8E) probably express varying degrees of diagenetic evolution. The scarcity of ‘neogenic’ microspar crystals within the conglomerate matrix or in the laminated argillaceous micrites, not affected by early lithification, confirms that most of the ‘neogenic’ microspar and spar crystal were formed early (Negra & Loreau, 1988). Because its formation has resulted in the early induration of the mound, microsparitization is considered to be one of the more important factors in the early consolidation of these mounds (Purser, 1980, 1983; Aissapui et al., 1986).

Concerning the early diageneric environment, the tops of rudist mounds do not exhibit traces of caliche crust, karst, fissuration or any features commonly associated with emergent surfaces. Nevertheless, the sparitic nature of cements and the preferential dissolution of aragonitic clasts are possible expressions of meteoric diagenesis.

**EROSIONAL PROCESSES AND THEIR CONTRIBUTION TO MOUND GEOMETRY**

The volume of conglomerate, which is thickest in the vicinity of the most clearly expressed mounds (Figs 3 & 4), is only slightly less than the volume of the mounds. Because most, if not all, the conglomeratic debris is derived from the mounds, it is clear that erosion is a major factor in mound morphology. Furthermore, because these conglomerates show clear traces of lateral movements, they are not the result of a simple, progressive erosion of the mound against which they are piled. Although these conglomerates tend to occupy depressions between mounds, most of the intermound depression is filled with laminated planktonic muds (Fig. 3). Thus the mound morphology is clearly expressed.

The preceding remarks indicate that the characteristic lenticular geometry of the mounds results from a combination of processes whose importance varies. Organic construction is minor (perhaps 5–10%), although the contribution of biogenic detritus which constitutes the essential part (if not all) of mounds, is very important. However, this material does not contribute actively to mound morphology unless it has been formed and trapped in situ. The stabilization of sediments could be due to some kind of cryptobacterial mats (Monty, 1984; Camoin, 1983). However, their traces have not been preserved. The hydrodynamic piling of biogenic detritus is certainly more important than biotic construction. The inclined surface on which certain rudists have grown may express hydrodynamic effects. This relief may also be the result of erosional processes. The latter seem to be an important factor in controlling mound relief and the final morphology. Together with a contemporaneous lithification of these massive carbonates, this erosion has sculptured the low relief formed by ecological and hydrodynamic processes, forming sharp, locally steep limits and accentuating the relief of these local highs.

**REGIONAL CONTEXT OF MOUND DEVELOPMENT**

At Jebel el Kebar, lateral variations between the north-west and south-east flanks of the structure suggest that the mounds formed on the edge of a shallow carbonate platform, perhaps on the slopes surrounding it. The close association between mounds and planktonic microfauna, including the matrix of the associated conglomerates, clearly indicates formation below wave base, at least during part of their history. Downslope transport of the conglomerates, which are in direct contact with the mounds, also confirms slope environments. On a more regional scale, mounds within the Merfeg Formation pass into well-bedded, slightly argillaceous limestones with abundant planktonic microfauna of the Abiod Formation. These sediments are very similar to the laminated argillaceous micrites which surround most of the mounds at Jebel el Kebar.

*Brief description of the Abiod Formation:* At localities surrounding Jebel el Kebar, the Abiod Formation includes many slumps and other re-sedimentation phenomena including spectacular groove, bounce and flute casts frequently indicating northward displacement (Negra, 1988). Mass flows
and large olistoliths, occasionally with corals and other shallow-marine faunas, also occur. These phenomena clearly express the existence of submarine slopes. It is therefore of considerable interest to note that periodic formations of conglomeratic mass flows within the Merfeg Formation are contemporaneous with similar phenomena within the deeper-marine facies of the Abiod Formation. This confirms regional tectonic instability during mud-mound development.

CONTRAST OF JEBEL EL KEBAR WITH OTHER CAMPANIAN RUDIST MOUNDS: JEBEL SERRAGUIA (TUNISIA), PRIOLO AREA (SICILY), PYRENEAN COMPLEX BUILD-UPS (SPAIN)

The rudist mound in Jebel Serraguia, 100 km to the west of Jebel El Kebar (Fig. 1) is Campanian–Maastrichtian in age. Contrary to Jebel El Kebar, it comprises a single asymmetric mound, 60 m thick (Fig. 9), which passes laterally and abruptly into breccia and conglomeratic sediments; the rudist mound-conglomerate complex is sealed by 30–60 m of laminated planktonic foraminiferal argillaceous micrites of the Abiod facies.

The lower part of the rudist lens consists of a series of sequences each measuring 0.1–2 m in thickness. Each sequence starts with rudist wackestones including gastropods, coral and echinoid debris, and peloids, and terminates with fine pack-grainstones, rich in bioclastic debris. These sequences are locally cut by channels up to 5 m wide and 2 m deep, each filled with poorly sorted bioclastic sands and gravels. Some channels locally exhibit cross-stratification oriented towards the west. Above, the rudist mound comprises a massive wackestone-packstone locally rich in caprinids (Sabinia, see Bernot-Rollande & Philip, 1981; Philip, 1986), and hippuritids (Vaccinites) rarely loosely packed and in growth position, and frequently fragmented.

Rudists in growth position are uncommon at Jebel Serraguia. In addition, broken rudists form graded sequences suggesting hydrodynamic accumulation. In contrast to Jebel El Kebar, bedded biogenic detritus, carbonate sands and gravels are widely represented and confirm the importance of hydrodynamic forces.

Conglomerates include olistoliths which measure up to 40 m in diameter; one block is composed of sequences tilted to nearly 90° from their original horizontal position. The associated blocks and pebbles are enveloped in a matrix rich in calcispheres, ostracodes, orbitoids and bryozaans. As at Jebel El Kebar, pebbles and blocks, deriving from the neighbouring rudist mound, are often composed of debris cemented by calcite. Some exhibit early blocky calcite cement overlain by internal sediment (M'Rabet et al., 1986). In addition, the interlocking to coalescing nanofabric characterizing micrites in the rudist mound and the frequency of 'composite' and sometimes 'amoeboid' microspar and spar crystals, all result from an early lithification.

Erosion is also important, olistoliths and associated blocks and pebbles being frequent. In addition, the contact between rudist mound conglomerates coincides with synsedimentary fractures indicating NE–SW distensive tectonics during the Campanian (Ben Ayed, 1986). As at Jebel El Kebar, final morphology of rudist mounds appears to be determined partly by erosion probably related to tectonic instability. However, although the anatomy of the mud-mounds in Jebel El Kebar and Jebel Serraguia is different, early lithification and erosion, in both examples, are important factors contributing to the final morphology of mud-mounds.

In the Priolo area of south-east Sicily (Camoin, 1983; Tronchetti & Camoin, 1986), rudist facies, in common with those at Jebel El Kebar, constitute massive mounds separated by laminated planktonic foraminiferal chalky limestones. However, the rudist mounds are mainly an alternation of pack-grainstones and rudstones containing bioclastic sands and gravels. As at Jebel Serraguia, entire rudists and corals are scarce, gravels, rudist and coral debris being the predominant components; they indicate that these mounds do not correspond to 'reefs', being accumulations of biogenic debris or 'sediment piles' (Wilson, 1974; Tronchetti & Camoin, 1986). The trapping of particles is due tostromatolitic encrustations and microbial coating enveloping preferentially coarse gravels. In addition, as shown in Jebel Serraguia, the bases of gravel layers frequently erode the underlying bioclastic packstones and sometimes the underlying chalks and marls, suggesting important early erosion and resedimentation.
In the complex buildups in the Pyrenean region, three main analogies with Tunisian mounds are noted: (i) their high mud and bioclastic sand content, mainly generated from rudists and corals; (ii) the absence of exclusive coral buildups or algal-coral communities; (iii) the persistent association of corals with rudists. These features were interpreted by Scott et al. (1990) as being characteristic of Late Cretaceous mounds and, perhaps, are expressions of global factors such as sea-level rise, marine productivity and oxygen content affecting the Cretaceous ocean.

**DISCUSSION: ORIGIN OF RUDIST MOUNDS IN CENTRAL TUNISIA**

Several distinct factors determine the composition and geometry of the Upper Cretaceous mounds reported.

**Role of rudists**

Of the 20 mounds examined on the south flank of Jebel el Kebar, 15 were type 1 mud-mounds, while five were type 2 composite mud-mounds sometimes including rudist frameworks in their upper part.

**Fig. 9. Rudist mound at Jebel Serraguia. (A) Generalized cross-section showing:**
1, Coniacian marls (Aleg Formation); 2, rudist mound; 3, conglomerates; 4, bioclastic flank debris; 5, laminated argillaceous micrites; 6, bedded pelagic carbonates; r, rudists; f, fault. (B) Field photograph showing facies illustrated in (A), especially rudist mound (2 in A) and laminated argillaceous micrites (5 in A).
Fig. 10. Block diagram showing the location, geometry and general composition of the three mud-mound types in Jebel el Kebir: (1) type 1 mud-mounds sensu stricto; (2) type 2 composite mud-mounds; (3) type 3 muddy rudist bioherms. (a) Aleg marl Formation; (b) mud-mounds of Merfeg Formation.

(Fig. 10). There are no notable differences in size between both types. *Hippurites* and *Vaccinites* constructions, although common, are generally small. More frequently, scattered rudists are found floating in the carbonate muds of type 1 and type 2 mud-mounds. The inclined disposition of closely packed rudists concentrated in the upper part of the type 2 mounds indicate that relief existed before their installation. Disintegration of rudists contributed biogenic debris to mounds, much of which remained in situ, increasing local relief. However, on the whole, the direct role of rudists and corals in the construction of the mud-mounds is modest.

**Hydrodynamics**

Lenticular geometry, in general, is frequently due to hydrodynamic factors (bars and ridges). However, the predominence of fine-grained carbonates (micrites and microspar) poses an obvious problem. Fine carbonate sands with well-developed cross-bedding are frequent, at least within the lower half of the mud-mounds situated on the south-east flank of Jebel el Kebir. However, they do not seem to constitute a major part of the pile. As already noted, their importance could be greater than first appears; bedding is often masked by Quaternary weathering and by intense (*Ophiomorpha*) bioturbation (Fig. 5). Traces of lamination occur throughout the mounds, suggesting a certain hydrodynamic influence in sedimentation. This seems to be confirmed by the asymmetric profile of at least two mounds (Fig. 4) which are steeper on their north-east flanks possibly due to currents from the south-west. Finally, many rudists, although in situ, are inclined towards the south-west. This preferred orientation may be in response to nutrient supply via currents from the south-west.

A number of factors inicate hydrodynamic influences which initially contributed to the local accumulation of fine detrital carbonate. It is also conceivable that muds may have been piled by hydrodynamic processes, as has been demonstrated by Bosence (this volume) for modern mud ridges in Florida Bay.
The importance of early diagenetic stabilization

The sharp contact between mounds and their surrounding sediments, the subvertical nature of the flank of many mounds and, especially, the presence of thick conglomerate bodies, all indicate an important early diagenetic consolidation of the mounds. This lithification is important because it permitted the creation of steep slopes and preserved the lenticularity of the mounds.

CONCLUSIONS

The Campanian-Maastrichtian rudist mounds in central Tunisia are the expression of four main processes: (i) hydrodynamic piling of relatively fine bionodrillar sediments; (ii) bioconstruction by rudists whose main contribution to the piles was their production of biogenic debris; (iii) stabilization of biosedimentary piles by early lithification, by meteoric microsparitization; and (iv) erosion of these lithified piles during periods of Upper Cretaceous tectonic instability. Interbedded pelagic muds and numerous gravity phenomena indicate that these mounds were formed on periplatform slopes.

ACKNOWLEDGEMENTS

The authors express their sincere thanks for technical assistance from personnel of the universities of Paris-Sud and Tunis, as well as the Paris Natural History Museum in the preparation of photographs, and to M. Bismuth for identification of microfaunas. They also acknowledge the critical review of this manuscript by Dan Bosence and Claude Monty.

REFERENCES


Negra, M.H. (1988) Ecoulements en masse et resédimen-


