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Entolium beds: Hiatal shell concentrations in starved pelagic settings (middle Liassic, SE Spain)

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Key words: Entolium, Bivalves, Pectinids, shell concentrations, Liassic, Betic Cordillera

ABSTRACT

Lower Domerian (upper Pliensbachian) *Entolium* shell concentrations characterise the transition between shallow-water carbonates and pelagic marls and marly limestones in the middle Liassic from the southern part of the Median Subbetic, one of the subdomains of the southern passive margin of the Iberian Massif. Rudstones and floatstones of *Entolium* valves probably formed below storm-wave base in a sediment-starved palaeoenvironment. Valve disarticulation and the scarce shell fragmentation were caused by bioturbation. Low sedimentation rate resulted in long preburial residence times that probably favoured the differential dissolution of aragonitic skeletons that are absent or scarce in the *Entolium* floatstones and rudstones but occur in the overlying crinoidal packstones to grainstones with *Entolium* fragments. These latter are made up of highly fragmented and abraded bioclasts incorporated in trough cross-beds and probably formed in shallower settings affected by storms. Some *Entolium* packstone laminae intercalated in the *Entolium* concentrations may represent distal storm deposits. The *Entolium* beds were deposited on the southern part of a bank separated from the Iberian Massif mainland by a trough located in the External Subbetic subdomain. Pelitic sediments were trapped in that trough, while to the south only condensed limestones and hardgrounds formed. This Median Subbetic bank was already active in the middle Carixian and deepened during the middle Domerian, eventually disappearing. The absence or scarcity of remains of other benthic organisms with calcitic skeletons and the small average size of *E. lunare* shells point to unfavourable sea-floor conditions that inhibited the growth of a diverse benthic community. *Entolium* is considered to be characteristic of dysaerobic environments, and the reported *Entolium* shell concentrations probably formed in a dysaerobic environment below storm-wave base. Taphonomic processes favoured the differential preservation of the calcitic *E. lunare* valves, thus enhancing their concentration. The *Entolium* beds were deposited at a time of global rising or high sea level. They can be considered as hiatal shell concentrations associated with transgressive or highstand regimes.

ZUSAMMENFASSUNG

Im unteren Domerium (höheres Pliensbachium) charakterisieren Schalenkonzentrationen von *Entolium* den Übergang von Flachwasserkarbonaten zu pelagischen mergeligen Kalken des mittleren Lias im südlichen Teil des Mittleren Subbetikums, eines Teilbereiches des südlichen passiven Randes des Iberischen Massivs. Rudstones und Floatstones aus *Entolium*-Schalen entstanden wahrscheinlich unterhalb der von Sturmwellen beeinflussten Zone, in einem sedimentararmen Milieu. Schalendisartikulation und die geringe Schalenfragmentierung wurden durch Bioturbation verursacht. Die geringe Sedimentationsrate verursachte eine lange Verweildauer der Schalen auf dem Meeresgrund; dies begünstigte wahrscheinlich die differenzierte Lösung von aragonitischen Skelettresten. Diese sind in den *Entolium*-Floatstones und -Rudstones selten oder gar nicht vorhanden, kommen aber in den überlagernden Krinoiden-Packstones und -Grainstones zusammen mit *Entolium*-Fragmenten vor. Krinoiden-Packstones und -Grainstones bestehen aus stark fragmentierten Bioklasten, die in tropförmigen Schrägschichtungslagen eingebettet und wahrscheinlich in einem von Sturmwellen beeinflussten Ablagerungsraum entstanden sind. Einige *Entolium*-Packstone-Laminae, eingeschaltet in die *Entolium*-Vorkommen könnten distale Sturmablagerungen darstellen. Die *Entolium*-Konzentrationen wurden im südlichen Bereich einer Bank abgelagert, die durch einen Trog von dem Iberischen Massiv abgetrennt war, und sich in der Externen Subbeticischen Subdomäne befand. Pelitische Sedimente finden sich im Trog, während sich weiter südlich nur kondensierte Kalke und Hartgründe bildeten. Diese Mittlere Subbeticische Bank war seit dem mittleren Carixium aktiv und vertiefte sich während des mittleren Domeriums, um schliesslich völlig zu verschwinden. Das Nichtvorhandensein oder nur seltene Auftreten von Resten anderer benthischer Organismen mit kalzitischer Schale und die geringe durchschnittliche Größe der Schalen von *E. lunare* lassen auf ungünstige Meeresbodenverhältnisse schliessen, die das Auftreten einer diversen benthischen Fauna verhinderten. *Entolium* wird als charakteristisch für dysaerobe Milieus angesehen. Die überlieferten Ansammlungen von *Entolium*-Schalen bildeten sich wahrscheinlich in einem dysaeroben Milieu unterhalb der Sturmwellenbasis. Taphonomische Prozesse begünstigten die differenzierte Erhaltung der kalzitischen *Entolium*, was zu ihrer Konzentration beitrug. Die *Entolium*-Konzentrationen wurden in einer Zeit des globalen Meeresspiegelanstiegs oder Höchststands abgelagert. Sie werden somit als hiatale Schalenkonzentrationen angesehen.

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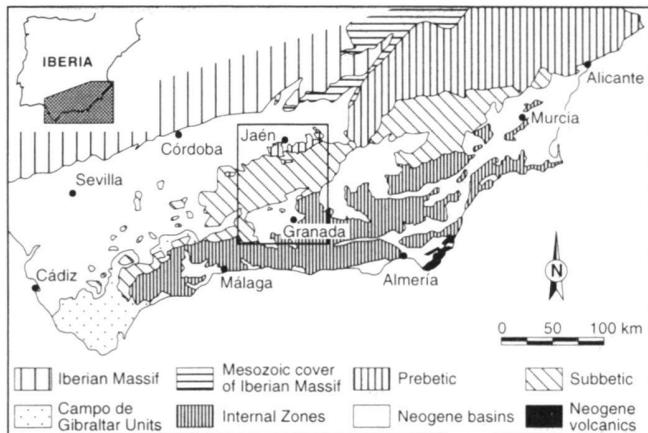


Fig. 1. Geological map of Betic Cordillera. Simplified from Foucault (1974). Inset shows area in Figure 2.

Introduction

Pectinids are common in fossil bivalve assemblages due to the high preservation potential conferred by the mostly calcitic nature of their shells. Members of this family are adapted to a broad spectrum of marine habitats and life habits, but most are free-living epibenthic organisms with diverse capacities for swimming. Pectinids of the *Entolium* group are suited for free-swimming (Gould 1971; Carter 1972; Johnson 1984) and *Entolium* itself, a Mesozoic genus, is supposed to be the first free-swimmer possessing a thin shell of foliated calcite as an advantageous innovation with respect to the prismatic shells of Palaeozoic pectinids (Waller 1972). Additional adaptations to swimming in *Entolium* are its smooth, sub-orbicular, low convexity valves (Johnson 1984). After the appearance of the genus in the Middle Triassic (Johnson 1984), the Early Jurassic *E. lunare* (Roemer) had a widespread palaeobiogeographical distribution recorded in open marine sediments from many localities from the Sinemurian on (Johnson 1984). This cosmopolitan distribution contrasts sharply with the strong provinciality of other swimming marine invertebrates such as ammonoids during the Jurassic.

Entolium constitutes, together with *Bositra* and other pectinaceans such as *Propeamuseum* and *Camptonectes*, the so-called “flat-clams” that are considered to be the dominant free-lying species on oxygen-controlled bottoms during the Mesozoic (Kauffman & Sageman 1990; Aberhan 1994). These flat-clams would have prevailed on dysaerobic, fine-grained substrates on which they lived with a “snowshoe” strategy: i.e. the thin, flat shells were able to lie on the soft bottom without sinking into the sediment (Carter 1972; Thayer 1975).

However, shell concentrations or high relative abundance of *Entolium* in fossil assemblages have also been recorded from a wide range of palaeoenvironments. They have been re-

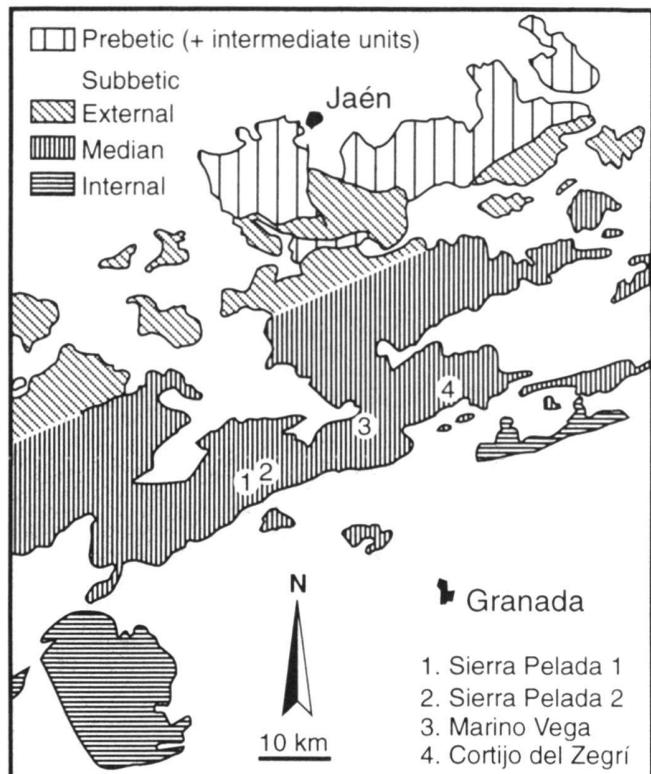


Fig. 2. Outcrops of Jurassic and Cretaceous rocks from External Zones in central sector of Betic Cordillera (Granada transverse) and distribution of Subbetic subdomains (from Azema et al. 1979). Sections studied are aligned N65E in southern half of Median Subbetic.

ported from shallow-water coarse-grained substrates to fine-grained sediments from the middle to outer shelf at different Mesozoic stages from European and American localities (Fürsich 1984; Aberhan 1992, 1994). Sometimes this pectinid constitutes monospecific assemblages in beds extending for hundreds of square kilometres, as in the Cenomanian from the USA Western Interior. These assemblages are supposed to be controlled by the oxygen levels at sea bottom and, as such, are considered to be indicators of dysaerobic benthic environments (Sageman 1989).

Until now, *Entolium* concentrations in the fossil record have been interpreted as the result of peculiar palaeoecological conditions favouring the proliferation of the genus representatives. We describe here *Entolium* shell concentrations from the Lower Jurassic from southern Spain that formed by selective taphonomic processes in sediment-starved depositional settings. Biostratinomic processes led to fossil assemblages entirely dominated by *E. lunare*. However, these processes probably simply enhanced the relative abundance of the species in a palaeocommunity already dominated by this taxon.

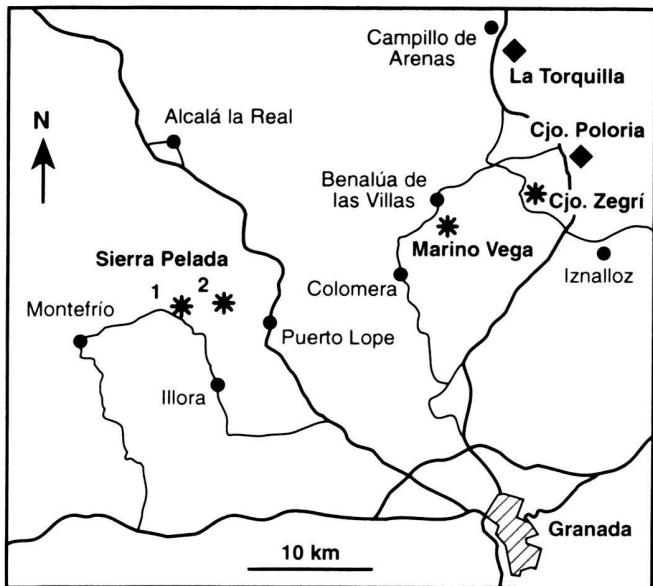


Fig. 3. Geographical location of sections studied and referred to in text.

Regional setting

The *Entolium* shell concentrations studied crop out in Granada province (southern Spain) along a N65E-trending belt in the Subbetic Zone, one of the palaeogeographic domains of the External Zones of the Betic Cordillera (Fig. 1, 2, 3). The External Zones represent the Mesozoic southern continental margin of the Iberian Massif. This margin was subdivided by rifting into different domains (García-Hernández et al. 1980; Vera 1988), of which two main zones have traditionally been recognised: The Prebetic constitutes the external domain where continental and shallow-marine sedimentation prevailed during the Mesozoic while the Subbetic, to the south, was a pelagic basin after the Early Jurassic (Fig. 1). In this latter zone individual blocks caused by rifting followed diverse sedimentary evolutions (Vera 1988), according to which the Subbetic is divided into subdomains. In the Granada transverse, in the central sector of the Betic Cordillera, three subdomains have been recognised from north to south: the External, Median and Internal Subbetic (García-Dueñas 1967) (Fig. 2).

The area where the study sections are located belongs to the Median Subbetic (Fig. 2, 3). Sequences in this subdomain record a change from continental and shallow platform environments that predominated during the Triassic and earliest Jurassic to pelagic, deep-water sedimentary settings from the Pliensbachian on (Rivas 1972; García-Hernández et al. 1976). During the early Pliensbachian (middle Carixian) the study area, in the central part of the Median Subbetic, was a shallow-

water bank affected by tides and storms, on which bioclastic carbonates, mostly crinoidal limestones, were deposited (Dabrio & Polo 1985). The *Entolium* beds overlie these crinoidal limestones at the vertical transition from shallow-platform to basin deposits.

Apart from these shell concentrations, *Entolium* are also found as minor components in fossil assemblages from many localities and ages in Jurassic and Cretaceous pelagic sediments from the Betic Cordillera.

Chronostratigraphy

Biogeographic traits of the Lower Jurassic ammonite faunas from the Mediterranean region have traditionally led to the use in the Betic Cordillera of (bio)chronostratigraphic units different from those in central and western Europe. For this reason, the Pliensbachian stage of the standard chronostratigraphic scale is substituted in southern Spain by the Carixian and Domerian stages, the limits and zones of which are based upon Mediterranean ammonite successions. However, comparisons of ammonite biostratigraphy from the European and Mediterranean realms allow accurate correlations to be established between the two chronostratigraphic scales. The Carixian and Domerian can be correlated with the early and late Pliensbachian respectively (Braga et al. 1982). The upper Carixian (Dilectum Zone) in the Betic Cordillera is equivalent to the Davoei Zone and the lower Domerian correlates with the Stokesi Zone (or the Stokesi Subzone of the Margaritatus Zone) of the late Pliensbachian defined in central Europe and the British Isles (Braga et al. 1982, 1984).

Taxonomy

Entolium is an almost equivalve and equilateral bivalve (Pectinacea, Pectinidae) with suborbicular, nearly completely smooth valves. Only one species, *E. orbiculare* (J. Sowerby), shows a concentric sculpture of commarginal grooves. The small and almost symmetrical auricles of the right valve are projected above the hinge (Johnson 1984). Rivas (1975) attributed the *Entolium* specimens from some Subbetic localities to *E. strionatis* (Quenstedt), following the diagnostic criteria of Sacchi-Vialli & Cantaluppi (1967). However, in his revision of the Mesozoic species of the genus, Johnson (1984) demonstrated that Quenstedt's type material of *E. strionatis* should be ascribed to *Camptonectes subulatus* (Münster), which shows a slight striation of the shell. Well-preserved samples of *Entolium* from the Sierra Pelada and Cortijo del Zegri sections show no sculpture or striation either on the inner or outer sides of the valves, except for growth lines (Fig. 4A). This, together with the presence of a slight byssal notch below the anterior auricle of the right valve is characteristic of *Entolium lunare* (Roemer), according to the diagnosis of Johnson (1984).

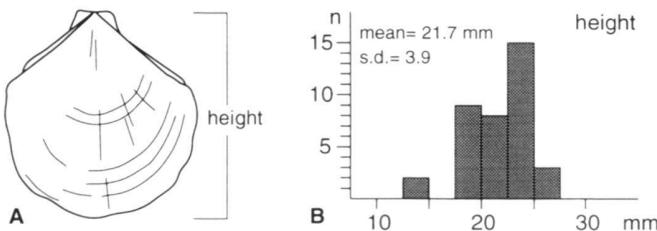


Fig. 4A. Sketch of *Entolium lunare* valve from Sierra Pelada 2. B. Height value distribution, mean and standard deviation (s.d.) for samples from Sierra Pelada 2 section.

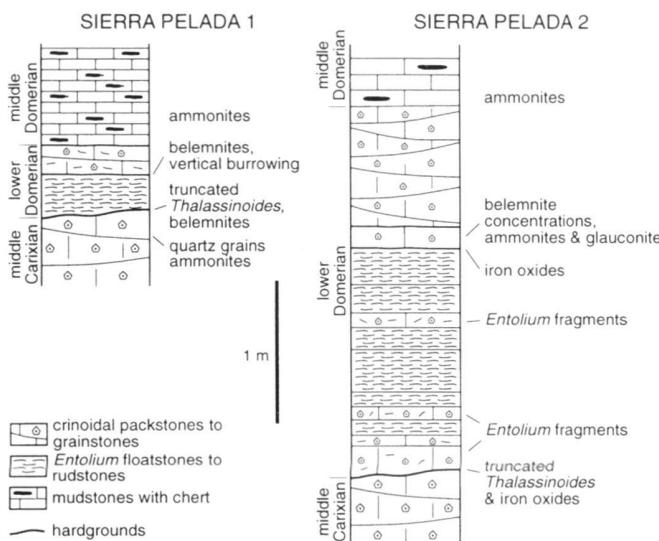


Fig. 5A. Sierra Pelada 1 stratigraphic section. B. Sierra Pelada 2 stratigraphic section.

Sections

Sierra Pelada 1

This section is located at the southwestern margin of Sierra Pelada, 200 m from the road from Illora to Montefrío (Fig. 3).

The *Entolium* beds overlie middle Carixian crinoidal limestones with quartz grains in their uppermost part (Rivas 1972; García-Hernández et al. 1976). The top surface of these limestones is an irregularly scoured hardground with truncated *Thalassinoides*, corroded belemnites, gastropods, brachiopods, small oysters and phosphatic and silicified ammonite moulds (*Tropidoceras* sp.) (Fig. 5A). The *Entolium* beds consist of bivalve floatstones to rudstones, up to 30 cm in thickness, followed by 25 cm thick crinoidal packstones with dispersed fragments of *Entolium*. Bivalve shells in the lower half of the floatstones-rudstones are mostly disarticulated and oriented parallel to the bedding, whereas in the upper half the shells, including occasional belemnites, are arranged steeply oblique to perpendicular in burrows up to 5 cm in diameter. The crinoidal

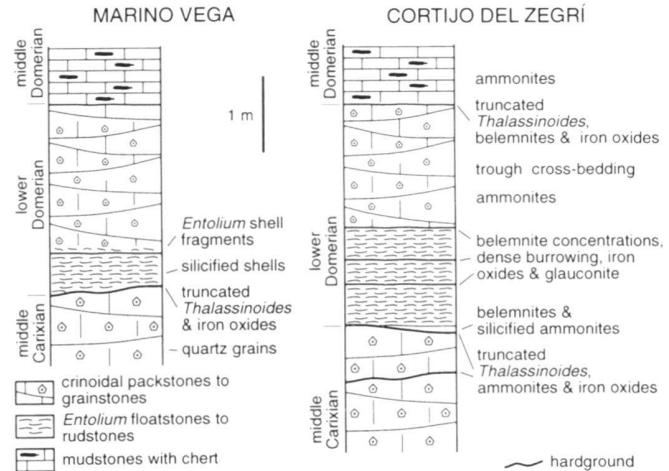


Fig. 6A. Marino Vega stratigraphic section. B. Cortijo del Zegri stratigraphic section.

packstones are overlain by marly limestones with chert nodules containing ammonites (*Arieticeras algovianum* (Oppel) from the middle Domerian (Fig. 5A).

Sierra Pelada 2

This section is located 2.4 km to the northeast of the previous one on the southern side of Sierra Pelada (Fig. 3).

The *Entolium* beds, 165 cm in thickness, lie on a yellowish hardground that developed over middle Carixian crinoidal limestones. Beds of crinoidal packstones, 10–30 cm thick, with dispersed fragments of *Entolium* alternate with *Entolium* floatstones to rudstones of similar thickness (Fig. 5B). In the latter, bivalve shells are disarticulated, parallel to the bedding or arranged steeply oblique to perpendicular in burrows. The top of the unit is a hardground overlain by a 15 cm thick burrowed crinoidal packstone. Higher up in the section crinoidal packstones gradually pass into marly limestones with chert and ammonites from the middle Domerian (*A. algovianum*) (Fig. 5B).

Marino Vega

This section (Fig. 6A) crops out 2.5 km to the south of Benalúa de las Villas, 100 m to the north of the track to the Cortijo Marino Vega (Fig. 3).

Entolium floatstones to rudstones, up to 50 cm thick, overlie the hardground that developed on top of middle Carixian crinoidal limestones rich in quartz grains (Rivas 1975). The shells are densely packed, mostly disarticulated and concordant. Rearrangement by bioturbation is scarce. Some *Entolium* shells are affected by silicification that tends to concentrate in laminae parallel to bedding. *Entolium* fragments are dispersed in the lowest 10 cm of the subsequent crinoidal packstones, up to 2 m in thickness, that change upwards into marly mudstones (Fig. 6A).

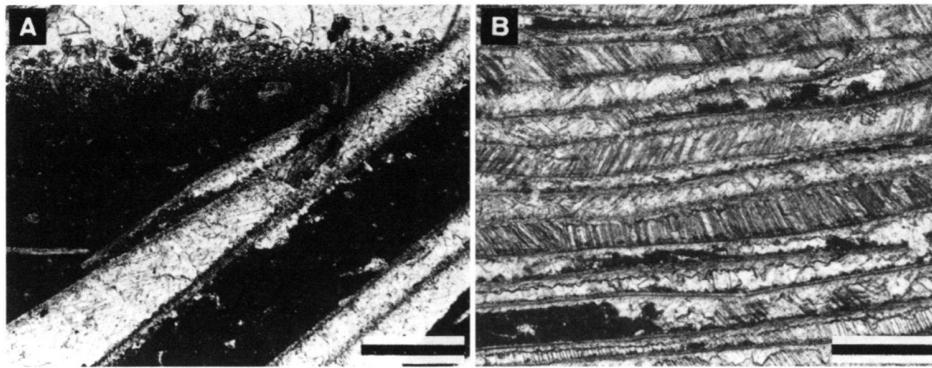


Fig. 7A. *Entolium* floatstone. Steeply oblique unbroken valves. Note inter- and intraskeletal voids partially filled with micrite and occluded by sparry calcite cements. Sample Pl. 2, Sierra Pelada 1. Scale bar = 500 µm. B. *Entolium* rudstone. Concordant (parallel to bedding) valves. Micrite infillings very scarce. Inter- and intraskeletal voids mostly filled with sparry calcite. Sample Zn. 2, Cortijo del Zegrí. Scale bar = 500 µm.

Cortijo del Zegrí

This section (Fig. 6B) is located 200 m to the southeast of the Cortijo del Zegrí, a farmhouse on the northern side of the Sierra de las Cabras (Fig. 3).

The *Entolium* beds overlie middle Carixian crinoidal limestones. Some silicified lower Domerian ammonites (*Fuciniceras* sp.) occur on the ferruginous hardground on top of these limestones. They are concentrated, together with corroded belemnites, in patches of silicified bioclastic grainstones preserved in the surface scours or in the horizontal galleries of truncated *Thalassinoides*. The *Entolium* beds consist of floatstones to rudstones, up to 120 cm thick, of densely packed, mainly disarticulated *Entolium* valves. Most valves are parallel to the bedding but oblique orientations, related to burrows, can also be observed. Hardgrounds with conspicuous bioturbation, belemnites, iron oxides and glauconite concentrations occur in the middle and top of the *Entolium* beds. These beds are overlain by up to 4 m of crinoidal packstones to grainstones with trough cross-bedding and ripples ending in a hardground with ammonites (*Lytoceras* sp.) and belemnites, and are followed by marly limestones with chert containing middle Domerian ammonites (*Arieticeras* sp.).

Facies and their taphonomic attributes

Entolium floatstone

This consists of loosely-packed, poorly sorted, mostly disarticulated *Entolium* valves with no preferred orientation in a micritic matrix. Shells constitute 15–20% of rock volume. Shell fragmentation is low: always less than 50% of valves are fragmented. Small benthic foraminifers (nodosariids), ostracods and crinoid fragments are also dispersed in the matrix. Locally, fragmented *Entolium* shells concentrate, together with crinoid fragments and foraminifers, in pods caused by bioturbation. The shells in the pods are reoriented and tend to be imbricate, steeply oblique to subvertical (Fig. 7A).

Most shells are recrystallised. Intraskeletal voids and shelter cavities left below some bivalve shells are totally or partially filled with micrite. The remaining spaces are fringed with sparry calcite cement and filled with blocky sparry calcite (Fig. 7A).

Entolium rudstone

This is made up of densely-packed, poorly-sorted, stacked shells that constitute more than 55% of rock volume. Shells show a preferred concordant (parallel to bedding) orientation although they have been locally reoriented by bioturbation (Fig. 7B). Shells in *Thalassinoides*-like burrows are steeply oblique to subvertical.

The abundant interskeletal shelter cavities and the intraskeletal ones were partially filled by several generations of micrite. The remaining voids were fringed by spar, dog-tooth calcite cement and filled by blocky calcite (Fig. 7B).

The *Entolium* rudstones alternate with mm-thick laminae or small lenses of *Entolium* floatstone and crinoid-foraminifer packstone-grainstone. A significant proportion of *Entolium* shells are broken by compaction. Shell fragments at the contact with crinoid-rich lenses are adapted to crinoid grains which are more resistant to compaction (Fig. 8A).

Entolium packstone

This facies consists of densely-packed, well-sorted fragments of *E. lunare* shells, crinoids, ostracods, foraminifers (nodosariids and ammodiscids) and sponge spiculae in a micritic matrix (Fig. 8B). Skeletal particles account for at least 40% of rock volume. Some fragments of molluses other than *Entolium* can also be found. Small interskeletal and intraskeletal voids are filled by blocky calcite.

The *Entolium* packstones occur as small, “centimetre-scale” lenses within *Entolium* floatstones or form laterally more continuous laminae intercalated with other *Entolium* facies.

Crinoid/foraminifer packstone to wackestone

This facies, which forms laminae, lenses and sometimes beds intercalated in the *Entolium* rudstones, becomes predominant at the top of the *Entolium* beds. Crinoid fragments, small benthic foraminifers (nodosariids, ammodiscids and textulariids), ostracods and brachiopod and gastropod fragments are surrounded by a micritic matrix (Fig. 9A). *Entolium* shell frag-

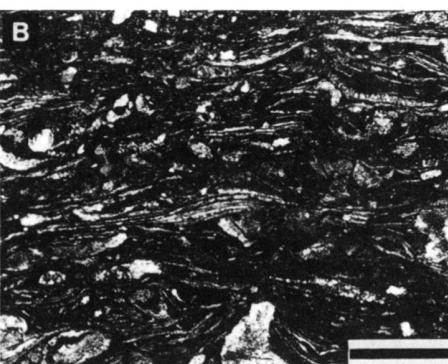
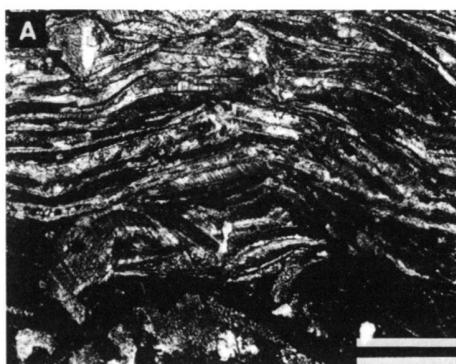


Fig. 8A. *Entolium* rudstone (upper half) and floatstone. *Entolium* valves broken by compaction adapt to more resistant crinoid fragments (bottom). Sample Zn. 7. Cortijo del Zegrí. Scale bar = 500 µm. B. *Entolium* packstone. Fragments of *Entolium* valves together with crinoid ossicles in a micritic matrix. Sample Zn. 2. Cortijo del Zegrí. Scale bar = 500 µm.

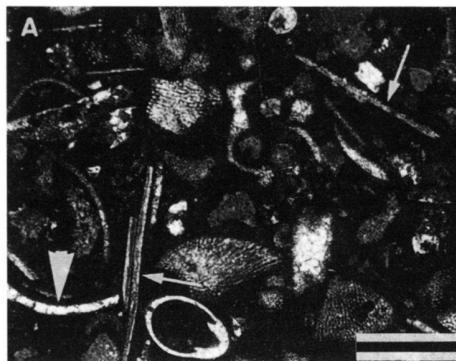


Fig. 9A. Crinoid-foraminifer packstone. Fragments of crinoids, benthic foraminifers (bottom center), *Entolium* fragments (arrows), and molluscs other than *Entolium* (arrowhead) in a micritic matrix. Sample Zn. 9. Cortijo del Zegrí. Scale bar = 500 µm. B. Crinoid grainstone. Crinoid fragments and some benthic foraminifers (arrow) cemented by syntaxial calcite growing from crinoid ossicles. Sample Zn. 22. Cortijo del Zegrí. Scale bar = 500 µm.

ments are dispersed and constitute less than 5% of the volume. A green silicate mineral, probably glauconite, and iron oxides are sometimes dispersed in the micrite.

Crinoid grainstone

Crinoid grainstones occur in some lenses and laminae included in the *Entolium* rudstones but reach their highest development in the trough cross-bedded limestones in the Cortijo del Zegrí section. There, they consist of well-sorted crinoid fragments together with some *Entolium* shell fragments, gastropods, ammonites, bivalves other than *Entolium*, brachiopods, small benthic foraminifers (*Involutina liassica* Jones, nodosariids and ammoniscids) and quartz grains. Syntaxial calcite cements grew around crinoid fragments (Fig. 9B).

Discussion

Taphonomy

Taphonomical attributes of *Entolium* rudstones and floatstones indicate that shells accumulated in quiet conditions with almost no sedimentation other than the biogenic. The relatively low degree of fragmentation of the delicate *Entolium* shells and the preferentially concordant (parallel to bedding) orientation (Fig. 7B) of valves point to very low hydraulic turbulence.

Steep oblique shell orientations, concentrated in burrows, were caused by bioturbation that may also have been responsible for most of the valve fragmentation prior to compaction. This may be the origin of the small lenses of *Entolium* packstones dispersed among *Entolium* floatstones.

Micrite deposition was very low when the rudstones formed. Micrite percolated down shell accumulations, partially filling the cavities between the valves but leaving most of the space empty (Fig. 7B). Two to three generations of micrite filling can be recognised in some cavities. Bioturbation probably contributed to micrite percolation by moving the shells. In fact, some floatstone patches, richer in micrite than the surrounding facies, are concentrated at the base of vertical burrows. Other *Entolium* floatstones formed by dilution of shells under locally higher micrite input.

The low sedimentation rate is presumably responsible for the scarcity of aragonite shells or molds of aragonitic skeletons. Long residence times of shells on the sea-floor or in the upper centimetres of the sediment, which was mainly a porous skeletal accumulation should have promoted differential (or selective) aragonite dissolution (Brett & Baird 1986; Powell et al. 1989). Most fossil remains are calcitic skeletons such as *Entolium* valves, belemnites, small benthic foraminifers and crinoid segments and spicules of siliceous sponges now replaced by calcite. The latter, easily dissolved before burial in shallow-water settings, dissolve much more slowly with decreasing tem-

perature as depth increases (Parsons & Brett 1991). Ammonites which are common in underlying and overlying deposits are absent in these facies and only very few fragments of aragonitic bivalve shells, now replaced by sparry calcite, can be found. Long preburial residence times may also be responsible for the high degree of disarticulation of *Entolium* shells (Brett & Baird 1986), as well as for that of crinoid skeletons included in the *Entolium* rudstones or floatstones as aggregates of separate ossicles concentrated in lenses parallel to bedding.

The above-mentioned taphonomic attributes indicate that *Entolium* shell concentrations formed on the underlying hard-ground surface in quiet conditions below storm wave base, since no signs of hydraulic turbulence can be recognised in these facies, except for the thin laminae of *Entolium* packstones. These laminae of broken, well-sorted bivalve shells mixed up with other bioclasts indicate hydraulic reworking and transport, and may represent distal tempestites (Fig. 8B).

Sediment starvation is especially remarkable in the shell rudstones. Micrite and clay supply was too low to dilute the shells that accumulated on the bottom and the interskeletal voids were only partially filled by fine-grained sediment (Fig. 7B). Part of the micrite may even be the product of bioerosion of accumulated bioclasts, as some were affected by microboring. The low sedimentation rate also promoted the formation of glauconite and iron oxides dispersed in the *Entolium* accumulations, and sometimes concentrated together with belemnites in well-defined horizons that can be interpreted as hiatal surfaces.

In all sections the *Entolium* concentrations are overlain by crinoid packstones and grainstones. Taphonomic and sedimentological features of these facies indicate hydraulic transport and reworking. Bioclasts, mainly poorly-classified crinoid segments, are incorporated into trough cross-beds and ripples. *Entolium* shells occur fragmented and dispersed within these deposits, together with benthic foraminifers, gastropods and ammonites (Fig. 9A, B). Preservation of originally aragonitic shells (gastropods and ammonites), now replaced by calcite, is probably promoted by rapid burial. These characteristics indicate that the crinoidal grainstones and packstones formed under the influence of storms at settings shallower than those of the *Entolium* concentrations.

The beginning of the marly pelagic sedimentation on top of the crinoid facies represents a later deepening of the sedimentary environment together with the start of terrigenous influx in the area.

The alternation of *Entolium* concentrations and crinoid packstones in the lower part of the Sierra Pelada 2 section may be the result of an intermediate palaeoenvironmental setting of this section at the transition between the shallower areas with crinoidal grainstone deposition, and the deeper ones where *Entolium* accumulations formed. This also indicates that differences in bathymetry between the two facies were relatively small. Afterwards, this section followed a sedimentary evolution similar to the rest of the sections, with a shallower interval of crinoidal limestone deposition succeeded by deeper-water marly sedimentation.

Palaeoecology

According to Stanley (1972) the members of the *Entolium* group (family Entolidae Korobkov, included in the family Pectinidae by Waller 1978), which appeared in the Late Palaeozoic, were the only swimming bivalves until the Early Jurassic. The byssal notch in *E. lunare* suggests a juvenile stage of benthic sessile life before becoming a free swimmer in adult stages. Its thin, smooth valves of sub-orbicular shape and low-convexity indicate *E. lunare* had a high swimming capacity (Kauffman 1969; Gould 1971; Stanley 1970, 1972; Johnson 1984). Carter (1972) considered the free-swimming bivalves to be relatively independent of the substrate for feeding and reproduction, but both present-day and fossil swimmers show a preference for fine-grained substrates in relatively deep-water settings (Kauffman 1969; Gould 1971; Stanley 1972; Hayami 1991; Aguirre et al., 1996).

According to Johnson (1984), *E. lunare* tends to occur in iron oolites and sandstones, in contrast to the similar, coeval species *Campstonectes subulatus*, (Münster) which is related to argillaceous and probably more turbid substrates. *E. corneolum* (Young & Bird) a species that succeeded *E. lunare* with a very similar morphology, is the dominant species of the free-living epifaunal guild of late Early Jurassic benthic communities both in coarse-grained shallow shelf and in mid- and outer-shelf environments (Aberhan 1994). *E. corneolum*, together with other "flat clams" (Kauffman & Sageman 1990) is also abundant in the late Early Jurassic oxygen-controlled, dysaerobic environments (Aberhan 1994).

The average size of *Entolium* in the studied sections (Fig. 4B) is significantly smaller than the size of samples described by Johnson (1984) from shallow-water, coarse-grained iron-stone and sandstone substrates, which may be up to 116 mm in height. Although no population data are available from the localities referred to by Johnson (1984), the small size of the Subbetic examples might point to unfavourable conditions for growth of *E. lunare* individuals on the bottoms of the study area.

The absence or scarcity of benthic organisms with calcitic skeletons, such as brachiopods, echinoids and foraminifers in the *Entolium* floatstones and rudstones cannot be explained by selective dissolution or differential preservation of their shells as in the case of other bivalves, ammonites, and gastropods. This absence points to unfavourable conditions on the sea bottom for the development of a diverse benthic community. The predominance of *Entolium* may indicate a dysaerobic palaeoenvironment according to Aberhan (1994), which may also be responsible for the small size of the individuals. Such dysaerobic conditions probably prevailed in quiet waters below storm wave base in the study area. The shelly, very coarse substrate offered by the *Entolium* accumulations presumably inhibited the presence of endosedimentary organisms which were not already excluded from this habitat by the low oxygen levels. Dysaerobic conditions may also be responsible for the absence of epibionts on the *Entolium* shells, whose

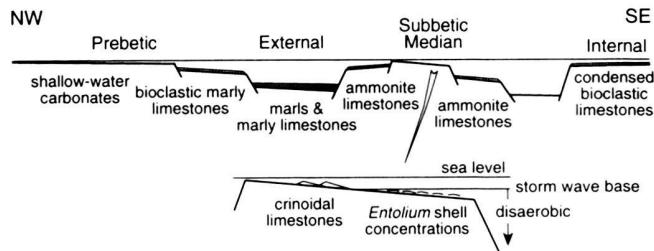


Fig. 10. Palaeogeographical sketch for Prebetic and Subbetic domains in the Granada transverse during early Domerian. Pelitic sediments were trapped in the External-Subbetic trough while diverse biogenic condensed limestones or hardgrounds formed to the south. *Entolium* concentrations formed below storm-wave base in the southern half of the Median Subbetic bank.

presence would have been promoted by the long residence time of valves on a sea bottom with low sedimentary input.

Regional context

According to Dabrio & Polo (1985), the underlying middle Carixian crinoidal limestones in the central sector of the Median Subbetic formed on a shallow isolated bank affected by storms and tides. This bank probably continued to exist at the time of deposition of the *Entolium* beds but was deeper, at least in its southern part (Fig. 10). Coeval lower Domerian deposits to the north, in the External Subbetic subdomain, consist of a few metres of alternating marly limestones and marls (Braga 1983). This subdomain constituted a trough where the small amounts of terrigenous influx from the emerged land (the Iberian Massif to the north) were trapped (Fig. 10). The shallower bank areas of the Median Subbetic to the south were starved and only different types of biogenic sediments formed, or there was no deposition at all, resulting in hardground hialt surfaces. At localities in the northern part of the Median Subbetic, such as La Torquilla (Fig. 3), lower Domerian deposits consist of wackestones to floatstones rich in ammonites and bivalves, including *Entolium*. In other sections of the subdomain, such as Cortijo de Poloria (Fig. 3), the lower Domerian is represented by crinoidal packstones to grainstones. The *Entolium* concentrations are distributed in localities in the southern half of the Median Subbetic bank (Fig. 10). Final deepening of the subdomain at the beginning of the middle Domerian and a general increase of the terrigenous influx resulted in widespread deposition of pelagic marls and marly limestones and turbidites which continued for the rest of the Mesozoic in the Median Subbetic.

Global context

The *Entolium* beds overlie a hardground surface on top of middle Carixian crinoidal limestones. In the Cortijo del Zegrí section, patches of silicified shells on the hardground and below the *Entolium* concentrations contain lower Domerian

ammonites. Middle Domerian ammonites occur in the marly limestones with chert that overlie the *Entolium* beds in the four sections. From these data, we assume that the *Entolium* beds are broadly coeval and early Domerian in age, but an older late Carixian age for part of the *Entolium* beds in sections Sierra Pelada 1 and 2 and Marino Vega cannot be discounted. In the Torquilla section, ammonite limestones rich in *Entolium* shells can also be dated as early Domerian (Braga 1983). As mentioned above, the lower Domerian in the Betic Cordillera can be correlated to the Stokesi Zone (or Subzone) of the late Pliensbachian of the standard chronostratigraphic scale. A phase of eustatic sea-level rise is recorded in the time interval of the Stokesi Zone from the coastal onlapping in the Atlantic (cycle UAB 4.1 of Haq et al. 1987). Graciansky et al. (1993) report a peak of transgression within the early Domerian (Stokesi Subzone) in the southern Subalpine Jurassic basin in the Dauphinois (France) and a rising sea-level is also recorded in the lower Domerian from Aquitaine (France) Brunel et al. 1995).

According to the accepted correlations, it seems that deposition of the *Entolium* beds took place in a time of global sea-level rise and, therefore, the *Entolium* beds may represent hialt shell concentrations in the sense of Kidwell (1991), promoted by sediment starvation related to ascending or high sea level. They are a peculiar type of condensed section (sensu Van Wagoner et al. 1988) in pelagic, deep-water facies of the Mediterranean Mesozoic.

Summary

Entolium shell concentrations occur in the southern part of the Median Subbetic (Betic Cordillera) (Fig. 1, 2) at the transition between shallow-water carbonate deposition and pelagic marly sedimentation in the Early Jurassic (late Carixian? – early Domerian).

Entolium rudstones and floatstones which show no sign of hydraulic reworking (Fig. 7, 8A) formed below storm-wave base in a sediment-starved setting. Bioturbation is presumably responsible for valve disarticulation and the low degree of shell fragmentation. Long residence times on the sea floor due to the low sedimentation rates probably promoted the selective dissolution and destruction of aragonite skeletons which occur in underlying and overlying deposits.

Trough cross-bedded, crinoid packstones to grainstones with *Entolium* fragments, intercalate with and mainly overlie the *Entolium* floatstones and rudstones. These facies were probably deposited in shallower settings affected by storms.

All these deposits formed on the southern part of a bank separated from the Iberian Massif mainland by a trough in which the scarce pelitic input was trapped (Fig. 10).

The small average size of *E. lunare* shells (Fig. 4) indicates unfavourable conditions for the growth of individuals. This, together with the absence of remains of other benthic organisms with calcitic skeletons that should not be affected by differential preservation, points to anomalous sea-bottom conditions

that inhibited the development of a diverse benthic community. The *Entolium* concentrations studied probably reflect a dysaerobic environment below storm-wave base. Taphonomic processes favoured differential preservation of the calcitic *E. lunare* valves, thus enhancing their concentration.

The *Entolium* beds formed at a time of global rising or high sea level. They can be considered as a peculiar type of hiatus shell concentration associated with transgressive or highstand regimes.

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