OLISTOLITHS FROM THE MIDDLE JURASSIC IN CRETACEOUS MATERIALS OF THE FARDES FORMATION. BIOSTRATIGRAPHY (SUBBETIC ZONE, BETIC CORDILLERA)

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ABSTRACT

The Middle Jurassic olistoliths studied are found within Cretaceous materials of the south-eastern part of the Montes Orientales region (province of Granada, Betic Cordillera), specifically in the Río Fardes sector. The cretaceous materials are here characterized by pelagic and hemipelagic facies with abundant turbidite and olistostrome insertions in a deep basin marine environment (Middle Subbetic), bounded to the SE by a pelagic ridge (Internal Subbetic). The transition between the two domains was an area with active paleoslopes which facilitated both the exposure and denudation of Jurassic and Cretaceous materials and the development of a clear synsedimentary tectonics (slumps and olistostromes). Paleocurrents show that the source area of materials forming the thickest beds was located towards the S-SW, though for the thinner beds they are more widely dispersed.

The sections under study have been dated by means of calcareous nannoplankton, planktonic foraminifera and radiolaria. The calcareous nannofossil assemblages enable us to distinguish Sissingh's zones CC-9, CC-10 and CC-13 for the Lower Cenomanian-Coniacian, which in turn determines the position of the Jurassic olistoliths within the sections. The precise age of the materials where the large-sized olistoliths are embedded is Coniacian (Marthasterites furcatus zone of calcareous nannoplankton).

Olistoliths from the Middle Jurassic are often sufficiently exposed and stratified to allow sampling level by level and the establishing of a detailed biostratigraphy. After a study of the ammonite fauna collected in two olistoliths we were able to distinguish the Murchisonae and Concavum zones in the Aalenian, and the Discites, Laeviuscula, Sauzei and Humphriesianum zones in the Bajocian.

In those areas with S-SW paleocurrents Aalenian materials are not found, but the Bajocian materials of some nearby sectors belonging to the Internal Subbetic have a similar lithology and faunal content.

Key words: South-Iberian Paleomargin, Betic Cordillera, Middle Subbetic, Biostratigraphy, Upper Cretaceous, Calcareous Nannoplankton, Planktonic Foraminifera, Radiolaria, Ammonites, Carbonated turbidites, Olisthostromes, Jurassic olistoliths.

RESUMEN

Los olistolitos de edad Jurásico medio estudiados se encuentran englobados en materiales cretácicos de la parte suroriental de la comarca de los Montes Orientales (provincia de Granada, Cordillera Bética), concretamente en el sector del Río Fardes. En este sector, los materiales cretácicos se caracterizan por presentar facies pelágicas y hemipelágicas con abundantes intercalaciones turbidíticas y olistostrómicas, características del depósito en un ámbito marino de cuenca profunda (Subbético medio), limitado al SE por un umbral pelágico (Subbético Interno). La transición entre ambos dominios constituyó un área con paleopendientes activas que permitieron tanto la exposición y desmantelamiento de materiales jurásicos y cretácicos, como el desarrollo de una tectónica sinsedimentaria manifiesta (*slumps* y olistostromas). Las medidas de paleocorrientes indican una procedencia desde el S-SW para los lechos más potentes, si bien los más finos dan valores con mayor dispersión.

Las secciones estudiadas han sido datadas por medio de nannoplancton calcáreo, foraminíferos planctónicos y radiolarios. Las asociaciones de nannoplancton calcáreo permiten diferenciar las zonas CC-9, CC-10, CC-13 de Sissingh, para el Cenomaniense-Coniaciense inferior, lo que permite determinar la posición de los olistolitos jurásicos dentro de la serie. La edad concreta donde están situados los olistolitos de grandes dimensiones se corresponde con el Coniaciense (zona de Marthasterites furcatus de nannoplancton calcáreo).

Los olistolitos de edad Jurásico medio presentan, a veces, exposición y estratificación adecuada para realizar muestreos nivel a nivel y establecer una bioestratigrafía detallada en los mismos. El estudio de las faunas de ammonites recogidas en dos de ellos nos permiten diferenciar las zonas de Murchisonae y Concavum en el Aaleniense y las de Discites, Laeviuscula, Sauzei y Humphriesianum en el Bajociense.

En las áreas de procedencia indicadas por las paleocorrientes (S-SW) no se conocen materiales aalenienses. Sin embargo los materiales bajocienses de algunos sectores próximos pertenecientes al Subbético Interno presentan una litología similar y un contenido faunístico no muy diferente.

Palabras clave: Paleomargen Sudibérico, Cordillera Bética, Subbético Medio, Bioestratigrafia, Cretácico superior, Nannoplancton calcáreo, Foráminíferos planctonicos, Radiolarios, Ammonites, Turbiditas calcáreas, Olistostromas, Olistolitos Jurásicos.

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1. INTRODUCTION

The South-Iberian Paleomargin developed during the Mesozoic under conditions of successive periods of rifting, which took place from the Triassic to the base of the Upper Cretaceous. During the Jurassic this paleomargin was framed in differents paleogeographic domains (Azema et al., 1979; García-Hernández et al., 1980; Vera, 1981). An important period of stretching began at the end of the Neocomian which brought about important changes in the physiography of the paleomargin (Comas and García-Dueñas, 1988). The tectonic reorganization caused in turn the creation of two larger troughs within the Jurassic Middle Subbetic. The northern trough was bounded to the north by the External Subbetic talus, while the southern one is located to the S of the Middle Subbetic Volcanic Crest and to the north of the Internal Subbetic talus; both are bounded by heights in the process of denudation.

In the central sector of the Betic Cordillera the massive gravitating facies (endolistostromes, slumping and debris flow) and the turbidite systems which characterize the sections from the Aptian to the Santonian show that some slopes which bordered on these troughs were fault scarps which exposed the Jurassic and Cretaceous substratum on the sea floor (Comas, 1978).

The Jurassic olistoliths studied here are found among the massive gravitating facies (endolistostromes), associated with carbonate turbidite systems which accumulated in one of these troughs, the southern Subbetic one. The olistoliths are found embedded within Cretaceous materials from the south-eastern part of the Montes Orientales region, Betic Cordillera (province of Granada) namely in the Río Fardes sector (Fig. 1). These Cretaceous materials typically show pélagic and hemipelagic facies with frequent turbidite and olistostrome insertions in a sea deep basin environment (Comas et al., 1982b).

The stratigraphical sections are found in the Fardes Formation, defined for this sector by Comas (1978). This formation can be divided into three members, according to the relative proportion of detritic and pelagic materials which they contain. Member I (lower) is mostly made up of green clays with sporadic turbidite insertions which are not very significant. Member II is characterized by clastic lithologies predominating over the thin hemipelagic detritics, while member III contains alternating layers of calcarenites and calcilutites with clay lithologies where there are only a few weak insertions of conglomerates. Comas (1978) claims that there are stratigraphic gaps within members II and III during the Lower Cenomanian, Turonian, Upper Santonian and Campanian. The presence of clastic facies proves that active slopes existed which caused slips and gravity-produced flows of sediments at different moments and in several sectors (Comas et al., 1982b).

In the External Zones of the Betic Cordillera there are other sectors where large olistoliths of differing ages and lithologies have been identified in Cretaceous materials. In the Intermediate Units (Sanz de Galdeano, 1973; Ruiz-Ortiz, 1980), the Peña de Martos comprises a Jurassic olistolith embedded in the Valanginian-Hauterivian materials. In the Moratalla area Hoedemaeker (1973) described olistostrome levels with large-sized olistoliths of varying age embedded in Upper Cretaceous materials. Comas (1978) also describes other sectors with large blocks embedded in Upper Cretaceous materials in the Montes Orientales region (Southern Middle Subbetic).

The term "olistostrome" refers to a chaotic mass without internal structure nor clear organization at all and which suggests movement in a semifluid state (debris flow). There is no limit to the size of these olistostromes (Abbate et al., 1970). Their constituent elements are called olistoliths. According to Stow (1986) olistostromes and/or debris flow are to be included among turbidite facies of the "debrites" type.

The main aim of the present study is to provide a combined (stratigraphic/paleontological) study of the Middle Jurassic olistoliths embedded in Upper Cretaceous materials. We have also undertaken a specially careful integrated biostraligraphic analysis of the facies in which the olistostromes are embedded. The study gives, then, valuable information about the type of relief

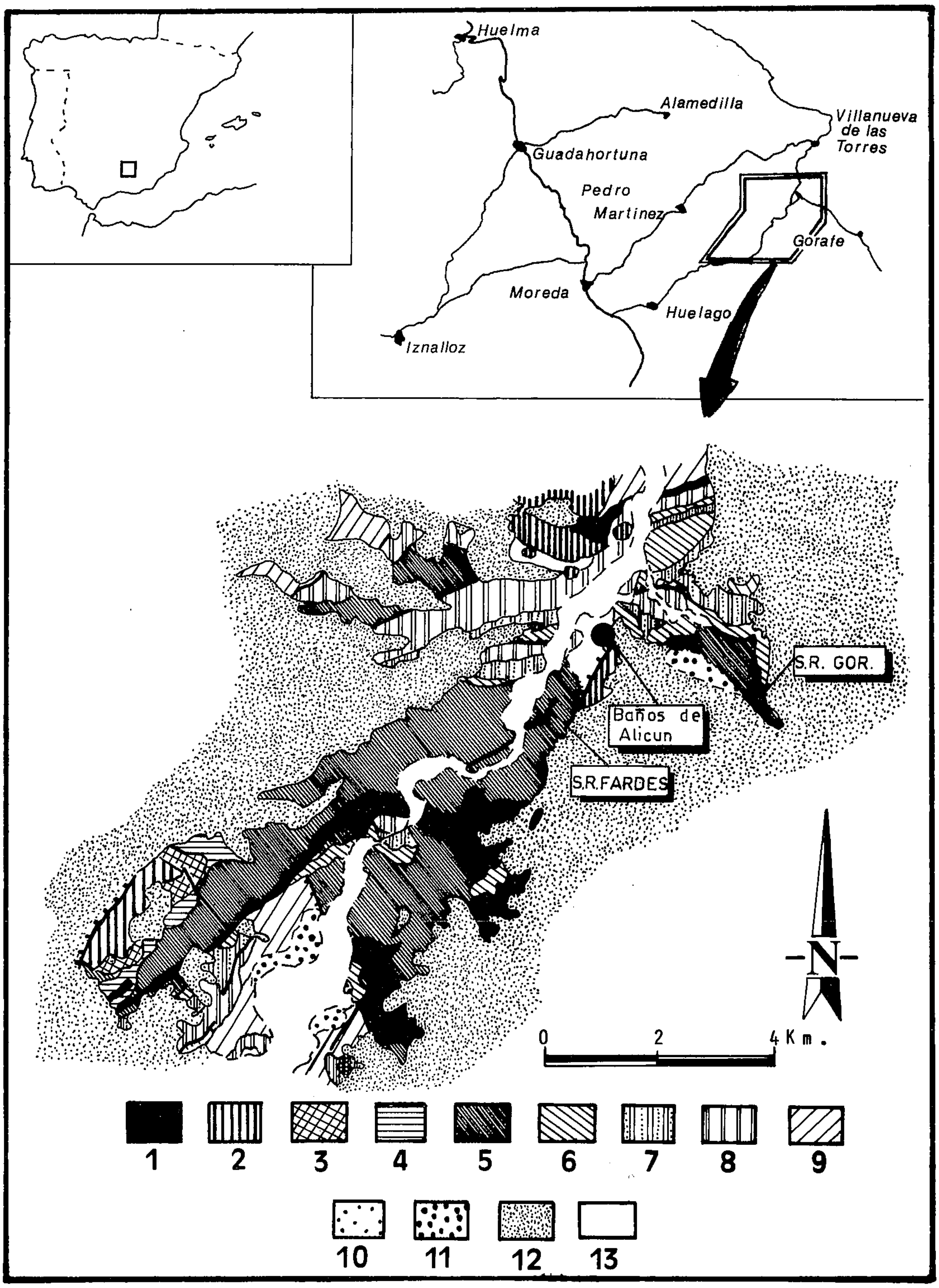


Fig. 1.- Sketch of the geographical and geological setting; 1.- Triassic. 2.- Lower Jurassic. 3.- Middle and Upper Jurassic. 4.- Neocomian, Peñon Formation. 5.- Fardes Formation. 6.- Alamedila Formation. 7.- Olivares Formation. 8.- Encebras Formation. 9.- Cañada Formation. 10.-Doña Marina Formation. 11.- Moreda Formation. 12.- Postorogenic materials; Guadix-Baza basin. 13.- Quaternary materials (After Comas, 1978).

Fig. 1.- Contexto geográfico y geológico y localización de las secuencias; 1.- Triasico. 2.- Jurásico inferior. 3.- Jurásico medio y superior. 4. Neocomiense, Formación Peñón. 5.- Formación Fardes. 6.- Formación Alamedilla. 7.- Formación Olivares. 8.- Formación Encebras. 9.- Formación Cañada. 10.- Formación Doña Marina. 11.-Formación Moreda. 12.- Materiales Postorogénicos; Depresión de Guadix-Baza. 13) Materiales cuaternarios (Tomado de Comas, 1978).

which was broken up on the sea floor.

Methodologically, the following steps were followed: the stratigraphical sections of the Cretaceous and Jurassic blocks were analyzed in detail; paleocurrent measurements were made and the situation and position of the olistoliths within the Cretaceous materials

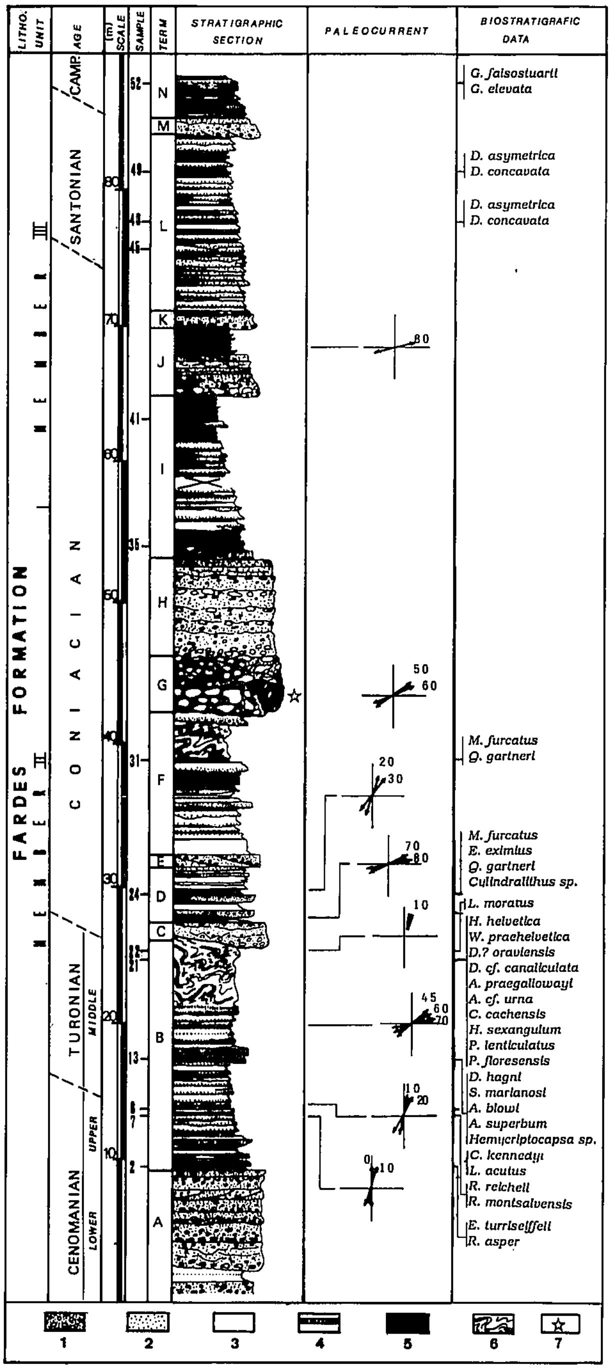


Fig. 2.-Rio Fardes section; 1.- Conglomerate. 2.- Calcarenites. 3.- Calcilutites. 4.- Black cherts. 5.- Argiles. 6.- Slumps. 7.- Olistolith -A- position.

Fig. 2.-Sección del Río Fardes; 1.- Conglomerados. 2.- Calcarenitas. 3.- Calcilutita. 4.-Sílex negro. 5.- Arcillas. 6.- Slumps. 7.- Posición del olistolito -A-.

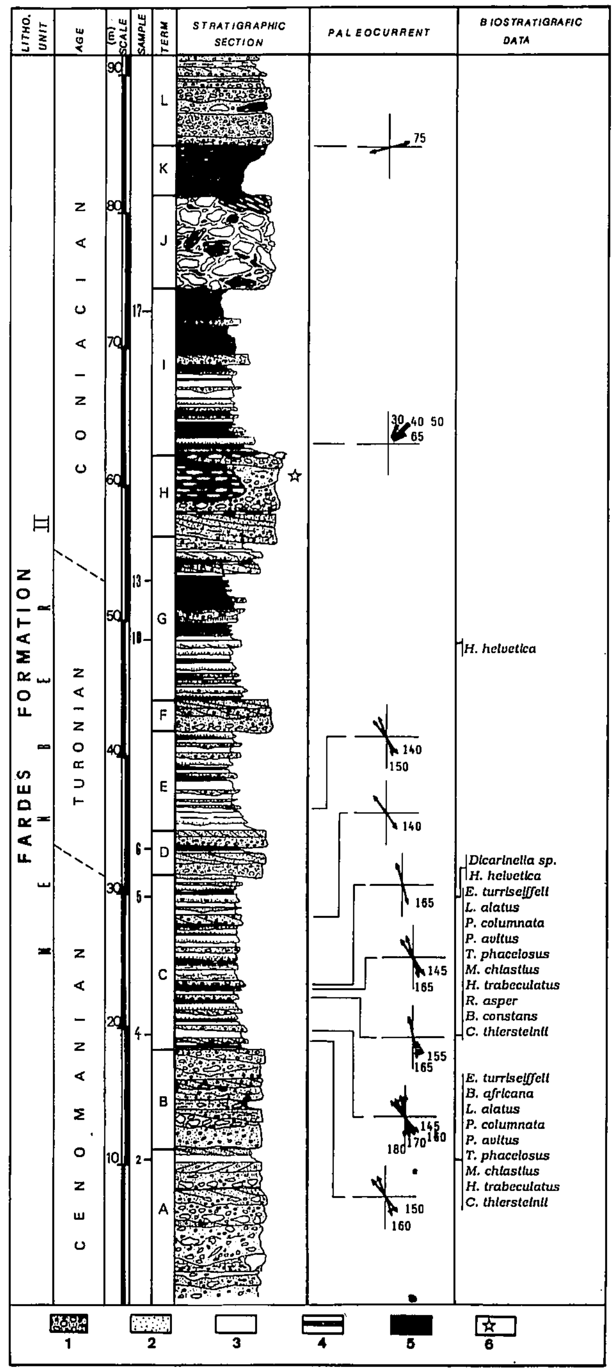


Fig. 3.-Rio Gor section; 1.- Conglomerate. 2.- Calcarenites. 3.- Calcilutites. 4.- Black cherts. 5.- Argiles. 6.- Olistolith -B- position.

Fig. 3.-Sección del Rio Gor; 1.- Conglomerados. 2.- Calcarenitas. 3.- Calcilutitas. 4.- Sílex negro. 5.- Arcillas. 6.- Posición del olistolito -B-.

were studied; we carried out a biostratigraphic study of the Jurassic materials using ammonites, and also of the Cretaceous materials by means of calcareous nannoplankton, planktonic foraminifera and radiolaria.

2. THE STRATIGRAPHICAL CONTEXT

From the Middle Berriasian onwards, the Cretaceous materials typically consist of pelagic and hemipelagic facies, which coexisted with turbidites. These in turn become more and more important from the Lower Cenomanian on and did not disappear until the base of the Campanian, where truly pelagic sedimentation is re-established.

2.1. *Sections studied*

Two sections (Fig. 1) have been studied: A (the Río

Fardes section) and B (the Río Gor section) (Figs. 2 and 3). Both belong to members II and III of the Fardes Formation (Comas, 1978), between the Lower Cenomanian and the base of the Campanian. They contain pelagic and hemipelagic materials which are found together with resedimented ones (turbibidites and olistostromes). Thick clastic sediments predominate over fine grained sedimentation (fine turbidites and hemipelagites).

Member II (Lower Cenomanian - Coniacian) has breccia and conglomerate layers of varying thickness, followed by layers and beds of microbreccias, calcarenites, calcilutites and dark green clays. Olistostrome levels and slumps appear locally (Figs. 2 and 3).

The characteristic feature of Member III (Coniacian-Campanian) is the clear alternance of fine-grained turbidite levels (calcarenites, calcilutites and purple-red clays); amalgamation surfaces are frequent (Fig. 3). A few channelized microbreccia layers also exist, and these are markedly wedge-shaped laterally.

The existing pelagic and hemipelagic sediment layers are dark green and black in colour (purple-red in the Santonian-Campanian), rich in clay minerals (60-90%) and poor in carbonates (less than 5%) (López-Galindo, 1986), and intercalate with turbidites. Radiolarian bearing claystones are also present, though to a lesser extent. Gypsum is abundant either as thin discontinuous layers or, more frequently, spread within very thin silty layers of a yellowish-brown colour. The mineralogical, geochemical and sedimentological features of these materials suggest that this was a restricted sector of the Subbetic Basin, where anoxic sedimentation prevailed (Sebastián-Pardo *et al.*, 1984; López-Galindo, 1986).

In the present study we will concentrate on those layers in which the Middle Jurassic olistoliths are found (Figs. 2, 3 and 8). These occur in turbidite facies of the 'debrites' type (debris flow deposits or olistostromes; Stow, 1986) of Coniacian age, and form a lithostratigraphic unit which is very characteristic in this sector. In both sections there is a great variety of heterometric cobbles in the nodular limestone layers with olistoliths, ranging from centimetric cobbles to large-sized olistoliths, and there is also a considerable variety of lithologies. In these resedimented facies we find a mixture of materials ranging from the Lower Lias to the Upper Cretaceous (Coniacian), an important synsedimentary tectonic activity being thus evident. These sections are exceptionally valuable examples of carbonate turbidites deposited at the base of submarine slopes.

2.1.1. *The Río Fardes section*

It is situated along the road running from Huélago to Villanueva de las Torres, about 1.3 km to the south of the junction to the Alicún de las Torres (Fig. 1). The following terms can be identified (Fig. 2):

A) Wedge-shaped, channelized layers of conglomerates, clearly visible at outcrop scale, and sandstone layers with wide-angle cross bedding. Turbidite facies A (A_1 and A_2) of Mutti and Ricci Lucchi (1972, 1975).
B) Alternance of microbreccias, calcarenites, calcilutites and darkgreen clays, slumped in the upper part. Frequent amalgamation surfaces and insertions of banded black chert, together with very fine grained calcarenites and calcilutites. The main turbidite facies are A_1, D (D_1 and D_2), C_2, F and G.
C) A conglomerate layer with lateral wedging out, fining upward in its lower part and coarsening upward in its upper part. Turbidite Facies A_1.
D) Alternance of thin bedded (10-50 cm) microbreccias, calcarenites, calcilutites and dark green clays. Turbidite facies A_1, C_2 and G.
E) A conglomerate layer with wide-angle cross bedding.
F) Alternance of microbreccias, calcarenites, calcilutites and dark green clays, slumped in its upper part, intercalated with banded black chert together with fine-grained calcarenites and calcilutites. The main turbidite facies are A_1, D (D_1 and D_2), C_2, E, F, and G.
G) An olistostrome level with large-sized olistoliths (12×8 m, see point 5.1). Turbidite facies G.
H) Thick layers of conglomerates (2-2.5 m), fining upward in the lower part and coarsening upward at the top. Turbidite facies A (A_1 and A_2).
I) Alternance of calcarenites, calcilutites and dark green clays, with frequent amalgamations. Turbidite facies C_2, D (D_1, D_2 and sometimes D_3) and G.
J) A fining upward conglomerate with large cobbles (0.5-1m) in its base and internal amalgamations. Above this there are alter nances of calcarenites, calcilutites and dark purple clays. Turbidite facies A_1, C_2, D and G.
K) A layer of conglomerates, fining upward in the lower part and coarsening upward at the top (turbidite facies A_1). Above this layer there is another with wide-angle cross bedding.
L) Alternances of calcarenites, calcilutites and very dark purplish clays; beds with frequent amalgamations. The main turbidite facies are D (D_1 and D_2), C_2, E and G.
M) A bed of fining upward conglomerates with lateral wedging out and a channelized base. Turbidite facies A_1.
N) Alternation of calcarenites, calcilutites and purplish clays with amalgamations. The turbidite facies are D (D_1 and D_2), C_2 and G.

In the Río Fardes section (Fig. 2) the olistolith A is found in the term G (Figs. 2 and 8) in a thick olistostrome level, characterized by its chaotic nature and by the lack of internal structure (Pickering *et al.,* 1986: facies F11; Mutti and Ricci Luchi 1972,1975: facies F). Laterally, and at the same level, large blocks are found (olistoliths up to 10x8 m).

2.1.2. *The Río Gor section*

This section is situated on the right margin of the Río Gor, some 200 m to the north of the road from Gorafe to the Alicún de las Torres (Fig. 1). The following terms have been identified (fig. 3):

A) Conglomerate layers with coarsening upward sequences in the lower part and fining upward at the top (turbidite facies A; A_1 and A_2, of Mutti and Ricci Lucchi, 1972, 1975). In the upper part beds with wide-angle cross bedding are found.
B) Thick beds of conglomerates (turbidite facies A1 and A2) with internal amalgamations and levels with wide-angle cross bedding at the base and narrow-angled at the upper part.
C) Alternance of microbreccia, calcarenites, calcilutites and dark green clays, with frequent amalgamations. The main turbidite facies are B_2, D (D_1, D_2, and sometimes D_3) and G.
D) Two conglomerate beds, fining upward, with wide and narrowangle cross bedding respectively.
E) Alternance of microbreccia, calcarenites, calcilutites and dark green clays with frequent amalgamations. Turbidite facies C_2, D (D_1, D_2 and D_3) and G.
F) A conglomerate level, fining upward at the lower part. At the upper part there are two beds with wide-angle cross bedding.
G) Alternance of microbreccia, calcarenites, calcilutites and dark green clays. Levels with banded black chert together with thin calcarenite and calcilutite levels. The main turbidite facies are C_2, D (D_1, D_2 and D_3) and G.
H) A lower layer with low angle cross bedding, on which a thick conglomerate level (5-6 m) overlays (turbidite facies A_1 and A_2), it is channelized ad autcrop scale, fining upward at the base and coarsening upward at the upper part. Olistoliths of nodular limestones occur (see point 5.1).
I) Alternance of microbreccias, calcarenites, calcilutites and dark green clays. Turbidite facies C_2, D (D_1, D_2 and D_3) and G.
J) A thick olistostrome level (8-10 m), with large-sized cobbles (5-10 m). This level can be correlated with term G of the Río Fardes section. Turbidite facies F.
K) Dark green clays with rounded cobble in the upper part.
L) Levels of conglomerates, fining upward at the base, with locally large-sized cobbles (1-3 m); turbidite facies A_1, A_2 and locally C_2. They are followed by a microbreccia bed with frequent amalgamations and levels with wide-angle cross bedding.

In the Río Gor section, the olistolith (B) is found at the top of a grooved layer of breccia and conglomerates (term H, Figs. 3 and 8). This layer has an erosional base and wedges out at outcrop scale. This thick bed is in general slightly disorganized (turbidite facies of type A11, Pickering *et al.,* 1986, and type A_2, Mutti and Ricci Lucchi, 1972, 1975), although a detailed inspection reveals a certain minimal organization. Irregular fining upward is present, having large protuberant-like cobbles at the top. The nodular limestone olistolith (20x10x10 m) "floats" (Fig. 3) within the conglomerate layer, as a "rigid plug" (Johnson, 1970, Middleton and Hampton, 1976). The matrix is scarce (less than 5‰), and composed of grain-supported debris flows which are normally developed in the furthermost parts of the lower slope (Tucker, 1990). They are very concentrated and very viscous sedimentary dispersions, plastic in nature and frequently found together with large cobbles at the top (Johnson, 1970; Fisher, 1971; Hampton, 1972; Walker, 1975).

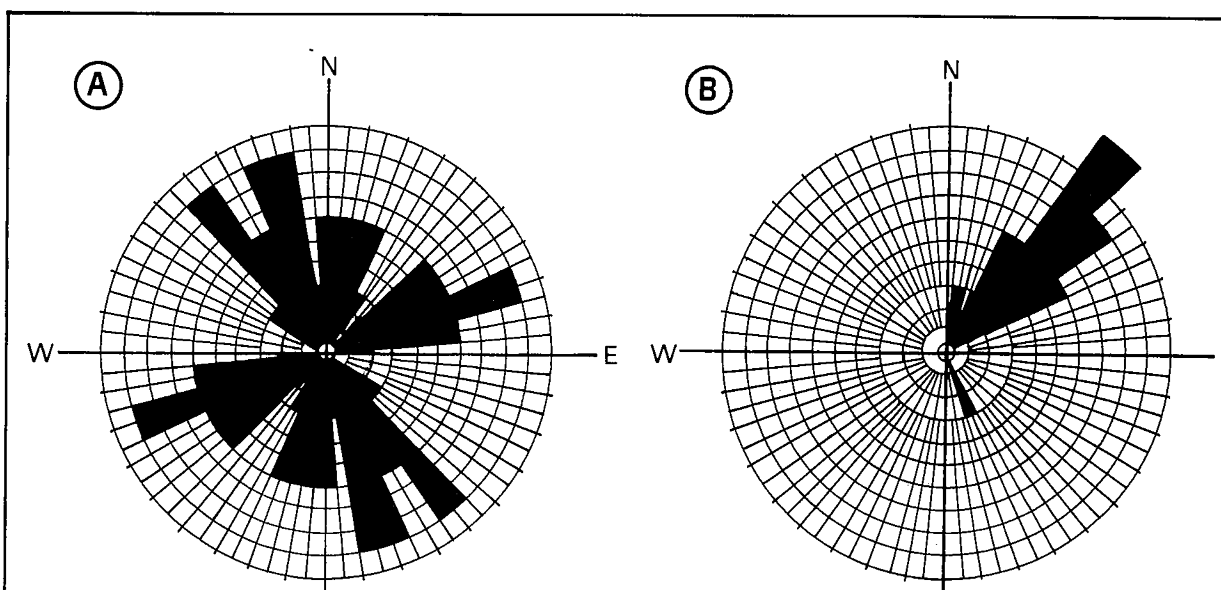


Fig. 4.-Paleocurrent measurements; A.- Direction: groove and bounce cast (32 measurement). B) Direction way: flute cast (15 measurement).
Fig. 4.-Medidas de Paleocorrientes; A.- Dirección: *groove* y *bounce cast* (n.° de medidas 32). B) Sentido: *flute cast* (n.° de medidas 15).

2.2. Paleocurrents

The paleocurrent analysis (Figs. 2, 3, and 4) shows that flows came from the S-SW, as far as the thickest layers are concerned. Thinner beds show more widely dispersed paleocurrents, even appearing opposite to the main trend. This may be interpreted as a consequence of the complicated morphology at the bottom of the basin, due to the presence of certain heights produced by halocynetic movements of Triassic materials. The edges of these heights were slopes pointing randomly. Some of these slope in the opposite direction to the main gravity flows, as Ruiz-Ortiz (1980) claimed in his study of the turbidites of the Cerrajón Formation in the Intermediate Units.

Fig. 4 shows the directions of the paleocurrents in the two sections under study, according to sedimentary structures: sole marks, tool marks, (groove and bounce casts, Fig. 4A) and scour marks (flute casts, Fig. 4B), which are present in the calcarenite beds. Despite the wide dispersal in the measurements (Fig. 4A), a bimodal character can be identified.

2.3 *Ichnofacies*

The Ichnofacies are represented by abundant *Zoophycos* (with a conic-helicoidal and lobulated plane morphology), *Chondrites* and *Scalarituba.* The traces are found within thinner-grained turbidite intervals (in general calcilutite levels). They correspond to the *"Zoophycos Ichnofacies"* (Seilacher, 1967; Frey and Seilacher, 1980) or to the *"Chondrites-Planolites-Zoophycos"* group (Ekdale *et al.*, 1984) having their origin in a deep-basin pelagic environment between the batial and abyssal zones, at depths between 200 and 2000 m. (Seilacher 1978, Howard, 1978).

Given the restricted character of the basin and its relative lack of oxygen, the presence of fossil traces and specifically the abundance of *Zoophycos* must be due

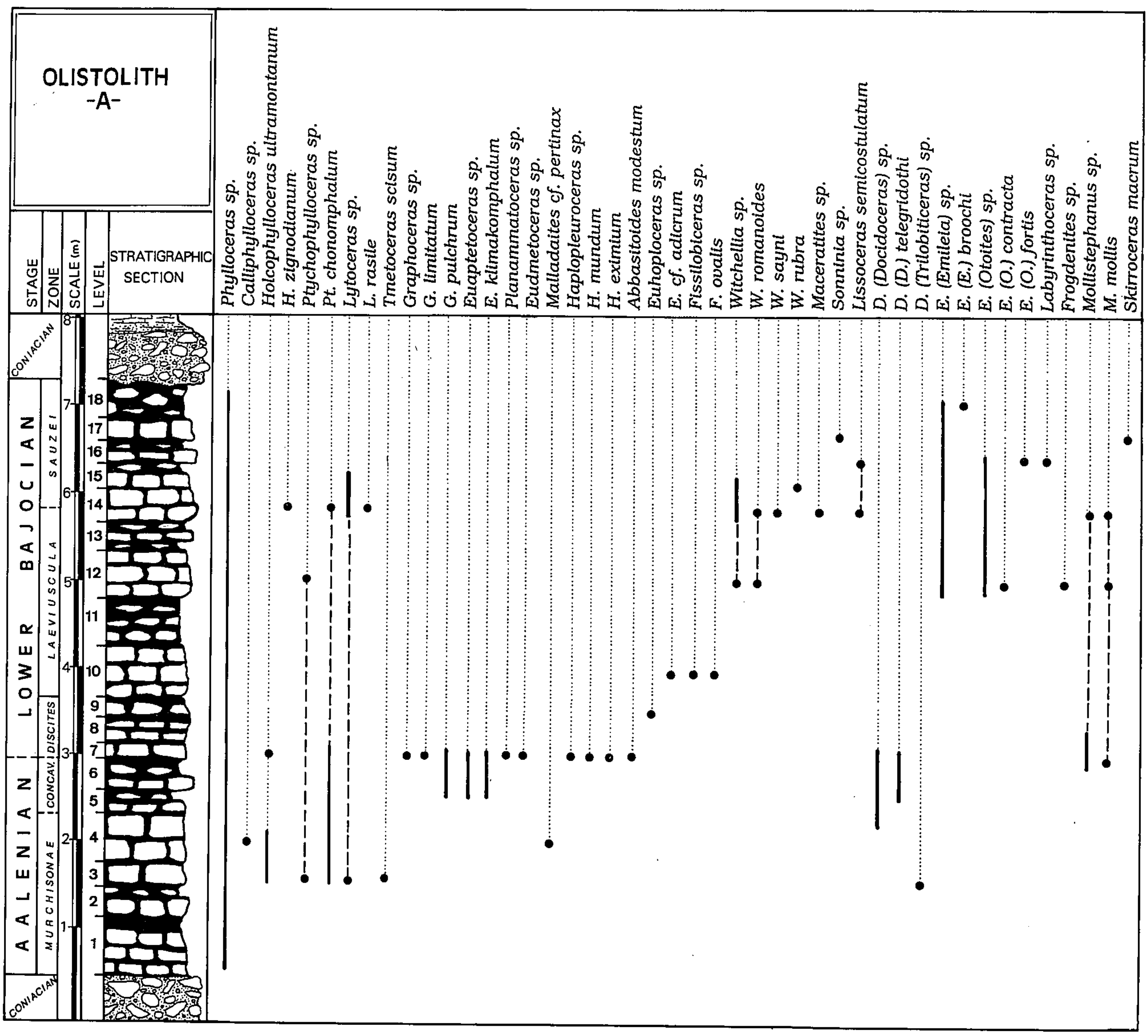


Fig. 5.-Stratigraphic section with the ammonite fauna distribution of olistolith -A-, Río Fardes.
Fig. 5.-Sección estratgráfica con la distribución de la fauna de ammonites del olistolito -A-, Río Fardes.

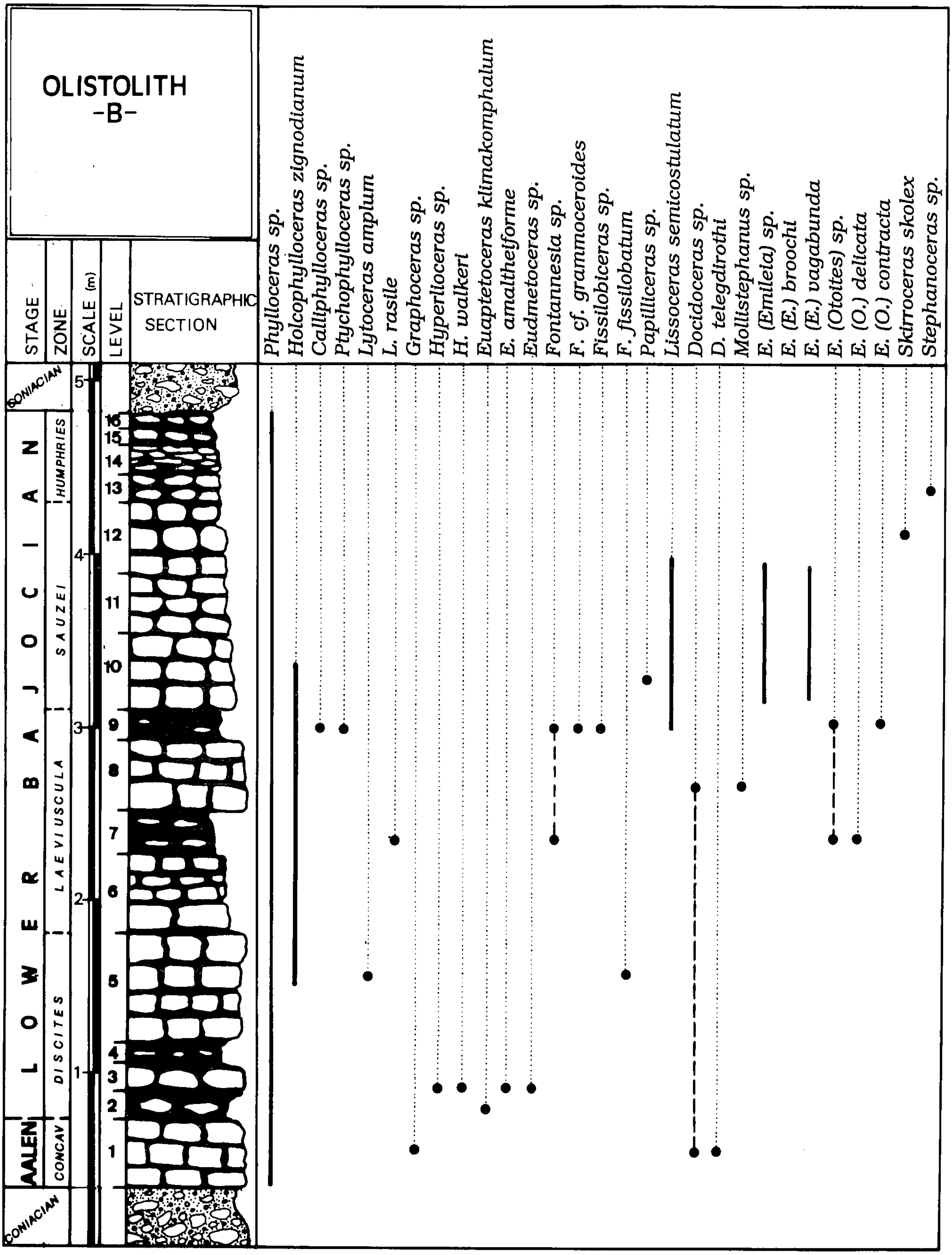


Fig. 6.-Stratigraphic section with the ammonite fauna distribution of olistolith -B-, Río Gor.
Fig. 6.-Sección estratigráfica con la distribución de la fauna de ammonites del olistolito -B-, Río Gor.

to the oxygenation of the sea floor provided by turbidite currents. As a result of these optimal conditions were created for the organisms during brief periods of time, which gave rise to these traces (García-Ramos *et al.,* 1987, 1989).

3. BIOSTRATIGRAPHY OF THE CRETACEOUS MATERIALS

3.1. *Calcareous nannoplankton*

In the Río Fardes section (Fig. 2) we have studied a total of 9 samples, 6 of which contain nannoflora. There are evidences of nannofossil dissolution and overgrowth. The specimens are in general poorly preserved, although some typical associations have been identified.

Sample 2 (the lowest in this section) shows a high dissolution level with low variability; the association is dominated by solution-resistant species (*Watznaueria barnesae, Eprolithus floralis, Zeugrhabdotus embergeri, Eiffellithus turriseiffelii, Biscutum constans).* Among the most typical species we may mention *E. turriseiffelii, Rhagodiscus asper, Seribiscutum* sp. and *B. constans. R. asper* and *Seribiscutum* sp. have their last occurrence near the beginning of the Turonian (Manivit *et al.,* 1977; Robaszynski *et al.*, 1990) and considering the absence of *Quadrum gartneri* - a species which would indicate the beginning of the Turonian (Manivit *et al.*, 1977; Robaszynski *et al.*, 1980, 1982, 1990) - to be representative, we can conclude that our sample is, at least, of Cenomanian age. The lower limit is marked by the presence of *E. turriseiffelii,* the first occurrence of which, at the end of the Albian, coincides with the base of the Rotalipora ticinensis zone of planktonic foraminifera (Manivit *et al.,* 1977; Aguado and Martínez-Gallego, 1990). We may infer, then, that this sample has an uppermost Albian to Cenomanian age.

Sample 4 is very poor in carbonates and has abundant clay minerals. The dissolution effects are strong, to such an extent that the nannofossils have practically disappeared; the only species identified is *Watznaueria barnesae.*

Sample 8 also shows the effects of a marked dissolution and overgrowth. However, compared to previous samples it is relatively rich in carbonates. Despite the fact that the nannoflora is poorly preserved, we have found a typical and relatively varied association. Among the most representative species we find: *Corollithion kennedyi, Lithraphidites acutus, Rhagodiscus asper, Microstaurus chiastius, Seribiscutum primitivum, Eiffellithus turriseiffelii, Axopodorhabdus albianus, and Eprolithus floralis.* This association is typical of the L. acutus zone (M. chiastius subzone) of Manivit *et al.* (1977), corresponding partly to the M. decoratus zone (CC-10) of Sissingh (1977). According to Manivit *et al.* (1977) and Aguado (in prep.) the L. acutus zone correlates approximately with the Rotalipora reicheli and R. cushmani zones of planktonic foraminifera, so that this would mean that our sample 8 is of Upper Cenomanian age.

Sample 22 is rather poor in carbonates and the presence of strong dissolution and overgrowth makes it impossible to identify most of the nannoflora. Among the most typical species there are *Eprolithus floralis, Lithastrinus moratus,* and *Prediscosphaera* sp. The age of our sample is not precise, but considering the presence of *L. moratus,* it can be dated as Upper Cenomanian

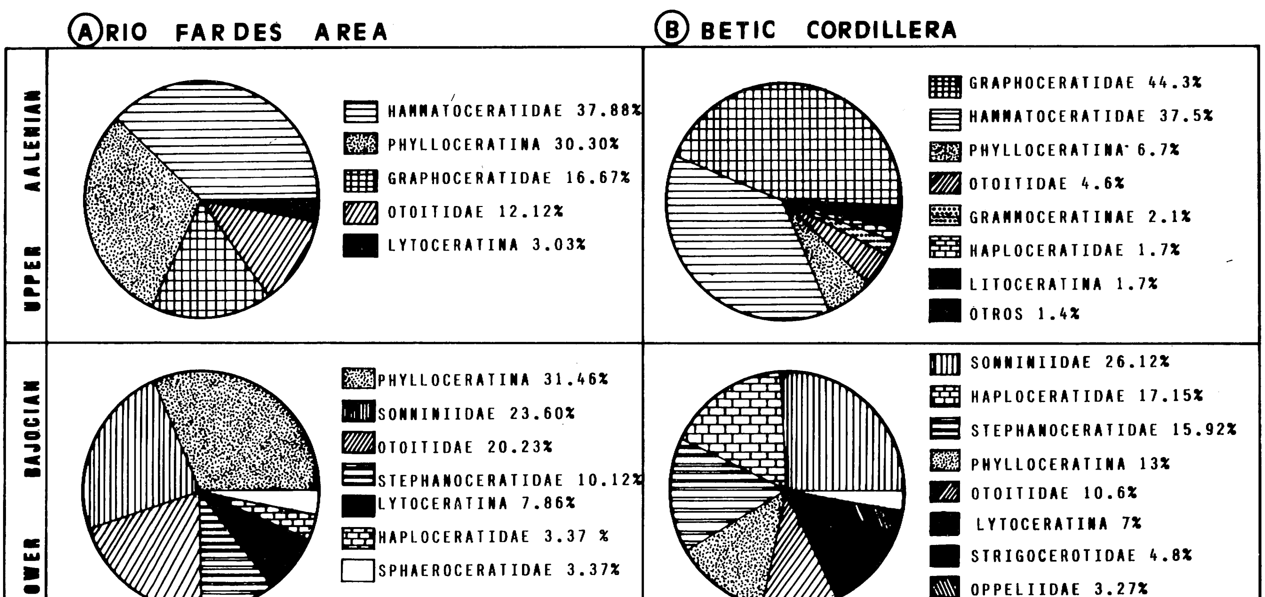


Fig. 7.-Relative frequences of the ammonite fauna in the upper Aalenian and lower Bajocian; from A) Río Fardes Area and B) Betic Cordillera.
Fig. 7.-Frecuencia relativa de la fauna de ammonites en el Aaleniense superior y Bajociense inferior de A) Sector del Río Fardes y B) Cordillera Bética.

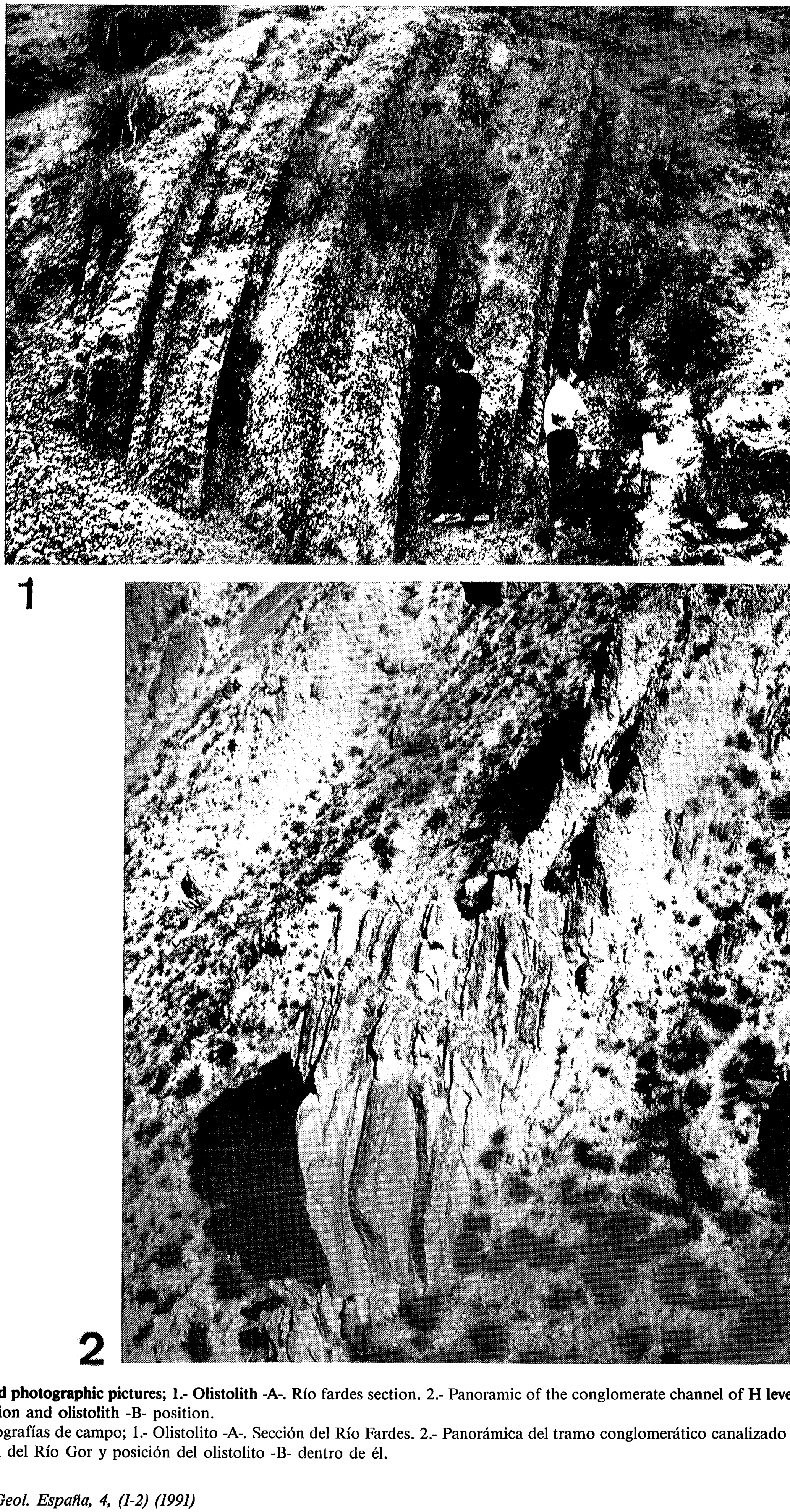


Fig. 8.-Field photographic pictures; 1.- Olistolith -A-. Río fardes section. 2.- Panoramic of the conglomerate channel **of H** level **of Río** Gor **section and olistolith -B-** position.

Fig. 8.-Fotografías de campo; 1.- Olistolito -A-. Sección del Río Fardes. 2.- Panorámica del tramo conglomerático canalizado H, de la sección del Río Gor y posición del olistolito -B- dentro de él.

to Turonian (Perch-Nielsen, 1985).

Sample 24 is highly dissolved, although overgrowth does not seem here to be so significant. A diversified and typical association is present. Among the most significant species from the biostratigraphic point of view we should mention *Marthasterites furcatus, Eiffellithus eximius, Quadrum gartneri, Lithastrinus moratus, Lucianorhabdus compactus, Cribrosphaerella ehrembergii* and *Cylindralithus* sp. This association is typical of the M. furcatus zone (CC-13) established by Sissingh (1977) and is Lower Coniacian in age.

Sample 31 is very rich in clay materials and contains neither nannofossils nor carbonates. Sample 35 has some carbonates but it is practically impossible to identify the scarce nannoflora due to dissolution and overgrowth. Among the few species we find: *Marthasterites furcatus* and *Quadrum gartneri.* If we bear in mind the absence of species which are highly resistant to dissolution, such as *Micula decussata,* then this sample would also belong to zone CC-13 (Sissingh, 1977) thus being Lower Coniacian in age.

Samples 41 and 49 are barren and extremely poor in carbonates, their mineralogy consisting basically of clays and dark minerals.

In the Río Gor section we have studied 5 samples distributed along the entire section. Of these, the three lower ones contain nannofossils. In general these nannofossils are poorly preserved, with clear signs of dissolution and overgrowth. Despite these deficiencies we have identified a large number of typical species in the two lowermost samples (2 and 4).

Sample 2 (the lowest in this section) contains *Eiffellithus turriseiffelii, Braarudosphaera africana, Prediscosphaera columnata, P. avitus, Helicolithus trabeculatus, Tranolithus phacelosus* and *Microstaurus chiastius* as the most representative species. This association is typical of the E. turriseiffelii zone (Manivit *et al.*, 1977) and of the lower part of zone CC-9 (Sissingh, 1977). Perch-Nielsen (1979, 1985) proposed the use of the last occurrences of *B. africana* and *Ellipsagelosphaera britannica* as markers for a subdivision of zone CC-9. In the Betic Cordillera, the last occurrence of *E. britannica* coincides approximately with the Albian - Cenomanian boundary, while that of *B. africana* extends within the Lower Cenomanian (Rotalipora brotzeni zone of planktonic foraminifera; Aguado, in prep.). If we apply, in part, Perch-Nielsen's criteria, we see that the presence of *B. africana* proves that sample 2 is of Lower Cenomanian age.

Sample 4 is characterized by *Eiffellithus turriseiffelii, Lithraphidities alatus, Helicolithus trabeculatus, Tranolithus phacelosus, Microstaurus chiastius* and *Eprolithus floralis* among the most representative species. This assemblage is typical of the same zone interval as the previous sample. The most marked difference between samples 2 and 4 is that the latter lacks *Braarudosphaera africana.* As we mentioned in the previous paragraph the last record of this species has been assigned to occur in the Rotalipora brotzeni zone of planktonic foraminifera. *Corollithion kennedyi* and Lithraphidites acutus have their fist occurrence in higher stratigraphic levels approximately coinciding with the beginning of the Rotalipora reicheli zone (Manivit *et al.*, 1977; Aguado, in prep.). Sample 4 belongs to the interval between the last occurrence of *B. africana* and the first occurrence of *C. kennedyi/L. acutus.* In correlation with the zonation of foraminifera this interval coincides with the upper part of the R. brotzeni zone and the lowermost part of the R. reicheli zone, so that our sample must also date from the Lower Cenomanian.

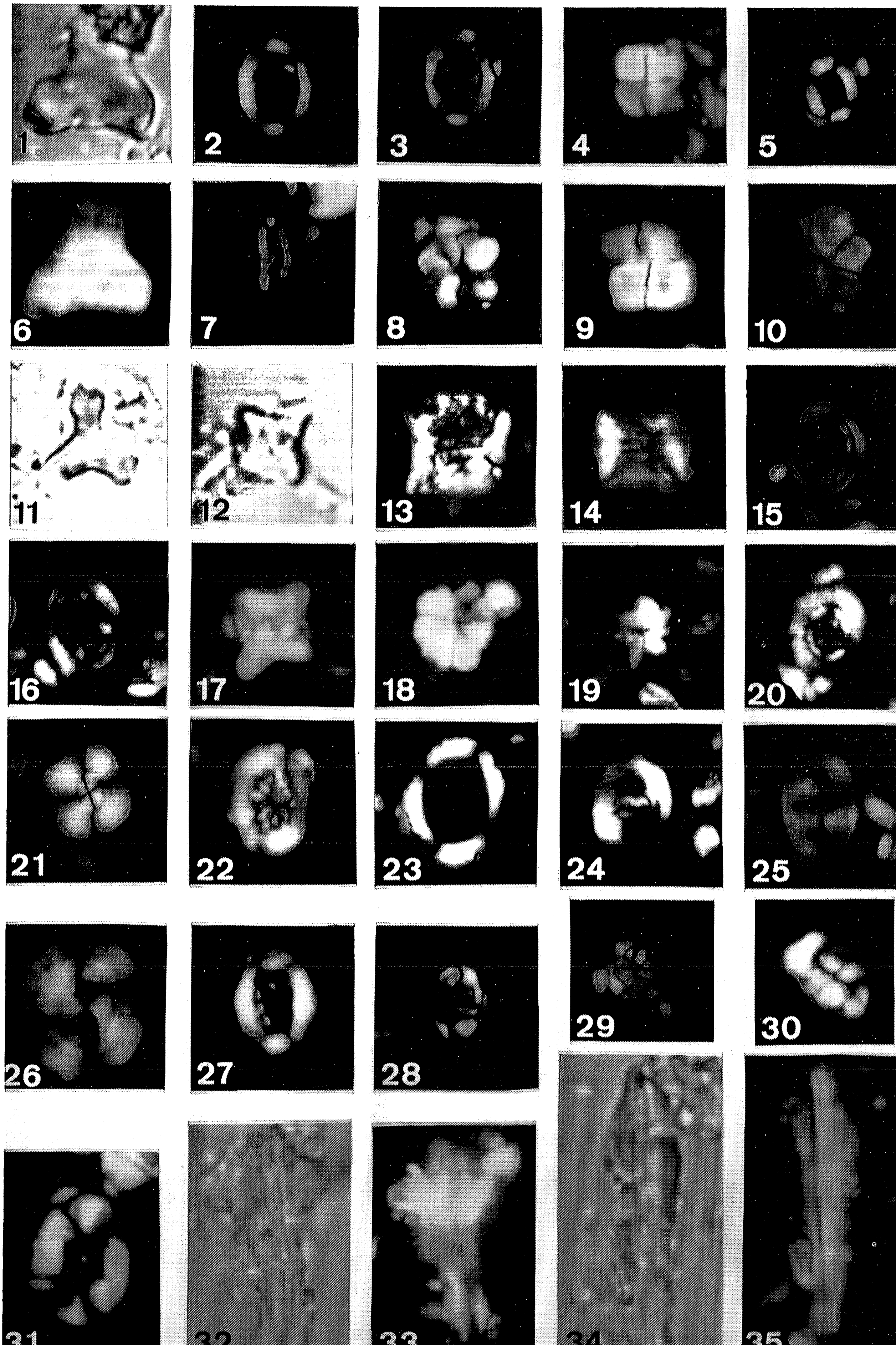
Nannofossils in sample 6 shows extensive etching, with the result that only very resistant species such as *Watznaueria barnesae* and fragments of *Manivitella pemmatoidea* have been found. Samples 13 and 17 lack in nannofossils; they are very poor in carbonates and very rich in clay minerals. The scarce carbonates consist of small (8-15 μ) rhombohedral dolomite crystals of probably secondary generation.

3.2. *Planktonic foraminifera*

The information provided by the study of planktonic foraminifera comes mostly from the Río Fardes section (Fig. 2). We have used normal levigation techniques for marly-clay materials together with thin sections for more calcareous turbidite beds. Furthermore, an association of silicified foraminifera appeared in the siliceous Turonian beds, being removed using the normal techniques for the radiolarian sample preparation.

The clayey materials have provided no planktonic microfauna. At the most, on extremely rare occasions we have identified a few benthonic foraminifera. For this reasons we have had to depend upon the study of more calcareous and hard levels by means of the thin section technique. Only a few of the numerous samples show typical sections of planktonic foraminifera which can be assigned to concrete species. Among these we should mention sample 7 (Fig. 2), in which *Rotalipora reicheli* and *R. montsalvensis,* allow us to date the Middle Cenomanian, and samples 47 and 48, where *Dicarinella concavata, D. asymmetrica* and *M. sigali* are indicative of a Santonian age; in the last beds of the section (sample 52), foraminiferal sections similar to *Globotruncanita stuartiformis falsostuarti / Globotruncanita elevata,* may indicate the beginning of the Campanian.

During the processing of samples to obtain radiolaria, we found, in the siliceous levels of the lower part of the section, a microfauna of planktonic foraminifera whose original calcitic wall had been silicified, having no negative effects on its preservation. Sample 13 (Fig. 2) contains *Whiteinella baltica, W. inornata, Sigalitruncana gr. marianosi, Dicarinella* gr. *hagni,* from the lower part of the Helvetoglobotruncana helvetica zone (Robaszynski *et al.*, 1990), of Middle Turonian age. Sample 21 contains among other forms: *Helvetoglobotruncana helvetica, Archaeoglobigerina cretacea, Dicarinella? oraviensis, D.* cf. *canaliculata, Schackoina ce-*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nomana, S. multispinata, Whiteinella aprica, W. archaeocretacea, W. baltica, W. kingi and *W. praehelvetica,* dating the upper part of the H. helvetica zone (Middle Turonian).

In the Río Gor section (Fig. 3) *Helvetoglobotruncana helvetica* and *Dicarinella* sp. occur in sample 5 and in sample 10 we have identified *Helvetoglobotruncana helvetica.* Both of them belong to the H. helvetica zone (Middle Turonian).

3.3. *Radiolaria*

As far as radiolarians are concerned, we have studied some samples belonging to siliceous beds located in the lower part of the Río Fardes section (Fig. 2). In this study we have found some quite diversified associations which were relatively well preserved.

There are few studies on biostratigraphy by means of radiolaria for the "Middle Cretaceous" (Pessagno, 1976, 1977; Taketani, 1982; Thurow and Kuhnt, 1986; Kuhnt *et al.,* 1986), the results given being often contradictory.

In samples 13 and 21 of the Río Fardes section the radiolaria associations consist basically of the following: *Acanthocircus* sp., *A. preclarus, Alievum praegallowayi, A. superbum, Archaeospongoprunum praelongum, Artostrobium* cf. *urna, A. tina, Bathropyramis campbelli, Cavaspogia antelopensis, Crucella cachensis, Dumitrica maxwellensis, Halesium (?) quadratum, H. (?) sexangulum, Hemycriptocapsa* sp., *Pseudoaulophacus floresensis, P. lenticulatus, P. puthaensis, Pseudodictyomitra pseudomacrocephala, Pyramispongia glasockensis, Spongosaturnalis moorei, S. yaoi, Squinabolella puthaensis, Stichocapsa* gr. *euganea, Ultranapora* cf. *spinifera, Vitorfus brustolensis, V. campbelli, V.* sp. B. Pessagno (1977) and *Williriedellum gilkeyi.* This suggests a Middle Turonian age for the siliceous beds underlying the olistostromic deposits.

Similar associations to those described here have been recorded by Pessagno (1976, 1977), Thurow and Kuhnt (1986) y Kuhnt *et al.* (1986). For these authors the appearance of species such as *Alievum superbum* (Fig,. 11.2) and *Crucella cachensis* (Fig. 12.2) would indicate the Cenomanian-Turonian boundary. Personal observation and works in course (O'Dogherty) in different areas of the Premediterranean Alpine Cordilleras (C. Bética, Northern Alps, Swiss Alps) show, however, that these species appear earlier (at least in the Barremian and the Upper Cenomanian, respectively) than those considered by those authors. Furthermore, the coexistence of well-preserved silicified planktonic foraminifera in these samples *(Dicarinella hagni, Sigalitruncana marianosi, Whiteinella archaeocretacea, W. baltica, W. prahelvetica(?), Helvetoglobotruncana helvetica,* etc.) allows us to determine accurately the age of this radiolaria association as Middle Turonian.

3.4. *Biostratigraphical considerations*

The integrated biostratigraphic study of the three fossil groups mentioned above allows us to date accurately the Río Gor and Río Fardes sections.

The study of the calcareous nannoplankton provides a general chronostratigraphical information on both sections. We have determined the assemblages belonging to zones CC-9 and CC-10 (Cenomanian) and CC-13 (Coniacian) of Sissingh (1977). Likewise we have reliably determined the age of the materials contai-

Fig. 9.-Calcareous nannoplankton from the Río Gor and Río Fardes sections. All specimens have a x3000 magnification.
Fig. 9.-Nannoplancton calcáreo de las secciones del Río Gor y del Río Fardes. Todos los especímenes presentan un aumento de 3000x.

1,6,11.- *Marthasterites furcatus* (Deflandre) Deflandre. Río Fardes section. Sample 24. Coniacian. (CC-13) M. furcatus zone. 1,11 transmitted light; 6 same as 1 under crossed nicols.
2,3,27.- *Rhagodiscus asper* (Stradner) Reinhardt. Río Gor section. Sample 2. Lower Cenomanian. All specimens under crossed nicols.
7.- *Rhagodiscus angustus* (Stradner) Reinhardt. Río Gor section. Sample 2. Lower Cenomanian. Crossed nicols.
4,9.- *Quadrum gartneri* Prins & Perch-Nielsen. Río Fardes section. Sample 24. Coniacian. (CC-13), M. furcatus zone. Crossed nicols.
5.- *Seribiscutum primitivum* (Thierstein) Filewicz *et al.* Río Gor section. Sample 2. Lower Cenomanian. Crossed nicols.
10.-*Braarudosphaera africana* Stradner. Río Gor section. Sample 2. Lower Cenomanian. Crossed nicols.
8,12,17,18.- *Lithastrinus moratus* Stover. Río Fardes section. Sample 24. Coniacian. 8,18, plan view, crossed nicols; 12,17, side view; 12 transmitted light, 17 crossed nicols.
13,14.- *Eprolithus floralis* (Stradner) Stover. Río Fardes section. Sample 24. Crossed nicols.
15.- *Crepidolithus thiersteinii* (Roth). Río Gor section. Sample 4. Cenomanian. Crossed nicols.
16.-*Axopodorhabdus albianus* (Black) Wind & Wise. Río Gor section. Sample 2. Lower Cenomanian. Crossed nicols.
19.- *Lithastrinus* cf. *grillii* Stradner. Río Fardes section. Sample 24. Coniacian. Crossed nicols.
20.- *Prediscosphaera cretacea* (Arkhangelsky) Gartner. Río Fardes section. Sample 24. Coniacian. Crossed nicols.
21.- *Watznaueria barnesae* (Black) Perch-Nielsen. Río Fardes section. Sample 24. Coniacian. Crossed nicols.
22.- *Stradneria crenulata* (Bramlette & Martini) Noël. Río Fardes section. Sample 24. Coniacian. Crossed nicols.
23.- *Manivitella pemmatoidea* (Deflandre ex Manivit) Thierstein. Río Fardes section. Sample 24. Coniacian. Crossed nicols.
24.- *Glaukolithus diplogrammus* (Deflandre) Reinhardt. Río Fardes section. Sample 24. Coniacian. Crossed nicols.
25,30.- *Tranolithus phacelosus* Stover. Río Fardes sequence. Río Fardes section. Sample 24. Coniacian. Crossed nicols.
26.- *Watznaueria biporta* Bukry. Río Gor section. Sample 2. Lower Cenomanian. Crossed nicols.
28,31.- *Eiffellithus turriseiffelii* (Deflandre) Reinhardt. Sample 2. Río Fardes section. Lower Cenomanian. Crossed nicols.
29.- *Corollithion kennedyi* Crux. Sample 8. Río Fardes sequence. Upper Cenomanian. Crossed nicols.
32,33.- *Lithraphidites acutus* (Verbeeek) Manivit. Río Fardes section. Upper Cenomanian. 32 transmitted light; 33 same as 32 under crossed nicols.
4,35.- *Lithraphidites alatus* Thierstein. Río Gor section. Lower Cenomanian. 34 transmitted light; 35 same as 34 under crossed nicols.

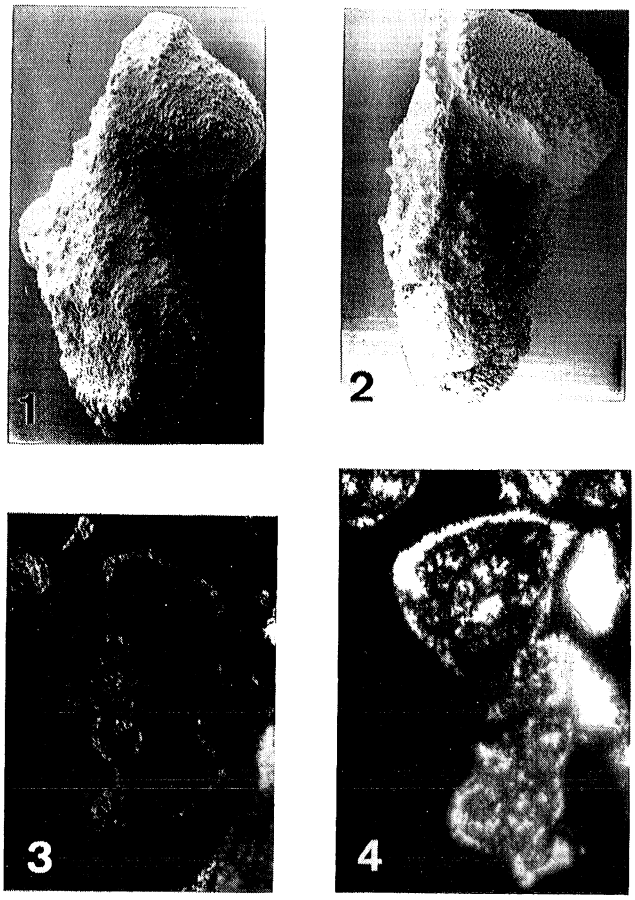


Fig. 10.- Some planktonic foraminifera from the Río Fardes section.
Fig. 10.- Algunos foraminíferos planctónicos de la sección del Río Fardes.
1.- *Dicarinella cf. primitiva* (Dalbiez). Río Fardes section. Sample 31. Coniacian. x130.
2,3.- *Dicarinella concavata* (Brotzen). Río Fardes section. 2.- Sample 31. Coniacian. x130. 3.- Sample 52. Santonian. x90.
4,5.- *Dicarinella asymetrica* (Sigal). Río Fardes section. Sample 52. Coniacian. x120.

ning the Jurassic olistoliths under study: their deposition took place during the Coniacian. Although this dating was only obtained in the Río Fardes section, we feel entitled to assign the Río Gor section the same age, given the clear lithological similarity between the two sections.

As we can see (Figs. 2 and 3) the chronostratigraphical information obtained from the planktonic foraminifera and radiolaria in the Río Fardes and Río Gor sections, although somewhat fragmentary, is consistent with and supports that obtained from the study of the calcareous nannoplankton. By means of planktonic foraminifera assemblages we have dated Middle Cenomanian, Middle Turonian (Helvetoglobotruncana helvetica zone) and Santonian (Dicarinella asymmetrica zone) materials.

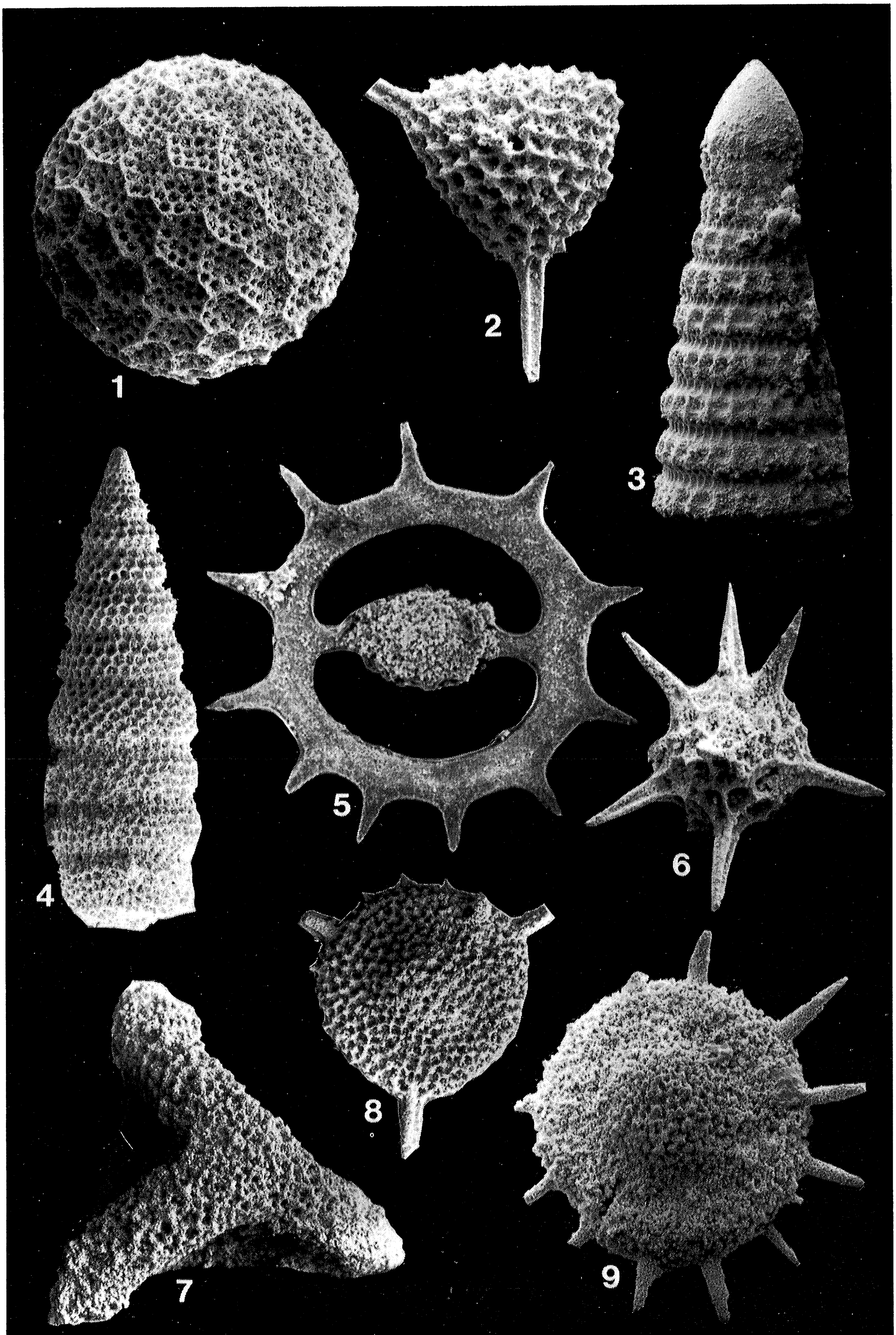
From the above discussion we state the presence, in the Río Fardes area, of Lower Cenomanian, Turonian, and Upper Santonian sediments which, according to previous authors (Fallot *et al.,* 1960; Comas, 1978), corresponded to stratigraphycal gaps.

4. JURASSIC OLISTOLITHS

Jurassic olistoliths occur frequently in the Río Fardes sector and are embedded in turbidite facies of member II of the Fardes Formation (Figs. 2, 3, 4 and 5). Their exposed surface seldom exceeds 10 m, but in some cases they enable us to sample level by level and to establish a detailed biostratigraphy.

Of the various olistoliths present we have studied two large blocks located near the Río Fardes and in the Río Gor, since these have good stratification, large dimensions and abundant and varied ammonite fauna. These olistoliths are embedded in Coniacian materials

Fig. 11.- All specimens figurated come from the 'Rio Fardes' section. Between parenthesis, material collection number.
Fig. 11.- Todos los ejemplares figurados provienen de la sección del Río Fardes. Entre parentesis se indica el número de depósito del material.
1.- *Hemycriptocapsa* sp., (90/0012); x260. Sample 13.
2.- *Alievum superbum* (Squinabol), (90/1004); x220. Sample 21.
3.- *Pseudodictyomitra pseudomacrocephala* (Squinabol), (90/0020); x190. Sample 21.
4.- *Stichomitra gr. asymbatos.* Foreman, (90/0013); x180. Sample 13.
5.- *Acanthocircus preclarus* (Foreman), (90/0004); x220. Sample 21.
6.- *Hexapyramis (?) pantanellii* Squinabol, (90/0002); x200. Sample 21.
7.- *Cavaspongia antelopensis* Pessagno, (90/0008); x220. Sample 21.
8.- *Pseudoaulophacus puthaensis* Pessagno, (90/0017); x210. Sample 21.
9.- *Pseudoaulophacus lenticulatus* Pessagno, (90/0018); x240. Sample 21.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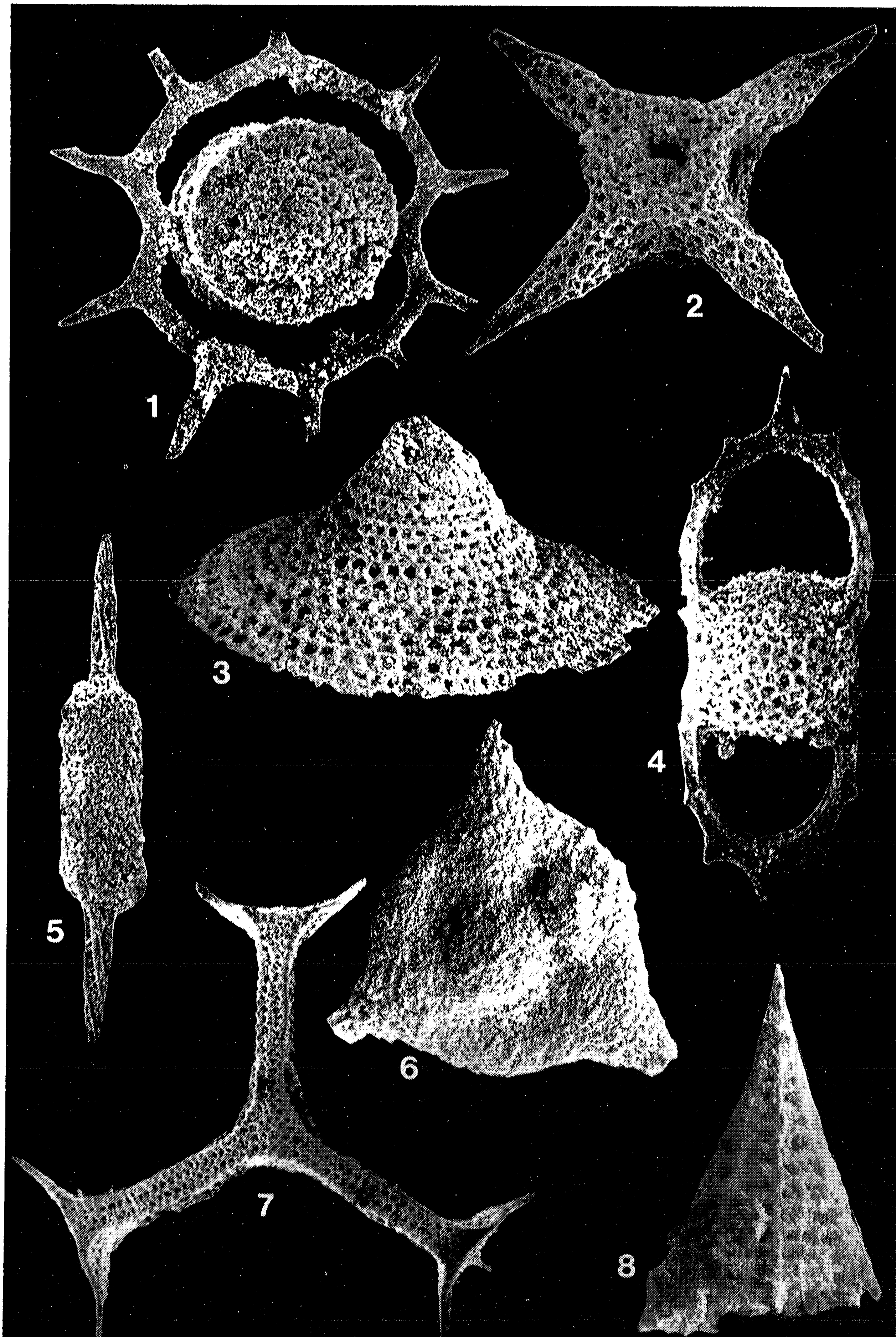
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(Marthasterites furcatus Zone of calcareous nannoplankton).

The Río Fardes olistolith A (Figs. 2, 5, and 8) is situated approximately 400 m SE of km 22 on the road between Huélago and Villanueva de las Torres (coordinates UTM: 414975/48975, sheet 993-I, Gorafe, Scale 1:25,000) and its surface is approximately 12 x 8 m. The Río Gor olistolith B (Figs. 3, 6 and 8) has an area about 9 x 15 m and is situated just on the right margin of the Río Gor, 200 m north of the road between Gorafe and Alicún de las Torres (coordinates UTM: 4151/49265, sheet 971-III, Villanueva de las Torres, Scale 1: 25.000).

In both olistoliths the dominant facies are nodular limestones, sometimes more or less brechoids, in levels which vary in thickness from a few cm to almost 1 m. The dominant textures are: wackestone to packstone with filaments and radiolaria, often found together with abundant ammonite embryos, protoglobigerinids (only at some levels), sponge spicules, some benthonic foraminifera, ostracods and pellets. The irregular accumulation of bioclasts deserves special mention (in some places these may constitute real grainstone) not being banded nor apparently laminated.

Apart from the olistoliths formed of Middle Jurassic materials there is another group of Upper Jurassic nodular limestone olistoliths. We have not observed any stratigraphical continuity between these two groups.

4.1. *Biostratigraphy*

4.1.1. *Aalenian*

The basal levels of the two main olistoliths we have studied (Figs. 5, 6 and 13) afford a rich fauna of Phylloceratina: *Phylloceras* sp., *Calliphylloceras* sp., *Holcophylloceras ultramontanum, Ptychophylloceras* sp., *Pt. chonomphalum,* and a few Lytoceratina: *Lytoceras* sp., and *L. rasile.* Though the Ammonitina are very rare and poorly preserved, we have identified a fragment of *Tmetoceras scisum,* and another of *Malladaites* cf. *pertinax;* also one specimen of *Trilobiticeras* sp. Even though *Tmetoceras* is found more abundantly in the Lower Aalenian, it also frequently occurs in the Subbetic Middle Aalenian (Linares, 1979; Linares, *et al.*, 1988; Linares and Sandoval, in prep.), and there are some records from the Upper Aalenian (Callomon and Chandler, 1990). *M. pertinax* is restricted to the final part of the Middle Aalenian (Bradfordensis subzone) and the lowermost part of the Concavum Zone (Linares and Sandoval, 1986). *Trilobiticeras* occurs in the upper part of the Murchisonae Zone and reaches the Lower Bajocian. Therefore, we can infer that the first beds of the olistoliths seem to correspond to the upper part of the Middle Aalenian, where *T. scisum* and *M.* cf. *pertinax* are most likely to be found together; however, we cannot reject the possibility that these levels represent the extreme base of the Upper Aalenian.

Levels 5 and 6 of olistolith A (Figs. 5, 6 and 13) and level 1 of olistolith B (Figs. 6 and 13) are poor in ammonite fauna. Besides *Phylloceras* and *Ptychophylloceras* similar to those found in lower levels, these levels have also yielded some ammonites: *Graphoceras* sp., *G. pulchrum, Haplopleuroceras* sp., *Euaptetoceras* sp., *E. klimakomphalum, Docidoceras* sp, and *D. telegdirothi.* This faunal assemblage is characteristic of the Upper Aalenian, Concavum Zone (Linares *et al* 1988; Cresta and Galacz, 1990; and Linares and Sandoval, 1990).

4.1.2. *Bajocian*

Levels 7 and 9 of olistolith A and levels 2-4 of olistolith B (Figs. 5, 6, 13-15) have provided abundant and varied ammonite fauna. Together with Phylloceratina and Lytoceratina similar to those found at lower levels, abundant Ammonitina occur, such as: *Euaptetoceras infernense, E. amaltheiforme, E. klimakomphalum, Planammatoceras* sp., *Rhodaniceras* sp., *Haplopleuroceras* sp., *H. mundum, H. eximium, Graphoceras limitatum, Hyperlioceras walkeri, Euhoploceras* sp., *Abbasitoides* sp., *Docidoceras* sp. and *D. telegdirothi.* This faunal association is typical of the Discites Zone of the Mediterranean Province, specially in ''ammonitico rosso'' facies (Sandoval, 1983, 1990; Cresta and Galacz, 1990; Linares and Sandoval, 1990).

Levels 10 and 11 of olistolith A and levels 5 to 8 of olistolith B (Figs. 5, 6, 13-15) again provide abundant Phylloceratina which are quite similar to those of underlying levels; some Lytoceratina *(Lytoceras amplum)* and many Ammontina: *Fontannesia* sp., *F. grammoceroides, Fissilobiceras* sp., *F. ovalis, Euhoploceras* cf. *adicrum, Docidoceras* sp., *Mollistephanus* sp., *M. mollis, E. (Emileia)* sp., *E. (E.) broochi. E. (Otoites) delicata.* This fossil association is typical of the lower part of the Laeviuscula Zone (Ovalis Subzone) in the Mediterranean and Submediterranean provinces (Pavia, 1983; Fernández-López, 1985; Sandoval, 1983,1990; Callomon and Chandler, 1990).

Levels 12 to 14 of olistolith A and level 9 of olisto-

Fig. 12.- All specimens figurated come from the 'Rio Fardes' section. Between parenthesis, material collection number.

Fig. 12.- Todos los ejemplares figurados provienen de la sección del Río Fardes. Entre paréntesis se indica el número de depósito del material.

1.- *Acanthocircus* sp., (90/0035); x220. Sample 21.

2.- *Crucella cachensis* Pessagno, (90/0003); x250. Sample 21.

3.- *Squinabolella puthaensis* Pessagno,(90/0032); x230. Sample 21.

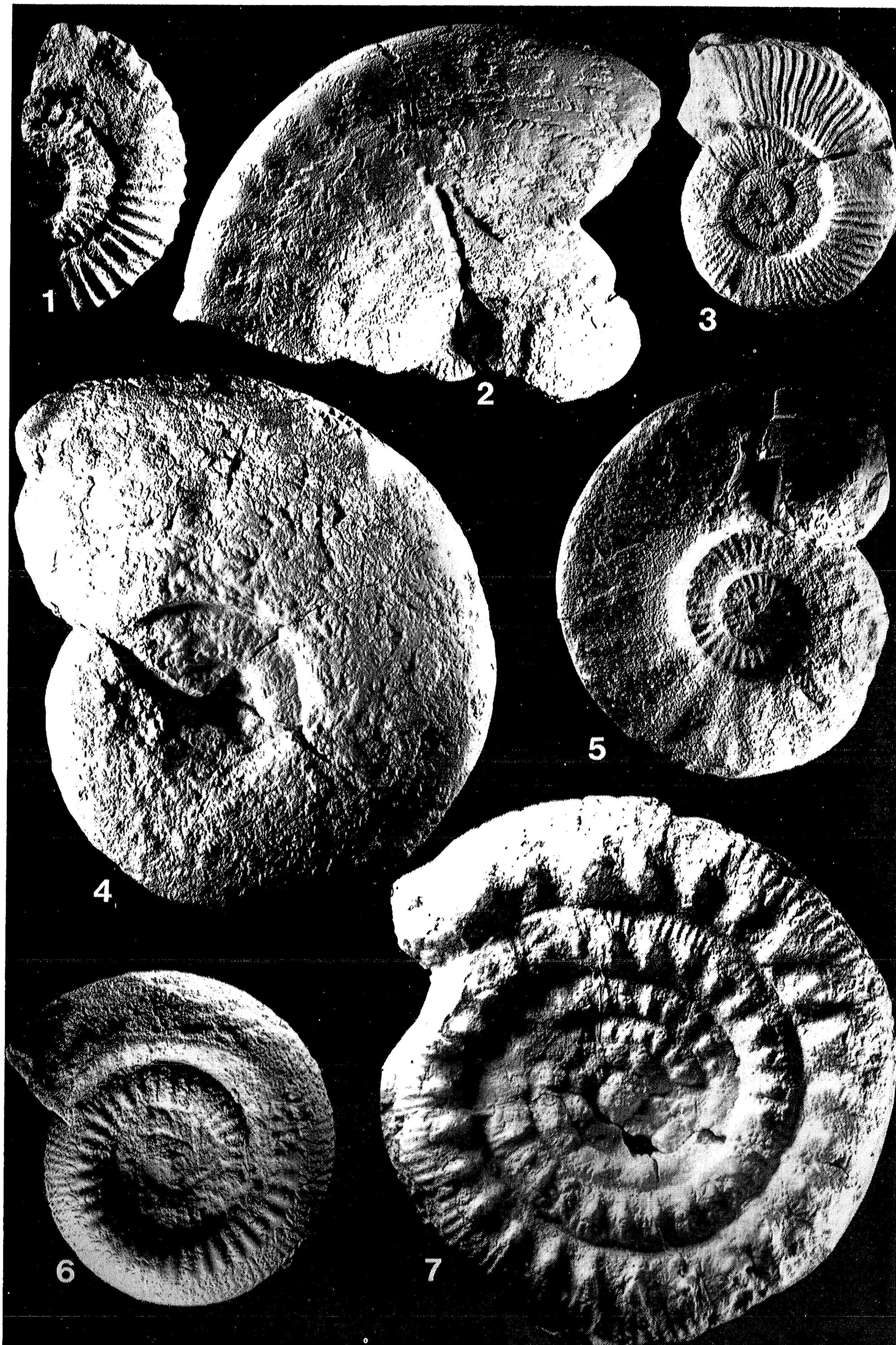
4.- *Bitorfus* sp. B in Pessagno (1977),(90/0005); x300. Sample 13.

5.- *Archaeospongoprunum praelongum* Pessagno, (90/0015); x240. Sample 13.

6.- *Dumitricaia maxwellensis* Pessagno, (90/0008); x220. Sample 21.

7.- *Halesium (?) sexangulum* Pessagno, (90/1002); x180. Sample 21.

8.- *Bathropyramis campbellii* Taketani, (90/0023); x330. Sample 21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lith B (Figs. 5, 6, 13-15) provide a fossil association which differs considerably from that of lower levels. The predominant Phylloceratina are now *Holcophylloceras zignodianum* and *Calliphylloceras* sp.. *Ptychophylloceras* sp., and *Pt. chonomphalum,* which already existed in lower levels. Lytoceratina are rare, and the most representative form is *Lytoceras rasile.* There are relatively abundant and varied Ammonitina: *Fontannesia* sp., *Lissoceras semicostulatum, E. (Emileia)* sp., *E. (E.) broochi, E. (Otoites)* sp., *E.(O.) contracta, Mollistephanus mollis* and *Frogdenites* ssp. (two morphotypes). This assemblage, with abundant *Witchellia* and *Emileia-Otoites,* is typical of the Laeviuscula Zone and subzone (Pavia, 1983; Sandoval, 1983, 1990; Fernández-López, 1985; Callomon and Chandler 1990). We should point out, however, the high relative abundance of *Frogdenites* and *Mollistephanus mollis* in this sector, which are very rarely found, or completely absent from other areas in the Subbetic.

The last levels of olistolith A and levels 10 and 12 of olistolith B (Figs. 5, 6, 13-15) contain some Phylloceratina and Lytoceratina similar to those mentioned in the previous paragraph, although these are generally rarer. Among the Ammonitina, which are still frequent, we have identified: *Witchellia* sp., *W. rubra, Sonninia* sp., *Papilliceras* sp., *Lissoceras semicostulatum, E. (Emileia)* sp., *E. (E.) broochi, E. (E.) vagabunda, E. (Otoites)* sp., *E. (O.) fortis, Labyrinthoceras* sp., *Skirroceras skolex* and *Sk. macrum.* The occurrence of *Labyrinthoceras, Skirroceras skolex* and *Sk. macrum* is characteristic of the Sauzei Zone of the Mediterranean Province (Sandoval, 1983, 1990; Galacz, 1988).

The last beds of olistolith B, on the Río Gor section (Fig. 6), are poor in fauna, and have provided one specimen of *Stephanoceras* sp., which dates, at least in its base, the Humphriesianum Zone. Taking thus the two main olistoliths together it is possible to identify the Middle-Upper Aalenian and the Lower Bajocian, where a good zonal succession can indeed be established.

4.2. *Some paleobiological considerations about ammonite fauna*

The ammonite fauna found in the Upper Aalenian and the Lower Bajocian of the olistoliths in the River Fardes sector contain a high percentage of Phylloceratina (even larger than in the rest of the Subbetic at the same age, Fig. 7), which emphasizes their Mediterranean character. In the same way Hammatoceratidae (also basically Mediterranean), Sonniniidae, Graphoceratidae, Otoitidae and Stephanoceratidae occur frequently and constitute a high proportion of the whole assemblage. Other groups such as Lytoceratina, Sphaeroceratidae, Haploceratidae and Strigoceratidae (the latter notably fewer in number) also occur in this sector, but they are much rarer than the formers.

The ammonite fauna is, in general, quite similar to that of the rest of the Subbetic (Fig. 7). However, some ammonites, especially Graphoceratidae and certain Hammatoceratidae, are larger in size than in deeper areas of the Subbetic Basin. This may possibly be due to the special paleoecological conditions developed in the pelagic ridges (the origin of the olistoliths), where there were large quantities of alimentary sources; this in turn allowed certain Ammonitina to reach greater sizes.

At late Aalenian (Concavum Zone) to lowermost Bajocian (Discites Zone) interval, the Otoitidae, specially *Docidoceras telegdirothi* occur much more frequently than in the Middle Subbetic, while other groups such as Graphoceratidae are much rarer. This phenomenon may well also be connected with paleoecological factors.

Of the Subbetic areas previously studied (Sandoval, 1983), a faunal association similar to the present one is found only in the Río Frío sector, to the south of Jaén (where there also exist ridge facies, of "ammonitico rosso" type, similar to those of the olistoliths in the Fardes sector).

Some ammonite faunas from other localities of the Mediterranean Province, especially the Gerecse Mountains of Hungary (Galacz, 1988; Cresta and Galacz, 1990) and the Northern Apennines (Cresta and Galacz, 1990), are in fact even more similar to those of the Fardes sector than the fauna from the same age found in other Subbetic areas.

5. SEDIMENTARY INTERPRETATION AND PALEOGEOGRAPHIC IMPLICATIONS

In the Upper Cretaceous the trough of the Middle Subbetic was bounded to the SE by a pelagic ridge, the Internal Subbetic (García-Hernández *et al.*, 1980). The transition between these domains was a zone with active paleoslopes which favoured both the exposure and denudation of Jurassic and Cretaceous materials and

Fig. 13.- Ammonite fauna. All specimens figured at natural size.
Fig. 13.- Fauna de ammonites. Todos los ejemplares figurados a tamaño natural.
1.- *Tmetoceras scisum* (Benecke). Middle Aalenian, Murchisonae Zone, level 3, olistolith -A-.
2.- *Graphoceras* sp. Upper Aalenian, Concavum Zone, level 6, olistolith -A-.
3.- *Haplopleuroceras mundum* Buckman. Lower Bajocian, Discites Zone, level 7, olistolith -A-.
4.- *Fissilobiceras ovalis* (Quenstedt). Lower Bajocian, Laeviuscula Zone, Ovalis subzone, level 10, olistolith -A-.
5.- *Witchellia sayni* (Haug). Lower Bajocian, Laeviuscula Zone and subzone, level 14, olistolith -A-.
6.- *Mollistephanus mollis* Buckman. Lower Bajocian, Discites Zone, level 8, olistolith -A-.
7.- *Skirroceras macrum* (Quenstedt). Lower Bajocian, Sauzei Zone, level 17, olistolith -A-.

the development of a clear synsedimentary tectonics (slump and olistostromes).

The presence within the pelagic and hemipelagic materials of finely-laminated layers without bioturbation, the existence of pyrite, the total organic carbon content and the lipid contents in the organic matter (Grimalt et al., 1990) indicate a paleogeographical marine environment where there was probably limited water circulation and where basically reducing conditions dominated, independently on the absolute depth (Comas et al., 1982a; López-Galindo *et al.,* 1985). At the same time mineralogical and geochemical evidences suggest that the alteration of submarine basic volcanic rocks had an important influence on the genesis of the bentonitic clays. This does not exclude the possibility of an additional detritic supply (Sebastián-Pardo *et al.,* 1984; López-Galindo, 1986).

The sedimentological, mineralogical and geochemical features of these layers allow us to differentiate a trough in the southern Middle Subbetic with respect to other Subbetic domains. García-Dueñas and Comas (1983) and López-Galindo *et al.* (1985) established a lack of connection between this and the northernmost troughs and propose a model of "hanging troughs" in an extended continental margin with limited water circulation. López-Galindo and Martín-Algarra (1991) differentiated this domain from others which were paleogeographically more septentrional, describing it as an area with poor nutritional possibilities, fine sedimentation and under the influence of deep water currents (contourites) which transported the clays. Those resulted from the alteration of submarine basalts in adjacent domains.

The microorganisms in these levels basically comprise the following: radiolaria, a few nannoflora with clear signs of dissolution and overgrowth, and very few (or no) planktonic foraminifera. As we have already seen (see point 3.1) the nannoflora of the Río Fardes and Río Gor sections is characterized, from the point of view of its preservation, by the strong influence of dissolution and crystalline overgrowth. These processes in turn lead, at sample level, to a complete absence of nannoplankton or to an impoverished nannofossil assemblage, where only relatively restricted associations containing solution-resistant species clearly predominate (Roth, 1984, Roth and Krumbach 1986). On the other hand, the most representative layers of autochthonous sedimentation have very low carbonate content compared to clay minerals. These carbonates frequently consist of small rhombohedra, whose size ranges from 5 to 15 μ and whose mineralogy is probably dolomitic (epigenetic). They constitute the micritic carbonate fraction which is most resistant to dissolution (Roth, 1984).

At this point, we can now raise the following question: which could be the causes for this carbonate deficit? Paleogeographical reconstructions (García-Dueñas and Comas, 1983; López Galindo 1986) suggest that there was a trough in the area where the materials which the two sections studied belong to were deposited. That is, we would be dealing with materials deposited at considerable depth such as ichnofacies show. On the other hand, a general compensation calcite depth (CCD) rise during the "Middle Cretaceous" is generally accepted. This CCD becomes unclear and variable at the same time, so that some authors describe a "calcite compensation zone" for this time-interval (Roth and Krumbach, 1986). Finally, we must bear in mind that the autochthonous (pelagic and hemipelagic) sediments are rich in organic carbon, so that the catabolic breakdown of organic matter could have given rise to an increase in the concentration of CO_2 in pore waters of the sediment; this in turn brought about changes in the preservation of the smaller carbonatic fraction (Roth 1984; Roth and Krumbach, 1986).

Sediments similar to those described here are frequently found in other areas of the External Zones of the Betic Cordillera (Dekker *et al.*, 1966; Baena *et al.*, 1977; Kuhry, 1975; Vera *et al.*, 1982; De Smet, 1984; López-Galindo, 1986; Martín-Algarra, 1987; and Aguado *et al.*, 1988.). The depositing of these facies may be connected whit the Cretaceous "Oceanic Anoxic Events" (Jenkyns, 1980) which are well-known on a world-wide scale (Bernoulli, 1972; Schlanger and Jenkyns, 1976; Herbin and Deroo, 1979; Jenkyns, 1980; Arthur *et al.*, 1987).

The associations of turbidite facies (see point 2.1.1 and 2.1.2) in member II of the Fardes Formation consist of positive cycles (thinning and fining upward sequences) which are well-developed and represent channelized sectors of the distributary system (Comas, 1978). Channel-filling sequences are represented, with periodic phases of channel activity. Member III of this formation typically shows facies and facies-associations which have channel-levee complexes (Comas *et al.*, 1982b).

A depositional model for members II and III of Fardes Formation involves an extensive development of channelized sectors in the distributary system. At certain moments breccia levels must have interrupted the process, transported in the absence of clear channels and conduits down the slope and distributed laterally throughout its length, accumulating at the foot like a wedge of heterogeneous sediments. In these stages the deposition model is similar to the "debris apron", the

Fig. 14.- Ammonite fauna. All specimens figured at natural size.

Fig. 14.- Fauna de ammonites. Todos los ejemplares figurados a tamaño natural.

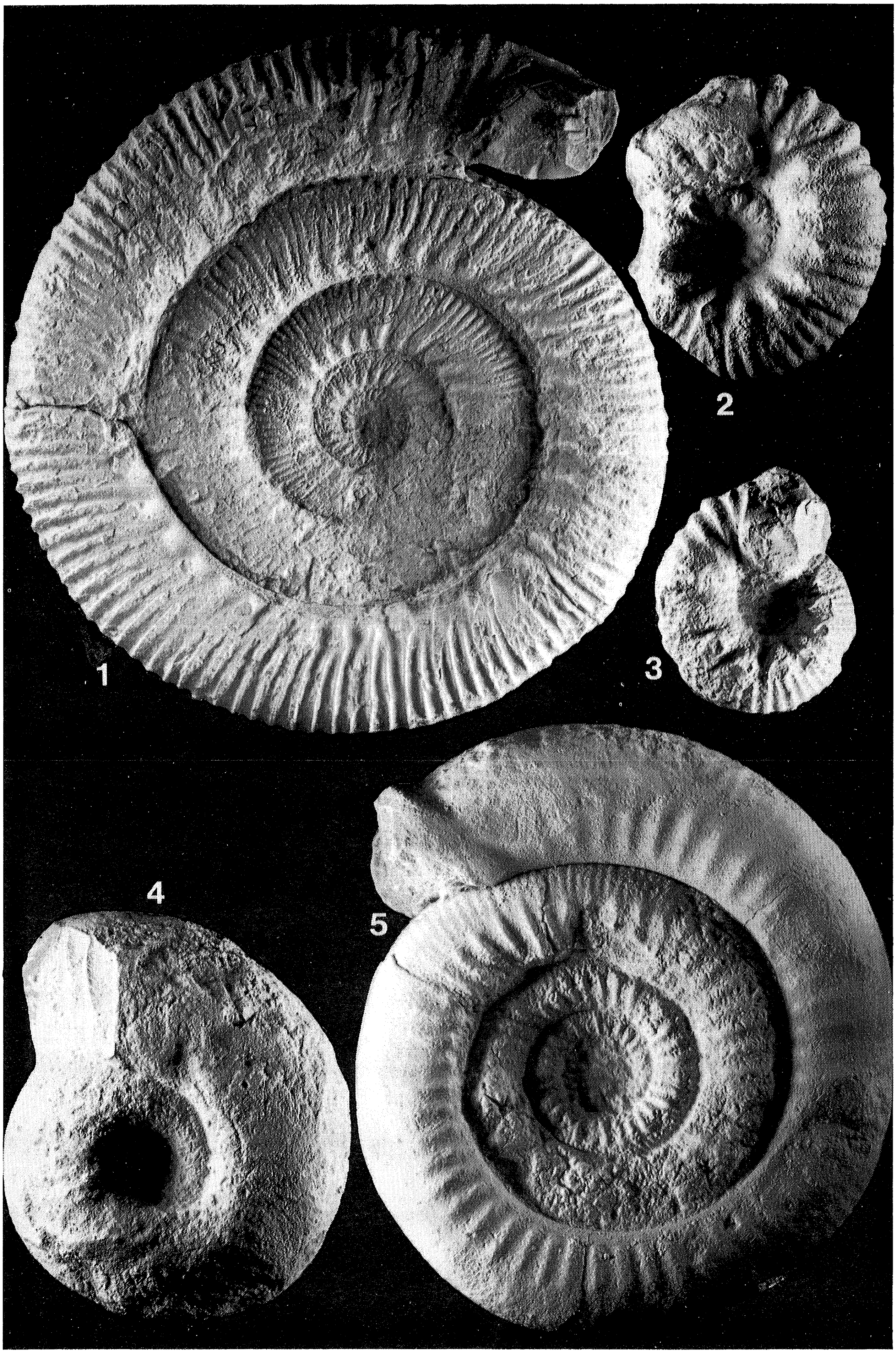
1.- *Skirroceras skolex* (Buckman). Lower Bajocian, Sauzei Zone, level 12, olistolith -B-.

2.- *Emileia (Otoites) contracta* (Sowerby). Lower Bajocian, Laeviuscula Zone, level 9, olistolith -B-.

3.- *Emileia (Otoites) fortis* Westermann. Lower Bajocian, Sauzei Zone, level 16, olistolith -A-.

4.- *Labyrinthoceras* sp. Lower Bajocian, Sauzei Zone,level 16, olistolith -A-.

5.- *Mollistephanus mollis* Buckman. Lower Bajocian, Sauzei Zone?, level 14, olistolith -A-.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development of which is typical of carbonated slopes (Cook, 1979; Choe and Chough, 1988). These deposits are commonly found at the base of slopes with inefficient channels in which the predominant processes are the flow of unchannelled masses, such as landslides, slumps, debris flow and turbid currents (Choe and Chough, 1988). Instead of "thickening and thinning upward" sequences, typical of a submarine fan, debris aprons consist of an arbitrary distribution of sediments deposited by gravity flows. They are linearly focused and usually parallel to the nearby slope (Mullins, 1983). Their distribution is conditioned by the basin form, tectonics, sedimentary supply, climate, and sea-level changes (Stow *et al.*, 1983; Casnedi, 1988; Tucker, 1990).

These departures are specially well-developed during the Coniacian (in layers where the nodular limestone olistoliths are found: member II of the Fardes Formation). This would correlate with an important and extensive synsedimentary tectonic activity.

At the same time, affecting and contributing to the denudation of the submarine relief, we find at this interval a moment of relatively low sea-level: this has been established both at the regional level (García-Hernández *et al.*, 1982; Martín-Algarra, 1987; Vera, 1988) and on a worldwide scale (Haq et al., 1987). During the Coniacian member II of the Fardes Formation developed at the same time as there occurred periods of low sea-level, which contributed to the development of mass and turbidite movements (Posamentier and Vail, 1988). Member III of this formation includes small-scale resedimentation processes with high sedimentation rates. They developed at times of relatively high sea-level, which produced an increase in the "accommodation" (Jervey in; Posamentier *et al.*, 1988), an a regression of the supply system. For Vail *et al.* (1990) the olistostrome levels in carbonate system are typical of the beginning of a moment of relatively low sea level.

The tectonic and geological context of the region, the type and amount of sedimentary supply and the gradient of the basin are all factors which, together with the changes in sea-level (Kolla and Macurda, 1988), have conditioned the evolution and development of the turbiditic system which is typical of the Fardes Formation.

5.1. *The origin of the Middle Jurassic olistoliths*

In areas which are geographically very close to the sector where the olistoliths are embedded, we find that there are no Upper Aalenian-lowermost Bajocian materials (Concavum to Laeviscula zones) with similar facies and fauna. Nevertheless, we do find Middle Aalenian materials with this type of facies and large quantities of Hammatoceratidae, Tmetoceras and a few Graphoceratidae at some points of Cerro Méndez, situated slightly to the NW of the Fardes Formation (Linares and Sandoval, in prep.). In other close-lying areas, such as Sierra Arana, to the SW, there exist Lower Bajocian materials (Sauzei and Humphriesianum zones), with nodular limestone facies and with a fossil similar association.

If we take into account the regional measurements of paleocurrents (Fig. 4) and the type of facies and fauna, the position where the materials forming the olistoliths were originally deposited was possibly very close to their present position, exactly on the Internal Subbetic ridge, although possibly closer to the Middle Subbetic compared to Sierra Arana.

6. CONCLUSIONS

The study we have carried out in this sector of the southern Middle Subbetic leads us to the following conclusions:

a) The olistoliths studied are embedded in Cretaceous materials of the Fardes Formation in a deep trough domain (Southern Middle Subbetic).

b) This domain is bounded to the SE by a pelagic ridge (Internal Subbetic). The transition between the two domains is a zone with active paleoslopes which favour both exposure and denudation of Jurassic and Cretaceous materials and also the development of a clear synsedimentary tectonic (slumps and olistostromes).

c) The depositional model for the Cretaceous materials is characterized by well-developed channelized sectors with sporadic intercalations of chaotic masses (olistostromes). It depends on the greater or lesser lineality of the supply point inside a extensional tectonic context of the region.

d) The "debrites" facies where the olistoliths studied are present coincided with periods of low sea-level.

e) Paleocurrent measurements suggest a S-SW source for the thickest layers, although the origin of the thinner ones is more widely dispersed.

f) The Ichnofacies found in both section characterize a quite deep marine basin.

g) Cretaceous materials have been dated by means of calcareous nannoplankton, planktonic foraminifera and radiolaria.

h) Nannoplankton assemblages analysis allows us to differentiate the following zones: CC-9 and CC-10 and CC-13 of Sissingh (1977), identifying the Cenomanian-Lower Campanian. The materials and the position of the Jurassic olistoliths within them have thus been dated.

i) The foraminifera have enabled us to identify part

Fig. 15.- Ammonite fauna. All specimens figured at natural size.

Fig. 15.- Fauna de ammonites. Todos los ejemplares figurados a tamaño natural.

1.- *Emileia (Emileia) vagabunda* Buckman. Lower Bajocian, Sauzei Zone, level 10, olitolith -B-.

2.- *Fontannesia cf. grammoceroides* (Haug). Lower Bajocian, Laeviuscula Zone, level 9, olistolith -B-.

3.- *Witchellia rubra* (Buckman). Lower Bajocian, Sauzei Zone, level 15, olistolith -A-.

of the Turonian, and the Santonian-Campanian in the highest layers of the sections; these ages had previously been considered as stratigraphycal gaps.

j) The ammonite fauna collected in the olistoliths lead to recognize the Murchisonae and Concavum zones in the Aalenian and the Discites, Laeviscula, Sauzei and Humphriesianum zones in the Bajocian.

k) The ammonite associations are of a markedly Mediterranean character. They contain percentages of Lytoceratina and especially of Phylloceratina higher than those of the Subbetic as a whole.

l) The presence of *Mollistephanus mollis* and *Skirroceras skolex* is especially remarkable, since these forms had not previously been identified in the Subbetic nor in other typically Mediterranean areas.

m) Source areas indicated by the paleocurrents lack Aalenian materials, but Bajocian materials of some nearby sectors belonging to the Internal Subbetic show a similar lithology and their faunal content is not very different.

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