CONTOURITES IN LAMINATED BLACK SHALE FACIES OF THE ALDEATEJADA FORMATION (PRECAMBRIAN/CAMBRIAN BOUNDARY RANGE, PROVINCE OF SALAMANCA, WESTERN SPAIN)

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ABSTRACT

Laminated black shale facies and phosphorite conglomerates that appear in the lower part of Aldeatejada Fm. (Precambrian/Cambrian boundary range, Province of Salamanca) are interpreted as contourites. In modern seas, contourites form beds related to stable currents of generally low near-bed velocity (2-15 cm/s) that flow coast- or slope-parallel like the actual Gulf Stream. These currents rework or deposit clay, silt or very fine sand depending on fluctuations of flow speed or position of the current. During periods of elevated velocity, features like non-deposition, erosion and formation of conglomerates occur. Such conglomerates appear in the Aldeatejada Fm. and are referred to as gravel-lag contourites. The countourite-producing current is considered as a shelf-impinging oceanic current which carried phosphate-rich water due to offshore upwelling. The current triggered high organic productivity and probably alimented anaerobic bacterial mats wich are preserved in the black shales.

Key words: Contourites, Precambrian/Cambrian boundary range, Laminated black shales, Phosphate conglomerates, Iberian Massif.

RESUMEN

Se describen las facies de pizarras negras laminadas y los conglomerados fosfatados que aparecen hacia la base de la Fm. Aldeatejada (ámbito del límite Precámbrico/Cámbrico) al Sur de Salamanca. Estas facies, que han sido descritas con anterioridad en otras áreas de la península, se interpretan por primera vez como contornitas. Las contornitas se reconocen en los mares actuales como depósitos relacionados con corrientes estables generalmente de muy baja velocidad (2-15 cm/sg) que circulan paralelas a las costas o taludes y retrabajan o depositan arcillas, limos y/o arenas muy finas dependiendo de fluctuaciones en su velocidad o posición. Las contornitas se caracterizan por presentar un bandeado centimétrico y milimétrico, con contactos bruscos a techo y muro, que no muestra ninguna ritmicidad ni orden o secuencia repetible. La baja velocidad de las corrientes relacionadas con su depósito no es suficiente para generar formas de *ripples* en la mayoría de los casos. Cuando las corrientes de fondo alcanzan mayor velocidad se puede desarrollar erosión (caso de la Corriente del Golfo actual) y depósitos de conglomerados. Tales conglomerados de cantos fosfatados aparecen en la Fm. Aldeatejada y son interpretados como contornitas de tipo *gravel-lag*. Se considera que las contornitas se generan por una corriente oceánica que choca con la plataforma y lleva aguas ricas en fosfatos aportados por las corrientes ascendentes. La corriente rica en nutrientes dispara el desarrollo de organismos y probablemente alimenta tapices de bacterias anaerobias que quedan preservados en las pizarras negras.

Palabras clave: Contornitas, ámbito del límite Precámbrico/Cámbrico, pelitas negras bandeadas, conglomerados fosfatados, Macizo Ibérico.

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1. INTRODUCTION

The recognition of contourites in the fossil record has up to now received little attention for comparatively minor distribution of the notion in literature, and for difficulties in distinction among superficially similar facies like distal turbidites and tempestites. Nevertheless, contourites are widespread in modern seas where they are mainly found on continental slopes, rises and deep oceanic basins (Stow and Piper, 1984). This gave rise to relate contourites to stable currents that flow along slope in relatively deep water (certainly below wave base, Lovell and Stow, 1981). However, stable oceanic current systems impinge also on the shelves of continents (e.g. the Gulf Stream off eastern North America) where they may cause erosion, non-deposition, condensation and deposition of contourites (Oczlon, 1990). At present, c. 3 % of continental shelf areas are affected by this type of currents (Swift *et al.*, 1986) which requires an enlargement of the definition previously given by Lovell and Stow (1981) as outlined by Oczlon (1992): "A contourite is a bed deposited or significantly reworked by a current that is persistent in time and space and flows parallel to the coast or the slope of a land area or in the deep sea. The current is the dominant factor controlling sedimentation which may take place in fresh or salt water; the cause of the current is not necessarily critical to the application of the term".

As such, contourites do not show any rhythmic arrangement or repetition of single beds as found in distal tempestites or turbidites, but rather an arbitrary pattern in the vertical distribution of mudstones, siltstones and very fine sandstones. The latter lithologies are most typical for contourites, generally arranged in beds at a millimetric and centimetric scale. Grain size over one bed is often stable or may vary leading to intrabed lamination at the sub-millimetric scale or to normal and reverse grading depending on fluctuations of flow speed of the depositing current. Lower and upper boundaries of contourites are sharp and lamination is plane, sometimes displaying low-angle cross-lamination. Plane lamination is frequent because the flow of contourite-depositing currents is often undercritical, i.e. less than 20 cm/s which is too low to build constructional bed forms such as ripples. Flow speeds in the range of 2-15 cm/s result from direct measurements over contourite drifts (empilement of contourites) in modern seas (Stow and Lovell, 1979).

Near-bottom currents as a result of oceanic wind-driven surface-flow may reach much higher speeds than

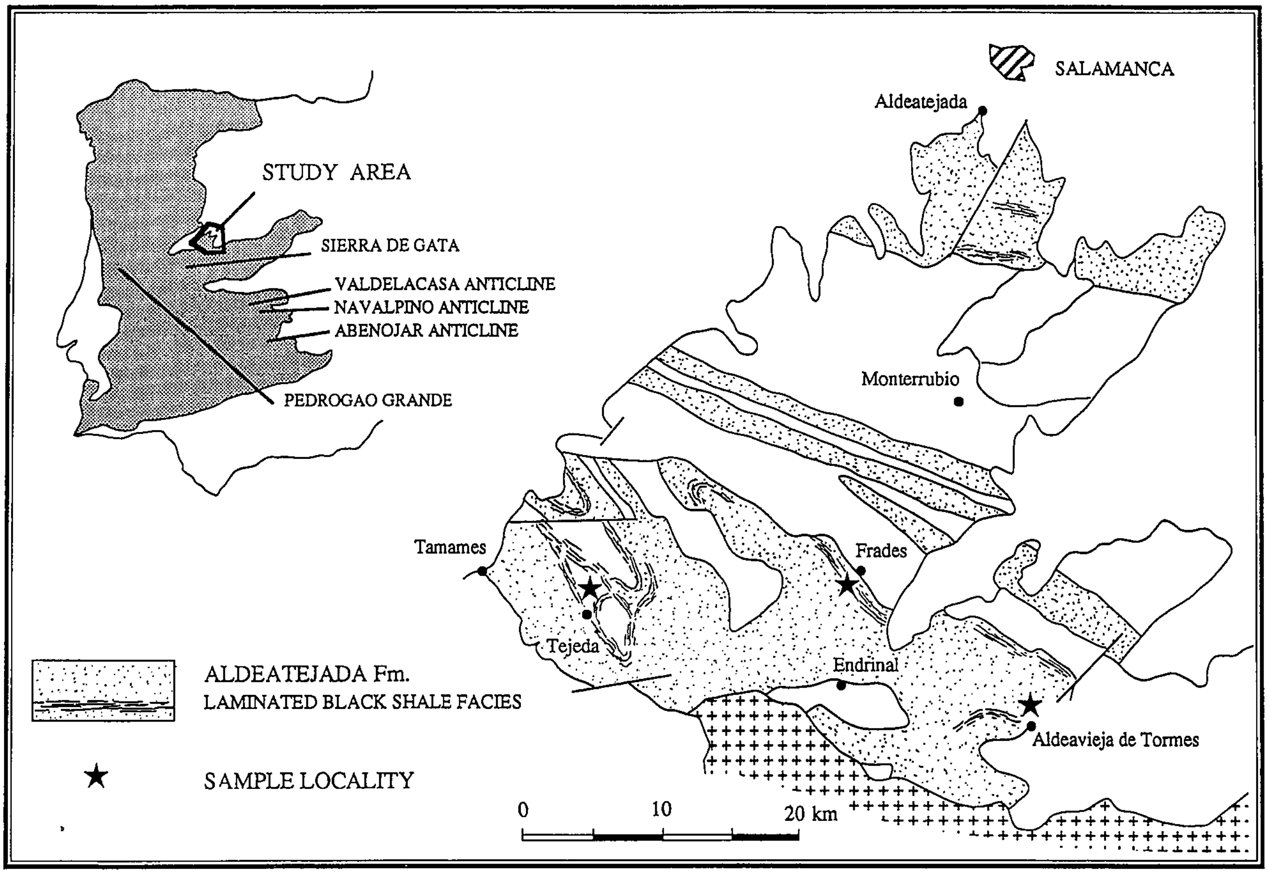

Fig. 1.-Overview of studied outcrops in the Aldeatejada-Fm. and regions with related lithologies on the Iberian Peninsula. Sample localities near Tejeda (long. 6° 0' 36"; lat. 40° 39' 10"), Aldeavieja de Tormes (long. 5° 36' 47"; lat. 40° 35' 30") and Frades (long 5° 47' 18"; lat.- 40° 39' 10").

Fig. 1.-Mapa esquemático con los afloramientos de la Formación Aldeatejada y la situación de otras regiones de la península donde afloran las mismas litologías y facies. Situación de las muestras estudiadas próximas a las localidades de Tejeda (long. 6° 0' 36"; lat. 40° 39' 10"), Aldeavieja de Tormes (long. 5° 36' 47"; lat. 40° 35' 30") y Frades (long 5° 47' 18"; lat. 40° 39' 10").

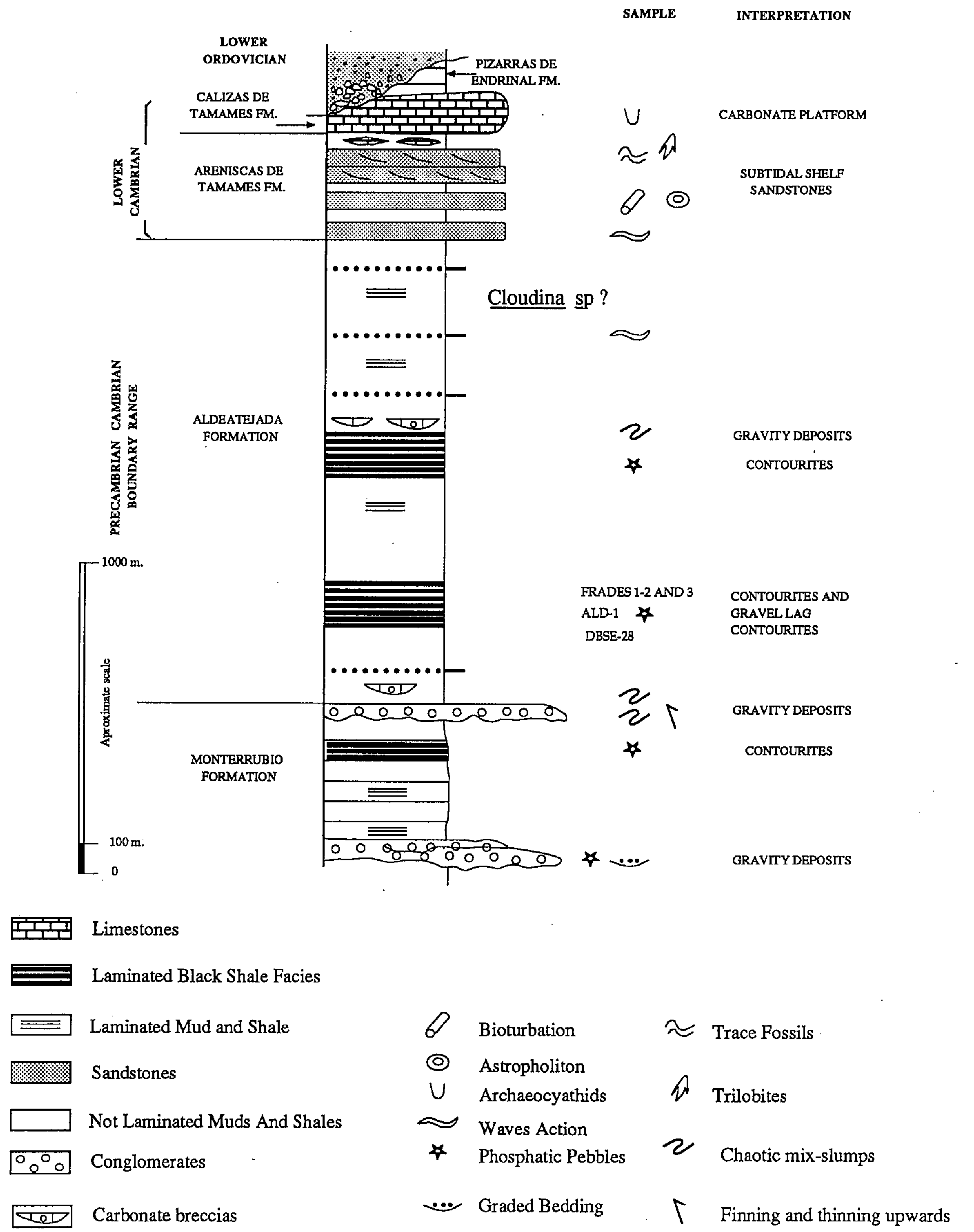

Fig. 2.-General stratigraphic scheme of the study area with the discussed formations. Positions of described and assumed contourites are indicated.

Fig. 2.-Columna estratigráfica general del área estudiada con las formaciones que se discuten en el texto y la localización de las contornitas descritas.

during deposition of contourites, being effective up to depths of 2000 m or more. Such currents are able to cause local erosion of the sea-floor and deposition of conglomerates which may be either current-swept or residual (e.g. Martin and Flemming, 1986; Martin *et al.*, 1982), referred to as gravel-lag contourites (Stow and Piper, 1984). Erosion of the sea-floor and cutting of along-shelf/slope channels is observed under the Gulf

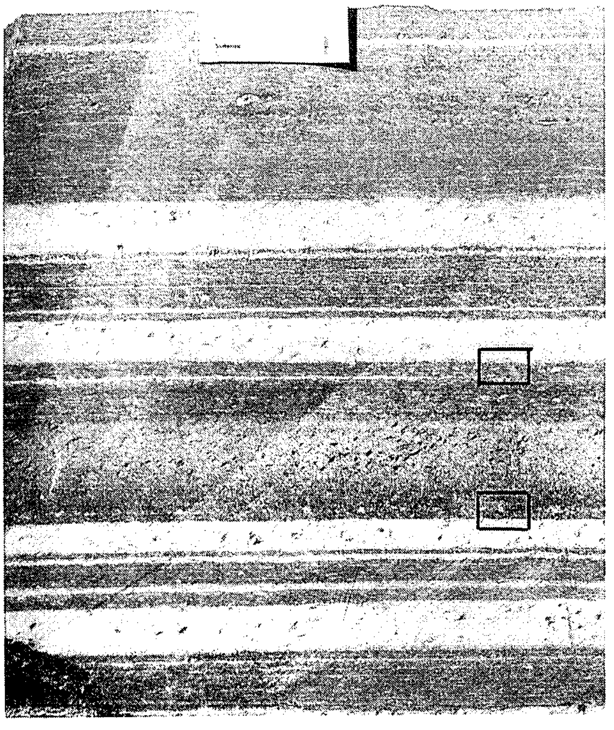

Fig. 3.-Frades 3; Laminated black shale facies with indications of thin-section photos in Figs 7 and 8. Scale bar = 1cm.
Fig. 3.-Muestra Frades 3; Aspecto de las pizarras negras bandeadas de Frades con la situación de las microfotografías de las figs. 7 y 8. Escala gráfica = 1cm.

Fig. 4.-Ald. 1 Sample; Conglomerate with flattened phosphate pebbles (black) interpreted as gravel-lag contourite. Aldeavieja de Tormes. Scale bar = 1cm.
Fig. 4.-Muestra Ald. 1 ; Conglomerado de fragmentos fosfatados (negros) interpretado como una contornita de tipo "gravel-lag ". Aldeavieja de Tormes. Escala gráfica = 1 cm.

Stream (Pinet and Popenoe, 1985). Finally, contourites and current-induced erosion or non-deposition are often associated with oceanic upwelling effects and eutrophication of shelf/slope waters leading to deposition of black shales and phosphorites (Riggs, 1985). Phosphorites may be entrained in strong bottom flow to form gravel-lag contourites as observed in Miocene Gulf Stream deposits (Mullins and Neumann, 1979) or as found associated with density currents (cold or hypersaline bottom flows) in the Mediterranean area (Pedley and Bennet, 1985; Soudry and Lewy, 1990).

Microscope studies in laminated black shales of the Aldeatejada-Fm. suggest the presence of contourites, whose description and palaeogeographic setting form the aim of this paper.

2. STRATIGRAPHY

The Aldeatejada-Fm. (Figs. 1 and 2), as defined by Díez Balda (1980), constitutes a more than 2500-m-thick largely pelitic succession. Remains of phosphatic shelly fossils as figured by Rodriguez-Alonso (1985) , probably *Cloudina* sp.(S.W.F. Grant pers.com.), suggest an age in the Precambrian/Cambrian boundary range, which is consistent with finds of acritarchs (*Micrystridium, Synsphaeridium*) in carbonates of the Aldeatejada-Fm. (Díez Balda and Fournier, 1981) and *Cloudina* sp. (S.W.F. Grant pers. com., Fig. 2). It grades apparently without discontinuity into the fossiliferous Lower Cambrian Tamames Sandstone-Fm. which contains a Pararedlichia trilobite fauna near the top (García de Figuerola and Martínez-García, 1972). It is underlain by the more conglomeratic Monterrubio-Fm. which attains a thickness of c. 2000 m.

The Aldeatejada-Fm. is composed mainly of shales and mud-/siltstones with minor intercalations of sandstones and some lenticular beds of gravity-deposited (debris-flow) brecciated limestones and pebbly mudstones (Fig. 2). Intercalations of laminated black shales appear preferentially in the lowermost part as well as in the upper part of the Monterrubio-Fm.

The laminated black shale facies can be clearly distinguished at outcrop and has been applied as a guide-level for mapping purposes (Díez Balda *et al.*, 1990). Thickness ranges between 10 m and 150 m and the lateral continuity attains 10 km or more. Its typical appearance and association with phosphates and phosphorite conglomerates allow wider regional correlations over the Iberian Peninsula (Fig. 1) as indicated, for example, by works of Díez Balda (1986), Rodriguez-Alonso (1985, north of Sierra de Gata), Nozal and Robles (1988, Valdelacasa anticline, Montes de Toledo), Picart Boira (1988, Navalpino anticline), Lorenzo Alvarez and Solé (1988, Abenojar anticline), and Gama Pereira (1984, Pedrógao Grande). The general importance of phosphates at the beginning of Cambrian time has been stressed by Brasier (1980).

The black shales are rich in sulfide (mainly pyrite) and geochemical analysis reveals elevated concentrations

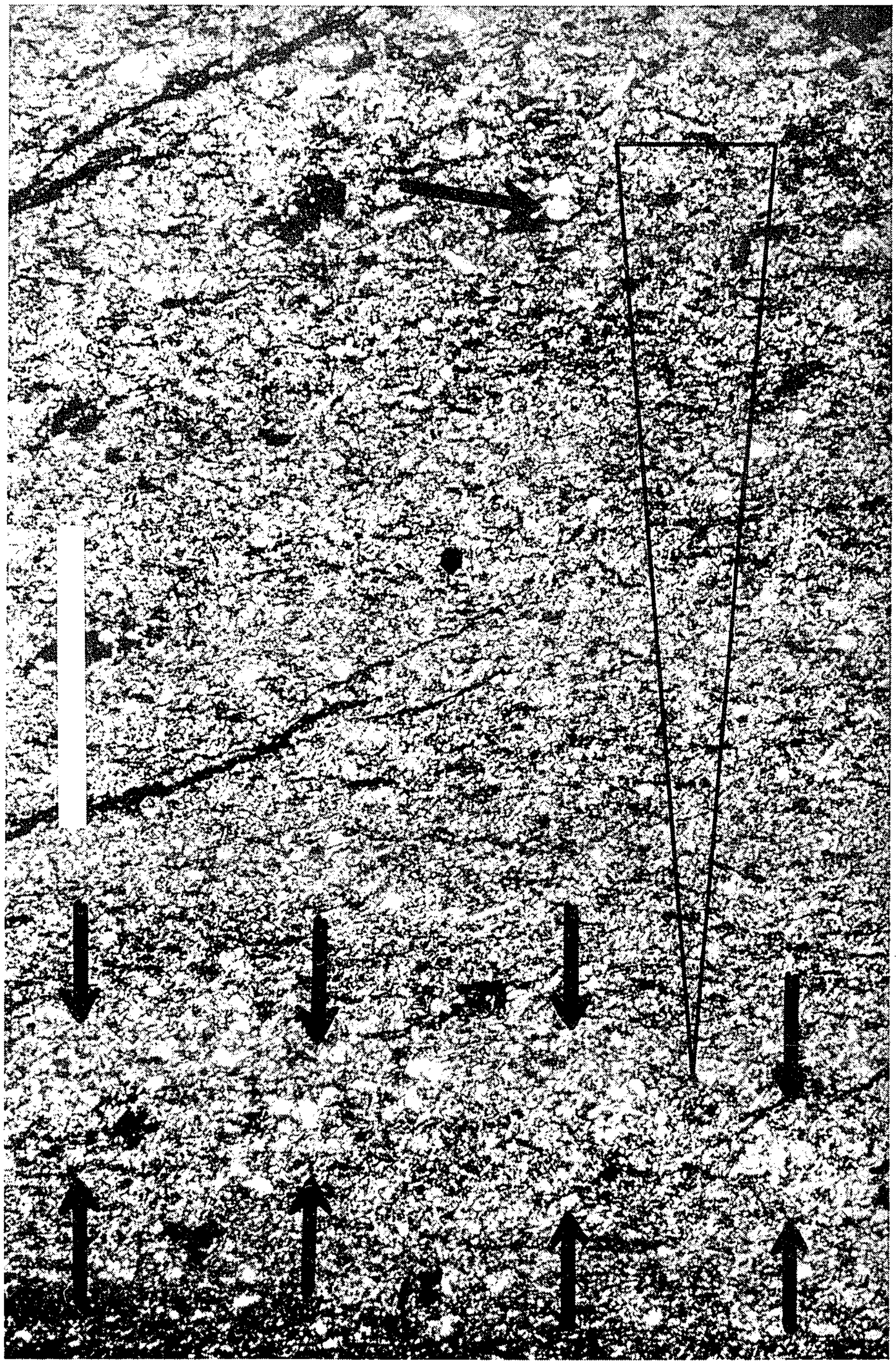

Fig. 5.-Frades 2 ; Black mudstone layer (bottom) followed by bright mudstone layer with lamina enriched in very coarse quartz silt near the base (between arrows). Following interval inversely graded (triangle) with quartz grains in the very fine sand range at the top (upper arrow). + N; escale bar = 1mm.

Fig. 5.-Muestra Frades 2; Nivel de limolita negra (abajo) seguido por otro de limolita de color claro que contiene láminas enriquecidas en granos de cuarzo de tamaño limo muy grueso cerca de la base (entre las flechas). Le sigue un intervalo con gradación inversa (triángulo) con granos de cuarzo de tamaño arena muy fina en el techo (flecha superior). Nícoles cruzados. Escala gráfica = 1mm

of U, Mo, Ni, Th, Cu, and organic matter (Arribas *et al.*, 1983), sometimes associated with remobilized Uranium deposits related to the Variscan orogeny (Martin-Izard and Arribas, 1984).

3. BLACK SHALE FACIES

The black shale facies consists of interlayered grey and black layers, each at a thickness of mainly 1 mm - 2 cm (Fig. 3), which appear homogeneous or consist themselves of various laminae. Lower and upper boundaries between layers are sharp and intra-layer lamination is due to changes of colour and/or grain size at the sub-millimetric scale.

Grey and black layers alternate arbritrarily, i.e. their arrangement is not rhythmic (no systematic increase/decrease of layer-thickness, no repetition of intervals). In-

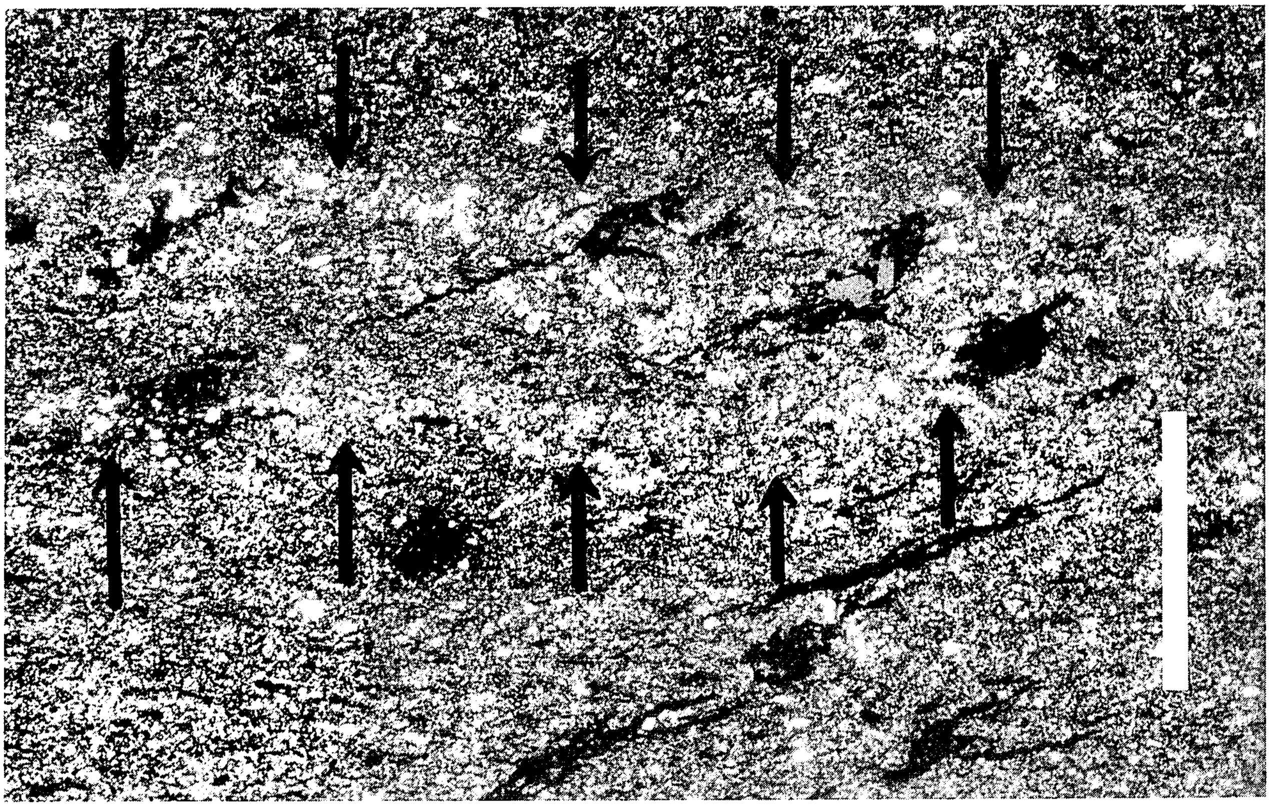

Fig. 6.-Frades 2; Upper part of bright mudstone layer with two laminae enriched in very coarse quartz silt (arrows), followed upwards by black mudstone layer. +N; scale bar = 1mm.

Fig. 6.-Muestra Frades 2; Parte superior de un nivel de limolita de color claro con dos láminas enriquecidas en granos de cuarzo de tamaño limo muy grueso (flechas), seguidas hacia arriba por un nivel de limolita negra. Nícoles cruzados. Escala gráfica = 1mm.

Fig. 7.-Frades 3; Streaky organic material in black layer (lower 2/3 of photo) interlayered with laminae and pockets of quartz grains in the coarse silt range, ocasionally up to very fine sand; black dots are pyrite. Upper third shows a bright layer with quartz grains in the medium silt range without grading. +N; position indicated in Fig.3; scale bar = 1mm.

Fig. 7.-Muestra Frades 3; Cintas o vetas de materia orgánica en un nivel negro (ocupando las 2/3 partes de abajo de la foto) intercalado con láminas y grupos de granos de cuarzo de tamaño limo y ocasionalmente de tamaño arena muy fina; los puntos negros son pirita. La tercera parte superior de la foto está constituida por un nivel de color claro con granos de cuarzo de tamaño limo, sin granoselección. Nícoles cruzados; posición indicada en la figura 3. Escala gráfica = 1mm.

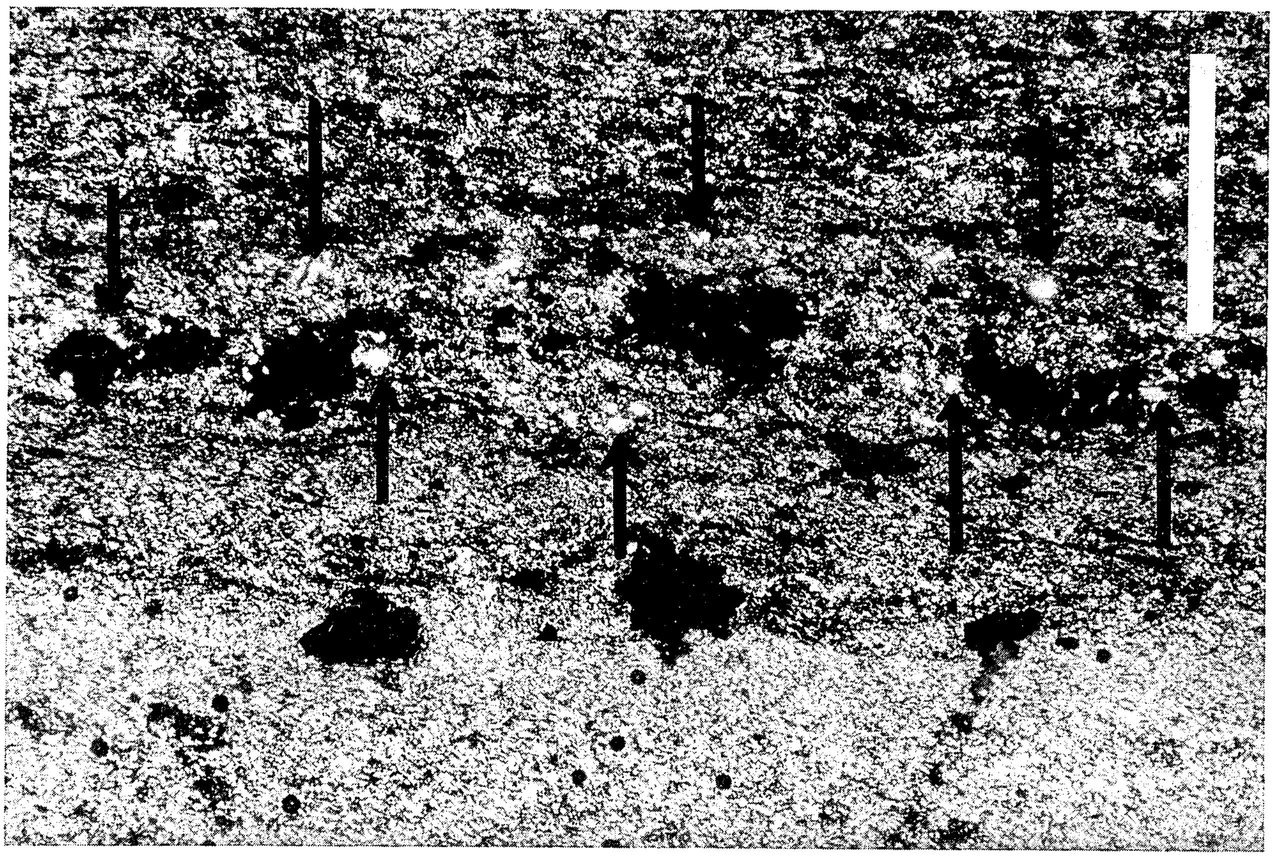

Fig. 8.-Frades 3; Black mudstone layer (upper 2/3 of photo) with lamina enriched in very coarse quartz silt (grains up to very fine sand size) and pyrite (black dots) between arrows. +N; position indicated in Fig.3; scale bar = 1mm.

Fig. 8.-Muestra Frades 3.; Nivel de limolita negra (2/3 partes superiores de la foto) con láminas enriquecidas en granos de cuarzo de tamaño limo muy grueso (y hasta de tamaño arena muy fina) y pirita (puntos negros) entre las flechas. Nícoles cruzados; posición indicada en la figura 3. Escala gráfica = 1 mm.

tercalated in black shales are 5-15-cm-thick sheets of conglomerates which consist of tectonically flattened phosphorite pebbles and minor quartz (Fig. 4).

3.1. *Results of microscope studies*

The bright layers in sample Frades 3 (Fig. 3) represent mudstones following the terminology of Lundegard and Samuels, 1980) and consist of c. 50 % clay matrix and 50 % well-sorted quarz of medium silt size with the coarsest grains in the coarse silt range. Distribution of matrix content and quarz grain size are constant throughout one layer which is devoid of grading either by decrease of grain size or increase of matrix content (Fig.7, up).

On the contrary, a bright layer investigated in sample Frades 2 (mudstone with c. 50 % matrix and grains up to very fine sand size) shows internal lamination with differences in grain size distribution (Fig. 5). Near the base occurs a 0.4-mm-thick lamina enriched with coarse quartz silt, which does not coincide with the change of colour being produced within the subjacent mudstone, i.e. better aereated conditions are not related to sudden influx of coarser material. The following interval shows reverse grading (Fig. 5), and two 0.2-mm-thick laminae of coarse quarz silt situated in the top part of the grey layer (Fig. 6).

Black layers of all samples show a more variable aspect and are composed of wavy laminae with opaque organic material (0.01 - 0.05 mm, Fig. 7, sometimes absent, Fig. 5) interlaminated with dark clay matrix. Within black layers occur laminae of medium to coarse quartz silt (Fig. 7) and enrichments of quartz grains up to very fine sand size which form the coarsest grains of the corresponding sample (Fig. 8). Enrichments of coarse grains are tied to opaque organic laminae (Fig. 9) and to laminae with elevated pyrite content (Fig. 8), which thus represent the levels with highest depositional energy.

3.2. *Interpretation*

None of the investigated samples shows evidence for deposition by gravity (decantation), but exclusively for either stable or fluctuating action of weak bottom traction currents over one layer (bed) which permits a classification as muddy contourites (comp. Stow and Lovell, 1979 ; Oczlon, 1992).

Wavy black laminae of opaque organic material in black layers may represent either concentrations of

Fig.9.- DBS 28; Wavy laminae composed of black organic matter, interpreted as anaerobic bacterial mats . Black laminae are grouped to form black mudstone layer and show good correlation with coarser quartz grains up to fine/very fine sand (arrows). Bright layers are composed of ungraded mudstone with 50-60% medium quartz silt. +N; scale bar = 1mm.

Fig. 9.-Muestra DBS 28; láminas de forma ondulada compuestas por materia orgánica, interpretadas como tapices de bacterias anaerobias. Las láminas negras están agrupadas formando lechos de limolita negra y muestran una buena correlación con la presencia de los granos de cuarzo más gruesos, tamaño superior al de arena fina/muy fina (flechas). Los niveles claros están compuestos por limolitas sin granoselección con 50-60% de granos de cuarzo de tamaño limo medio. Nícoles cruzados; escala gráfica = 1mm.

dead organisms after red tides (mass dying) or mats of sulfate-reducing bacteria. Such mats occur in recent anoxic environments and are likely to be producers of similar facies as found in Toarcian (Jurassic) black shales (O'Brien, 1990). An origin as mats of sulfate-reducing bacteria can explain the correlation with coarse quartz grains by acting as a trap for grains from the overflowing currents' suspension (micro-relief, high cohesion). Further, the correlation of pyrite and relatively high depositional energy (Fig. 8) suggests high amounts of free S^{2-} produced by sulfate-reducing bacteria in such laminae. It is, therefore, concluded that the current alimented bacterial mats with organic matter or supported their growth in an other way which was inhibited as flow speed waned leading to deposition of brighter (grey) layers.

4. DISCUSSION

The contourites described in this work occur among a variety of genetically different sediments which include gravity deposits (debris-flows, turbidites) and probably also wave-influenced deposits (tempestites) which have been found in the underlying Monterrubio Fm. Phosphorite conglomerates treated in the present work are not graded and have a rather sheet-like appearance overlying or cutting slightly into subjacent black shales; they do not occur as classical channel-fills as observed in turbidite fan systems. Such occurrences are likely to represent gravel-lag contourites as described above resulting from steady botton current activity with removal of the finer material and concentration of remaining phosphorite nodules. Similar relations are described by Picart Boira (1988) from the Navalpino anticline and by Lorenzo Alvarez and Solé (1988) from the Abenojar anticline in the southern Iberian Massif (Fig.1). Phosphorite conglomerates are interpreted by the latter authors as hardground pavements which is consistent with an origin as gravel-lag contourites.

A related stratigraphic succession , referred to as "Pusa Siltstones Fm.", is known from the Valdelacasa anticline in the Montes de Toledo (Fig.1, comp. Gabaldón *et al.* (1989), Santamaría Casanovas, 1988). According to the description of Gabaldón *et al.* (1989), the Pusa Siltstones Fm. appears correlatable with the study area, whereas the highest part (their subunit 6) corresponds to the Aldeatejada Fm., while subjacent units are comparable with the Monterrubio Fm., Gabaldón *et al.* (1989) indicate the abundance of gravity deposits and the presence of tempestites (hummocky cross bedding). They also describe condensed intervals with phosphatization associated with clayey«silty beds and intervals of "Well Laminated Muds" with alternating dark and bright layers, containing characteristics similar to the ones described in the present paper. The Well Laminated Muds are interpreted by Gabaldón *et al.* (1989) as dilute turbiditic deposits, a view which is also favoured by Santamaría Casanovas (1988). Yet, in their conclusion on the origin, Gabaldón *et al.* (1989) anticipates that the condensed phosphatic and laminated facies are related to (oceanic?) upwelling effects due to sea-level high-stands. During such periods, platform reworking with development of gravity deposits from gullies and downcutting canyon heads was largely inhibited.

It is here suggested that high-stands of sea-level allowed the impingement of an oceanic surface current system on the shelf/slope environment of the Aldeatejada Fm./Pusa Siltstones Fm. and related succesions of the Iberian Peninsula. It is likely that such a current system was responsible for the input of nutrient-(phosphate-) rich waters by offshore upwelling in a not far distant oceanic area. As such, features like deposition of anoxic sediments, formation of phosphates, deposition of muddy- and gravel-lag contourites, condensation and submarine erosion can be genetically related to one process.

During low-stands of sea-level, the previously formed phosphorites and other sediments in the shelf/slope environment may have been partly engaged in reworking and gravitational transport to form graded conglomerates and related facies types as described by Díez Balda (1986), Rodríguez Alonso (1985) or Gabaldón *et al.* (1989).

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