DEPOSITIONAL PROCESSES OF SUBMARINE CHANNEL-FILL CARBONATE (LATE PRECAMBRIAN, SALAMANCA, SPAIN)

M.I. Valladares (*) and M.D. Rodríguez Alonso (*)

ABSTRACT

In the SW of the province of Salamanca (Spain) there are extensive outcrops of late Precambrian rocks commonly termed the «Complejo Esquisto Grauwackico (CEG)». These rocks contain, in their upper part, several discontinuous siliciclastic-carbonate bodies.

Carbonate sediments overlie an erosive surface which cuts 10 m into underlying siliciclastic deposits. Nine sequences are observed in these carbonates. Each sequence is composed of two facies: calcareous breccias at the base and thin-bedded carbonates towards the top. The breccias are generally clast-supported, with flat and angular clasts. The thin-bedded carbonates are mainly composed of sandstone-limestone couplets that are either parallel and current-ripple cross-laminated, or structureless. In the thin-bedded carbonates there are also pebbly-sandy limestone layers with inverse grading, and a few layers with large-scale cross-lamination.

These carbonate sequences are interpreted as submarine channel fill deposited by viscous debris flows, density modified grain flows and high-density sandy turbidity currents. Sporadic tractional processes and low-density turbidity currents, fluidization and load processes also occur.

Key words: Calcareous breccias, Thin-bedded carbonates, Debris flows, Grain flows, High-density sandy turbidity currents, Channel-fill.

RESUMEN

En el SW de la Provincia de Salamanca afloran extensamente los materiales del Precámbrico terminal pertenecientes al «Complejo Esquisto Grauwackico (C.E.G.)», en cuya parte superior se encuentran cuerpos carbonatados discontinuos. El presente trabajo estudia uno de estos cuerpos.

Los sedimentos carbonatados se encuentran sobre una superficie erosiva que corta 10 m de materiales siliciclásticos. En estos carbonatos se reconocen nueve secuencias. Cada secuencia está constituida por dos tipos de facies: brechas calcáreas en la base y carbonatos estratificados en capas finas en el techo. Las brechas son de cantos aplanados, angulares y generalmente clasto-soportadas. Las capas finas están constituidas fundamentalmente por dobletes arenoso-carbonatados con laminación paralela y laminación cruzada por migración de «ripples» de corriente o sin estructuras; por calizas arenosas con cantos, generalmente con granoselección inversa y esporádicamente aparecen algunas capas con laminación cruzada.

Estos depósitos se interpretan como el relleno de un canal submarino próximo a un talud por procesos de «debris flows» viscosos, «grain flows» de densidad modificada y corrientes de turbidez arenosas generalmente de alta densidad, junto con esporádicos procesos tractivos y corrientes de turbidez de baja densidad. Además se deducen procesos de fluidificación y carga, que serían responsables de la formación de algunas de las brechas.

Palabras claves: Brechas calcáreas, Capas finas, «Debris flows», «Grain flows», Corrientes de turbidez arenosas de alta densidad, Relleno de canal.

Valladares, I. y Rodríguez Alonso, D. (1988): Depositional processes of channel-fill carbonate (Late Precambrian, Salamanca, Spain). *Rev. Soc. Geol. España,* 1, (1-2), 165-175.

Valladares, I. y Rodríguez Alonso, D. (1988): Procesos deposicionales en un canal carbonatado (Precámbrico terminal de Salamanca, España). *Rev. Soc. Geol. España,* 1, (1-2), 165-175.

1. INTRODUCTION

The outcrop studied is situated in the western part of the Iberian Peninsula (Fig. 1). The rocks studied occur within a monotonous succession late Precambrian slates and sandstones, with minor conglomeratic and carbonate intercalations, known as the «Complejo Esquisto Grauwackico (CEG)». The section is situated below and in stratigraphic continuity with lower Cambrian metasediments. Stratigraphic and sedimentologic studies

---

(*) Department of Geology. University of Salamanca. 37008 Salamanca. Spain.

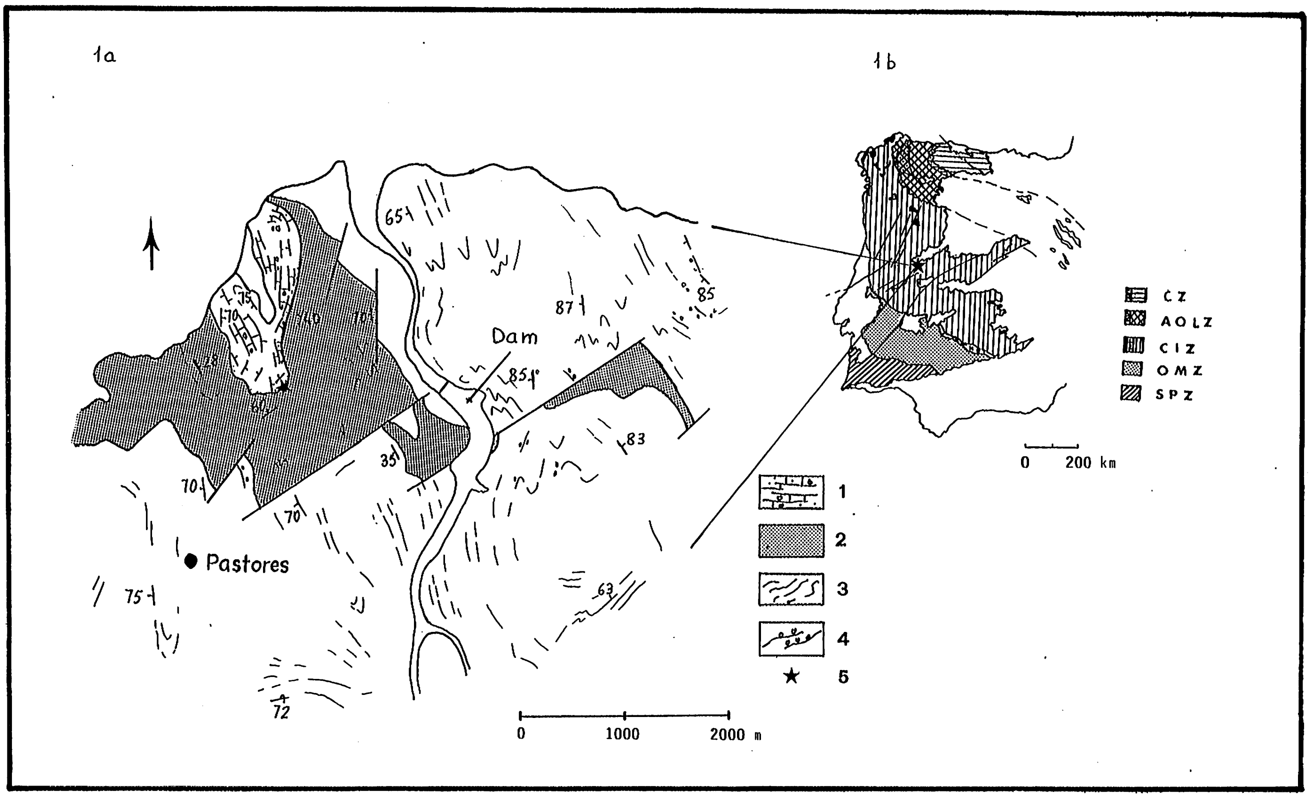

Fig. 1.—a) Location map and regional geological sketch of the «Complejo Esquisto Grauwackico» in the study area after Rodríguez Alonso (1982). 1. Siliciclastic-carbonate levels. 2. Black slates and related rocks. 3. Sandstones and slates. 4. Conglomeratic levels. 5. Outcrop of Pastores. b) Hercynian belt divisions after Julivert *et al.*, (1972): CZ-Cantabrian Zone, AOLZ-West Asturian Leonese Zone, CIZ-Central-Iberian Zone, OMZ-Ossa-Morena Zone, SPZ-South-Portuguese Zone.

Fig. 1.—a) Esquema geológico regional del «Complejo Esquisto-Grauwackico» en el área de estudio (Rodríguez Alonso, 1982). 1. Niveles siliciclástico-carbonatados. 2. Pizarras negras y sedimentos asociados. 3. Areniscas y pizarras. 4. Conglomerados. 5. Afloramiento de Pastores. b) Divisiones de la Cadena Hercínica (Julivert *et al.*, 1972): CZ-Zona Cantábrica, AOLZ-Zona Astur Occidental Leonesa, CIZ-Zona Centro-Ibérica, OMZ-Zona Ossa-Morena, SPZ-Zona Sur-Portuguesa.

indicate that this stratigraphic section consists largely of deep-marine turbidites that progressively shallowed upwards (Rodríguez Alonso, 1982, 1985; Díez Balda, 1982; Bernardo de Sousa, 1982).

In the area of Las Hurdes-Sierra de Gata (W sector of Spanish Central System) Rodríguez Alonso (1982, 1985) distinguishes two units within CEG: The Lower Unit is essentially sandy and is characterized by interbedded sandstones and slates with minor intercalations of amphibolitic rocks, diverse conglomerates, and chaotic deposits, these last particularly in the upper part of the unit. The Upper Unit is mainly pelitic and contains several stratigraphic levels of black slates with pelitic, sandy and conglomeratic interbeds. Discontinuous beds of siliciclastic-carbonates, quartz-amphibolitic rocks and conglomerates composed of phosphate clasts are present locally.

The mixed siliciclastic-carbonate sedimentation is of little quantitative importance compared with the remaining materials composing the CEG. It is seen to be associated with different stratigraphic levels of black slates. Within these mixed deposits is included a group of well-bedded sandy limestones and calcareous breccias that passes both laterally and vertically into interbedded calcareous and/or siliceous (locally subarkosic) conglomerates, sandstones and pelitic deposits. The whole succession is commonly chaotic, with slumps, breccias and olistostromes. The characteristics exhibited by these materials suggest they are shelf-carbonate sediments, which were redeposited with siliciclastic sediments at different times, in an unstable slope setting (Rodríguez Alonso, 1982, 1985).

One such siliciclastic-carbonate deposit crops out in the neighbourhood of the village of Pastores (Fig. 1) in the SW part of province of Salamanca. In order to infer the depositional mechanisms of such deposits, a detailed study of their geometric, lithologic and sedimentological characteristics is presented, based upon the best available exposure.

2. FACIES

The carbonated section of Pastores is composed of a succession of channel-fill facies (Fig. 2). The channel surface is irregular with observed erosional relief of about 10 m and a visible lateral extent of 120 m.

Channel-fill carbonates are composed of two lithofacies: calcareous breccias and thin-bedded carbonates. These facies occur together in nine depositional sequences with breccias in the lower portion and thin-bedded carbonates in the upper part.

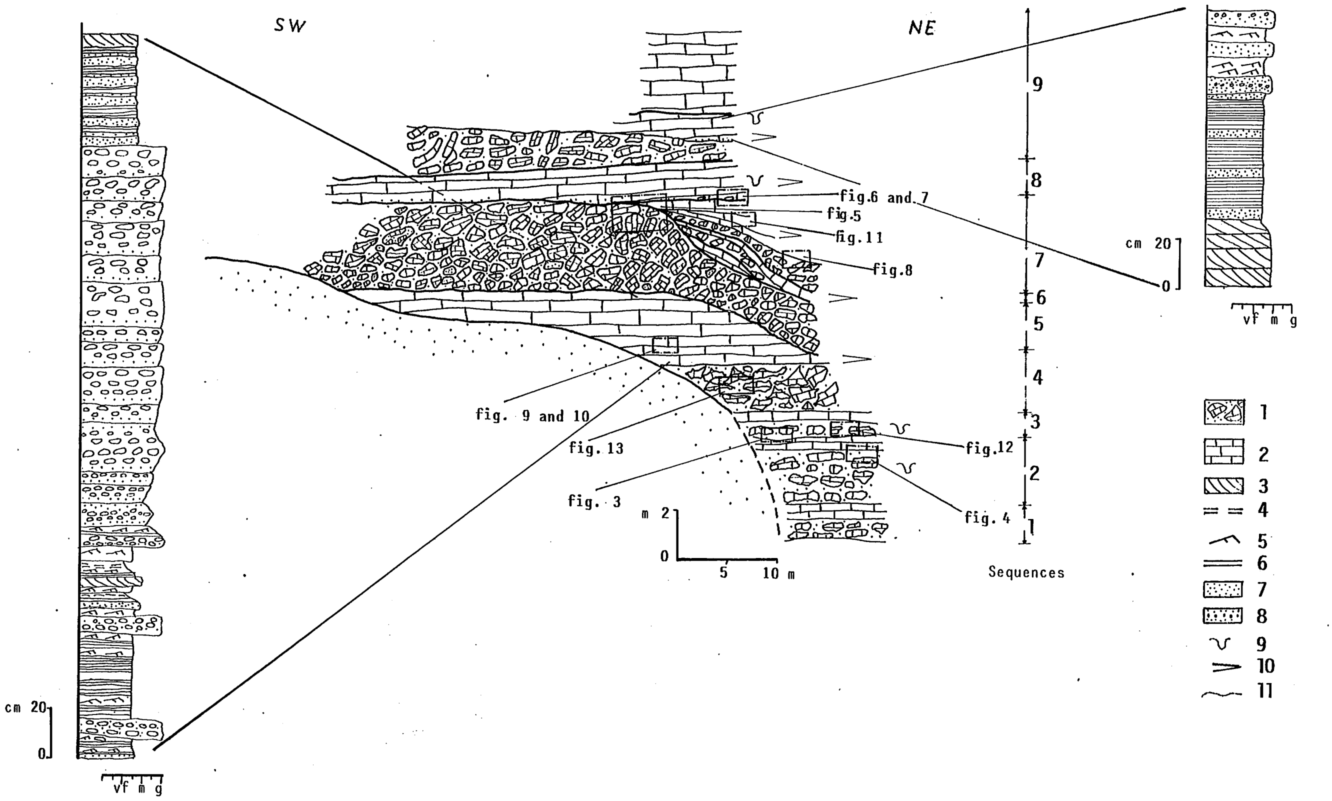

Fig. 2.—Geometry of the channel filled with nine sequences and thin-bedded carbonated sections of sequences 4 and 9. 1. Calcareous breccias. 2. Thin-bedded carbonates. 3. Cross-lamination (dunes). 4. Parallel lamination in silts. 5. Current ripples. 6. Parallel lamination in sands. 7. Massive. 8. Inverse to normal grading. 9. Load structures. 10. Amalgamation. 11. Erosive surface. vf-Very fine sand. m-Medium sand. g-Gravel.

Fig. 2.—Geometría del canal con las nueve secuencias que lo rellenan y columnas detalladas de las capas finas de las secuencias 4 y 9. 1. Brechas calcáreas. 2. Capas finas. 3. Laminación cruzada (dunas). 4. Laminación paralela en limos. 5. «Ripples» de corriente. 6. Laminación paralela en arenas. 7. Masivo. 8. Granoselección inversa a normal. 9. Estructuras de carga. 10. Amalgamación. 11. Superficie erosiva. vf-Arena muy fina. m-Arena media. g-Grava.

2.1. *Calcareous breccias*

2.1.1. *Matrix-or grain-supported calcareous breccias*

These are calcareous breccias composed of flat, angular, pebble-to cobble-size (sizes range from 1 up to 25 cm) clasts in a structureless matrix-or grain-supported fabric. Most clasts (more than 95%) are composed of dark-grey sandy limestone with sand-sized grains of quartz and rock fragments. Most clasts are parallel laminated; some are distorted. Up to 3% of the clasts are rounded pebbles (2-3 cm) of light-grey micritic limestone.

Petrographically, the most abundant clasts are composed of sandy-crystalline limestone, probably originally possessing a wackestone texture. They are composed of irregular pseudospar crystals and, to a lesser extent, of microspar, with disseminated organic matter. Within this array of crystals, there are allochem ghosts; some resemble serpulids worm tubes, others have irregular forms with a single calcite crystal surrounded by an envelope of organic matter. These latter ghost fabrics may be recrystallized grains with micritic envelopes, perhaps produced by boring. There are also sand-sized grains of quartz, plagioclase, quartz-biotite rock fragments.

The lithological and sedimentological characteristics of the clasts described above are the same as those of some thin-bedded carbonates which occur above the breccias and which are discussed below. Locally, these thin-bedded carbonates are seen to be fragmented *in situ* by load and fluidization processes which have initiated a brecciation (Fig. 12).

The breccia matrix is a beige coloured silty-sandstone. It is composed of subangular to subrounded, fine sand-and silt-sized quartz grains with lesser amounts of feldspar, and sericite. These lithological and textural characteristics are identical to those of some sandy beds* in the thin-bedded carbonates situated above the breccias.

In general, the lower limits of the breccias are poorly exposed, but where they are visible, as in the case of the boundary between sequences 2 to 3 (Fig. 3), there appears to be a gradual transition from the lower thin-bedded carbonates to the breccia above. Likewise, the base of the carbonate succession, which at present constitutes the deepest par of the channel, is not visible. The

---

(*) The term *layer* is used for *sedimentation unit* and usually corresponds to a lithologic couplet; the term *bed* is used for the *lithologic unit* forming part of the layer (or the whole layer where it is incomplete: i.e. sandstone-missing or carbonate-missing) and (Ricci Lucchi, 1981).

Fig. 3.—Transition of sequences 2 to 3. Note the gradual transition from the lower thin-bedded carbonates to the upper breccia.

Fig. 3.—Tránsito de las secuencias 2 a 3. Obsérvese el paso gradual de las capas finas inferiores a la brecha de encima.

Fig. 4.—Gradual transition from breccia to thin-bedded carbonates in sequence 2.

Fig. 4.—Transición gradual de brecha a capas finas en la secuencia 2.

upper limit (Fig. 4) is a gradual transition to the thin-bedded carbonates, due to a decrease in brecciation, until the layers acquire a lateral continuity. The thickness of the breccias ranges from 1.40-2.20 m.

Breccias of such characteristics constitute the base of sequences (1-4) that fill the channel. All of them rest on a basal erosive surface at some point (Fig. 2).

2.1.2. *The poorly sorted calcareous breccia*

This is a grain-supported and poorly sorted calcareous breccia (Fig. 5). The lower limit is an erosive surface cutting up to 2.5 m of thin-bedded carbonates of the previous sequence. Locally, the breccia lies over sequence 4, while in others places it rests on the basal erosive surface of the channel (Fig. 2).

Clast size varies between 1 cm and 1 m. The larger clasts are angular whereas the smaller clasts are subrounded to rounded. Generally, no internal organization is apparent, though in places a very rough inverse grading is apparent. Clasts are composed of limestone, sandy-limestone, siliceous sandstone and calcareous breccia. The first two types, which represent more than 80% of the clasts, commonly contain planar laminae and/or current-ripple cross-laminae. Petrographically, the calcareous clasts are composed of iron-rich pseudospar crystals, with abundant organic matter. The laminations are marked by very fine sand-and silt-sized quartz grains and, to a lesser extent, of plagioclase and rock fragments composed of microcrystalline quartz ± sericite.

The matrix is sandy-pelitic or silty-sandstone, with an irregular distribution. It is composed of fine and very fine sand and silt-sized quartz grains.

No bedding surfaces were observed within the breccia and its thickness varies laterally between 2 and 3.5 m. The upper surface of this unit is erosional with 3.6 m of relief. This breccia constitutes the base of the sequence 5 and may be followed for a lateral extension of some 60 m.

2.1.3. *Flat-clast calcareous breccias*

These are grain-supported calcareous breccias with flat clasts. The lower limit is an almost planar, slightly scoured surface, (with a relief of a few cm only, Fig. 6).

Clast size is variable ranging from pebble to boulder size. Maximum clast size is between 45-70 cm. These breccias are disordered and display a few flat clasts oriented with their largest dimensions perpendicular to the bedding, though more commonly they are parallel to it.

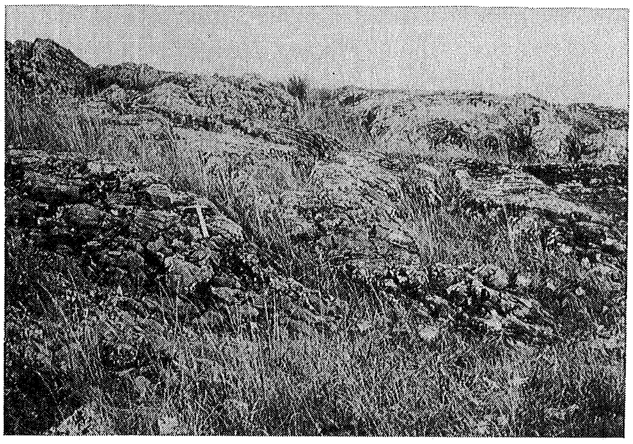

Fig. 5.—The poorly sorted calcareous breccia, sequence 5, overlaid by thin-bedded carbonates of sequences 7 and 8.

Fig. 5.—En primer plano; aspecto de la brecha calcárea heterométrica, secuencia 5. Encima y al fondo, capas finas de las secuencias 7 y 8.

Fig. 7.—Detail of sequence 8 showing clasts with parallel lamination and with wave ripples.

Fig. 7.—Detalle de la foto anterior en la que se ven cantos con laminación paralela y con «ripples» de olas.

Locally, a slight imbrication can be observed, together with a reduction in the number of clasts towards the top. The breccias are composed of four types of clasts: (1) dark-grey limestone clasts (more than 80%) which are flat and angular and commonly display planar laminae and/or rippled cross-laminae (some of them wave ripples) (Fig. 7). Petrographically, they are composed of iron-rich pseudospar crystals with relatively abundant organic matter. Laminations are composed of very fine sand-sized quartz grains. There are also some irregular rock fragments composed almost exclusively of sericite with small amounts of microcrystalline quartz. (2) Grey limestone clasts with abundant sand-sized quartz grains. Petrographic examination shows that these are composed of iron-rich pseudospar crystals and skeletal ghosts that resemble serpulids worm tubes. Sand-sized quartz grains, plagioclase or sericite are also present. (3) Dark-grey micritic limestone clasts, moderately rounded. These are the least abundant among the carbonate clasts. (4) Quartz sandstone clasts. These represent less than 1% of the clasts.

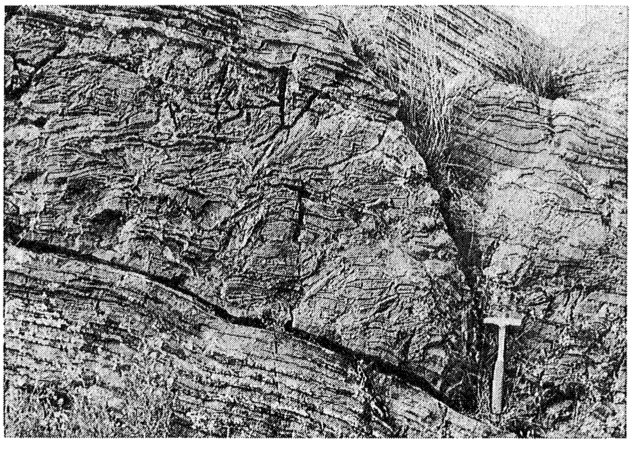

Fig. 6.—Sequence 8. Flat-clast calcareous breccia. Note the planar erosive basal surface.

Fig. 6.—Secuencia 8. Brecha calcárea de cantos tabulares. Obsérvese la superficie inferior erosiva planar.

The breccia matrix is a beige coloured calcareous pelitic-sandstone. It is composed of fine to very fine sand- and silt-sized quartz grains, with lesser amounts of feldspar and pelitic rock fragments within a sericite mass.

No bedding surfaces are visible within the breccias and the upper surface is irregular. The overlying thin-bedded carbonates drape over this irregular surface (Fig. 8). The thickness of the breccias typically varies between 0.2-2.0 m and is locally seen to be lenticular.

Flat-clast calcareous breccias constitute the base of each of the upper sequences (6-9) (Fig. 2).

2.2. *Thin-bedded carbonates*

In the present work the term «thin-bedded» is employed to refer to those beds less than 20 cm thick (after Nelson *et al.*, 1978). Three kinds of thin-bedded carbonates are recognized.

2.2.1. *Sandstone-limestone couplets*

Thin-bedded carbonates composed of what has been termed «sand-stone-limestone couplets» are comprised of two beds: (i) 2 mm-2 cm of beige coloured sandy limestone or fine to medium grained sandstone over which rests, (ii) another bed of 2-5 cm of dark-grey limestone with less than 10% of fine to coarse sand-sized quartz grains and rock fragments (Fig. 9). The lower surface of the couplet is a planar erosive surface, while the transition from the more siliciclastic bed to the more calcareous one occurs either by sharp surfaces or by a transition of various milimeters.

Two kinds of couplets predominate throughout the thin-bedded carbonates. One kind of couplet is structureless, or in places, normally graded. The other kind of couplet is parallel laminated. There are fewer couplets in which the succession of structures can be interpreted as a function of the flow regime: T_{bc} of Bouma (1962)

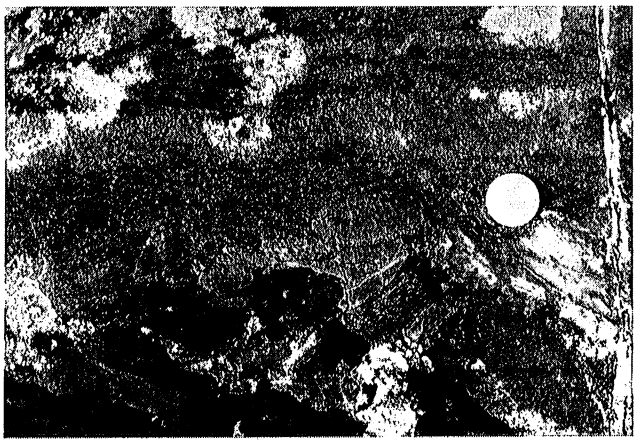

Fig. 8.—Upper limit of flat-clast calcareous breccia in sequence 7. Note the clasts protruding out and above the thin-bedded carbonates with parallel lamination adapting to these irregularities.

Fig. 8.—Límite superior de la brecha de cantos tabulares de la secuencia 7. Obsérvese los cantos sobresaliendo y las capas finas con laminación paralela adaptándose.

(1962) and rarelly the top missing sequences of Bouma (T_{ab}, T_{ac}, T_{abc}, T_{bcd}).

Amalgamation, scour and fill, and load structures occur in the different thin-bedded calcareous successions. These latter are common in the lower sequences (1-3) where flame structures and fracturing of certain beds can be noted. These also occur locally in sequences 5, 7 and 8.

Petrographic studies show that the grey limestone beds are composed of iron-rich pseudospar and microspar, with allochem ghosts (worm tube sections? and others) rich in organic matter. They contain fine, very fine sand -and silt-sized quartz grains and, to a lesser extent, plagioclase grains. The sandy-limestone beds are composed of crystals of iron-rich pseudospar and locally of dolospar with fine, very fine sand -and few silt-sized quartz grains. In both beds, specially in the grey limestones; there are relatively abundant medium-coarse sand-sized volcanic rock fragments, some with geometric forms and others that are highly irregular, composed of sericite, microcrystalline quartz and a few plagioclase microlites. The sandy beds are composed of calcareous quartz sandstones containing quartz grains and lesser amounts of feldspars and rock fragments (microcrystalline quartz and pelite).

Fig. 9.—Sandstone-limestone couplets in sequence 4. Note the planar erosive basal surface and the transition from one bed to another. The more siliciclastic bed is darker. All couplets have parallel lamination.

Fig. 9.—Aspecto de los dobletes arenoso-carbonatados en la secuencia 4. Se puede observar la superficie inferior erosiva planar y el paso de un término a otro. El término arenoso es el más oscuro. Todos los dobletes presentan laminación paralela.

2.2.2. *Pebbly-sandy limestone layers*

Another kind of thin-bedded carbonates are pebbly-sandy limestone layers, generally less than 10 cm in thickness, though in a few instances reaching 20 cm. The pebbles are calcareous and siliciclastic with a modal size of 3-4 cm, though cobble-sized clasts of up to 8 cm have been recorded. These layers are consistently interbedded between couplets. The lower limit is a planar erosive surface and the internal organization of the layers may be structureless or may be inversely and/or (more rarely) normally graded (Middleton, 1967) (Fig. 10). It is also possible to note inverse grading in the lower half of a layer and normal grading in the upper half. The same layer may change laterally so that the whole layer is either normally or inversely graded. Wedgings and amalgamations of layers are usually found. Siltstones are locally intercalated wit the thin-bedded carbonates, though they are scarce.

Petrographically, the pebbly-sandy limestone layers are composed of a mass of iron-rich pseudospar and microspar with organic matter, and some allochem ghosts containing disperse calcareous clasts. These clasts are rich in organic matter and exhibit an irregular shape and a size greater than 2 mm. Likewise, fine to coarse sand-sized grains of quartz, microcrystalline volcanic rock fragments and plagioclases are common. The siltstone layers are composed of faintly laminated subangular quartz grains and very scarce grains of feldspar.

2.2.3. *Layers of dunes*

Layers of dunes with heights of 6-27 cm and wavelengths of 1.43-2.65 m occur above certain breccia levels or interbedded between structureless or parallel laminated couplets. These layers of dunes display large-scale planar cross-laminae (Fig. 11) with ripples locally developed toward the top. More rarely, several layers of dunes are superimposed one above the other.

The different groups of thin-bedded carbonates described above overlie the breccias. In sequences 1-3 the breccia to thin-bedded carbonates transition is gradual (Fig. 4). In sequence 5 they are separated by an erosive surface. In sequences 6-9 (Fig. 8) they are separated by an irregular surface which is moulded around the pebbles emerging from the breccias.

Finally, it should be noted that the thin-bedded carbonates of the three lower sequences show an upward thinning of the sandy limestone or sandstone beds and an upward thickening of the grey limestone beds. In the thin-bedded carbonates of the four upper sequences (6-9)

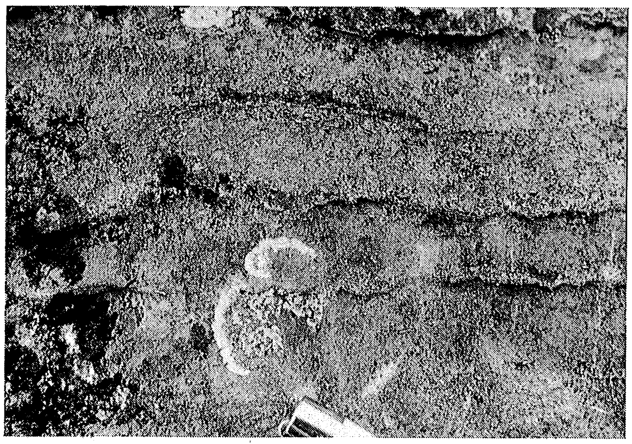

Fig. 10.—Sequence 4. Pebbly-sandy limestone layers with both inverse coarse tail-grading or structureless.

Fig. 10.—Secuencia 4. Capas de calizas arenosas con granoselección negativa en la cola gruesa y sin estructuras.

the opposite occurs. The sandy limestone or sandstone beds thicken upwards and the grey limestones thin upwards, both within each sequence and in successive sequences. This seems to point to a gradual impoverishment in siliciclasts in the lower part of the calcareous succession and a later enrichment, also gradual, in its upper part.

3. INTERPRETATION: DEPOSITIONAL MECHANISMS

The carbonate rocks of the CEG occur as laterally and vertically restricted lenticular deposits within a thicker section of siliciclastics. The outcrop studied (Fig. 2) presents a basal erosive surface visibly cutting up to 10 m of sandy materials. These relationships, together with the facies association and the type of sequences suggest that the carbonates occur as a channel-fill deposit of which, at present, only a part is exposed.

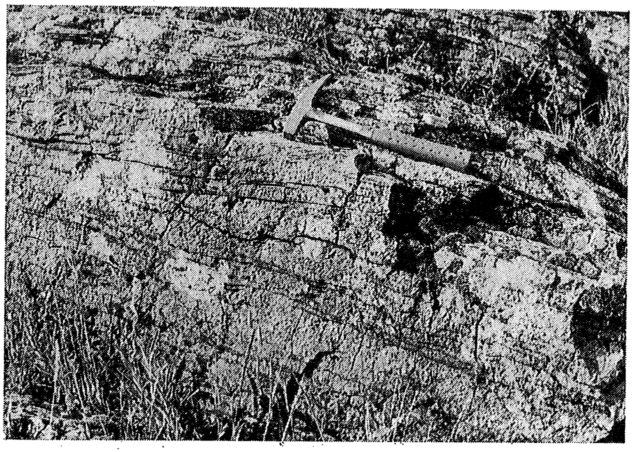

Fig. 11.—Sequence 8. Large-scale planar cross-lamination interbedded between other types of thin-bedded carbonates.

Fig. 11.—Secuencia 8. Laminación cruzada planar a gran escala, intercalada entre otras capas finas.

This channel-fill deposit is composed of mixed siliciclastic-carbonate rocks comprising two facies: breccias and thin-bedded carbonates. Though the textural characteristics of both have been outlined above, some further details concerning the thin-bedded carbonates are given below. In the sandy bed of the sandstone-limestone couplets, grain size ranges between fine and very fine and very fine sand. In the calcareous bed, which always exhibits a certain amount of siliciclasts, the grains are fine to coarse sand-sized, though an intense post-depositional recrystallization prevents one from determining the initial grain-size and composition of the calcareous components and only locally is possible to identify fine sand-sized allochem ghosts.

The lack of knowledge concerning grain size of the calcareous component makes it necessary to consider two possibilities: (i) The original carbonate component could have been a predominantly micrite. This is in conflict with the fine to coarse sand-size of the associated siliciclasts and with the low number of allochems observed. (ii) More probably, it could be composed largely of sand-sized allochems. In the first case, one would be dealing with a rough normal grading between the lower siliciclastic bed and the upper calcareous one, whereas in the second case, there would be a difference in specific weight between some siliciclastic components and the calcareous and volcanic ones. Those of the former would be larger, perhaps because many of the calcareous particles are hollow and the volcanic ones more porous, meaning that they would have a lower weight for a given size (Folk, 1962; Colacicchi and Passeri, 1981).

The lower portion of the channel-fill is composed of several sequences each consisting of breccias overlain by thin-bedded carbonates. The sedimentologic characteristics and stratigraphic relationships of the four lower breccias suggest that they were derived from the thin-bedded carbonates through fluidization and load processes.

The thin-bedded carbonates comprising the lower sequences are «sandstone-limestone couplets». Its internal structures include parallel laminae or structureless couplets developed in both lithologies. In the first case, the couplets are interpreted as the result of deposition in the traction stage of high-density turbidity currents transporting essentially sand-sized particles (Lowe, 1982). In the second case, sedimentation would have taken place in the suspension stage by currents similar to those of the previous case, at higher suspended-load fallout rates, when there was insufficient time for the development of tractive structures (Lowe, 1982). This type of currents has high sedimentation rates.

Following deposition of up to 6 m of couplets by these mechanisms, the calcareous beds were partially lithificated, possibly due to early pressure-solution and subsequent cementation (Colacicchi and Passeri, 1981). Lithification was most extensive in the lower beds, and decreased upwards, perhaps because in these latter the burial pressures were less (Lowe, 1975). At the same time, the siliciclastic beds of the couplets remained unconsolidated. Brecciation occurred latter by fluidization and load processes, possibly in response to regional instability (Colacicchi and Passeri, 1981). The lower cemented calcareous beds behaved in a brittle manner, creating the breccia clasts of sequences 1 to 3 (Fig. 12). These clasts are flat, angular, chaotic and of the same lithology as the calcareous beds of the couplets. The upper less cemented carbonate beds behaved plastically creating the breccia of sequence 4. These clasts have a more irregular and rounded morphology (Fig. 13). At the same time, the siliciclastic beds which had remained unconsolidated reacted plastically, producing load and flame structures and thereby forming the matrix of the breccias. Grain-supported breccias occur where siliciclastic beds were thin whereas matrix-supported breccias occur where siliciclastic beds were thick. This points to *in situ* brecciation of semilithificated sediments of different density.

It is possible to distinguish several cycles in the original thin-bedded carbonates. Each is characterized by a gradual increase in carbonate content upwards within siliciclastic beds of the couplets. This was responsible, for more rapid cementation in the upper parts of the cycles. Likewise, at the base of these cycles the siliciclastics part free of carbonate component exhibited a plasticly behaviour and flowed easily, thereby producing the brecciation. This accounts for the development of several levels of breccias within the succession and the gradual transition from the breccias to the thin-bedded carbonates above and from thin-bedded carbonates to the upper breccias.

Consequently, the following succession of events may be said to have taken place: (1) Rapid sedimentation of a group of thin-bedded carbonates from high-density sandy turbidity currents by successive traction and suspension sedimentation stages. (2) Very early lithification of the calcareous beds. This is more pronounced in the lower beds. (3) Simultaneous brecciation by fluidization and load processes at several levels where the siliciclastic beds of the couplets are thicker and have little or no carbonate.

Over this succession of breccias and couplets are arranged up to 3 m of thin-bedded carbonates (Fig. 2). These thin-bedded carbonates are composed of couplets which have parallel laminae and ripples at the top, separated by planar erosive surfaces, together with pebbly-sandy limestone layers which display inverse and/or normal grading. Towards the upper part are common structureless couplets alternating with couplets with planar laminae. All of the couplets are separated by planar erosive surfaces. Within these thin-bedded carbonates (Fig. 2), it is possible to observe two layers of slightly larger ripples (up to 6 cm in height). At the base of this group and at about 85 cm above it, it is possible to note certain top-missing sequences of Bouma (1962) of type T_{abc} and T_{bcd} sequences. Amalgamation and scour and fill structures are commonly found throughout these layers.

The strong predominance of couplets which are structureless or parallel laminated rather than parallel and ripple laminated at the top suggests that the deposits formed by high-density sandy turbidity currents occurring during traction and suspension sedimentation stages *sensu* Lowe (1982). The Bouma sequence is therefore not applicable. Only occasionally would low-density turbidity currents have been involved, giving rise to real turbidites.

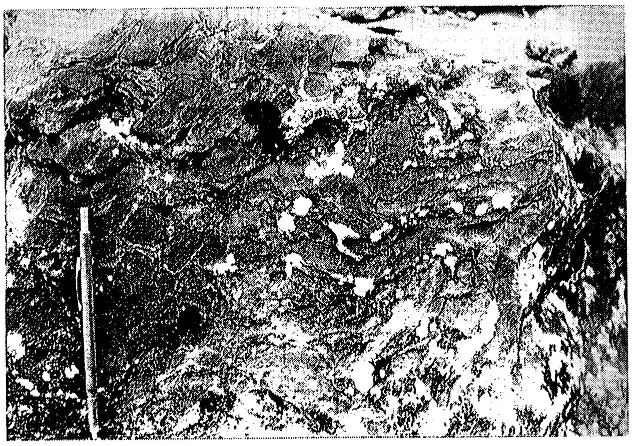

Fig. 12.—Breccia of sequence 3. Note the brittle behaviour of the carbonate bed (darker) which breccifies in situ whereas the siliciclastic part (lighter), that constitutes the matrix, presents a plastic behaviour.

Fig. 12.—Secuencia 3. Brecha con el término carbonatado (el más oscuro) brechificado in situ. El término siliciclástico más claro que constituye la matriz, muestra un comportamiento plástico.

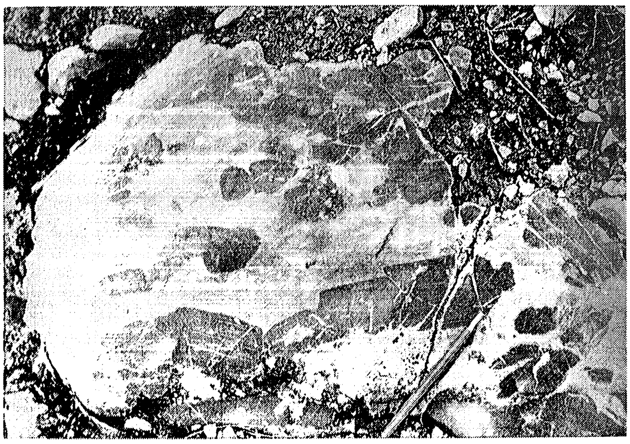

Fig. 13.—Sequence 4. Note a more irregular and rounded morphology of the clasts in the breccia owing to a lesser consolidation when the brecciation took place.

Fig. 13.—Secuencia 4. Obsérvese el redondeamiento de los cantos que indica una consolidación menor cuando se produjo la brechificación.

The pebbly-sandy limestone layers with inverse and/or normal grading (Fig. 10), correspond to sedimentation by mass emplacement of density modified grain flows in transition to high-density turbidity currents (Lowe, 1976, 1982). The deposition of these layers thus represents a turbulence-free mechanism involving flows which were denser than those originating the couplets, where tractional processes and settling were scarce.

The layers with large ripples are the result of the tractive reworking of deposits, previously sedimented by very rapid overloaded dispersions, in an area of sedimentary by-pass. Thes sediments may have been reworked by the same depositional currents or by other later ones (Mutti and Ricci Lucchi, 1975; Mutti, 1977).

This group of thin-bedded carbonates corresponding to the upper part of sequence 4 is cut by an erosive surface with up to 2.5 m of relief (Fig. 2). Erosion was probably the result of successive currents moving through the channel; no other record of such currents remains in the zone.

Over this erosive surface is the poorly sorted calcareous breccia. Owing to the absence of bedding and to the textural characteristics shown by this breccia, it is interpreted as a mass emplacement event (Middleton and Hampton, 1973). Sedimentation occured as a highly viscous debris flow, as evidenced by the angularity and poor sorting of the clasts and their chaotic organization (Cook *et al.,* 1972; Cook and Taylor, 1977). The clasts were mostly derived from the consolidated bottom over which the debris flow moved as there is a predominance of clasts with lithologies similar to the substrate over which the breccia is found. However, clasts of other sources are also found. It is a question of a grain-supported debris flow deposit and hence the content in matrix is low, though probably sufficient to maintain the buoyant lift and lubricate the grains (Middleton and Hampton, 1973; Lowe, 1982). The scarcity of clay material, which is also characteristic of the whole succession studied, suggests the probable scarcity of clay in the source area.

The top of this debris flow deposit is also an erosive surface produced by successive non-depositional currents moving through the channel. Over this surface, there are several sequences composed of flat-clast calcareous breccias and thin-bedded carbonates which successively onlap onto margins of the erosive surface (Fig. 2).

The breccias (figs. 6 and 8), appear to have been deposited by fairly viscous debris flow mechanisms (Davies, 1977; Cook and Taylor, 1977; Lowe, 1982). Most of the clasts were derived from erosion of the sea floor over which the debris flows passed, though additional contributions made by other source areas may also be found, such as a carbonate shelf affected by waves (clasts with wave ripples, Fig. 7) or quieter and more distant areas with micritic carbonate sedimentation (very rounded clasts of micritic limestone). The debris flow deposits are also grain-supported, with a very little pelitic-sandstone matrix.

The thin-bedded carbonates of these upper sequences are composed of structureless and parallel- to ripple-laminated couplets (Fig. 9). Amalgamation and scour and fill structures are common. Again, the laminated layers are interpreted as having been deposited by high-density sandy turbidity currents in the traction sedimentation stage. The structureless layers are the result of suspension sedimentation when such currents decelerated (Lowe, 1982).

The dunes interbedded between the couplets of sequences 8 and 9 (figs. 2, 11), represent reworking by tractional currents of material previously deposited, either by the same currents overloaded with sediments, or by later currents which exhibited a transition from a high-to-low flow regime (Mutti and Ricci Lucchi, 1975). Such tractional currents were more common towards the upper part of the channel-fill succession.

Moreover, terrigenous siliciclastic content in creases in the thin-bedded carbonates of the upper sequences (8 and 9) such that the beds of sandy limestone became calcareous sandstones. Ball and pillow structures are present, probably formed by the more plastic behaviour of the sandy bed within the couplets.

Filling of the upper part of the channel is marked by a repetitive succession of very viscous debris flows and high-density sandy turbidity currents in successive traction and suspension sedimentation stages. In view of the type of contact between the debris flow deposits and those deposits produced by high-density turbidity currents immediately above (Fig. 8), a direct connection may be established between them. The former evolved into the latter once the debris flows had deposited the coarsest load by mass emplacement. They are but different phases of a single depositional event (Davies, 1977; Cook and Taylor, 1977; Middleton and Hampton, 1973). Occasionally, and mainly towards the top of the channel-fill succession, tractional episodes occurred.

4. CONCLUSIONS

The sedimentological characteristics described above have allowed us to interpret the materials in question as submarine channel-fill deposits in successive stages of abandonment. This is shown by the basal channel surface over which is found a succession of depositional sequences with thicknesses between 1 and 5 m. Most of these begin with an erosive surface overlain by limestone breccias and the thin-bedded carbonates. In turn, the entire channel-fill succession constitutes a depositional megasequence in which the breccias exhibit increasingly reduced thicknesses upwards in the succession. The thin-bedded carbonates of each sequence display the opposite tendency.

The depositional sequences are composed of two groups of facies. (1) Thin-bedded carbonates, deposited mainly by high-density sandy turbidity currents, to a lesser extent by density modified grain flows, and some reworked by tractive currents, correspond to channel margin facies in view of their association with coarse grain facies (Cazzola *et al.,* 1981). Locally it is possible to observe an *in situ* brecciation, by fluidization and load processes, in the lower portion of the channel fill. (2) The breccias of sequences 5-9, interpreted as debris flow deposits, correspond to channel axis facies (Cazzola *et al.,* 1981). A transition can be seen from the debris flow deposits to the high-density turbidity current deposits.

The debris flows were esentially fed by autochthonous materials derived from erosion of the channel margin, indicating an important instability. To a lesser extent, they would have been fed by allochthonous material derived from a shallow-marine carbonate shelf.

The scarcity of clay in the matrix of the debris flow deposits, in the high-density sandy turbidity current deposits and in the density modified grain flow deposits, suggests that this material was very scarce in the source area. This supports what has been reported concerning the allochthonous clasts of the debris flow deposits. That is, the source area was a mixed shelf (siliciclastic-carbonated) affected by wave action in which the clay content was very low (Nelson and Kulm, 1973; Howell and Normark, 1982; Colacicchi and Passeri, 1981).

The restricted areal extent of these deposits, the low clay content, the characteristics of the source area and the sedimentology of these materials seem to show that the sediments studied in the present work are a submarine channel-fill facies close to a slope (Lowe, 1972; Cook *et al.,* 1982).

5. ACKNOWLEDGMENTS

The autors wish to acknowledge Dr. G.V. Middleton and Dr. D. Yurewicz who kindly accepted to make a critical review of the manuscript and offered numerous helpful suggestions for its improvement. We are also grateful to Dr. J. Rosell for the many times he has kindly shown us the excellent outcrops of the Southern Spanish Pyrenees which were very helpful in the study of this region where exposures are not so good. He read the manuscript and made valuable comments on it, too. We also wish to thank N. Skinner for the translation of the original manuscript into English. This paper was first presented at the 6th I.A.S. European Regional Meeting, 1985 (Lerida, Spain).

6. REFERENCES

Bernardo de Sousa, M. (1982): *Litostratigrafía e estructura do «Complexo xisto-grauvaquico ante-ordovicico»-Grupo do Douro (Nordeste de Portugal).* Univ. Coimbra, Portugal, 222 págs.

Bouma, A.H. (1962): *Sedimentology of some flysch deposits. A graphic approach to facies interpretation.* Elsevier, Publ. Co. Amsterdam, 168 págs.

Cazzola, C., Fonnesu, F., Mutti, E., Rampone, G., Sonnino, M., and Vigna, B. (1981): Geometry and facies of small, fault controlled deep sea fan systems in a transgressive depositional setting (Tertiary Piedmont Basin, Northwestern Italy). *2nd Europ. Reg. Mtg. Sedim. Excursion 1,* 7-56. Bologna, Int. Assoc. Sedim.

Colacicchi, R., and Passeri, L. (1981): Mesozoic pelagic sequences and their relations to carbonate platform margin in Umbria-Marche Apennine. *2nd. Europ. Reg. Mtg. Sedim. Excursion 2,* 59-76. Bologna, Int. Assoc. Sedim.

Cook, H.E., and Taylor, M.E. (1977): Comparison of continental slope and shelf environments in the upper Cambrian and lowest Ordovician of Nevada. In: *Deep-water carbonate environments.* (H.E. Cook, and P. Enos Ed.). *Soc. Econ. Paleont. Mineral.* Spec. Publ. 25, 51-81.

Cook, H.E., Field, M.E., and Gardner, J.V. (1982): Characteristics of sediments on modern and ancient continental slopes. In: *Sandstone depositional environments.* (P.A. Scholle and D. Spearing Eds.). *Amer. Assoc. Petrol. Geol.* Mem. 31, 329-364.

Cook, H.E., Mc Daniel, P.N., Mountjoy, E.W. and Pray, L.C. (1972): Allochthonous carbonate debris flows at Devonian bank («reef») margins Alberta, Canada. *Can. Petrol. Geol. Bull.* 20, 439-497.

Davies, G.R. (1977): Turbidites, debris sheets, and truncation structures in Upper Paleozoic deep-water carbonates of the Sverdrup basin, Arctic Archipelago. In: *Deep-water carbonate environments.* (H.E. Cook, and P. Enos Eds.). *Soc. Econ. Paleont. Mineral.* Spec. Publ. 25, 221-247.

Díez Balda, M.A. (1982): *El complejo Esquisto-Grauváquico, las series paleozoicas y la estructura hercínica al sur de Salamanca.* Tesis Doct. Univ. Salamanca, Spain, 279 págs.

Folk, R.L. (1962): Spectral subdivision of limestone types. In: *Classification of carbonate rocks.* (W.E. Ham Ed.). *Amer. Assoc. Petrol. Geol.* Mem. 1, 62-84.

Howell, D.G., and Normark, W.R. (1982): Sedimentology of submarine fans. In: *Sandstone depositional environments.* (P.A. Scholle, and D. Spearing Eds.). *Amer. Assoc. Petrol. Geol.* Mem. 31, 365-404.

Julivert, M., Fontbote, J., Ribeiro, A. and Conde, L. (1972): *Mapa tectónico de la Península Ibérica y Baleares, escala 1/1.000.000.* Inst. Geol. Min. Esp., Madrid, Spain.

Lowe, D.R. (1972): Submarine canyon and slope channel sedimentation model as inferred from Upper Cretaceous deposits, western California. *24 th Int. Geol. Congr. Montreal,* 6, 75-81.

Lowe, D.R. (1975): Water escape structures in coarse-grained sediments. *Sedimentology,* 22, 157-204.

Lowe, D.R. (1976): Grain flow and grain flow deposits. *Jour. Sedim. Petrol.,* 46, 188-199.

Lowe, D.R. (1982): Sediment gravity flows: II. Depositional models with special reference to the deposits of high-density turbidity currents. *Jour. Sedim. Petrol.,* 52, 279-297.

Middleton, G.V. (1967): Experiments on density and turbidity currents. III. Deposition of sediment. *Can. Jour. Earth Sci.,* 4, 475-505.

Middleton, G.V., and Hampton, M.A. (1973): Sediments gravity flows: mechanics of flow and deposition. In: *Deep turbidites and deepwater sedimentation.* (G.V. Middleton and A.H. Bouma Eds.). *Soc. Econ. Paleont. Mineral. Pacific Section,* Short Course, 1-38.

Mutti, E. (1977): Distinctive thin-bedded turbidite facies and related depositional environments in the Eocene Hecho Group (South-Central Pyrenees, Spain). *Sedimentology,* 24, 107-131.

Mutti, E., and Ricci Lucchi, F. (1975): Turbidite facies and facies associations. In: *Examples of turbidite facies and facies associations from selected formations of the Northern Appennines. Guidebook A-11. 9th Int. Congr. Sedim.,* 21-36, Nice.

Nelson, C.H., and Kulm, L.D. (1973): Submarine fans and deep-sea channels. In: *Turbidites and deep water sedimentation.* (G.V. Middleton and A.H. Bouma Eds.). *Soc. Econ. Paleont. Mineral. Pacific Section,* Short Course, 39-78.

Nelson, C.H., Normark, W.R., Bouma, A.H., and Carlson, P.R. (1978): Thin-bedded turbidites in modern submarine canyons and fans. In: *Sedimentation in submarine canyons, fans and trenches.* (D.J. Stanley and G. Kelling, Eds.). Stroudsburg, Pa. Dowden, Hutchinson & Ross, 177-189.

Ricci Lucchi, F. (1981): The Miocene Marnoso-Arenacea turbidites, Romagna and Umbria Apennines. *2nd. Europ. Reg. Mtg. Sedim. Excursion 7, Part I,* 231-275. Bologna, Int. Assoc. Sedim.

Rodríguez Alonso, M.D. (1982): *Contribución al conocimiento del Complejo Esquisto-Grauwackico en el sector occidental del Sistema Central Español (Las Hurdes y Sierra de Gata).* Tesis Doct. Univ. Salamanca, Spain, 296 págs.

Rodríguez Alonso, M.D. (1985): El Complejo Esquisto Grauwackico y el Paleozoico en el Centro-Oeste español. *Acta Salmant., Ser. Ciencias,* 51, Ed. Univ. Salamanca, 174 págs.

Recibido el 29 de mayo de 1987
Aceptado el 13 de agosto de 1987