The sedimentological significance of a clastic wedge in the western basin margin of the Triassic Tethys (Iberian Range, Spain)

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ABSTRACT

The Middle Triassic in the NW of the Iberian Basin consists of both carbonate and terrigenous sediments. A new sedimentary model is proposed for the clastic wedge of the Cuesta del Castillo Sandstones and Siltstones (CCSS) Formation (García-Gil, 1990), and its relationship with the Upper Muschelkalk carbonate Formations.

The model will take account of the following characteristics:

1. Low depositional gradient being integrated in a homoclinal carbonate ramp.
2. Combined tectonic, climatic and eustatic controls.
3. Presence of continental and shallow marine facies associations.
4. Homogeneity of textural facies.

The sedimentation of the CCSS Formation took place during a relative sea level rise (high stand system tract).

Key words: Iberian Ranges, Triassic, Muschelkalk, homoclinal ramp, alluvial delta, continental facies, shallow marines facies, terrigenous, depositional sequences.

RESUMEN

El Triásico Medio del NW de la Cuenca Ibérica está compuesto por

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sedimentos carbonáticos y terrígenos. Se propone un nuevo modelo de sedimentación para la cuña clástica que representa la Formación «Areniscas y Lutitas de la Cuesta del Castillo» (García-Gil, 1990), y su relación con las formaciones carbonáticas del Muschelkalk Superior.

El modelo considera las siguientes características:

1. Bajo gradiente deposicional, estando integrado en una rampa carbonática homoclinal.
2. Combinación de efectos tectónico, climático y eustático.
3. Presencia de asociaciones de facies continentales y marinas someras.
4. Homogeneidad textural de las facies.

La sedimentación de la Formación CCSS tuvo lugar durante una subida relativa del nivel del mar.

Palabras clave: Cordillera Ibérica, Triásico, Muschelkalk, rampa homoclinal, delta aluvial, facies continentales, facies marinas someras, terrígenos, secuencias deposicionales

INTRODUCTION

The term «delta» has been traditionally associated with rivers, to denote a coastal prism of land derived sediment, transported by rivers into either lakes or the sea (Barrel, 1912; Johnston, 1921; Holmes, 1965; Coleman & Wright, 1975; Elliot, 1978, 1986; Coleman, 1981; Miall, 1984).

The increase in the number of modern delta descriptions is evidence that they vary enormously in their characteristics, and that many «deltas» are not «delta shaped» at all. The term has thus lost its original geometrical meaning, and become essentially a genetic one.

The connotation of the term «delta» has become even more general than the traditional definition, with the introduction into the literature of terms like fan delta (Holmes, 1965) braidplain delta (Orton, 1988), slope-apron delta (Busby-Spera, 1988) and lava delta (Holmes, 1965).

Holmes (1965) defined a fan delta as an alluvial fan prograding into a standing body of water from an adjacent highland.

The problem of the classification of alluvial deltas has attracted considerable interest, and new classification schemes seem to be proliferating, with wide ranging discussions on terminology and field criteria. Nemec (1990), suggested that the general term «alluvial delta» be adopted, primarily to allow researchers to avoid the difficulty of categorizing the alluvial feeder of a delta. When the principal feeder system can be identified, more specific terms are applied (i.e. river delta, alluvial-fan delta, scree-apron delta etc.).

In addition, a few papers relating to ephemeral sandy systems have been published, Frostick & Reid (1986); Hicks & Inman (1987); Dam & Andreasen (1990).

In this paper a new sedimentary model is proposed for the clastic wedge of the Cuesta del Castillo Sandstones & Siltstones (CCSS) Formation (Garcia-Gil, 1990, 1991) and it relationship with the Upper Muschelkalk carbonate formations of the Middle Triassic.

The model attempts to explain the processes of continental sedimentation, especially from ephemeral streams, the interplay with shoreline processes and the lateral change into shallow marine carbonates. It differs from current fan-delta models in both the sedimentary processes invoked and in the shape of the basin which is a very low gradient area with a small potential volume to accommodate sediments. A sequential analysis of the series identifies the system tracts, using the methods of Hubbard *et al.* (1985), Haq *et al.* (1987) and Vail *et al.* (1987). A comparison with the global third degree cycle of Vail *et al.* (1987) is attempted.

GEOLOGICAL AND STRATIGRAPHICAL SETTING

Most of the sedimentary and tectonic features of the Alpine cycle of the Central Iberian Peninsula are determined by late Hercynian faulting (Fig. 1).

Parga (1969) proposed the first synthesis of what he called «Late Hercynian tectonics» related to widespread granite intrusions. The main tectonic features were (1) a wrench fault system beginning to be active in the Stephanian and continuing until the early Permian, (2) a period of extensional faulting beginning in the late Permian.

The main wrench fault systems are orientated NE-SW, NNE-SSW, NW-SE (Fig. 1) with subordinated systems N-S and E-W (Capote, 1983). The NE-SW and NNE-SSW systems are dominant in terms of their frequency, length and horizontal displacement, and are orthogonal to the Hercynian tectonic grain and usually sinistral.

The NW-SE fault system acted as wrench faults during the Stephanian and Early Permian, but altered to a normal fault regime by the end of the Permian (Sopeña *et al.*, 1977; Virgili *et al.*, 1973), with large vertical throws (Hernando, 1977). Steep reliefs were formed, feeding important accumulations of clastic sediments into the sunken blocks. Some basement faults like the Somolinos, Bronchales and Cincovillas faults, orientated NW-SE acted as the boundary faults of the Permian basins, the basins developing on the northern hanging wall of the fault bounded blocks.

The characteristic extensional tectonic regime of the Late Permian, led during the Mesozoic, to a basin and range configuration with fault blocks and volcanism (Capote & Carbó, 1983) that lasted until the late Cretaceous. The origin of this tectonic regime was the separation, at increasing rates, of the African and European plates during the Late Permian, this tectonic activity controlled the formation of the Iberian Basin (Aulacógeno Celtibérico, Alvaro *et al.*, 1979).

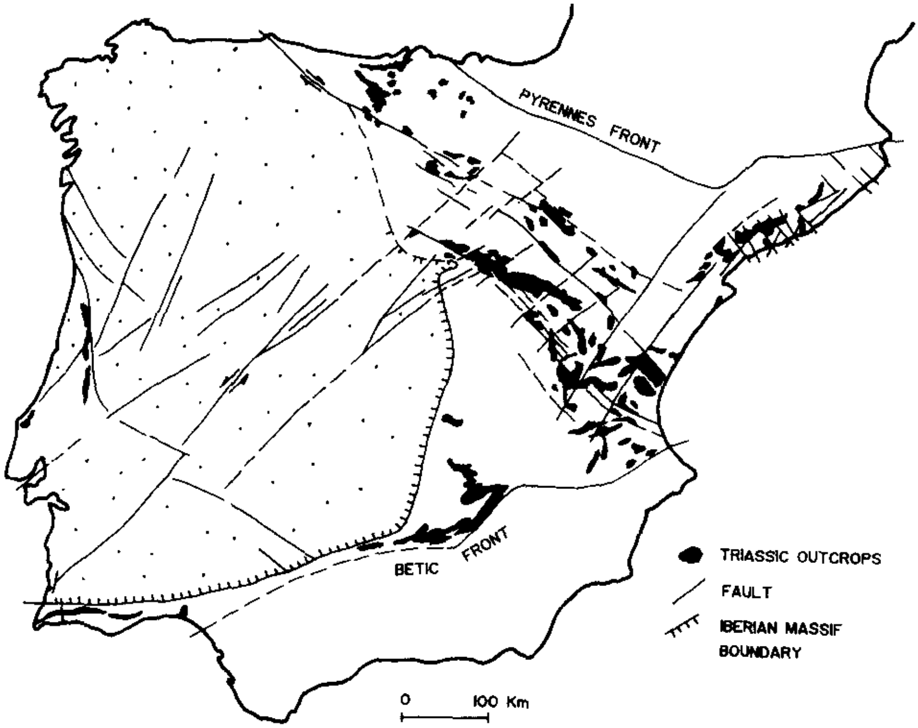


Fig 1.—Regional Triassic and main late-Hercynian fault distribution in the Iberian Peninsula. Modified from Capote 1983.

Fig 1.—Distribución de afloramientos triásicos y fallas tardi-hercínicas en la Península Ibérica. Modificado de Capote (1983).

During the Late Triassic this tectonic regime changed, the tectonic model also changes allowing for crustal extension and thinning.

The stratigraphy of the Iberian Range reflects this changing tectonic regime, with thick sedimentary units of varying facies, especially in the terrigenous facies (Fig. 2). A vertical section of the Triassic from the base to the top is:

1. Buntsandstein: Conglomerates, Sandstones, Mudstones and restricted Evaporite deposits (maximum 850 m, locally absent).
2. Lower Muschelkalk: Dolostones and Limestones. (maximum 50 m).
3. Middle Muschelkalk: Sandstones, Mudstones and Evaporites. (maximum about 25 m, locally absent).
4. Upper Muschelkalk: Dolostones, Limestones, Sandstones, Siltstones and Marls (minimum 35 m - maximum 90 m).
5. Keuper: Sandstones, Siltstones, Evaporites and Marls (minimum 60-maximum 400).
6. *Imon Formation: Dolostones (minimum 10-maximum 30).*

NW SECTOR OF THE IBERIAN TRIASSIC BASIN

The NW sector of the Triassic Iberian Basin is at the junction of the Central System and the Iberian Ranges (Fig. 3).

The geometry of the Basin and sedimentary infilling were controlled, especially during the Buntsandstein, by the reactivation of the Late Hercynian wrench faults, acting now as normal faults (Fig. 2).

The NW-SE fault systems delineate a series of highs and depressions (Graben stage, Alvaro *et al.*, 1979). The Cincovillas fault in the study area is a clear example, with more than 800 m of Buntsandstein facies to the east and about 100 m to the west.

The top of the Buntsandstein facies is an unconformity surface (Fig. 2, Alcolea de Pinar), of gentle erosive relief (Garcia-Gil, 1990, 1991). Below this surface, paleocurrent directions are to the SE, whilst above, current directions change to the NE for the siliciclastic sediments, passing laterally to the Upper Muschelkalk facies. Field data indicates that the palaeoslope changed after the formation of the unconformity (Garcia-Gil, 1990). Sedimentation restarted with the Torete variegated Siltstones and Sandstones Formation (TvSS) Ramos, (1979), and the Cuesta del Castillo Sandstones and Siltstones (CCSS) Formation (Garcia-Gil, 1990, 1991). The latter is equivalent in time to the Upper Muschelkalk facies (Fig. 2), both these formations onlap the unconformity surface (Garcia-Gil, 1990). The source area for the siliciclastic sediment was located in a region of high relief to the west.

The (CCSS) Formation consists of alternating sandstones, siltstones and mudstones and has been sub-divided into two units (Fig. 4):

A *lower silty unit* consisting of irregular interbedded siltstones and sandstones. The siltstones are grey in colour and occur in centimetre or decimetre horizons, whilst the sandstones are grey or yellow, very fine grained and occur in centimetre thick beds. The thickness of this unit ranges from about 1.5 to 11 m, pinching out towards the east, and passing laterally into carbonates.

The *upper sandy* unit consists of fine to medium grained sandstones, with subordinate siltstone horizons. The lower horizons are grey but they change to red towards the top. These sands occur in beds with lenticular geometries some meters thick, in sharp contrast to the lower unit geometry.

SEDIMENTARY FACIES

Sedimentary facies have been distinguished in the (CCSS) Formation using informal terminology. The synoptic list shows these facies and their interpretation.

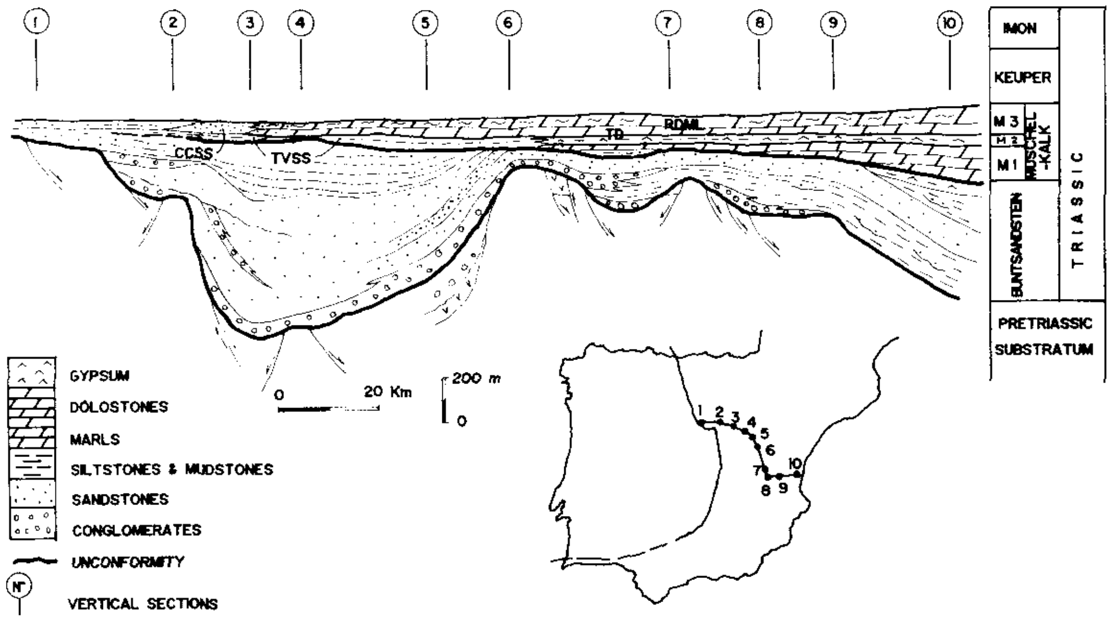
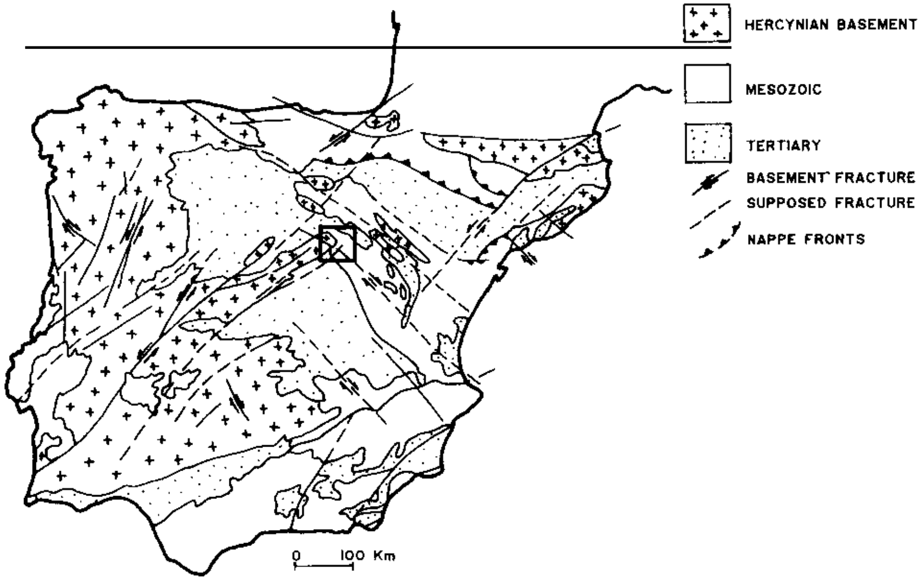


Fig 2.—Stratigraphic section of the Triassic in the Iberian Basin, from the border of the Iberian Massif (1) until Mediterranean coast (10). The top of the Upper Muschelkalk is the datum level (M3), Middle Muschelkalk (M2), Lower Muschelkalk (M1). Note the Muschelkalk onlap onto the gently eroded Buntsandstein top (unconformity). The studied region is extended between vertical sections numbered (2) to (5). The *formations involved in this paper are: TvSS «Torete variegated Siltstones and Sandstones»; CCSS «Cuesta del Castillo Sandstones and* Siltstones»; TD «Tramacastilla Dolostones»; RDML «Royuela Dolostones, Marls and Limestones».

Fig 2.—Sección Estratigráfica del Triásico de la Cuenca Ibérica, desde el borde del Macizo Ibérico (1) hasta la costa mediterránea (10). El nivel de referencia es el techo del Muschelkalk Superior (M3), Muschelkalk Medio (M2), Muschelkalk Inferior (M1). Véase el «onlap» del Muschelkalk sobre el suave relieve erosivo en el techo del Buntsandstein (discordancia). La región estudiada se extiende entre las secciones verticales números (2) a (5). Las formaciones involucradas en este trabajo son: TVSS «Limos y Areniscas abigarrados de Torete»; CCSS «Areniscas y Lutitas de la Cuesta del Castillo»; TD «Dolomías de Tramacastilla; RDML «Dolomías, Margas y Calizas de Royuela».



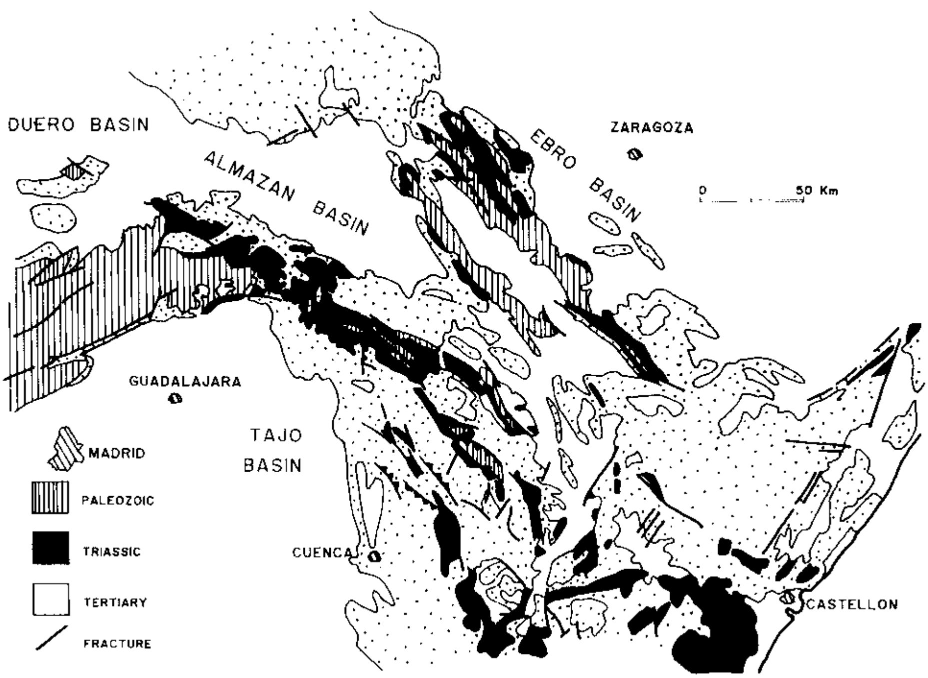


Fig 3.—Geological setting of the study region within the Iberian Basin.
Fig 3.—Situación geológica de la región estudiada dentro de la Cordillera Ibérica.

Sm. Very fine to fine grained massive sandstones coloured yellow-ochre or grey. Intensive bioturbation, sometimes with *Rhizocorallium sp.* Inner platform shelf.

St. Fine grained sandstones with trough cross-stratification, coloured yellowish grey. Abundant plant and wood fragments. Intensive bioturbation. Channel-fill and bed forms in foreshore deposits.

Sp. Fine grained sandstones with planar cross-stratification and occasional reactivation surfaces, coloured grey. Foreshore deposits, shoreface bedforms and storm deposits (climbing megaripples).

Sr. Very fine to fine grained sandstones, ripple cross-laminated (wave and current), coloured yellowish or grey. Abundant bioturbation, frequent ichnofauna (*Rhizocorallium sp*, ofiuroidea and vertebrate foot prints), plant fragments. Shoreface, inner shelf and coastal plain deposits.

Sh. Very fine to fine grained sandstones with horizontal laminations, coloured grey-yellowish. Intensive bioturbation, plant fragments and bivalves. Sand-sheets and shoreface deposits (during storm periods).

Sa. Very fine to fine grained sandstones with low angle cross-stratification, grey colour. Bioturbated and sometimes with plant and wood fragments. Sand-sheets and foreshore deposits.

Sc. Fine grained sandstones with parallel lamination to the basal geometry, greyish colours. Bioturbated. Channel fill deposits.

Fm. Massive mudstones and siltstones, coloured red, green or grey. Intense bioturbation, sometimes containing bivalves and palynological associations. Coastal plain deposits.

Fr. Ripple cross-laminated siltstones (wave and current ripple), coloured red, yellowish or grey in colour. Generally bioturbated and occasionally containing palynological associations. Coastal plain or inner shelf deposits.

Fh. Mudstones and siltstones with horizontal laminations, red, green or grey colours. Abundant plant fragments, sometimes with palynological associations. Coastal plain or inner shelf deposits.

Dt. Dolostones with tepee structure and abundant evaporite pseudomorphs, yellow colours. Coastal plain deposits (supratidal).

FACIES ASSOCIATIONS

Channel facies association

Description

This facies is present in the western part of the study area, it consists of lenticular, yellow or red sandstone bodies with trough cross stratification

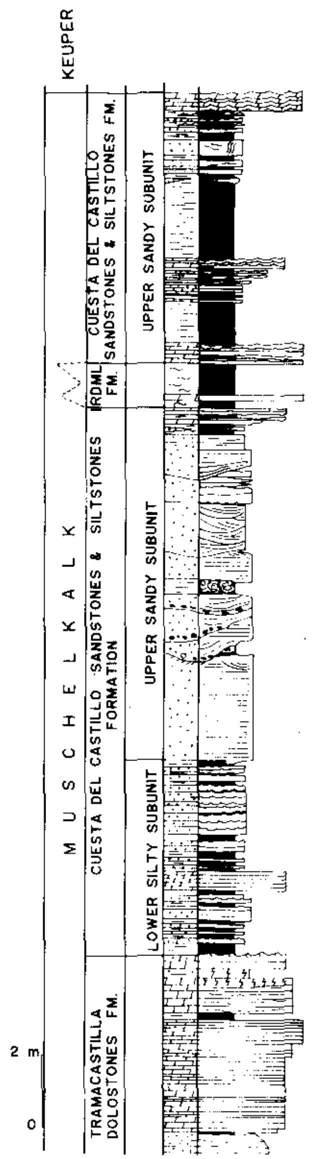


Fig 4.—Stratigraphic section of the (CCSS) Formation and its vertical relationship with the other Muschelkalk Formations (TD y RDML). Two sub-units can be recognized, lower silty subunit and upper sandy subunit.

Fig 4.—Columna estratigráfica de la Formación (CCSS) y su relación vertical con las otras Formaciones del Muschelkalk (TD y RDML). Se reconocen dos subunidades, la inferior lutítica y la superior arenosa.

and horizontal lamination (St and Sh dominant, see sedimentary facies code), and some planar cross-stratification (Sp facies). The base is concave and erosive, the top being flat with evidence of subaerial exposure i.e. mud cracks and iron crusts and containing the marine bivalve *Neoschizodus laevigatus* (Goldfuss). The channel body has frequent wood fragments orientated N54°E. Paleocurrent directions are towards the NE (50-62°). There are also smaller lenticular bodies (1.5 x 20 m) composed of grey, fine grained sandstones, concave base with Sc facies and wave ripples on the top surface. Paleocurrent directions are also towards the NE (32°).

Interpretation

The large lenticular bodies are distal fluvial channels with some marine influence (marine bivalves, Fig. 5), the smaller bodies (Fig. 6) are shallow submarine equivalents.

Sand sheet facies association

Description

Sandstone bodies up to 2 meters thick and several tens of meters wide (Fig. 7), with horizontal and low angle parallel laminations (Sh and Sa facies dominate) some with ripples and trough cross bedding (Sr and St). These bodies have a slightly erosive base showing flute and grove casts (Fig. 8). Paleocurrents point to the N 53-74° E. Occasional water-escape structures at the base, always verging towards the north east, suggesting a palaeoslope in this direction (Figs. 7b). The top of these bodies are flat, with current ripples and vertebrate footprints (Fig. 9).

Interpretation

These sandstone bodies were deposited swiftly, structures like wave ripples showing marine reworking, indicates that they were deposited into a standing body of water, probably either foreshore or shoreface environments

Foreshore facies association

Description

This association is commonly found in the NW part of the study area and consists of grey, fine grained sandstones with high energy, parallel laminations direction towards the sea, NE, with associated parting lineations direction N

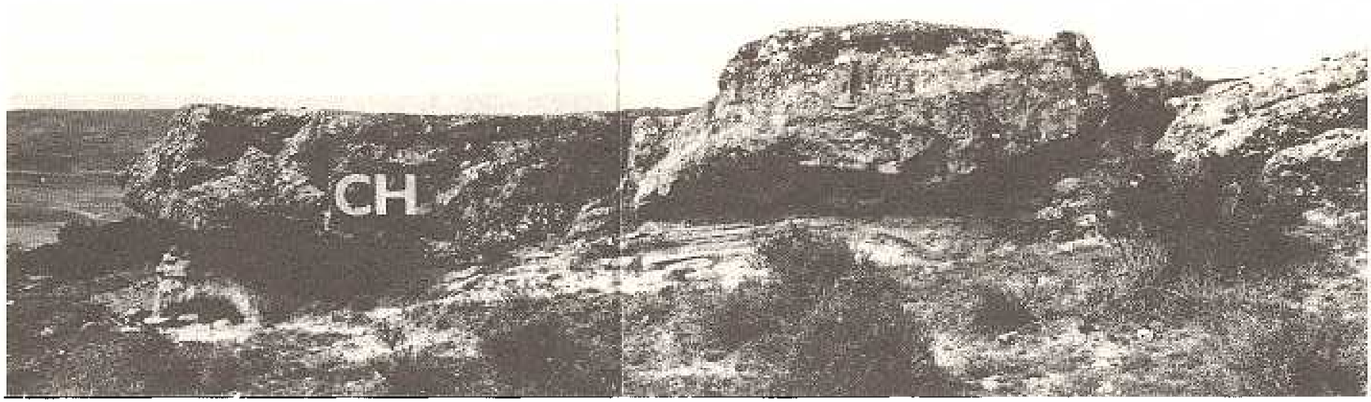


Fig 5.—Large lenticular body representing a large channel (CH) in the distal areas with concave and scoured base. The top is flat and occasionally contains marine bivalves (*Neoschizodus laevigatus*) denoting the marine influence.

Fig 5.—Cuerpo lenticular que representa a un canal de mayor (CH) con la base cóncava y erosiva, en las áreas distales. El techo es plano y ocasionalmente contiene bivalvos marinos (*Neoschizodus laevigatus*) que denotan la influencia marina.

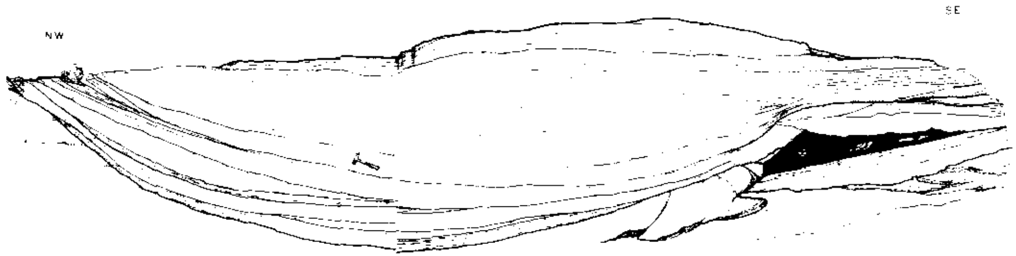


Fig 6.—Smaller lenticular body than Fig. 5. Paleocurrent N 32° E. Concave base and flat top representing channels in a shallow marine environments.

Fig 6.—Cuerpo lenticular, menor que el de la figura 5. Las paleocorrientes indican hacia N32ºE. La base es cóncava y el techo plano; representa a un canal en la zona marina somera.

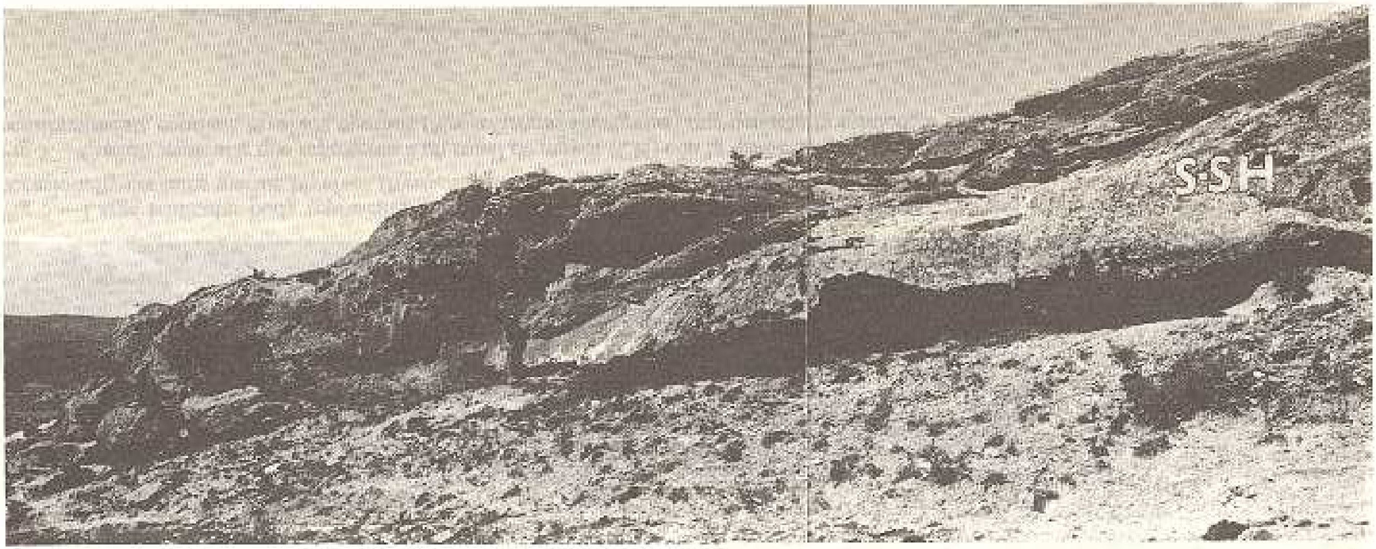


Fig 7a.—Sand-sheet (S-SH) with slightly erosive base, paleocurrents pointing to the NE.

Fig 7a.—«Sand-sheet» (S-SH) con base suavemente erosiva: las paleocorrientes indican hacia el NE.

Fig 7b.—Water-escape structures at the base of a sand-sheet, verging towards the NE suggesting a palaeoslope in this direction.

Fig 7b.—Estructuras por escape de agua en la parte inferior del «sand-sheet» de la Fig. 6a, que vergen hacia el NE, sugiriendo una paleopendiente en este mismo sentido.

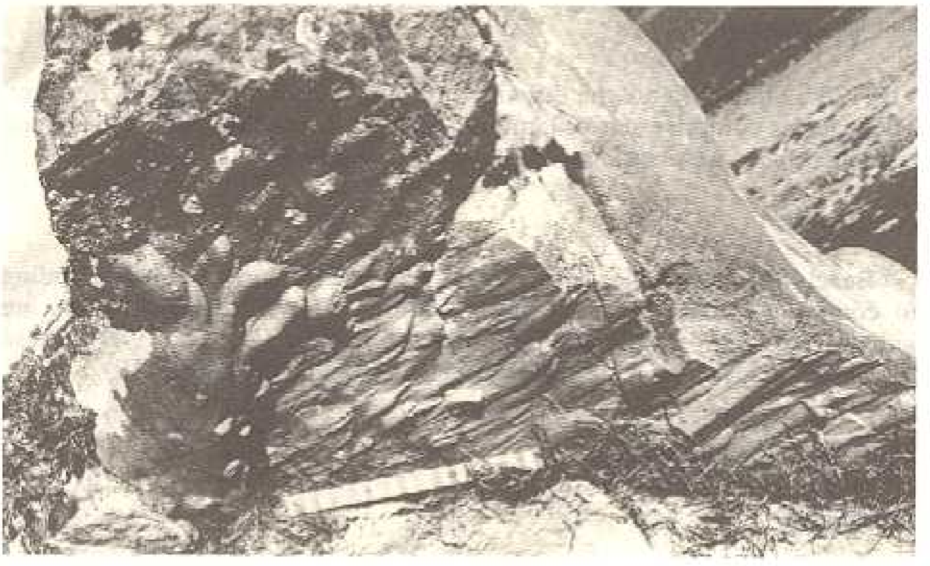


Fig 8.—Flute casts at the base of a sand-sheets. Paleocurrents point to the NE.

Fig 8.—«Flute casts» en la base de un «sand-sheet». Las paleocorrientes indican hacia el NE.

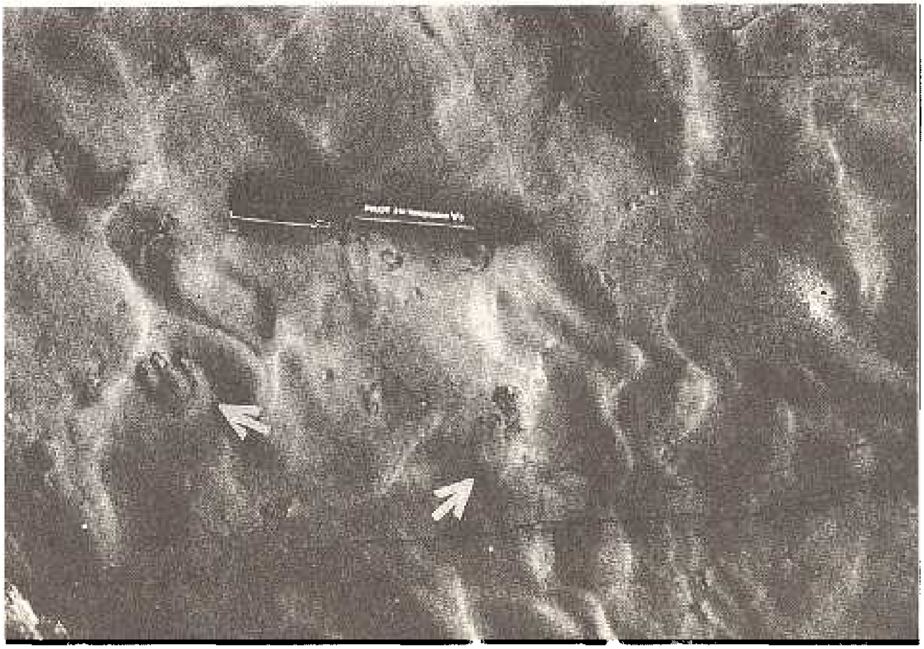


Fig 9.—Footprints and ripple marks on top of the sand-sheet suggesting shallow water conditions.

Fig 9.—Huellas de vertebrados y ripples en el techo de un «sand-sheet», sugiriendo condiciones bajo aguas someras.

110-120°. Sh and Sa are the dominant facies, Sp facies being less frequent. These facies comprise sets of laminae, each set discordant to the others, and separated by erosive surfaces, prograding towards the NE.

Interpretation

Beach foreshore facies associations with erosive surfaces corresponding to continuous changes of the beach profile. These erosive surfaces are indicative of the periodic levelling of the foreshore (Dabrio, 1989). These foreshore facies show a clear migration towards the open sea (NE).

Shoreface facies association

Description

This association (Fig. 10) is comprised of grey, fine grained sandstones and siltstones, their internal structures varying laterally in the following ways.

Fig 10.—Shoreface (SF) and foreshore (FS) facies association. Both show a clear progradation of the system towards the NE.

Fig 10.—Asociaciones de facies de «shoreface» (SF), y «foreshore» (FS). Se observa una clara progradación del sistema hacia el NE.

1. Fining upwards sequences of hummocky cross-stratification, and several centimetres of very fine grained sandstones with wave ripples, crests orientated N 127° E, capped by a mud drape (Fig. 11).
2. Mega (20 cm) climbing ripples, paleocurrents pointing to N72° E (Fig. 12).
3. Sequences similar to Bouma turbidites (Fig. 13) with paleo-currents pointing to the N.
4. Several units of fine grained sandstone containing abundant tree and plant fragments, with horizontal laminations (Sh) and trough cross stratification (St). These units prograding towards the NE (Fig. 14).

Interpretation

The fining upwards sequences are similar to those described by Dabrio (1989) for shoreface storm deposits. The climbing megaripples being formed during storm conditions. The third sequence, similar to Bouma turbidites, but here generated in a different depositional environment. The genetic processes however are similar, i.e. fast, high energy events with a high volume of sediment load. These three facies associations correspond to shore face environments during storm conditions. They are very frequent in the (CCSS) Formation. The fourth facies association shows the shoreface deposits prograding towards the sea.

Fig 11.—Hummocky cross-stratification. In detail, fining upwards sequences are recognized, being formed during storm conditions.

Fig 11.—Estratificación cruzada «hummocky». En detalle se observan secuencias granodecrecientes. Se generan durante condiciones de tormenta.

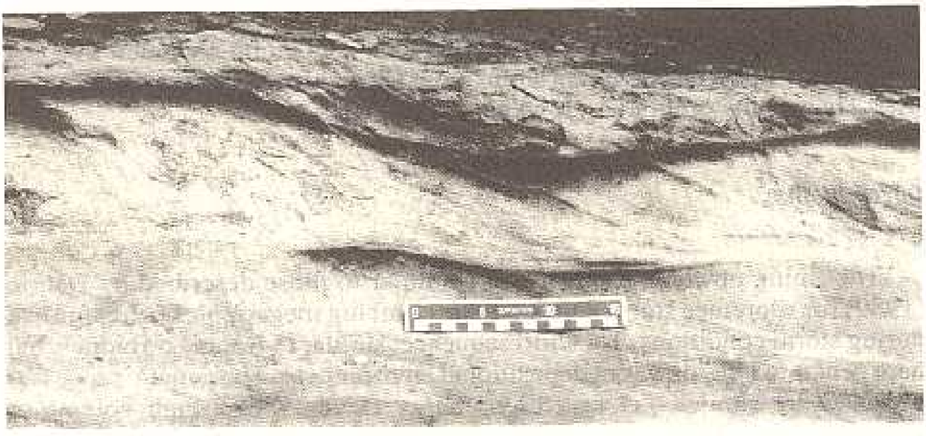


Fig 12.—Climbing megaripples associated with the shoreface facies. Paleocurrent point to N 72° E. Formed during storm conditions in the shoreface environment.

Fig 12.—«Climbing megarriples» en la zona de shoreface. Las paleocorrientes indican hacia N72°E. Se generan durante condiciones de tormenta.

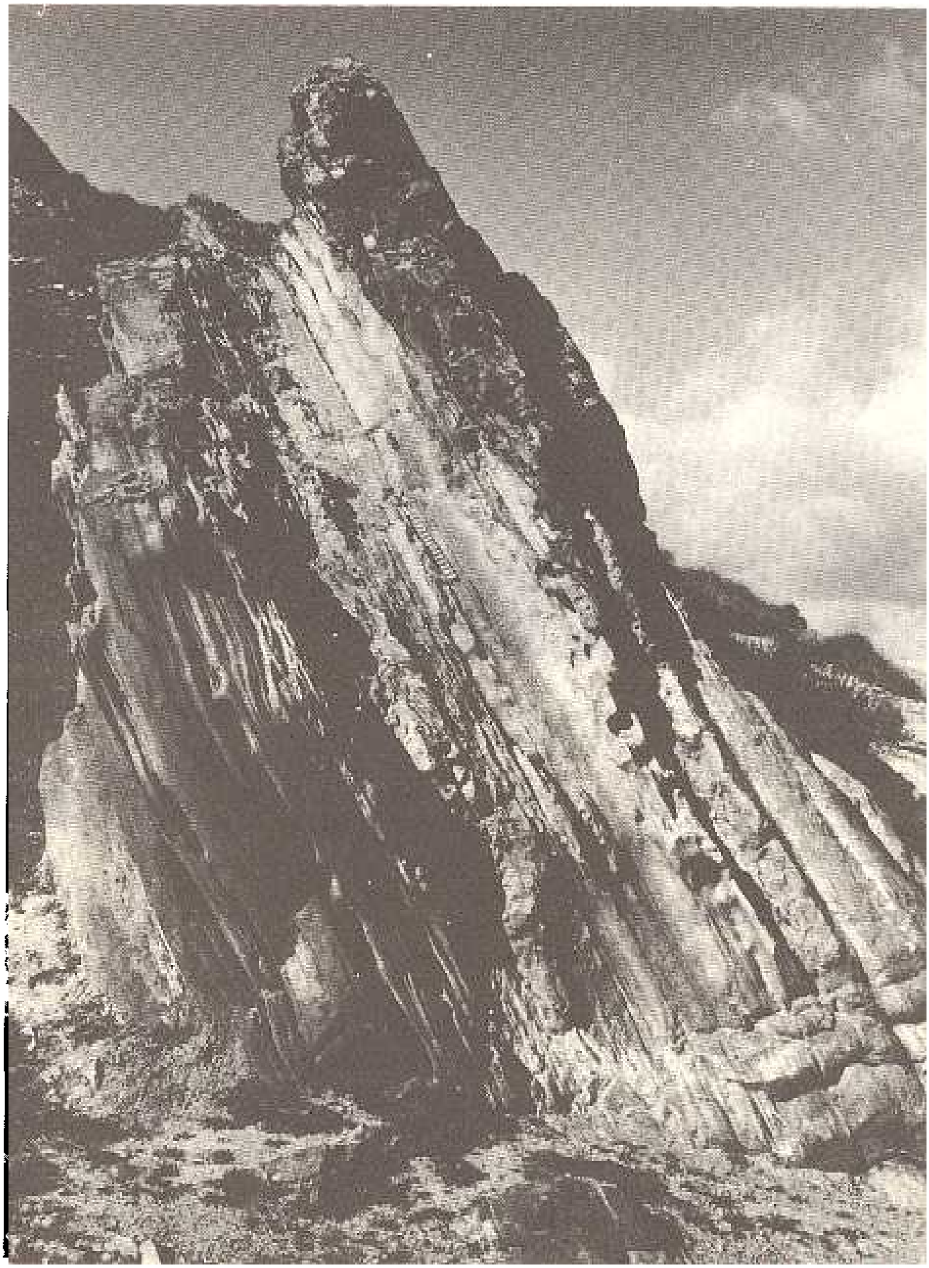


Fig 13.—Sequence similar to Bouma turbidites. Paleocurrents point to NE. Formed during storm conditions in the shoreface environment.

Fig 13.—Secuencia similar a la de Bouma para turbiditas. Las paleocorrientes indican hacia el NE. Aquí se genera durante condiciones de tormenta en la zona de «shoreface».

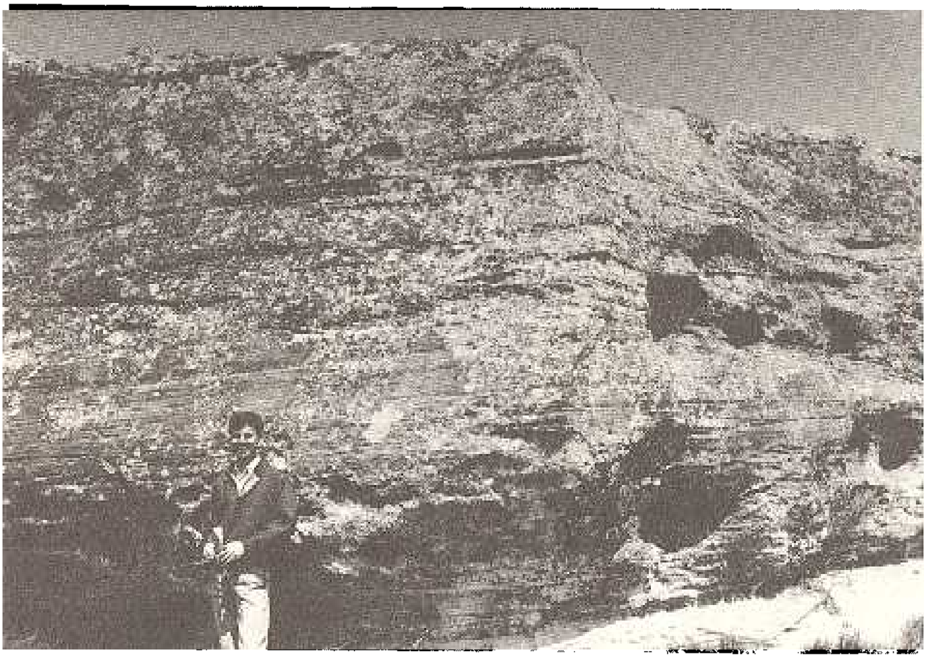


Fig 14.—Parallel lamination cut by sets of trough cross-stratification corresponding to the shoreface. The paleocurrents show a general progradation towards the NE, some of the erosive surfaces originated during storm conditions.

Fig 14.—Laminación paralela cortada por sets de estratificación cruzada de **surco**, correspondientes a la zona de «shoreface». Las paleocorrientes indican una progradación general hacia el NE; algunas de las superficies erosivas internas fueron originadas durante episodios de tormenta.

Inner shelf facies association

Description

This facies association in the **proximal** areas is mainly located in the lower part of the (CCSS) Formation. It is represented by irregular, centimetre thick interbedded very fine grained sandstones, siltstones and mudstones. The more frequent facies are Sr, Fr with current and wave ripples; Sh, Fr and Sm with no internal structure because of intensive bioturbation.

Bivalve moulds are abundant in the sandstone horizons. The fauna that existed here are grouped in the *Costatoria-Lyriomyophoria* (CL) association (Márquez-Aliaga & García-Gil, 1991). This association is composed of a large number of *Costatoria goldfussi* (Alberti) and *Lyriomyophoria sublaevis* (Schmidt), with a limited number of *Lyriomyophoria* aff. *elegans* (Dunker), *Neoschizodus laevigatus* (Goldfuss), *Pleuromya elongata* (Scholotheim) and *Pleuromya brevis* (Assmann).

The ichnogenera *Rhizocorallium* sp (Fig. 15) is very abundant in several sandstone horizons. The existence of *Asteriacites* (Fig. 16) in the very fine grained sandstones is characteristic, and probably represents (García-Ramos *et al.*, 1989) the print of a small *Ofiuroidea* sp.

Fining-upwards sequences are composed of sandstones, Sh, Sr and Sm facies interbedded with siltstones and mudstones, Fh, Fr, and Fm facies. These sequences are similar to those described by Dabrio (1989), in the shoreface environment, and originated during storm periods.

The **distal** inner shelf facies associations consist of grey marls and white dolostones, with ripple and horizontal laminations. Within the marls are well preserved brachiopods *Lingula tenuissima* (Brown), and vertebrate fragments. In the dolostones the bi-valve moulds of *Pseudocorbula gregaria* (Munster) are abundant. Márquez-Aliaga & Garcia Gil (1991) define the *Lingula-Pseudocorbula* (Li-P) association in the highest stratigraphical horizons of the sequence (Fig. 2). These horizons correspond to the «Royuela Dolostone, Limestone and Marls» (RDMC) Formation, and occur interbedded with the (CCSS) Formation horizons, being lateral changes of facies between both formations (Garcia-Gil, 1991).

In general these inner shelf sediments show intense bioturbation, with no recognizable internal structure. In the siltstone and mudstone horizons palynological associations are frequent, pollens and spores giving Upper Ladinian age.

Interpretation

The CL association present in the sandstone horizons, palaeoecologically represents benthic infaunas. Associations like this are considered characteristic of the soft floor of the «Lettenkohle» Formation, corresponding to shallow marine environments close to the open sea i.e. lagoons (Brunner & Hagdorn, 1985).

This association shows a low specific diversity, which corresponds with a faunal colonization in low stability environments, not allowing the establishment of more mature ecosystems (Márquez-Aliaga & García-Gil, 1991).

The presence of *Rhizocorallium jenense* in two horizons (Gazdizicki & Trammer, 1978), the Reinodden and Ahlstradodden sections of the Bellsund area, indicates a continuously submerged, but very shallow zone, i.e. a shallow subtidal zone according to Ager & Wallace (1970), Wincierz (1973) and Fursich (1975), and is in agreement with the bathymetrical zonation of García-Ramos (1983). *Rhizocorallium* occurs in the transitional littoral and shallow marine environments.

The fining upwards sequences described above, are interpreted as distal facies, that during storm periods would be transported to the proximal inner shelf.

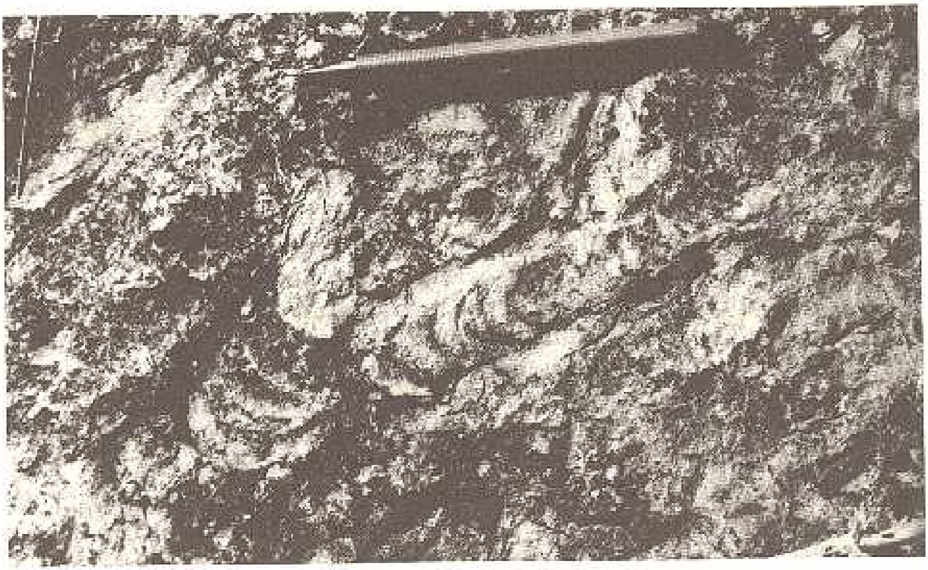


Fig 15.—*Rhizocorallium sp* in a very, fine grained sandstones horizon in the proximal inner shelf areas denoting shallow marine conditions.

Fig 15.—*Rhizocorallium sp* en un nivel de areniscas de grano muy fino, denotando condiciones marinas muy someras. Corresponde a las áreas de plataforma interna proximal.

Fig 16.—*Asteriacites* in very fine grained sandstone horizon in the proximal inner shelf area.

Fig 16.—*Asteriacites* sp en un nivel de areniscas de grano muy fino en las áreas de plataforma interna proximal.

The Li-P association defined by Márquez-Aliaga & García-Gil (1991), shows in some of the marl horizons a large population of specimens, of a monospecific character. Their presence is indicative of existence in shallow marine environments. These environments are characterized by high variability in both salinity and terrigenous input, these conditions making survival impossible for more selective organisms (Prats *et al.*, 1987).

The presence of *Pseudocorbula* sp. in the dolomitic horizons, indicates deposition in shallow marine conditions, with little or no terrigenous input. This bivalve was infaunal, behaving as an opportunist species, and is recognized by the large population, each individual being of small size. It is interpreted as a biological indicator of low stability environments (Márquez-Aliaga, 1985).

Coastal plain facies association

Description

This association occurs most frequently in the upper part of the (CCSS) Formation. It is composed of:

1. Very fine grained sandstones that occur in centimetre and decimetre beds, with intensive bioturbation.
2. Siltstones, Fr, Fm and Fh facies, showing frequent evidence of subaerial exposure in the form of root marks and mud cracks.
3. Yellow coloured dolostones, appearing in millimetre and centimetre beds, disrupted by tepee structures. There are abundant evaporite crystals of halite and gypsum and ferruginous crusts.

There is a gradual colour change from grey at the base to red in the upper part of this formation.

Interpretation

The red colour is dominant in the upper part of the (CCSS) Formation, this colour changes in relationship to the phreatic level (water table). The red colours correspond to the lower levels of the phreatic level, allowing oxidation, whilst the grey colours represent the reducing conditions during high phreatic levels.

INTERPRETATION AND DISCUSSION OF THE SEDIMENTARY MODEL

The sedimentary model proposed for this Middle Triassic clastic wedge, located in the NW part of the Iberian Basin tries to integrate epeirogenic sea-level changes with more local tectonic and climatic events (Fig. 17). These events cause a shifting of facies belts, either towards the sea or the continent. Because of the basin geometry, small relative sea level changes can cause extensive subaerial emergence or flooding.

From the genetic point of view, the model (Fig. 18) takes into account the lateral transition from shallow marine carbonate facies to terrigenous facies (García-Gil, 1991).

Santisteban & Taberner (1988) propose the «Centelles Model», where reef facies are dynamically related to deltaic deposits. The sediments comprising the (CCSS) Formation, described earlier show certain common characteristics, but also notable differences.

1. In the (CCSS) Formation, patch reefs, associated with mouth bars do not exist, although the presence of sponge mounds, oolitic shoals, stromatolites and other shallow marine carbonate facies, probably associated with relative highs within the basin (Fig. 18), could have developed in a similar way to the reefs.

2. In neither the study area nor regionally, is it possible to recognize slope facies that indicate a break in the shelf, this suggests that sedimentation took place in a marine basin with a very shallow topographical gradient (Fig. 18) similar to a carbonate ramp, in the sense of Read (1982, 1985) and Tucker (1985),.... «a gentle dip surface with a few degrees gradient, with shallow marine carbonates passing progressively towards deep basin deposits».

Calvet & Tucker (1988), proposed that the Upper Muschelkalk in the Catalan Basin was deposited in a carbonate homoclinal ramp context. In comparison with other ramp models (Markello & Read, 1981; Aigner, 1984, 1985; Wright, 1986), they point out that there is little evidence for storm deposits. These carbonates are equivalent to the Upper Muschelkalk in the Iberian Basin, which in the NW area passes laterally in to the (CCSS) terrigenous. The models could be similar, but account has to be taken of the existence of frequent storm deposits within the Iberian Basin. Pérez-Arlucea (1991) proposed a homoclinal carbonate ramp type fringing-bank, passing to barrier shoal-complex ramp for the Upper Muschelkalk carbonates of the central Iberian Ranges.

Roberts & Murray (1988) studied alluvial fans in the Arabian Gulf and the Red Sea. Both these studies showed active terrigenous and carbonate facies interaction. The alluvial fans being related to high relief, up to 2000 m, the arid climate not providing a constant supply of siliciclastic material. Evaporite deposition (Sabkhas) were forming on the coastal plains, with associated carbonates i.e. reefs. In the Gulf the margins prograded by a combination of alluvial deposition during ephemeral flooding and the subsequent stabilization of terrigenous fans by carbonates during intervening periods.

Friedman (1988), showed the contemporaneous deposition of both clastics and reefs in the Elat Gulf (Red Sea), Java Sea and the Negev Neogene Basin (Israel). In the Gulf, fine terrigenous deposition inhibited carbonate production

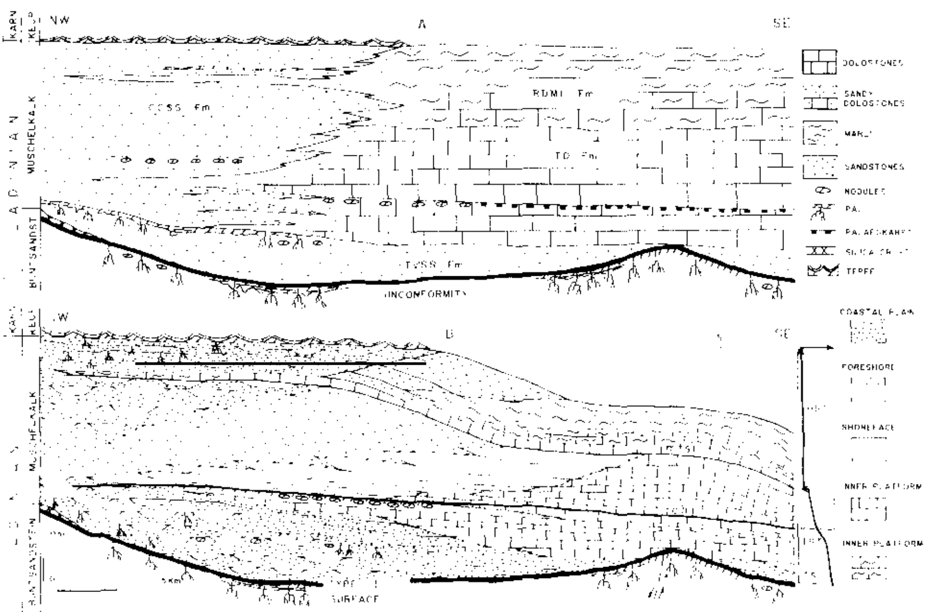


Fig 17A.—Cross-section showing the former stratigraphical correlation.

Fig 17A.—Sección que muestra la correlación estratigráfica previa.

Fig 17B.—Cross-section showing the new proposal of depositional system tracts in the studied region for the terrigenous of the (CCSS) Formation passing laterally into the carbonate Formations (DT y RDML). The strata patterns are controlled by relative changes of sea-level, the low volume for the accommodation and the terrigenous supply. The unconformity surface on Buntsandstein top represents a transgressive surface (ts). The depositional System tracts that can be recognized are: transgressive (TST), involves the «TvSS» and «DT» Formations; highstand (HST) involves «CCSS», «TD» and «RDML» Formations. (ch) is the condensed horizon, (mfs) is the maximum flooding surface and (sl) is the sea level.

Fig 17B.—Sección mostrando la nueva propuesta de correlación y «systems tracts» deposicionales para la Formación (CCSS) en tránsito lateral con los carbonatos de las Formaciones (TD) y (RDML). La forma de los estratos está controlada por los cambios relativos del nivel del mar, el escaso espacio para la acomodación de sedimento y el aporte de terrígenos. La superficie de discordancia, en el techo del Buntsandstein, representa la superficie transgresiva (ts). Los «systems tracts» que se pueden reconocer son: transgressive (TST), en que se involucran las Formaciones «TvSS» y «TD»; highstand (HST), en que se involucran las Formaciones «CCSS», «TD» y «RDML». (ch) es el horizonte de condensación, (msf) es la superficie de máxima inundación, y (sl) es el nivel del mar.

and storm waves transporting large volumes of material from one facies to another.

Sedimentary processes are strongly affected by climatic conditions. For example in areas of general aridity punctuated by occasional high precipitation, ephemeral floods emerging from wadis build as alluvial fans, whilst reef complexes develop along the slope break.

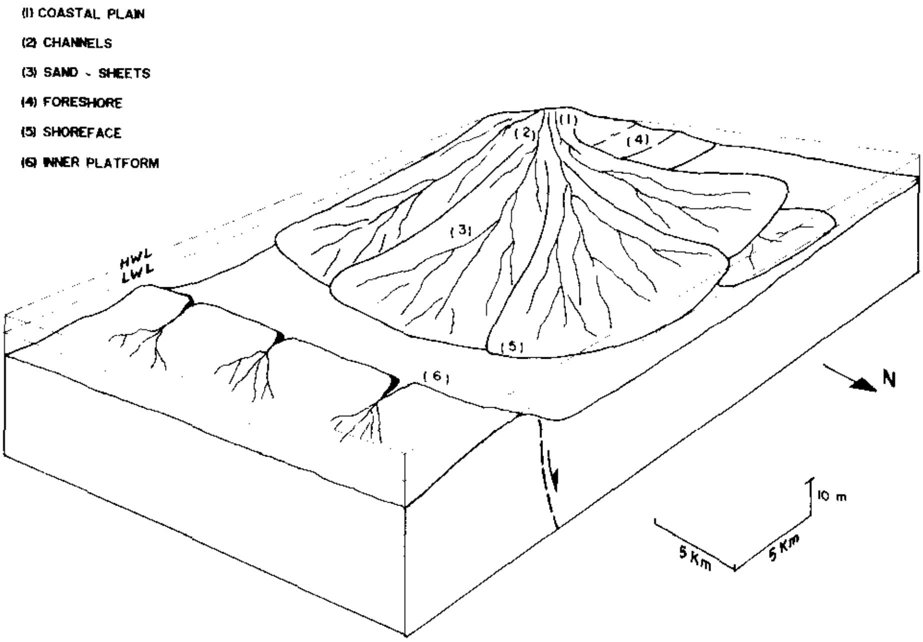


Fig 18.—Proposal for a sedimentary model of the (CCSS) Formation and its relationship with the Upper Muschelkalk carbonates. (1) Coastal plain, (2) Channels, (3) Sand-sheets, (4) Foreshore, (5) Shoreface, (6) Inner platform terrigenous, (8) Inner platform carbonates.

Fig 18.—Propuesta de modelo sedimentario para la Formación (CCSS) en realación con los *carbonatos del Muschelkalk Superior.*

In all these complexes where there exists an interaction between continental sediments and marine carbonates. Several common characteristics can be observed:

1. Deltas and alluvial fans flowing directly into the sea.
2. Coastal plains are usually narrow.
3. Frequently a slope break exists in relationship to active margins (rifts).

In the NW part of the Iberian Basin there are notable differences when compared with the previously described models, as well as there being several similarities.

First it is important to remember that the area occupied by the terrigenous sediments of the (CCSS) Formation extends over an area of about 82 km^2, having a relatively small surface area in comparison with other deltaic systems. The facies association characteristic of the different deltaic environments (delta plain, front deltas etc) are not found in this NW area of Iberian Basin. However, channel facies associations containing wood and bivalves on the upper surfaces; sand sheets; shoreface deposits etc., indicating that sedimentation took place in transitional coastal environments, with alternating continental and marine influence are found. These details require a fan delta model that takes account of these sedimentary conditions.

The fans would be related to the NW -SE fault systems located to the west of the study area (Fig. 1). Such fractures would be responsible for the relief necessary for fan delta genesis, the fan deltas building out into the sea to the east. In addition, certain NE-SW fractures would probably generate relative highs, conditioning both terrigenous and carbonate distribution. However, the fault controlled basin bottom irregularities could be responsible for the incomplete isolation of lagoons from the sea, as shown by the faunal evidence (Fig. 18).

From a study of the literature certain standard features become evident for coarse fan delta models.

1. High depositional gradients.
2. Remarkable tectonic control.
3. Existence of relatively deep, i.e. slope, turbidites etc., marine facies associations.
4. Large textural differences between terrigenous facies, i.e. sandstones, breccias, conglomerates etc.

The proposed model will therefore have to take into account the following characteristics.

1. Low depositional gradient being integrated in a homoclinal carbonate ramp, after Read (1982, 1985).
2. Combined tectonic, climatic and eustatic controls.
3. Presence of continental and shallow marine facies associations.
4. Remarkable textural homogeneity in the sandstone, siltstone and mudstone facies.

The climate was arid as shown by the existence of tepee structures in the carbonates of the coastal plain and abundant evaporite moulds in the shallow marine carbonates that pass laterally into the terrigenous (CCSS) Formation. Under these climatic conditions the terrigenous feeder system would have ephemeral characteristics, with high rhythmic sediment discharge periods, with minor terrigenous input in-between. During low energy periods marine processes would be stronger, whilst during high energy periods the channels feeding directly into standing marine water, would deposit larger volumes of terrigenous material, forming sand-sheets in the submerged areas. The wave ripples on the top of these sand-sheets are an indication of marine processes.

The low depositional gradient of the basin floor (Fig.18), with infrequent and small irregularities, indicates that the space available for sediment accommodation was not large, because of this sedimentary accumulation shows a tendency to lateral extension, rather than to vertical aggradation (Fig. 17). The presence of a large number of marine bivalves with low specific diversity in the finer facies (sandstones and siltstones), are indicative of a unstable shallow marine environment.

INTERPRETATION FROM DEPOSITIONAL SYSTEM TRACTS

Depositional sequences have been defined in the Triassic of the Iberia Peninsula by different authors (i.e. Garrido-Megias & Villena, 1977; Ortí, 1987; Marzo & Calvet, 1985). Calvet *et al.* (1990) all establish the facies, system tracts, sequences and control factors for the Middle Triassic carbonate ramp systems in the Catalan Basin (NE Spain).

The Middle Triassic horizons in the NW area of the Iberian Basin can be integrated as a depositional sequence (Fig. 17) beginning above the unconformity surface on the Upper Buntsandstein and ending with Keuper sedimentation (Fig. 19).

In the Iberian Basin, the sequence began with lowstand clastic and / or evaporites, these sediments do not occur in the NW part of this basin because of the development of the unconformity surface on the Buntsandstein (surface type I). This surface is capped by an onlapping terrigenous-carbonate transgressive sequence (Fig. 19), passing laterally into the aggradational terrigenous and carbonate sediments of the highstand system tract (HST).

In resume, the third order cycle 2.1 of Haq *et al.* (1987) is not recognizable in this region, neither is the lower part of the 2.2 cycle (sediments placed in the western and south-eastern areas of the Iberian Basin, Fig. 2). The sediments of the transgressive system tract (TST) and HST of the 2.2 cycle are, however, represented in this area.

The TST deposits are represented by terrigenous facies (continental and transition environments) and marine carbonates onlaping the unconformity surface (García-Gil, 1990). The change to the HST sediments is marked by a condensation horizon showing iron crusts and the results of other diagenetic processes (Fig. 17 and 19).

During the HST, the progradation of continental, coastal and shallow marine terrigenous sediments (CCSS Formation), as well as the equivalent shallow marine carbonates (Upper Muschelkalk), took place. As a result, the facies belts shifted towards the sea (NE y E). However, a short marine episode is represented by carbonate horizons (marls, dolostones with marine fossils on coastal terrigenous facies) of the RDML formation (Fig. 17). This marine flooding can be due to local subsidence of tectonic origin. Immediately after this episode, a HST facies regressive tendency followed, with the development of a coastal plain representing the final stage of the cycle. The end of this cycle is represent ed by a regional tepee horizon generated during the relative sea level fall at the end of Ladinian times. On this tepee horizon were deposited the Keuper coastal sabkha facies.

It should be noted that the Triassic sediments of the Iberian Basin, as well as those of the Catalan Basin, were deposited during phases of crustal extension and rifting (i.e. Buntsandstein), resulting in large thickness variations through the basin, followed by regional subsidence (i.e. Muschelkalk carbonates).

It should be further noted that although the cycle here has been described

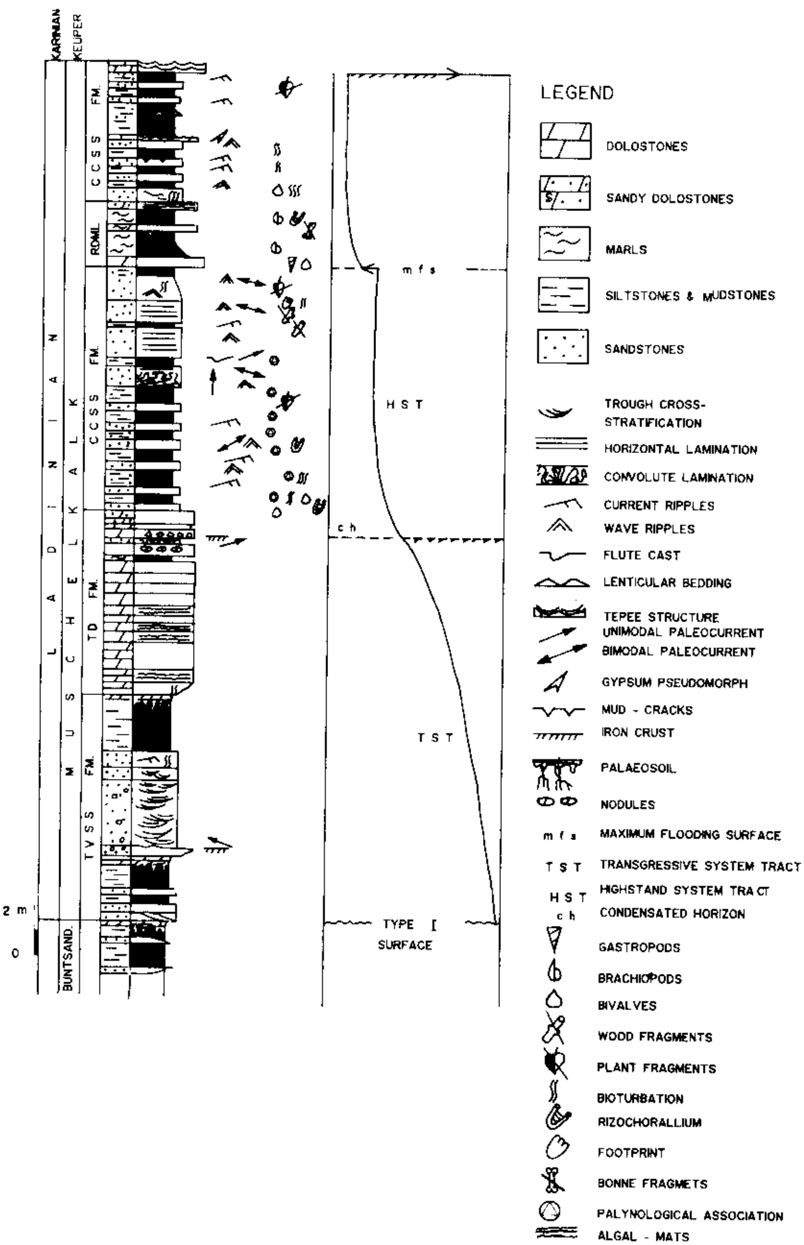


Fig 19.—Stratigraphical, chronostratigraphical and depositional sequences of the Upper Muschelkalk (Middle Triassic) of the Iberian Basin.

Fig 19.—Secuencias estratigráfica, cronoestratigráfica y deposicional del Muschelkalk Superior de la región de estudio.

in terms of eustastism, it could also be explained as a function of the extensional tectonic regime (Calvet *et al.*, 1990).

CONCLUSIONS

The depositional environment of the sediments of the Cuesta del Castillo Sandstones and Siltstones (CCSS) Formation is presented as an ephemeral stream delta system. The system drained from the W-SW and was deposited in a basin situated to the E.

The formation is divided into two units:

i. lower silty: corresponding to distal shoreface and inner platform deposits.

ii. upper sandy: corresponding to coastal plain, foreshore and shoreface deposits.

The vertical evolution of the formation shows a coarsening upward sequence.

The vertical distribution of facies associations reflects a general progradation of the sedimentary environment towards the NE.

On reaching the standing marine water body, the rivers produced strong currents which transported sediments seaward and deposited them as subaqueous sand-sheets.

The stacking and distribution of sand bodies was controlled by the low depositional gradient in the basin, causing more lateral extension than vertical accretion.

The CCSS Formation was deposited during a general sea level rise (Ladinian), and mainly corresponds with the HST, although locally there was some tectonic activity.

Deposition took place in an arid to semi-arid climate, controling the fluvial regime and facies distribution.

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