Neogene fan deltas in the northern Guadalquivir basin (Andújar, Jaén, Spain)

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ABSTRACT

The Neogene of Andújar (Guadalquivir Basin) consists of siliciclastic and carbonate rocks of Upper Tortonian and Messinian age. They are grouped into a laterally-related facies assemblages that form two megacycles. The lower of these cycles has debris-flow, proximal and distal braided-channels and sandy plain sediments, all them with subaerial and subaqueous features, plus marine littoral bars and carbonate shelf deposits. Lateral arrangement of facies allow to interpret these rocks as deposited in delta settings with variable name depending on the criterion used: braided delta (McPherson *et al.*, 1987) or fan delta (Nemec & Steel, 1988). In Postma's (1990) proposal of classification the described case-study sedimented in a shallow delta system fed by alluvial systems. It is an intermediate between types A and B, with bed-load dominance at the river-mouth and shoal-water profile, developed over a carbonate shelf. Sea-level fluctuations controlled the evolution of the system as deduced from spatial arrangement of the described rocks. This fluctuation was in turn related to variations of the basin's volume related to synsedimentary movements along the south margin (although this is a passive margin, it locates at the northern edge of a basin with a complex geodynamic behaviour during Cainozoic).

Key words: Neogene, Alluvial systems, Marine-continental transition, Deltas, Fan deltas, Sedimentation controls.

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RESUMEN

El Neógeno en el área de Andújar (Cuenca del Guadalquivir) está compuesto por sedimentos terrígenos y carbonatados de edad Tortoniense 2-Messiniense. Este conjunto se ordena en dos ciclos de los cuales el primero es objeto del presente estudio. En este ciclo se pueden identificar depósitos de debris-flow, canales trenzados proximales y distales, llanura arenosa (todos éstos sedimentados tanto en condiciones subaéreas como subacuáticas), barras litorales y plataforma carbonatada. En base a la ordenación espacial de estos depósitos el conjunto se puede interpretar de distintas maneras en función de los criterios utilizados. Siguiendo a McPherson *et al.* (1987) correspondería a un delta *braided* mientras que según los criterios de Nemec & Steel (1988) se interpretaría como un *fan-delta*. Como alternativa, los criterios dados por Postma (1990) ofrecen un medio de individualizar el sistema atendiendo a sus propias características, según éstos los materiales estudiados se habrían sedimentado a partir de un sistema deltaico de aguas someras alimentado por un sistema de tipo mixto A-B con dominio del transporte por carga de fondo en la desembocadura y un perfil de tipo «somero» (*shoal-water profile*) (Postma, 1990) sobre una plataforma carbonatada. El análisis de las características espaciales de los sedimentos muestran que la evolución de dicho sistema vendría condicionada por las variaciones del nivel del mar, las cuales probablemente serían debidas a las variaciones de volumen de la Cuenca del Guadalquivir provocadas por los movimientos de su borde sur (aunque este es un borde pasivo corresponde a una cuenca con un comportamiento geodinámico complejo durante el Cenozoico).

Palabras clave: Neógeno, Sistemas aluviales, Transición marino-continental, Deltas, *Fan deltas*, Controles sobre la sedimentación.

INTRODUCTION

Along the northern edge of the Guadalquivir Basin, between Marmolejo and Espelúy (Fig. 1), Neogene sediments unconformably overlie granitic, metamorphic and non-metamorphic rocks of Paleozoic and Triassic age.

These Upper Tortonian-Messinian and Pliocene age (Tjalsma, 1971, Perconig & Martínez Díaz, 1977, Porcuna Unit of Roldán *et al.*, *in press*) deposits are siliciclastic (conglomerates, sands and shales) and carbonate rocks (calcarenites and marls). They are grouped into laterally-related facies assemblages that form two megacycles (Fig. 2) (Santisteban Navarro & Martín-Serrano, *in press*).

The first megacycle rests unconformably upon a paleorelief cut on the substratum in the northern part; toward the south its lower limit is an intra-

Tortonian discontinuity (Garrido Megías *et al.*, 1983). This fining upward cycle shows a transgressive trend and the transition from terrestrial to marine environments. Large input of terrestrial sediment generated deltaic bodies (Portero & Alvaro, 1984). This cycle is equivalent to the Tortonian 2 - Messinian 1, Ne-4 TSU of Garrido Megías *et al.* (1983) and to the «Unidad basal transgresiva» (Transgressive Lower Unit) and «Unidad margas azules» (Blue Marls Unit) of Portero & Alvaro (1984).

Sediments forming the second cycle rest paraconformably over the former or unconformably over the substratum. These are regressive alluvial-fan conglomerates (Santisteban Navarro & Martín-Serrano, *in press*). Although no fossils were collected from these rocks, we correlated them with the Ne-5 TSU (Messinian 2-Pliocene 1) of Garrido Megías *et al.* (1983) by facies similarity and the regressive trend.

Small faults affect and tilt the otherwise subhorizontal Tertiary sediments: in some places close to the northern E-W fault (Fig. 1) beds dip up to 40°. Another important fault system directed NE-SW juxtaposes the Cainozoic rocks to the substratum.

The aim of this paper is to describe and interpret the first of this Neogene cycles based on detailed mapping and sedimentological work.

FACIES ASSOCIATIONS AND SEDIMENTARY ENVIRONMENTS

Mapping of Tertiary units showed a gradual facies change from N (conglomerates) to S (marls) thorough sands and calcarenites. Agreeing to this we separated various lithological assemblages, the interpretation of which is the basis of the proposed environmental reconstruction.

In the following description and interpretation these assemblages are arranged from north to south, i. e. in decreasing order of abundance, using Postma's (1990) nomenclature.

Debris flow deposits

They are tabular (Fig. 3 A) (wedge-shaped in map scale) or channel-shaped bodies (Fig. 3 B) hundreds to thousands of metres long but only up to 2 m thick. Beds lay subhorizontal or dip less than 10° (sedimentary dipping).

They are poorly sorted, mud-supported conglomerates (Gmm) with clast sizes up to 50 cm. Clasts are well-rounded, with polished surfaces owing to their poly-cyclic nature. Clast orientation is random. Prevailing components are granitic and metamorphic rock fragments; some of them come from distant source areas. Matrix is a poorly-sorted, arkosic sandy mud coming from nearby reliefs.

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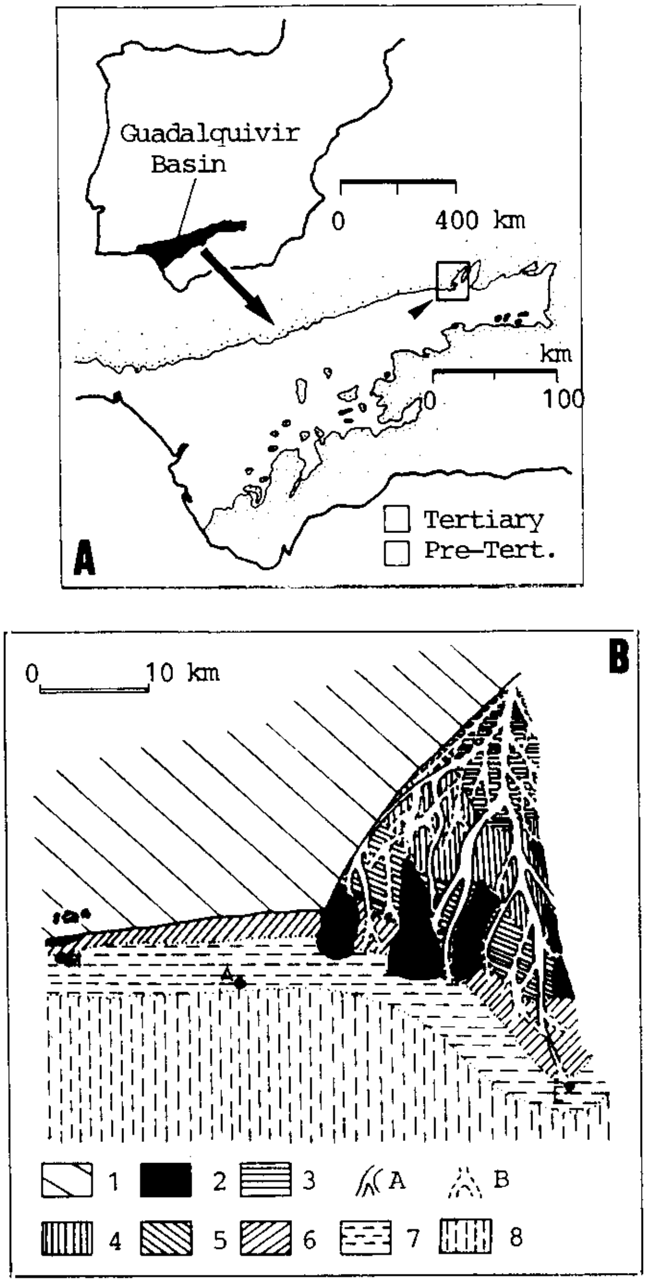

Fig. 1.—(A) Location map of the Guadalquivir Basin and studied area. (B) Sketch map of Tertiary sediments near Andújar. Key: Villages, M: Marmolejo; A: Andújar; E: Espelúy; 1: Metamorphic and granitic terrains; 2: Triassic terrains; 3: Lower Conglomeratic Assembly

Textures and geometries, joined to paleogeographical position allowed us to interpret these deposits as unconfined (tabular bodies similar to P. 1 facies of Kazanci & Varol, 1990) or channelized (channel-shaped bodies) debris-flow. Transport of sediment, as deduced from geometries and dip of beds was from N to SE and SW.

Near the central sector of the studied area, debris-flow deposits are related to Triassic paleohills which show features of marine immersion: carbonate muds bearing marine molluscs, limpets sticked to the clasts (Fig. 3. C) and green colours. Conglomerates are clast-supported (Gms) (Fig. 3. B). Colella *et al.* (1987) interpret this feature as a matrix removal because of sediment-laden waters input into a static water body. Wescott & Ethridge (1983) and Colella *et al.* (1987) described similar deposits.

Channel deposits

They are channel-shaped bodies of sandy conglomerates to conglomeratic sands. Clast composition is similar to those of debris-flow deposits; sand is similar to the conglomerate matrix (arkose). Muds are scarce.

Paleocurrent measurements yielded values similar to those of debris-flows, but the south vector dispersion is smaller.

Geometry, size and sequences permitted to differentiate four facies:

Main proximal channels

Channel-shaped bodies of conglomerates with width/depth ratios about 25:1. They show many overlapped scour surfaces. Channel-fills are fining up sequences of Gm, Gt and Gp types, rich in sandy muddy matrix (Fig. 4. A) indicative of high suspension load. Sandy mud drapes between both set surfaces and sequences prove the episodic behaviour of flow and the fill of the channel. Scour surfaces and channel stacking suggest a high (torrential)

(North zone); 4: Lower Conglomeratic Assembly (South zone); 5: Marine-Continental Transition Assembly; 6: Calcarenites and Sands Assembly; 7: Marine Transition Assembly; 8: Marly Assembly; A: Main distal channels; B: Main proximal channels and secondary channels. Assemblages referred to the distribution of facies associations explained in the text.

Fig. 1.—(A) Mapa de situación de la cuenca del Guadalquivir y el área estudiada. (B) Mapa esquemático de los sedimentos terciarios cerca de Andújar. Clave: Pueblos: M: Marmolejo; A: Andújar; E: Espelúy. 1: Materiales metamórficos y graníticos; 2: Materiales triásicos; 3: Conjunto Conglomerático Inferior (zona norte); 4: Conjunto Conglomerático Inferior (zona sur); 5: Conjunto de transición marino-continental; 6: Conjunto de calcarenitas y arenas; 7: Conjunto de transición marina; 8: Conjunto margoso; A: Canales principales distaless; B: Canales proximales principales y canales secundarios. Los conjuntos se refieren a la distribución de las asociaciones de facies explicadas en el texto.

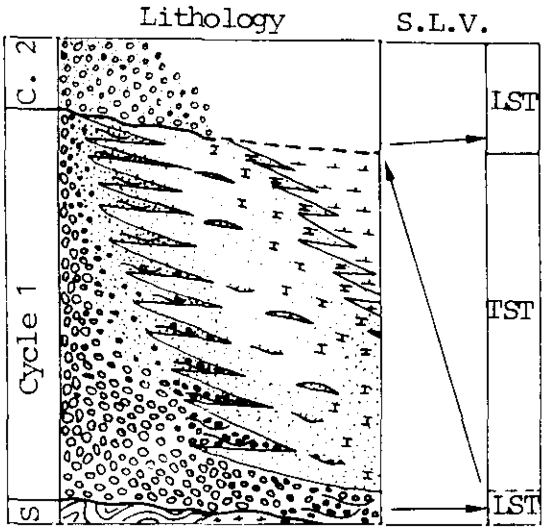

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Fig. 2.—Stratigraphic sketch showing the distinguished major cycles. Lithologies: conglomerates and sands (terrestrial), sands and calcarenites (marine-terrestrial transition) and marls (marine). S. L.V. sea-level changes, to the right sea-level drop (regression) and to the left sea-level rise (transgression). LST: Lowstand Systems Tract, TST: Transgressive Systems Tract.

Fig. 2.—Esquema estratigráfico para indicar los ciclos mayores diferenciados. Litologías: conglomerados y arenas (continental), arenas y calcarenitas (transición marino-continental y margas (marino). S. L.V. cambios de nivel del mar, a la derecha, caida del nivel del mar (regresión) y a la izquierda, subida del nivel delmar (transgresion). LST: Cortejo de facies de nivel del mar (Lowstand Systems Tract), TST: Cortejo de facies transgresvo (Transgressive Systems Tract)

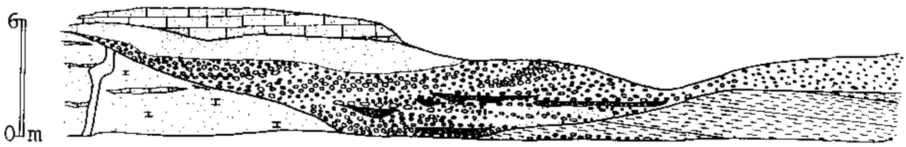
hydric regime with frequent channel shifting within the main river-bed. These features and the scarcity of flood-plain deposits lead us to interpret them as deposits of braided fluvial systems with high sediment load (suspended and bed load) and migration of transverse or cross bedding simple bars (Allen 1983) (Fig. 4 B). Huo (1990) and Pollard *et al.* (1982) described similar deposits in sandyer lithologies. Local occurrence of deposits rich in oyster and gastropod shells and little secondary channels filled by shell fragments suggest shallow-marine interdistributary bays near (and laterally to) the channels.

Main distal channels (single channel or low-sinuosity channels)

These are small channel-shaped bodies (Fig. 5), a few decametres wide (w/d rates about 10:1) filled with heterometric sediments (gravel to sandy-silt).

3.A

3.B



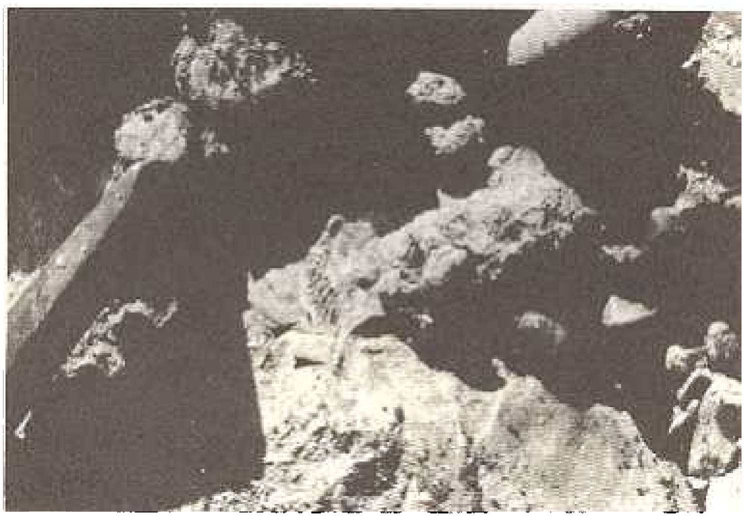


Fig. 3.—(A) Field sketch of tabular debris-flow bodies. Two tabular-shaped bodies of Gmm facies with a Gt interbed related to ephemeral channels. (B) Field sketch of a channel-shaped body of debris flow filled by Gms and Sm facies. Note the overlapping calcarenite body (visible at the top) resting upon calcarenites and sands (left) and carbonate muds (right). Arrow at the left limit shows displacement of a small fault. (C) Limpets sticked to a clast (detail of Fig. 3. B).

Fig. 3.—(A) Esquema de campo de los cuerpos de debritas. Dos cuerpos tabulares de Gmm con una intercalación de Gt relacionados con canales efímeros. (B) Esquema de campo de un cuerpo de debritas de morfología canalizada rellenos con facies Gms y Sm. Notar el cuerpo solapante de calcarenitas (visible hacia el techo) descansando sobre calcarenitas y arenas (izquierda) y barros carbonatados (derecha). La flecha en el límite izquierdo señala el desplazamiento de una pequeña falla. (C) Lapas fijas a un clasto (detalle de la Fig. 3 B).

4.B

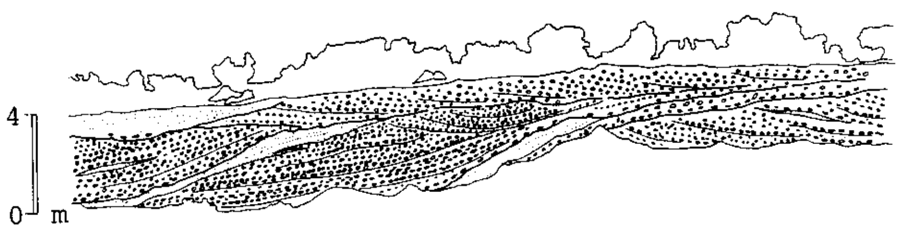


Fig. 4.—(A) Sequence of filling of a main proximal channel: Gt—>Gp with sands and vegetal debris to the top. Dark layers are conglomerates rich in organic matter. (B) Field sketch of transverse bars arrangement and scale.

Fig. 4.—(A) Secuencia de relleno de un canal principal proximal: Gt—>Gp con arenas y restos vegetales a techo. Las capas oscuras son conglomerados ricos en materia orgánica. (B) Esquema de campo de la disposición y la escala de las barras transversas.

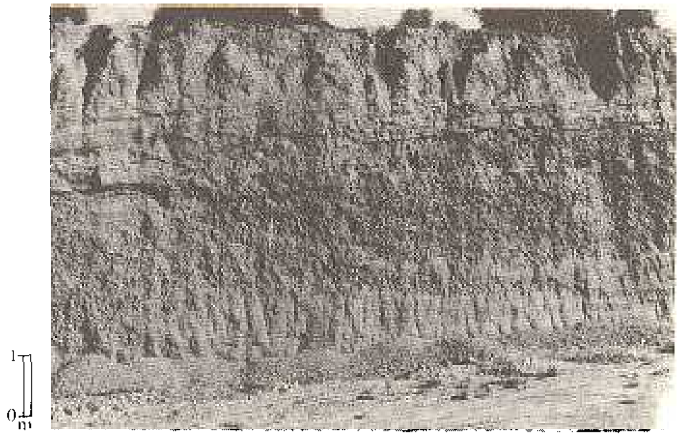


Fig. 5.—Field aspect of the main distal channels. Sands are more abundant and better organized than in proximal channels.

Fig. 5.—Aspecto de campo de los canales principales distales. Las arenas son mas abundantes y están mejor organizadas que en los canales proximales.

These bodies appear intercalated as lenses into massive sands interpreted as sandy plain deposits. Channel-fill took place in subaerial (showing oxidizing features, small crusts and rootlets) and submarine (marine gastropod and bivalve shells in situ) realms with several facies arrangements. The more common sequences are Gt—>Gp—>St—>Sr and St—>Sp—>Sr—>Fl (intensely burrowed). Mud drapes separating successive sequences witness episodic flow in the channel. These deposits are interpreted as a single channel network of low sinuosity and intermittent flow related to proximal channels. Transverse bars, composite-compound bars (*sensu* Allen, 1983), and 3D megaripples are the main forms moving along these channels although there are lateral accretion units related to development of lateral bars. Channel shifting is less frequent than in the proximal channels owing to a higher channel stability; this allows a better preservation of sandy flood-plain deposits. These deposits developed over a wider, flatter area which was temporarily flooded by the sea. Examples of this channel type are the A1, A2 and A3 architectural elements (Marzo *et al.*, 1988) and transition zone deposits (Ori, 1982).

Crevasse channels

They are small sand-filled channels with a w/d ratio between 2:1 and 3:1 (width up to 4 m, depth up to 1.5 m). Filling sequences begin with a 10 to 40 cm-thick coarse gravel lag (Gm) (clasts sizes up to 20 cm) followed by Sm facies (Fig. 6). It is alternatively entirely composed of sandstones (Ss). There are features indicating temporary inundation by sea waters. They lay laterally

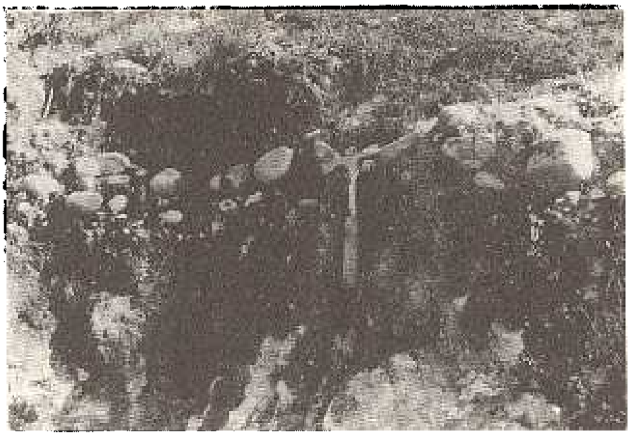


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Fig. 6.—Crevasse channels. Coarse-grained (conglomeratic) lag followed up by massive sands in a 40 cm-thick sequence (hammer is 30 cm long).

Fig. 6.—Canales de derrame. Lag de grano grueso (conglomerático) seguido por arenas masivas en una secuencia de 40 cm de espesor.

from distal channels with a paleocurrent divergence up to 80°. They cut sandy plain deposits and both deposits can be amalgamated. We interpret them as crevasse channel deposits related to flooding events. Huo (1990) found similar deposits within flood-plain facies.

Secondary channels

They are very similar to the crevasse channels from a geometric point of view but sequences and paleocurrent pattern are different. They are filled with sands with scarce small pebbles arranged in sequences like: Sm—>St—>Sr; Sm—> I—> Sp—>Sr or St—>Sp—>Sr (Fig. 7). These sequences formed in channels with a low suspended load where small transverse bars and megaripples migrated. Paleocurrent patterns are similar to those of the major channels (roughly N-S). In outcrop they are isolated lenses into sandy-plain deposits. We interpret them as single low-sinuosity sandy channels laterally related to the main distal channels. As in the former types, they can show features of sea-water influence. Similar deposits are Kazanci & Varol's (1990) P. 4 facies, interpreted as minor braided channels flowing on the lower delta plain, and Vos'(1981) Facies 2, interpreted as distributary channels.

Sandy plain deposits

They are massive arkosic sands (Sm) forming the largest volume of sediments in the central belt of the study area. Significative features are low-

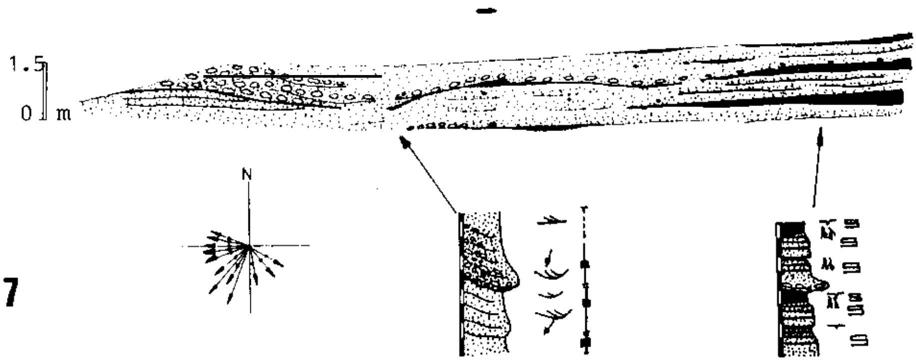

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Fig. 7.—Field sketch of secondary channels. Sequences show channel fill and adjacent sandy-plain facies. Pointless arrows show paleocurrents measured in channel deposits. Pointed arrows show paleocurrents measured in sandy-plain deposits; note that they show a dispersion greater than the channel (flood deposits).

Fig. 7.—Esquema de campo de los canales secundarios. Las secuencias muestran el relleno del canal y las facies vecinas de llanura arenosa. Las flechas sin punta indican paleocorrientes medidas en los depósitos de llanura arenosa; nótese que su dispersión es mayor que la de los canales (depósitos de inundación).

angle cross-bedding, association with wedges of low-angle cross-laminated and cross-bedded sands (interpreted as crevasse lobes), pedogenic imprints (in subaerial areas), accumulations of marine shells and burrowing by infaunal biota in submarine areas (Fig. 8).

All the described deposits are associated: channel and sometimes, debris-flow deposits may show intercalated marine bar deposits (described afterwards).

Considering their relative positions and the associated deposits, we interpret them as a subaerial sandy flood-plain and a subaqueous sandy plain (deltaic plain?). Its origin was related to periodic flooding of the fluvial system. The occurrence of marine shells and bars in areas far from the influence of channels suggest reworking by marine agents along the shore and accumulation of beach (although we could not recognize definite beach sequences) and shelf deposits, as proved by the presence of carbonate-siliciclastic bars.

Marine bar deposits

They are calcarenitic (carbonate-siliciclastic) bodies with width ranging from 10 to 50 m and thickness from 1 to 3 m. They occur as individual lens-shaped bodies within sandy plain deposits or as amalgamated bodies forming tabular-like beds reaching lengths of some kilometres and thickness up to 15 meters.

Carbonate components are bioclasts (fragments of mollusc shells, forams, echinoid plates, algal mats, Fig. 9) and marly or calcarenitic intraclasts. Siliciclastics are quartz, feldspars, micas, fragments of metamorphic rocks and silty-muddy clasts.

We found sequences composed of trough cross-bedding, planar cross-bedding and current (or wave) ripple cross-lamination. Paleocurrents point to N-NE.

These deposits record reworking of the sandy plain by waves and littoral currents and mixing up with carbonate-shelf deposits that moved along the shore as bars. Roldán *et al.* (*in press*) and Portero & Alvaro (1984) described similar facies not far to the south and interpreted them as deposits of a high-energy shallow shelf.

Carbonate shelf deposits

They are massive grey-blue marls with a little amount of siliciclastics. Fossil content (forams and especially to the north, small algal mats) is high. Locally we found shallow-marine thin diatomitic intercalations (Fig. 10).

Rarely it is possible to observe a gradual change in composition from the carbonated-shelf to the sandy-plain deposits shown by a variation in siliciclastic contents and matrix composition (from marly to clayey).

These deposits settled from suspension and precipitated on shallow-marine, shelf areas below wave base. The small algal mats in life position point to sedimentation in the photic zone where joined shallow diatoms. Roldán *et al.* (*in press*) interpreted these facies as deep, basinal marine, whereas Portero & Alvaro (1984) consider them as open-shelf deposits.

SPATIAL DISTRIBUTION OF FACIES ASSOCIATIONS

Mapping of Tertiary deposits shows that the analyzed facies associations of the first cycle show a well-defined spatial distribution. Certain facies

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Fig. 8.—Sands of the sandy-plain deposits burrowed by marine biota. There are shells of marine molluscs in the low-angle cross-bedded sands. Hammer is 30 cm long.

Fig. 8.—Arenas de los depósitos de llanura arenosa bioturbadas por biota marina. Hay conchas de moluscos marinos en las arenas con estratificación cruzada de bajo ángulo. El martillo mide 30 cm.

Fig. 9.—Detail of calcarenite with abundant fragments of marine shells (lens cap is 5 cm in diameter).

Fig. 9.—Detalle de calcarenita con abundantes fragmentos de conchas marinas (la tapa de la cámara mide 5 cm de diámetro).

Fig. 10.—Parallel-laminated diatomitic layers composed of alternating dark (rich in carbonate clays and organic matter) and light levels (rich in diatoms).

Fig. 10.—Capas diatomíticas con laminación paralela compuestas por niveles oscuros (ricos en arcillas carbonatadas y materia orgánica) y claros (ricos en diatomeas)

associations tend to occur in fixed areas which, to our purpose, we consider as paleogeographic domains. In this paper, we call them assemblages; these are mappable and owe paleogeographic entity.

From north to south we differentiate the following assemblages (Fig. 1. B):

— Lower Conglomeratic Assemblage.
— Marine-Continental Transition Assemblage.
— Calcarenites and Sands Assemblage.
— Marine Transition Assemblage.
— Marly Assemblage.

Lower Conglomeratic Assemblage (Cerro del Moro Conglomerates)

This assemblage occurs in the NE of the studied area, resting unconformably upon pre-Tertiary rocks. The minimum thickness reaches 100 m and it shows a fan morphology with its apex to the north. Paleocurrents show a radial arrangement ranging from SO to SE.

It is composed of debris-flow and proximal channel deposits. Lithology and sedimentological features allowed us to distinguish two zones:

Northern zone: It is characterized by the dominance of debris-flow deposits. The size of clasts decreases from boulder to pebble (40 to 15 cm) when moving from north to south. First-cycle clasts are sharp-edged and unpolished whereas those of a poly-cyclic nature are well-rounded and show a polished surface. There is scarce massive arkosic sand, very similar to the matrix of conglomerates, with hydromorphic features and local planar cross bedding.

We interpret this zone as proximal fan because of the dominance of debris-flow deposits.

Southern zone: Here, proximal channel deposits dominate, with a minor presence of debris-flow deposits. Both deposits exhibit subaerial features to the N whereas to the S they include subaqueous features (marine fossils and green-yellow colours) as well. Laterally this area relates to the north zone.

The width/depth ratio of channels increase to the south, with a decrease of clast sizes. Distal-channel and sandy-plain deposits also occur in that direction.

This zone corresponds to the transition from proximal to middle fan (with anastomosing to braided channels evolving to braided ones) and the beginning of distal fan indicated by crevasse and sandy-plain deposits, related to a change of slope.

As a whole, this Conglomeratic Assemblage shows a dominance of sediment gravity flow processes to the north changing southwards into a marine-influenced, braided fluvial system with episodic behaviour.

Marine-Continental Transition Assemblage

It occurs between the Lower Conglomeratic and the Calcarenites and Sands Assemblages. It is composed of a variety of lithologies: we found all the previously-mentioned deposits, although distal channel, sandy plain and marine bar deposits dominate. Deposits of main proximal channel are restricted to some drainage axis along paleovalleys incised into Triassic rocks.

There are two main types: Arroyo de la Fresneda and Aldehuela.

Arroyo de la Fresneda type includes distal-channel, secondary-channel, crevasse-channel and sandy-plain deposits. All them exhibit features, burrowing and fossils indicative of a subaqueous marine origin. It is interpreted as submerged deltaic plain with low-sinuosity single channel fills recording diverse flooding events (multistorey channels).

Aldehuela type is a more complex assemblage composed of main proximal-distal channel, sandy-plain (including related interdistributary bay deposits) and marine-bar deposits. The latter shows a N to S compositional trend, from terrigenous to mixed carbonate-siliciclastic. This type is interpreted as the main underwater fluvial outputs, generated by fans, with a well-developed deltaic plain and mouth bars evolving to marine bars because of shore dynamics.

This assemblage corresponds to the transition from terrestrial to marine environments in the delta plain.

Calcarenites and Sands Assemblage (Espelúy Calcarenites and Sands)

This up to 120 m thick Assemblage is bounded to the north by the earlier described Marine-Continental Transition Assemblage and to the south by the Marine Transition Assemblage described in the next section. It consists of intensely-burrowed, greenish sandy-plain and marine-bar deposits.

Textural maturity of the sandy plain deposits increases to the south plus a compositional change from clay to marl.

Locally, sigmoidal and lenticular bodies, 2 to 4 m thick and 1 to 4 km long occur. These bodies show scour-and-fill, low-angle cross-bedding and cross-lamination owed to current and wave ripples. There are also scour surfaces, up to 80 cm deep and 2 m wide, filled with massive bioclastic sands and clasts. This assemblage corresponds to shoreface and foreshore deposits.

Marine bar deposits show channelized (north) and tabular (south) morphologies depending on their relation with confined (channels) or unconfined (shore) currents. Siliciclastic content decreases to the south as well. They represent shore bars moving on a shallow siliciclastic shelf.

This Assemblage corresponds to deposits on the transition area between the shoreface and the shallow open shelf where bar development is subjected to interaction between fluvial and shore processes.

Marine Transition Assemblage

This assemblage occurs as thick tabular bodies in an irregular belt between the Calcarenites and Sands Assemblage and the Marly Assemblage. They are marly to clayey sandy-plain deposits with bituminous marls and clays deposited in the carbonate shelf. This Assemblage records shelf sedimentation between fair-weather and storm wave-base level (shore to shelf transition).

Marly Assemblage (Vegas de Triana-Marmolejo Marls)

It outcrops in the southern third of the studied area: it is the more extensive assemblage. We presume that its geometry is tabular although it wedges to the north. Both its top and bottom are not exposed but the smallest measured thickness surpasses 140 m.

It is composed of carbonate deposits, with a variable clay content and abundant fossils. Bedding is not well visible but we could trace laterally some layers of calcarenite.

This assemblage is interpreted as shelf deposits, below storm wave base.

DISCUSSION OF DELTA MODELS

In the former paragraphs we showed a complex pattern of sedimentary environments including subaerial and submarine fans, braided fluvial, delta plain, shore and shelf in less than 10 km in direction normal to the main shore.

When we try to build a model we confront the classic segregation between delta and fan-delta models depending on scales and facies. However, several researchers suggest nowadays that such segregation of models is an artificial barrier; they propose alternative points of view.

McPherson *et al.* (1987) grouped classic deltas and fan-deltas as a single class formed by three types according to the feeding alluvial system: fan deltas, braided deltas and «common» (meander) deltas. They restricted the term fan delta to mass-flow dominated, tectonically-controlled, alluvial fans that prograde into static water masses (seas or lakes).

Nemec & Steel (1988) disagree with this opinion. They consider that the fan delta concept must include greater alluvial fans with low gradient, muddy-sandy composition, fluvial dominated and not related to tectonics.

Postma's (1990) fan deltas are deltaic systems fed by alluvial fans. He considers them as a second level classification into the more general model of deltas.

The sediments described in this paper belong to a delta system because we find a continuous change from terrestrial, alluvial-fan sediments to marine, shelf deposits. A question raises from this reflexion: what type of alluvial system fed our delta? On the one hand we must consider every sedimentary environments as separated from the others by environmental changes like slope, energy, etc. So, we are looking a complex paleogeography with alluvial fans (north) that change into a fluvial plain with low-sinuosity, single channels owing to a change in slope near the sea. Drowning of channels and delta plain during transgression or channel progradation, results in the development of a delta with mixed carbonate-siliciclastic delta front. Siliciclastics come from reworking of deltaic sediments by coastal processes. Carbonates generate in deeper parts of the shelf (or prodelta).

If we consider the presence of debris-flow deposits, the short distances separating environments, the occurrence of similar deposits in both subaerial and subaqueous realms and the high-energy gradient, we conclude that these closely-interconnected environments are parts of a fan delta.

We consider that choosing one or another model is a subjective matter because we find criteria supporting both models. If we follow McPherson *et al.* (1987), we must consider the described deposits as a braided delta, but Nemec & Steel's (1988) ideas point to a fan delta. Our opinion is that differentiation between braided delta and fan delta passes through the question of system (model) bounds. A choice is Postma's (1990) proposal based on the description of the feeder system, basin depth, diffusion processes at the mouth of the feeding river and delta profile.

In our example, the feeder system shows intermediate features between Postma's (1990) A and B types because there is record of both alluvial systems with mass-flow phenomena and braided system with well-delimited channels. This is related to variations induced by paleoreliefs that affect slopes and define paleodrainage axes which controlled the development of several systems.

The basin was a high-energy shallow sea and bed-load transport dominated at the channels mouth. Despite the favourable slope, the delta could not reach a Gilbert-type profile. An explanation is that continuous coastal reworking of sediment prevented further growth.

CONTROLS OF SEDIMENTATION

Before proposing a sedimentary model, we will refer to the controls on sedimentation.

The most frequently invoked controls are sediment input, climate, tectonics and sea level changes (Colella *et al.*, 1987, van Wagoner *et al.*, 1988, Pardo *et al.*, 1989, Santanach, 1989, Postma, 1990). We must discriminate the relative real influence on sedimentation of everyone of them.

Concerning sediment input, we observe two facts. First, the spectrum of clast lithologies indicative of far source areas. The recycled nature and arkosic composition of the matrix (derived from nearby areas) strongly suggest reworking of previous deposits found nearby. This agrees with the second fact. Detailed mapping shows that the sediment contributed by areas external to the system is not volumetrically important, as suggested by low rates of vertical aggradation and high rates of horizontal redistribution.

Climatic indicators (paleosoils, fossil content, etc.) do not change importantly during sedimentation. Calcimorphic red soils suggest a warm Mediterranean climate.

Regarding tectonics, several authors refer to two distension events: pre-Tortonian 2 (Early Tortonian) and intra-Messinian (or Early Pliocene) age. The first of them defined the basin along ENE-WSW and NE-SW faults inherited from Mesozoic lines (Sanz de Galdeano, 1983 a & b). The second one changed the original arrangement of sediments in Early Pliocene times (Sanz de Galdeano, 1983 b). By other way C. Quesada (*pers. comm.*, 1991) considers that these reaches of the basin (Bailén basin) occupy a NE-SW tectonic trough, probably in transtensional pull-apart related to a movement of Guadalquivir Fault. Synsedimentary tectonics was of little importance as shown by the homogeneous areal spread of synsedimentary faults and its short length. We did not find unconformities or sediment gravity flows that might record movements along the master (ENE-WSW and NE-SW) faults. Portero & Alvaro (1984) consider that the Tortonian 2-Messinian period was post-tectonic in areas close to the studied one. However, although we consider a passive northern margin, as C. Quesada (*pers. comm.*, 1991) points out, the south margin of the Guadalquivir Basin shifted owed to displacements of the African Plate since Lower Cainozoic times that caused variations in basin's dimension. Moreover, smaller movements of the northern Hesperic Massif must lead to uplift of the northern hercinic reliefs. Summarizing, local tectonic movements are of little importance related to sedimentary events. But regional geodynamic context must control sediment input to the basin (from the northern areas) and changes of basin dimensions (related to southern margin movements) along time.

The last control (sea level changes) is recorded by shoreline migration along time (Fig. 2). During the early episodes of sedimentation the shoreline was to the south and topographically lower. We assume a rapid sea-level fall to justify the underlying discontinuity surface (type 1 surface van Wagoner *et al.*, 1988) cited by previous authors (Garrido Megías *et al.*, 1983, Portero & Alvaro, 1984) and the progradation of the systems that generated a poor-developed Lowstand Systems Tract (van Wagoner *et al.*, 1988). The following transgression implied a gradual sea-level rise that deposited a Transgressive Systems Tract composed of delta, shallow siliciclastic shelf and carbonate shelf sediments. We must consider that these sea-level changes are relative. They must be related both to global sea level changes and to tectonically-induced changes in the basin.

SEDIMENTARY MODEL

We propose a sedimentary model for the Upper Miocene rocks of Andújar based upon the sedimentary environments and processes recorded:

1. The clear differentiation of the various parts of the system (proximal fan, distal fan, submerged distal fan and shelf) implies a low rate of vertical aggradation related to intense redistribution of sediment by sedimentary agents.
2. Fan behaviour, except for early times, is retrogradational. According to the previous point, this implies a continuous building of sedimentary bodies but surpassed by marine redistribution of sediments. Portero & Alvaro (1984) pointed out this fact in deltaic sediments of the same age but placed to the west.
3. There is not preferential drainage axis over the alluvial plain. Drainage followed paleovalleys related to paleoreliefs dug into the Triassic rocks forming the local substratum.
4. Subaerial and subaqueous deposits are similar as shown by marine shells or rootlets found in the same, coeval facies but in different paleogeographic location.
5. Source area is nearby as showed by sediment textures.

From these data and observations we conclude that the Tortonian 2-Messinian sediments in Andújar deposited along a lineal shore broken down in an embayment that acted as receiving basin of sediments coming from nearby reliefs. Alluvial fans with mass-flow deposits to the apex and braided fluvial systems to middle and distal parts entered the bay from the land. Small debris-flow connected to the slopes of the emergent paleoreliefs developed. Drainage axis began to define whereas a sandy plain developed in areas adjoining the paleohighs. Secondary channels filled with conglomerates and sandstones crossed the delta plain. In the lowermost part of the plain the sea created interdistributary bays. Transport of conglomeratic deposits surpassing the edge of the embayment, continued *via* channelized flows because of the large amount of bed-load carried by alluvial system. This fact invokes an active uplifting of the northern reliefs which location is not known nowadays. Sandy fraction was redistributed rapidly alongshore greatly reducing the accumulation of steep delta foresets. Carbonate sediments deposited in quieter areas of the shelf during these times. Marine currents and waves acting on the carbonate-rich bottom during high-energy peaks reworked these deposits bringing them to the shore where they mixed with siliciclastic sediments to form migrating bars at the beach.

CONCLUSIONS

The Tortonian 2-Messinian sediments of Andújar area record a mixed terrigenous-carbonate system with siliciclastic fluvial input and mostly carbonate marine sediments.

Analysis of the sedimentary systems' features allows us to interpret them as braided-delta deposits (in McPherson *et al.*'s, 1987 nomenclature) or fan-delta deposits (agreeing to Nemec & Steel, 1988). Alternatively, Postma's (1990) proposal of classification is an aseptic manner to individualize systems by their own features. This scheme has its proper set-back because names always impose artificial barriers. However, according to Postma (1990) we consider the described case-study as sedimented in a shallow delta system fed by alluvial systems; it is an intermediate between types A and B with bed-load dominance at the mouth of the rivers and shoal-water profile developed over a carbonate shelf. Sea-level fluctuations, related both to global sea level changes and basin dimension variations of tectonic origin, controlled the evolution of the system.

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