A lacustrine fan-delta system in the Pliocene deposits of the Guadix Basin (Betic Cordilleras, South Spain)

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ABSTRACT

The Villanueva Complex is a lacustrine fan-delta system, dominated by debris and stream flows, which developed along a northern, extensional margin of the Guadix basin (Betic Cordilleras, S. Spain). Two main zones exist: 1) a subaerial zone characterized by massive conglomerates deposited in an alluvial fan, and 2) a subaqueous zone on which fine sedimentation (marls and calcilutites) predominates, interspersed with beds of conglomerates with different thickness and geometry.

This second zone can be further divided into two sub-zones of different depths (mudflat and lacustrine) related by lateral changes in the facies. The recognizable stratigraphic sequences, which are of decametric thickness, both thicken and coarsen upwards. These sequences show a gradual evolution in geometry and thickness of conglomeratic bodies related to a rising base level. On a larger scale, the whole sequence shows a clear thinning and fining-upward tendency as a result of retrogradation during the three main phases of the fan delta's construction. This situation bears witness to the northerly displacement of the lacustrine areas due to the progradation in the same direction of the alluvial cones associated with the drainage of the relief at the southern margin.

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Key words: lacustrine fan delta, sequences, geometry of sedimentary bodies, base level oscillations.

RESUMEN

El Complejo de Villanueva constituye un sistema de abanico deltaico lacustre dominado por procesos de *debris-flow* y *stream-flow*, desarrollado en relación con un margen de cuenca de tipo extensional. Se diferencia una zona subaérea representada por conglomerados masivos depositados en un ambiente de *abanico aluvial* y una zona subacuática, con predominio de sedimentación fina (margas y calcilutitas) en la que se intercalan bancos de conglomerados de espesor y geometría variable y en la que se diferencian en función de su profundidad, dos subambientes (*llanura lutítica* y *lacustre*) relacionados mediante cambios laterales de facies. Desde el punto de vista estratigráfico se reconocen secuencias de orden decamétrico, estrato y grano-crecientes, en las que se aprecia una evolución gradual en el espesor y geometría de los cuerpos conglomeráticos en relación con un ascenso del nivel de base. A una escala mayor, la sucesión muestra una clara tendencia estrato y granodecreciente resultado del comportamiento retrogradante de las tres principales fases de construcción del abanico deltaico. Esta situación es consecuencia del desplazamiento de las áreas lacustres hacia el norte debido a la progradación, en este sentido, de los conos relacionados con los drenajes de los relieves del borde sur de la cuenca.

Palabras clave: abanico deltaico lacustre, secuencias, geometría de cuerpos sedimentarios, oscilaciones del nivel de base.

INTRODUCTION

The Guadix basin is located in the central part of the Betic Cordilleras (Fig.1). It lies along the contact between the South Iberian palaeomargin and the Alboran crustal domain and is crossed in the north by an important fault line (the Cádiz-Alicante fault zone) which crosses the Betic orogen from the Atlantic to the Mediterranean. Both faults trend N60-70E and must have played an important role in the basin's early development. The highly active NW-SE and NE-SW fault lines were probably responsible for the physiographical changes which affected the extent and the structure of the Pliocene-Pleistocene basin compared to the Miocene basin (Fernández *et al.*, 1991).

The basement of the basin consists towards the NW of sedimentary rocks belonging to the External Zone (South Iberian palaeomargin) and, towards the

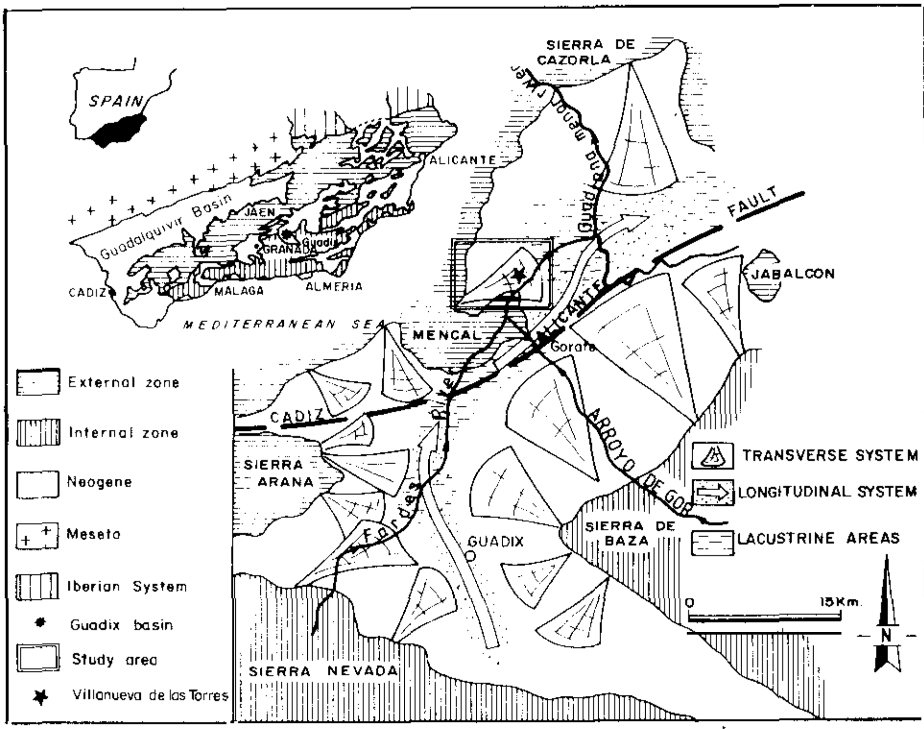

Fig. 1.—Geological setting of the Guadix Basin and the location of the study area in the context of the Betic Cordilleras.

Fig. 1.—Situación geológica de la Cuenca de Guadix y localización geológica del área de estudio en el contexto de las Cordilleras Béticas.

SE, of metamorphic rocks belonging to the Internal Zone (Alboran crustal domain) (Fig. 1).

The basin-fill consists of a Tortonian (late Miocene) lower marine unit separated from a Pliocene-Pleistocene continental ensemble by an unconformity indicating an erosion stage along the margins and shallows of the basin.

The Pliocene basin is clearly asymmetrical, with a tectonically active northern margin and a less active southern margin. Its axis runs close to the northern border where the lacustrine areas, the basin's longitudinal drainage system, and the main line of tectonic activity coincide (Fig. 1) (Viseras, 1991). Transverse alluvial systems with their base level in the lacustrine area developed in relation to the phases of relief creation and the reactivation of drainage systems. The transverse systems from the north gave rise to fan deltas, while the southerly ones (on gentler slopes and with a higher sediment supply/subsidence ratio) produced fluvial systems which systematically oscillated laterally, creating large cones (Viseras & Fernández, 1989;

Fernández, Soria & Viseras, 1989; Fernández, Viseras & Bluck, 1989; Viseras, Fernández & Bluck, *in press*).

The fan-delta system described here was fed with Mesozoic and Tertiary basement material found at the northern margin of the basin. It crops out extensively on both sides of the river Fardes (Fig. 1), near Villanueva de las Torres, for which reason we have informally called it the Villanueva Complex or Villanueva Conglomerate. This paper concentrates on the effect of lake-level oscillations on sediment recycling processes, on the geometry of the alluvial sedimentary bodies and on the resultant sedimentary sequences.

FACIES ANALYSIS

The Villanueva lacustrine fan-delta complex, dominated by debris and stream flows, developed along a clearly extensional margin of the Guadix basin. The predepositional topography is that of a shelf-type fan delta (Ethridge & Wescott, 1984) characterised by the accumulation of large quantities of material on a platform, the extensive development of delta-front deposits, and marked cyclic episodes in the stratigraphic record. In this case the fan-delta sediments did not accumulate on a marine platform, however, but rather on a margin of the basin with a relatively flat topography (though affected by a number of extensional faults) connected to a lake. This circumstance has produced a stratigraphy characterized by very extensive lateral facies changes.

The focal points of sediment intake, in conjunction with the effects of differential subsidence in the basin, determined the existence and distribution of the various sub-environments (Fig. 2).

ALLUVIAL FAN DEPOSITS

The subaerial proximal facies of the fan delta are included under this heading. They form a unit at the margin of the basin and lie unconformably either on Mesozoic material from the Subbetic realm (External Zone) or on Miocene marine materials. The unit is some 70 m thick and is composed of massive conglomerates which, further from the edge of the basin, incorporate finer sediments such as lutites and calcilutites. This zone is subdivided into apex and medial facies.

Apex facies These extremely localized facies lie unconformably on the Subbetic basement. The succession (Fig. 3) is composed of some 40 m of coarse conglomerates with boulder-sized clasts in which two parts can be distinguished. The lower zone (21 m thick) is composed of chaotic conglomerates with a grain size of around 30 cm, a relatively abundant fine

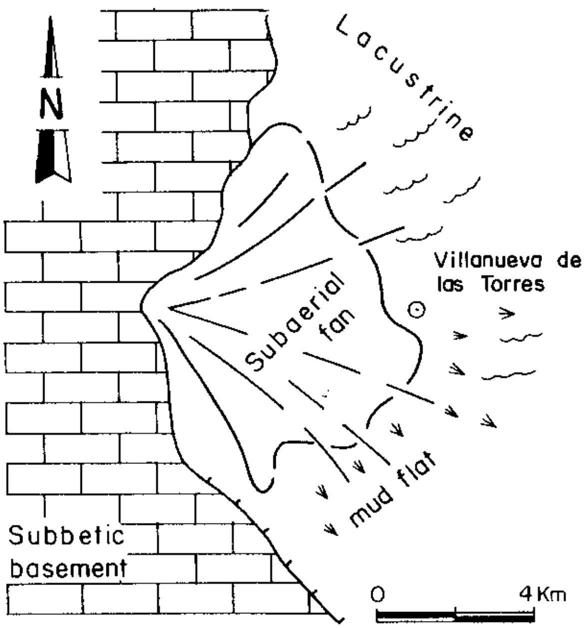

Fig.2.—Differentiation of sedimentary environments in the Villanueva lacustrine fan-delta complex.

Fig. 2.—Diferenciación de ambientes sedimentarios en el complejo de fan delta lacustre de Villanueva.

matrix, matrix-supported fabric, and some blocks towards the top with a size of some 1.50 m. These characteristics point towards a sediment gravity flow (Middleton & Hampton, 1973) of the relatively cohesive debris flow type (Lowe, 1982).

The upper zone contains boulder-sized clasts, which are nevertheless smaller than those in the lower zone. In spite of a rather low level of internal organization, the following may be distinguished: a) Beds of clast-supported conglomerates organized in upward-coarsening sequences with the larger clasts arranged in the form of transverse clast dams. This would suggest stream-flow deposits on relatively steep slopes in proximal areas (Bluck, 1987). b) Massive matrix-supported clast conglomerates with the largest clasts projecting above the top. These are the result of fairly cohesive debris-flow deposits. c) Layers of open-work gravel resulting from the washing out of the matrix of the debris-flow deposits by flows of clear water (Nemec *et al.*, 1984).

The succession as a whole represents a fining- and thinning-upward megasequence in which particle size diminishes towards the top in conjunction with more internal organization. The sequence is composed of two parts. The

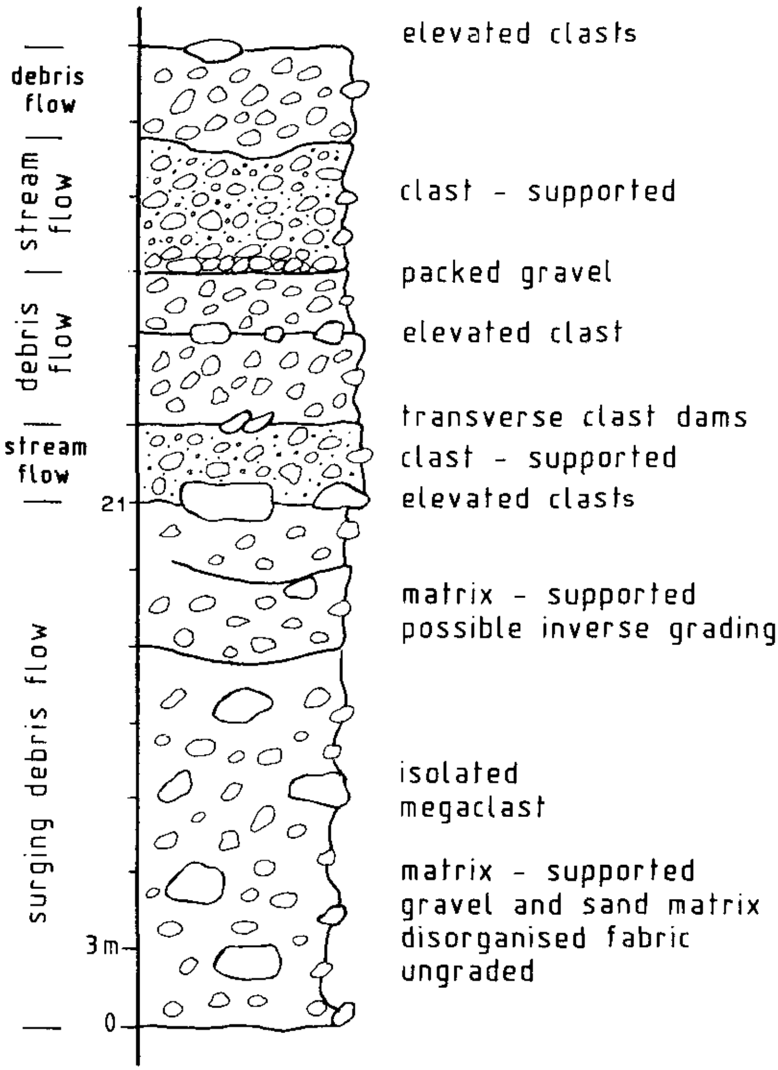

Fig. 3.—Vertical profile of the subaerial alluvial fan (apex facies). The coarser lower part with a matrix-supported fabric corresponds to debris-flow deposits. The finer upper part, with matrix-supported, clast-supported, and open-work fabrics corresponds to debris and stream flows.

Fig. 3.—Perfil vertical del abanico aluvial subaéreo (facies apical). La parte inferior de grano más grueso con una fábrica matriz-soportada corresponde a depósitos de flujos de derrubios. La parte superior más fina con fábricas soportadas por la matriz, por los cantos o sin matriz corresponde a flujos de derrubios y de corrientes.

lower one (from 0 to 21m) is coarser, matrix-supported and caused by viscous flows. The upper one has finer grains with more organised internal structure.

Evidence in the upper zone of matrix-supported, clast-supported, and open-work gravel indicates that it was deposited as much by debris flows as by turbulent stream flows. The fact that the megasequence fines upward may indicate two retrogressive episodes during the formation of the fan, the upper one being more distal than the lower.

Medial facies: The medial fan deposits are composed of beds of conglomerates with centimeter-thick intercalations of fine sediments which are greyish toward the bottom and red toward the top. The conglomerates, with boulder-sized clasts, are arranged in amalgamated layers several meters thick (Fig. 4). Morphologically, some of these layers represent lobes and others the filling in of zones between lobes (channels).

The lobes are about 4 m thick on average, and characteristically coarsen upwards, with upward-thickening of the components units. The top has locally preserved a layer of clay some 10-30 cm thick. The fabric varies from

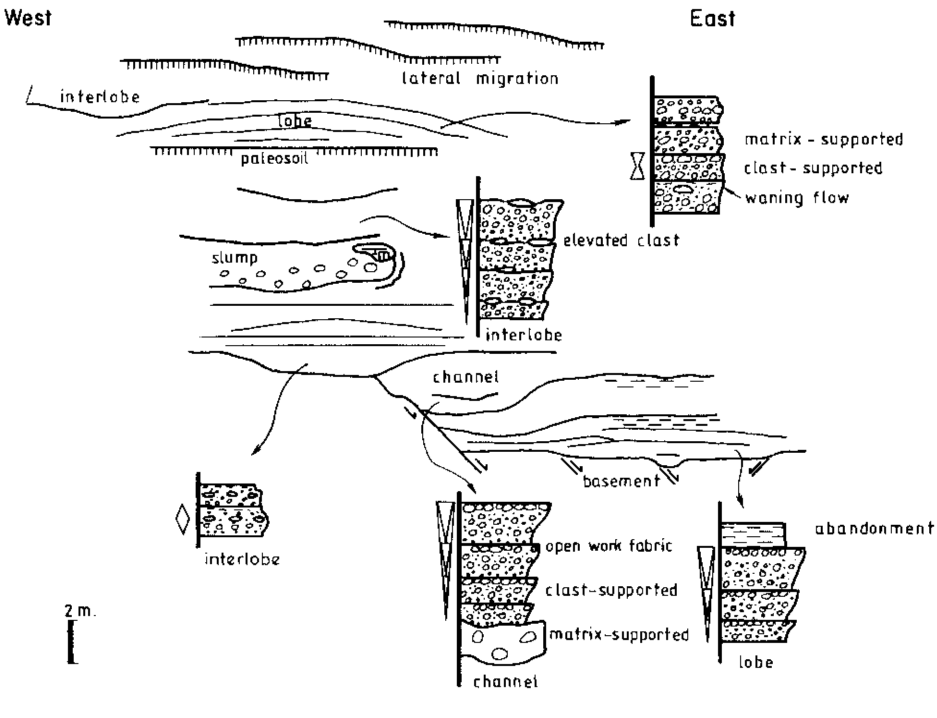

Fig. 4.—Mid-fan deposits (subaerial). Lobes and interlobe areas are the main morphologic systems. Their facies and sequences are shown. Some interlobe areas behave as channels. The sketch corresponds to an outcrop. The situation coincides with column 2, figures 8 and 9.

Fig. 4.—Depósitos de abanico medio (subaéreo). Los principales sistemas morfológicos son las áreas de lóbulo e interlóbulo, cuyas facies y secuencias se muestran. Algunas áreas interlóbulo se comportan como canales. Los esquemas corresponden a un afloramiento. La situación coincide con la columna 2, figuras 8 y 9.

clast to matrix-supported. A close look at the sequences of components units makes it clear that the upward-coarsening sequences often end in a layer of open-work gravel, a consequence of washing. Furthermore, some of the sequences first coarsen upward due to a shearing effect, then fine upward as a result of a declining phase in the water flow. Other sequences, however, first fine upward and then coarsen upward, with the intermediate phase corresponding to a period of lesser turbulence in the water flow (Nemec & Steel, 1984).

To sum up, these are debris-flow deposits with important variations in their degree of viscosity. There may even have been periods of stream flow with relatively clear water.

Geometrically, the zones between lobes have a channel-like form. They are not very erosive, however, and their facies are similar to those described in the lobate zones. Some particularly coarse, chaotic deposits are also notable features of this section of the fan. They have large blocks (1 m) projecting upward with signs of crushing and deformation of the underlying deposit. They are probably slump deposits related to slump scars on the most proximal, apex, parts of the fan, with the crushing and deformation of the underlying material being due to inertial effects on the slump mass. These deposits, together with the presence of transverse clast dams in proximal areas, point toward the existence of a fairly steep slope. They also indicate that there may have been mass-gravity transport during the construction of these parts of the fan.

The fine facies correspond to layers of sand and clay. The gray colour toward the base and the red with traces of soil formation toward the top indicate a transition zone from a subaqueous to a subaerial environment in this area of the fan.

FAN-DELTA DEPOSITS

The transition from subaerial alluvial fan to fan delta can be seen in canyons, carved out by the present rivers, which cut the system from proximal to distal areas. Within the fan-delta system there are two sub-zones (mud-flat and lacustrine, Fig. 2) differentiated by their depth and resultant fine facies.

Mud flat. The mud flat deposits are composed of whitish-gray and pinkish lutites bearing gastropods and organic matter. In distal zones there is bioturbation caused by roots and there are also some soil horizons. The most notable feature of these deposits is their salmon color. They also contain beds of conglomerates of variable thickness and shape, and sand layers with cross-lamination. Conglomerate beds correspond to the following geometric types:

1. Channels.

The channels are small features (2-5 m wide by 1-3 m deep) with a V-profile sometimes emphasized by synsedimentary faulting toward their vertices. The infill is differentiated by successive phases of vertical accretion with more and more frequent, progressively larger overbank wings (Fig. 5). This ribbon-type morphology (Friend, Slater & Williams, 1979) is connected to the relative proportion of vertical accretion in the channel and adjacent areas. The wings correspond to periods of maximum discharge in the channel, during which crevasse splays may also have originated. The period in which the wings were smallest may have been either a period of accretional processes in the channel and adjacent zones or else a period of incision during which the main processes were scouring and degradation.

In the facies, clast-supported conglomerates with an abundant matrix and localized open-work conglomerates predominate. They are organized in sequences of components units which coarsen upwards to form a sequence of the same type, on a larger scale, that construct the channel infill. They were deposited in the context of highly turbulent currents and local debris flows.

2. Pseudotabular bodies.

These are pseudotabular features with an irregular bottom and a flat or gently convex top. The width varies between 3m and 5m and they extend for some hundred metres. In proximal zones they are tabular with large grooves in the base, while in distal zones they are lenticular with channels in the base (Fig. 6).

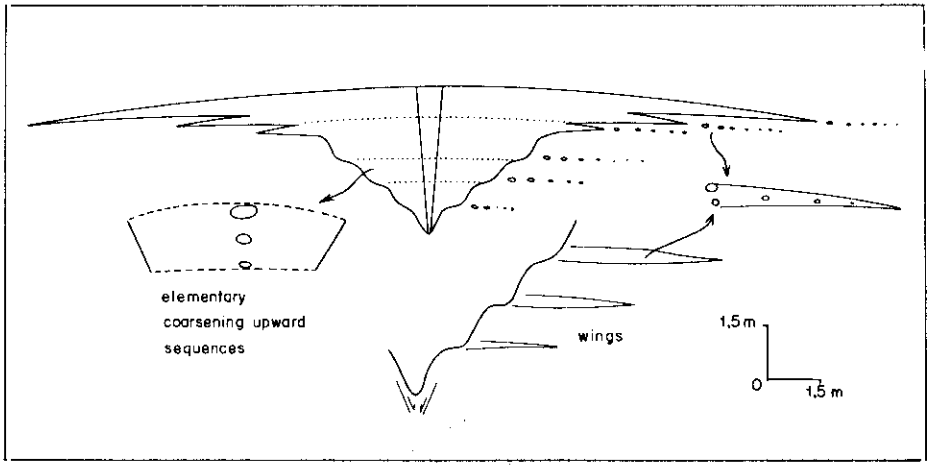

Fig. 5.—Geometry of ribbon-type sedimentary bodies built up by vertical infilling from fixed channels. The infill shows a coarsening-upward sequence (made up of several smaller sequences of the same type) and increasing thickness towards the top (thickening upwards). Successive, progressively larger wing-development phases are genetically related.

Fig. 5.—Geometría de los cuerpos sedimentarios en forma de cordón construidos por el relleno vertical de canales fijos. El relleno muestra una secuencia granocreciente (constituida por varias secuencias más pequeñas del mismo tipo) y estratocreciente. Las fases sucesivamente mayores de desarrollo de alas están genéticamente relacionadas.

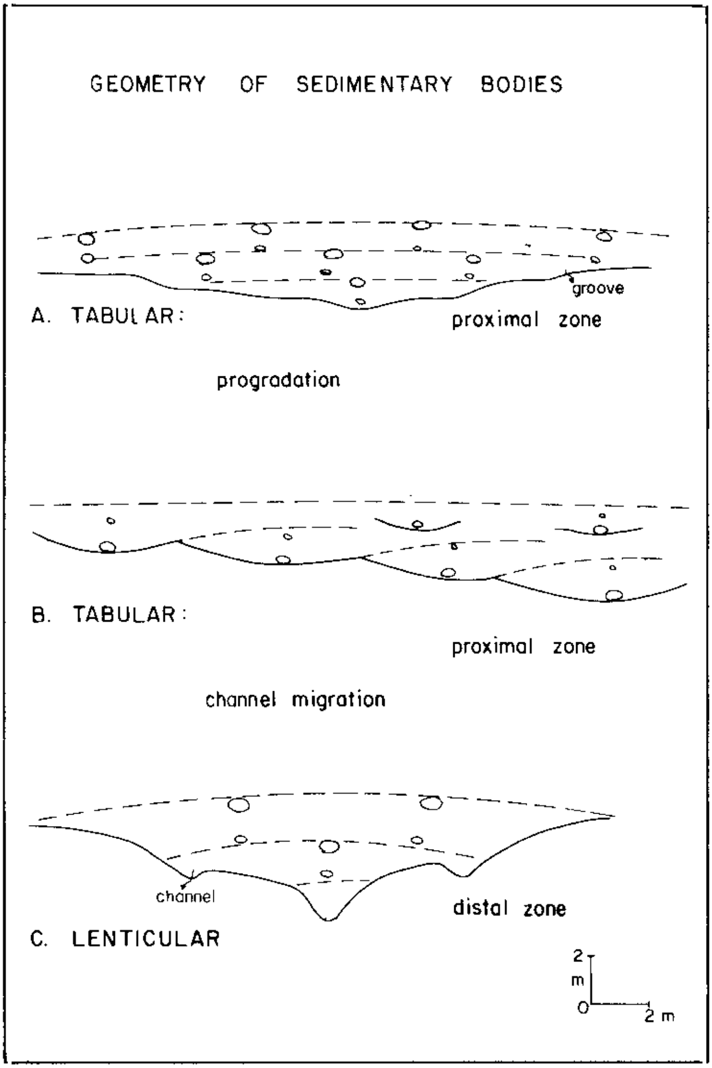

Fig. 6.—Geometry and internal structure of tabular bodies. A: Tabular body related to the progradation of the distributary system in proximal areas of the fan delta. Elemental sequences coarsen upwards. B: Tabular body related to the lateral migration of the channel in proximal areas of the fan delta. Elemental sequences fine upwards. C: Lenticular body developed at the mouth of the distributary channel. Elemental sequences coarsen upwards.

Fig. 6.—Geometría y estructura interna de los cuerpos tabulares. A: cuerpo tabular relacionado con la progradación de un sistema distributario en áreas proximales del fan delta. Las secuencias elementales son granocrecientes. B: Cuerpo tabular relacionado con la migración lateral de un canal en áreas proximales del fan delta. Las secuencias elementales son granodecrecientes. C: Cuerpo tabular desarrollado en la desembocadura de un canal distributario. Las secuencias elementales son granocrecientes.

Internally, these bodies are composed of mainly planar or gently convex bedding and they have a clear tendency to coarsen upward. The orientation of channels and grooves at the bottoms of the layers points to a radial flow, which, depending on the width of the lens, converges at a point upstream of the section under consideration. Based on these observations, the following growth mechanisms may be proposed for these layers: the channel at the lowest point of the layer was the first and often the largest. Vertical accretion by this channel formed an extensive wing which then prograded laterally. As alluviation occurred within the channel, the water level raised in it and the overbank gravel levees grew out from either side. The water which transported the gravel to the levees continued to flow over the levee complex and cut channels into the adjacent lacustrine clays. The growth of both levees of the trunk channel and levees of the adjacent smaller channels radiating out from the trunk channel levee complex resulted in the amalgamation of all the overbank sheets into one main pseudotabular lithosome (Fig. 7).

Lacustrine. We have included under this heading both fine facies, which may be autochthonous, and coarse facies, corresponding to sections of the fan deposited underwater. The fine facies are grey marls and calcilutites with a high degree of terrigenous contamination. They also contain small quantities of gastropods, charophytes, and redeposited globigerinids. Bioturbation is abundant, especially toward distal areas.

The coarse facies are composed of beds of conglomerates which have a similar geometry and facies to those of the mud-flat zone. Associated with these conglomerate beds are others only centimeter-thick with coarse-sand to pebble-sized particles. They also show abundant bioturbation, which tends to be vertical, as well as cross-bedding and cross-lamination, the latter due to wave ripples.

In more distal areas, outside the influence of the sedimentary alluvial body, the lacustrine succession is composed of marls, calcilutites, some layers of micritic limestone, and also some layers of sand with wave ripples. Bioturbation, tending to be horizontally inclined, is abundant, and the bases of some sequences have layers of evaporites, thicker towards the top of the succession.

STRATIGRAPHIC ARCHITECTURE

Following the fan-delta deposits away from the source area, there is a decrease in the percentage of gravel as well as in the thickness and lateral extent of the gravel bodies (Figs. 8 and 9). The particle size of the gravel does not diminish in the same direction, however.

The nature of the channels also varies in a proximal to distal direction. The channels tend to be deeper and more isolated in proximal areas, and have

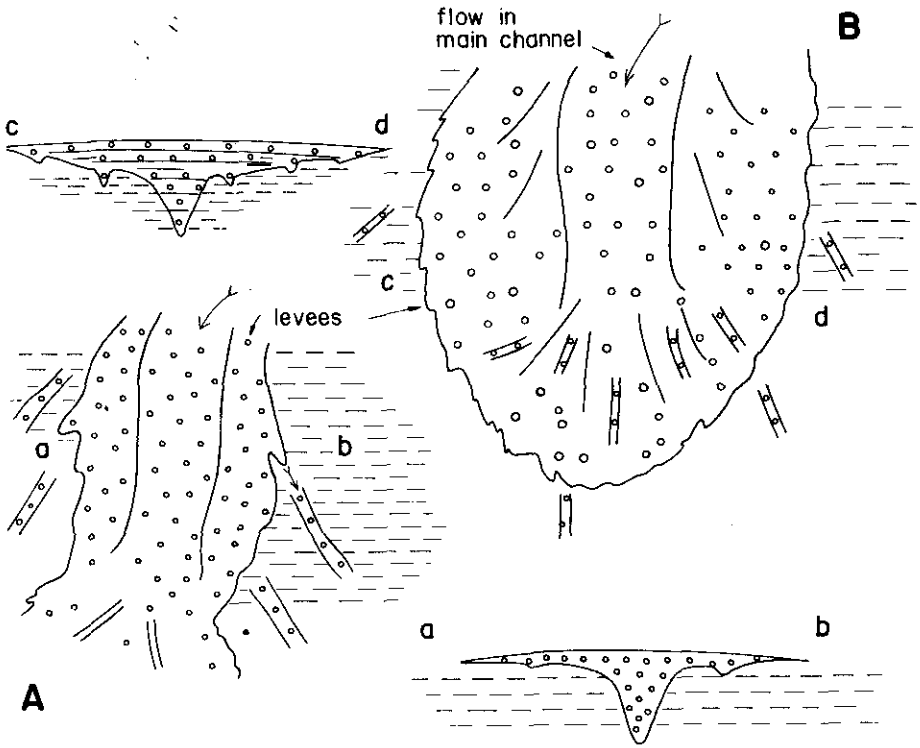

Fig. 7.— Genetic processes for pseudotabular bodies. A: Early stages of development with alluvial and wing development. B: Stage when radiating channels developed. There are tabular, sheet-like bodies in proximal areas and lenticular bodies in distal areas.

Fig. 7.—Procesos genéticos de los cuerpos pseudotabulares. A: Estadios iniciales con desarrollo aluvial y de alas. B: Estadio en el que se desarrollaron los canales radiales. Hay cuerpos tabulares, en forma de lámina en las áreas proximales y cuerpos lenticulares en las distales.

scoured out earlier gravel deposits. The channel bodies have either very small wings or none at all and were formed during periods of general degradation. In distal areas the channels are shallower.

The gravel bodies are tabular toward the proximal areas and lenticular toward the distal areas, which suggests that overbank processes were more frequent in the proximal areas. Here, grooves at the bases of the beds suggest they were emplaced far more quicker than those in distal areas.

Taking into account the conglomerate layers, the sequences would seem to be mainly both thickening and coarsening upward (Figs. 8 and 9). A gradual transition from V-shaped channels to pseudotabular layers may be seen in these sequences (Fig. 10). This gradual transition is related to the behaviour of the base level: the sequence began with a lowering in the lake level which then caused lake retraction and abrupt scouring of the channels (Fig. 11). At

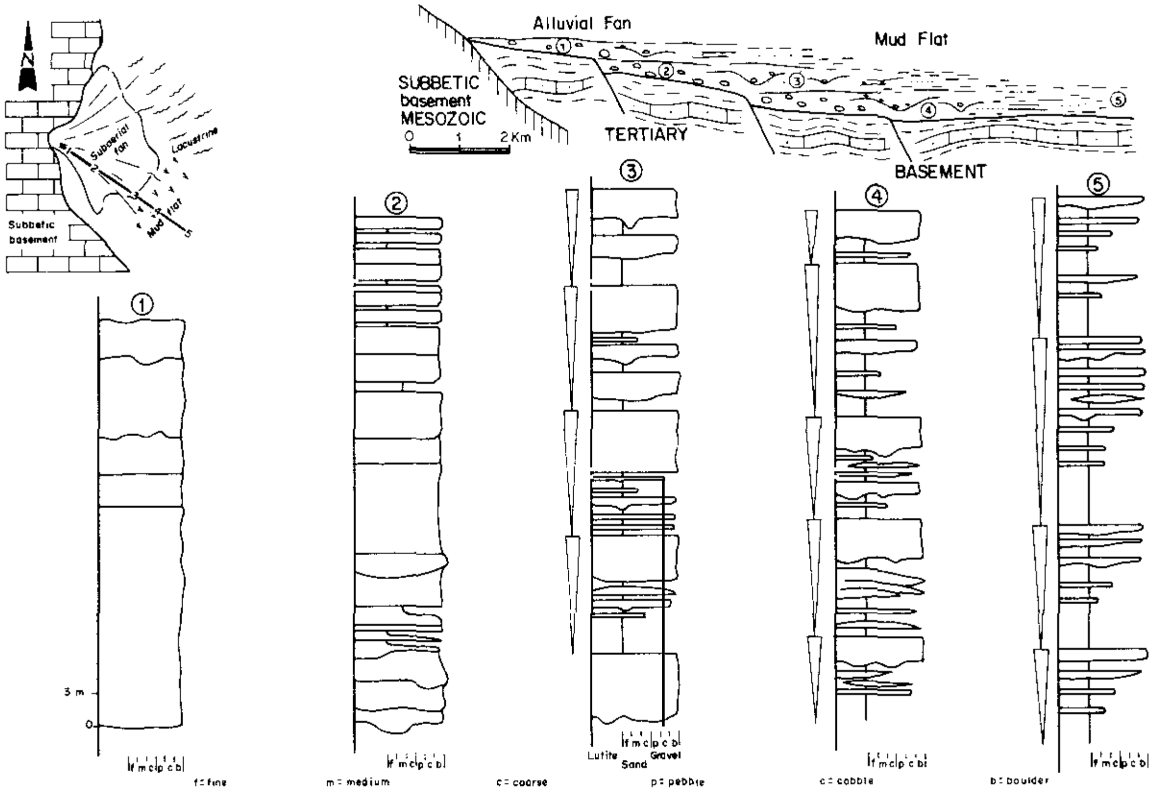

Fig. 8.—Subaerial fan - mud flat evolution. Facies and sequence evolution is shown as well as the retrogressive character of the main phases of the fan-delta's construction. Column 2 corresponds to an intermediate position between the sections of figures 8 and 9.

Fig. 8.—Evolución abanico subaéreo - llanura fangosa. Se presentan las facies y la evolución secuencial, así como el carácter retrogradacional de las fases principales de construcción del fandelta. La columna 2 corresponde a una posición intermedia entre las secciones de las figuras 8 y 9.

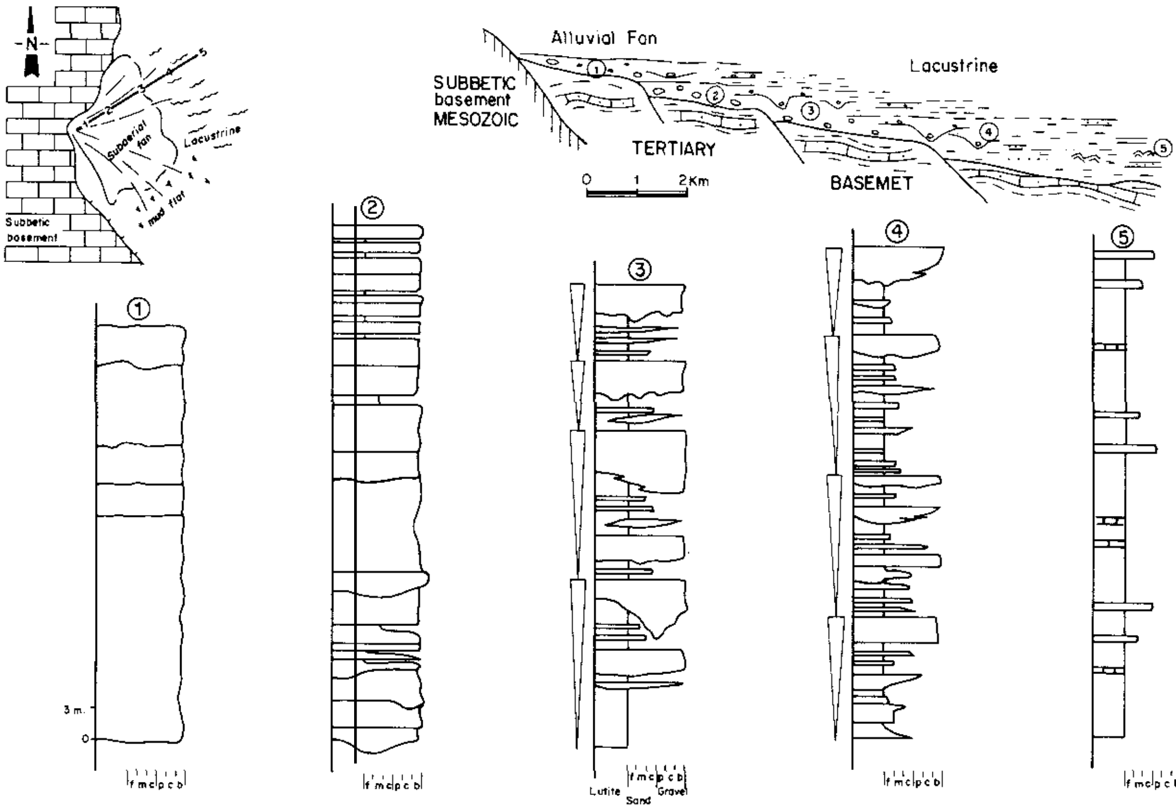

Fig. 9.— Subaerial fan - lacustrine evolution. Facies and sequence evolution is shown as well as the retrogressive character of the main phases of the fan-delta's construction.

Fig. 9.—Evolución abanico subaéreo - lacustre. Se presentan las facies y la evolución secuencial, así como el carácter retrogradacional de las fases principales de construcción del fan delta.

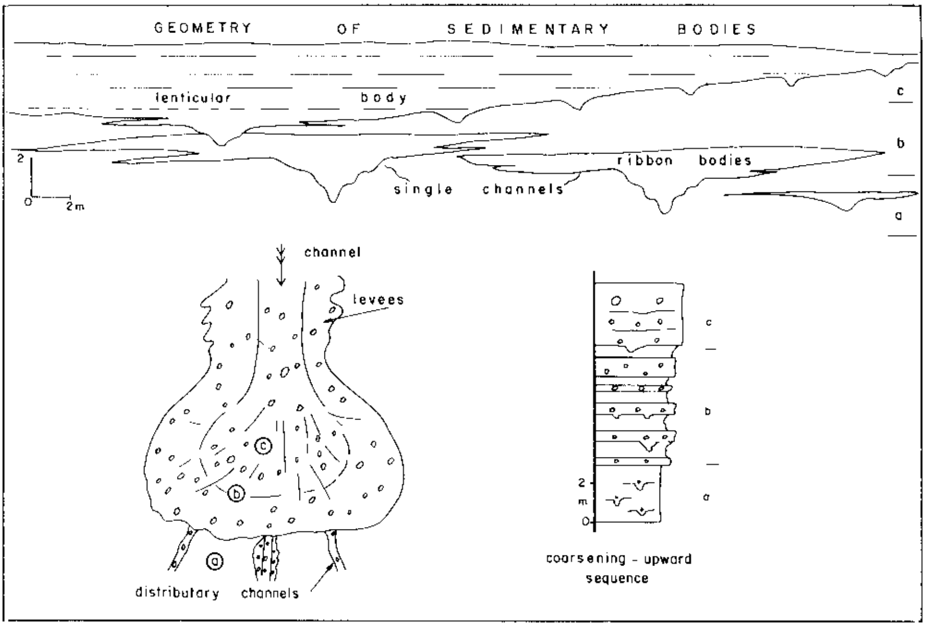

Fig. 10.—Evolution of the size and geometry of the sedimentary bodies in the coarsening- and thickening-upwards sequences. Both the sedimentary model and the sequence resulting from its progradation are shown.

Fig. 10.—Evolución del tamaño y la geometría de los cuerpos sedimentarios en las secuencias granocrecientes y estratocrecientes. Se muestran el modelo sedimentario y la secuencia generada por la progradación.

the same time, the original profile of the fan became unstable and began to be eroded from its most distal sections. The increase in sediment supply to the lacustrine area resulting from the erosion of the fan triggered a progressive rise in the lacustrine level which begins to slow down as the lake occupies a more extensive area. This rise in the lacustrine level was responsible for significant vertical accretion of mud flat sediment, affecting in turn the vertical growth of the scoured-out channels, which seldom developed overbank wings.

The slowdown in the rise of the lacustrine level and the increase in area of the drainage zone to cover the more recent, unstable sediments produced a decrease in the vertical accretion of the mud flat with respect to the channels and therefore facilitated overbank processes, with a corresponding increase in wing development (Fig. 11). At the same time, up sequence, we find materials contributed by more proximal areas which are therefore coarser in size.

A critical point was arrived at, however, when the rise of the lake was halted. This occurred when the lacustrine level became high enough to

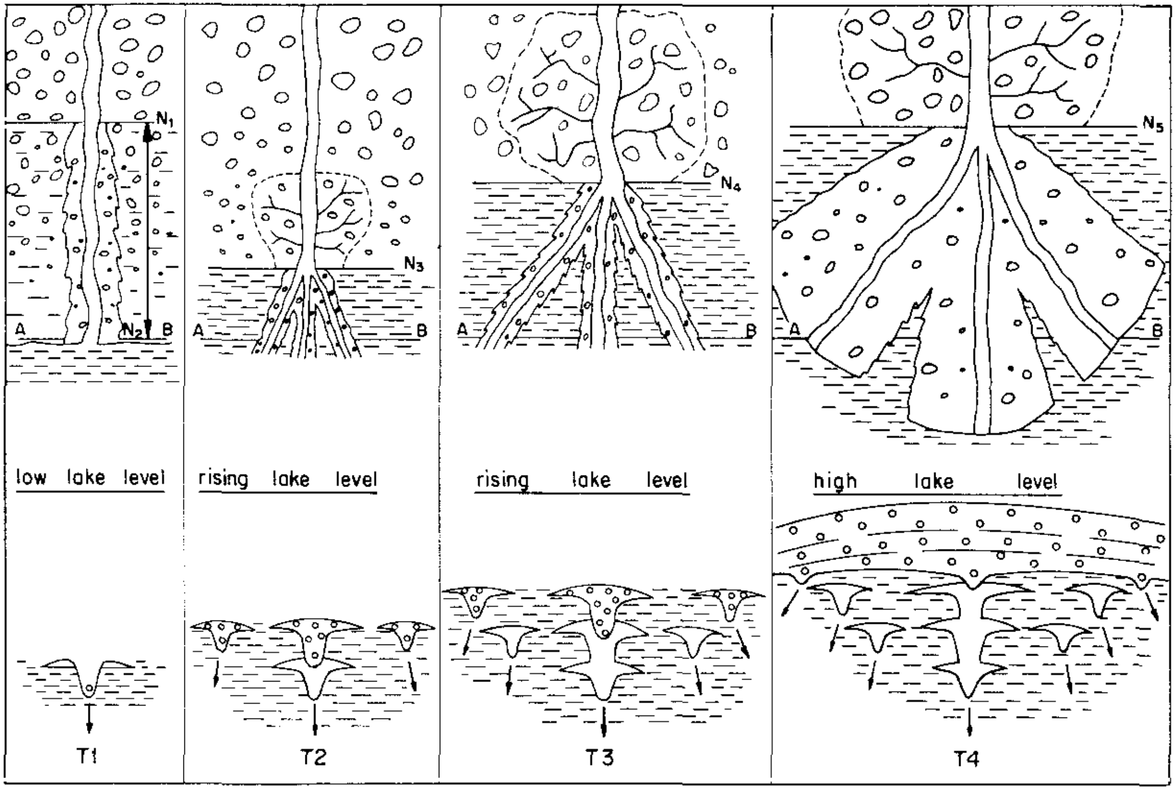

Fig. 11.—Geometry of sedimentary bodies in relation to lake-levels. N 1, 2, ... lake-levels (plan view). T 1, 2, ... successive stages in its evolution (cross-section).

Fig. 11.—Geometría de los cuerpos sedimentarios en relación con los niveles del lago. N 1, 2, —niveles del lago (en planta). T 1, 2,— estadios sucesivos de su evolución (corte).

overflow the dam-like barrier formed by sediments. At that point, the entrance of sediments which caused the rise now only regulated the partial drainage of the lake toward the NE. This was the highest and most stable base level of the lake, and it caused the distributary system to prograde, generating lenticular bodies at the mouths of the channels. These bodies are sheet-shaped (Friend *et al.* 1979) in more proximal areas where lateral channel migration contributed to their construction (Fig. 6). This is also a period during which the largest volume of sediments (since the drainage area was more extensive) and the largest-sized particles, drained into this body of stagnant water.

Another lowering in the level of the lake marks the beginning of a new sequence in the progressive scouring-out of the channels from distal to proximal areas. Moving up sequence, evidence indicates that the basin became broader and then shallower, for there is both a thinning-upward tendency in the decametric-order sequences and a greater proportion of evaporites in the higher sequences.

In proximal sections of the fan delta, which were affected by frequent reworking, the instability of the new slopes created by erosion provoked block slumping from the walls of small valleys. This process would also explain the occasional appearance in these sectors of large clasts intercalated in the channel infills. The position of these clasts would not be easily explicable in terms of fluvial processes.

Finally, the genetic mechanism which we propose also explains why the only area in which there is a progressive decrease in the Maximum Particle Size (MPS) parameter is in the most proximal regions of the fan where reworking processes do not take place. From this point on, the distribution of particle size is determined by successive recycling mechanisms.

Taking the succession as a whole, it shows a clear fining- and thining-upward tendency, the consequence of the retrogressive dynamics of the successive fan-delta systems vertically piling-up on this northern margin. This situation is caused by the northward displacement of lacustrine areas due to the progressive expansion of successive alluvial cones from the southern margin toward the centre of the basin (Viseras, 1991).

GENERAL COMMENTS

The Villanueva conglomerate is a lacustrine fan-delta complex of the type described by McPherson, Shanmugam & Moiola (1987) which has been previously written up by Fernández & Soria (1988) and by Fernández *et al.* (1989 a and b). Its development in the lower Pliocene coincides with a singular period in the evolution of the basin. After the Messinian eustatic decline, the basin became continental; the calcarenite marine platforms which had formed during the Tortonian along its margins fractured, and new drainage systems were produced, creating fan deltas and alluvial-fan systems along the new margins.

In this case, the alluvial body was connected to a lacustrine area which was very shallow at its southern end (mud flat) and somewhat deeper (lacustrine) toward more northerly sectors (a bit more distal in relation to the axial valley of the basin). The development of both zones was determined by their positions in the basin relative to the axial system as well as by tectonic activity, which controlled the subsidence of different areas of the basin.

The alluvial-fan deposits represent the subaerial section of the fan delta and developed on a relative steep slope. They were mainly constructed by debris-flow deposits and eventually by mass-gravity transport. They formed a system of lobes and infilling in interlobe areas.

In the subaqueous area, two sub-environments with different water depths can be distinguished (mud flat and lake). Coarse materials (related to turbulent stream flows) are similar in both areas, but fine materials are characteristic in each.

The stratigraphy of the fan-delta deposits is strongly controlled by the dynamics of the lake-level oscillations. The upward-coarsening decametre thick unit sequences, as well as the geometry of the sedimentary bodies, can be explained by a slowdown in the rising of the lake level. The cyclic character is a result of periodical base-level changes, implying recycling processes. These changes are related to tectonically-controlled dynamics of sediment supply to the lake from the alluvial systems.

On a larger scale, the general fining- and thinning-upward cycle is the result of the retrogressive tendency of the successive fan-delta units. This tendency is a consequence of a continuous northward displacement of the lake due to the progradation of the larger alluvial cones of the southern-relief drainage.

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