Late Oligocene-Early Miocene syntectonic fluvial sedimentation in the Aragonese Pyrenean domain of the Ebro Basin: facies models and structural controls

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RESUMEN

Se estudia un sector del margen Norte de la Cuenca del Ebro (Fig. 1), cuyo relleno molásico Oligoceno superior-Mioceno inferior (Formación Uncastillo) corresponde mayoritariamente a un extenso sistema fluvial: el sistema de Luna, que drenaba la Unidad de Garvarnie y que emergía en la cuenca al Oeste de las Sierras Exteriores Aragonesas. Este sistema colectaba pequeños abanicos aluviales o marginales adosados a las Sierras Exteriores. Al Este, fuera del ámbito estudiado, el sistema fluvial de Huesca también constituía un importante colector.

En la Formación Uncastillo se diferencian tres unidades tectosedimentarias (Figs. 2, 3 y 4), cuya evolución estuvo controlada por la tectónica que afectaba a las áreas fuente. El estudio de las diferentes litofacies reconocidas, de sus relaciones laterales y de su distribución areal a lo largo del tiempo (Fig. 5) permite establecer modelos sedimentarios para los abanicos marginales y para el sistema fluvial de Luna (Fig. 6).

El sistema de Luna estaba formado por la coalescencia de dos abanicos fluviales (Figs. 6 y 7). Aunque la red fluvial fue esencialmente radial, ésta estuvo controlada por los pliegues sinsedimentarios de Uncastillo y Fuencalderas, dentro de la Cuenca del Ebro. Estos pliegues dieron lugar a importantes variaciones de potencia de las unidades, así como a la creación de suaves abanicos de capas en el interior de la cuenca. El progresivo levantamiento de estas estructuras canalizó parte de la descarga paralelamente al margen de la cuenca (Figs. 6 y 7). Otra parte importante de la descarga fluía hacia el centro de la cuenca desde las terminaciones periclinales de aquéllos. La sedi-

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mentación en los surcos sinclinales situados al Norte de los anticlinales compensó el levantamiento de éstos, suavizando la pendiente y originando así rellanos morfológicos dentro de la pendiente general del abanico. En estas áreas de baja pendiente se desarrollaron cursos arenosos de alta sinuosidad en sectores proximales del sistema, a tan sólo 5,5 km del margen actual de la cuenca.

Palabras clave: Sedimentación fluvial, Tectónica sinsedimentaria, Formación Uncastillo, Neógeno, Cuenca del Ebro.

ABSTRACT

This contribution deals with a part of the northern margin of the Ebro Basin (Fig. 1). The Upper Oligocene-Lower Miocene molassic infilling in that part (Uncastillo Formation) mainly corresponds to an extensive fluvial system: the Luna system, which drained the Gavarnie unit area and emerged in the basin to the west of the Sierras Exteriores Aragonesas. Small, marginal alluvial fans originated along the Sierras combined in the Luna fluvial system, as well as in the eastern Huesca fluvial system, outside the study area.

Three tectosedimentary units (T.S.U.) were differentiated in the Uncastillo Formation (Figs. 2, 3 and 4), the evolution of which was controlled by tectonics affecting the drainage basins. The study of the different lithofacies, their lateral relationships and their areal distribution through time (Fig. 5) led to establish sedimentary models for the marginal fans and Luna fluvial system (Fig. 6).

The Luna system resulted from coalescence of two fluvial fans (Figs. 6 and 7). Despite the fluvial network appears mainly as radial, it was controlled by the syndepositional development of the Fuencalderas and Uncastillo anticlines, within the Ebro Basin. Syndepositional folding is shown by important thickness variations in T.S.U., as well as by the formation of wedge systems within the basin. Progressive uplift of these structures channeled part of the discharge parallel to the basin margin (Figs. 6 and 7), while another portion flowed basinward from the periclinal ends. Vertical accretion in the synclinal areas north of the anticlines compensated the anticlinal uplift, making the slope more gentle and originating bench terraces within the general fan slope. In these areas of gentle slope meandering sandy rivers developed in proximal sectors of the system, 5.5 km far from the margin at present.

Key words: Fluvial sedimentation, Syndepositional tectonics, Uncastillo Formation, Neogene, Ebro Basin, Spain.

INTRODUCTION

The Uncastillo Formation (Soler and Puigdefàbregas, 1970) comprises alluvial and fluvial sediments deposited in the northern-central part of the Ebro Basin during the Late Oligocene-Early Miocene. During this period, the principal configuration of the Sierras Exteriores Aragonesas took place and the Ebro Basin started its last stage of evolution as the southern foreland basin of the Pyrenean Ranges, while the older molassic Jaca Basin became an area of erosion.

The Uncastillo Formation or the equivalent Sariñena Formation (Quirantes, 1978) mostly corresponds to deposition in two large (>2x10^3 km^2 each) terminal fluvial systems (Fig. 1): the Huesca and Luna fluvial systems (Hirst, 1983; Nichols, 1984; Hirst and Nichols, 1986). Both were distributary systems with quasi-radial paleocurrent patterns. Sediment source areas were an-

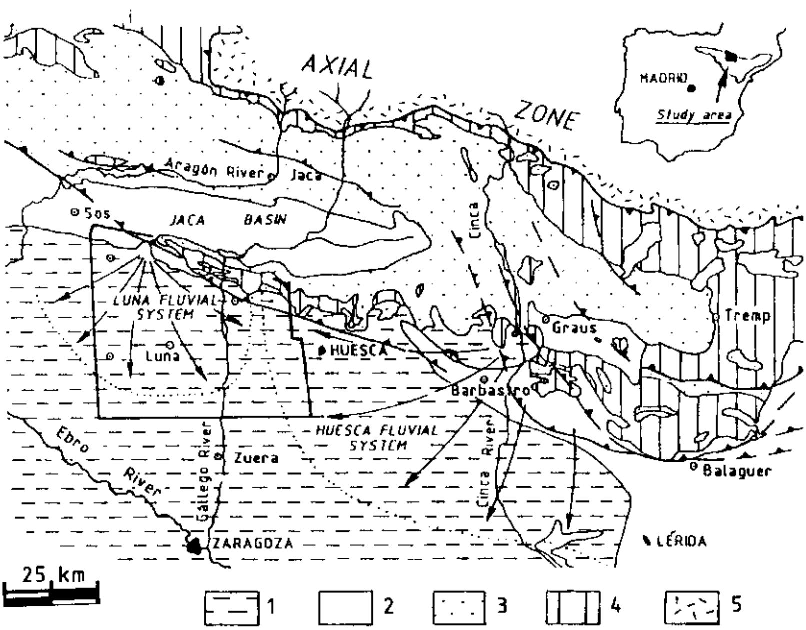


Fig. 1.—General location map with indication of the two large fluvial systems defined by Hirst and Nichols (1986). 1: Miocene. 2: Oligocene. 3: Paleocene-Eocene. 4: Mesozoic. 5: Paleozoic.
Fig. 1.—Situación general del área de estudio, con indicación de los dos grandes sistemas fluviales definidos por Hirst y Nichols (1986). 1: Mioceno. 2: Oligoceno. 3: Paleoceno-Eoceno. 4: Mesozoico. 5: Paleozoico.

cient Pyrenean Eocene-Oligocene basins (Jaca Basin for the Luna system), the Sierras Interiores and Axial Zone of the Pyrenees. The apices of these fluvial systems were placed in structural lows: the western end of the Sierras Exteriores for the Luna system and the area between Mediano and Boltaña anticlines for the Huesca system (Hirst and Nichols, *op. cit.)*. Both fluvial systems enclosed several small (generally < 15 km^2) alluvial or marginal fans directly fed from the Sierras Exteriores. At present, their proximal, conglomeratic facies are exposed as tower bodies called *mallos*.

Recent studies on these fluvial systems have analysed geometry aspects of sand bodies and their environmental controls (Hirst, 1983; Nichols, 1984; Hirst and Nichols, 1986; Friend, Hirst and Nichols, 1986; Nichols, 1987a and 1989; Friend, 1989). Some authors have also studied the relationships between sedimentation and tectonics: Nichols (1987b) pointed out that syndepositional folding affected the marginal fan sediments (Agüero fan), but he considered that the Luna system was not affected by syndepositional deformation and estimated that basin margin deformation to the west of the Sierras Exteriores and folding within the basin («Luesia anticline») were post-Early Miocene structures (Nichols, 1987a and 1989). Nevertheless, Arenas (1993) underlined the syntectonic character of the Luna system (Uncastillo and Fuencalderas folds, Figs. 2 and 3). In that sense, Teixell and García-Sansegundo (1995) have proposed the existence of a basal, buried thrust under the Sierras Exteriores that caused the formation of detached folds within the Ebro Basin. These authors postulate that folding diminishes toward the top of the Uncastillo Formation. Finally, a detailed study of tectonics along the Sierras Exteriores Aragonesas has been carried out by Millán (1996)

The present contribution deals with the stratigraphy, sedimentology and paleogeography of the Luna system (Fig. 1) and is focussed on the influence of syndepositional tectonics on the proposed facies models.

To obtain the results of this contribution, exhaustive field work was done. Field work included 28 stratigraphic sections in the Uncastillo Formation, correlation of these sections throughout the study area and sedimentological analysis of specific deposits. Aerial photographs (at scales 1:33,000 and 1:18,000) were essential for correlation, cartography of lithofacies and stratatigraphic units and identification of structural features (such as cumulative wedge systems within the basin).

STRATIGRAPHIC AND TECTONIC FRAMEWORK

The Uncastillo Formation lies unconformably on Mesozoic and older Tertiary formations that constitute the Sierras Exteriores Aragonesas, but to the west of Fuencalderas (Figs. 2 and 3) it forms a large cumulative wedge system with the undelying Campodarbe strata (progressive unconformity of

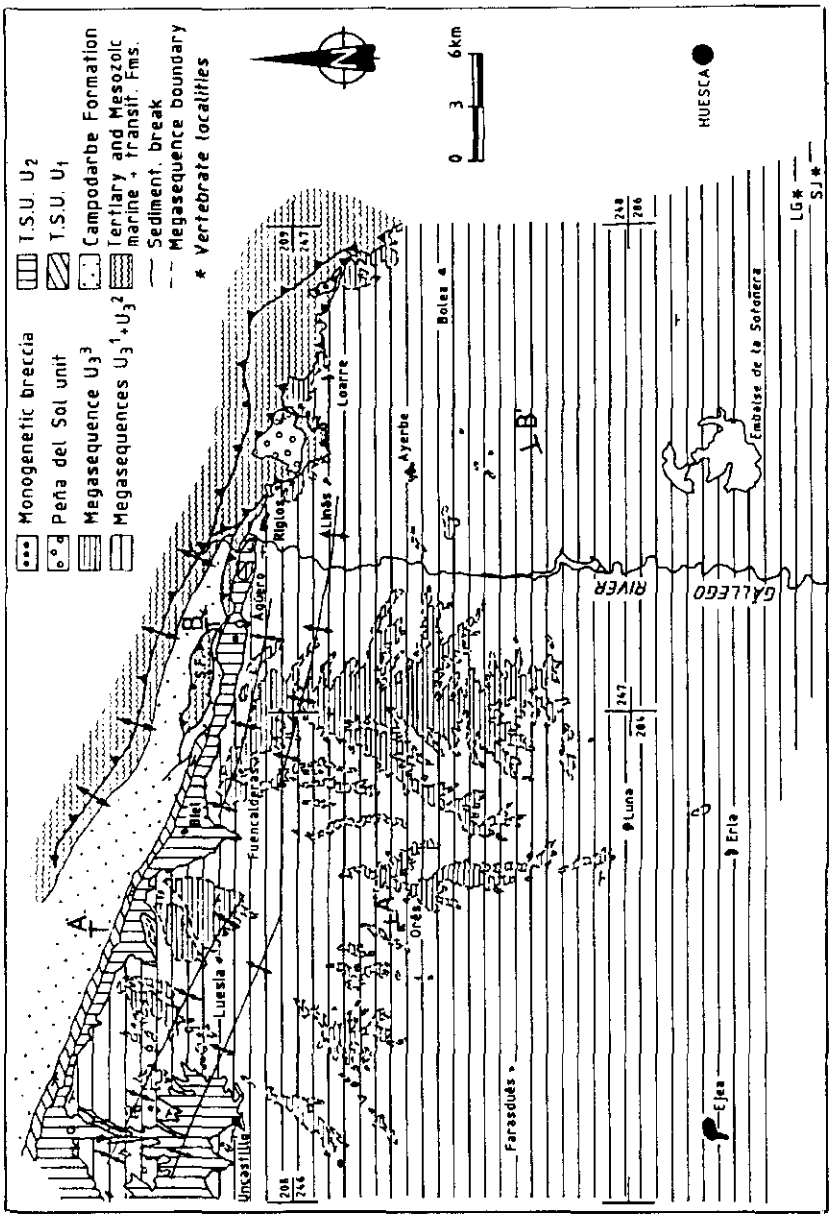


Fig. 2.—Geological map of the study area. S.F.: San Felices. A-A´ and B-B´: geological cross-sections of Fig. 3. Vertebrate localities: LG: La Galocha, SJ: San Juan.
Fig. 2.—Mapa geológico del área estudiada. S.F.: San Felices. A-A´ y B-B´señalan las trazas de los cortes geológicos de la Fig. 3. Yacimientos de vertebrados: LG: La Galocha, SJ: San Juan.

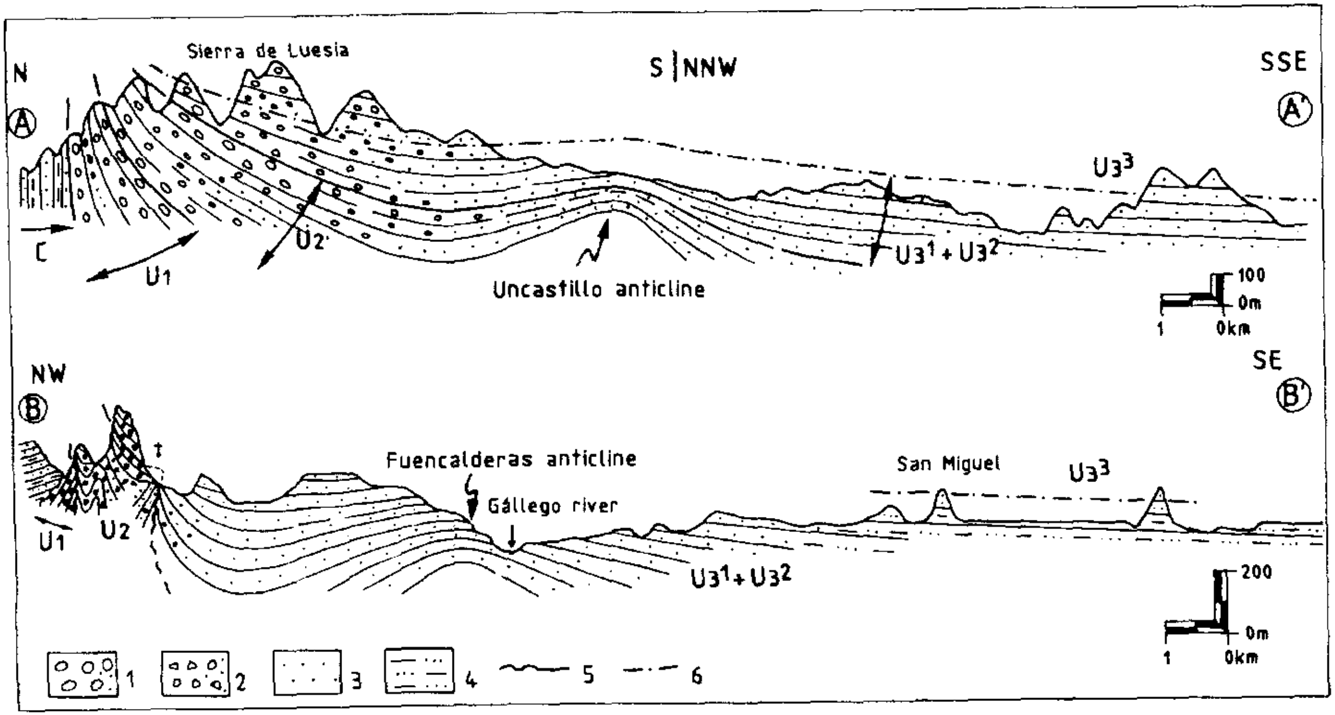


Fig. 3.—Geological cross-sections (Location in Fig. 2). C: Campodarbe Formation. Lithofacies: 1: Luesia-type conglomerates and sandstone and Luesia-type conglomerates. 2: Mallo-type conglomerates and sandstones and mallo-type conglomerates. 3: Sandstones and mudstones. 4: Mudstones and sandstones. 5: Sedimentary break: Unconformity and correlative conformity. 6: Megasequence boundary.

Fig. 3.—Cortes geológicos (véase su localización en la Fig. 2). C: Formación Campodarbe. Litofacies: 1: Conglomerados y areniscas y conglomerados tipo Luesia. 2: Conglomerados y areniscas y conglomerados tipo mallo. 3: Areniscas y lutitas. 4: Lutitas y areniscas. 5: Ruptura sedimentaria: discordancia y conformidad correlativa. 6: Límite de megasecuencia.

Biel-Gallipienzo, after Soler and Puigdefàbregas, 1970). In this area, the Campodarbe and Uncastillo successions have an apparent conformity relationship and the boundary between both is given by a sharp granulometric change (passage from sandstones and mudstones to conglomerates), while paleocurrent directions change from E-W to N-S (Puigdefàbregas, 1975).

In the Uncastillo Formation, Arenas (1993) and Arenas and Pardo (1994a) characterized three allostratigraphic or tectosedimentary units (T.S.U.) with a cyclic tendency (Figs. 2, 3 and 4; See also Fig. 2 of Arenas and Pardo, 1994a, for more stratigraphic information). All of them have a lower fining-upward megasequence, which records a retrogradational stage of the marginal and fluvial fans, followed by an upper coarsening-upward megasequence, which corresponds to a progradational stage of the fans. Unit U3 is more complex, as its upper part consists of two megasequences ($U3^2$, coarsening, and $U3^3$, fining-coarsening) separated by a relative granulometric maximum, which was used for correlation throughout the study area and between this and southward lacustrine areas of the basin (Arenas, 1993). Boundaries between units U1, U2 and U3 are sedimentary breaks recognized as changes from coarsening to fining-upward in the sequential tendency. To the west of Fuencalderas these boundaries are conformities within cumulative wedge systems located along the basin margin and along the Fuencalderas and Uncastillo folds within the basin. The latter are located 5 to 8 km south of the basin margin (Figs. 2 and 3). To the east of Fuencalderas, boundaries between units are syntectonic intraformational unconformities within the marginal alluvial fan deposits (Fig. 3B).

Dating of units U1, U2 and U3 (Arenas, 1993) is based on vertebrate localities (San Juan and La Galocha, from Álvarez Sierra *et al.*, 1990) found in megasequences $U3^1$+$U3^2$ (Fig. 2), on reinterpretation of magnetostratigraphic data from Hogan (1993) and on correlation of those units with other well-dated areas of the Ebro Basin (Arenas, 1993). The dating proposed is: U1: Upper Oligocene (up to Agenian, MN1); U2: Agenian (MN1-MN2); U3: Agenian (MN2 or Zone Y) to Lower Aragonian (Lower Miocene, MN4). Although the top of unit U3 is not represented in the studied alluvial series, it is known in the lacustrine sequences located southward, where the equivalent unit N1 is entirely represented.

During those time intervals, tectonic activity affected the drainage basin of the Luna system, the Sierras Exteriores and the Ebro Basin. Sequential tendencies of T.S.U. were controlled by topography variations in the sediment source area (Gavarnie unit); according to Nichols (1987a), these variations could be due to out-of-sequence thrusting. The marginal fan deposits show syndepositional folding and syntectonic intraformational unconformities related to tectonic uplift in the Sierras Exteriores (Nichols, 1987b). The formation of all these marginal fans was not simultaneous, but evolved from east to west, and was related to the setting of successive thrust sheets that compo-

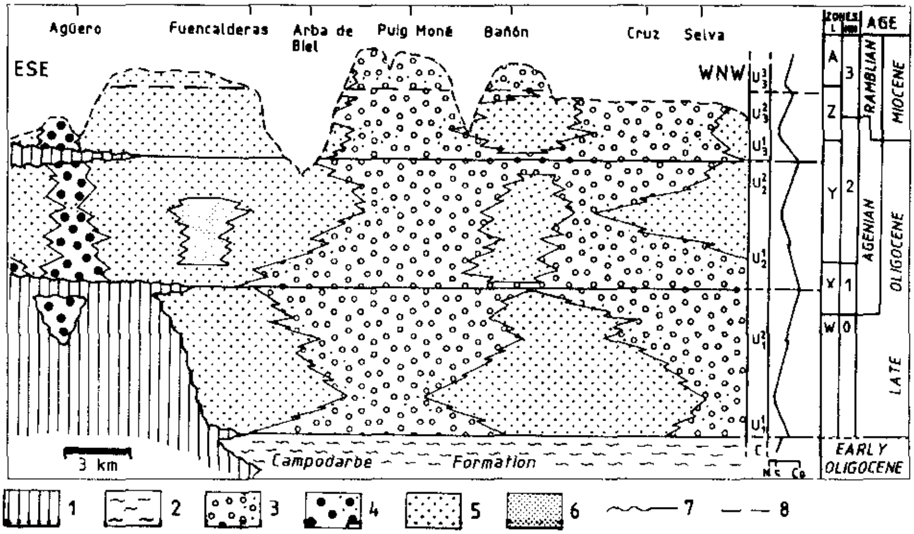


Fig. 4.—Chronostratigraphic scheme showing lithofacies changes and stratigraphic relationships of the Uncastillo Formation from west to east, parallel to the basin margin. Vertical axis is not at real time-scale, but arbitrarily referred to thickness in the Luesia area (Puig Moné and Bañón region), where U1 + U2 + U3 = 1600 m thick (minimum). L: Local zones and MN: Mein zones. Zones and ages from Calvo *et al.* (1993). 1: Stratigraphic lacuna. 2: Sandstones and mudstones (Campodarbe Formation). 3: Luesia-type conglomerates ± sandstones. 4: Mallo-type conglomerates ± sandstones. 5: Sandstones and mudstones. 6: Mudstones and sandstones. 7: Sedimentary break: Unconformity and correlative conformity. 8: Megasequence boundary.

Fig. 4.—Esquema cronoestratigráfico Este-Oeste mostrando los cambios de litofacies y las relaciones estratigráficas de la Formación Uncastillo paralelamente al margen de la cuenca. La escala vertical no es una escala de tiempo, sino referida a la potencia en el área de Luesia (sector de Bañón y Puig Moné), en donde U1 + U2 + U3= 1600 m de potencia como mínimo. L: Zonas locales, MN: zonas Mein. Zonas y edades tomadas de Calvo *et al.* (1993). 1: Laguna estratigráfica. 2: Areniscas y lutitas (Formación Campodarbe). 3: Conglomerados tipo Luesia ± areniscas. 4: Conglomerados tipo mallo ± areniscas. 5: Areniscas y lutitas. 6: Lutitas y areniscas. 7: Ruptura sedimentaria: discordancia y conformidad correlativa. 8: Límite de megasecuencia.

se the complex south-Pyrenean thrust front (Arenas, 1993; Arenas and Pardo, 1994b; Millán, 1996) (See Fig. 7 below). Within the basin, the Fuencalderas and Uncastillo folds are syndepositional structures that were active at least during U2 and U3 sedimentation (Fig. 3). Unit U3 crops out extensively throughout the study area; the sedimentological analysis of its deposits allows folding influence on fluvial system development to be evaluated.

Apart from the three units mentioned, there are some localized outcrops of the Uncastillo Formation placed directly on the Sierras Exteriores. Dating is not known yet. These are Peña del Sol conglomerates (mainly derived from the Jaca Basin) and monogenetic breccias (formed from the Sierras Exteriores) (Fig. 2). Both lie unconformably on megasequence U3^3 strata and then constitute younger allostratigraphic units, but the cronostratigraphic relationships between Peña del Sol conglomerates and breccias are unknown.

ALLUVIAL AND FLUVIAL FACIES MODELS

In the study area, the Uncastillo Formation is composed of several lithofacies (mappable facies associations defined by their lithology, texture, deposit geometry and sedimentary structures). Each one represents the sedimentation in a specific sector of an alluvial or fluvial environment. The following lithofacies have been distinguished:

* Conglomerate lithofacies (>85% conglomerates and <15% sandstones+mudstones). According to the texture and internal organization two types are distinguished:

— Mallo-type conglomerates (MC): they constitute localized, reddish, tower-shaped bodies *(mallos)* 200 to 400 m high and 0.5 to 4-5 km^2 in outcrop area, composed of thick tabular bodies, commonly with crude stratification. Those have clast-supported textures with dominant angular to poorly rounded, mainly calcareous clasts.

— Fluvial, Luesia-type conglomerates (LC): they form large, brown and gray masses, up to 7 km long and tens of km wide in outcrop surface. Very well rounded clasts, mainly of Campodarbe sandstones and minor limestones and black chert, constitute clast-supported, lenticular and tabular deposits.

* Sandstone and conglomerate lithofacies (SC)(40-80% sandstones, 20-60% conglomerates and up to 30% mudstones). Based upon the conglomerates, two types are differentiated:

— Sandstone and mallo-type conglomerate lithofacies (SMC), organized as metre to decametre, flat base, tabular sequences. Theses can be either coarsening or fining-upward, or cyclic coarsening-fining-upward in tendendy.

— Sandstone and Luesia-type conglomerate lithofacies (SLC), organized as metre to decametre, gently channeled base, tabular sequences. These are mainly fining-upward in tendency.

* Sandstone and mudstone lithofacies (SM)(40-80% sandstones and 20-60% mudstones).

* Mudstone and sandstone lithofacies (MS) (60-90% mudstones and 10-40% sandstones; locally, up to 10% limestones).

SM and MS lithofacies occupy a large part of the study area. Both have similar sandstone deposits:

— Sheets made of lenticular bodies

— Sheet and lenticular deposits composed of lateral accretion bodies

— Isolated lenticular or ribbon deposits
— Sheets formed of laminar bodies

All of them can be simple or multistorey and can occur in both SM and MS lithofacies, being the main difference between both the thickness and frequency of occurrence of such deposits.

* Mudstone lithofacies (M)(>80% mudstones and low percentages of sandstones, limestones and locally gypsum). Sandstones mainly constitute thin sheet bodies.

Lateral relationships (Figs. 3 and 4) and areal distributions of these lithofacies through time will allow to characterize the facies models for the studied successions. Figure 5 shows two examples of lithofacies distribution: Fig. 5A represents a retrogradation stage and Fig. 5B a progradation stage of the fluvial and marginal fans. These relationships show the existence of two main lithofacies associations (Fig. 6A and B):

1) MC → SMC → (SM) → MS → M, referable to marginal, alluvial fan systems (SM is an occasional term)

2) LC → SLC → SM → MS → M, referable to the Luna fluvial system

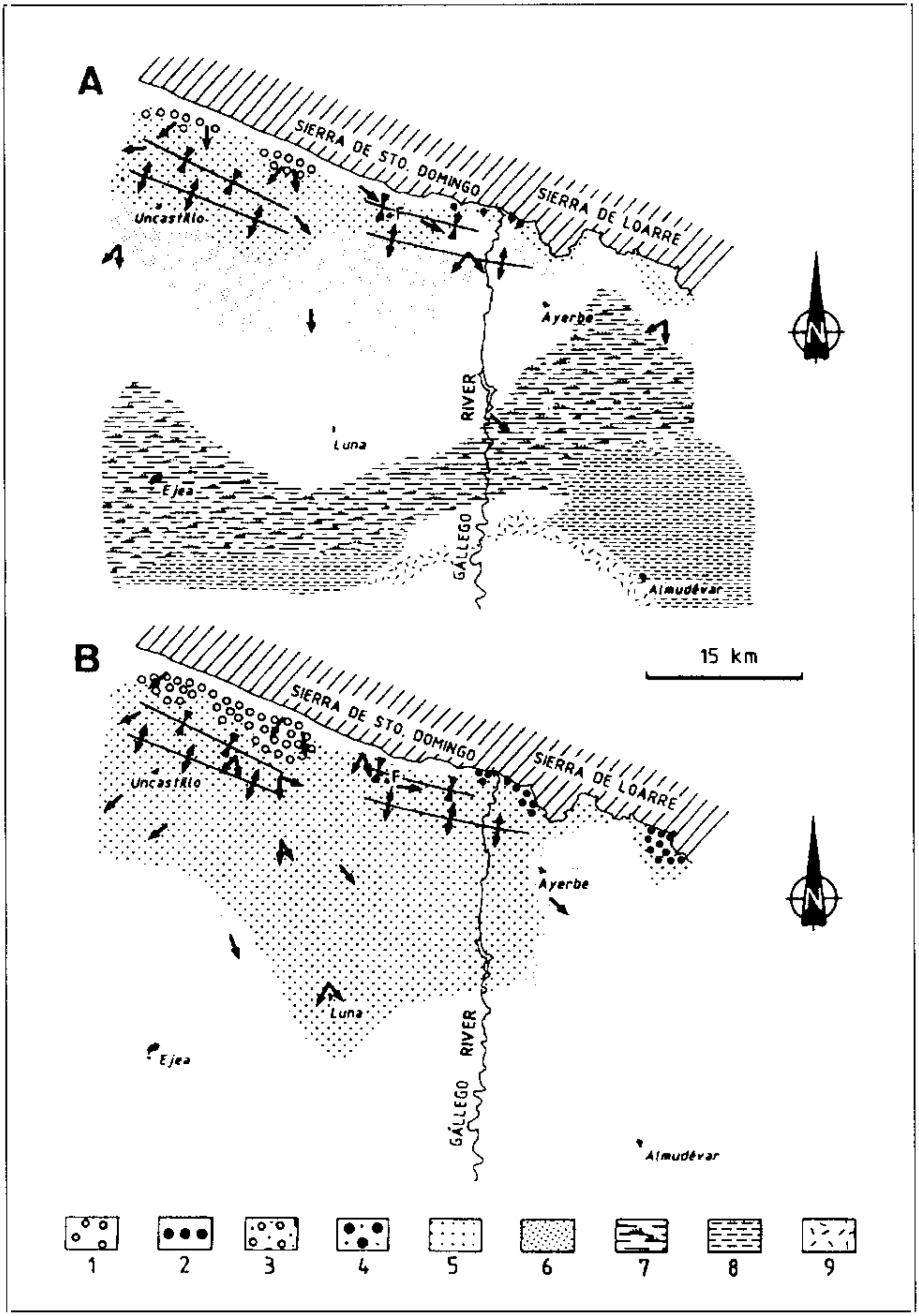
These two systems coexisted during units U1, U2 and U3, but their entire development is recognized only in unit U3. For the older U1 and U2, lithofacies distributions are exposed only parallel to the basin margin, but are coherent with the areal relationships observed for unit U3. The main characteristics of the two models proposed are:

1) The *first association* represents short and small alluvial fans (Fig. 6A) in which three sectors existed:

= *Proximal sector:* Most deposits of this sector (lithofacies MC) originated from unconfined flows (sheet floods), which in some cases gave rise to lobe coarsening-up sequences. Lithofacies MC may also fill paleovalleys where massive deposits produced by high energy confined flows are present; there,

Fig. 5.—Lithofacies distribution for the base (A) and top (B) of megasequence $U3^2$ (Agenian (Y2)-Ramblian (Z)). Lithofacies: 1: Luesia-type conglomerates. 2: Mallo-type conglomerates. 3: Sandstones and Luesia-type conglomerates. 4: Sandstones and mallo-type conglomerates; 6: Sandstones and mudstones. 6: Mudstones and sandstones. 7: Mudstones. 8: Sandstones, mudstones and limestones. 9: Mudstones and gypsum. F: Fuencalderas.

Fig. 5.—Mapas de distribución de litofacies para la base (A) y el techo (B) de la megasecuencia $U3^2$ (Ageniense (Y2)-Rambliense (Z)). Litofacies: 1: Conglomerados tipo Luesia. 2: Conglomerados tipo mallo. 3: Areniscas y conglomerados tipo Luesia. 4: Areniscas y conglomerados tipo mallo. 5: Areniscas y lutitas. 6: Lutitas y areniscas. 7: Lutitas. 8: Areniscas, lutitas y calizas. 9: Lutitas y yesos. F: Fuencalderas.


A
SIERRA DE STO. DOMINGO
SIERRA DE LOARRE
Uncastillo
F
Ayerbe
Luna
Ejea
GÁLLEGO
RIVER
Almudévar
N
B
15 km
SIERRA DE STO. DOMINGO
SIERRA DE LOARRE
Uncastillo
F
Ayerbe
Luna
Ejea
GÁLLEGO
RIVER
Almudévar
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turbulent mass flow processes could also exist. Locally, talus monogenetic breccias are found.

= *Middle sector:* Lithofacies SMC and SM form this sector. SMC mostly corresponds to lobe sequences and minor fluvial braided system deposits. Channel and bar braided systems, locally low sinuosity channels and sheet flows are recorded by lithofacies SM, which also displays overbank sediments.

= *Distal sector:* Lithofacies MS is dominant upstream while M extensively occurs downstream. Extense flood plains with sheet flows and rare sand ribbons originated in this sector.

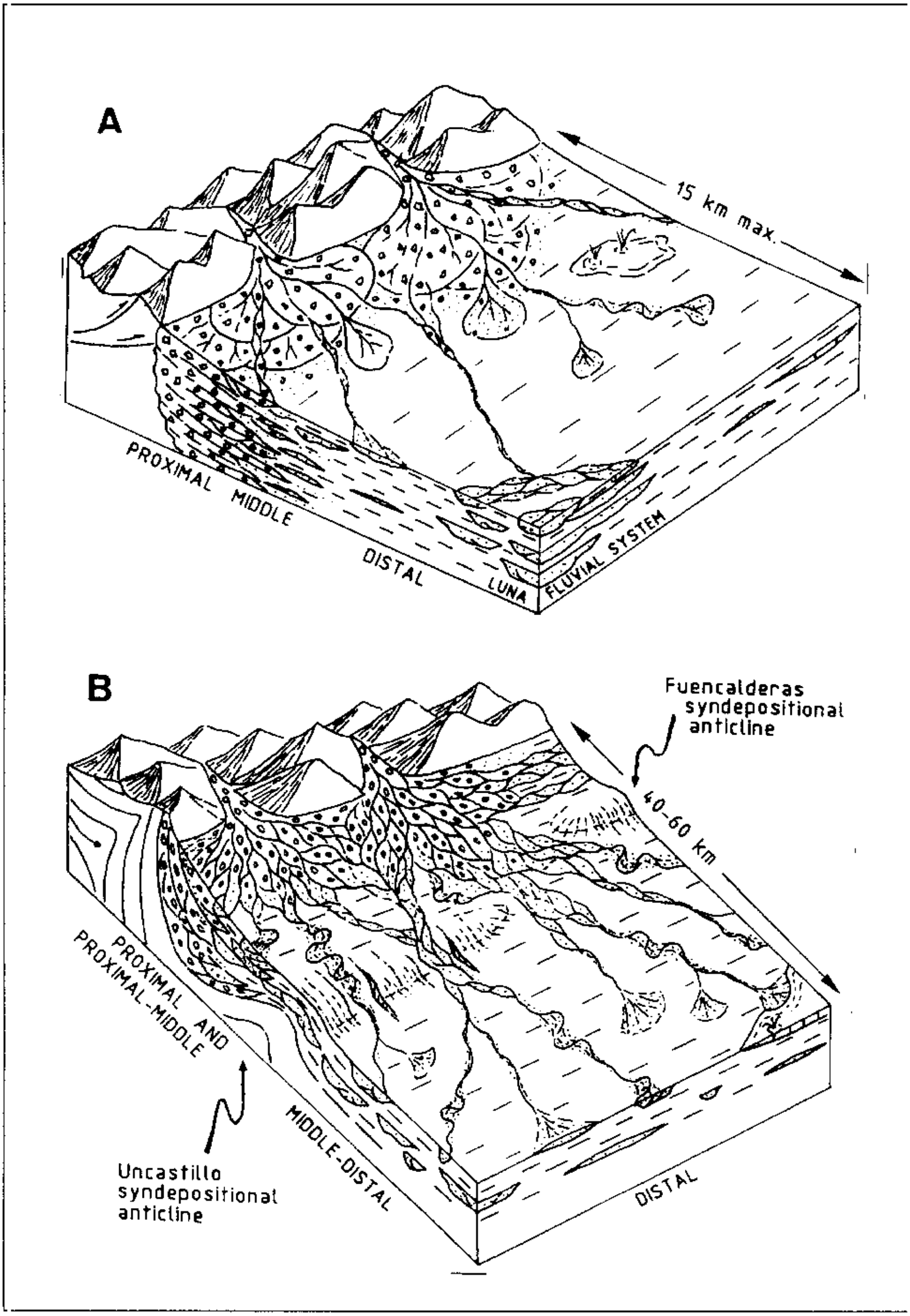
Alluvial fans with this association were up to 15 km long, as in the case of Aniés fan (NE Ayerbe), although shorter dimensions were common (5 km) because middle and distal sectors usually combined in larger fluvial systems (second association). Proximal sectors were up to 3 km long and about 1-2 to 4 km wide. These sharply graded into middle sectors, which also had reduced areas across. Large surfaces of these fans were occupied by flood plains of distal sectors. These features indicate low transport efficiency for these alluvial fans. They had small drainage basins in the Sierras Exteriores; Nichols (1984, 1987b and 1989) obtained surfaces of about 5 km^2 for Riglos fan and 20 km^2 for Linás fan drainage basins. These fans lie unconformably along the Sierras Exteriores and their evolution was associated with thrust sheet movements. Overturned anticlines within the basin that affect some of these fans (Agüero, Murillo and Riglos fans; see Fig. 3B) may have conditioned the limited extension of conglomeratic proximal sectors, as the crests of these folds are close to the southern boundary of the conglomerate outcrops. These folds were then active during alluvial fan deposition and perhaps were related to buried thrust sheets. These features are not represented in Figs. 2 and 6A due to their small size.

2) The *second association* represents the large fluvial system of Luna (Fig. 6B), with four sectors:

= *Proximal sector:* Lithofacies LC is characteristic, with disorganized or massive facies (flash flood deposits) at very proximal areas, but with dominant channel and bar deposits, which represent shallow braided gravel systems. The presence of two distinct lithosomes in the lithofacies LC (Figs. 4 and 5) indicate that the Luna system resulted from coalescence of two different fluvial fans.

Fig. 6.—Sedimentary facies models: A: Marginal fan association. B: Fluvial fan association (Luna system).

Fig. 6.—Modelos de facies: A: Asociación de abanicos marginales. B: Asociación de abanicos fluviales (sistema de Luna).


A
15 km max.
PROXIMAL
MIDDLE
DISTAL
LUNA
FLUVIAL SYSTEM
B
Fuencalderas
syndepositional
anticline
40-60 km
PROXIMAL AND
PROXIMAL-MIDDLE
MIDDLE-DISTAL
DISTAL
Uncastillo
syndepositional
anticline

= *Proximal-middle sector:* The existing lithofacies are SLC and SM. Conglomeratic and sandy channels and bar braided systems, in places with two distinct topographic levels, were predominat. However, north of Fuencalderas and Uncastillo anticlines, and in the second case close to proximal conglomerates, sandy meandering deposits are present. The syndepositional folds within the basin represent the boundary of this sector.

= *Middle-distal sector:* Typically, this is represented by lithofacies SM, with development of low and high sinuosity rivers, ephemeral or with limited lateral migration. Sinuosity changes through space and time indicate changing slopes and/or important discharge variations. Flood plain deposits become thicker and spread downstream grading into lithofacies MS.

= *Distal sector* (lithofacies MS and M): Sheet flow sand deposits (splay deposits) and rare, low or high sinuosity, shallow channels are found within wide mud flood plains, which downstream are almost entirely formed of mudstones with thin lacustrine, sulphate or carbonate intercalations.

The fluvial systems with such sectors were 40 to 60 km long, with radial paleocurrent patterns (Nichols, 1987a; Jupp *et al.*, 1987). All the sectors are well represented and lithofacies changes are gradual. Proximal sectors are characterized by braided systems, while proximal-middle and middle-distal sectors show a great variety of fluvial styles. These features refer to alluvial systems with dominant fluvial processes or «high transport efficiency fans» after Colombo (1989) or «fluvial fans» after Díaz Molina *et al.* (1985). Drainage area surface (including the Jaca Basin, Sierras Interiores and part of the Axial Zone) in the Gavarnie unit is not possible to be determined exactly, but it was extremely larger than those of the marginal fans.

PALEOGEOGRAPHY AND TECTONIC CONTROLS ON SEDIMENTARY FEATURES

As indicated above, the Luna system resulted from coalescence of two different fluvial fans: the Uncastillo fan, to the west, and the Luesia fan, to the east (Figs. 4, 6B and 7), the apices of which were located to the northwest of Selva and north of Puig Moné points. Luesia fan apex remained at the same place through time, but Uncastillo fan apex moved eastward, and at the time of sedimentation of units U2 and $U3^1$ + $U3^2$ it was placed to the north of Cruz point. For megasequence $U3^3$ there is not sedimentary record of conglomerates of the Uncastillo fan. This may be due to later erosion, but it is not probable as geomorphological features of the area do not reflect it. Arenas (1993) suggested that during megasequence $U3^3$ deposition, the drainage basin of the Uncastillo fan was captured by the main flow of the Luesia fan: the Luna system consisted then of a single apex (Fig. 7). At that time, a new rejuvenation phase of the source area topography, caused by increasing tectonic activity, gave rise to progradation of proximal sectors of the fluvial system. However, the capture event cannot be attributed to any particular structure of the Gavarnie unit.

Figure 5A shows for megasequence U3^2 the coexistence of two fluvial conglomerate bodies with three discrete mallo-type conglomerate outcrops (Agüero, Murillo and Riglos marginal fans). Downstream, fluvial conglomerate lithofacies are fringed by sandstone and mudstone lithofacies, the outcrops of which show an elongated shape or flattening against the margin. Thus, proximal-middle and middle-distal sectors tended to elongate parallel to the basin margin. This fact determined that the marginal or short fans combined in the larger Luna fluvial system in areas near the basin margin.

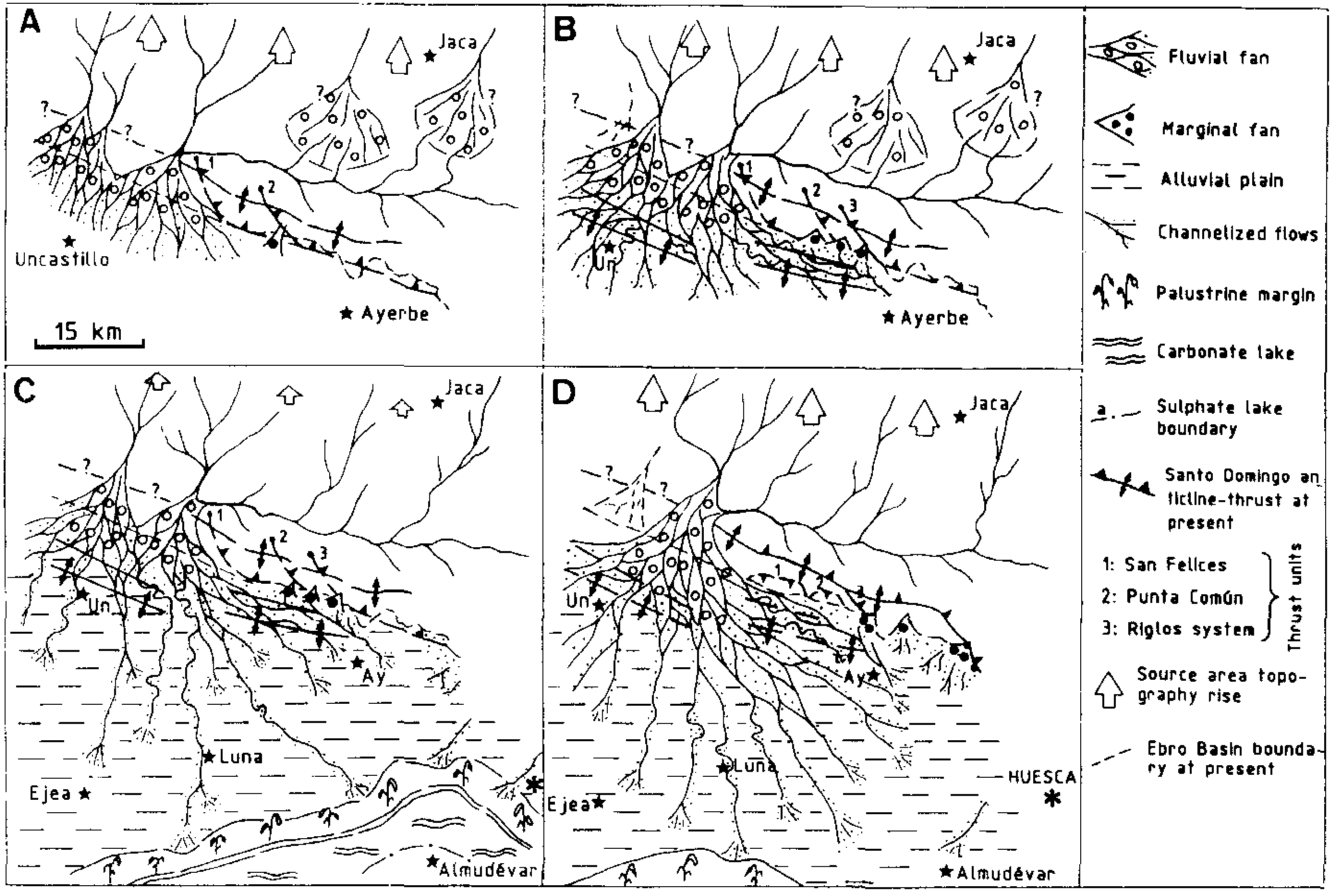
This particular distribution could have been present during the whole Uncastillo Formation deposition, but its presence can only be reported for units U2 and U3 (Fig. 7): That distribution proves that a part of the Luna system discharge was driven parallel or quasi-parallel to the adjacent margin, as shown by the WNW-ESE oriented, thick sandy channels that are found near the basin margin (e.g., Biel and Agüero-Murillo areas). Such well-developed longitudinally-flowing rivers suggest that a part of the basin margin was underfilled. That part corresponded to the region adjacent to the Sierras Exteriones structural high. Locally-increased subsidence, caused by thrust sheet stacking, could lead to such situation, but syndepositional folding within the Ebro basin, at least from unit U2 sedimentation, is a more simple explanation (Figs. 6 and 7): the uplift of the Uncastillo and Fuencalderas anticlines led to channel part of the fluvial discharge along the synclinal subsident zones. Then, deep, mostly low sinuosity channels flowed axial-oriented enlarging the middle sectors of the Luna system parallel to the basin margin.

Some other sedimentary features of the Luna system can also be attributed to the development of syndepositional folds in the Ebro Basin:

1) The limited basinward development of the conglomerate and sandstone and conglomerate lithofacies (up to 6-7 km), in contrast to the whole length of the system (about 40 to 60 km long). More extended proximal sectors should be expected from a fluvial system that transported clasts up to 75 cm in diametre.

2) The sharp transition in proximal sectors from braided gravel deposits to amalgamated, lateral accretion sandstones deposits of about 5 m thick. This is common to the north of the anticlines, where lateral accretion sandstone deposits are found 5.5 km south of the basin margin, as in the case north of Luesia village (Arenas, 1993).

These features were directly related to the local change in the general alluvial fan slope caused by the anticline development. Nevertheless, the Uncastillo and Fuencalderas anticlines did not constitute a restrictive barrier, as the Luna system net is essentially radial. Within this situation, two principal


A
B
C
D
Jaca
Uncastillo
Ayerbe
15 km
Un
Ay
Luna
Ejea
Almudévar
HUESCA
Fluvial fan
Marginal fan
Alluvial plain
Channelized flows
Palustrine margin
Carbonate lake
Sulphate lake boundary
Santo Domingo anticline-thrust at present
1: San Felices
2: Punta Común
3: Riglos system
Thrust units
Source area topography rise
Ebro Basin boundary at present

structural re-entrants existed in relation to the anticlines: the unfolded areas located i) between the two anticline-syncline pairs, south of Biel village, and ii) east of the Fuencalderas folds, north of Ayerbe. An important portion of the Luna system discharge emerged across the former structural low, feeding an active sector of the system that flowed southward. Trunk channels could reach areas far from the proximal sectors, and at maximum progradation phases that part of the fluvial system (middle-distal sector) extended to regions as far as south of Luna village, as evidenced by the extension of lithofacies SM (elongation of SM lithofacies outcrops toward the southeast of the Luna system, Fig. 5B). In the second structural re-entrant, north of Ayerbe, emergent channels became unconfined due to a local lowering in the fan slope. The expanded flows originated an area dominated by sheet sand deposits. Such is the case of Concilio-Ayerbe region (Arenas, 1993). In contrast, in the area of Uncastillo village (Fig. 5B), alluvial fan progradation phases did not cause an enlargement of middle-distal sectors toward the south, as no structural re-entrants existed there.

Apart from these facts, on the crests of the syndepositional anticlines, and particularly on the Uncastillo anticline, vertical accretion is recorded and overbank deposits also formed there. Deep channel incision is not an extensive feature of particular zones of this fold. Thus, the existence of an antecedent fluvial net cannot be argued to explain the fluvial growth basinward. Moreover, some lateral accretion bodies are found on the flexure areas of the Uncastillo anticline (Arenas, 1993). Uncastillo anticline uplift rate seems to have been compensated by vertical accretion rate in the adjacent northern synclinal region, which received the greatest part of the discharge of the Luna system. Then, northern flanks of the anticlines acted as bench terraces within the general fan slope. In contrast, southern anticline flanks had higher gradient than the flat northern ones, and greater development of sandy bodies with little lateral migration and moderate incision are common features. In other words, general slope across the Uncastillo anticline area was basinward, with very gentle slope in the northern flank and slightly higher slope in the southern flank (Fig. 6).

South of the anticlines, middle-distal sectors of the system possessed characteristics of a difluent net of mostly laterally stable channels, as considered by Nichols (1989). Unconfined flow deposits are typical features of distal sectors. Avulsion was a common autocyclic process in both sectors, and frequent changes in fluvial architecture through time have been described. Base level

Fig. 7.—Paleogeographic reconstructions for units U1^2 (A) and U2^2 (B), base of megasequence U3^2 (C) and middle part of megasequence U3^3 (D).

Fig. 7.—Reconstrucciones paleogeográficas de las unidades U1^2 (A) y U2^2 (B), base de la megasecuencia U3^2 (C) y parte central de la megasecuencia U3^3 (D).

changes in the adjacent central lacustrine systems were controlled by climatic cycles (Arenas, 1993; Arenas and Pardo, in press), but their relationships with the changing fluvial architecture is still under study.

Concerning the origin of the Uncastillo and Fuencalderas folds, recently Teixell and García-Sansegundo (1995) have proposed that the existence of a buried thrust under the Sierras Exteriores affecting the Tertiary succession of the Ebro Basin may have originated detached folds within the basin. Syndepositional deformation in the studied series in the present contribution suggests that such folds were active at least during the deposition of units U2 and U3 (at least, since Agenian, Late Oligocene times). Thus, this buried thrust was active until the deposition of megasequence $U3^2$ (Ramblian, Early Miocene), as $U3^3$ strata record a progressive attenuation of the deformation through time.

CONCLUSIONS

In the study area, the Uncastillo Formation resulted mostly from deposition in the terminal, Luna fluvial system. Since its existence, its evolution followed successive progradation-retrogradation stages controlled by tectonics in the drainage basin (Jaca Basin, Sierras Interiores and Axial Zone). West of the Sierras Exteriores Aragonesas, thrust sheets are not present and syndepositional deformation along the basin margin (progressive unconformity of Biel-Gallipienzo) does not explain such progradation-retrogradations stages.

Progradational and retrogradational stages, and probably lacustrine base level fluctuations too, may have caused fluvial architecture variations through time. These variations were described by Nichols (1989) for middle sectors of the fan. Nevertheless, fluvial net distribution did not change essentially through time, and its development was greatly controlled by Agenian-Ramblian syndepositional folding within the Ebro Basin. The most relevant consequences were the deviation of a part of the discharge parallel to the basin margin and the formation of high sinuosity rivers in proximal sectors of the fluvial system.

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