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Wave-dominated siliciclastic and carbonate sedimentation in a Lower Cretaceous lake (Cameros basin, northern Spain)

Sedimentación siliciclástica dominada por la acción del oleaje y carbonatada en un lago del Cretácico Inferior (cuenca de Cameros, norte de España)

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ABSTRACT

According to structural, sedimentary and biostratigraphic data, the north-eastern Cameros rift basin (northern Spain) has recorded almost 8 000 meters of nonmarine Late Jurassic to Early Cretaceous deposits with minor marine incursions. Our purpose is: (1) to document within this basin both carbonate and siliciclastic facies of the Enciso Group; (2) to illustrate a depositional model; and (3) to discuss palaeoenvironmental reconstruction of a large lacustrine system. Our depositional model is based on an integrated approach involving both mapping and stratigraphic section analysis. Three sedimentary environments are recognized on six stratigraphic sections and are outlined by various outcrop observations in the Enciso Group. They are: 1) open lacustrine environment; 2) siliciclastic marginal lacustrine environment (distributary channel, mouth-bar delta, shoreface lake-fringing marsh facies associations and 3) carbonate lake-margin facies environment (storm-dominated, desiccated open lacustrine, palustrine facies associations). Two types of lake margin settings alternate through time: a wave-dominated siliciclastic *vs* a low-gradient carbonate ramp setting. A climatic control on the onset of the two types of lacustrine depositional settings is suggested.

Keywords: Cameros basin, Lower Cretaceous, lakes, palaeoenvironments, palaeoclimate.

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RESUMEN

De acuerdo con los datos estructurales, sedimentológicos y bioestratigráficos disponibles, la cuenca de rift del noreste de Cameros (norte de España) presenta el registro de unos 8000 metros de depósitos de sedimentos continentales de edad Jurásico Superior a Cretácico Inferior, con incursiones menores de origen marino. El propósito del presente trabajo es: (1) documentar la presencia en esta cuenca de las facies carbonatadas y siliciclásticas del Grupo Enciso; (2) proponer un modelo deposicional; y (3) realizar la reconstrucción paleoambiental de un gran sistema lacustre. Nuestro modelo deposicional está basado en la integración de datos cartográficos con los procedentes del análisis de secciones estratigráficas. A partir del estudio de seis secciones estratigráficas, se han podido identificar tres asociaciones de facies diferentes, reconocidas a su vez en otros afloramientos del Grupo Enciso. Estas asociaciones de facies son: 1) asociación de facies de ambiente lacustre abierto; 2) asociación de facies de ambiente lacustre marginal siliciclástico (canal distributario, barra de desembocadura y facies pantanosas de *shoreface lake-fringing*) y 3) ambiente lacustre marginal de facies carbonatada (asociaciones de facies palustres dominadas por tormentas y lacustre abierta con desecación). A lo largo del tiempo se alternan dos tipos de margen lacustre: uno siliciclástico, dominado por la acción del oleaje, y otro carbonatado según un modelo de rampa suavemente inclinada. Se sugiere que el establecimiento de estos dos tipos de depósitos lacustres estuvo controlado por factores climáticos.

Palabras clave: Cuenca de Cameros, Cretácico Inferior, lagos, paleoambientes, paleoclima.

INTRODUCTION – GEOLOGICAL SETTING

During Mesozoic times, intraplate rifting stages related to the opening of the Biscay Gulf are responsible for the emplacement of a set of extensional basins within the Iberian Domain (Álvaro *et al*., 1979; Salas and Casas, 1993; Casas-Sainz and Gil-Imaz, 1998). The Cameros basin was initiated during the main rifting period (Late Jurassic-Early Cretaceous) and corresponds to the thickest western depocentre. According to structural, sedimentary and biostratigraphic data (Tisher, 1966; Salomon, 1982; Guiraud, 1983; Martín-Closas y Alonso-Millán, 1998) the northeastern Cameros basin recorded almost 8.000 meters of nonmarine Late Jurassic to Early Cretaceous deposits with minor marine incursions (Alonso y Mas, 1993; Gómez-Fernández and Mélendez, 1994; Alonso-Azcárate *et al*., 1995). Tisher (1966) established the initial stratigraphic framework subdividing the synrift deposition into five lithostratigraphic groups (namely, Tera, Oncala, Urbión, Enciso, Oliván). This model was further discussed by authors leading to several synrift sedimentary and sequence stratigraphic interpretations (Salomon, 1982; Guiraud, 1983; Guiraud and Séguret, 1985; Mas *et al* ., 1993). Our purpose is: (1) to document both carbonate and siliciclastic facies of the Enciso Group (late Barremian to Aptian); (2)

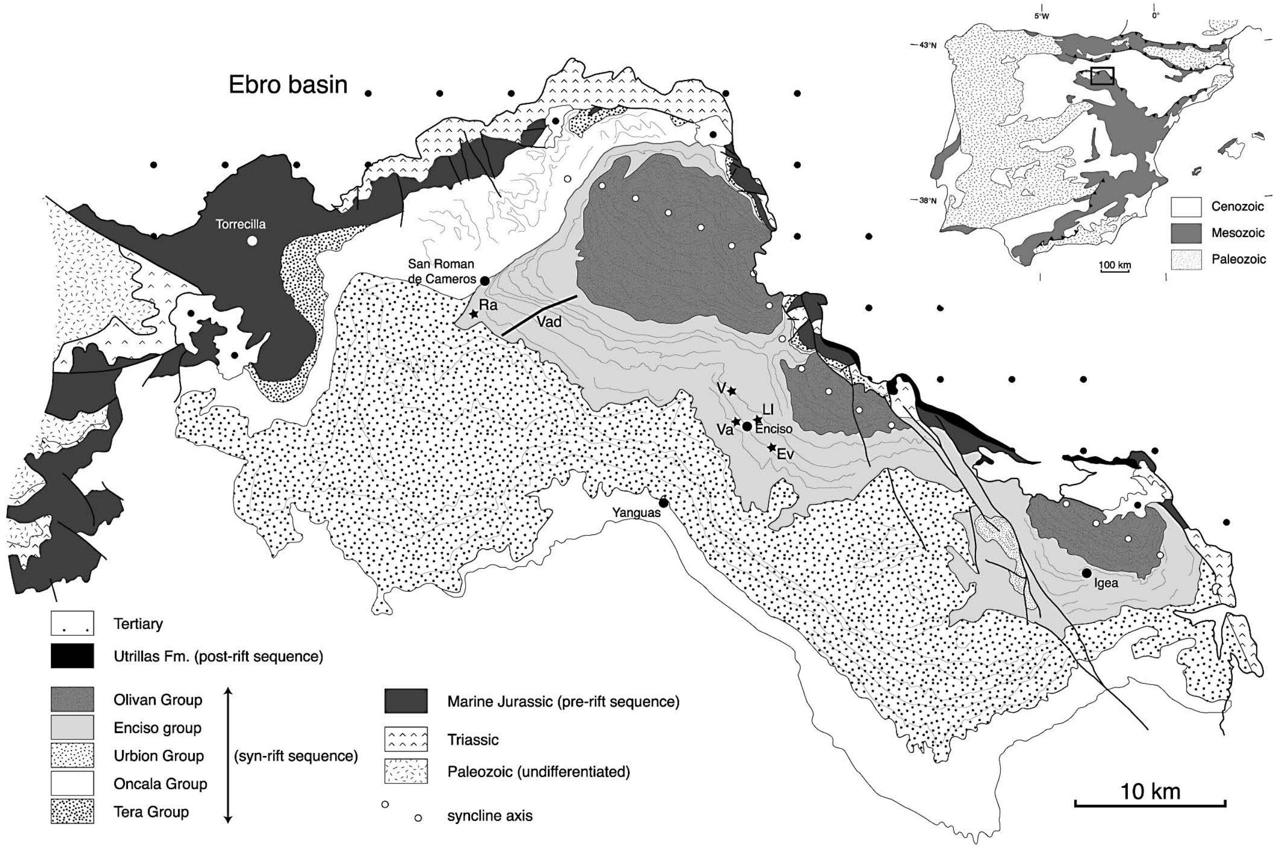

FIG. 1.- Geological map of the eastern Cameros basin showing logged sections (Vadillos, Vad; Rabanera, Ra; Valdevigas, V; Valderrès, Va; Los Llanos, Ll; El Villar de Enciso, Ev). Modified after Guiraud and Séguret (1985) and Mata *et al.* (2001).

FIG. 1.- Mapa geológico del sector oriental de la cuenca de Cameros en el que se muestra la situación de las secciones estudiadas (Vadillos, Vad; Rabanera, Ra; Valdevigas, V; Valderrés, Va; Los Llanos, Ll; El Villar de Enciso, Ev). Modificado a partir de Guiraud y Séguret (1985) y Mata *et al.* (2001).

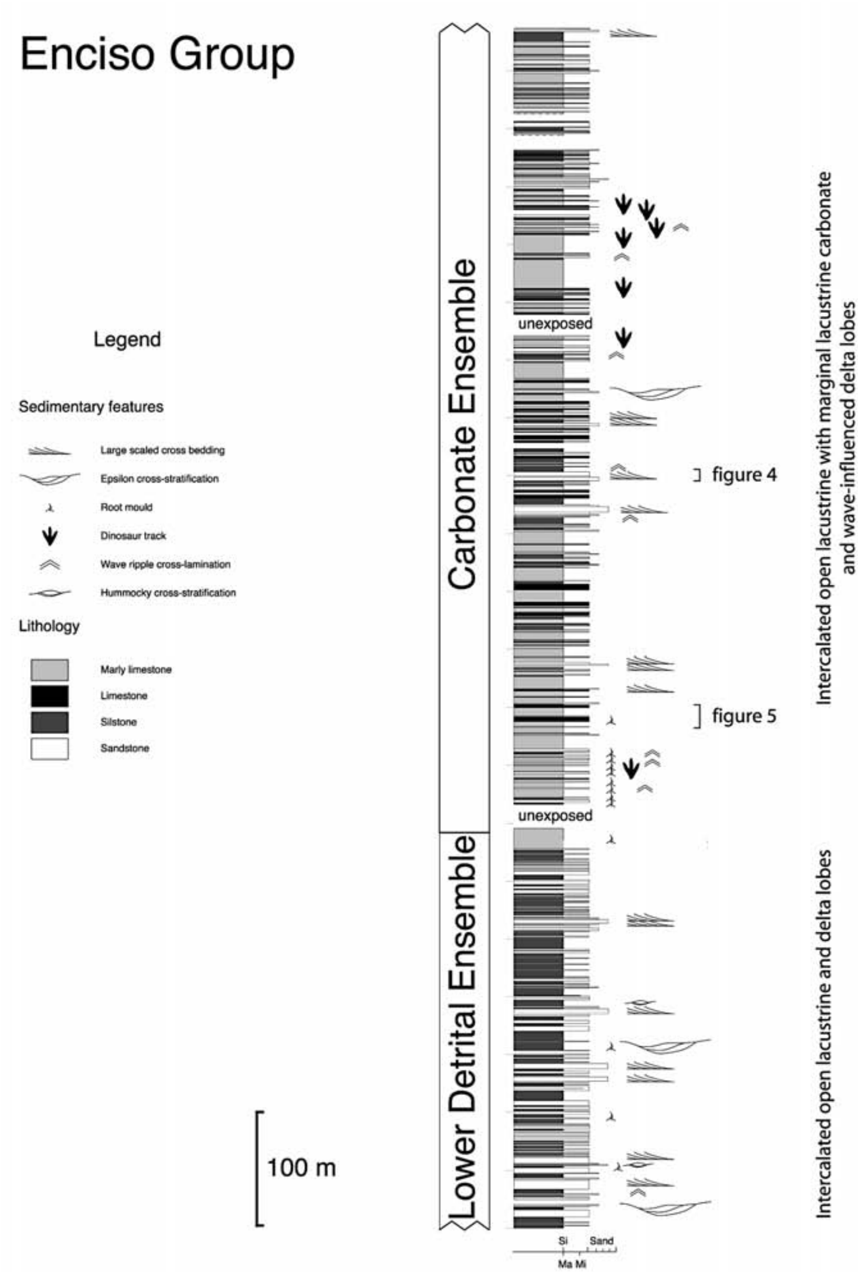

FIG. 2.- Vertical sedimentological log (Vadillos section) through the Enciso Group. See Fig. 1 for location.
FIG. 2.- Columna estratigráfica del Grupo Enciso (sección de Vadillos). Ver Fig. 1 para su localización.

to illustrate a depositional model and (3) to discuss palaeoenvironmental reconstruction of a large lacustrine system.

METHODOLOGY

The Enciso Group, 300-1500 m thick, crops out in the north-eastern Cameros basin (Fig. 1). Our depositional model is based on an intregrated approach involving both mapping and stratigraphic section analysis. Three facies associations are recognized on six stratigraphic sections and are outlined by various outcroup observation in the Enciso Group. A vertical section was logged through the Enciso Group (Vadillos section; Fig. 2) and completed by other sections: Rabanera, Valdevigas, Valderrés, Los Llanos and El Villar de Enciso (see Fig. 1 for location). All the sec-

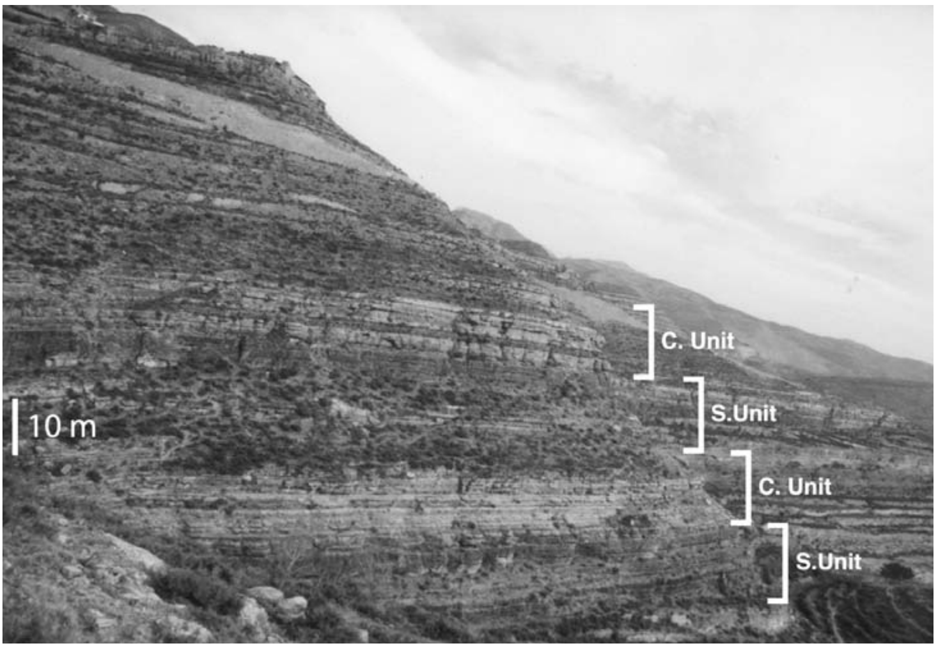

FIG. 3.- Exposure of the Enciso Group near San Vicente (Munilla). Stacked siliciclastic and carbonate lacustrine facies alternate with open lacustrine marls. Both siliciclastic and carbonate units (S. Unit and C. Unit) are laterally continous over tens of kilometers with only little changes in thickness. Sandstones are dominated by shoreface deposits while yellowish limestones mostly consist of marginal (emersive) lacustrine facies.
FIG. 3.- Afloramiento del Grupo Enciso cerca de San Vicente (Munilla). Los apilamientos de facies siliciclásticas y carbonatadas lacustres alternan con margas lacustres de medio abierto. Las unidades siliciclástica y carbonatada (Unidad S. y Unidad C.) se extienden lateralmente en continuidad a lo largo de decenas de kilómetros sufriendo sólo pequeños cambios en su espesor. Las areniscas están dominadas por depósitos de *shoreface* mientras que las calizas amarillentas consisten en su mayor parte en depósitos de facies lacustre marginal (con emersiones).

tions were carried out using facies analysis criteria (grain size, lithology, fossils, sedimentary and biological structures). Thin sections and hand samples are also examined for interpretation of carbonate facies. The geometry of sedimentary bodies was characterized from field observations and outcrop photographs. As biostratigraphic data from the Enciso Group remain very scarce (Martín-Closas y Alonso-Millán, 1998; for a review) correlations are based on 1:10.000 mapping of marker beds, *i.e.* lateral extent and facies variations as well as geometry of sedimentary intervals between each marker (Fig. 3).

SEDIMENTARY ENVIRONMENTS AND FACIES ASSOCIATIONS

The sediments of the Enciso Group are arranged into carbonate and siliciclastic units and divided into open-lacustrine, siliciclastic marginal lacustrine, and carbonate lake-margin environments.

OPEN LACUSTRINE FACIES ENVIRONMENT

This environment is dominated by both siliciclastics and carbonates arranged into three distinct facies associations.

Siliciclastic facies is dominated by blue-greenish bioturbated micaceous siltstones (Fig. 4). These homogeneous siltstones are massive and frequently exhibit soft-sediment microfaulting related to compaction (Guiraud and Séguret, 1987). Sedimentary structures as well as fossils are virtually absent. The low-diversity trace fossil assemblage is dominated by abundant simple horizontal to vertical burrows that can be several tens of centimetres deep.

Carbonate units display mid- to dark-grey micrite interbedded with grey marls and calcareous claystones (Fig. 5). They often contain laminated ostracod-shell skeletal debris. Vertebrate bone fragments including vertebrae, crocodile teeth and more frequently fish scales and teeth have been noticed. Bioturbation when observed is diffuse.

Heterolithic sedimentary units consist of alternating marls, limestone beds and ostracod-rich sandstones. Limestones appear as single ostracodal calcarenite beds laterally persistent over kilometers. They are sharp-based and display a upper undulating surface. Internal structures are featured by erosive surface producing hummocks and swales mantled by ostracodal laminae. These structures are distinctive of hummocky cross-stratifications (Fig. 6-1). Sandstones occur as graded centimeter-thick beds few meters in extend. Occurrence of incipient starved wave ripples attest of active wave reworking. Sandstone beds are interpreted as tempestite-like deposits (*sensu* Aigner, 1985). In vertical section, they are stacked into fining-upward sequences which alternate with carbonate beds and marls (Fig. 5).

Facies described suggest fine-grained sedimentation in an oxygenated open lacustrine setting. Absence of sedimentary features diagnostic of subaerial exposure induces a permanent water column. Both siliciclastic and carbonate sedimentary units record low-energy sedimentation. They contrast with heterolithic units where

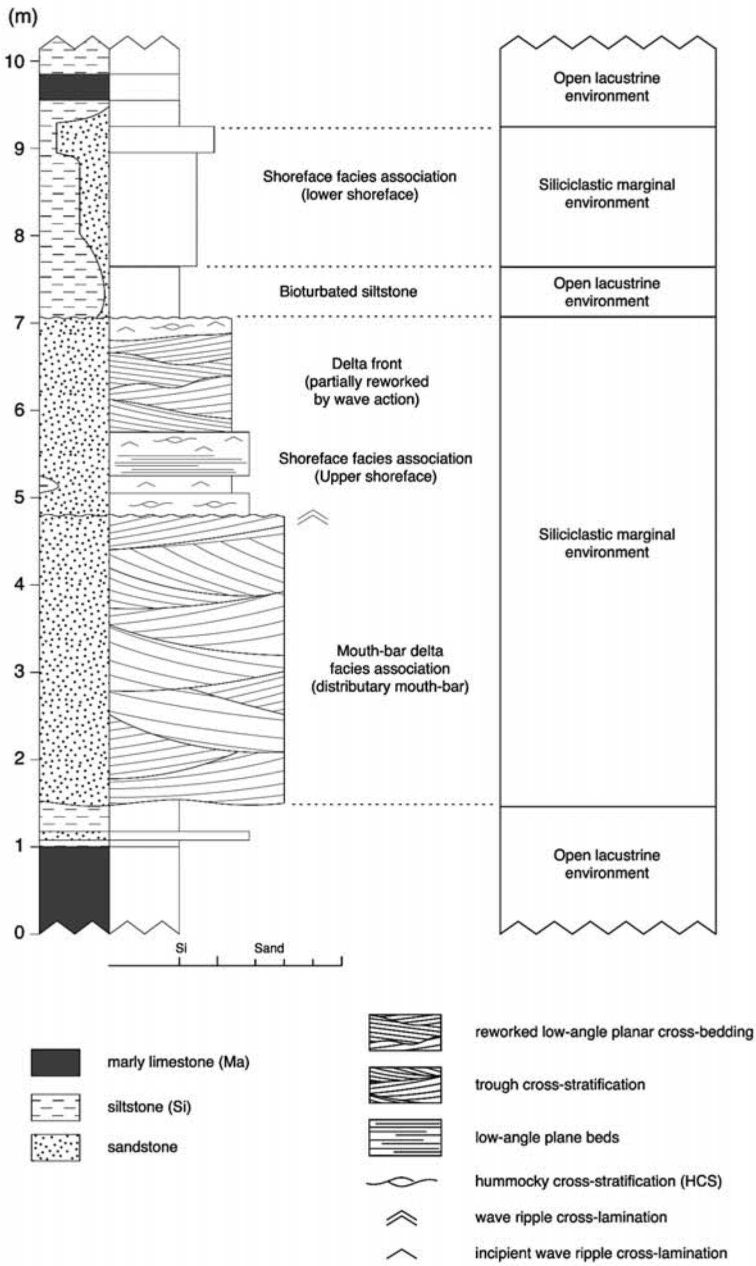

FIG. 4.- Vertical section (Los Llanos section) showing siliciclastic marginal lacustrine succession. See figures 1 and 2 for location.

FIG. 4.- Sección estratigráfica (Los Llanos) que muestra una sucesión lacustre siliciclástica marginal. Ver figuras 1 y 2 para su localización.

occurrence of tempestites and HCS suggest storm-dominated open lake conditions.

Siliciclastic marginal lacustrine environment

The siliciclastic marginal lacustrine environment is composed of siltstones and very fine to medium sandstones. This environment is represented by distributary channel, mouth-bar delta, shoreface and marginal lacustrine marsh facies associations.

The distributary channel facies association

This facies association is present within single fining-upward channel sandstones, 2.5 to 4 m thick. Grain size decreases upward from medium- to very fined-grained sandstones. In cross section, sandbodies show flat top and U-shaped erosional base sometimes with thin lag conglomerate containing logs (Fig. 6-2). They are simple although several display internal bounding surfaces. Commonly wedge-shaped massive silty sandstones known as wings extend laterally and thin over meters into silty deposits. Sandbody infill is dominated by lateral accretion (epsilon) cross-bedding associated with planar cross-beds.

On the basis of the W/T ratio, channel sandstones are reported as ribbon sandstones or laterally restricted channel sandstones (Friend *et al*, 1986). Epsilon cross-stratifications suggest lateral migration. Ribbon sandstones are interpreted as isolated ephemeral channels cutting down into lacustrine deposits.

Mouth-bar delta facies association

Mouth-bars form single or stacked individual lobate sandstones, 0.1 to 4 m thick. In strike section, single bedset extension considerably vary from 25 m to more than 1000 m, but facies arrangement and lobate geometry remain constant. In cross section, lobes consist in convex-up lens-shaped sandbodies. They frequently overlie fine deposits (open lacustrine sediments) with sharp scouring lower bounding surfaces (Fig. 6-3), but in some cases, transition from fine deposits is gradual and correspond to parallel-laminated siltstones. Central sandstone bodies display trough cross-stratifications which laterally pass into tangential and planar cross-stratifications. Small-scaled hummocky cross-stratified sands may occur interbedded with single lenticular bedsets. Reworking of cross beds is locally present as undulating erosive surfaces (Fig. 4).

Geometry and facies recognized in sandstones suggest lobate delta systems. Parallel-laminated siltstones record prodelta deposits, while sandstone beds characterize the proximal part of delta. The arrangement of sedimentary structures within single lobe allow us to define several domains. The proximal delta which records migration of dunes (trough cross beds) in a channelized flow is reported here as the distributary mouth-bar. Laterally, as the flow speed decreases, sandwaves (tabular cross beds) can form on the delta front (Figs. 4 and 6-4). Towards lobe margins, erosions as well as HCS sandstones tend to record a more effective wave activity.

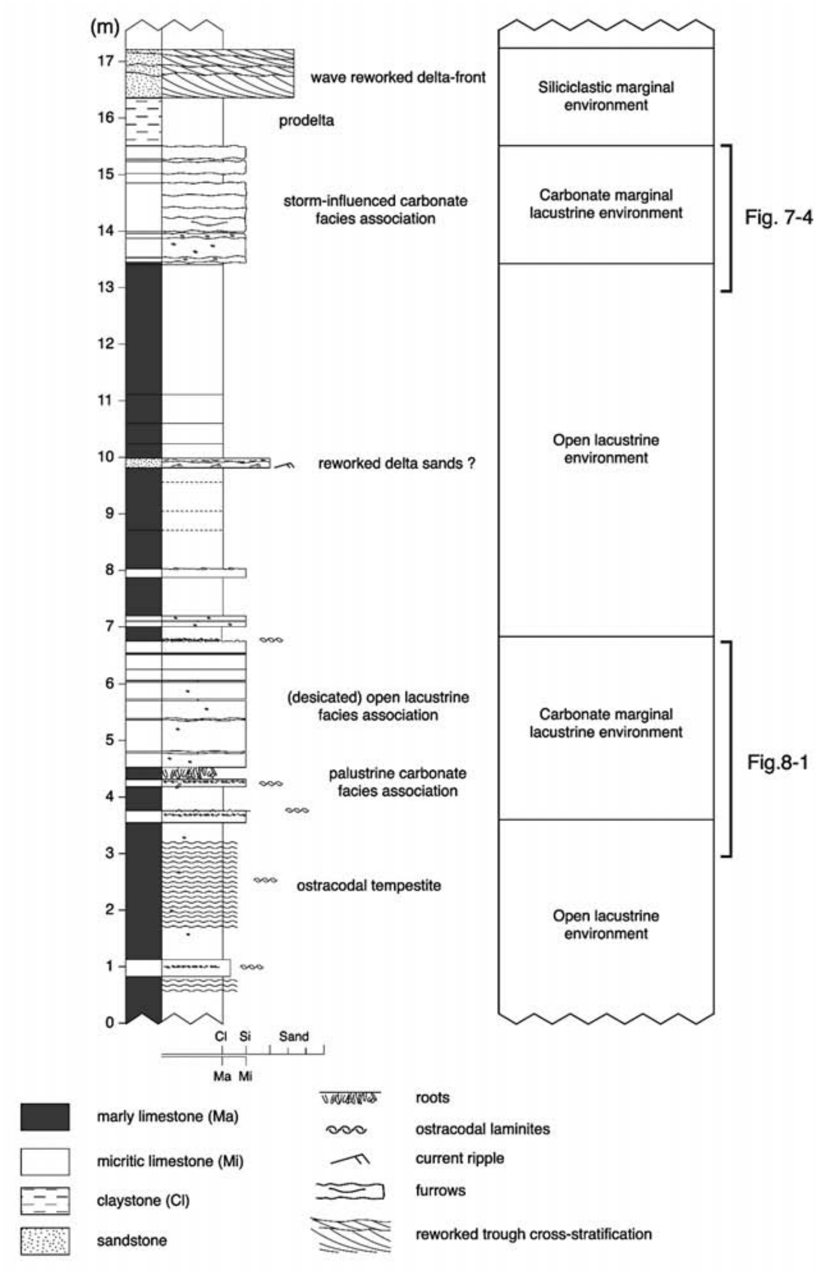

FIG. 5.- Vertical section within the Vadillos log showing vertical alternances between open lacustrine, siliciclastic and carbonate lacustrine units. See figures 1 and 2 for location.
FIG. 5.- Sección estratigráfica de detalle (Vadillos) en la que se muestra la alternancia vertical entre las tres unidades lacustres (abierta, siliciclástica y carbonatada). Ver figuras 1 y 2 para su localización.

SHOREFACE FACIES ASSOCIATION

Deposits recognized in this facies association are arranged units 1.5 to 3.5 m thick and few kilometers in lateral extend.

The lower part is dominated by silty to very fine grained micaceous sandstones. They consist in laterally homogeneous bedforms which normally grade from open lacustrine deposits. Sedimentary structures displayed comprise flat to low angle cross laminations interdigitated with symmetrical ripples or symmetrical ripple-form sets less than 1 cm thick. Very small-scaled hummocky cross-stratification have been also observed. These sandy deposits show diagnostic features of wave action (Harms *et al.*, 1982). Occurrence of even lamination associated with wave ripples and small-scaled HCS suggests a lower shoreface setting.

In vertical section, lower shoreface deposits are overlain by stacked lenticular sandstone beds. Thickness as well as lateral extend of these well sorted fine grained sandstones are similar to those of small single delta lobes. Amalgamated small-scaled HCS and wave-ripple bedsets are the more common features but larger HCS sandstones and undulating low-angle flat beds also occur (Fig. 7-1). Numerous vertebrate tracks preserved over large rippled surfaces attest of occasional emergence.

Most of internal structures of lenticular sandstones show features characteristic of wave and storm action in the upper shoreface. Flat beds indicate oscillatory upper flow-regime conditions and suggest high flow velocity and shallow water depth (Harms *et al.*, 1982). Large- as well as small-scaled HCS beds record storm events the upper shoreface. Storm-influenced marginal lacustrine settings are both extensively documented in modern and ancient lakes (*e.g.* Eyles and Clark, 1986; Greenwood and Sherman, 1986; Dam and Surlyk, 1991; Martel and Gibling, 1991). Modern example of hummocky cross-stratifications from Ontario lake similar to those observed typically form in the surf zone at very shallow depth (Greenwood and Sherman, 1986).

In vertical section, lower and upper shoreface are arranged in coarsening-upward successions similar to those observed in mouth-bar environment (Fig. 7-2). Both environments display a general shallowing-upward tendency marked by sedimentary structures and an increase in sand content and grain size. Upper shoreface are often associated with distributary mouth bars or delta front deposits (Fig. 4). Local presence of reworked trough cross bedding and lenticular geometry of shoreface sandstones and their close association to delta lobes imply that shoreface formed at wave-influenced river mouths.

SILICICLASTIC LAKE-FRINGING MARSHES FACIES ASSOCIATION

This facies is composed of dark grey silts and sandstone beds. Their most striky feature is occurrence of root moulds up to 5 cm in diameter (Fig. 7-3). Single rooted horizons can be stacked to form sandstone units up to 4 m thick. Sandstones preserved from rooting display faint wave ripples and parallel laminations.

Although root typifies pedogenic modification, pedoturbated units lack of other

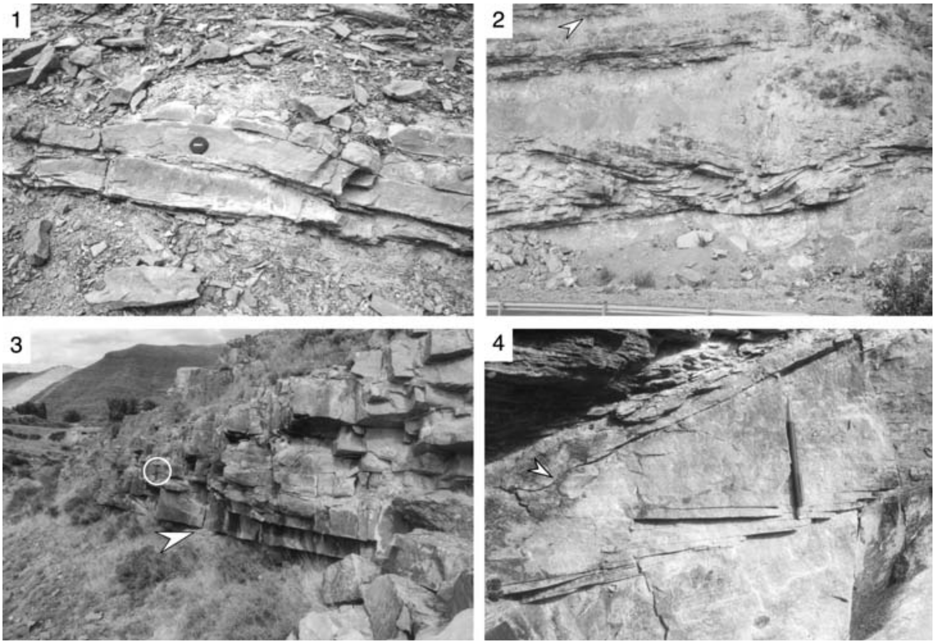

FIG. 6.- Open lacustrine and siliciclastic marginal lacustrine facies associations (see figure 1 for location) 1.- Hummocky cross-stratified ostracodal calcarenite (heterolithic open lacustrine facies association). Carbonate bed is sharp-based and internal erosive surfaces typically form vertically stacked hummocks. Erosive surfaces are draped by ostracodal laminae. They dip at low angle, thicken into swales (on the right part of the picture) and thin over hummocks. HCS bed is interbedded with wave-rippled ostracodal tempestites (lens cap for scale). Valderrés section. 2.- Vertical profile showing a channel sandbody incising into open lacustrine mudstones. Scouring surfaces suggest the ribbon has at least two storeys. Delta front sandstones occur at the top of the profile as sandsheets 1 to 2 m thick and almost 500 m wide. They are interbedded with a rooted surface (arrowed). Sandbody is 5 m in thickness. Rabanera road near San Roman de Cameros. 3.- Sharp-based delta front sandstones. 4m thick cross stratified sandstones overlie erosionaly open lacustrine limestones (arrowed surface). Hammer for scale (cercled). Vadillos road near San Roman de Cameros.- 4.- Planar cross-stratification in a delta lobe (delta front). Undulating to planar erosive surface (arrowed) reflect wave reworking (pencil for scale). Close-up of the delta lobe illustrated in figure 6-3.

FIG. 6.- Asociaciones de facies lacustre abierta y siliciclástica marginal (ver figura 1 para su situación). 1.- Calcarenita con ostrácodos y estratificación cruzada tipo *hummocky* (asociación de facies lacustre abierta heterolítica). El estrato carbonatado posee una base neta y presenta superficies erosivas internas características del apilamiento vertical de los *hummocks*. Las láminas de ostrácodos se sitúan sobre las superficies erosivas. Se inclinan suavemente, engrosándose hacia la zona deprimida (hacia la parte derecha de la foto), y se adelgazan sobre los *hummocks*. La capa con HCS está interestratificada con tempestitas con ostrácodos que presentan ripples de oleaje (ver tapa del objetivo de la cámara como escala). Sección de Valderrés. 2.- Sección vertical en la que se observa un cuerpo canalizado arenoso encajado en *mudstones* de ambiente lacustre abierto. Las superficies erosivas permiten diferenciar, al menos, dos etapas. Areniscas de frente deltaico aparecen en la parte alta del perfil como láminas arenosas de 1 a 2 m de espesor y unos 500 m de continuidad lateral. Están interestratificadas con superficies afectadas por raices (marcadas con flechas). El cuerpo de arenas tiene 5 m de potencia. Carretera de Rabanera, cerca de San Román de Cameros. 3.- Areniscas de frente deltaico con bases netas. Areniscas con estratificaciones cruzadas de 4 m de espesor se superponen erosionalmente a calizas lacustres abiertas (superficie marcada con flechas). El martillo, encerrado en un círculo, sirve de escala. Carretera de Vadillos, cerca de San Román de Cameros. 4.- Estratificación cruzada planar en un lóbulo deltaico (frente deltaico). La superficie erosiva, de ondulada a planar, (señalada con flechas) refleja una removilización por efecto del oleaje (ver lápiz como escala). La fotografía se ha tomado cerca del lóbulo deltaico que se ilustra en la figura 6-3.

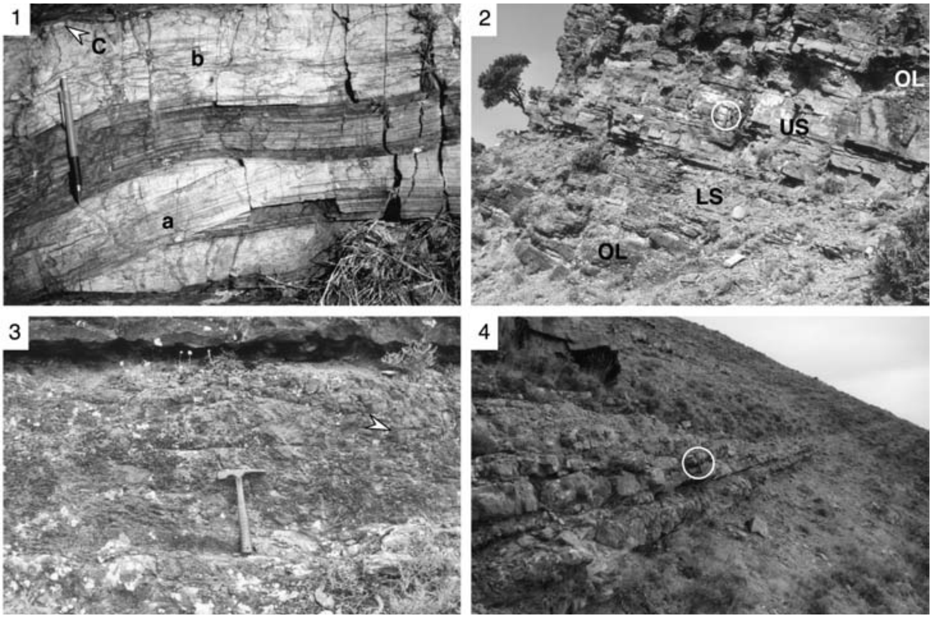

Fig. 7.- Siliciclastic marginal lacustrine facies and carbonate lake-margin environments (see figure 1 for location). 1.- Upper shoreface sandstone. Low- to high-angle undulating plane beds (a) interbedded with amalgamated small-scaled HCS (b) and wave ripples (c). Pencil for scale. 2.- Gradational-based shoreface sandstones. Wave-reworked upper shoreface deposits (US) occur as convex-upward lobes tens of meters in extent resulting from delta-front reworking. Wave-reworked lower shoreface (LS) consists in wave and storm influenced very fine grained sanstones. Together with open lacustrine (OL), shoreface deposits are laterally persistent over hundreds of meters; Hammer (cercled) for scale. El Villar section. 3.- Lake fringing marsh facies illustrated by paleosol preserved into lacustrine nearshore deposits. Pedogenesis is only attested by presence of root moulds (2 to 6 cm in diametre) suggesting very immature paleosol. Notice poorly preserved primary bedding in areas where rooting developed weakly. The paleosol is sharply overlain by an erosional delta sandsheet. Valderrés section. Hammer for scale. 4.- Storm-dominated limy facies. Beds are stacked into laterally persistent units (as shown above) alternating with open lacustrine marls and deltaic sandstones. Limestones exhibit irregular furrowed surfaces attributed to erosive storm wave activity. Hammer for scale (cercled). Vadillos section (see figures 1 and 5 for location).

Fig. 7.- Facies lacustres marginales siliciclásticas y ambientes carbonatados lacustres marginales (ver figura 1 para su situación). 1.- Areniscas del *shoreface* superior. Capas con superficies onduladas de bajo a alto ángulo (a), interestratificadas con HCS amalgamados de pequeña escala (b) , y ripples de oleaje (c). Ver lápiz como escala. 2.- Areniscas de base gradacional del shoreface. Los depósitos de la parte superior del shoreface (US), retrabajados por la acción del oleaje, aparecen como lóbulos de decenas de metros de extensión y convexos hacia techo, como resultado del retrabajamiento del frente deltaico. La parte inferior del shoreface (LS), retrabajada por la acción del oleaje, está constituida por areniscas de grano muy fino con influencia del oleaje y las tormentas. Al igual que los depósitos lacustres abiertos (OL), los de shoreface se extienden lateralmente a lo largo de centenares de metros (como escala, ver el martillo rodeado por un círculo). El Villar. 3.- La presencia de un paleosuelo preservado en el interior de los depósitos lacustres de nearshore ilustra las facies pantanosas de lake-fringing. Los procesos pedogenéticos están verificados exclusivamente por la presencia de moldes de raíces (2 a 6 cm de diámetro), lo que sugiere un paleosuelo muy inmaduro. Nótese la escasa preservación de la estratificación original en aquellas áreas en las que se desarrolla, aunque sea débilmente, el proceso de enraizamiento. Las areniscas deltaicas se superponen de forma erosiva a este paleosuelo. Sección de Valderrés. Ver martillo como escala. 4.- Facies calcáreas dominadas por la acción de tormentas. Las capas se disponen en unidades con gran extensión lateral (como se muestra más arriba) y alternan con margas lacustres de medio abierto y areniscas deltaicas. Las calizas presentan superficies con surcos irregulares que se atribuyen a la actividad erosiva del oleaje durante las tormentas. El martillo, rodeado por un círculo, sirve de escala. Sección de Vadillos (ver figuras 1 y 5 para su localización).

characteristic features such as nodules or mottling. These pedoturbated units are interpreted as immature paleosol formed in lake-fringing forested-marsh setting (Moore, 1987). Laterally, paleosols are associated with distributary channels. Weak pedogenetic features documented in paleosols could reflect poor drainage related to the lake water level.

Carbonate lake-margin environment

This environment comprises mudstone and wackestone carbonates and marls. Carbonate facies typically outcrop as tabular, sheet-like beds extending both in dip and strike sections over tens of kilometers. Limestone beds are frequently stacked to form stratigraphic successions several meters in thickness intercalated with open lacustrine facies. We distinguish storm-dominated carbonate, palustrine carbonate and desiccated open lacustrine limestone facies associations.

Storm-influenced carbonate facies association

These carbonates consist in tabular silty to sandy micrites as thick as 1 to 3 m with very scarce desiccation cracks. Fossil content is low and mostly represented by ostracod shells although occurrence gyrogonites has been documented in one case. Limestones develop individual near symmetric furrows, 5 cm deep and 30 to 45 cm long. Furrows can amalgamate to form ondulating bed surfaces visible along several kilometers (Fig. 7-4). They are infilled with micrite containing low to moderate amounts of intraclatic pebbles and quartz sand grains. The clastic particles are frequently dispersed in the matrix to form homogenous sandy micrite. But where the pourcentage of sand is greater, particles are arranged into draping laminae alternating with featureless micritic laminae to form small-scaled hummocky cross-stratifications.

These facies are interpreted as storm-influenced carbonates whose sedimentary structures record storm events in permanent water column above storm-weather wave base.

Desiccated open lacustrine limestone facies association

These limestones occur as massive monotonous units composed of stacked tabular uniform beds (Fig. 8-1). Micrite are homogeneous and display faint millimetre scale silty laminae. In thin-section micrite display rhythmically laminae laterally disrupted by bioturbation (Fig. 8-2). Sand content is low and consist in millimeter- to centimeter-thick horizontal laminae. Thin to very thin breccia occur within limestone beds over large areas (100s of meters). Brecciated limestones contain well-rounded intraclasts associated with clastic particles and ostracodal shell fragments. Bed tops are planar and frequently exhibit preserved dinosaur foot prints with desiccation cracks (Fig. 8-3).

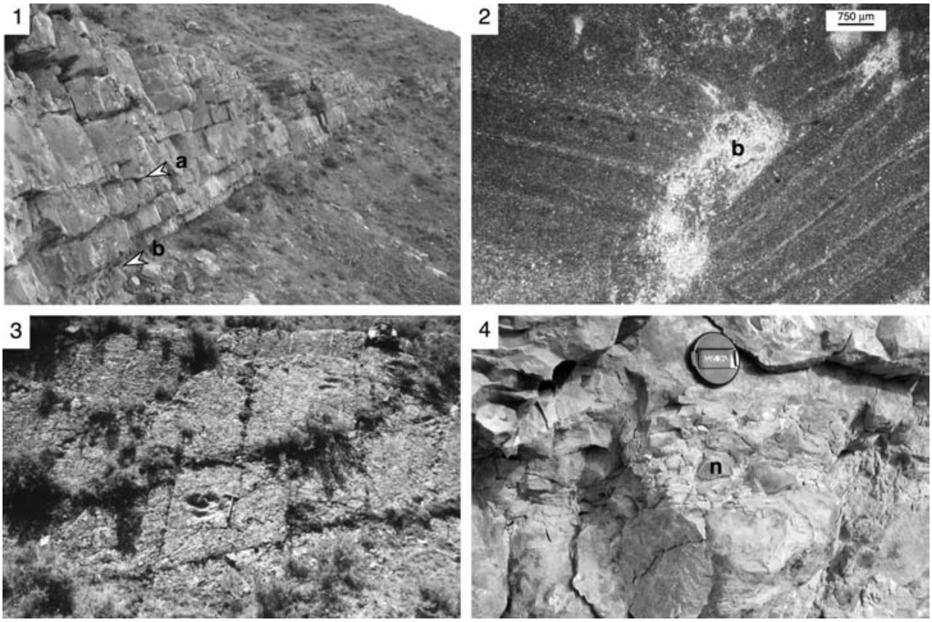

FIG. 8.- Carbonate lake-margin environment (see figure 1 for location). 1.- Open lacustrine limestone. This facies consists in yellowish tabular beds stacked into several meter thick units. They are laterally persistent over kilometers. Rare furrows record weak episodic storm activity (a). Carbonate unit is 5 m in thickness. (b) palustrine carbonate shown in figure 8-4. Vadillos section (see also figures 2 and 5 for location). 2.- Thin section of rhythmically laminated limestone. Each couplet is made up of a light lamina (clastic material) which grades into a thicker dark micritic lamina. Alternating clastic and micritic laminae suggest discontinuous clastic sedimentary influx on the lake bottom. Primary bedding is disrupted by burrowing (b) which tend to generate a chaotic fabric (upper part). Los Llanos section. 3.- Ornithopod trackways at Navalsaz. Footprints are preserved at the top of a tabular micritic yellowish limestone 50 km in lateral extend. This limestone recorded stable open lacustrine conditions before it experienced subaerial exposure shown by dinosaur tracks. It is thus interpreted as desiccated open lacustrine facies. Hammer for scale. Vadillos section. 4.- Palustrine micritic limestone (dolostone) with subcylindrical nodules (n) developed around roots. Paleosol extends over 50 km. Lens cap 55 mm across. Vadillos section (see also figures 5 and 8-1 for location).

FIG. 8.- Asociación de facies carbonatadas de margen lacustre (véase la figura 1 para su localización). 1.- Calizas lacustres abiertas. Estas facies consisten en estratos tabulares amarillos dispuestos en unidades de varios metros de potencia. Tienen continuidades laterales de varios kilómetros. Los surcos registran débiles episodios de tormentas (a). La unidad carbonatada tiene 5 m de potencia (b). En el apartado 4 de esta misma figura aparece un detalle de los carbonatos palustres señalados con la flecha. Sección de Los Vadillos (ver figuras 2 y 5 para su localización). 2.- Lámina delgada de una caliza rítmicamente laminada. Cada ritmo está constituido por una lámina clara, de material detrítico, que cambia gradualmente a otra, más potente y oscura, de naturaleza micrítica. La alternancia de láminas de naturaleza detrítica y micrítica sugiere la presencia de aportes discontinuos, de naturaleza detrítica, en el fondo del lago. La bioturbación rompe la estratificación original (b) y tiende a generar una fábrica caótica (parte superior). Sección de Los Llanos. 3.- Pisadas de ornitópodo en Navalsanz. Las pisadas están preservadas en el techo de calizas micríticas amarillas, tabulares, de 50 km de extensión lateral. Estas calizas registran condiciones lacustres abiertas estables antes de la emersión que es deducida por la presencia de las pisadas de dinosaurios. Se interpretan como facies lacustres abiertas emergidas. Ver el martillo como escala. Sección de Vadillos. 4.- Calizas micríticas de origen palustre (dolostone) con nódulos subcilíndricos (n) desarrollados en torno a las raíces. El paleosuelo tiene una extensión lateral de unos 50 km. El diámetro de la tapa del objetivo de la cámara tiene un diámetro de 55 mm. Sección de Vadillos (ver también figuras 5 y 8-1 para su localización).

Facies and fossil content suggest low-energy open lacustrine sedimentation over long periods without subaerial exposure. Breccia are interpreted as wave-reworked desiccated micrite (Freytet, 1984). Together with vertebrate tracks and desiccation cracks, brecciated limestones are indicative of occasional emergence events.

PALUSTRINE CARBONATE FACIES ASSOCIATION

They occur as rooted marls and yellow dolostones extensive over tens of kilometres among the Enciso Group. They consist in nodular limestones showing little development. Subvertical nodules are weakly develop around roots (Figs. 8-1 and 8-4). In the matrix, abundance of ostracods attest of the lacustrine origin of lime. This facies is quite rare in the group and interpreted as palustrine carbonate indicative of marginal carbonated swamps.

DISCUSSION AND CONCLUSIONS

Lithological and sedimentological data suggest that sedimentation took place in a lacustrine setting. Emersive tabular limestone beds and sheet-like sandstones can be traced over the entire basin. They allow both dip and strike stratigraphic architecture of the Enciso lacustrine system to be documented at a high time resolution (10 to 50 kyr).

Siliciclastic units include littoral deposits and open lacustrine siltstones. The proximal part of the littoral zone is dominated by distributary channels and lake-fringing marshes. Isolated channel sandbodies documented in the Enciso group are different as compared to thicker and wider multistorey channel belts located in non-lacustrine alluvial settings (Ryder *et al.*, 1976). They are frequently intercalated in both open lacustrine and shoreface deposits recording major terrigeneous sediment inputs into the lake basin. Laterally to channels, occasional occurrence of weakly developed paleosol sequences is consistent with lake-shoreline fluctuations. Lakeward sediment supplied by distributaries form lobate deltaic sandbodies. Internal organization as well as geometry of delta lobes resemble lobate delta models reported in modern and ancient lakes (*e.g.* Ayers, 1986; Dam and Surkyk, 1991; Glover and O'Breine, 1994; Scholz, 1995; Lemons and Chan, 1999). In strike section, active mouth-bars are bordered by inactive delta lobes which display abundant wave-generated structures typical of shoreface conditions. Both shoreface and delta deposits are arranged in sheet sandstone which grade into open lacustrine deposits in dip section.

Limestones form laterally persistent sheet-like stacked beds mostly indicative of open lacustrine conditions. In dip section, tabular desiccated limestones pass gradually into storm-dominated carbonates. In tabular limestone poorly preserved rhythmical lamination and intense bioturbation activity record sedimentation from particle settling in a well-oxygenated low-energy environment. Although frequent, features indicative of emergence only consist in desiccation surfaces (desiccation cracks, dinosaur tracks, brecciated limestones) typical of a low to very low pedogenetic modification. Intensity of pedogenetic overprint is known to increase with time exposure (Gómez-Fernández and Meléndez, 1991; Alonso-Zarza *et al.*, 1992). Thus the weakness of pedogenesis documented in tabular limestones suggests open lake conditions with only occasional subaerial exposures during short-lived low-lake periods. Very extensive subaerial exposures at top of beds suggest low-gradient lake margin similar to the ramp-type lake margin as discussed by Platt (1989a), Platt and Wright (1991). Owing to the low-gradients, lake-level fluctuations cause likely exposure of large areas of open lake, even in distal parts.

Almost lacking of palustrine facies and continuous lacustrine facies deciphered in the Enciso group imply the existence of one single lake, variable in time and reached at least 500 km^2. Presence of a permanent fluctuating lake during the Enciso group in the eastern Cameros basin is likely the result of the regional extensive tectonics in a context of continental rifting.

Laterally persistent sheet-like geometry of deposits document absence of lateral transition between carbonate and siliciclastic units. According to the sedimentary column maximum thickness (1500 m) and the duration of the Enciso group (late Barremian to Aptian; Martín-Closas y Alonso-Millán, 1998) we can suspect that carbonate and siliciclastic units (10 to 20 m thick) alternated at a high time resolution (roughly 10 to 50 kyr).

This implies that during some periods, carbonate sedimentation extended over the whole area reflecting reduced clastic supply from the alluvial domain. Variable lacustrine clastic input may reflect fluctuating drainage conditions. It suggests a climatic control (roughtly wet/dry conditions) on the onset of the two types of lacustrine depositional settings.

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