EXAMPLE OF A MIOCENE COARSE-GRAINED MEANDER LOOP IN THE CIUDAD RODRIGO BASIN (SPAIN)

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ABSTRACT

A description is offered of a sedimentary body from the Miocene situated in the Ciudad Rodrigo Basin (Spain). The lithosome is interpreted as a coarse-grained meander loop whose development has been conditioned by the paleorelief of the eastern border of the basin.

Five sedimentary units are established; these are related to the subenvironments of scour-pool, low point-bar, chute channels, accretionary bank and overbank deposition. The facies comprising the meander loop are articulated in a complex sequence whose most salient characteristic is the absence of a well-defined fining upward trend.

The meander loop is composed of two adjointing point-bars exhibiting different sections as the result of a change in the direction of the displacement of the channel.

Key words: Miocene, Ciudad Rodrigo Basin, Point-bars.

RESUMEN

Se describe un cuerpo sedimentario en el Mioceno de la Fosa de Ciudad Rodrigo (España). El litosoma ha sido interpretado como el depósito en un arco de meandro de un sistema fluvial de gravas, cuyo desarrollo ha estado condicionado por el paleorelieve del borde este de la Fosa.

El litosoma se ha dividido en cinco unidades sedimentarias que han sido relacionadas con los subambientes de «scour-pool», «point-bar» bajo, canales de «chute», banco de acreción y «overbank». Las facies que comprenden el arco de meandro se articulan en una secuencia compleja, cuya característica principal es la ausencia de un trazado «fining-upward» bien definido.

El arco de meandro está compuesto por dos «point-bars» adyacentes que muestran diferente sección a causa de un cambio en la dirección de desplazamiento del canal.

Palabras clave: Mioceno, Fosa de Ciudad Rodrigo, Barras de meandro.

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1. INTRODUCTION

The Ciudad Rodrigo Basin is situated in the extreme SW of the Duero Basin (Spain) (Fig. 1) and is related to the sedimentological evolution of the latter. The trend of the basin is SW-NE and its origin is related to the reactivation in the Alpine cycle of late Hercynian fractures in the same direction. The basement over which it is developed is composed of igneous and metamorphic rocks of the Central Iberian Zone of the Hercynian belt (Julivert *et al.,* 1972). Paleoreliefs of Ordovician rocks cross the Basin from SW to NE defining three sectors: the Ciudad Rodrigo sector, the Sancti Spiritus and the Salamanca ones (Corrochano and Carballeira, 1983) (Fig. 1).

The lithostratigraphic sequence of the Tertiary rocks in the Salamanca sector is formed from bottom to top by the Salamanca Sandstone Formation (Paleocene), the Villamayor Sandstone Formation (Eocene-Oligocene ?) and the El Cubito Formation (Miocene) (Fig. 1).

The El Cubito Formation was defined by Gracia Plaza *et al.,* (1981) and has been reported to be of Miocene age on the basis of the presence of remains of mastodons (*Gomphotherium angustidens*) (Mazo and

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Jiménez, 1982). The formation is composed of red beds of conglomerates, sandstones and muds, with a thickness of 20 m. Their compositions show a mixed igneous and metamorphic source area, accounted for by the association of heavy minerals, the arkosic nature of the sediment and the petrography of the conglomerates. The environment of the deposit was a braided fluvial system flowing towards the NE (Alonso Gavilán, 1982; Cordero *et al.,* 1982).

The aim of the present paper is to describe and interpret a SW-NE oriented outcrop situated at the base of the El Cubito Formation. The outcrop is a lithosome organized in five sedimentary units (Fig. 2) that differ in their position, facies, granulometry and genetic significance. Conceptually, the units coincide with the internal architectural elements defined by Allen (1983) and Miall (1985) and the facies described by Ramos and Sopeña (1983). The most significant methodological aspects for their separation and definition are: 1) the range of hierarchy in the contacts (Allen, 1983; Miall, 1985); 2) their geometry, determined as a function of the width/depth ratio (Friend *et al.,* 1979) and 3) the facies, characterized according to the codes proposed by Miall (1977, 1978) and Rust (1978), adapted to the characteristics of these deposits.

2. SEDIMENTARY UNITS AND FACIES

2.1. *Unit I*

This unit constitutes the base of the lithosome; its geometry is tabular and it has an average thickness of 1 m (Fig. 2). Its lower limit is the contact of highest range in the lithosome, corresponding to an irregular surface that is erosive, cut over the mottled muds of a previous fluvial cycle.

Conglomeratic Lag (Ge facies). This is formed by lineations of large pebbles (extra- or intraclasts). It is present and repeated in the vertical section of the outcrop, covering the basal surface, filling the concave surfaces of scours and also carpetting the upper convex surfaces of sandy forms. This facies is similar to that described by Massari (1983) and Forbes (1983), and has the same genetic meaning as the Ss and Se facies defined by Cant and Walker (1976) and Miall (1978), for sandy fluvial systems.

The lithology of the pebbles shows a predominance of metamorphically-originated clasts (quartzite and schists) over sedimentary clasts (lower Tertiary formations) (Fig. 3). Their shape is varied; orientations of the long axes and imbrications of the elongated and flat pebbles, respectively, being frequent.

Contrasting with the directional results (Fig. 4) it is seen that the measures in the scours coincide with the general trend deduced for the channel and that the long axes (a) of the pebbles are arranged transversely to the main direction of flow. The dip of the major planes of clasts (ab) is upstream; these measures are apparently divergent, probably because of the scarce concentration of pebbles on the bed. Such findings are in agreement with those reported by Rust (1972) for large pebbles of the river Donjek.

Trough cross-bedding sandstones (St facies). These are very coarse-grained arkoses with pebbles (Fig. 3) in which the internal structure is poorly defined. Together with the conglomerates of the Ge facies they form repeated fining-upwards trends (FU). Related to this facies, centimeter-thick levels of calcretes (P facies) and bioturbated green muds (Fm facies) are found; these latter fill microtopographies at the top of the Unit and cover the bed forms.

2.2. *Unit II*

This Unit has a tabular geometry with dimensions of 200 m in length and 2.5 m. average thickness (Fig. 2). Its lower limit is an erosive surface and its facies are the most conglomeratic of the lithosome.

Massive conglomerates (Gm facies). These are clast-supported conglomerates, whose main feature is the absence of internal organization and a poor calibration, (Fig. 3). However an organization into isolated sets of trough-cross bedding and a poorly-defined horizontal stratification are sometimes observed. Its thickness varies and is adapted to the lower limit of the Unit, with a mean value of 0.30 m. Always below this facies there are small isolated scours (2 × 0.30 m) filled with conglomerates (Ge facies). The axes (a) of the pebbles are oriented transverse to the main direction of flow and the dip of the plane (ab) of the clasts is downstream (Fig. 4).

Large-scale tabular cross bedding conglomerates (G_p facies). These constitute accretionary units (Fig. 5) in which the fore-sets are of two types: heterolytics and exclusively conglomeratics. The former are composed of couplets of white conglomerates and red sandstones, sometimes laminated. The base of the couplet is tangential with respect to the underlying facies (Gm) and the top has an angular relation with the overlying facies (Gt). The thicknesses of the fore-sets range between 0.20 and 0.40 m and there is a direct relationship between the relative thickness of the sandy foreset member and the whole couplet. Although the most generalized structural feature is the FU trend, with an accumulation of coarse material at the base of the slope of the fore-set, coarsening-upward trends (CU) can also be seen.

The exclusively conglomeratic layers are differentiated from the previous ones in their composition, their reduced thickness and in their angular contact of the base with the underlying facies.

These accretionary units contain in their interiors reactivation surfaces, dipping in the same sense as the laminae, concave upwards, and sometimes draped by finer-grained beds. Only three slightly convex surfaces separating cosets have been identified (Fig. 2).

The angles of dip of the laminae range between 5 and 35° (Fig. 4) the highest values corresponding to the

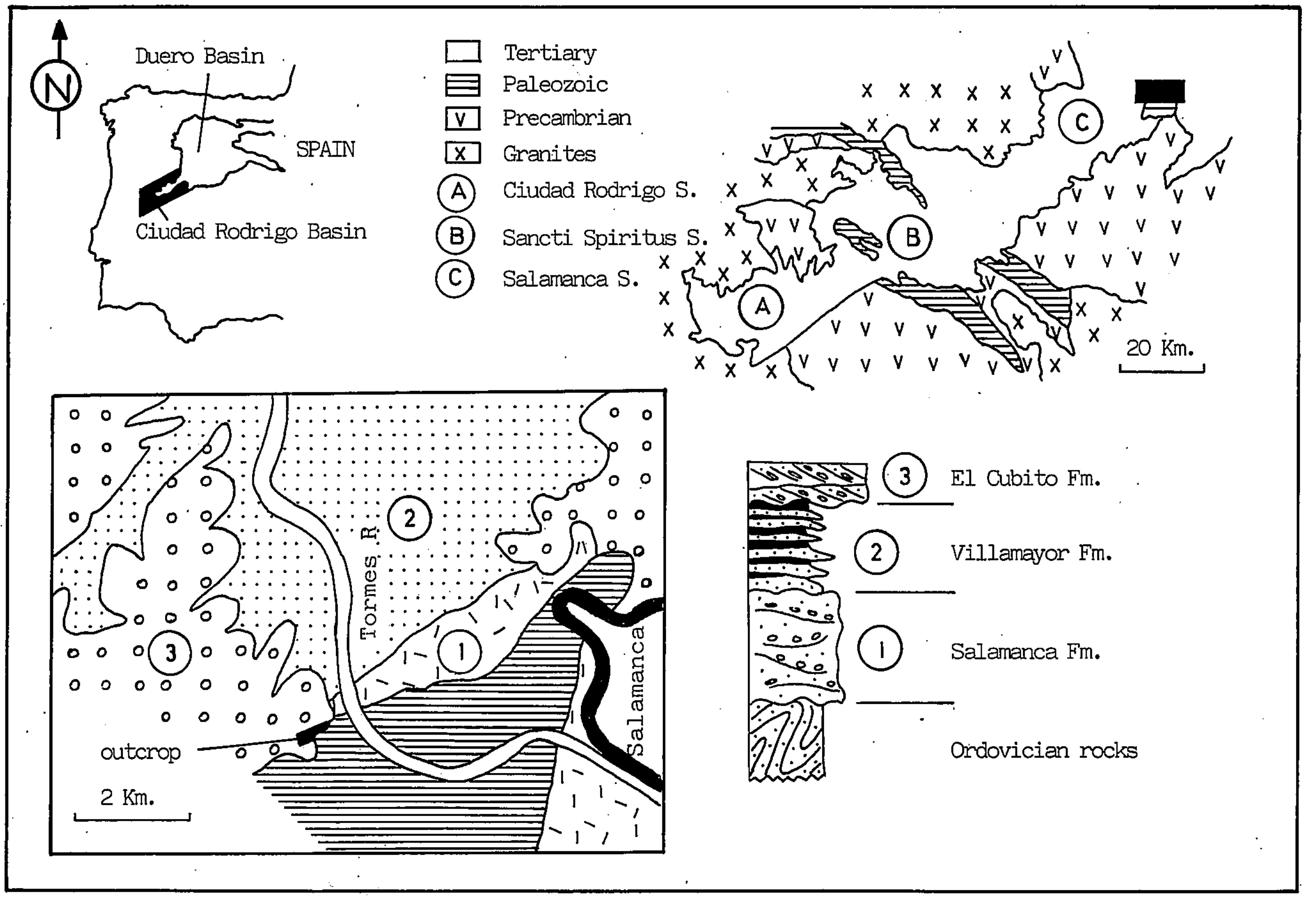

Fig. 1.—Situation of the outcrop and general stratigraphic sequence of the Tertiary in the Salamanca sector (Ciudad Rodrigo Basin).

Fig. 1.—Situación del afloramiento y secuencia estratigráfica general del Terciario en el sector de Salamanca (Cuenca de Ciudad Rodrigo).

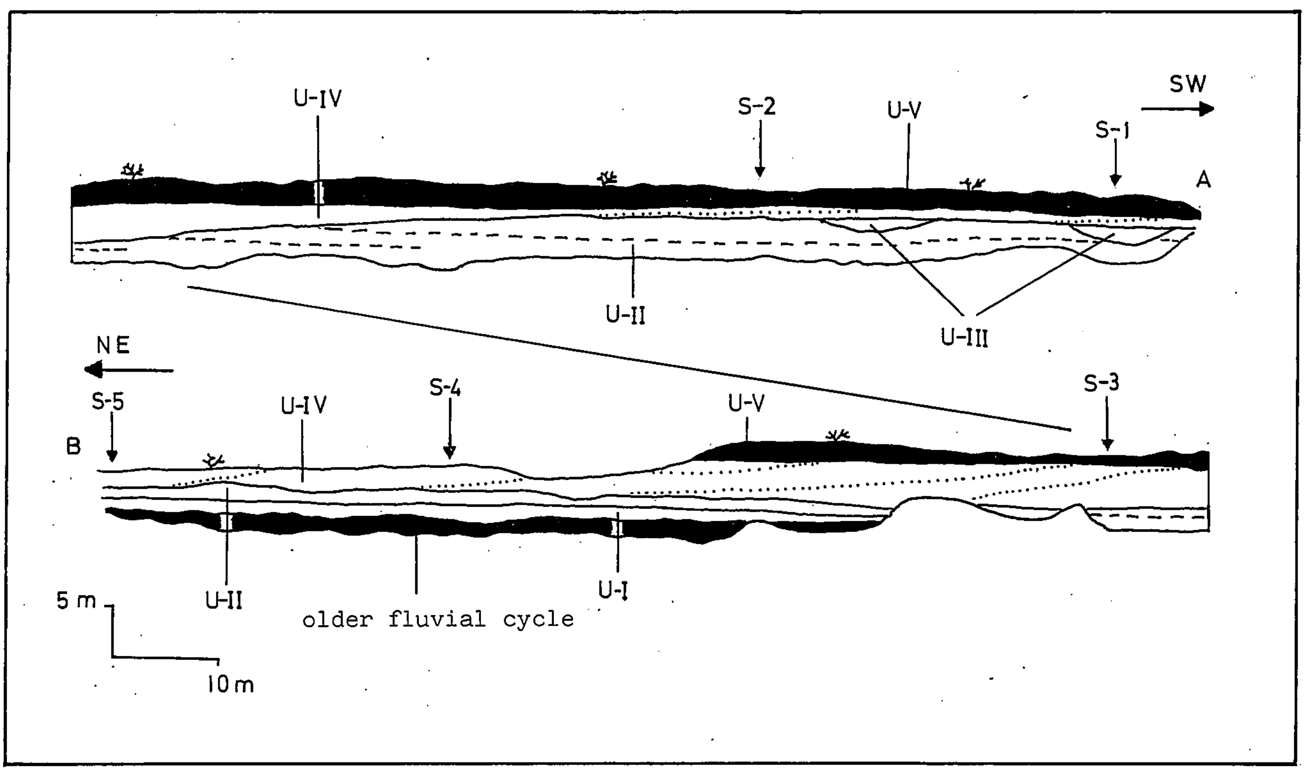

Fig. 2.—Scheme of outcrop showing the geometry of the units and the position of the sections. Compare with Fig. 8. The continuous lines are contacts between units; the discontinuous lines represent contacts between cosets and the dotted lines represent accretion surfaces.

Fig. 2.—Esquema del afloramiento mostrando la geometría de las unidades y la posición de las secciones. Compárese con la Fig. 8. Las lineas continuas son contactos entre unidades; las discontinuas, contactos entre «cosets» y las punteadas representan superficies de acreción.

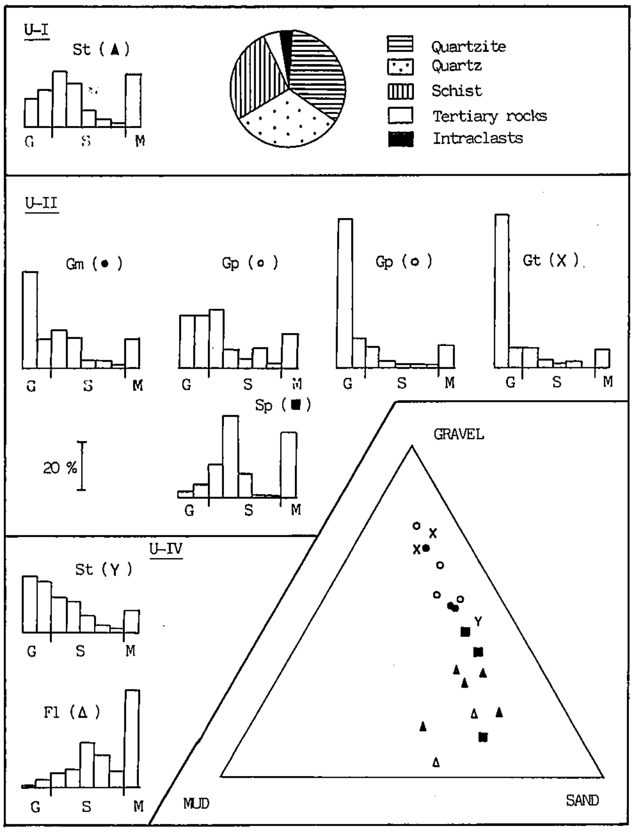

Fig. 3.—Textural characteristics of the facies and petrological nature of the conglomerates.

Fig. 3.—Características texturales de las facies y naturaleza petrológica de los conglomerados.

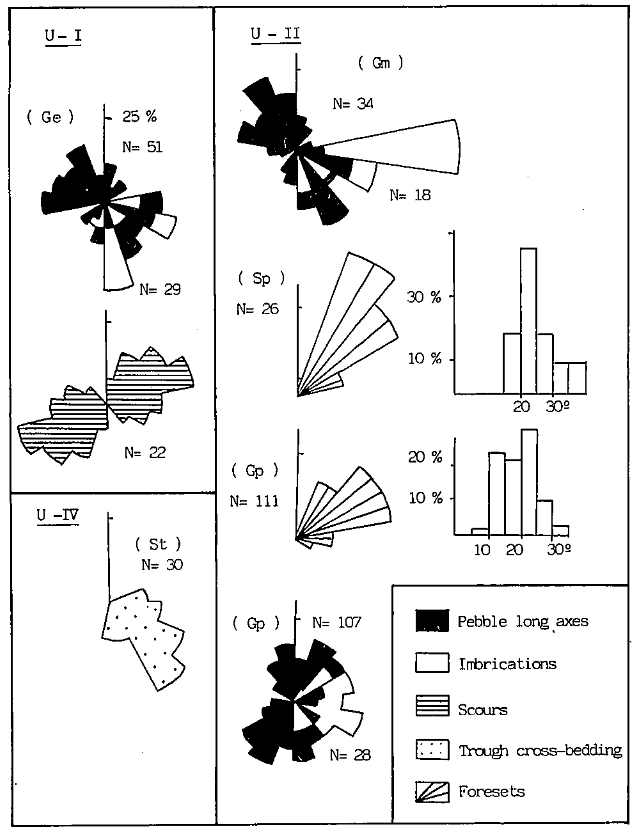

Fig. 4.—Rose diagrams of the paleocurrents and histograms of the dip of the laminae in Gp and Sp facies.

Fig. 4.—Diagramas en rosa de las paleocorrientes e histogramas de los valores de buzamiento de las láminas en las facies Gp y Sp.

exclusively conglomeratic layers. The direction of dip of the laminae, and hence the direction of accretion is NE-vergent. The axes (a) of the clasts in both types of fore-sets are parallel to the slope of the fore-set; this fact was already mentioned by Massari (1983) in Messinian conglomerates. The dip of the plane (ab) of the clasts is down-slope, though it deviates by approximately 40°.

Trough-fill cross-bedded conglomerates (Gt facies). These are conglomerates that fill isolated or laterally-associated troughs, giving rise to extensions of 3-4 m and a thickness reduced to a single set with a mean value of 0.25 m. This facies is always situated above the Gp facies.

Conglomeratic lag (Ge facies). This has characteristics similar to those described for Unit I though with smaller pebbles. It fills scours and carpets the Gp and Gt facies in the form of a pavement.

Small and medium-scale tabular cross-bedding sandstone (S_p facies). These constitute the fore-sets with considerable lateral extension, superimposed and with internal reactivation surfaces. A common feature is that the fore-sets are separated by a relatively thin interval of sandstones with horizontal lamination (Sh facies). The dip of the fore-sets, like the Gp facies, is NE-vergent. Their dips lie between 15 and 35°, most of them between 20-25° and they are thus greater than the layers of the Gp facies (Fig. 4). The sets exhibits an FU trend manifested by the upwards decrease in grain size and the thickness of the fore-set from 0.40 to 0.10 m.

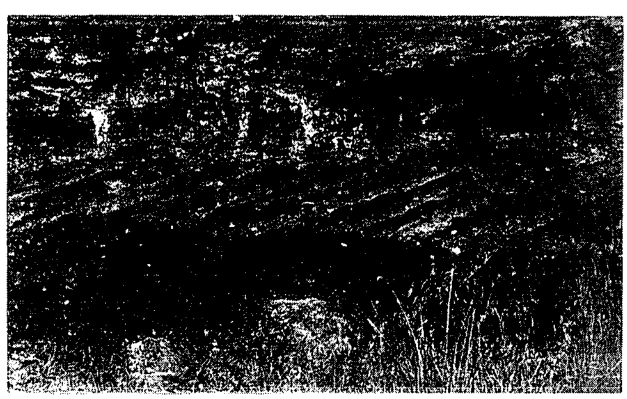

Fig. 5.—Large scale tabular cross-bedding (Gp facies).

Fig. 5.—Estratificación cruzada tabular a gran escala (facies Gp).

2.3. *Unit III*

This is formed of two channelled bodies with a strongly erosive base and similar dimensions; the bodies are inserted in different topograhical levels of Unit II, (Fig. 2). Their arrangement is almost transversal to the orientation of the outcrop and the facies comprising their filling —Gm, Gp, St and Fm— (Fig. 6) have similar features to those described above.

2.4. *Unit IV*

This has wedge-shaped geometry whose dimensions are 200 m in length and 4 m of maximum thickness (Fig. 2). It is separated from the underlying unit by a non-erosive well-defined surface.

Trough-fill cross-bedding sandstone (St facies). These are very coarse-grained sandstones with pebbles (Fig. 3). The size of the sets, at whose base the coarsest material is concentrated, ranges between 3.60 m and 1 m in width and 0.90-0.30 m in depth.

The direction of the paleocurrent has a SW direction showing a strong obliquity with respect to the measures observed in the facies of the previous units (Fig. 4).

Sandstones and silts (Fl facies). These are medium to fine-grained sandstones (Fig. 4) whose most important characteristics are: 1) internal structure in wavy lamination; 2) internal positive gradation; 3) moderate bioturbation and 4) superimposed pedogenetic processes.

They adopt the form of sheets whose direction and dip vary between N80°E/8°N and N40°E/8°NW (figs. 2 and 7) forming large accretionary surfaces. This facies is always gradational with the previous one, showing well-defined FU trends.

2.5. *Unit V*

The top of the lithosome is a blanket of 1-2 m in thickness that is transitional with Univ IV (Fig. 2). It is formed of muds similar to the Fl facies described above but is finer-grained, contains roots, is red in colour and is affected by an intense pedogenesis.

3. INTERPRETATION

The lithosome described is interpreted as a coarse-grained meander loop with a tabular geometry, a minimum lateral extension (W) of 200 m, a mean thickness (h) of 5 m and a W/h relationship of 40; these sedimentary features coincide with those reported by Ori (1983) for the point-bars of the Reno alluvial fan. The meander loop is composed of two adjoined point-bars; the sedimentary units defined represent different subenvironments within the meander loop.

Unit I is related to the scour-pool subenvironment in a channel with strongly fluctuating discharges that was subjeted to strong variations which affected the whole bed. The following facts support such an interpretation: 1) Its situation in the sequence, at the bottom of the sequence representating the base of the channel filling. 2) It is formed of cores of superimposed bars (whose morphology has been preserved). Some sedimentary features of this Unit can be compared with the riffle-tail facies of the River Endrick (Bluck, 1971), which would constitute the facies of the scour-pool filling. The bifurcation of the pool current originated by the riffles might also account for the above-mentioned divergence in the Ge

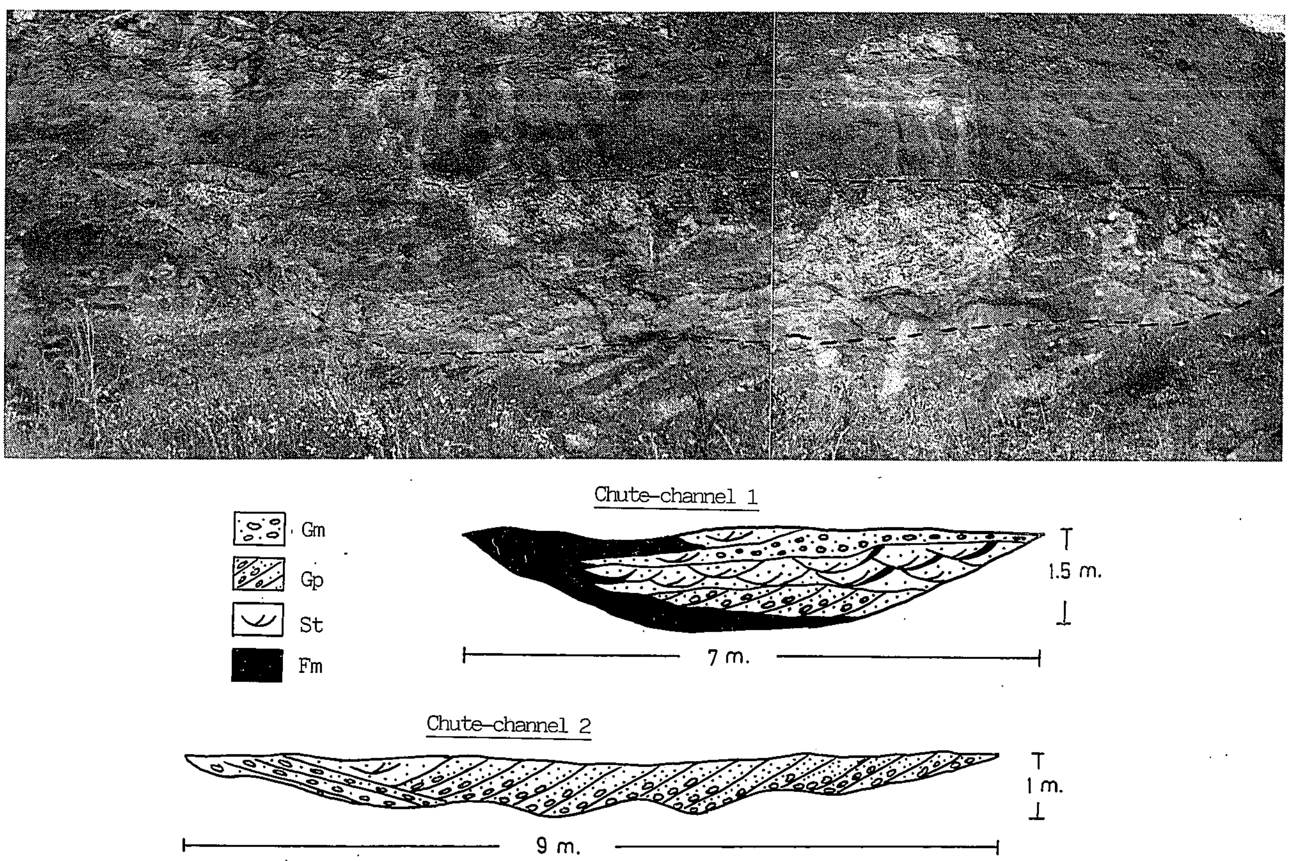

Fig. 6.—Field-sketch of the chute channels filling and photograph of nº 1. Note the different depositional episodes.

Fig. 6.—Esquema de campo del relleno de los canales de «chute» y fotografía del canal nº 1. Nótese los diferentes episodios deposicionales.

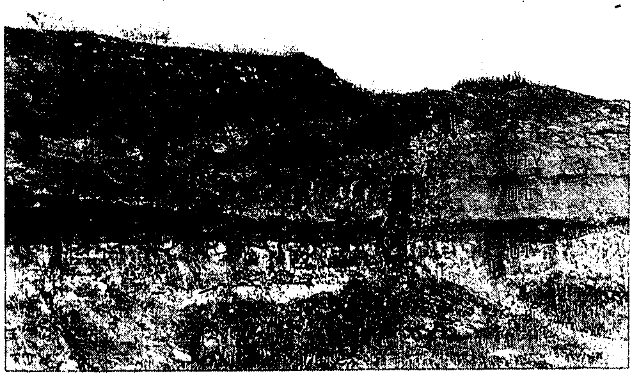

Fig. 7.—Accretion surfaces dipping towards the channel near S-4 (sequence C of Fig. 8). The scale hammer, shown with arrow, rests on the base of the lithosome.

Fig. 7.—Superficies de acreción buzando hacia el canal cerca de la S-4 (secuencia C de la Fig. 8). El martillo de escala, señalado con una flecha, marca la base del litosoma.

Ge facies between the imbrications of the pebbles with respect to the main direction of flow. They have also been attributed to environments of scour-pool facies, very similar to the present ones, that were described by Nijman and Puigdefabregas (1978) in a coarse-grained point-bar from Eocene in the South Pyrenean basin.

Unit II exhibits two associations of facies: 1) an association of gravels (Ge, Gm, Gp, Gt and Ge) and 2) an association of sandstones (Sh and Sp). The first corresponds to mesoforms, in the sense of Jackson (1975), migrating downstream and superimposing themselves and the second to microforms that were installed over the top of the mesoforms.

In all the forms, the bottom-set is composed of the Gm and Sh facies. The former was originated by a mixture of coarse-grained sediments arising from the slip face and finer sediments accumulated from the suspension. Both types of sediments were removed by the pool current, as may be deduced from the existence of scours at the base of the Unit and the clast orientation of the Gm facies.

The growth of the forms, marked by the Gp and Sp facies, was produced by the progradation of the slip-faces dowstream, towards the NE, influenced by the current of the bar-head (Bluck, 1971) in high flow regime conditions. The resulting type of internal structure has been generally attributed to transverse bars (Smith, 1970; Miall, 1977).

The formation of heterolytic layers, in the case of the Gp facies, requires that the sediment should have been previously selected by migration of bed forms over the top of the bars (Jopling, 1965; Smith, 1972). The exclusively conglomeratic layers indicate more vigorous flows, capable of transporting sheets of gravels over the top of the bars to the slip-face and to put into suspension the finer sizes, which would have been deposited downstream.

The origin of the inclined reactivation surfaces may have been due to changes in flow regime during the growth of the forms (McCabe and Jones, 1977) or to the interaction between them at steady-state (Allen, 1973). Haszeldine (1983) has also reported that the limiting surfaces between upward concave fore-sets, covered with fore-sets with a tangential base and the same dip as the underlying fore-set may have been originated during steady-state flows by changes in the forms of the crests. The horizontal surfaces and the slightly convex surfaces identified have resulted from the superimposition of avalanching fronts downstream.

The top-set of the mesoforms comprises the Gt and Ge facies. The first of these must have been intimately related to the flow conditions that enabled the migration of smaller forms over the top of the mesoform. The reason why it is not always present is perhaps due to its poor preservation potential, since the facies would have been removed easily by erosion. The Ge facies is a conglomerate pavement that carpets the upper surface of the mesoform.

The internal structure of the mesoforms has a CU textural trend, as may be deduced from Fig. 3. This trend has already been described by Crowley (1983, Fig. 10) for the three kinds of macroforms of the Platte River Basin; this author explained the phenomenon on the basis of changes in the velocity and depth of the water, associated with the variation in the topography of the macroforms. However, the trend of the top of Unit II is FU owing to a decrease not only in grain-size but also in the dimensions of the forms migrating over the top of the mesoforms.

According to its position, Unit II corresponds to the lower point-bar; the most important process would have been slip-face accretion of transverse bars in high flow regime conditions. Its situation inside the point-bar would be similar to those reported for the river Wabash which were developed next to the mean level of low waters (Jackson, 1976, Fig. 15). Moreover, Gustavson (1978) in the river Nueces and Levey (1978) in the Upper Congaree river have described transverse bars characterizing the lower part of the accretion face of the point-bars.

The bodies of the Unit III are chute channels which characterize the upper point-bar. These chute fills have been identified in three depositional events separated by mud drapes (Fig. 6). The first corresponds to the construction of channel 1 and its later filling by muds. The second reflects an increasing flow conditions and is marked by the installation and growth of transverse and/or linguoid bars, whose paleodirection was N36°E. Among the sets comprising the internal structure of the bar are numerous mud drapes, which points to important decreases in flow during this stage. The third episode, common to both channels (1 and 2) has characteristics similar to those of the former. McGowen and Garner (1970, p. 85-86) have described a chute-fill in the point-bar of the river Amite with similar depositional episodes to those described here. Also, Bryant (1983, Fig. 5) has reported a channel fill in braided beds from the Pleistocene similar to channel 2 described in this paper.

Unit IV is related to another point-bar. The surface that separates it from the previous point-bar, has been interpreted as a meander bend reactivation surface that

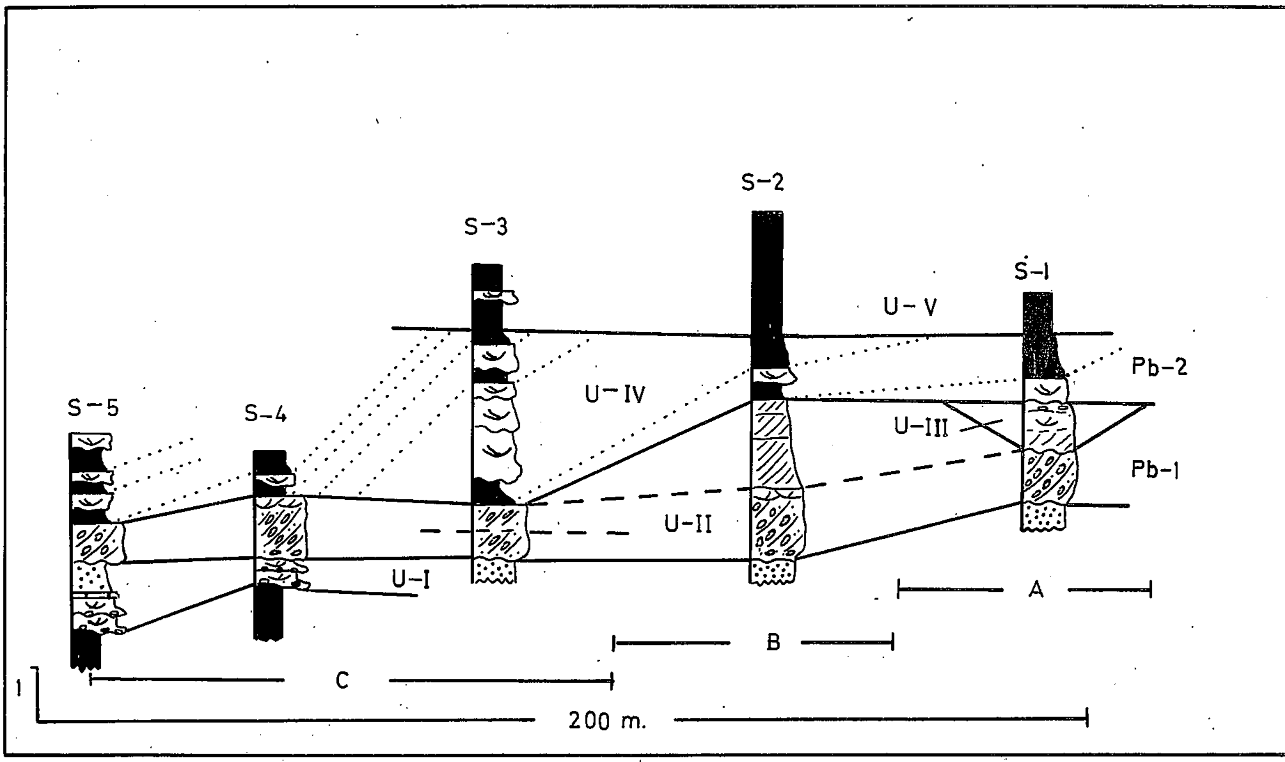

Fig. 8.—Relationship between point-bars 1 and 2 and different vertical sequences (A, B and C) in the meander loop. Same legend as for Fig. 2.
Fig. 8.—Relación entre los «point-bar» 1 y 2, y secuencias verticales diferentes (A, B y C) dentro del arco de meandro. Igual leyenda que la Fig. 2.

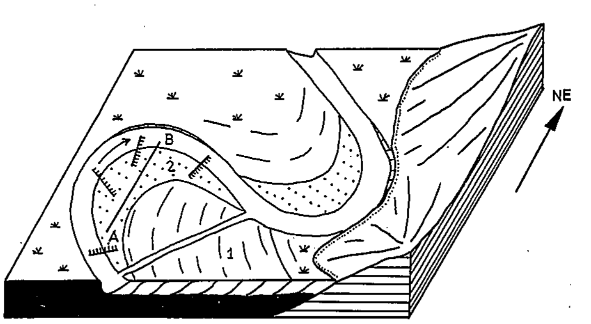

Fig. 9.—Paleogeographic model showing evolution and relationship between point-bars with the paleorelief. The line A-B represents the outcrop.

Fig. 9.—Modelo paleogeográfico que muestra la evolución de los «point-bar» y su relación con el paleorelieve. La línea A-B representa el afloramiento.

coincides with a previous depositional topography (Díaz Molina and Bustillo, 1985). The St facies would have been originated by the migration of dunes, in high-flow regimes, over the convex bank. Its paleo-direction strongly oblique to the trend of the channel is probably due to the helicoidal motion within the body of water of the pool current in bank-full conditions.

The Fl facies corresponds to the accretionary bank. Occasionally it is seen to define banks with a very weak dipchannel, with the materializing of vertical sedimentation over the accretionary surfaces. The paleosoils reflect the long periods of interruption of the accretionary processes in this point-bar. Bluck (1971) and Nijman and Puigdefabregas (1978) have described similar deposits in the internal accretionary bank. Finally, this point-bar is covered by the overbank deposits (Unit V) characterized by intense pedogenesis and a red colour.

The relationship between the units exhibits three types of sequence: A, B and C which follow each other spatially from the extreme SW to the NE of the outcrop (Fig. 8). The most complete sequence is A in the sense that in all the units, and hence all the subenvironments, follow each other vertically. Unit III (chute channels) is lacking in the rest of sequences, which are differentiated by the predominance of Unit II (point-bar 1) —sequences B— of the predominance of Unit IV (point-bar 2) —sequences C—.

In spite of what has been put forwards above, it is possible to generalize and simplify a single sequential trend for the whole of the meander loop: 1) trough-filled cross-bedding; 2) large-scale tabular cross-bedding; 3) medium-scale trough-filled cross-bedding and 4) finer accretionary bank facies and overbank deposits. This complex sequence is similar to others described in the literature for coarse-grained point-bars. However, it should be noted that the most important is the existence of two adjoined point-bar bodies, that exhibit a cross-section close to the longitudinal section of the ancient point-bar and almost transverse to the modern point-bar respectively (Fig. 9). Such rotation was possible owing to a sharp change in the direction of displacement of the channel.

In the paleogeographic context of the fluvial system of the El Cubito Formation, with a longitudinal trend to the basin and flowing SW-NE, the build up of the meander loop described here was probably originated by structural control of the trend of the channel of the

Ordovician rocks forming the E border of the basin at this point.

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