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THE SEDIMENTARY FACIES AND SETTING OF EOCENE POINT BAR DEPOSITS, MONLLOBAT FORMATION, SOUTHERN PYRENEES, SPAIN[1]

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ABSTRACT

S. Van der Meulen 1982 The sedimentary facies and setting of Eocene point bar deposits, Monllobat Formation, Southern Pyrenees, Spain – Geol. Mijnbouw 61: 217-227.

Point bar deposits from a small, Eocene, molasse-type basin have been studied in detail in order to establish a spatial point bar model, which can be used to locate a vertical section in a threedimensional sence. A model is designed which shows the sedimentation processes in the palaeochannel and the evolution of point bars. However, some of the deposit characteristics can only be explained in terms of the wider, environmental setting.

The development of facies and of larger sedimentary features can be recognised in the surface of a meander lobe, associated palaeochannel and fine fill, and in the vertical section of a comparable meander lobe. Most deposits comprise a lower, medium- to coarse-grained sandstone facies with trough-shaped crossbedding (0.15 m thick) and an upper facies with an inclined interbedding of sandstone and mudstone. Epsilon Cross Stratification has been developed extensively. Strong mottling has destroyed most of the sedimentary structures in the upper lithofacies interval.

The exposed palaeochannel varies considerably in width and depth. Palaeochannel sediments are well graded in a vertical sense; laterally, however, there is only a minor gradation. During high discharge the lower lithofacies developed on a low platform at the point bar base. The upper facies originated on a steep upper point bar slope. Mud drapes were deposited during falling discharge. During periods of low discharge the upper part of the deposits was exposed to the air and strongly mottled and oxidized.

Point bar deposits are arranged in meander lobes. A uniform dip direction often appears in transverse sections. Lateral grain-size variation in these sections can be large. In this respect the relatively coarse, initial part is important. Mud fills are found in the last stage channel. A fine member is present, but not all fine material was deposited by meandering rivers. The meander lobes developed in the distal parts of a small, highly energetic, alluvial system with marked fluctuations in discharge. In the sedimentary basin there was strong tectonic control on the sedimentation.

INTRODUCTION

Detailed descriptions are given of point bar deposits, whose general characteristics have been shown to resemble the features of ancient point bar deposits (scoured base, upward decrease in grain-size and energy of stratification types in combination with arcuate point bar geometry). PUIGDEFABREGAS & VAN VLIET (1978) pointed out this resemblance in a general article on point bar deposits in the S Pyrenees.

This paper describes and reconstructs a meander lobe and the morphology of the surrounding palaeochannel in three dimensions. In this channel a small part of the original, fine fill is present. In addition the vertical section of another meander lobe reveals sedimentary structures and grain-size distributions.

The terminology of NANSON (1980) for the subenvironments of the meandering river is used. The *point bar* is the sediment body against the convex bank of a river bend. The *meander lobe* is the total alluvial land-form within a meander loop and is used in a three-dimensional sense. The *flood plain* is the area adjacent to the river channel, which is subject to periodic flooding. Point bar and flood plain deposits constitute in the main the coarse and the fine member respectively of the meandering river environment. During the lateral migration of a meander the succession of point bar layers constitutes Epsilon Cross Stratification – E C S (ALLEN, 1963).

The purpose of this paper is to establish a three-dimensional meander lobe model which can be used to locate exposed point bar deposits. The interpretation of the origin of individual point bar layers and the arrangment of these layers are important elements of the model.

On the basis of a general sedimentological description a reconstruction has been made of the factors that determine the environment on a large scale. Finally the relationships between point bar sedimentation and general environmental conditions are investigated.

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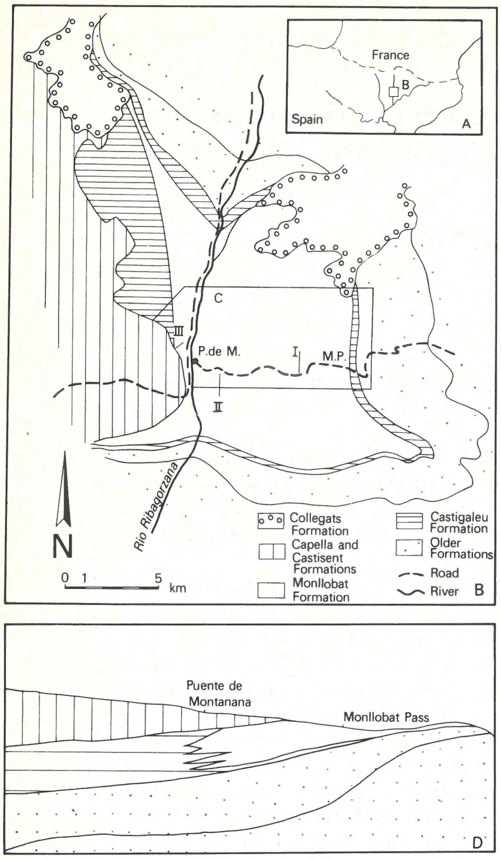

Fig. 1.
Location map.
A Situation of the study area in the S Pyrenees.
B The geological map with the locations of the sections and the outline of the study area (C).
D The vertical relation of the formations.

GEOLOGY AND TOPOGRAPHY

The Monllobat Formation belongs to the lower part of the Eocene Montañana Group, which partly constitutes the fill of the Tremp-Graus basin of the Southern Pyrenees (NIJMAN & NIO, 1975). In this elongated basin – during the Eocene – continental depositional environments passed into marine environments in a W to NW direction. In this sense the Monllobat Formation passes laterally into the marine Castigaleu Formation (Fig. 1). The latter is also present with varying thickness at the base of the Monllobat Formation. The formations are concordantly overlain by the Castisent and Capella Formations. The Oligocene Collegats Formation discordantly overlies the Montañana Group.

Previous work on the Montañana Group was carried out by VAN EDEN (1970), NIJMAN & NIO (1975) and NIJMAN (1981). Fluvial deposits were studied by NIJMAN & PUIGDEFABREGAS (1978) and PUIGDEFABREGAS & VAN VLIET (1978).

The 170 m thick, Monllobat Formation is defined by the occurrence of multicoloured siltstone and mudstone with intercalated sandstone and conglomerate bodies (NIJMAN & NIO, 1975). The multicolouring and the frequently appearing carbonate nodules (caliche) are considered to be the products of palaeopedogenesis. The coarse material has been deposited in meandering and braided rivers (NIJMAN & NIO, 1975).

The Monllobat Formation is mainly exposed in the regions around Puente de Montañana. The results presented here are based on a study of the area outlined in Fig. 1. The outcrop conditions are good, there is a low tectonic dip and only a minor tectonic disturbance. Stratigraphic levels can be traced over distances of several kilometres. The study area is incised by several mountain streams. Individual vertical sections along valley walls attain lengths of 60-150 m.

GENERAL SEDIMENTOLOGICAL DESCRIPTION

The point bar deposits that were studied in detail are outlined in Fig. 2. From sections I, via II to III, i.e. from E to W, (locations in Fig. 1) the conglomerate content decreases, whereas point bar deposits and intercalations of the Castigaleu Formation become increasingly important. Section I is located in an E-W valley just N of the road from the Monllobat Pass to Puente de Montañana (Fig. 1). In the

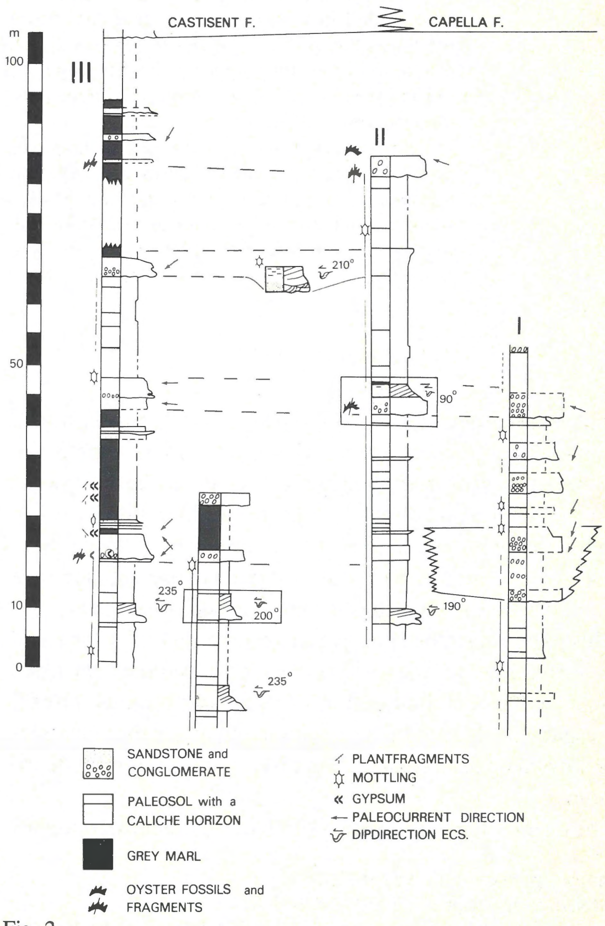

Fig. 2.
Sections through the Monllobat Formation (location in Fig. 1).

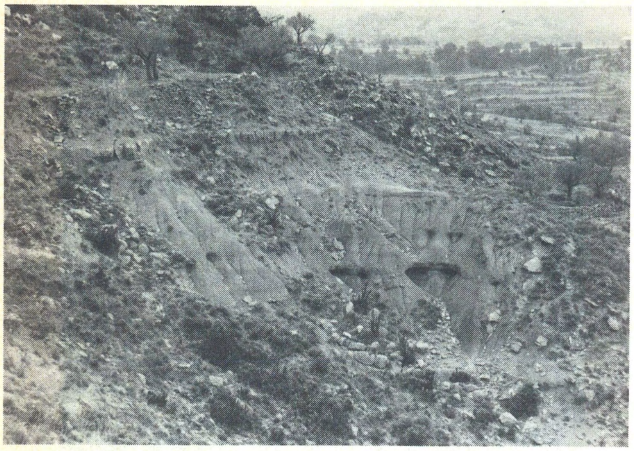

Fig. 3.
Upper part of the general section II above the meander lobe exposure. Nodular carbonate horizons stand out in the flat bedded sediment.

vicinity of this section coarse lithosomes, several kilometres wide and up to 10 m thick, are embedded in a matrix of fines. The cores of these bodies consist of massive or flatbedded conglomerates. In the margins (conglomeratic) sandstone is the major constituent. Several lithosomes of this type can be juxtaposed (Fig. 2). In S and W directions transitions towards flatbedded, fine sediment with occasional conglomerate lenses and towards layers with E C S can be observed.

In section II the extensive, coarse layers with oysters are assigned to the Castigaleu Formation. Coarse, fluviomarine deposits and grey marls constitute a major part of section III. In the area examined, deposits of the Castigaleu Formation show hardly evidence of reworking by tidal or wave action.

Apart from coarser deposits the Monllobat Formation contains 70-80% fine material (Fig. 3). The flat beds are extensive with a uniform thickness (dm-m). In the basically brown to ochre coloured beds vertical mottles are blue and occasionally blue-red or red. Within the beds the colour does not vary. Caliche appears as concretions or as a cement in fine sediment that has no clay fraction. The caliche is mainly confined to horizons that can be traced over large areas.

Palaeocurrent directions

Conglomerate layers in general show SW palaeocurrent directions, perpendicular to the basin axis. In most conglomeratic and (very) coarse-grained sandstones directions range from SW to NW, while deposits with ECS have palaeocurrent directions to the NW, following the plunge of the basin axis. This palaeocurrent distribution agrees with the general pattern in the basin (NIJMAN & NIO, 1975).

Petrography

Conglomeratic components consist of dark-blue or grey, micritic limestone and a minor amount of white vein quartz. There are some granitic pebbles. Sandstones often contain more than 90% detritic limestone grains with low percentages of quartz, chert and alkalic feldspar grains.

DESCRIPTION OF TWO LARGE EXPOSURES OF POINT BAR DEPOSITS

Vertical section of a meander lobe

Location: The exposure is situated in a valley wall above the Puente de Montañana-Aren road at the bifurcation towards Montañana (Figs 1 and 2, section III). Section III is situated in a shallow syncline with a high S/Sh ratio.

Setting: In the valley there is a 600 m wide section perpendicular to the accretion planes. Fig. 4 shows the excellent exposure of the E part of the section. At the base there is a mottled, flat-bedded layer with some small conglomerate lenses. The major part of the exposure is covered by multicoloured mudstone, but at the NE margin grey coloured channel fills and a conglomeratic layer are present.

Description: The initial part at the NE margin is relatively thick and coarse. The layers consist of (very) coarse sandstone with conglomerates and slumped mottled material. The succeeding, finer layers make up the major part of the exposure. With the fining the dip of the point bar layers increases. The dip direction is generally to the SW. At the SW margin there is a fine channel fill. A cut bank is also exposed (see PUIGDEFABREGAS & VAN VLIET, 1978, figure 8).

The point bar profile underneath the fine fill is not simply sigmoidal. A main channel is associated with a small channel cut in the top of the point bar sequence. The exposure at the SW margin is considered to contain one single point bar sequence instead of two separate layers as described by PUIGDEFABREGAS & VAN VLIET, 1978 (figure 5A). The base consists of large SW dipping foresets. Flat tabular sets in

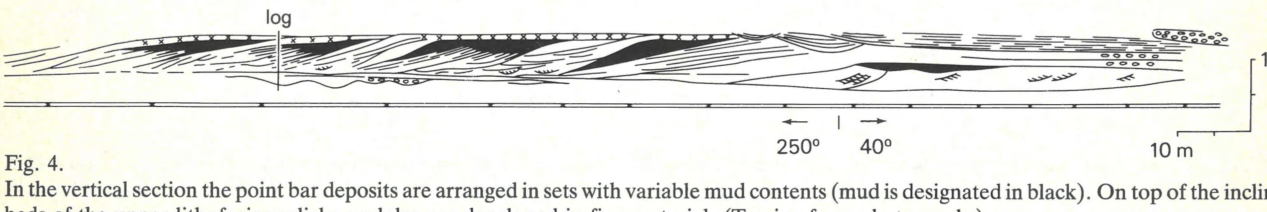

Fig. 4.
In the vertical section the point bar deposits are arranged in sets with variable mud contents (mud is designated in black). On top of the inclined beds of the upper lithofacies caliche nodules are developed in fine material. (Tracing from photographs).

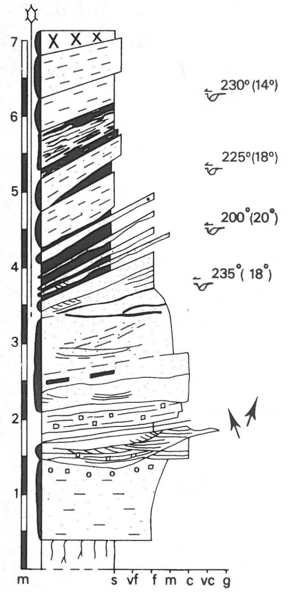

Fig. 5.
The log of the vertical section (location in Fig. 4).

Fig. 6.
Arcuate features in the top of a sandstone layer.

medium sandstone make up the middle part, while the top interval consists of a mottled interbedding of inclined mudstone and sandstone beds. Some layers with tabular sets are intercalated within the SW dipping beds at the top.

As shown in Fig. 4, point bar layers are arranged in sets (or bundles, PUIGDEFABREGAS & VAN VLIET, 1978) with varying mud content. Most boundary planes truncate preceding sets. Several sets show an extension of layers over the flat top.

The sedimentary facies found in the major part of the section is represented in the log (Fig. 5). A lower lithofacies is made up of coarse- and medium-grained sandstone with large-scale (up to 0.15 m thick) trough-shaped crossbedding in moderately inclined beds (dip up to 15°) In the lower lithofacies interval there is a blue-coloured horizon. On the NE margin this horizon has an extension towards the top of the relatively coarse-grained deposits. The upper lithofacies consists of steeply inclined (dip 11-26°) sandstone beds fining upwards to siltstone. Mud interbeds lie concordantly on top of these beds, which have a basal, erosional surface. The interval is strongly mottled.

Palaeocurrents from the lower interval are oriented slightly obliquely to the strike of the inclined beds or are directed up against the accretion planes.

Surface of a meander lobe

Location: The exposure is situated (Figs 1 and 2, section II) in a valley on the S side of the Puente de Montañana – Tremp road (km pole 3).

Setting: Arcuate structures stand out on the 150 × 150 m^2 surface of a 1.5 to 2.5 m thick layer (Figs 6 and 8). The surrounding palaeochannel defines the extension of the layer: a meander lobe. The lobe is an isolated body at the top of two coarse layers, the lower being continuous and the upper one pinching out in a SW direction (Fig. 7). The lower layer shows

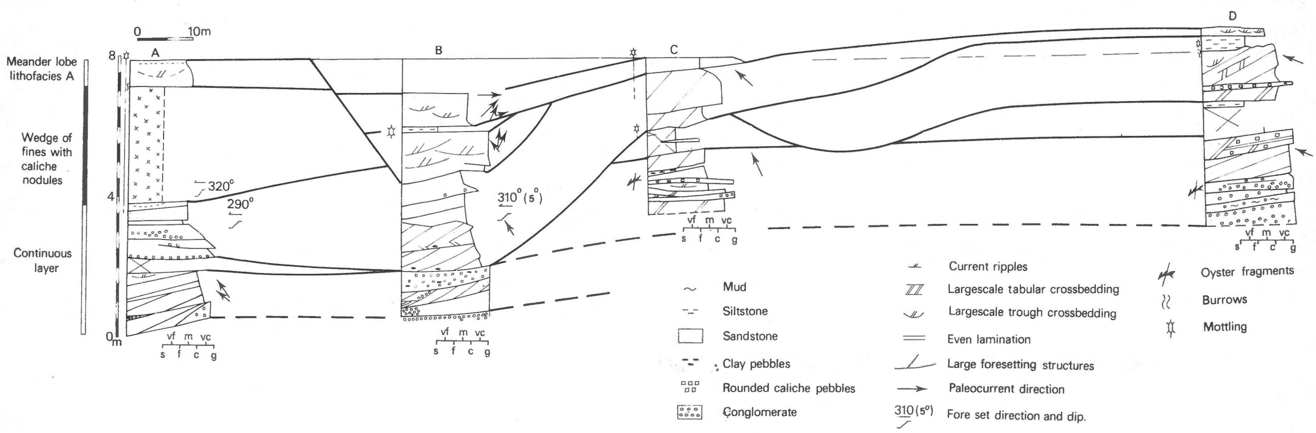

Fig. 7.
Logs located at the southern margin of the surface exposure of a meander lobe (Fig. 8). The major part of the logs is formed by sections of a continuous and of a wedging layer. At the top of logs A and B the lower point bar facies is exposed. At the base of this unit there is in log A a wedge of fine, mottled material with caliche concretions whereas in log B there is a lenticular channel fill with large trough-shaped sets.

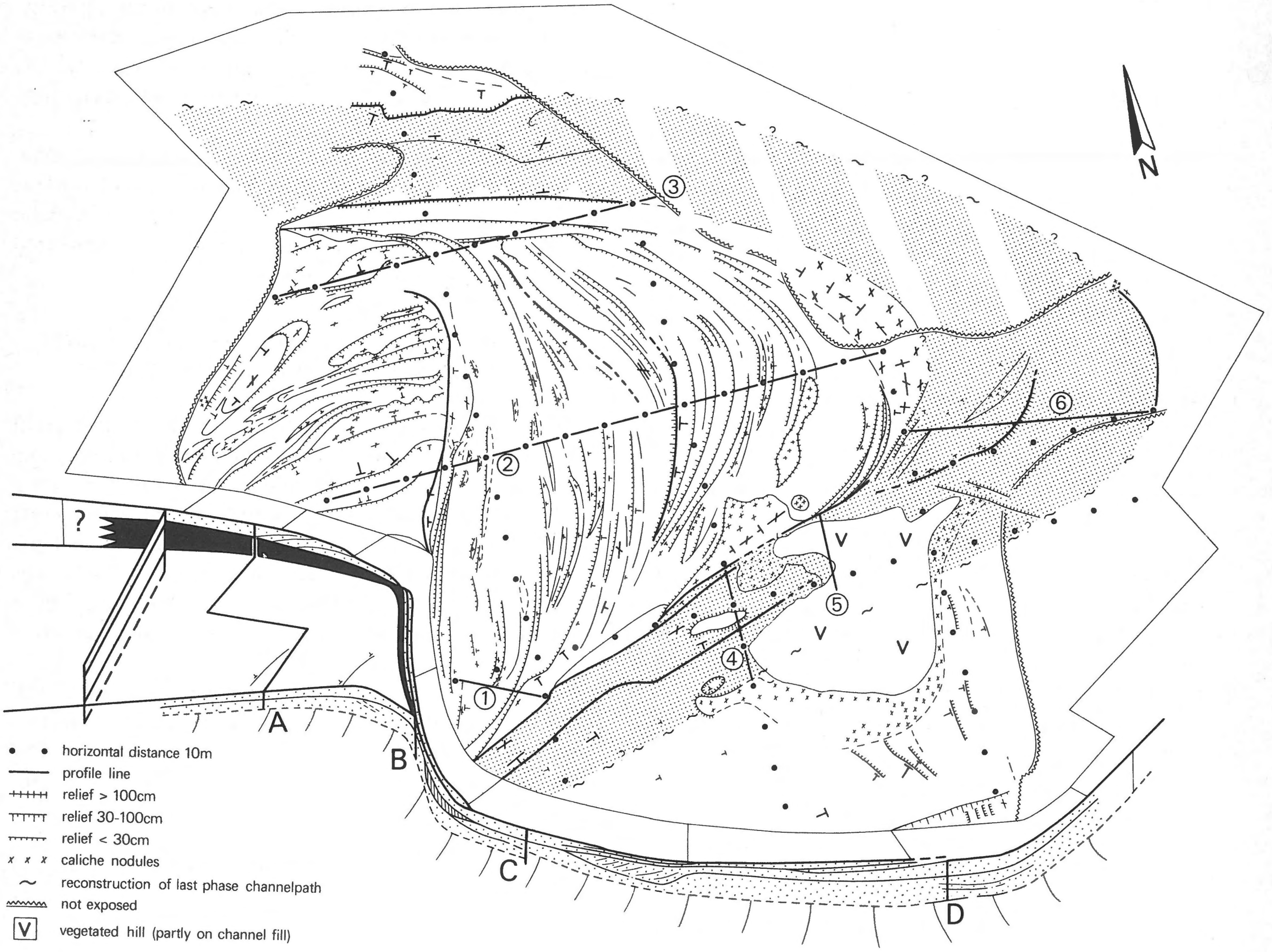

Fig. 8.
The geometry of the meander lobe and associated palaeochannel (section III) and the location of profile lines. (S part of the exposure).

large foreset structures. Some oyster fossils are present. The layers are embedded in a thick mudstone interval (Fig. 2, section II). Most of the fine sediment cover of the lobe has been removed by recent erosion. This interval of mottled mud is topped by a 0.5 m thick sandstone layer with oyster fossils.

Just to the W of the platform there is a vertical SE-NW fault. The SW layers have been displaced a few metres. Close to the fault several layers show thickening.

Description of the meander lobe (Fig. 8): On the basis of the dip directions of the accretion planes the lobe can be divided into two parts. A W unit with dip directions to the N and an E unit with dip directions to the E.

The completely mottled W unit consists of a medium-grained sandstone layer on top of which longitudinal ridges occur. The ridges are made up of inclined, medium- to fine-grained sandstone beds. Some beds drape over ridges. Underneath the flat base of the E unit a channel fill occurs with trough-shaped crossbedding (set thickness 0.5 m). The top of the fill consists of mottled mud (log B, fig. 7).

In the E unit two lithofacies units can be recognized, that correspond with the lower and upper lithofacies described earlier from the vertical section. The lower unit (coarse- to medium-grained sandstone with trough crossbedding and low angle accretion planes) thins towards the E. The mottled upper unit (steeply inclined medium- and (very) fine-grained sandstone and siltstone beds) thickens to the E. Mud interbeds only appear on the E margin. The upper lithofacies comprises convex-upward ridges which occupy only a part of the point bar. Palaeocurrent directions in the S margin of the exposure are to the NE along strike and up against lateral accretion planes.

The largely exposed palaeochannel is associated with the E unit. A distinct elevation of the base and the top of the E unit follows from the fact that to the N the base of the palaeochannel cuts the top of the W unit. Within the E unit several minor breaks in the accretion pattern are associated with elevations of the top of the lower and upper lithofacies. Nonmottled deposits of the lower lithofacies are found in

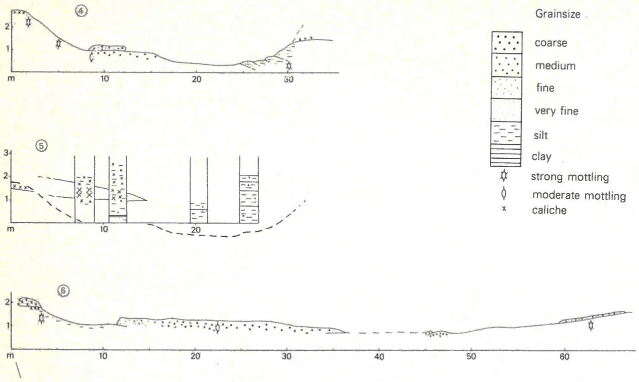

Fig. 9.
Profile lines 4 and 6 (Fig. 8) represent palaeochannel profiles with steep upper point bar slope (s), lower point bar platform (p) and cutbank (c). In profile 5 the caliche layer on top of the point bar wedges into the channel fill. Also at the cutbank caliche nodules are present.

several cases on top of mottled beds belonging to the upper lithofacies.

The width and depth of the palaeochannel vary strongly; 30 × 2 m at the site of profile 4, and 65 × 1 m at profile 6 (see Figs 8 and 9).

Three zones can be distinguished (Fig. 9 in the palaeochannel profiles:

- zone s, a steep slope with a strongly mottled deposit of very fine sandstone grading upwards into siltstone (corresponds with the upper lithofacies interval). The colour is brown with blue traces.
- zone p, a rather flat slope over a much larger distance (profile 6) or a platform with a steep downward slope at the edge (profile 4). Coarse– and medium-grained sandstone contains some oncolites at the top. The colour is blue-grey with faint brown mottles. (The interval corresponds to the lower lithofacies).
- zone c, a concave, erosive surface. The upper part is locally covered with laminated, fine sediment (profile 6). Coarse sediment fills scours in the deeper part of the channel.

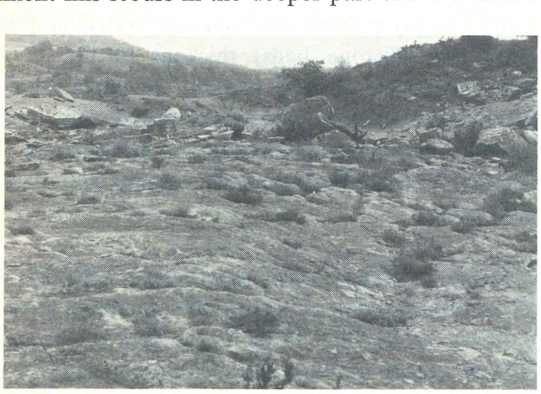

Fig. 10.
The horizontal top and steep edge of the lower point bar platform (E part of the exposure).

Zones p and s are also found in the N part of the exposure. Zone p partly corresponds to the steep-edged platform of profile 4. The surface of the upstream part dips gently. The sediment is mainly coarse with some rounded caliche pebbles.

Nodular caliche is found on either side of the palaeochannel. The caliche layer on top of the point bar extends into the channel fill (profile 5). At the base the fine channel fill contains lenses of coarse sediment. The fill is browncoloured with a strong, (grey-)blue mottling.

RECONSTRUCTION OF THE PALAEOCHANNEL FACIES AND DISCHARGE CONDITIONS

The palaeochannel is reconstructed in Fig. 12. The division of the point bar into two zones with greatly differing dip resembles the point bar morphology as described by BLUCK (1971) and BLUCK & FERGUSON (1981) for the meandering River Endrick. A large variation in channel width and depth (widening at the centre of a bend) is known from the Nueces River as described by GUSTAVSON (1978). In both cases major differences in grain-size distribution and sedimentary structures appear.

The alternation of sandstone, siltstone and mud beds adjacent to the palaeochannel and in the vertical section (Fig. 5) points to the existence of a discontinuous discharge. The following sequence of discharge events can be reconstructed, analogous to LEOPOLD ET AL. (1964):

- the channel profile was cut during a period of rising discharge. Inclined erosion planes were formed on the lower and upper point bar.
- during high discharge trough-shaped crossbedding developed on the lower point bar. At the upstream part of the platform, where the top is flat, high angle foresets accreted at the pool-facing margin. The head area was enriched by (very) coarse sediment and caliche pebbles. Fine sand grading upwards to silt was deposited on a part of the steeply inclined upper point bar.

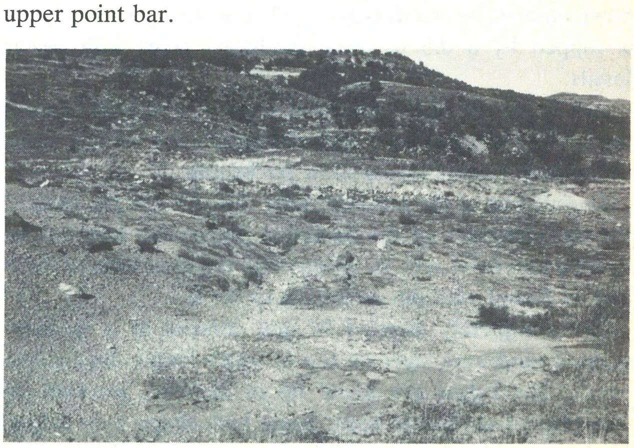

Fig. 11.
The steep upper point bar slope and the flat top of the lower point bar platform (S part of the exposure).

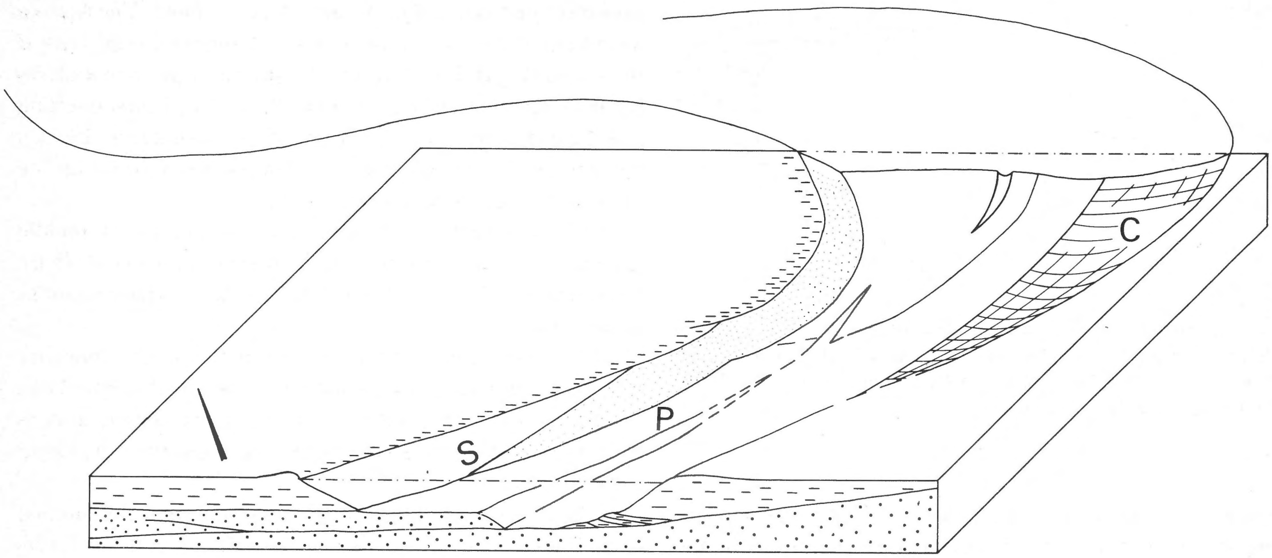

Fig. 12.
An impression of the E part of the palaeochannel without fine-grained fill. In the channel with variable width and depth the steep upper point bar slope (s), the lower point bar platform (p) and the cutbank (c) are indicated.

– during falling discharge mud drapes were deposited. Mud layers were preserved particularly on the upper point bar surface.

Sedimentary structures which correspond to a period in between peak discharge events have not been found. During this stage the upper interval was oxidized. The lower lithofacies interval remained saturated with water that contained amounts of organic matter and thus prevented the establishment of oxidizing conditions (MOODY STUART, 1966). With stagnant ground water, blue colouring could develop in the lower lithofacies interval.

The outer channel bank was predominantly an area of erosion, its outward migration involved the succession of point bar layers at the inner bank (forming ECS). Several types of stratification planes can be distinguished:

– 1 erosion planes (all over the point bar).
– 2 planes established by lithology changes (on the upper point bar).
– 3 boundary planes of sets (all over the point bar).

Type 3 planes are more distinct than planes of type 1 and 2. Type 2 planes are often difficult to trace in the lower lithofacies interval. PUIGDEFABREGAS & VAN VLIET (1978) describe a massive character of this interval in thick lithosomes with ECS. However, type 1 planes are also present in those cases.

Channel widths can be estimated easily from the vertical section since the horizontal projection of the ECS plane equals approximately 2/3rd of the total channel width (ALLEN, 1965). This rule applies well for the palaeochannel profiles 4 and 6, Fig. 9. Widths estimated from the well exposed part of the vertical section (Fig. 4) are at most 60 m. The amount of discharge can be calculated if channel dimensions and meander wave length of the rivers are known (LEEDER, 1973). The widening of the palaeochannel at the point bar centre, however, and the variable width/depth ratio are not accounted for in equations (see LEEDER, 1973). Only W×D is consistent. In addition to the difficulty of obtaining representative mean W and D values another problem is the facies variation in exposures. It is likely that during the formation of meander lobes mean W and D values varied considerably.

DEVELOPMENT OF THE COARSE AND THE FINE MEMBER

The point bar deposits were preserved after a major lateral and a minor vertical channel migration. It is possible to reconstruct the migrating channel at the last stage of activity (Fig. 12). The combination of all the point bar features described leads to a point bar plan (Fig. 13B). An attempt has been made to reconstruct the path of currents, after comparing data with models from recent meandering rivers (BLUCK, 1971; BLUCK & FERGUSON, 1981; JACKSON, 1976).

Currents were deflected at the point bar head. A high angle slope at the upstream part of the platform was maintained by a combination of currents through the pool and over the platform into the pool. Fanning at the mid point bar was followed by a concentration of currents at the tail, with the flow directed up and against a moderately inclined surface. A helicoidal current pattern would probably not completely develop in the shallow channel. With the widening of the channel at the point bar centre important flow separation (analogous to LEEDER & BRIDGES, 1975) could take place at the upper point bar surface. The concentration of stream lines at the cutbank was highest, and thus erosion strongest, somewhat downstream of the centre of the bend.

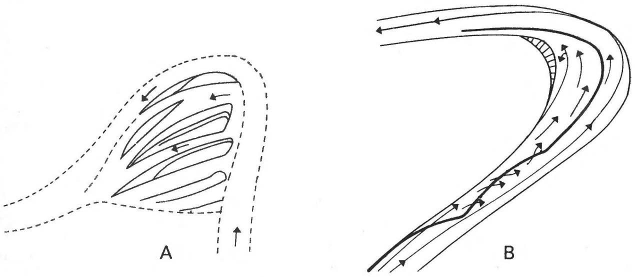

Fig. 13.
A. Reconstruction of the channel plan of the W unit. At high discharge flooding of the lateral bar occurred. B. Channel plan reconstructed on the basis of the palaeochannel described. Some current lines have been drawn in.

Sedimentary structures were formed during periods of rising and high discharge. Foresets were deposited in the accretion direction. Further palaeocurrent directions from the lower point bar interval were mainly along, or more or less up against, the point bar slope. Occasionally sets are rather tabular. Layers of this type may extend into the upper lithofacies interval, but never reach the top of the point bar. Therefore there is no scroll and swale relief (see Fig. 4). The upward directed sets originated at right angles from elongated scours in the lower point bar. At the apex of the point bar scours are directed slightly away from the upper point bar surface, at the point bar centre parallel to the face, and in the tail area towards the surface (see Fig. 15). Across current the upward directed sets will also show this trend; therefore it is possible to establish the location of a vertical section in terms of point bar geometry.

The erosional path of the channel is reconstructed in Fig. 14. Orthogonals to the accretion planes indicate the erosional path lines and the erosional axis, which is the longest erosional path line (HICKIN, 1974). The accretion direction of the W unit was probably both perpendicular to and in the current direction. Accretion of the E unit started in a straight reach with an irregular point bar. In the tail area there was a minor adjustment to the former accretion direction. With increasing lateral migration there was also a minor downstream migration.

With increasing curvature, extension of the point bar appeared in combination with symmetry changes. It is likely, that with increasing sinuosity the degree of flow separation also increased. A current pattern initiating a platform with flat top and high angle margin also only occurred during a high sinuosity phase. There is an analogy between this platform and platform development in high sinuosity, tidal channels, as described by BRIDGES & LEEDER (1976). However, the decreasing channel depth and changing point bar morphology towards the centre of the bend (Fig. 12) indicate that in this case the influence of low discharge flow can be ruled out.

The lithofacies found in the exposures shows far more variation than is accounted for in the analysis of point bar evolution just given. The W unit deviates most. The surface morphology in combination with the channel fill at the base of the E unit (log B, Fig. 7) resembles the description of a lateral bar from an outwash plain (BLUCK, 1974). The isolated setting and the lack of gravel in the W unit distinguish it from Bluck's description. A possible channel plan has been drawn on the basis of the resemblance (Fig. 13A).

In Fig. 15 transverse sections of the upstream (1), middle (2) and downstream (3) part of the meander lobe (Fig. 7) are reconstructed. The distribution of the coarse and fine member is indicated.

(1) The smallest part of the lobe. Only the lower lithofacies interval is exposed. Unstratified mud is assumed to have been present in the upper interval. The general aggradation is expressed by the draping of platform deposits over the top of earlier platforms.

(2) The largest part of the lobe. The upper lithofacies interval is well developed. The strike of the upper point bar layers shows only a minor variation.

(3) A narrow elongated part of the lobe with strongly curved strike-lines in the upstream part. The upper point bar deposits consist of mottled mud.

In Fig. 15 the general aggradation of the E unit is indicated by a large amount of mottled mud on top of the deposits. Several phases of aggradation can be distinguished in the E unit. The beginning of each phase is expressed by a break in the growth pattern (Fig. 14) and instantaneous elevation of the top level of the point bar deposits. There are major truncations at the pattern breaks, and mud appears in places where the channel withdrew partly from the point bar surface. It is probable that the shifts in the growth pattern are reflected in the formation of sets in vertical sections. Variation in the mud content of sets can be attributed to a point bar

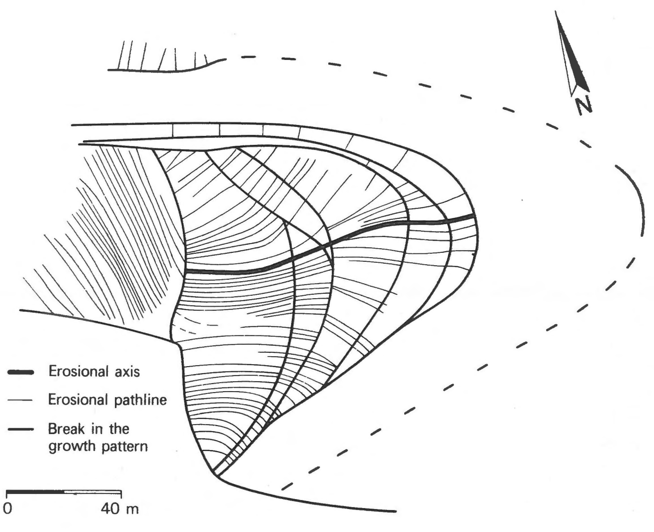

Fig. 14.
Orthogonals to the accretion pattern give the erosional pathlines and the erosional axis. The pattern of the W part is regular, while in the E part there are breaks in the growth pattern.

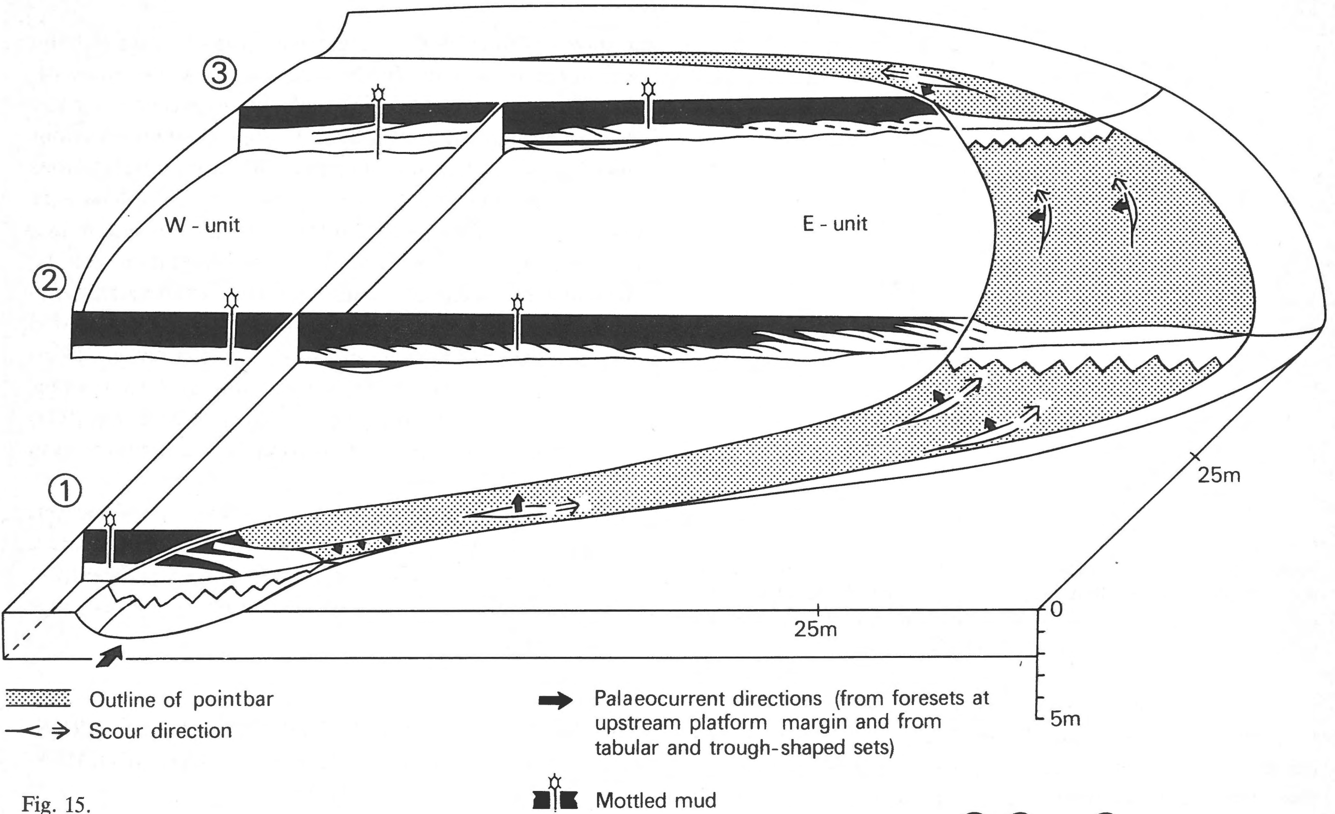

Fig. 15.
Transverse sections of the meander lobe constructed on the basis of profile lines over the surface (Fig. 8, ①, ②, and ③). Mud was deposited outside the channel during vertical accretion of the E unit. Palaeocurrent directions in two types of crossbeds give an indication of the location of the sets with respect to point bar geometry.

sedimentation process. It is likely that the site of maximum sedimentation in the flow separation zone moved over the point bar during formation of the meander lobe.

It can be concluded that the deposits originated in a river with major regime changes. After the initial, high energy phase a sudden transition took place towards a relatively low energetic river. With continuing activity there was a major lateral accretion in combination with a minor downstream migration and a distinct aggradation. River bed abandonment occurred due to avulsion.

The sedimentary facies of the vertical section described agrees largely with the section through the middle part of the meander lobe (Fig. 15; section 2). Palaeocurrent directions from the very well exposed NE part (Fig. 5) point to an origin somewhat downstream of the centre of the bend. In the SW margin a platform foreset facies has been found. Further directions derived from inclined tabular sets also point to an origin at the point bar apex area.

The dimensions obtained from both exposures are not directly comparable. The maximum width of the meander lobe in the vertical section is at least four times and the thickness twice larger than the meander lobe depicted in Fig. 15, whereas palaeochannel widths fall within the range of channel widths from the surface exposure.

SETTING OF THE MEANDERING RIVER IN AN ALLUVIAL ENVIRONMENT

An attempt has been made to relate the origin and characteristics of the meandering river to the setting in an ancient alluvial environment. Factors which determine the development of alluvial systems are:
Relief (as a consequence of crustal movements and eustatic sea-level movements).
Nature of the material in which the system developed.
Climate (especially temperature and precipitation).
Vegetation.
JACKSON (1978) and READING (1978) present a review of the literature in this field.

In Fig. 16 the information of the general sedimentological description is compiled with emphasis on the grain size distribution. Debris from a NE uplifted area was brought into the basin by a small alluvial system. The transition of a wide, gravel-carrying stream to relatively fine-grained meandering rivers is known from Alaskan outwash fans (BOOTHROYD & NUMMEDAL, 1978). The transition is a consequence of a decrease in gradient, in this case accompanied by a deflection towards the NW plunge of the basin axis. Synsedimentary NW directed faults and flexures played an important role in this transition. In the distal part of the system extensive, fine layers were deposited by sheetfloods (analogous to HEWARD, 1978).

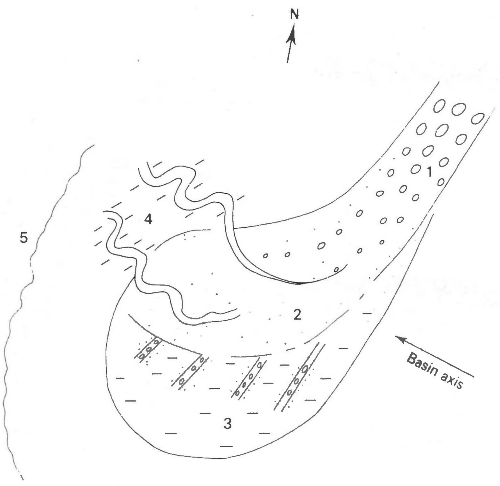

Fig. 16.
Sediments from the depositing part of an alluvial system grade downstream from conglomerate (1) to sandstone (2). Sheetfloods (3) and meandering rivers (4) deposited large amounts of fines. Marine conditions dominated in the W regions (5).

Long-term sedimentation was strongly influenced by tectonic conditions (see also NIJMAN, 1981). Deposition of thick conglomerates is linked to transgressions. Eustatic sea level rises lower gradients and would be associated with relatively finer deposits. Tectonic activity created and maintained gradients and supplied variable amounts of material. Relatively small-scale tectonic activity played an important role in the development of meandering rivers. The meander lobe was formed in a depression in front of a small deltaic build up (Fig. 8). The depression was situated in an active flexure close to the present vertical fault.

The extension of the meandering part of the system varied. The meander lobe of the surface exposure developed only after the system had deposited large amounts of (very) coarse sand and gravel in a shallow marine environment and meandering was limited to the final stage of alluvial system evolution. In the vertical section (Fig. 4) the meander lobe succeeds sheetflood deposits with minor amounts of gravel, while at the top a conglomerate layer wedges out into a scour that is filled mainly with non-mottled sediment.

The proximity of the sea might have created a tidal regime. However, sedimentary structures due to a tidal influence have not been found. The oxidation of the major part of the point bar deposits and the lack of tidal influences reflected in the deposits of the Castigaleu Formation in the study area seem to exclude a tidal influence on point bar deposition.

The type of multicolouring of the fine sediment and the caliche development agree with the characteristics of Pseudogley soil formation as given by BUURMAN (1980). This implies a seasonal, hot climate with marked dry and wet periods. A discontinuous discharge has been interpreted in the analysis of point bar deposits. The large width and the shallowness of the braided stream and the connection of coarse layers with extensive flat layers of mottled fine material also point to an alternation of high discharge periods (with sheetfloods) and low discharge periods (with little or no sedimentation). However, HASELDONKX (1973) took the occurrence of *Nypa* pollen as an indication of a humid, tropical climate without marked periods of aridity. The two different interpretations of the climate may be the consequence of the sedimentary situation. The sedimentary activity of an alluvial system in a small drainage area with only scarce vegetation can be determined by precipitation during storm conditions (MCGOWEN, 1971). Because of the thin vegetation cover in sheetflood areas (analogous to the situation described by HEWARD, 1978) the soil will have been extensively subjected to weather conditions. The coastal plain vegetation (HASELDONKX, 1973) will have been restricted to the margins of the sedimentation areas.

Variation in sedimentary characteristics in vertical sections cannot be due to changes in the climate and/or vegetation type. The palaeosol character does not change significantly in the Monllobat Formation and there is no evidence of a change in vegetation type.

THE RELATIONSHIPS OF THE PALAEOENVIRONMETAL CONDITIONS AND POINT BAR SEDIMENTATION

With decreasing gradient and loss of energy in the alluvial system (expressed by the lack of gravel) a transition from unconfined to more or less confined flow took place. A high bank stability (causing a high frictional resistance to flow) was very important in this respect. The bank stability was caused by margins of synsedimentary flexures and the presence of large amounts of fine material (with some vegetation). A high suspended load/bed load ratio in the channel was also important in establishing the transition. The thick mud beds intercalated in the upper point bar deposits point to a high suspension load. Thick mud drapes can develop on point bars during stagnant periods. In the sketched situation this could take place during storm conditions, when rapid run-off through the more proximal parts of the system caused flooding of the low gradient, coastal plain. The major part of the bed load (especially the gravel) remained in the proximal parts of the system.

The initial coarse phase of the meander lobe in the top surface exposure was the first reaction of the system to a newly developed, favourable gradient through a flexure. The high discharge was through the channel and over the lateral bars. A period of active sedimentation of the channel lowered the gradient and consequently a lower energy type of river developed. Lateral accretion in this river was characterized by an alternation of phases with a regular accretion and (short) phases of aggradation, accompanied by major shifts in the accretion pattern.

Prior to avulsion, sedimentation took place in a shallow meandering river during occasional high discharges. In the centre of the highly sinuous meander bend the channel was twice as wide as at the inflection point. The width increase was associated with a distinct decrease in the depth.

CONCLUSIONS

1 A point bar in a palaeochannel shows a well-established grading (fining upwards) in a vertical sense only. Nevertheless, there can be a large variation in sedimentary facies in transverse sections of meander lobes. Therefore, an analysis of point bar sediments has to be combined with a reconstruction of general environmental conditions.
2 Large-scale environmental conditions have put distinct marks on point bar sediments. In this respect the most striking features are the reconstructed discharge events through a channel with highly variable W/D ratio, the setting of point bar layers in isolated meander lobes with a coarse initial part, and the setting of meander lobes in associations with sheetflood deposits.
3 Reconstructions of point bar sedimentation processes and the environmental setting lead to a three dimensional model. The location of vertical sections in this model can be established by comparing sedimentary facies and palaeocurrent directions.

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