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Oligocene meandering stream sedimentation in the eastern Ebro Basin, Spain

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ABSTRACT

The Oligocene meandering stream deposits of the Cervera region, Catalunya, are characterized by well-developed epsilon cross-stratification formed by lateral accretion of point bars, textural and structural heterogeneity at meander bends, simple and differentiated point-bar surfaces, abundant chutes, muddy chute fills and locally chute bars, and abandoned fine grained channel fills. These rivers drained a Pyrenean source area.

Sand bodies are isolated in a thick fine grained matrix. Avulsion rates were moderate to high and the alluvial valley essentially unrestricted, thereby producing an alluvial stratigraphy characterized by low interconnectedness. The hypothesis of abnormally high floodplain aggradation rates, necessitating an additional supplier of fines, is rejected.

ZUSAMMENFASSUNG

Das östliche Ebrobecken bildete im Oligozän eine weite intermontane Senke, in welcher sich der von den Pyrenäen und dem katalanischen Küstengebirge stammende Abtragungsschutt als Molassesedimente vorwiegend in Form mächtiger fluviatiler und z.T. lakustrischer Abfolgen anhäufte. Mehrere mächtige Konglomeratschuttfächer am Fusse beider Gebirge markieren die Austrittsstelle der oligozänen Flüsse. Die Schuttfächer bestehen am südlichen Beckenrand aus mehrstöckigen Konglomeratrinnen, welche beckenwärts in geradlinige, lokal schwach gewundene, einstöckige Rinnen übergehen (ALLEN et al., in press).

Im Beckenzentrum (Cervera) finden sich dagegen Ablagerungen mit strukturellen und texturellen Merkmalen mäandrierender Flüsse wie die bei der lateralen Anlagerung an Gleithängen entstehende Epsilon-Schrägschichtung, tonig-siltige Altwasserablagerungen und «Chute»-Füllungen sowie «Chute»-Bänke. Diese Flüsse flossen aus den Pyrenäen gegen Süden.

Rinnensandsteine finden sich als isolierte Körper in tonig-siltiger Matrix. Berechnungen ergeben eine mittlere bis hohe Verlagerungsrate der Flüsse sowie ein lateral relativ unbeschränktes Flachland bzw. Tal. Unter diesen Bedingungen ist die theoretisch zu erwartende geometrische Anordnung der Rinnen charakterisiert durch eher geringe Überlappung. Damit kann auch die Hypothese ausgeschlossen werden, dass das Auftreten isolierter Rinnen in Mergelmatrix auf abnorm hohe Auflandungsraten im Schwemmebenenbereich zurückzuführen sei, was einen weiteren Zulieferer von Schwebstoffen erfordern würde.

Introduction and regional setting

Sedimentation in the Tertiary Ebro Basin has been dominated by the three mountain chains that delineate its triangular shape; the Pyrenees in the north, the Iberian chain in the southwest and the Coastal Catalan chain (Catalanides of LLOPIS 1947) in the southeast (Fig. 1).

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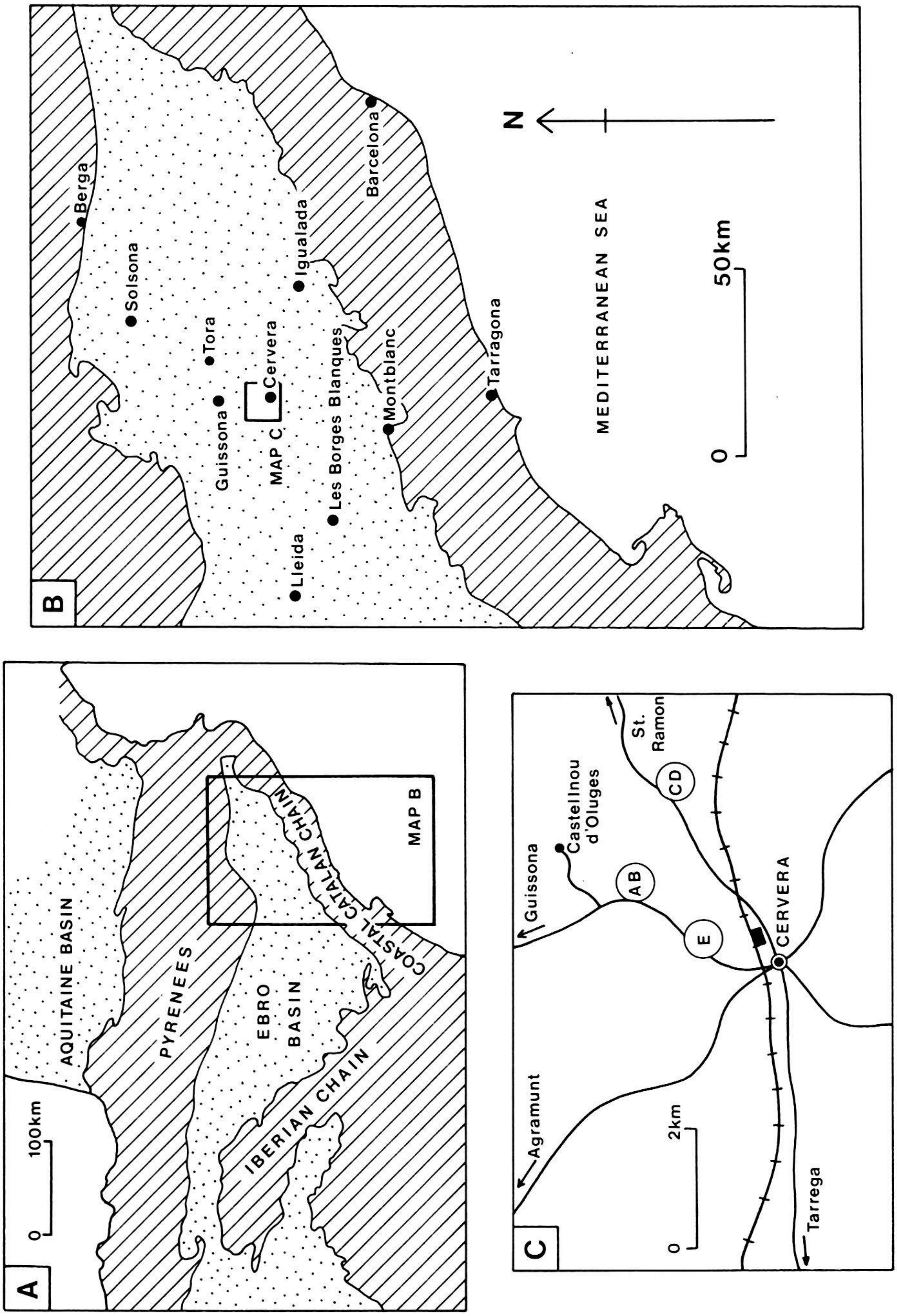

Fig. 1. Location of study area and the three bounding mountain chains of the Ebro Basin.

The northern margin of the Ebro Basin is structurally complex and sedimentologically variable. In particular, the South Pyrenean Trough, which was initiated by the first of two periods of décollement from the Pyrenean orogen (SEGURET 1970), was filled by a westward progradational system in earliest Paleogene times (ROSELL & PUIGDEFÁBREGAS 1975), which caused the advancement of alluvial, deltaic, littoral and tidal sediments over marine offshore and turbiditic facies. The sedimentological evolution of the Tremp-Graus (VAN EDEN 1970, NIJMAN & NIO 1975), Ager (FERRER et al. 1971, GHIBAUDO et al. 1973, MUTTI et al. 1972, 1973) and Jaca basins (PUIGDEFÁBREGAS 1975, PUIGDEFÁBREGAS et al. 1975, MUTTI et al. 1972) of the South Pyrenean Trough has been developed to an advanced stage and, in the context of fluvial sedimentology, has provided case-study examples of coarse grained point bar deposition and more generalized meandering stream lithofacies models (NIJMAN & PUIGDEFÁBREGAS 1978, PUIGDEFÁBREGAS 1973, 1975, PUIGDEFÁBREGAS & VAN VLIET 1978).

By contrast, the eastern margin of the basin against the Catalanides has received little specialist sedimentological attention. All along this margin alluvial fan and fan-delta conglomerates of Eocene-Oligocene age overlie syntectonic unconformities produced during compression of the Catalanide orogen (ALLEN et al., in press, ANADON et al., in press, COLOMBO 1980). The underlying Eocene and older strata are highly variable, comprising fluvial, lacustrine and marine sediments (ANADON & MARZO 1975, COLOMBO 1980).

As a generalization, sedimentation prior to Oligocene was variable and frequently marine. During the Oligocene (and especially during the Miocene in the central areas of the Ebro Basin) sedimentation was emphatically continental. This paper describes the characteristics of Oligocene (Stampian) river channel bodies in the eastern Ebro Basin centred around the town of Cervera (Fig. 1). Although planwise information on surface topography is generally lacking, the excellent vertical quarry and road-cut exposures in this region provide case-study examples of this particular ancient meandering stream lithofacies.

Some remarks on Paleogene fluvial sedimentation in the eastern Ebro Basin

Eocene to earliest Stampian fluvial sediments, exposed near the Catalanides basin edge, have been described by ANADON & MARZO (1975) and WEISS (1980) from the Igualada region (Montserrat fan) and by ALLEN et al. (in press) from the area of Montblanc (Scala Dei Group fan). Spectacular exposures along the newly constructed A2 motorway between Montblanc and Les Borges Blanques (Fig. 1) allowed ALLEN et al. (in press) to study the lateral and downfan variations in fluvial style. Multistorey channel bodies made of conglomerate (clasts up to 10 cm) near the basin edge are composed of large scale foresets representing laterally attached bars. Flow in these bed-load rivers was interpreted to be high and ephemeral.

Towards the basin centre, on the flank of the Scala Dei Group fan and in quiet zones between the main feeder channels single-storey ribbons of low width/height ratio are common. These ribbons were constructed by ephemeral streams with long straight reaches but prominent bends. Only in the channel bends are lateral accretion deposits found, and complex meander belts are absent.

The alluvial deposits of the Montserrat fan in the area northwest of Igualada (Weiss 1980) possess striking similarities with those of the Scala Dei Group. Most channel fills are conglomeratic and both single- and multistorey. Evidence of lateral accretion is generally lacking and the internal structures of the channel bodies indicate affinities with braided streams rather than meandering types (Weiss 1980, p. 14–17). Only towards the very top of the Sannoisian section northwest of Igualada are the rivers of mixed-load meandering type, with chutes, chute bars, epsilon cross-stratification (Allen 1963) representing point bar accretion and muddy channel fills (Weiss 1980, p. 52, Fig. 37).

The fluvial sediments deposited by Oligocene rivers draining the Pyrenees are poorly known in the region north of Cervera. In the region north of Guissona (Fig. 1b) the Sannoisian to early Stampian sand bodies possess steep cutbanks, the lateral accretion surfaces and "benches" of topographically-differentiated point bars and chutes with small chute bars and fine grained chute fills. They share many characteristics with the fluvial sand bodies of the Cervera region, described below. Further north in the region of Tora (Fig. 1b), some 20 km north of Cervera ("Solsona Molasse" of Riba 1975 or "Tora Facies" of Malmsheimer & Mensink 1979) the sandstone bodies possess steep cutbanks and prominent lateral accretion surfaces due to the migration of point bars in sinuous channels. Farther to the north ("Solsona Molasse" and "Berga Conglomerates" of Riba 1975 or "Berga Facies" and "Serrateix Facies" of Malmsheimer & Mensink 1979) the sediments are coarser and channels larger (up to 6 m deep) but no detailed sedimentological work has been carried out in this region.

Features of individual channels

The examples chosen are all located very close to Cervera, which has the advantage that they occur within a very limited stratigraphic range. Sand bodies A to D also occur within a documented (this paper) and well-exposed vertical sequence. One drawback with all the examples is that nowhere is the surface topography of the sand bodies well displayed, in contrast to the meandering stream deposits described by Nami (1976) or Puigdefábregas (1973).

Sand Body A

The general vertical trend is of well-developed fining-up in grain size (Fig. 2). The base is erosive and irregular and is overlain commonly by trough cross-stratified medium sandstone, but locally (in the east, locality A) by larger planar cross-sets. This basal unit is overlain by plane beds or northwestward-dipping, grouped, small scale, asymmetrical ripples and climbing ripples in the east, but by low angle ($< 10°$) westward-dipping accretionary stratification in the west (AS, Fig. 2). Megaripples at the bases of the accretionary surfaces (MR, Fig. 2) indicate flow to the south. These two portions of the sandstone unit are separated by an interstorey scour (IS, Fig. 2) which, in the central part of the exposure, overlies a fine grained swale or chute fill

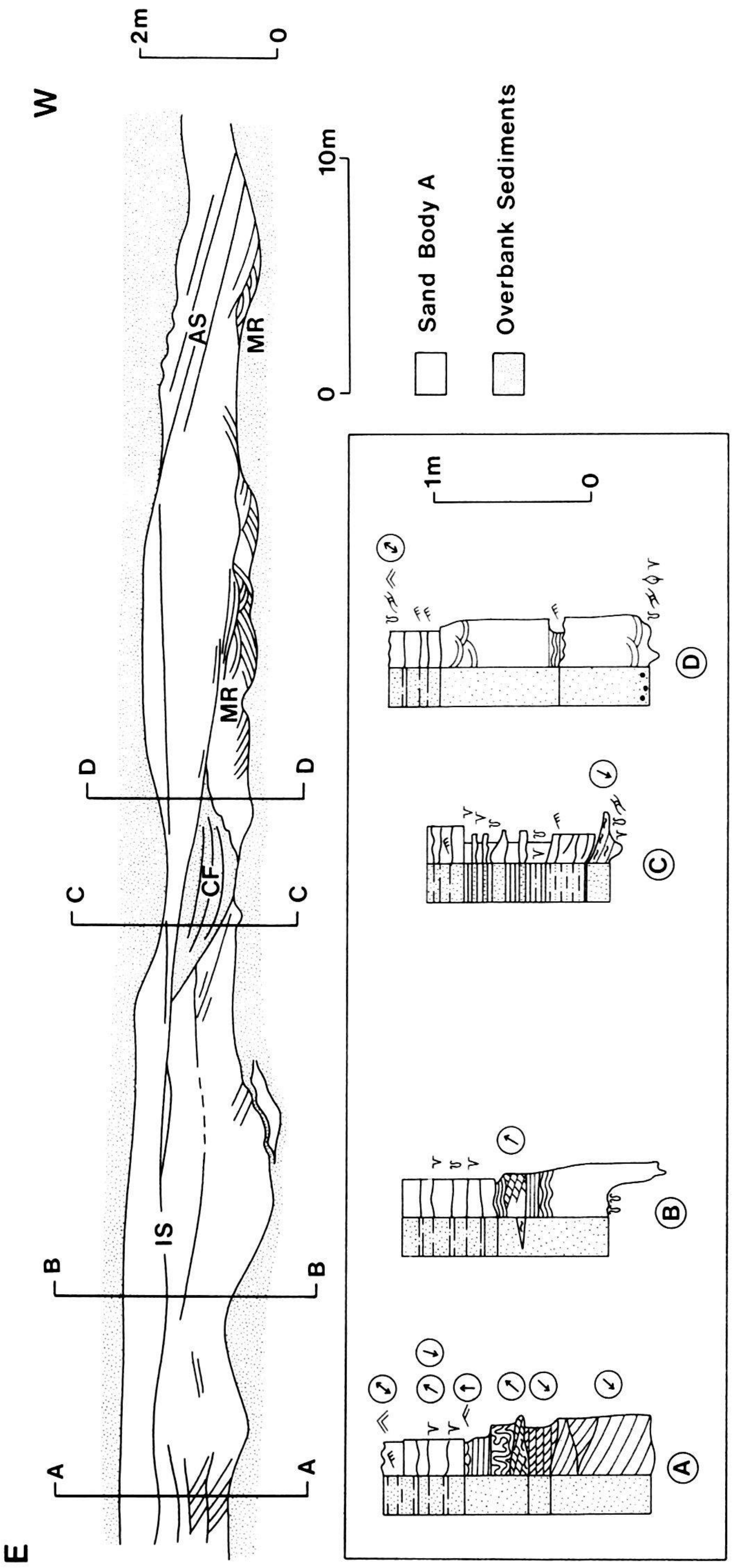

Fig. 2. Sectional view of Sand Body A with details of the vertical sequence through the sand body at four localities.

(CF, Fig. 2). The interstorey scour most likely represents scour by the migrating thalweg of an aggrading channel. This feature is similar to the generally larger scale storeying produced by the superimposition of different channel belts (ALLEN 1978, FRIEND et al. 1979, ALLEN et al., in press). Since the interstorey scour erodes to almost the same level as the basal scour of the lowermost storey, channel belt and floodplain aggradation must have been small.

The uppermost sediments shown in the vertical logs are composed of interbedded mudstone and fine sandstone which resemble BLUCK'S (1971) accretionary bank sediments, but they may also represent levee deposits (ALLEN 1965 for summary). The top surface of the sandstone unit is characterized by rib and furrow topography, vertical cylindrical burrows and horizontal trails. This top surface has, in places, suffered a small amount of reworking by short-period waves, as demonstrated by small wavelength, symmetrical wave ripples which erase older burrowed structures.

The major features of this sandstone unit can therefore be summarized as low-angle accretionary bedding representing successive point-bar slopes (particularly in the upper part), grouped trough cross-stratification produced by the migration of trains of megaripples or dunes (in the lower part), and, elsewhere, more complex vertical fining-up sequences involving bar growth and small scale ripple migration.

The ratio of coarse member to total cycle thickness is 0.45 or less depending on the distinction of the upper limit of the cycle (Fig. 3).

Sand Body B

The most important features of this sandstone unit are the presence of perfectly displayed epsilon cross-stratification in the north (ECS, Fig. 4a) and a steeply incised channel passing southwards into levees. Gutter casts at the base of the epsilon unit and at the base of the steeply incised channel indicate a flow along an east-west axis (Fig. 4a). This is independently supported by the geometry of the incised channel and the appearance in section of trough cross-stratification at the base of this body. Lateral accretion took place towards the northwest (producing the epsilon unit), somewhat oblique to the local channel trend suggested by gutter casts (Fig. 4a), but was evidently highly intermittent based on the thickness of draping fine grained sediment between epsilon cross-strata. A fine grained fill comprises the abandoned channel (CF on Fig. 4a), probably due to sudden neck cut-off or avulsion. The cut-off or avulsive event is now probably represented by the steeply incised channel sandstone towards the south. This (?) avulsed channel contains no evidence of lateral accretion, but had a complex flow history indicated by its multistorey nature and splitting to the south. The presence of an interstorey scour suggests channel-belt aggradation, of the order of 0.6 m between successive levee-building events (see Fig. 4a).

The upward passage into shelly and charophytic lacustrine limestones (Fig. 3) emphasizes that these streams were close to their local base levels and spatially in the vicinity of the basin centre.

The ratio of coarse member to total cycle thickness is 0.66, taking the upper limit to be the occurrence of freshwater limestones.

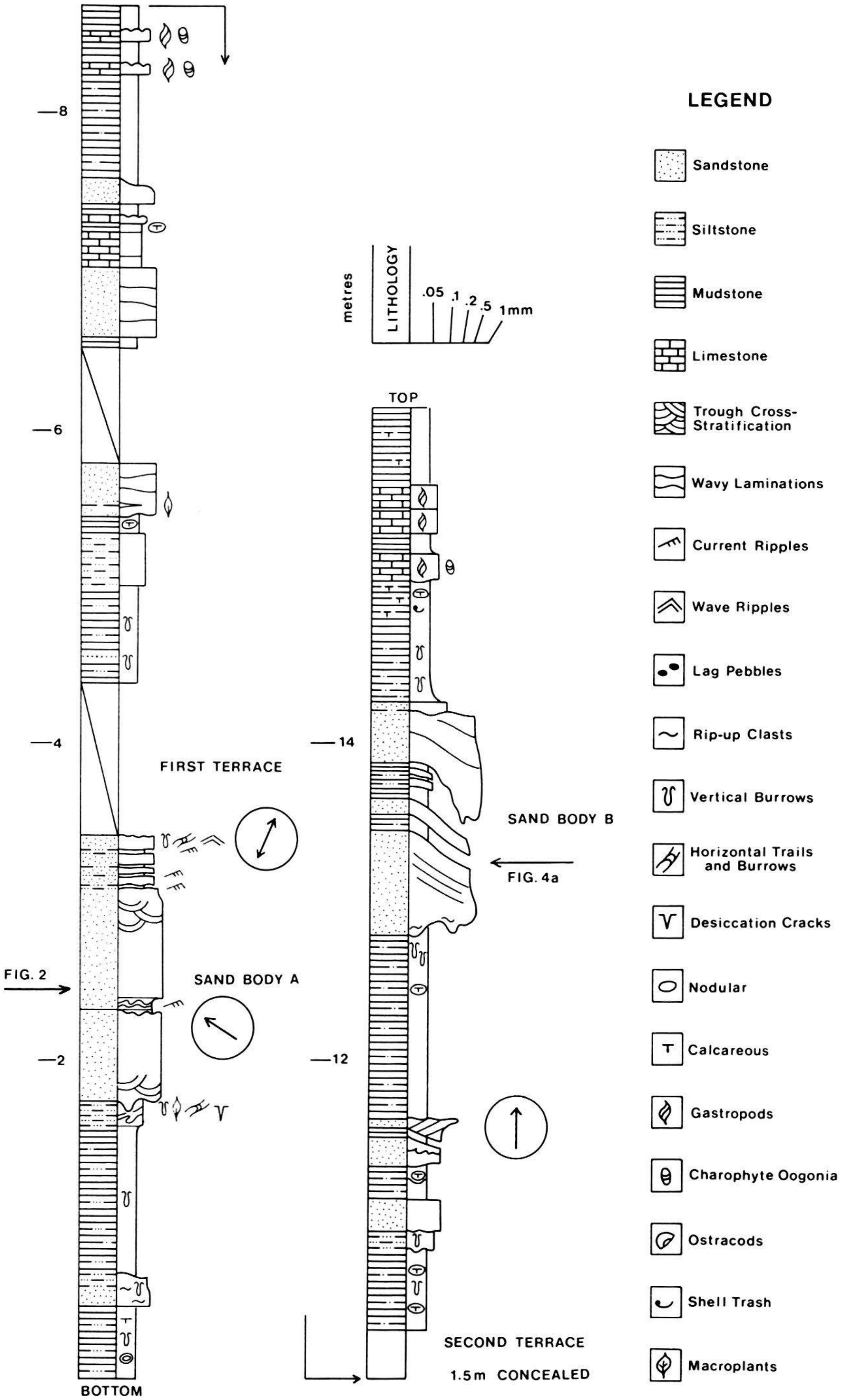

Fig. 3. Sedimentological log at the quarry 3 km north of Cervera on the road to Guissona.

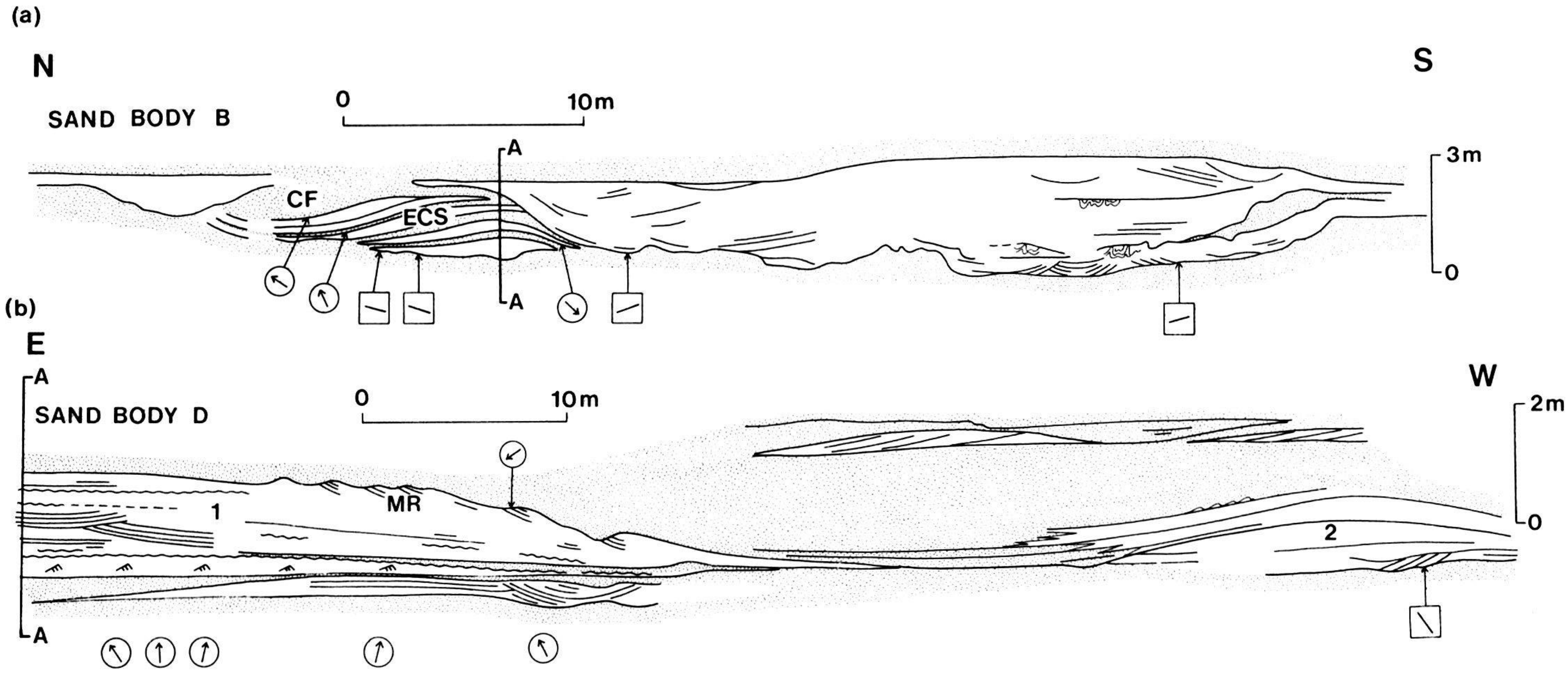

Fig. 4. (a) Sectional view of Sand Body B. A–A represents sequence documented in Figure 3. (b) Sectional view of the two sediment lenses comprising Sand Body D. A–A represents sequence documented in Figure 5.
Square boxes contain azimuths of gutter casts. Circles contain directions of cross-strata.

Sand Body C

The quality of exposure of this sand body is poor, but its highly incisive nature is clearly displayed, together with the northwestward-dipping cross strata. It is important only as a striking comparison with the flat-based Sand Body D 2 m above (Fig. 5). The ratio of coarse member to total cycle thickness is 0.54.

Sand Body D

This sandstone unit consists of two convex-up components (1 and 2, Fig. 4b) separated by a trough of fine grained alluvium. The most important features are the laterally persistent, symmetrically-rippled surfaces overlain by red mudstone drapes, the low-angle nature of internal stratification and the presence of a train of megaripples on the western flank of the main sandstone body (MR on Fig. 4b). Most of the small scale linguoid and cuspate ripples present in this unit indicate a flow to the north or northwest.

The symmetrically undulating appearance of the rippled surfaces is produced by an oblique section through a linguoid current ripple train. Ripples of the "washed-out" type (Singh 1980) are also present. The bioturbation and desiccation phenomena found in fine grained interbeds within this sandstone unit indicate considerable fluctuations of flow depth and flow strength, that is, a tendency towards ephemerality. The low-angle surfaces represent the positions of point-bar slopes and the convex-up nature of the sediment lenses suggests that the section is almost normal to the direction of lateral accretion. The lower levels of the point-bar surface were moulded by megaripples before abandonment.

The meander wavelength (from crest to crest of the convex-up lenses) is approximately 60 m. A plan-view reconstruction is shown in Figure 6.

The ratio of coarse member to total cycle thickness is 0.59 or less, depending on the exact definition of the upper limit of the cycle.

Sand Body E

This sandstone unit, which is 1.80 m thick, is characterized by a basal scour with a markedly stepped appearance (steps marked A, B, C in Fig. 7), overlain by cross-stratified sediments of various styles. Near the base the sandstones are composed of large troughs representing dunes which migrated under a flow moving perpendicular to the plane of the section, that is, east–west. At other levels the cross-stratification is planar indicating bedforms with essentially linear slip faces, and in most cases the cross-stratal dips are to the north or northwest. However, the most impressive feature of Sand Body E is the presence of prominent low-angle, locally erosional surfaces dipping southward. Three of these surfaces are marked by 1, 2 and 3 and may correspond to the steps in the basal surface marked A, B, C on Figure 7. These surfaces, which are interpreted as due to lateral accretion on a meander bend, gradually become asymptotic as they extend towards the base of the sandstone unit and in their upper levels flatten out to near-horizontal, thereby displaying the classical sigmoidal shape. Finally, after at least three periods of lateral accretion the

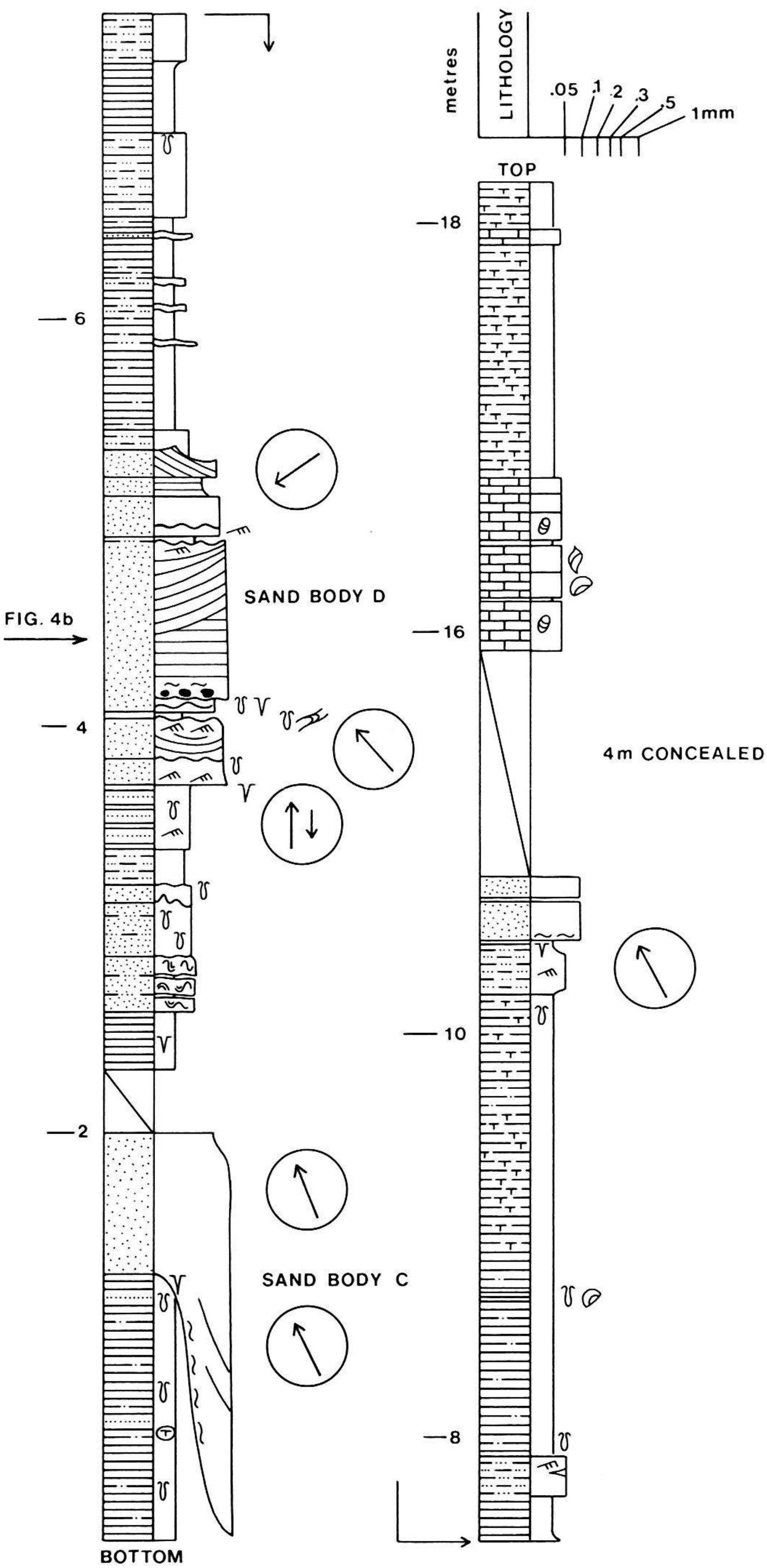

Fig. 5. Sedimentological log at the quarry 4 km northeast of Cervera on the road to St. Ramon.

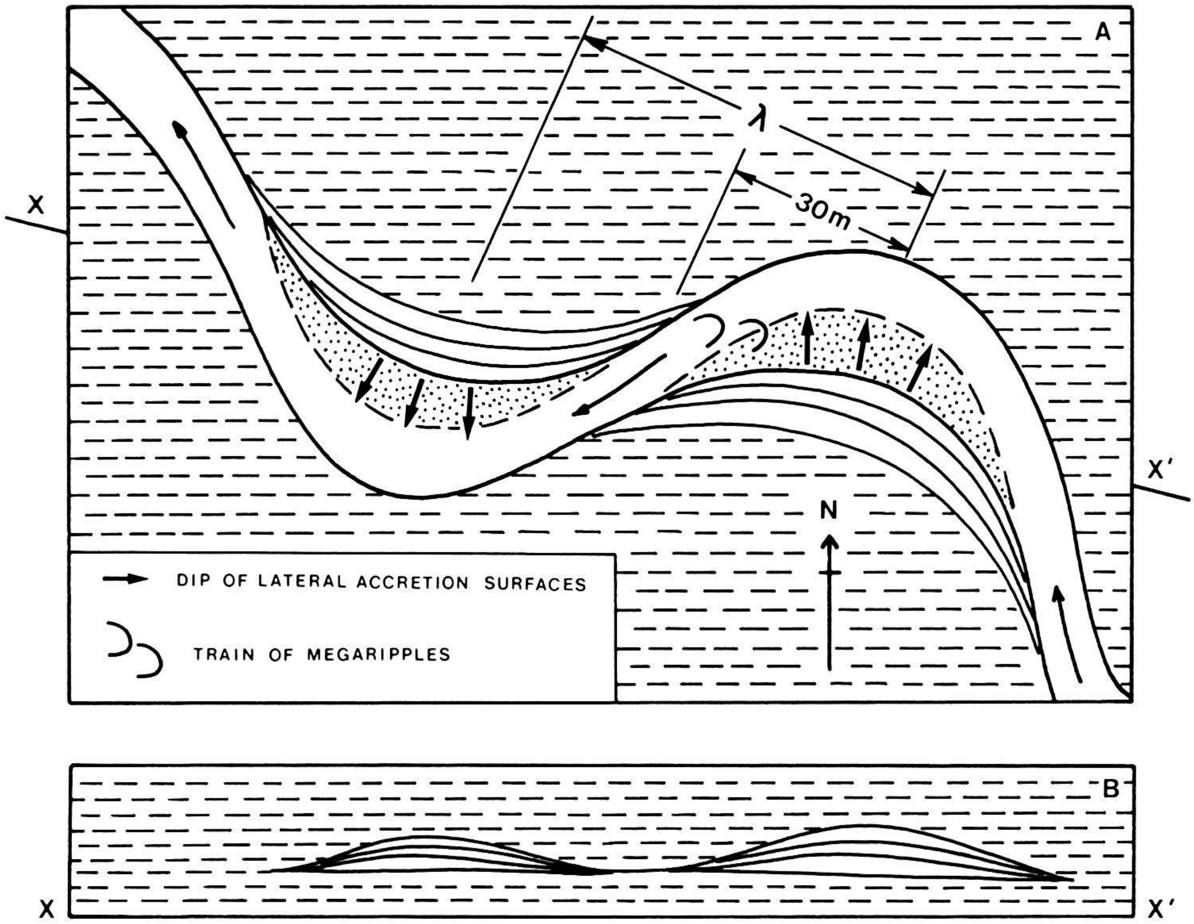

Fig. 6. Plan view reconstruction of the environment of deposition of Sand Body D.

channel was filled by fine grained alluvium (CF, Fig. 7) due to abandonment. The abruptness of abandonment suggests avulsion.

Swales or chutes are present in the upper levels of this sandstone unit and are filled by thinly bedded sandstones and mudstones in the north (D, Fig. 7), but by cross-stratified sandstones in the south (E, Fig. 7), demonstrating that these chutes, at least locally, possessed bedload accumulations (chute bars).

There must remain some speculation whether the steps in the basal scour can be positively matched, in terms of causality, with the major accretionary episodes. However, the vertical planes of the steps are consistently in the north, which must be interpreted as the inner bank of the meander bend based on the attitude of the lateral accretion surfaces, and these steps therefore cannot be viewed as the cut-banks of a sinuous stream. They must represent three periods of rapid downcutting which marked the establishment of lateral accretion and which terminated in each of the three surfaces 1, 2 and 3. The preservation of the steps A, B and C was probably favoured by early burial by point-bar sediments, whereas the true cut-banks were continually destroyed by thalweg migration.

Certainly, the history of Sand Body E was complex. The preservation of the section illustrated in Figure 7 is indeed fortuitous, providing a section approximately normal to (interpreted) local flow, and hence displaying the classical meandering

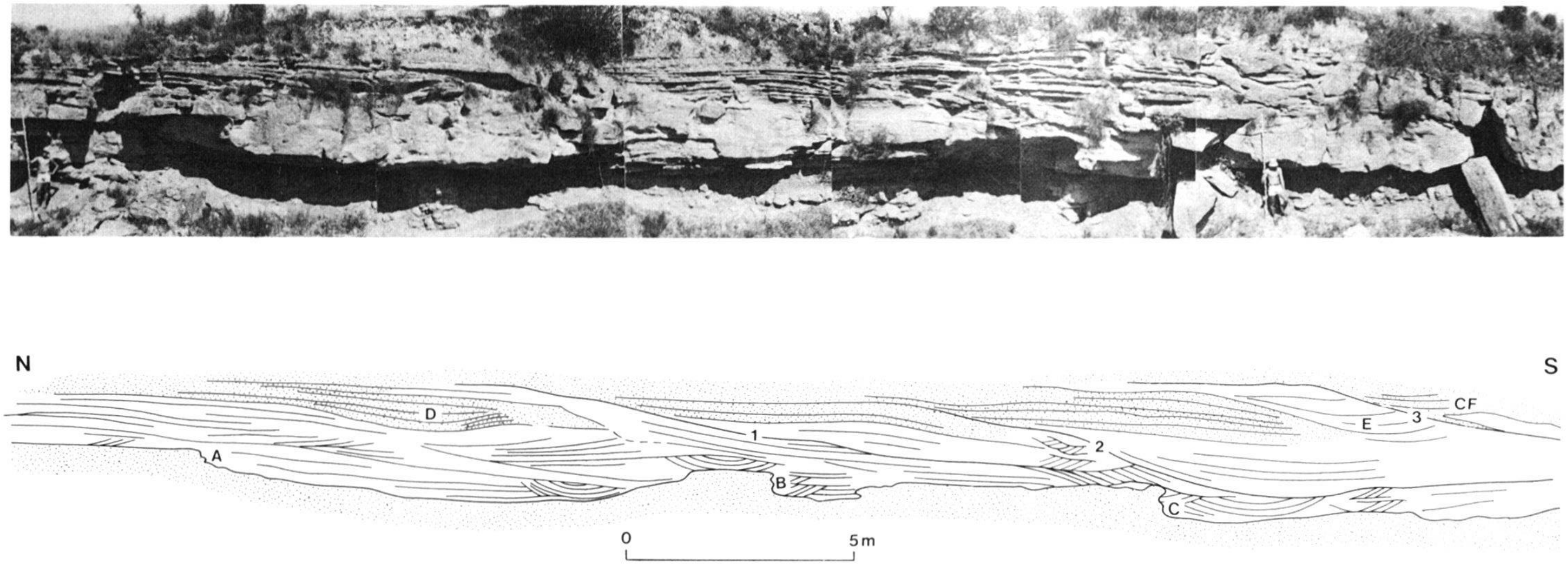

Fig. 7. Semi-interpretive sketch and photo-montage of Sand Body E. Stippled areas represent fine grained sediment. Road cutting 2 km north of Cervera on the road to Guissona.

stream motif. Channel belt and floodplain aggradation must have been negligible to allow the successive downcutting to a uniform level. Little can be said about the avulsion rate in this example; the three distinct pulses of lateral accretion within the same sand body suggests that the periodicity was longer than in the previous examples.

All of these sand bodies were deposited by rivers draining a Pyrenean source (MALMSHEIMER & MENSINK 1979, ALLEN & MANGE-RAJETZKY, in press). The prominent features of these and other Stampian channels of the Cervera region are good point-bar development, textural and structural heterogeneity at meander bends, simple and differentiated point bar surfaces, abundant chutes, muddy chute fills and locally chute bars, and abandoned fine grained channel fills. Levees are locally prominent and locally absent. All examples represent isolated sandstone bodies within a fine grained background, which suggests that individual river courses were short-lived and the system dominated by frequent avulsive events. The Eocene Montañana Group of the Southern Pyrenees and scattered Miocene examples from the Ebro Basin (PUIGDEFÁBREGAS & VAN VLIET 1978) appear to conform to this general type. Sand Body A and particularly Sand Body B suggest finite channel belt aggradation whereas Sand Body E indicates negligible channel belt aggradation during three successive periods of lateral accretion. All channel belt aggradation estimates are, of course, in this case, relative to the lifetime of individual water courses (residence interval).

A lithofacies model

There appears to be a possibly erroneous assumption amongst sedimentologists that to each channel pattern (straight, meandering, etc., LEOPOLD & WOLMAN 1957) must correspond a distinctive lithofacies. JACKSON (1978), recognizing this, has tentatively constructed five lithofacies classes which are based on the geomorphological and sedimentary features of recently investigated meandering rivers, principally in the United States. These lithofacies classes form a continuum from muddy fine grained streams to coarse gravelly streams.

The grain sizes, width/depth ratios (from Fig. 2, 4, 6 and 7), sedimentary structures and geometries of the examples described above suggest that they fall into JACKSON's class of "sand-bed streams with modest thickness of fine member" (class 2, p. 562) and possibly the class of "muddy fine grained streams" (class 1, p. 562).

Interestingly, streams of class 2 include Little Dry Creek, Wyoming, which is an ephemeral stream occupying a narrow meander belt on a broad lacustrine plain. The large number of chutes, the presence of major scouring surfaces (interstorey scours), the vertical sequence of sedimentary structures, the (locally) prominent levees and muddy channel fills are all features common to class 2 rivers and the Stampian examples.

Discussion: alluvial stratigraphy

PUIGDEFÁBREGAS & VAN VLIET (1978) suggested that the great thickness of fine grained sediment associated with their Eocene and Miocene channels could not have been produced by overbank deposition from those channels, and postulated an additional supplier of fines. They concluded that isolated sand bodies (very low interconnectedness) might be produced by channels of short residence time and avulsion periodicity, high rates of floodplain aggradation and an additional supplier of fines. An indication of the relative importance of these factors can be obtained from simulations of alluvial stratigraphy by LEEDER (1978) and BRIDGE & LEEDER (1979).

Taking first the Oligocene Cervera examples, let us utilize the appropriate channel deposit thickness (C_h in LEEDER 1978) of 2 m and assume a rather fast avulsion rate (A_r) of once per 500 years (modern avulsion rates average about 1000 years, BRIDGE & LEEDER 1979) and a wide, essentially unrestricted alluvial valley expressed as a dimensionless multiple of whole channel deposit widths ($W'p = 100$).

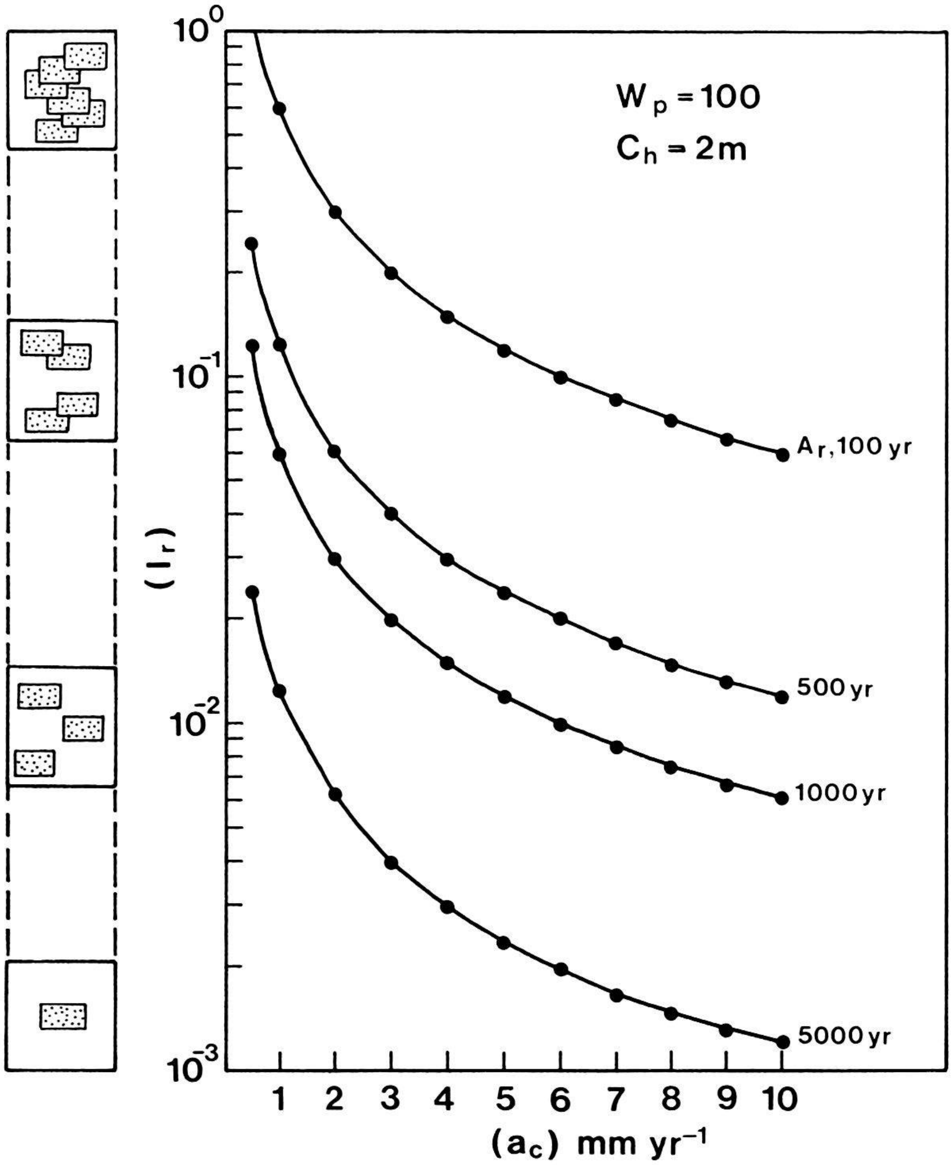

Fig. 8. Interconnectedness ratio (I_r) of high sinuosity channel deposits of the Cervera region as a function of alluviation rate (a_c) and avulsion frequency (A_r). W'p taken as 100 and channel deposit thickness (C_h) as 2 m. Curves calculated using $I_r = 3C_h/(A_r \cdot a_c \cdot W'p)$, equation (8) of LEEDER (1978, p. 592).

Then, assuming nodal avulsion (LEEDER 1978) the interconnectedness ratio (I_r) varies according to alluviation rate (floodplain aggradation rate, a_c) (Fig. 8) such that if $a_c = 0.001$ m yr^{-1}, $I_r = 0.12$ and at higher alluviation rates of 0.01 m yr^{-1}, $I_r = 0.012$ (equation 8, LEEDER 1978). The interconnectedness ratios are sufficiently low to explain the occurrence of isolated sand bodies without resorting to particularly high alluviation rates[2]), thereby removing the necessity for additional suppliers of fines. With longer avulsion periodicities (e.g. 1000 years) the sand bodies would be even more widely dispersed in their fine grained "matrix" ($I_r = 0.06$ and 0.006 for alluviation rates of 0.001 m yr^{-1} and 0.01 m yr^{-1} respectively).

A slightly different approach is possible using the vertical sequences illustrated in the sedimentary logs (Fig. 3 and 5). We shall assume that one river was responsible for both the sandstone channel and the overlying fine grained sediments. Assuming the Oligocene fine grained sediments to be fully compacted, we can deduce for each couplet of channel and fines an avulsion periodicity if a reasonable floodplain aggradation rate is assumed. Results for an essentially unrestricted alluvial valley ($W'p = 100$) and compacted alluviation rates (a'_c) of 0.0005 and 0.005 m yr^{-1} indicate avulsion periodicities of about 8000 and 800 years respectively, which can be regarded as infrequent to moderate avulsion. The corresponding interconnectedness ratios are 0.015. Since the sedimentological details suggest moderate to frequent avulsion, alluviation rates were probably of the order of 0.01 m yr^{-1} but there is no need to to invoke additional suppliers of fines.

Performing similar operations on the vertical sequence data shown by PUIGDEFÁBREGAS & VAN VLIET (1978, Fig. 3, p. 472, and Fig. 4, p. 474) from the Eocene Montañana Group, the avulsion periodicities for an essentially unrestricted alluvial valley ($W'p = 100$) and compacted alluviation rates of 0.0005 and 0.005 m yr^{-1} are 32,000 and 3200 years respectively, which are long. The interconnectedness ratio in these instances would be 0.008.

Because PUIGDEFÁBREGAS & VAN VLIET inferred more frequent avulsion there is a need to invoke considerably higher alluviation rates. The fines may have been derived in part from a second active channel or some unspecified additional supply.

In summary, the isolated sand bodies of the Montañana Group suggest high floodplain aggradation rates of a system characterized by more than a single active channel. The sedimentological data from the Oligocene Cervera examples suggest relatively frequent avulsion and, at test avulsion periodicities of 500 and 1000 years and moderate floodplain aggradation rates, the interconnectedness ratios are low, thereby explaining the isolated occurrence of these channel deposits in the alluvial stratigraphy.

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[2]) A range of floodplain aggradation rates from present-day alluvial valleys is presented by BRIDGE & LEEDER (1979, Table 1). BRIDGE & LEEDER's computer simulations of alluvial stratigraphy used a_c values of 0.005, 0.01, 0.02 and 0.04 m yr^{-1}. The values for compacted floodplain aggradation rate (a'_c) are high compared to the figures stated by FRIEND (1978, p. 534) for much of the Old Red Sandstone of Spitzbergen and Greenland and by KELLER et al. (1977) and OPDYKE et al. (1979) for the Upper Siwaliks. The Devonian and Tertiary aggradation rates represent averages over long periods including many hiatuses whereas present rates are essentially instantaneous by comparison. If BRIDGE & LEEDER's values for a_c are an order of magnitude too high for the examples discussed in this paper, it would imply considerably higher interconnectedness ratios for the same avulsion periodicity.

Conclusions

The main sedimentological features of several Oligocene fluvial sand bodies of the Cervera region are ubiquitous epsilon cross-stratification formed by point-bar accretion, textural and structural heterogeneity at meander bends, simple and differentiated point-bar surfaces, abundant chutes, muddy chute fills and locally chute bars, and abandoned fine grained channel fills. Sand bodies are well isolated in a matrix of fine grained sediment. Such low interconnectedness was probably due to moderate to frequent avulsion in an essentially unrestricted alluvial valley.

The rivers resemble those described by JACKSON (1978) and incorporated into his lithofacies class of "sand bed streams with modest thickness of fine member" or "muddy fine grained streams".

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