COMPARATIVE ANALYSIS OF FAN-DELTA FACIES FROM THE CARBONIFEROUS OF NORTHWESTERN SPAIN

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Abstract: Coarse sandstone and conglomerate, associated with Hercynian mountain building in the eastern Cantabrian Zone, constitute two shallowing-upward fan-delta successions. The older Succession A contains sediment-gravity flows of limestone conglomerate (toe of delta slope). These are overlain by fossiliferous limestone and shale of the prodelta, conglomerate and sandstone of a delta-front beach, and a thin coal of the delta plain. The younger Succession B begins with graded turbidite sandstones (toe). These are succeeded by fossiliferous sandstone and shale of the prodelta, sandstone of a barrier-beach and lagoonal limestone (front), and conglomerate, sandstone, and coal of a braided-stream system (delta plain). Facies differences between the two deltas express the sedimentary response to changes in source area, delta geometry, and tectonism. Provenance and relief in surrounding uplands determined sediment texture and mineralogy: limestone boulders, cobbles, and pebbles for Succession A and quartz pebbles, sand, and abundant mud for Succession B. The delta profile influenced grain-size distributions. The front of the first delta was narrow and steep, allowing coarse limestone clasts to be swept across the delta and downslope. The second delta, broad and flat, trapped coarse clasts and checked their seaward distribution. Extreme coarseness of conglomerates in Succession A and their inverse grading suggest high tectonic relief and a very steep slope in adjacent uplands. Succession B, though, is late-posttectonic, having formed after topographic relief had been smoothed by erosion.

Key words: facies analysis, conglomerates, fan delta, Carboniferous, Cantabrian Zone.

Resumen: En la Zona Cantábrica oriental existen dos sucesiones constituidas por conglomerados y arensicas de grano grueso de tipo fan-delta somerizantes, relacionadas con la orogénesis Hercínica. La sucesión A, más antigua, contiene flujos sedimentarios gravitatorios de conglomerados calcáreos (borde del abanico deltaico), recubiertos por calizas y lutitas fosilíferas de prodelta, conglomerados y areniscas de playa de frente deltaico y un delgado carbonero de llanura deltáica. La sucesión B, más moderna, comienza con areniscas turbidíticas granoclasificadas (borde), a las que siguen areniscas y lutitas fosilíferas de prodelta, areniscas de playa de barrera y calizas de *lagoon* (frente), así como conglomerados, areniscas y carbón de un sistema fluvial anastomosado (llanura deltaica). Las diferencias de facies entre los dos deltas expresan la respuesta sedimentaria a los cambios del área fuente, geometría del delta y actividad tectónica. El área fuente y el relieve de las elevaciones circundantes determinaron la textura y mineralogía de los sedimentos: bloques y cantos de caliza en la sucesión A y cantos de cuarzo, arena y arcillas abundantes en la suceción B. El perfil del delta infuyó en la distribución de tamaños de grano. El frente del primer delta era estrecho y empinado, permitiendo a los cantos gruesos de caliza su distribución por el delta y ladera abajo. El segundo delta, ancho y plano, atrapó los clastos gruesos, controlando su distribución mar adentro. El extremo grosor de los conglomerados de la sucesión A y su gradación inversa sugiere un relieve pronunciado y fuertes pendientes en las tierras elevadas circundantes. Sin embargo, la sucesión B es tardi a posttectónica y se formó tras la suavización de la topografía por erosión.

Palabras clave: análisis de facies, conglomerados, fan delta, Carbonífero, Zona Cantábrica.

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The Hercynian orogeny of Spain's Cantabrian Zone (Fig. 1) lasted throughout much of the Late Carboniferous, and synsedimentary tectonism is well represented in the stratigraphic record. Folding and the advancement of nappes produced widespread unconformities which define three phases of the orogeny (Wagner and Martínez García, 1974; Truyóls Santonja, 1983). During this period the basin depocenter migrated eastward over 120 km and experienced extremely rapid subsidence rates (Marcos and Pulgar, 1982; Heredia *et al.*, 1990). Conglomerates with clasts of local origin were cannibalized as thrusting and uplift proceeded across the basin (Truyóls Santonja, 1983; Fernández *et al.*, 1988). Lastly, large-scale tectonic movements led to the emplacement of turbidites and olistoliths (Martínez García, 1981; Heredia *et al.*, 1990).

Moscovian-Kasimovian strata in the Picos de Europa mountains of the eastern Cantabrian Zone have been only briefly examined to date. They contain a number of interesting conglomerates and sandstones here interpreted as the deposits of coarse-grained deltas. A detailed knowledge of these rocks will better resolve the stratigraphic and tectonic evolution of the Picos de Europa area during the middle or Leonian phase of Hercynian mountain building.

More importantly, by comparing and contrasting the features of two dissimilar coarse-grained deltas, the predominant controls over facies development can be documented. A growing body of literature is now attempting to identify the signatures of varying sedimentary-tectonic processes on fan deltas (see papers in Nemec and Steel, 1988; Colella and Prior, 1990; Frostick and Steel, 1993a). These processes include, among others, the geometry of the feeder alluvial system, rate of sediment supply, sea-level changes, and synsedimentary tectonism. We intend to add that notable variations in grain size, composition, and facies character between two Cantabrian fan deltas express the sedimentary response to changes in provenance, delta profile, and tectonic relief.

Moscovian-Kasimovian strata at Demués

Upper Moscovian and Kasimovian strata of the northern Picos de Europa are exposed along a narrow east-west belt 40 km in length (Fig. 1). Along the road southeast of the village of Demués, five outcrops of a composite section were measured and described. Rocks of this study, outcropping over a distance of 3 km, belong to the uppermost Moscovian and Lower Kasimovian Series (Fig. 2), based on their contained fusulinids (Elisa Villa, *personal communication*, 1997), and they are informally called the lower-middle Gamonedo beds. A finalized stratigraphic framework awaits the completion of regional structural mapping and biostratigraphic zonation.

The Upper Moscovian section is dominated by limestone conglomerate and limestone. Fifty-eight meters are well exposed at Demués where the rocks rest unconformably on the Lower Carboniferous Barcaliente Formation. In contrast, Lower Kasimovian rocks consist primarily of quartzose sandstone and shale. This unit at Demués is partly covered, and its exact thickness is unknown. From initial geological mapping of the area, we estimate it to be 100 m thick. The overlying strata, called the upper Gamonedo beds, consist of 100 m of fossiliferous limestone and shale.

The lower-middle Gamonedo beds at Demués can be divided into two vertically stacked packages, here labeled Succession A (Upper Moscovian) and B (Lower Kasimovian). Both successions are composed of interbedded conglomerate, sandstone, shale, limestone, and coal (Fig. 3 and 4), but the two differ substantially in detail. These differences, as described below, are interpreted to reflect changes in regional geography at the time of deposition.

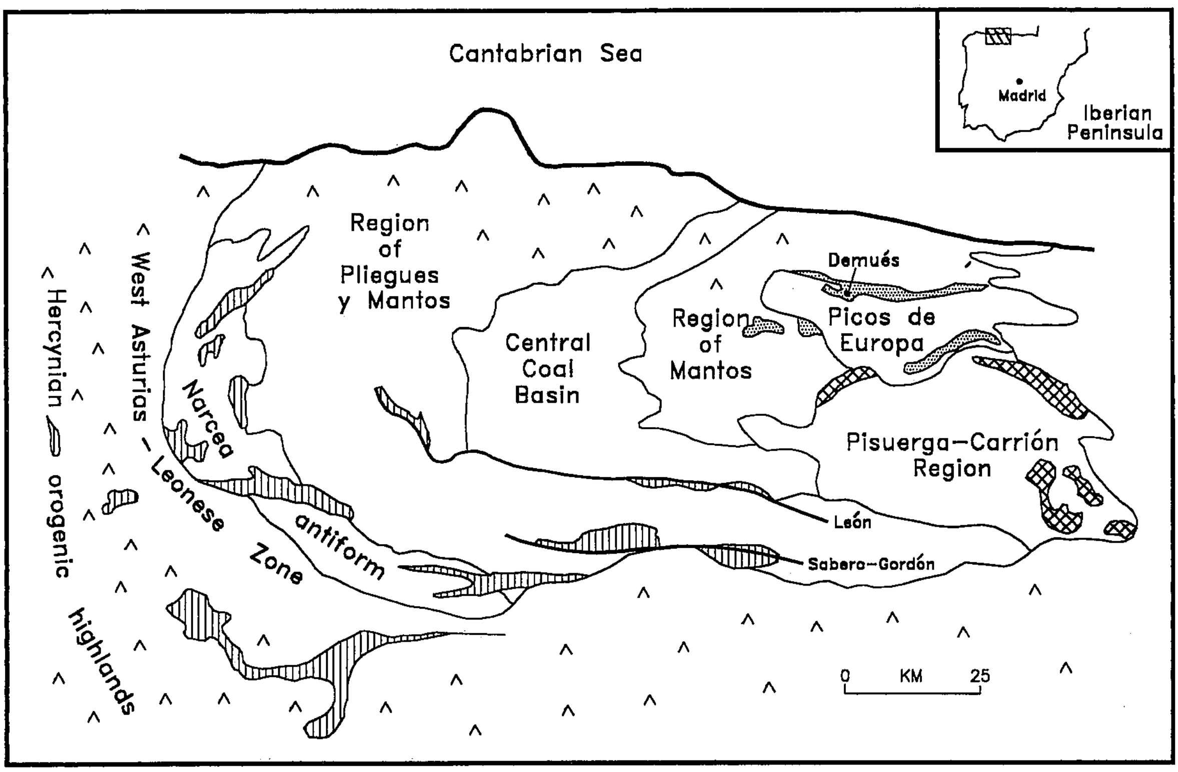

Figure 1.-Late Carboniferous paleogeography of the Cantabrian Zone in northwestern Spain. Highlands of the Hercynian orogeny wrapping around the southern, western, and northern basin margins; continental beds of the western and southern regions (lined); continental and marine beds of the eastern Pisuerga-Carrión region (crosshatching); and mostly marine beds of the northeastern Picos de Europa and Region of Mantos (shaded). Outcrops of this study are located at Demués in the Picos de Europa.

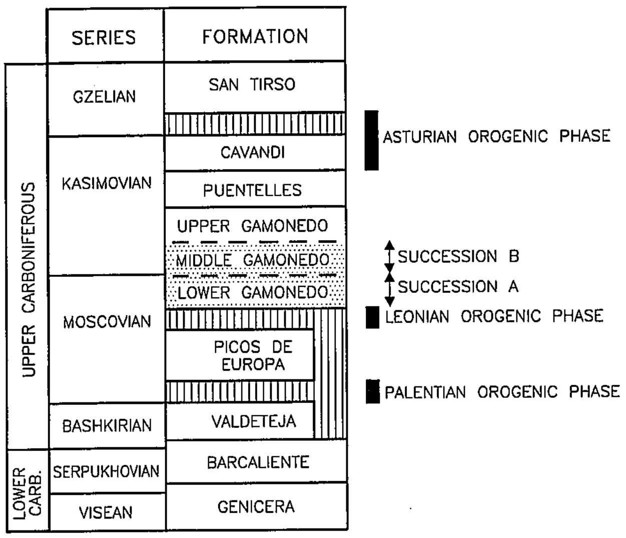

Figure 2.-Chronostratigraphic chart of Carboniferous strata in the Picos de Europa area, eastern Cantabrian Zone. Succession A corresponds to the uppermost Moscovian Series, and Succession B to the Lower Kasimovian. Rocks of this study are informally referred to as the lower-middle Gamonedo beds. Also shown are the three principal phases of the Hercynian orogeny. No scale intended.

Toe-of-Slope Facies

Succession A

Twenty-one beds of limestone conglomerate occur in the lower section (Fig. 5 and 6). They are usually stacked one atop another, and their basal contacts may be abrupt or gradational. Clasts are well rounded to subrounded, poorly sorted, and generally lacking orientation. They consist of limestone rock fragments and large fossils (corals and crinoids) as well as rare quartz and chert grains and sandstone rock fragments. Finer limestone clasts, quartz sand, and skeletal debris of crinoids, fusulinids, brachiopods, and gastropods constitute the matrix.

Most of the beds are best described as normally graded-to-laminated limestone conglomerate (Fig. 3, columns 1 and 2). They may be classified as glGS using the facies code of Ghibaudo (1992). The lower conglomeratic portion of these beds has no internal stratification but does display normal grading. The upper portion is a parallel-laminated calcarenite composed of skeletal grains identical to the conglomerate's matrix.

Several of the beds are normally graded limestone conglomerate similar to those described above but lacking a laminated cap (facies code gG). The content of sand-sized skeletal matrix is usually high, and in fact the large clasts of one bed appear to be sand-supported, though still normally graded (facies code gGyS).

Three additional beds consist of inversely graded and inverse-to-normally graded, sand-supported conglomerate. They are classified as type (i)gGyS, (in)gGyS, and (in)glGyS. The beds contain rounded to angular limestone clasts set in an abundant matrix of coarse skeletal sand. In two of these beds the conglomerate is capped by laminated and normally graded or disorganized crinoidal calcarenite (Fig. 5C).

We interpret the normally graded and graded-laminated, clast-supported conglomerates (glGS and gG) to have been transported by gravelly high-density turbidity currents (compare with Lowe, 1982; Nemec and Steel, 1984; Pickering *et al.*, 1989; Ghibaudo, 1992). Normally graded conglomerate is a single unit of coarse sediment deposited from suspension, whereas graded-laminated conglomerate consists of a coarse basal suspended-sediment unit overlain by a sandy unit with traction structures.

Inversely graded, inverse-to-normally graded, and normally graded, sand-supported conglomerates (gGyS and glGyS) were likely transported by gravelly debris flows or density-modified grain flows (compare with Heward, 1978; Lowe, 1982; Kleinspehn *et al.*, 1984; Nemec and Steel, 1984). These deposits probably formed by cohesive or frictional freezing although normally-graded sections may have accumulated under more turbulent conditions in which grains settled from suspension.

Sandy parallel-laminated caps to several of the sediment-gravity flows (glGS and glGyS) were perhaps the product of a residual current that reworked the conglomerate soon after deposition (Lowe, 1982). Alternatively, they may be the product of a thin grain flow that separated by gravity-winnowing from the front of the next overlying turbulent gravity flow (Postma, 1984).

Succession B

Seven beds of pebbly sandstone constitute one facies in the lower portion of Succession B (Fig. 7). These quartzose sandstones exhibit graded bedding but incomplete Bouma divisions (facies code gSM of Ghibaudo, 1992). Their base can be either planar or a scour surface, and graded pebbly sandstone passes upward to very thin beds of black or gray-green shale (T_{ade} Bouma divisions). Only two of the units show sedimentary structures (code glSM): one displays parallel laminae in the middle portion (T_{abde} and the other, parallel laminae and small-scale planar cross-laminae (T_{abcde}).

An additional number of thin- to medium-bedded sandstones show normal grading but otherwise lack distinguishing sedimentary characteristics (code gS). These graded beds alternate in the stratigraphic section with fine- to very-coarse-grained, thin- to medium-bedded sandstone and shale of the prodelta/shelf facies. Prodelta/shelf sandstone, by way of contrast, is nongraded, poorly sorted, rippled, fossiliferous, and burrowed.

Another facies of Succession B consists of dark shale with thin interbeds of sandstone (code glMS). The laminated shale possesses rare brachiopods, crinoids, and bryozoans. Intercalated sandstone is normally graded, parallel- or ripple-laminated, and contains shale partings at the top of each bed.

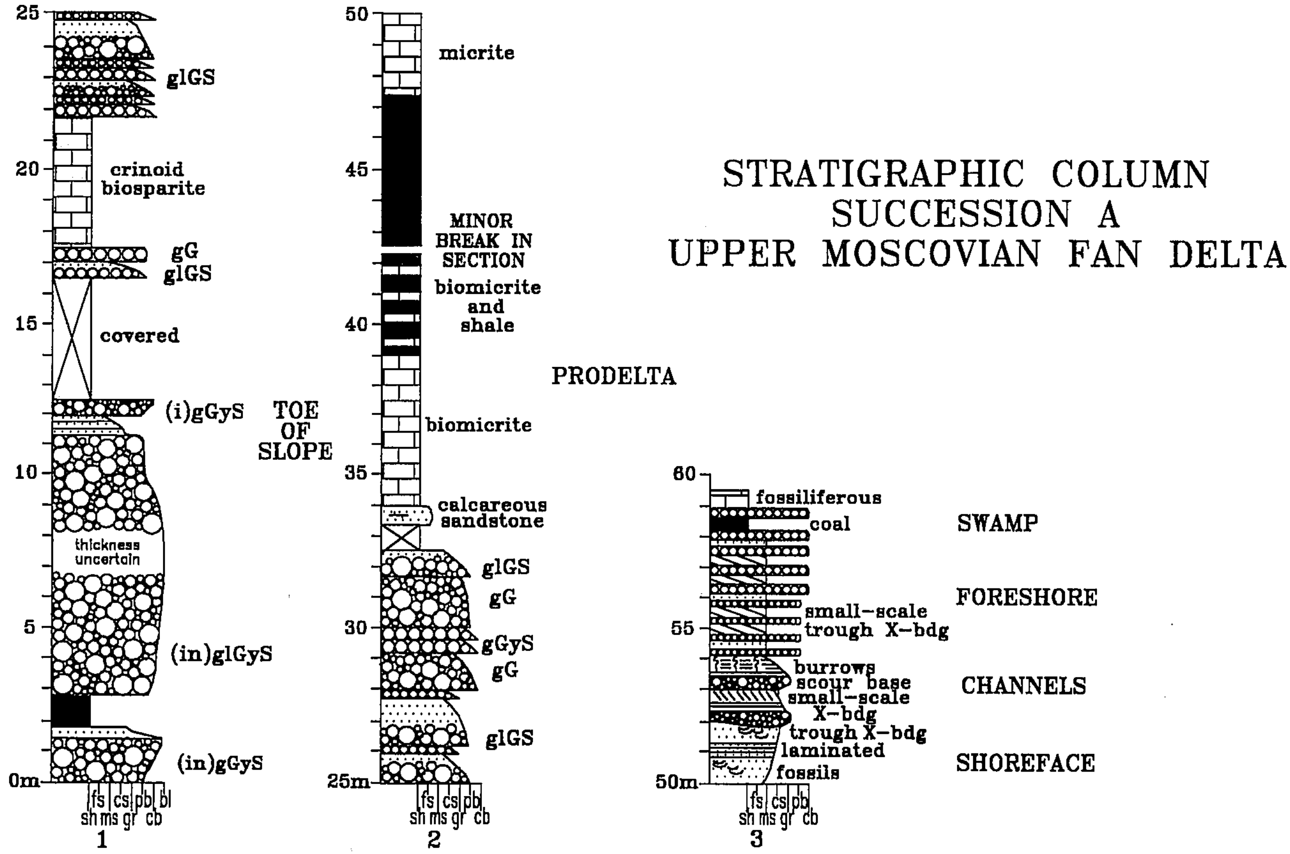

Figure 3.-Stratigraphic column and sedimentologic log of Succession A, Upper Moscovian strata at Demués. These rocks rest unconformably on the Lower Carboniferous Barcaliente Formation. The lowest 50 meters (columns 1 and 2) are interpreted as toe-of-slope and prodelta/shelf deposits. Code letters adjacent to the columns identify sediment-gravity flows discussed in the text. The overlying 8 meters (column 3) consist of delta-front (shoreface, foreshore, and distributary channel) and delta-plain (swamp) facies.

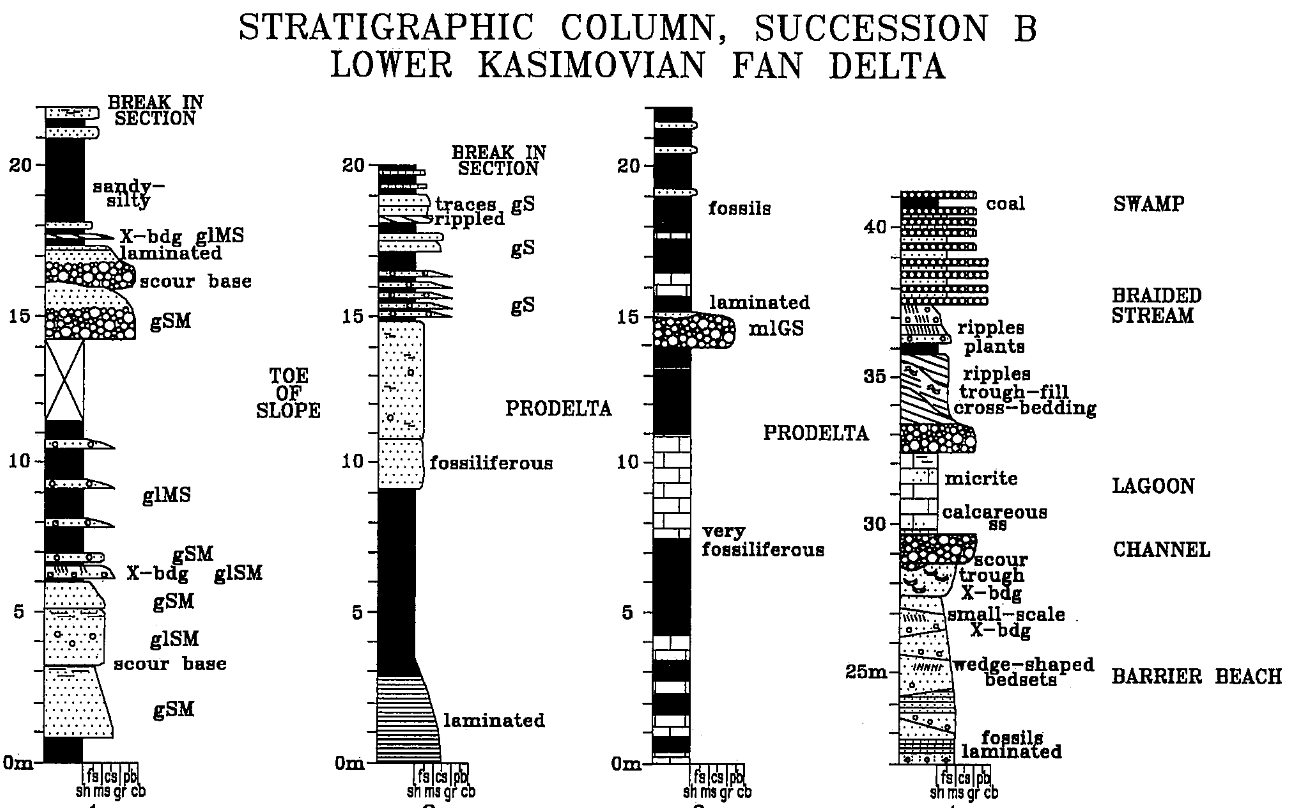

Figure 4.-Stratigraphic column and sedimentologic log of Succession B, Lower Kasimovian strata at Demués. The lowest 64 meters (columns 1, 2, and 3) represent toe-of-slope and prodelta/shelf facies. Code letters adjacent to the columns identify sediment-gravity flows discussed in the text. The uppermost 19 meters (column 4) make up the delta-front (barrier-beach, lagoon, and distributary channel) and delta-plain (braided stream and swamp) facies.

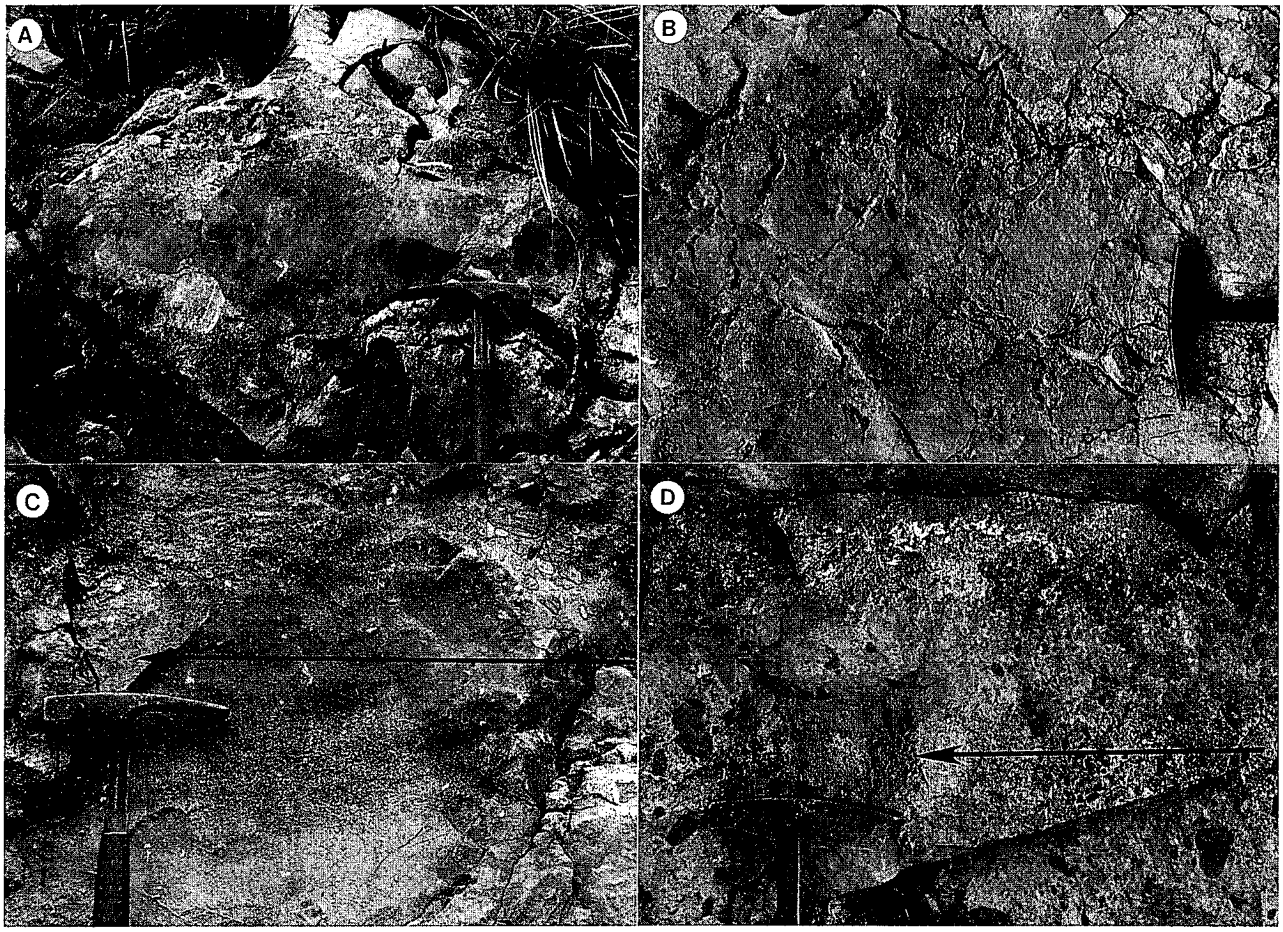

Figure 5.-Outcrop photographs showing sediment-gravity flows of Succession A. In all four pictures, bedding is nearly vertical and stratigraphic up is to the left. Hammer for scale. **A)** Poorly sorted conglomerate with clasts up to boulder in size. **B)** Coarse pebble-sized clasts of limestone set in a matrix of granule-sized clasts, fossils, and quartz sand. Irregular fractures mark the general outline of clasts, which are more rounded than they appear in the photo. **C)** Two-part sediment-gravity flow (arrow). The basal limestone conglomerate (at right) is inversely graded and sand-supported; the upper capping unit (center) is a parallel-laminated calcarenite. **D)** Normally graded turbidite (arrow) with rounded clasts oriented subparallel to bedding. Limestone conglomerate of the next overlying turbidite is seen at level of the hammer.

The last of the coarse-grained facies in the lower section (Fig. 4, columns 1-3) is a massive-laminated limestone conglomerate (code mlGS) containing disorganized pebbles of limestone, well rounded quartz, and skeletal debris (whole coral and crinoids). An upper unit of laminated calcarenite sits atop the conglomerate with an erosional contact.

Graded pebbly sandstones with and without Bouma divisions (gSM, glSM, and gS) are interpreted as the product of sandy, high-density turbidity currents (Lowe, 1982; Walker, 1984; Ghibaudo, 1992). Most pebbles are shale clasts, having been eroded from underlying muds by the passing current. The dark shale (glMS) formed by slow and uniform deposition from suspension in a low-density turbidity current, and intercalated sandstone reflects bed-load transport beneath a dilute turbidity current (compare with Lowe, 1982; Pickering et al., 1989). The single limestone conglomerate (msGS), like those of Succession A, seems to be the deposit of a debris flow or modified grain flow, reworked somewhat by residual currents.

Prodelta/Shelf Facies

Succession A

About half of the lower section (Fig. 3, column 1 and upper part of column 2) consists of skeletal limestone, shale, and calcareous sandstone. The skeletal limestone is thin- to medium-bedded biomicrite and biosparite. Fossil abundance and diversity are high; the assemblage includes crinoids, fusulinids and other foraminifera, brachiopods, rugose corals, ramose bryozoans, phylloid algae, oncolites, gastropods, and scaphopods. The biomicrite is somewhat argillaceous and interbedded with buff-colored shale, whereas the biosparite may be sandy and pass into calcareous sandstone. Moreover, the biosparite displays parallel laminae (occasionally disrupted by burrows), small-scale cross-bedding, and erosional intraclasts of micrite.

The skeletal limestone, interbedded shale, and rare calcareous sandstone are interpreted to represent deposition in a shallow sea with normal salinity and good circulation. This hospitable environment supported a wide diversity of invertebrates and algae.

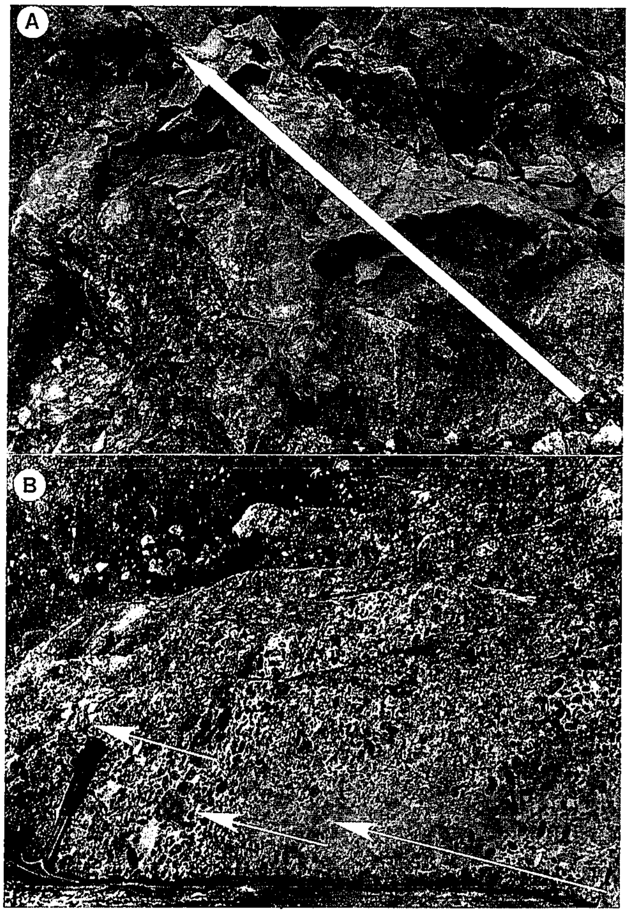

Figure 6.-Outcrop photographs showing sediment-gravity flows of Succession A. In both pictures bedding is nearly vertical and stratigraphic up is to the left. Hammer for scale. **A)** Normally graded turbidite (arrow): basal limestone conglomerate, appearing dark in the photo, grades upward to light-colored calcarenite. Dark basal conglomerate of the next turbidite appears at upper left (above hammer). **B)** Three stacked, normally graded conglomerates (arrows), ranging from 19 to 27 cm in thickness. Sharp basal contacts are lacking.

Water depth varied from below wave base where calcareous and terrigenous muds accumulated, to above wave base where moderate wave action moved the coarse skeletal sediment, quartz sand, and intraclasts. The invertebrate communities probably flourished when the delta was temporarily inactive and the sedimentation rate, low. In a similar setting, reefs and skeletal sands are today accumulating on nearshore slopes of fan deltas in Jamaica and the Gulf of Aqaba (Wescott and Ethridge, 1980; Hayward, 1985).

Succession B

The lower section (Fig. 4, columns 1-3) contains significant shale, sandstone, and skeletal limestone. The sandstone is fine- to coarse-grained, medium- to thick-bedded, and limonitic. Sedimentary structures include parallel laminae and ripple bedding. Brachiopods, gastropods, bivalves, fusulinids, crinoids, comminuted plant debris, and trace fossils (including *Zoophycus*) occur in the moderately fossiliferous sandstone. Medium to thick beds of limestone are composed of biomicrite, locally sandy, often with limonitic concretions, and generally burrowed. The fossil content is both abundant and diverse: crinoids, brachiopods, rugose and tabulate corals, bryozoans, sponges, phylloid algae, trilobites, scaphopods, gastropods, cephalopods, and comminuted plant debris. Gray shale interbedded with the skeletal limestone is very fossiliferous, containing an identical assemblage of invertebrates. On the other hand, gray and buff shale interbedded with the sandstone is silty/sandy and only sparsely fossiliferous, with few brachiopods, comminuted plant debris, and burrows.

The shale, sandstone, and limestone record offshore environments similar to those of Succession A, the only major difference being a much greater influx of sand and mud. Based on rock types, sedimentary structures, and fossil content, the basin in which these offshore rocks formed is thought to have been relatively shallow. Maximum water depth during deposition of both the Moscovian A and the Kasimovian B successions was somewhat greater than wave base.

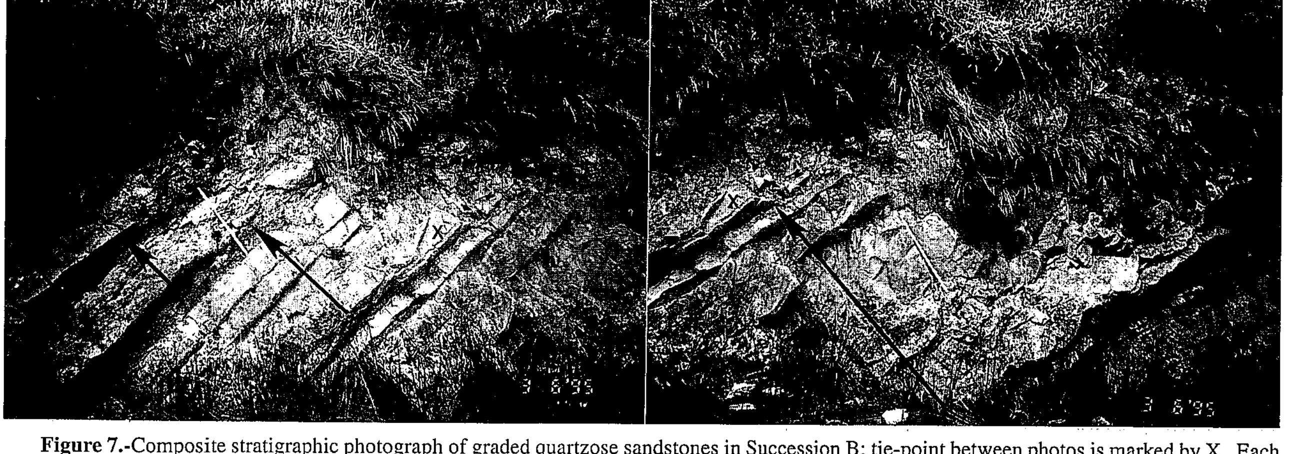

Figure 7.-Composite stratigraphic photograph of graded quartzose sandstones in Succession B; tie-point between photos is marked by X. Each turbidite grades from a sharp-based, medium-grained sandstone upward to shale. The four stacked turbidites shown here (arrows) become progressively thinner up-section to the left: 1.9 m, 1.0 m, 0.5 m and 0.3 m. Scales equal 63 cm.

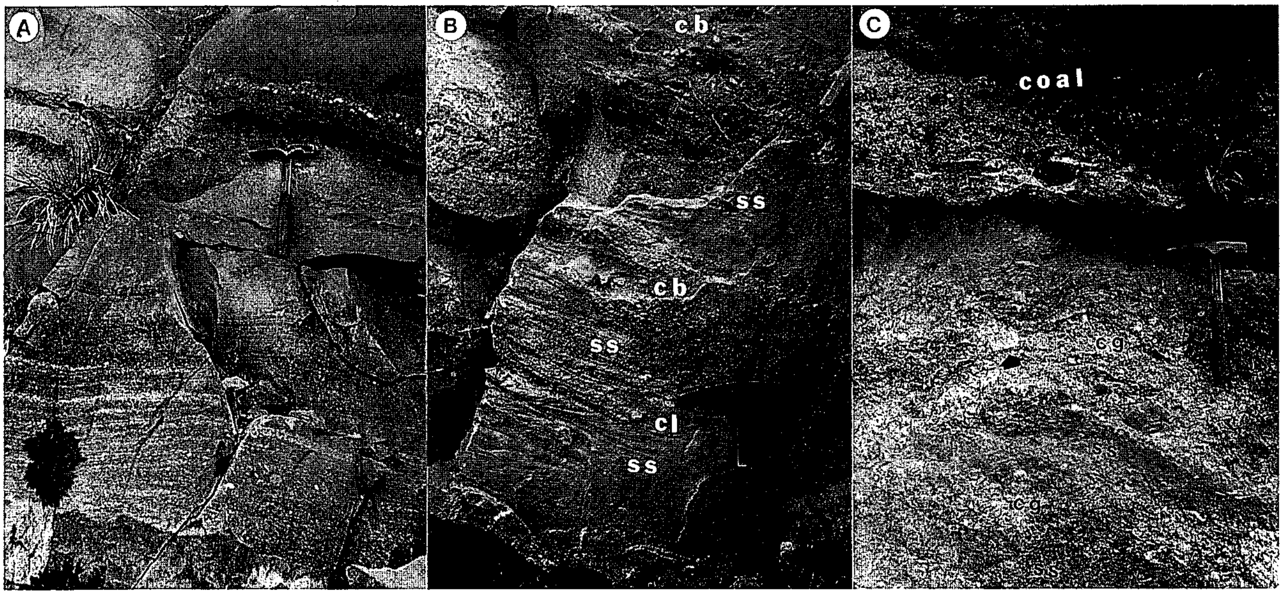

Figure 8.-Outcrop photographs of delta-front and delta-plain facies of Succession A. Hammer for scale. **A)** Fining-upward sequence of conglomeratic sandstone. The scour base is immediately overlain by cross-bedded conglomerate interbedded with laminated sandstone. The middle section (just below hammer) is parallel-laminated, medium- to coarse-grained sandstone, and the upper section (at level of hammer) consists of burrowed fine sandstone. A thin conglomerate above marks the base of the next higher sequence. **B)** Intercalations of conglomerate beds and lenses (cb, cl) with parallel-laminated and cross-laminated sandstone (ss). Conglomerate grain size as well as bed thickness increase upward. **C)** Interbeds of quartzose conglomerate (cg, maximum clast size at arrow is 12 cm) and fine sandstone (ss) are overlain by coal seam.

Delta-Front Facies

Succession A

Eight meters of sandstone and conglomerate lie above the offshore facies in the Upper Moscovian section (Fig. 3, column 3, 50-58 m). Strata within this package are dominated by cross bedding, as opposed to the graded bedding observed in underlying sediment-gravity flows, and exhibit an overall coarsening-upward trend.

At the base is a fossiliferous sandstone containing crinoids, gastropods, brachiopods, bryozoans, and comminuted plant debris. The predominant sedimentary structures are small- and large-scale trough cross-laminae, though parallel laminae are also present.

Two overlying conglomeratic sandstones have a lenticular geometry and fine upward (Fig. 8A). The base of each is marked by a scour surface and cross-bedded conglomerate with well rounded pebbles of quartz, limestone, fossils, and rare shale fragments. The middle section of both units is parallel-laminated, medium- to coarse-grained sandstone with some granules. And the upper section consists of fine- to medium-grained sandstone with scattered pebbles, comminuted plant debris, and brachiopods. In one unit, the upper sandstone exhibits low-angle planar cross-laminae, but in the second the upper section has been extensively bioturbated.

The upper half of the stratigraphic section is composed of conglomerate and sandstone couplets (Fig. 8B and C). Above a slightly erosional base, each conglomerate contains well rounded pebbles and cobbles of quartz, limestone, crinoids, and sandstone rock fragments in a matrix of quartz sand. Interbeds of fine- to medium-grained sandstone have a few dispersed quartz granules and abundant plant debris. Sedimentary structures include parallel laminae and small-scale trough and planar cross-laminae. Horizontal trace fossils can be present at the top of these sandstone beds.

Based on the studies of Clifton *et al.* (1971), Hunter *et al.* (1979), Clifton (1981), and Bourgeois and Leithold (1984), we interpret these rocks to have originated in a high-energy, nonbarred, shoreline environment. The lower fossiliferous sandstone represents a sandy shoreface characterized by ripples and dunes (small- and large-scale trough cross-laminae). The higher conglomerate-sandstone couplets mark the surf and swash zones of the foreshore where breaking waves segregated sand from gravel. The lenses of conglomeratic sandstones, however, formed in a fluvial channel: thin layers of pebbles line shallow scours and fine upward to laminated and burrowed sand (compare with Kleinspehn *et al.*, 1984). Channels appear to have been ½-1 m deep, and they denote an interruption of the shoreline by distributaries. Coarse sediment was thus transported to the shore through these distributary channels but then continuously reworked by strong waves (compare with Orton, 1988; Bardaji *et al.*, 1990; López-Blanco, 1993).

Succession B

In the Lower Kasimovian section, ten meters of laminated sandstone and sandy limestone lie above the offshore facies (Fig. 4, column 4, 22-32 m). The sandstone consists of medium- to very-coarse-grained quartz in wedge-shaped beds, ranging in thickness from 0.25 to 1.2 m (Fig. 9A). Quartz pebbles, shale clasts,

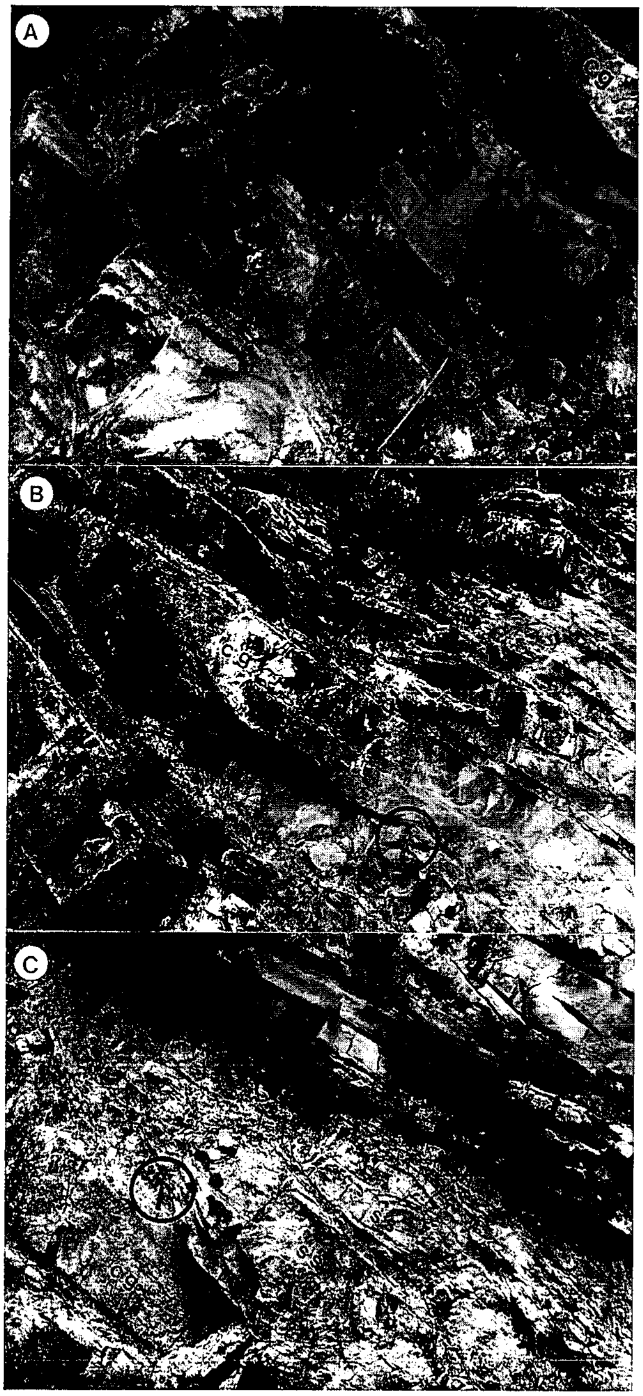

Figure 9.-Outcrop photographs of delta-front and delta-plain facies of Succession B. In all three pictures stratigraphic up is to the right. **A)** Thick, wedge-shaped beds of coarse-grained, parallel-laminated sandstone. The uppermost bed is a conglomerate (cg). Scale equals 63 cm. **B)** The same conglomerate as above has clearly eroded into the underlying sandstone. Hammer (in circle) for scale. **C)** Massive basal conglomerate (cg); sandstone (ss) exhibiting trough-fill cross-bedding; and thin overlying shale (sh). Hammer (in circle) for scale.

crinoidal debris, and corals constitute thin coarse-grained layers at the base of these wedges, and trace fossils occur at the top of the bedsets. Dominant structures are (1) parallel laminae and low-angle, bidirectional planar cross-laminae and (2) large-scale planar and trough cross-laminae. The uppermost bed is a conglomeratic, fossiliferous sandstone that has scoured into the laminated sandstone (Fig. 9B).

The overlying limestone is laminated unfossiliferous micrite, but intercalations of fine- to medium-grained sandstone are common. These thin calcareous sandstones have a lens shape, scour base with granules, ripple cross-laminae, abundant plant debris, trace fossils on their bedding planes, and shale partings.

The coarse-grained sandstone is thought to have accumulated on a high-energy barrier beach. Wedge-shaped sets of parallel and low-angle laminae with coarse storm lags constitute common depositional structures of shoreline sands (McCubbin, 1982; Reinson, 1984). Subaqueous dunes and sand waves migrating under the influence of waves and currents generated the large-scale cross-bedding (McCubbin, 1982; Davis, 1985). Behind the barrier beach lay a restricted lagoon in which micrite accumulated. Minor washovers of beach sediment across the barrier led to the thin lenses of sandstone intercalated with lagoonal limestone. Lastly, the conglomeratic sandstone formed in a shallow distributary channel that cut across the barrier-beach. We interpret the coarse sediment of this facies association to have been transported to the shoreline through distributary channels and then reworked by wave action into barrier-beach deposits (compare with Mather, 1993).

Delta-Plain Facies

Succession A

A shaly coal, 0.3-0.6 m thick, constitutes the top of Succession A (Fig. 3, column 3, 58 m). It is the product of a fresh-water coastal swamp (Fig. 8C). In an analogous modern setting, organic mud accumulates in a coastal Jamaican swamp situated at the foot of a small mountain chain and adjacent to the sand and gravel beach of a fan delta (Wescott and Ethridge, 1980). The overlying 1 m consists of quartz-limestone conglomerate and sandy oncolitic-fossiliferous limestone which represent nearshore facies of the next transgression.

Succession B

The uppermost section (Fig. 4, column 4, 32-41 m) is a mix of coarse-grained rock types (Fig. 9C). A thick, basal sandy conglomerate contains pebbles of micritic limestone and quartz. Above this lies a laminated, medium- to coarse-grained sandstone with both trough-fill and planar cross-beds (30-70 cm thick). Small-ripple bedding and burrows occur along the top of some sandstone beds. Comminuted plant debris is abundant. A thin sandy shale caps this fining-upward unit.

The highest unit comprises several conglomerate-sandstone alternations in which bedding is only poorly preserved. Multiple scour surfaces, a crude vertical cyclicity, and numerous grain-size reversals characterize the unit. Thin, lenticular conglomerates have a sharp base, well rounded clasts, and a matrix of medium- to coarse-grained quartz. They rarely display a fining-upward sequence. Interbedded sandstones are medium- to coarse-grained, calcareous, and vaguely laminated. Some beds contain small-scale trough and planar cross-laminae. Comminuted plant debris is abundant. Succession B is capped by 0.2 m of coal, which in turn is overlain by another thin conglomerate.

These interbedded conglomerates and sandstones contain features typical of a Donjek-type of braided-stream deposit (compare with Nemec and Steel, 1984; Hayward, 1985; Miall, 1996). Massive conglomerate of the lower unit represents lag deposits in a major active channel. The overlying sandstone formed as part of a transverse bar; large-scale planar cross-bedding accumulated by foresets of the migrating bar, whereas trough-fill cross-bedding formed in scour troughs located in front of the bar (see McGowen and Garner, 1970). Sandy shale may represent deposition on an inactive, topographically higher part of the transverse bar. The stratigraphically higher unit of alternating conglomerate and sandstone suggests that scour-and-fill sedimentation occurred repeatedly in minor braid channels with variable stream flow.

Paleogeographic-Sedimentary-Tectonic Inferences

Deltaic Sedimentation

The deltaic nature of Successions A and B is illustrated by a number of features: (1) Each stratigraphic pattern is that of a thick, fining-then-coarsening-upward sequence, comparable to one of two fan-delta models of Ethridge and Wescott (1984). (2) Coarse-grained deposits with wave-generated structures (delta front) are underlain by fine-grained siliciclastic and carbonate rocks (prodelta/shelf) and sediment-gravity flows (toe-of-slope) and overlain by fluvial and/or swamp facies (delta plain). (3) These conglomerates and sandstones clearly built outward into a shallow sea as they themselves are fossiliferous and interfinger with marine limestone, shale, and sandstone.

Succession A is identified as the rock record of a fan delta (Fig. 10), based primarily on its very coarse grain size (compare with McPherson *et al.*, 1987; Orton, 1988; Colmenero *et al.*, 1988; Nemec, 1990). Indeed, half of the stratigraphic section consists of conglomerate. The fan-delta front is considered to have been wave dominated. Although distributary channels cutting across the delta front indicate a fluvial influence, wave processes strongly modified the sediment into shoreface-foreshore beach deposits. Delta fronts are often wave dominated where the sediment supply is infrequent, allowing marine processes to rework the fluvial input (Orton, 1988). Subaerial portions of the fan-delta plain were only poorly preserved. Upper Carboniferous coarse-grained facies of alluvial-fan origin have been described elsewhere in the Cantabrian zone, and these include braided-stream conglomerate and sandstone, mud-supported mass-flow conglomerate, and sheet-flow sandstone (Heward, 1978; Iwaniw, 1985). At Demués, however, delta-plain sediments are absent except for a thin coal seam.

Succession B is identified as the rock record of a second fan delta (Fig. 11). It exhibits many of the same stratigraphic patterns as the underlying delta; however, overall grain size is somewhat finer. Conglomerate makes up only 10 percent of the total section. Delta-plain facies, critical to an interpretation, are well preserved: coal and coarse-grained channel deposits of a braided stream. The wave-dominated delta-front facies include distributary-channel conglomerate, beach sandstone, and lagoonal limestone.

Source Area

Tectonic movements of the Leonian and Asturian orogenic phases, primarily in the form of kilometer-scale folds and faults (Martínez García, 1981), created uplands around the margins of the Cantabrian basin (compare with Heward, 1978; Colmenero *et al.*, 1988; Fernández *et al.*, 1988). Uplift of a new source area is documented in this present study by the sudden appearance and abundance of large clasts in the Moscovian-Kasimovian section immediately overlying a regional unconformity.

During accumulation of Succession A, several lower Carboniferous formations must have been exposed in these nearby uplands: laminated micrite of the Barcaliente Formation; biosparite of the Valdeteja Formation; fossiliferous biomicrite and biosparite, laminated micrite, nodular red limestone, chert, and shale of the Picos de Europa Formation; and alternating shale, sandstone, and limestone of the Beleño and Fito Formations (western and northwestern equivalents of Picos de Europa limestones). Many limestone clasts of the Upper Moscovian match the rock types of these slightly older limestones, particularly laminated micrite of the Barcaliente and red limestone of the Picos de Europa. Detrital quartz grains plus rare chert and sandstone rock fragments are of secondary importance; these may have been reworked from the Picos de Europa, Beleño, and Fito Formations.

In contrast, pebbles of Succession B are predominantly quartz; limestone clasts are rare. Sandstone and conglomerate of the Upper Devonian Ermita Formation and sandstone with interbedded shale of the Ordovician Barrios Formation are the parent rocks. The Ermita occurs directly beneath the thick succession of Carboniferous limestones; the Barrios lies unconformably beneath the Ermita but had been elevated in the vicinity by Hercynian thrust faulting (Martínez García, 1981). In addition to abundant quartz clasts, Succession B contains a significant

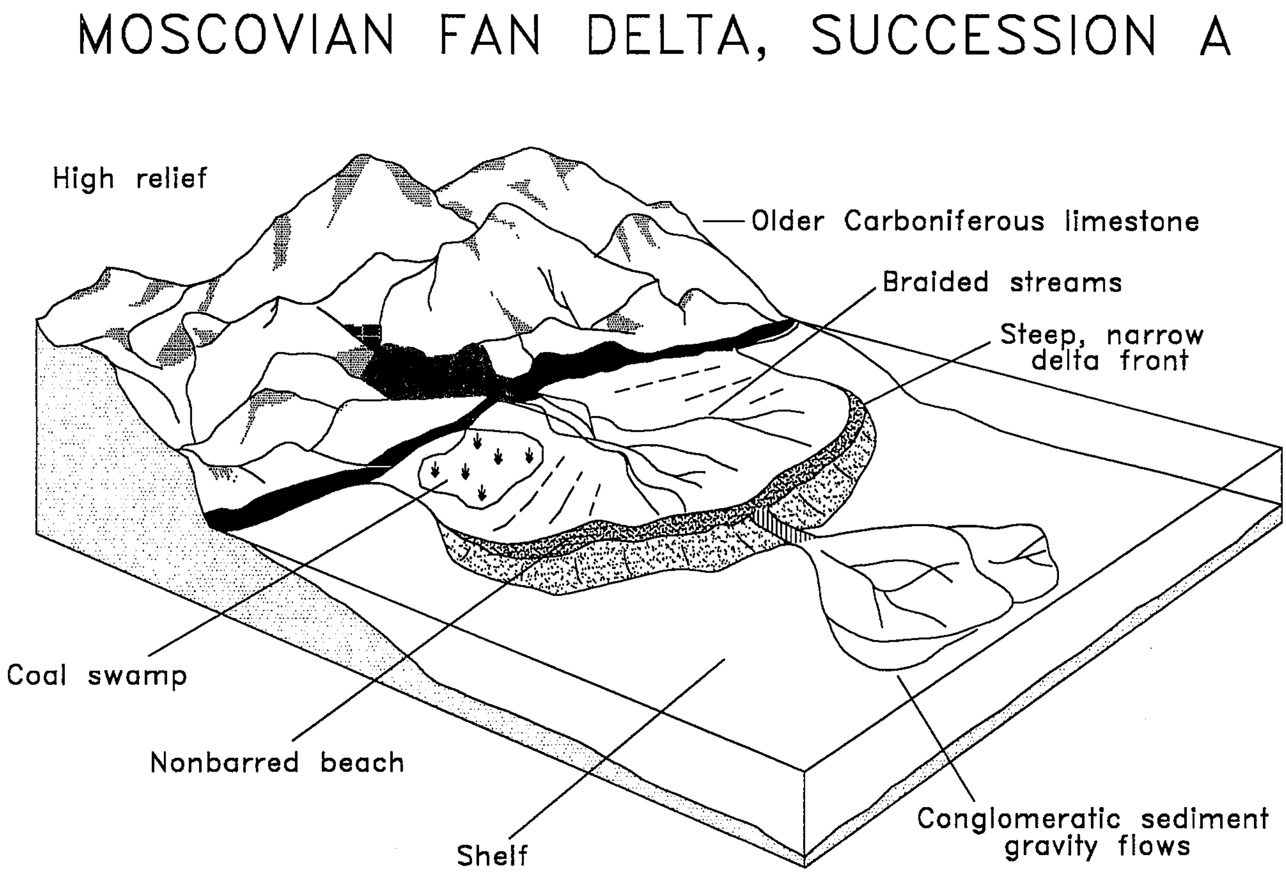

Figure 10.-Hypothesized geological setting for stratigraphic Succession A illustrates a high-relief source area exposing older Carboniferous limestone formations, a coal swamp on the delta plain, nonbarred beach and narrow delta front of steep gradient, prodelta/shelf facies, and conglomeratic sediment-gravity flows at the delta's toe.

volume of shale (30% of the exposed section and twice as much as that of Succession A), confirming a provenance of siliciclastic rocks.

We envision a source area whose rock types changed through time (Fig. 10 and 11). Initially Carboniferous limestones were exposed to erosion in the surrounding uplands, contributing sediment to the fan delta of Succession A. But with time Devonian and Ordovician sandstones became exposed, providing sediment of different mineralogy and texture to the fan delta of Succession B. The source area for both deltas, though, consisted of the same fold-thrust structures north of the study area. The first fan delta was probably not any more distant from the uplands than the second.

Delta Profile and Grain-Size Distribution

Lowermost sediment-gravity flows of the Moscovian section are inversely graded and inverse-to-normally graded conglomerates (Fig. 3, column 1, 0-12 m). Clasts in these beds include the largest recorded at Demués (up to 50 cm; Fig. 5A). If grain size were related to topographic relief (Rust and Koster, 1984), the tectonic uplands along the basin margin must have been quite high. Moreover, the large shear stress required to produce inverse grading implies a very steep slope (Harms *et al.*, 1975; Walker, 1975). These bouldery, inversely graded debris flows, therefore, appear to have been the product of tectonic movement; the initial fan-delta sediments probably formed in response to uplift of a nearby fold-thrust structure.

Normally graded conglomerates of the Moscovian fan delta (Fig. 3, columns 1 and 2, 16-32 m) are thought to have accumulated at the toe of a steep, but slightly gentler slope as sediment aggradation and progradation continued through time. Transport of these coarse-grained limestone clasts across the delta front and to the toe may have been triggered by major floods, storms, seismic disturbances, or tectonic movements. Successive pulses of gravelly high-density turbidity currents led to a stacking of conglomerates at the toe of the slope.

The delta front is inferred to have been steep and narrow (Fig. 10), perhaps similar to Oregon's high-energy shoreline which has a width of 200 m and slope of 1½° (Pacific coast of western USA; Clifton *et al.*, 1971). Intense wave action would have abraded and rounded Gamonedo limestone clasts eroded from nearby highlands, ultimately producing delta-front sediments of conglomerate, conglomeratic sandstone, and coarse sandstone. Except for the lowermost

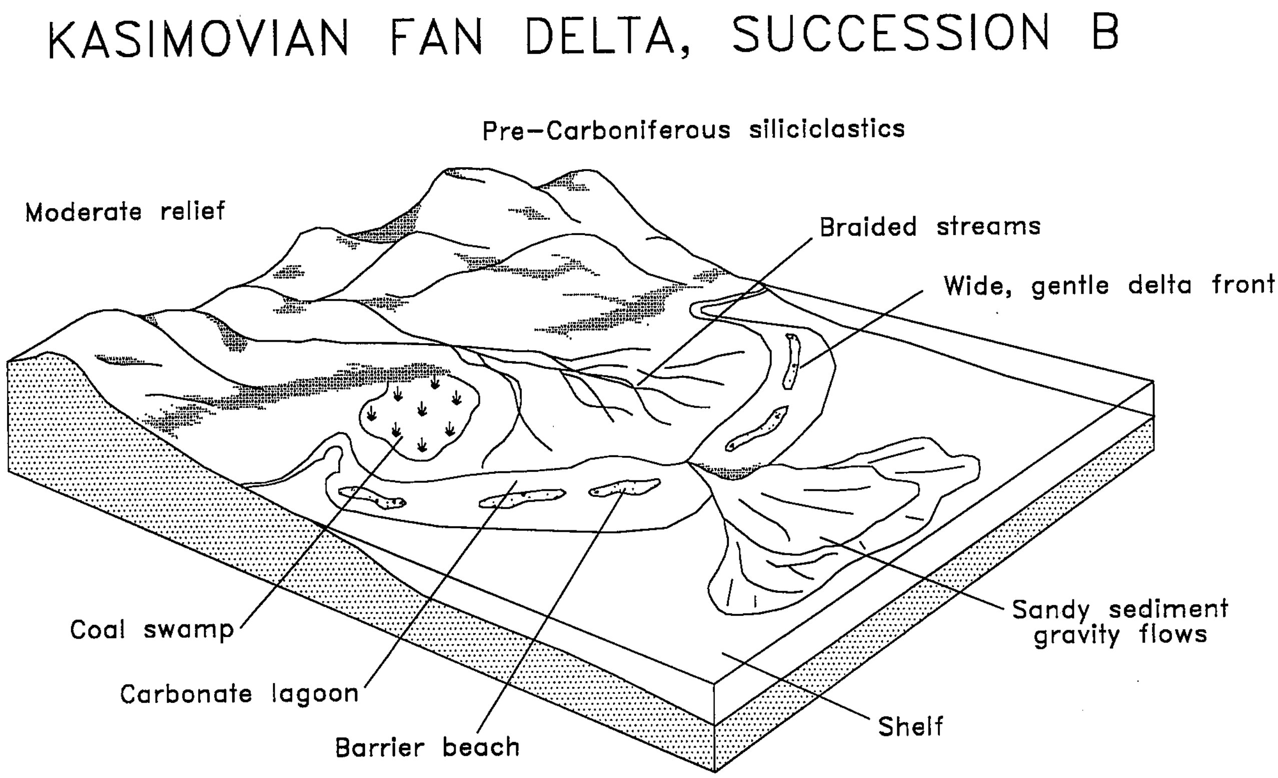

Figure 11.-Hypothesized geological setting for stratigraphic Succession B involves a source area of moderate relief developed on pre-Carboniferous siliciclastic rocks, braided streams and coal swamp of the delta plain, a wide delta front with gentle slope containing barrier beach and restricted lagoon, prodelta/shelf facies, and sandy sediment-gravity flows at the delta's toe.

inversely graded debris flows, toe-of-slope conglomerates of this fan delta have a maximum clast size (4-14 cm) not much different from the delta-front sediments (3-12 cm). Thus limestone clasts of the steep fan delta, ranging from very large pebble to small cobble, occurred in both delta-front and delta-toe environments. There was no significant change in grain size in a downfan direction.

During deposition of the succeeding fan delta of Kasimovian Succession B, erosion had cut deeper into the surrounding uplands exposing older siliciclastic rocks. A major influx of quartz sediment now entered the basin, and its relatively fine grain size (maximum of only 4 cm) suggests a lowered relief in the source area. Braided streams of moderately steep gradient drained these uplands and transported well rounded quartz pebbles and sand (Fig. 11).

The fan-delta front of Succession B, consisting of barrier beach and restricted lagoon, was probably wider and gentler than that of Succession A. An analogous barred, coarse-grained delta in Alaska has a delta front that extends seaward 20 km with a shoreface slope of much less than 1° (Galloway, 1976). The wide Cantabrian delta front was the depositional site of medium- to coarse-grained sandstone with only minor conglomerate.

Toe-of-slope sedimentation produced Kasimovian turbidites (Fig. 11) but of a drastically different character than those of the first delta: graded sandstone deposited quickly from high-density sandy currents and interbedded shale and sandstone deposited more slowly from dilute muddy flows. These changes relate to a lowering of relief in the source area, reduction of the depositional slope angle, and a slowing of current velocity. Tectonic uplift and steep relief, which seemingly gave rise to the Moscovian fan delta, seems not to have played a major role in development of the succeeding delta.

The delta of Succession B apparently acted as a sediment trap for gravel-sized quartz grains. Accumulating in the braided-stream channels were pebbles with a maximum size of 4 cm, and on the barrier beach, pebbles of 2 cm. But only rarely were quartz clasts coarser than 1 cm transported by sediment-gravity flows down to the delta toe. As opposed to Succession A, there was a significant decrease in grain size in a seaward direction.

Conclusions

The two fan deltas at Demués illustrate some lithologic similarities but also a number of important differences (Table I). Both are coarse grained with a substantial conglomerate component and a complex fining-then-coarsening-upward sequence. Both prograded into a shallow coastal sea. Finally, the deltaic nature of both is demonstrated by the presence of delta-front deposits with wave-generated structures, underlain by slope deposits of sediment-gravity flows and overlain by coal-bearing sediments of a delta plain.

	FAN DELTA	BRAID DELTA
succession thickness	58 m	83+m
vertical grain-size trend	fining-then-coarsening upward	fining-then-coarsening upward
percent conglomerate	50%	10%
maximum grain size	12-50 cm	1-4 cm
percent shale	15%	30%
facies		
delta plain	coal swamp	braided stream and coal swamp
delta front	nonbarred beach	barrier beach and carbonate lagoon
prodelta/shelf	neritic limestone and shale	neritic shale and sandstone
toe-of-slope	gravelly high-density turbidity currents	sandy high-density and muddy low-
	and density-modified grain flows	density turbidity currents
parent rock	carbonate	siliciclastic
relief in source area	high	lowered by erosion
distance to source	close	close
delta profile	narrow and steep	broad and flat
grain-size change across delta	no change from delta front to slope	size decreases from delta plain to front to slope
relation to tectonism	early-posttectonic	late-posttectonic

Table I.-Comparison of fan delta and braid delta at Demués

Differences reside in the assemblage of lithofacies: (1) Delta-plain facies of Succession B include braided stream and coal swamp. Only a thin coal seam marks the delta-plain facies of Succession A; sediments of this steeper, narrower delta plain may have been more susceptible to later removal by erosion. (2) The wave-dominated delta front of Succession A comprises conglomerate and conglomeratic sandstone of a nonbarred beach, whereas barrier-beach sandstone and restricted-lagoon limestone accumulated on the delta front of Succession B. (3) Prodelta/shelf lithologies associated with Succession A include fossiliferous limestone and shale. Sandstone and shale, however, were deposited on the prodelta/shelf of Succession B. (4) Limestone conglomerates at the delta's toe (Succession A) formed as gravelly, high-density turbidites and debris flows/density-modified grain flows. In contrast, sandstone and shale turbidites at the delta's toe (Succession B) were generated by sandy high-density and muddy low-density currents.

Results of this study suggest that a collection of geographical, sedimentary, and tectonic factors acting in concert governed the facies development. One controlling factor was provenance. Parent rocks exposed in the source area and the topographic relief determined not only clast mineralogy but grain size of sediment made available to the deltas: gravel to the first fan delta but pebbly sand to the second. Transport distance from source area to delta was probably the same in both cases.

Delta geometry, particularly the width of the delta front and the overall slope angle of the delta's profile, was another major influence. The broad, flat, and barred profile of the Kasimovian delta served to trap coarse sediment on the delta plain and front. The narrow, steep, and nonbarred profile of the Moscovian delta, on the other hand, facilitated the sweep of coarse sediment seaward. Moreover, the texture and volume of sediment delivered to the delta slope, plus the slope angle itself, influenced the nature of sediment-gravity flows. Thus conglomerates deposited from high-density turbidity currents accumulated on the steeper front of the Moscovian fan delta, but sandstones from low-density currents accumulated on the gentler front of the Kasimovian delta.

The last control was relative timing between tectonic activity and deltaic sedimentation. Emplacement of kilometer-scale nappes is thought to have raised the source area, leading to deposition of the early-posttectonic fan delta of Succession A. With denudation and a reduction of relief, subsequent sedimentation produced the late-posttectonic fan delta of Succession B. Tectonism, though, was not a separate control on fan-delta architecture; it was directly or indirectly related to the other major influences (see Colella, 1988; Frostick and Steel, 1993b). Tectonic activity had a bearing on rate of uplift and erosion in the source area, rate and fluctuation of sediment supply, grain size and mineral content of sediment produced, gradient of the coastline and adjacent sea floor, and the nature of sediment-gravity flows.

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