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Romeo M. Flores

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SEDIMENTOLOGY OF UPPER CRETACEOUS AND TERTIARY SILICICLASTICS AND COALS IN THE RATON BASIN, NEW MEXICO AND COLORADO

ROMEO M. FLORES
U.S. Geological Survey, Denver, Colorado 80225

Abstract—The Raton Basin was a major site of siliciclastic and coal accumulation in coastal and alluvial plains from the Late Cretaceous to early Tertiary. The coastal plain was developed along the western margin of the Cretaceous epeiric seaway and consisted of barred and non-barred siliciclastic coastlines. The barred coastline included coastal-attached beach ridges, estuarine-fluvial channels and a back-beach marsh-swamp complex. The barred coastline was attached laterally to the non-barred coastline, which was constructed by delta systems that were fluvially dominated but minimally affected by wave and tidal processes. The Upper Cretaceous Pierre Shale, Trinidad Sandstone and Vermejo Formation were deposited in these siliciclastic coastal environments.

During the Laramide orogeny, the coastal plain was transformed into an alluvial plain of through-flow fluvial systems that drained on a foreland basin. The alluvial plain was built by braided, meandering and anastomosed streams. The braided streams generated sand-dominated facies, and the meandering and anastomosed streams produced fine-detritus-dominated facies. Coals are preferentially associated with the fine-detritus-dominated facies in which autocyclic processes of the fluvial systems, increased basin subsidence concurrent with diminished uplift of the source area and climate favored organic accumulation. The Maestrichtian and Paleocene Raton and Poison Canyon formations were deposited in these siliciclastic alluvial environments.

INTRODUCTION

The Raton Basin (Figs. 1, 2) in Colorado and New Mexico contains large coal resources that occur in the Upper Cretaceous Vermejo Formation and Upper Cretaceous and Paleocene Raton Formation. The coal beds that constitute these resources, which range from subbituminous to anthracite in rank, have been explored and developed for the past few decades without regard to the stratigraphic and sedimentologic facies frameworks. This paper focuses on the occurrence of coal beds in the Raton Basin with emphasis on their stratigraphic distribution, their association with depositional systems and the tectonic influence on the accumulation and preservation of coals. In order to assess these relationships, the sequence of coal-bearing and non-coal-bearing Upper Cretaceous and lower Tertiary formations will be discussed.

The Upper Cretaceous Pierre Shale, Trinidad Sandstone and Vermejo Formation and Upper Cretaceous and lower Tertiary Raton and Poison Canyon formations in the Raton Basin represent a progradational or regressive sequence (Fig. 3). The sequence records a progressive deposition of marine, marginal marine, coastal and alluvial sediments from the Late Cretaceous to early Tertiary, a time of episodic syntectonic sedimentary infilling during the Laramide orogeny. The paleoenvironmental and paleotectonic changes controlled the stratigraphic and geomorphic distributions of coal beds in the Raton Basin. Stratigraphically, coal beds are more numerous and better developed in the upper part of the sequence. Significant variation of siliciclastic depositional environments and their relation to coal-forming environments, particularly in the Vermejo and Raton formations, will be compared.

Major siliciclastic depositional environments that have been ascribed to the regressive Upper Cretaceous-lower Tertiary coal-bearing deposits include delta and alluvial plains behind barred (barrier) and non-barred coastlines. Matuszczak (1969), Pillmore and Maberry (1976) and Leighton (1980) interpreted certain segments of the Upper Cretaceous coastline during deposition of the siliciclastics of the Trinidad Sandstone and Vermejo Formation as barred or barrier complexes. That these barred complexes were laterally juxtaposed with non-barred complexes (fluvial-influenced delta plain) was indicated by Billingsley (1978), Flores

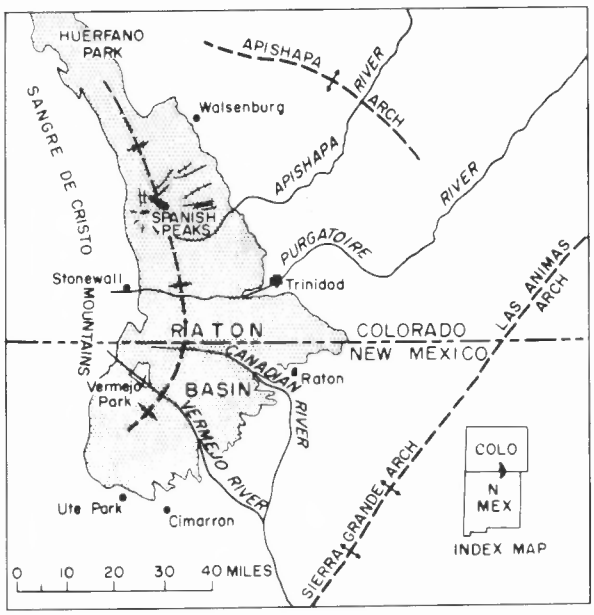


FIGURE 1. Locality map of the Raton Basin in New Mexico and Colorado.

AGE		FORMATION NAME	GENERAL DESCRIPTION	SYMBOL	APPROX. THICKNESS
TERTIARY	PALEOCENE	POISON CANYON FORMATION	SANDSTONE - COARSE TO CONGLOMERATIC; BEDS 15 TO 50 FEET THICK, INTERBEDS OF SOFT YELLOW-WEATHERING CLAYEY SANDSTONE. THICKENS TO WEST AT EXPENSE OF UNDERLYING RATON		500+ FT
		RATON FORMATION	SANDSTONE - VERY FINE GRAINED TO FINE GRAINED WITH INTERBEDS OF CLAYSTONE, SILTSTONE, AND COAL. LOWER 50 TO 150 FEET CONGLOMERATIC; COAL BEDS IN UPPER 1500 FEET INTERTONGUES WITH POISON CANYON TO THE WEST. SHARP EROSIONAL CONTACT WITH UNDERLYING VERMEJO		0?-1600 FT
MESOZOIC	UPPER CRETACEOUS	VERMEJO FORMATION	SANDSTONE - FINE GRAINED TO MEDIUM GRAINED, WITH MUDSTONE, CARBONACEOUS SHALE, AND COAL. EXTENSIVE THICK COALS. LOCAL SILLS		0-400 FT
		TRINIDAD AND OLDER FORMATIONS	TRINIDAD SANDSTONE - FINE GRAINED TO MEDIUM GRAINED. CONTAINS CASTS OF *OPHIOMORPHA*		0-130 FT
			PIERRE SHALE. BLACK SHALE, LIMESTONE CONCRETIONS, SILTY IN UPPER 300 FEET GRADES UP TO FINE SANDSTONE		200+ FT

K/T BOUNDARY

FIGURE 2. A generalized stratigraphic column of the rocks in the Raton Basin. Adopted from Flores et al. (1985).

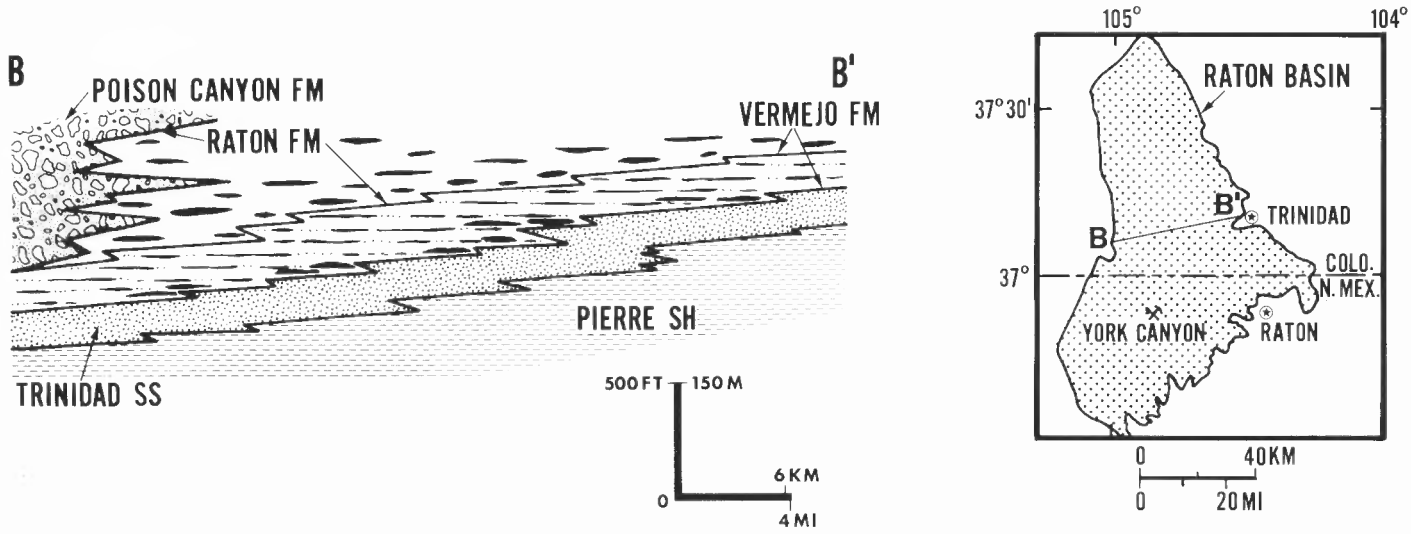


FIGURE 3. Schematic diagram of the regressive units from marine to nonmarine deposits including the Pierre Shale, Trinidad Sandstone, Vermejo Formation, Raton Formation and Poison Canyon Formation.

and Danilchik (1978) and Flores and Tur (1982). This coastline retreated eastward and was succeeded by lower Tertiary alluvial plains during deposition of the Raton and Poison Canyon formations (Flores, 1984; Pillmore and Flores, 1984; Flores et al., 1985). The alluvial plains were sites of syntectonic siliciclastic fills resulting from the Laramide orogeny (Flores and Pillmore, in press).

STRATIGRAPHIC AND LITHOFACIES FRAMEWORKS

Pierre Shale

The Pierre Shale, which is the oldest unit of the study interval, consists mainly of shale as much as 580 m thick. Scott (in Flores et al., 1985) indicated that the top of the Campanian is about 30–45 m below the top of the Pierre Shale near Raton, New Mexico. This interpretation is based on the occurrence of *Haploscaphites nodosus* (*Owen*), which is assigned the same age as *Baculites reesidei*, assigned to earliest Maestrichtian time by Obradovich and Cobban (1975). The uppermost part of the Pierre Shale, which is through the transition zone of the Maestrichtian, consists of interbedded sandstone, siltstone, mudstone and shale lithofacies (Fig. 4).

Flores and Danilchik (1978) observed that the sandstone lithofacies in the transition zone thickens upward and laterally merges with the overlying Trinidad Sandstone near Trinidad, Colorado. Here the transition zone consists of a coarsening-upward sequence of a shale-rich lower part and a sandstone-rich upper part. The shale lithofacies in the lower part is laminated and marked by comminuted plant fragments. Where this lithofacies is not laminated and burrows are common, the unit is best classified as a mudstone lithofacies. Moreover, lenticular-bedded sandstone and siltstone lithofacies (Fig. 5) are commonly intercalated with the shale and mudstone lithofacies. The sandstone lithofacies is fine grained and commonly graded bedded; the graded beds display sole marks in the form of prod marks, flute casts and cast of horizontal burrows (Fig. 6). In addition, the sandstone commonly exhibits cross lamination, parallel-horizontal lamination and ripple lamination. Flaser bedding, graded bedding and climbing ripple laminations are common. The sandstone lithofacies is interbedded with ripple laminated and bioturbated siltstone and mudstone lithofacies. Slumped and diapiric structures and growth faults are associated with these transition zone lithofacies as well as those of the overlying Trinidad Sandstone.

Trinidad Sandstone

The Trinidad Sandstone, which is generally about 30–40 m thick, is a prominent cliff former around the margins of the basin. The formation is composed of one to three sandstone units. Each of these sandstone lithofacies is a coarsening-upward sequence of very fine- to fine-grained sandstone separated by interbedded sandstone and siltstone lithofacies (Fig. 7).

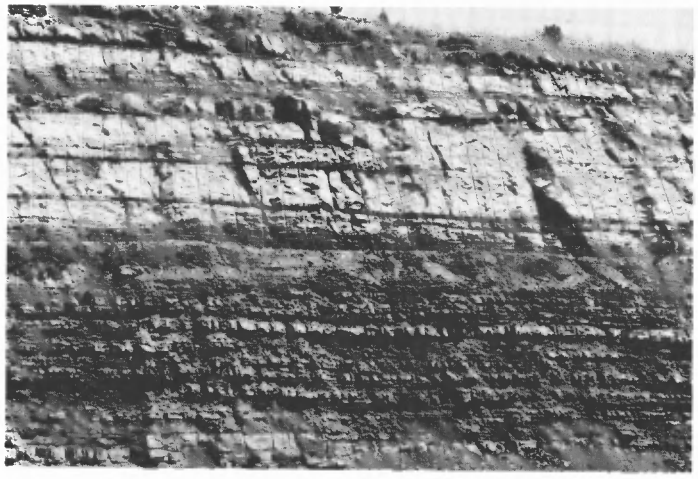


FIGURE 4. The silty sandstone and mudstone couplets of the Pierre Shale overlain by thin- to thick-bedded Trinidad Sandstone.



FIGURE 5. Lenticular bedded, rippled sandstone interbedded with intensely burrowed siltstone and mudstone in the upper part of the Pierre Shale.



FIGURE 6. Flute cast, prod mark and horizontal-burrow east along the bedding plane of graded sandstone in the upper part of the Pierre Shale.

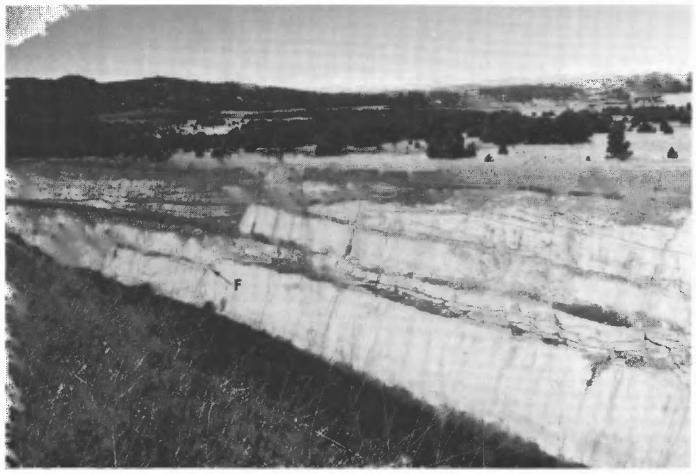


FIGURE 8. A growth fault (F) showing stacked, lenticular, scour-based sandstone bodies on the downdropped block in the Trinidad Sandstone.

Each sandstone lithofacies generally consists of a ripple-laminated lower part and a cross-laminated upper part. However, cross lamination is more common in the upper part of the Trinidad Sandstone where small-scale cross lamination is common in the lower part, and large-scale cross lamination is common in the upper part. The cross lamination is planar and trough crossbeds as well as hummocky cross stratification. Convolute lamination and bioturbation are common; the latter occurs locally as thin-to-thick sandstone intensely bioturbated by trace fossils of *Ophiomorpha* and *Diplocraterion*.

The upper sandstone unit is interrupted locally by basally scoured, fine- to medium-grained sandstone lithofacies. This lithofacies is lenticular and occurs either as a single isolated body or as multiple stacked, nested bodies. The stacking of these sandstone bodies is often controlled by growth faults as shown in Figure 8. The sandstone lithofacies is a generally fining-upward sequence that commonly exhibits trough and planar crossbeds, and some convolute lamination as well as rare, inclined heterolithic stratification or IHS (Koster, 1985; Smith, 1985; Fig. 7). This lithofacies also contains coal spar, carbonaceous shale, siltstone and ironstone lag-deposits. Herringbone sedimentary structures have been observed in a few of these sandstone lithofacies.

Vermejo and Raton formations

Although the Vermejo Formation underlies the Raton Formation, these formations are discussed together because of the similarities in lithofacies and because both are coal bearing. The Vermejo Formation, which is as much as 119 m thick, forms the slope above and conformably overlies the Trinidad Sandstone. The Raton Formation, which is as much as 640 m thick, in part unconformably overlies the Vermejo Formation. The contact is marked by pebble conglomerate and granule, quartzose sandstone lithofacies immediately above the erosional base of the Raton Formation. Lee (1917) divided the Raton Formation into a basal conglomerate, a lower coal zone, a barren series and an upper coal zone. Orth et al. (1981), Pillmore et al. (1984) and Flores and Pillmore (in press) placed the Cretaceous/Tertiary boundary near the top of the lower coal zone below the barren series and included the basal conglomerate in the lower coal zone.



FIGURE 7. The Trinidad Sandstone showing two coarsening-upward sandstone units overlain by lenticular, basally scoured sandstone with IHS (inclined heterolithic stratification).

Lee (1917) described the Vermejo and Raton formations as consisting mainly of sandstone, siltstone, shale, mudstone, carbonaceous shale and coal. The Raton Formation also contains conglomerate. The most abundant lithofacies is sandstone followed by siltstone, mudstone, shale, carbonaceous shale, coal and conglomerate in order of decreasing importance. Flores and Pillmore (in press) divided these formations into three coarsening-upward megacycles; each contains an upper part of coal-poor, sand-dominated facies (Fig. 9) that are composed chiefly of sandstone and conglomerate lithofacies. The lower part of the coarsening-upward megacycle is characterized by coal-rich, fine-detritus dominated facies that include sandstone, siltstone, mudstone, carbonaceous shale and coal lithofacies.

The sandstone lithofacies consist of two types: a fining-upward, scour-based sandstone lithofacies and a sandstone lithofacies that caps a thin coarsening-upward sequence of shale, mudstone and siltstone lithofacies (Figs. 10 and 11). The fining-upward sandstone lithofacies is composed of single or multiple units interrupted by mudstone and siltstone drapes (Fig. 12). This lithofacies is trough and planar crossbedded in the lower part, and convoluted, rippled and rooted in the upper part. The sandstone lithofacies that caps the coarsening-upward sequence (Fig. 11) contains ripple lamination, climbing ripple lamination and root marks. It is locally incised by a basally-scoured sandstone lithofacies. The basally-scoured sandstone consists of trough and planar crossbeds in the lower part, and ripple laminations and convolutions in the upper part. The shale, mudstone and siltstone lithofacies, which comprise the lower part of the coarsening-upward sequence, are burrowed and ripple laminated. In contrast to the mudstone lithofacies, the shale lithofacies is fissile. Closely associated with both sandstone lithofacies types is a basally scoured, lenticular body of interbedded sandstone, siltstone and mudstone lithofacies.

The sandstone lithofacies types are commonly interbedded with the carbonaceous shale and coal lithofacies (Fig. 11). The carbonaceous shale lithofacies contains abundant plant fragments, leaves, stems and splinters. The coal lithofacies consists of less than 33% ash, and the remainder is in the form of organic macerals. The carbonaceous shale and coal lithofacies are commonly interbedded and pass laterally into one another as well.

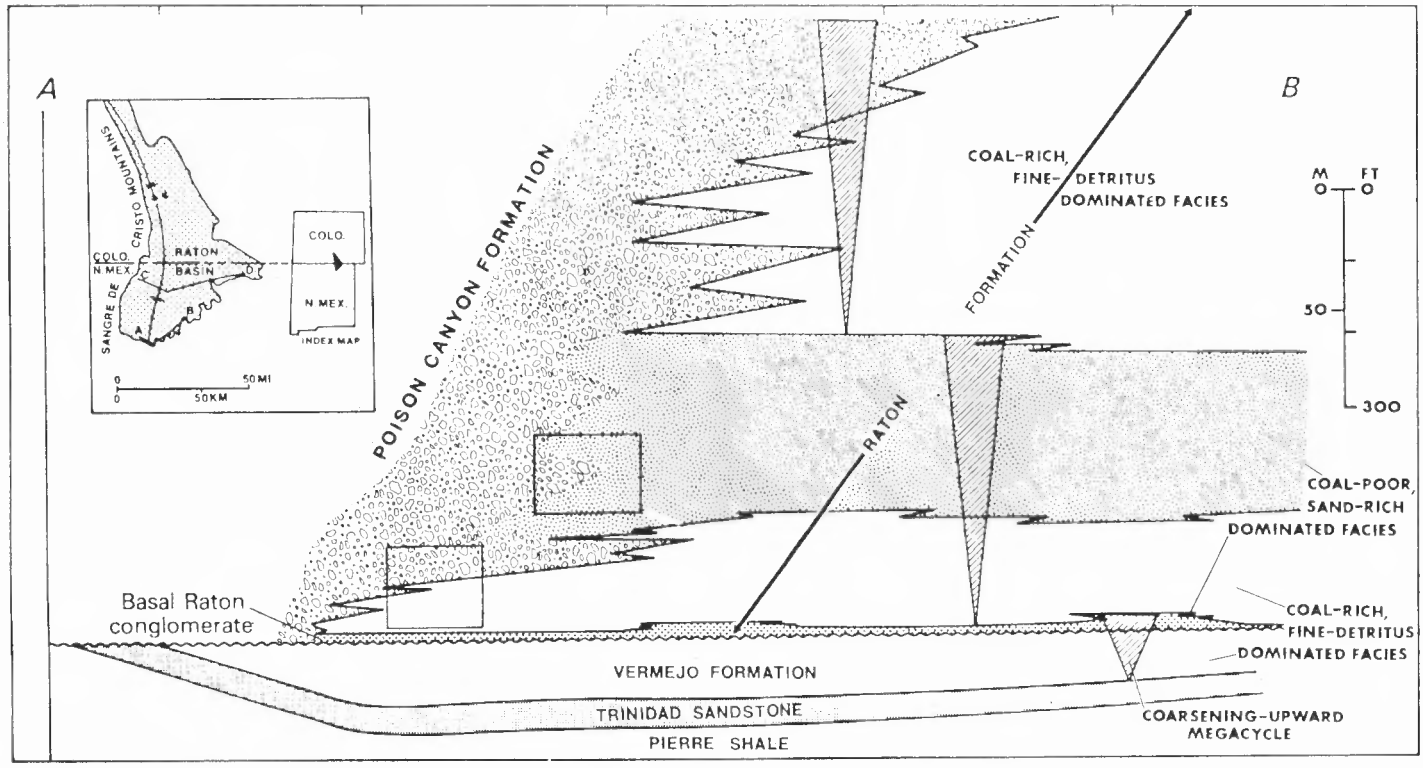


FIGURE 9. A cross section showing the three coarsening-upward megacycles, each interpreted by Flores and Pillmore (in press) as a succession of deposition during basin subsidence followed by increased uplift of source area.

Poison Canyon Formation

The Poison Canyon Formation, which is the youngest unit of the study interval, is as much as 198 m thick and conformably overlies the Raton Formation. The formation also intertongues laterally with the Raton Formation and thickens to the west. The formation is conglomerate-dominated to the west and sandstone-siltstone dominated to the east. Hills (1888) and Johnson et al. (1966) described the Poison Canyon Formation as consisting mainly of interbedded coarse-grained to conglomeratic sandstone, mudstone and siltstone. The formation contains little coal and carbonaceous shale.

The sandstone lithofacies of the Poison Canyon Formation is closely similar to those of the Vermejo and Raton formations, particularly that part of the formation in the central Raton Basin. However, the fining upward, erosional, basal sandstone lithofacies is commonly composed of multiple stacked bodies in the west where it is conglomerate dominated. The sandstone is very coarse to medium grained and arkosic (Fig. 13). The conglomerate consists of sedimentary, igneous and metamorphic rock fragments. The sandstone lithofacies that caps the coarsening upward sequence, which is common in the Vermejo and Raton formations, is not common in the Poison Canyon Formation. In the Poison Canyon Formation, the siltstone lithofacies is sandy and rooted; it is yellowish orange to reddish orange, and the mudstone lithofacies is silty, rooted and variegated.

UPPER CRETACEOUS COASTLINES

The Upper Cretaceous siliciclastic coastlines during deposition of the Pierre Shale, Trinidad Sandstone and Vermejo Formation can be classified into barred and non-barred coastlines. The barred siliciclastic coast-

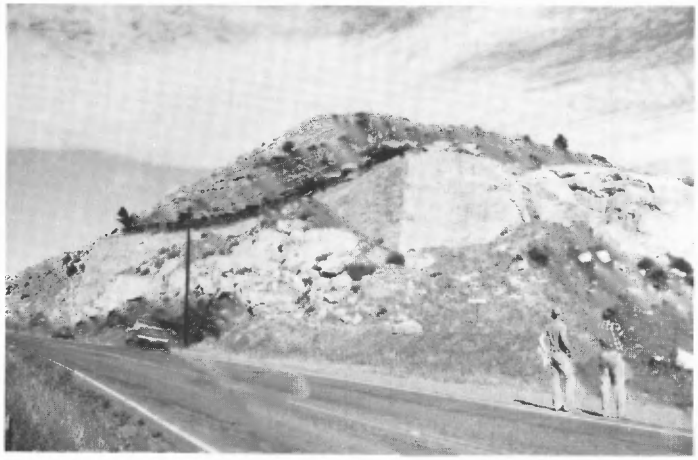


FIGURE 10. A fining-upward, scour-based sandstone underlain by coal and overlain by interbedded sandstone, siltstone, mudstone, carbonaceous shale and coal (arrow) in the Raton Formation.



FIGURE 11. Coarsening-upward mudstone, siltstone and sandstone bounded by carbonaceous shale and coal (arrow) in the Vermejo Formation.

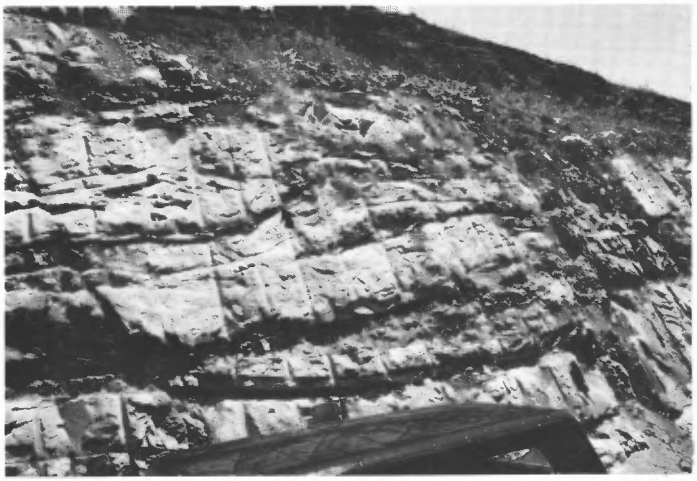


FIGURE 12. Sandstone units separated by mudstone and siltstone drapes (arrow) in a fining-upward sandstone body in the Vermejo Formation.

line is characterized by development along the coast of beach-ridge complexes that consist of shoreface-foreshore, beach, estuary and back-beach swamp environments. The physical regime of this coastline is influenced by wave processes such as longshore and rip currents, and fair-weather and storm waves. The non-barred siliciclastic coastline is recognized by deltas which consist of distributaries that culminate landward into a trunk stream and interdistributaries that are marked by swamps and bays. The physical regime of this coastline is influenced by fluvial processes accompanied by subordinate wave-reworked processes; the latter processes assisted in sediment dispersal after deposition by fluvial currents.



FIGURE 13. A conglomeratic sandstone in the Poison Canyon Formation.

Barred coastline

Siliciclastic environments

The siliciclastic environmens of the barred coastline consist of shoreface, foreshore, beach, estuarine-riverine and back-beach swamp. These environments are attached to the land, in contrast to barrier islands which are separated from the land by coastal lagoons. The main component of the environments is the beach face that includes the shoreface, foreshore and beach where wave-induced processes operated.

Leighton (1980) recognized a barred coastline (Fig. 14) during the deposition of the Pierre Shale, Trinidad Sandstone and Vermejo Formation near Raton, New Mexico. Here, Leighton (1980) described an association of shoreface, foreshore, beach and estuarine-inlet depositional facies in the upper part of the Pierre Shale and in the Trinidad Sandstone. The upper part of the Pierre Shale contains a sandstone lithofacies that is parallel-horizontal bedded, small-scale trough cross-bedded, fining-upward, graded bedded and ripple laminated. This lithofacies is interbedded with siltstone and mudstone lithofacies bioturbated by trace fossils of *Asterosoma, Rhizocorallum, Teichichnus* and *Ophiomorpha*. This lithofacies association is interpreted by Leighton (1980) to be deposited in a transition zone of shelf muds and coastal sands, or in the lower shoreface.

The lower shoreface facies grades up the beach face (shoreface and foreshore) where the Trinidad Sandstone was deposited. Here, the Trinidad Sandstone consists of multiple coarsening-upward sequences in the lower part. The coarsening-upward sequences, which contain hum-

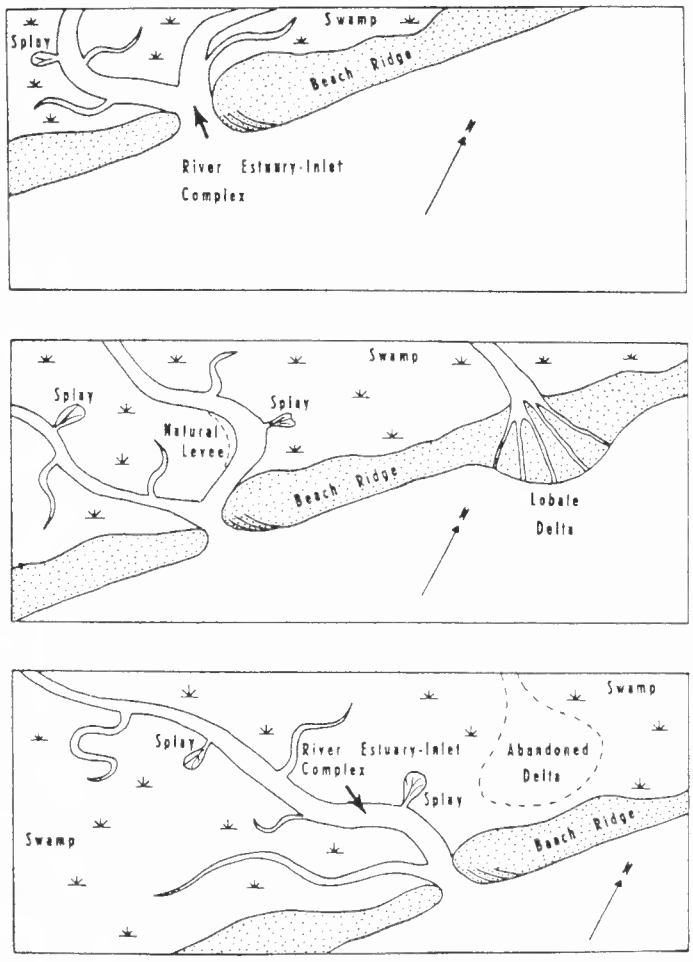


FIGURE 14. Diagram showing barred coastline environments during deposition of the Pierre Shale, Trinidad Sandstone and Vermejo Formation. Adopted from Leighton (1980).

mocky structures (Harms et al., 1975), are interpreted as deposits of strong wave surges during storms. During storm events, scouring by increased wave energy obliterated fair-weather-generated bedforms (e.g., trough and planar crossbeds). These events also account for the transportation and deposition into the lower shoreface of density-current-generated graded beds. Obliteration of bedforms in the shoreface-foreshore environment is also accomplished by the burrowing of small animals that leave trace fossils (Weimer and Hoyt, 1964; Kumar and Sanders, 1976). Bioturbation by *Ophiomorpha, Asterosoma, Skolithos* and *Thalassinoides* in this environment indicates a slow rate of sedimentation which encouraged normal feeding activities of the burrowing organisms.

The upper part of the Trinidad Sandstone described by Leighton (1980) near Raton, New Mexico, is characterized by a fining-upward complex that he described as estuarine-riverine deposits. The vertical variation in grain size reflects infilling by fluvial-influenced channels in which bedload was initially deposited by riverine waters into the open sea. Fluctuations in flow regime in the estuarine-inlet (mouth of the channel) as indicated by variations in bedforms (e.g., herringbone structures) reflect tidal influence. The extensive distribution of the estuarine-inlet deposits near Raton according to Leighton (1980) probably resulted from lateral migration of the channel which concurrently eroded and redistributed sediments of the beach-foreshore complex. Leighton (1980) described the beach-foreshore deposits, where preserved, as massive to horizontally bedded sandstone lithofacies. Although Leighton (1980) did not observe cross laminations in the beach deposits, Pillmore and Maberry (1975) recognized crossbeds that they considered to be beach and dune deposits. The presence of crossbeds in the beach deposits may represent ridges and runnels that were observed in many beaches of the Atlantic coast by Hayes and Kana (1976).

Coal-forming and associated environments

The Vermejo Formation, which overlies the beach face and estuarine-inlet deposits of the Trinidad Sandstone and Pierre Shale, represents deposits of back-beach, swamp-marsh and estuarine-fluvial channel environments. The estuarine-fluvial channel represents channelized flow landward of the inlet. The estuarine channelized flow is affected by tidal currents, while the flow in the fluvial channels is not controlled by these currents. The presence of the IHS in the estuarine channel deposits differentiates between deposits of these environments. Leighton (1980) observed that the estuarine channel-sandstone lithofacies grades upward into interbedded sandstone and silty shale lithofacies. These fine-grained couplets, which may contain burrows, are interpreted as IHS by Smith (1985) and Koster (1985). The couplet probably indicated alternating high energy or high-tide flow (e.g., sandstone) and low energy or low-tide flow (e.g., silty shale).

Marginal to the estuarine-fluvial channel complex lies the swamp-marsh environment where organic deposits accumulate. This environment includes areas of freshwater vegetation (swamp) and brackish water vegetation (marsh). Carbonaceous shale and coal lithofacies are the products of organic accumulation in this environment. The carbonaceous shale is a mixture of clay and organics resulting from influx of detritus into the swamp-marsh environment. Staub and Cohen (1979) suggested that clay flocculation is well developed in brackish-water marsh. Thus, freshwater swamp and swamp-marsh settings far removed from sediment influx and developed on abandoned estuarine-fluvial channel complexes and beach ridges are conducive to organic accumulation. In modern settings, moderately thick peat deposits are formed in swamps on top of beach ridges in the Snuggedy swamp (Staub and Cohen, 1979) and in swamps behind beach ridges in the Okefenokee Swamp (Cohen, 1984). These modern analogs yield low sulfur and low ash peat deposits which may reflect the trace-element composition of some of the coals in the Vermejo Formation.

Non-barred coastline

Siliciclastic environments

The siliciclastic environments of the non-barred coastline, which is geomorphologically lateral to the barred coastline, consist of prodelta, delta-front and delta-plain settings. These environments, which formed in a deltaic complex seaward of river mouths, served as a depocenter and a point source for sediments of the barred coastline. A delta is either a fluvial or wave-influenced system depending on whether the dominant process of deposition is fluvial or marine. Billingsley (1978), Flores and Danilchik (1978) and Flores and Tur (1982) suggested that the deltaic systems formed during the deposition of the upper part of the Pierre Shale, the Trinidad Sandstone and the Vermejo Formation were fluvially influenced. The presence of abandoned deltaic facies in the form of destructional deposits and delta front-prodelta turbidite (e.g., graded beds, sole marks) and mass movement (e.g., slumped, diapiric and faulted structures) deposits suggests fluvial influence typical of the Mississippi River delta. In addition, development of numerous distributary channels in the upper part of the delta front indicates fluvial influence.

The occurrence of rare IHS in some distributary channel-sandstones reflects some tidal influence in the deltaic system. However, the tidal influence was not observed in the seaward dipping component of the delta front where linear, tidal-current sand ridges are not developed. Here, localized mouth bars that exhibit coarsening-upward sequences with small- to large-scale cross laminations were formed from the lower to the upper part (Flores and Danilchik, 1978). These mouth-bar sequences are thick, adjacent to distributary channels and thin away from these depoaxes. Thus, the delta front was probably formed as localized cuspate or arcuate protuberances in the vicinity of distributary mouth-bars. The delta front was flanked by beach ridges reflecting partial reworking of sediments by moderate wave action but minimal tidal action as typified by the Rhone delta (Kruit, 1955; Straaten, 1959; Oomkens, 1967).

Coal-forming and associated environments

The coal-forming environments in the deltaic complex are in swamps and marshes in the interdistributary areas and in abandoned subdeltas of the delta plain shown on Figure 15 (Billingsley, 1978; Flores and Tur, 1982). It has been suggested by McCabe (1984) that delta plains are not sites of significant peat accumulation. The proximity of the swamps and marshes to active detrital influx and tidal incursion produces high-ash prone peats that result in carbonaceous shales. Thus, low-lying marsh-swamp complexes in delta plains are low-potential areas of peat accumulation. However, the marsh-swamp environments removed from detrital and tidal incursions such as in raised and floating bogs are high-potential areas of peat accumulation. The raised bog is elevated above channelized flows and floodplains and displays a convex-upward surface profile bounded by steep margins. The floating bog is a free-floating or substrate-attached peat bog. The raised bog was recognized as a potential precursor of economic coals in modern deltaic settings by Anderson (1964) and Styan and Bustin (1984). The floating

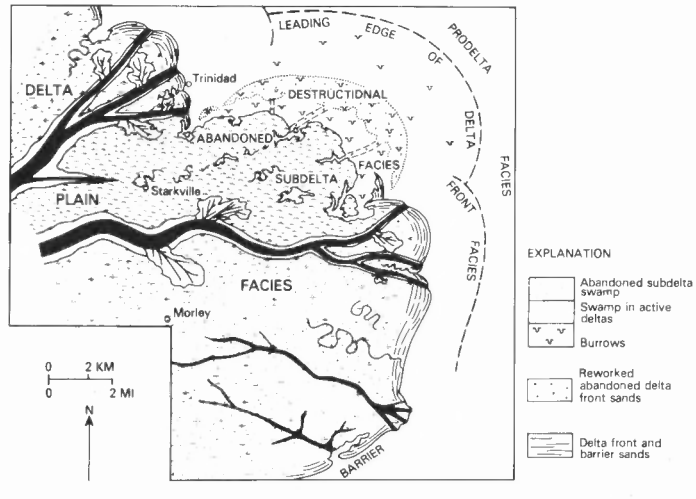


FIGURE 15. Diagram exhibiting non-barred coastline environments of the Pierre, Trinidad and Vermejo formations. Modified from Flores and Tur (1982).

bog may be an important coal-forming environment in the modern Mississippi River delta (Kosters, 1983).

In the Raton Basin, coal-forming environments in the Vermejo Formation may be a combination of low-lying, raised and floating bogs. The lithofacies association of the coals with coarsening-upward crevasse-splay sequences of mudstone, siltstone and sandstone and fining-upward channel sandstone suggests juxtaposition of coal-forming environments with areas of active sedimentation such as in interdistributaries and distributaries. The most common lithofacies association of coal with associated detrital sediments is a regional relationship of economic coal directly underlain by deposits of interdistributary crevasse-splays and adjacent distributary channels. The coal, in turn, passes laterally into a similar lithofacies association, suggesting that these sediments were laid down by geomorphologically juxtaposed environments. In order for one lithofacies association (e.g., crevasse splay and distributary-channel deposits) to be vertically juxtaposed with another group (e.g., coal lithofacies), it is suggested that the succession was formed by one group passing into the other group by autocyclic shift. That is, the group of crevasse-splay and distributary-channel deposits were probably deposited in a subdelta that was abandoned upon reaching maximum aggradation due to fluctuations in sediment supply, subsidence and sea level. The abandonment of the subdelta, which resulted from diversion of channelized flows elsewhere in the delta plain, provided a hiatus in detrital influx permitting organic accumulation in succeeding swamps. Here, raised bogs may form above abandoned deposits of distributaries and levees which provide higher topography than adjoining areas. That is, coarse sediments of the channel-levee complex are relatively more uncompactible than adjacent finer-grained sediments of the interdistributary crevasse splay-floodplain complex, which is low lying and prone to fluvial and tidal incursions. Isolated, low-lying areas in this abandoned subdelta which were covered by ephemeral lakes may have formed floating bogs.

EARLY TERTIARY ALLUVIAL PLAINS

The Upper Cretaceous barred and non-barred coastlines in the Raton Basin were transformed into alluvial plains during the Late Cretaceous and early Tertiary with the advent of the Laramide orogeny and the withdrawal of the sea. The transformation of the coastal plain into a Laramide basin was culminated by establishment of the alluvial plains drained by the through-flow fluvial systems exhibited in Figure 16 (Strum, 1985; Flores and Pillmore, in press). Deposits of these fluvial systems are represented by the Upper Cretaceous and Paleocene Raton and Poison Canyon formations. The alluvial plains probably grade into alluvial fans to the west and southwest. Based on the vertical variation in grain size of sediments of the Raton and Poison Canyon formations, Flores and Pillmore (in press) identified sand- and fine-detritus-dominated facies (see Fig. 9) of the alluvial plains. The sand-dominated facies is characterized by abundant channel sandstone. The fine-detritus-dominated facies is recognized by abundant crevasse splay-floodplain sediments and backswamp coal and carbonaceous shale. These alluvial-plain-facies types form three coarsening-upward intervals from fine-detritus-dominated facies to sand-dominated facies and were interpreted

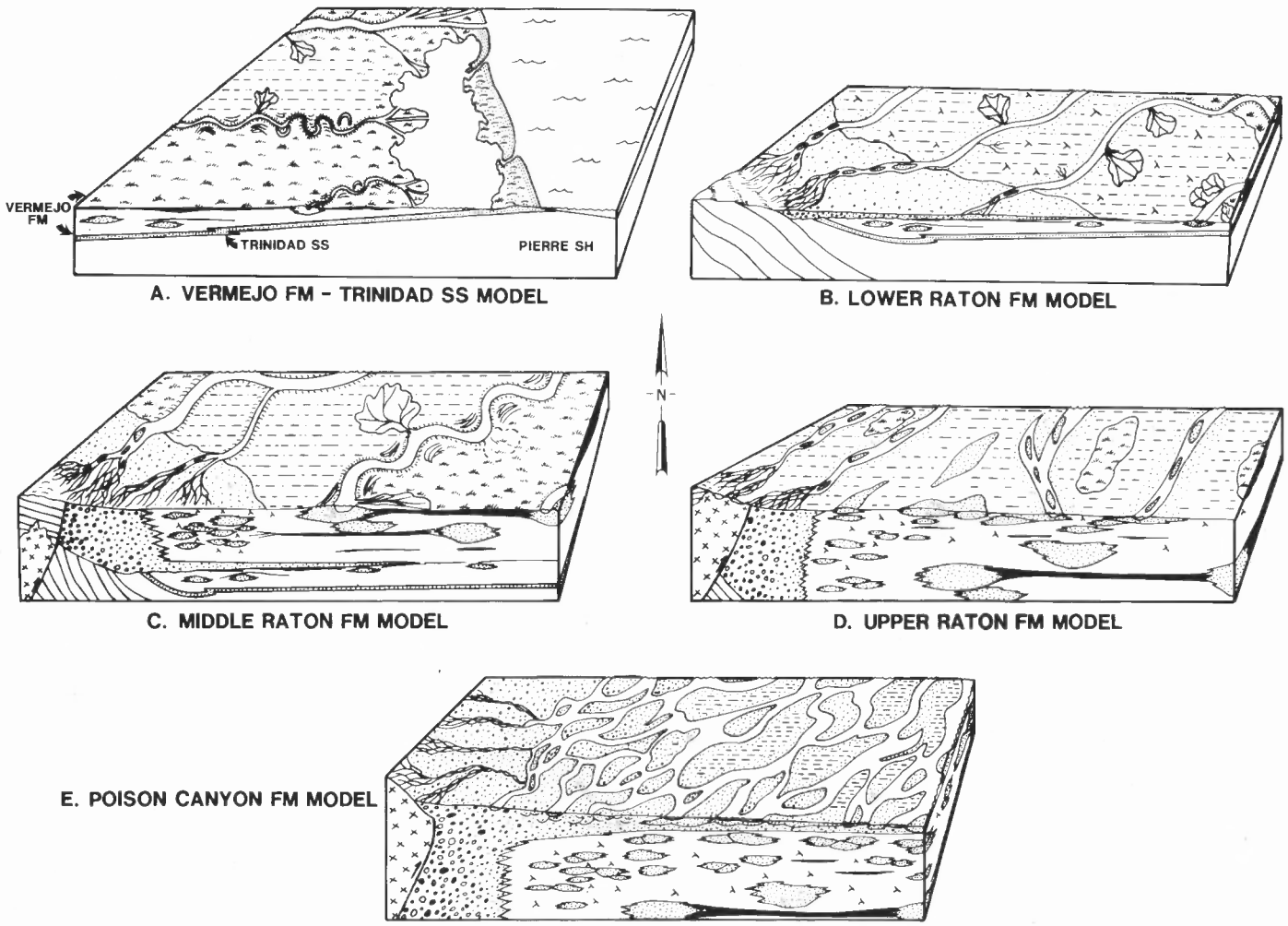


FIGURE 16. Evolution of the depositional and tectonic settings of the Raton Basin from Late Cretaceous to early Tertiary. Environments of deposition in barred and non-barred coastline (A) were transformed into an alluvial plain drained by meandering, anastomosed and braided streams as well as into alluvial fans (B to E). Adopted from Flores et al. (1985).

by Strum (1985) as deposits of low gradient and high gradient fluvial systems, respectively. The low gradient fluvial system is composed of meandering streams, and the high gradient fluvial system is represented by braided streams. Flores and Pillmore (in press) indicate that development of these fluvial-facies types was directly related to tectonism. That is, the sand-dominated facies was deposited by braided and high bedload meandering streams during periods of tectonic uplift in the source area and diminished basin subsidence. The fine-detritus-dominated facies was deposited by meandering and anastomosing streams during periods of increased basin subsidence and stable conditions in the source area. Thus, the alluvial plains may be classified into sand-rich and fine-detritus-rich environments.

Sand-rich alluvial plains

Siliciclastic environments

The siliciclastic environments of the sand-rich alluvial plains include channel, levee-overbank and crevasse splay-floodplain settings. The coarse-grained sediments of the channel and levee-overbank environments make up the bulk (greater than 50%) of the deposits. The channel deposits, which are mainly medium-grained, fining upward sandstones, are internally multiscoured and sheetlike. These trough and planar cross-bedded channel-sandstones are interpreted as deposits of braided streams choked with longitudinal and transverse bars. The internal scours suggest multiple cut-and-fill by a generally laterally-aggrading braided stream. These channel sandstones, which become coarse grained and conglomeratic to the west, are interpreted to pass laterally into deposits of alluvial fans. The channel sandstones merge laterally to the east with discrete, closely spaced, offset channel sandstones intepreted as deposits of bedload and mixed load meandering streams.

The fine-grained sediments associated with the channel sandstones are composed of coarsening-upward sequences of mudstone, siltstone and sandstone of crevasse splays, and interbedded mudstone and sandstone of floodplains. These sediments represent infilling of interfluves during high-water discharges. The coarsening-upward sequences of mudstone, siltstone and sandstone are more usually associated with channel sandstones formed by meandering streams where sediment-choked floodwaters discharged into the floodplains via breaches through levees. The interbedded sandy mudstones and sandstones, which are widespread, are commonly related to channel sandstones of braided streams indicating that interfluve sedimentation was dominated by overtopping of the levee-overbank during floods. The subordinate fine-grained crevasse splay and floodplain deposits in the sand-rich facies may be a function of erosion by the laterally aggrading braided streams instead of nondeposition.

Coal-forming and associated environments

Coal and carbonaceous shale are not commonly associated with the interfluve sediments of the sand-rich alluvial plains, particularly those formed in the Poison Canyon Formation. This relationship is best displayed in the braided fluvial system where associated swamps are either choked by overbank detritus or oxidized. In addition, the small proportion of interfluve sediments in the sand-rich alluvial plains suggests interfluve areas may be too small to develop permanent swamp conditions.

Some coal and carbonaceous shale beds are interbedded with interfluve sediments of the bedload and mixed load meandering streams. The coal beds are thin and discontinuous, and are commonly bounded by carbonaceous shale beds. In this setting, organic matter accumulated briefly in swamps between episodes of detrital influx into the interfluves. However, the carbonaceous shale suggests extensive introduction of muds into the swamp during floods. The coal was probably formed in a swamp of distal interfluves where high ground-water tables were maintained.

Fine-detritus-rich alluvial plains

Siliciclastic environments

The siliciclastic environments of the fine-detritus-rich alluvial plains are very similar to those of the sand-rich alluvial plains. However, the most important environments in terms of bulk sediments accumulated in the alluvial plains are those of the crevasse splays, floodplains and backswamps. Sediments formed in these environments make up greater than 50% of the total volume of sediments deposited in the alluvial plains. The coarsening upward, crevasse-splay sequences frequently are stacked and locally incised by numerous crevasse channels infilled by fining-upward sandstones. These channels served as conduits of floodwaters into the floodplains. The crevasse channels aggrade the floodplain, bifurcate and, as progradation proceeds, merge and diverge, exhibiting an anastomosed pattern. These crevasse splay-anastomosed channel complexes are loci of deposition in the floodplains. The principal pathways of sedimentation in these complexes are the anastomosed streams with mixed and suspended loads. Aggradation by the crevasse splay-anastomosed stream complexes continued with subsidence due to differential compaction of sediments and tectonism. These complexes are either abandoned due to healing of the breaches through the levees or propagated by a process in which the trunk crevasse-channel is captured by avulsion and enlarged as a major conduit. Concentration of flow in this channel concurrent with diminished flow in the associated minor channels transforms the major conduit into an embryonic meandering stream.

Channel sandstones deposited by meandering streams are overall fining-upward sequences that consist of point-bar sandstones draped by mudstones and siltstones. The channel sandstones are simple lenticular bodies arranged *en echelon*, suggesting deposition by lateral shifts following cut-and-fill processes. That the channels laterally migrated is indicated by the fining-upward sequence. In addition, the facies association of the channel sandstones with channel deposits of interbedded mudstone, siltstone and sandstone suggests channel plug deposition in abandoned meander bends which is common in a mixed-load fluvial system.

Coal-forming and associated environments

The abundance of economic coals in the mud-rich alluvial plain facies of the upper part of the Raton Formation is an enigma. Moreover, the absence of coals in the same type facies of the Poison Canyon is equally perplexing. Like the delta plain, the alluvial plain is an active area of detrital influx that is detrimental to organic accumulation in associated swamps. Accumulation of peat in swamps of modern fluvial systems has been documented by Anderson (1964), Smith and Smith (1980) and Smith (1983). These fluvial systems include meandering and anastomosed streams. Anderson (1964) described development of raised peat bogs (as much as 15 m thick) associated with a meandering fluvial system (Fig. 17). Smith (1983) described peat bogs (as much as 3.5 m thick) associated with an anastomosed fluvial system. These peat swamps are either developed in interfluve or abandoned areas of the alluvial plain. The raised peat swamp commonly formed in interfluves, and, much like the raised bogs in the delta plain, exhibits a steep margin that records a rise in elevation of 7 m over 0.6 km. Anderson and Muller (1974) observed that raised bogs are more pronounced in ele-

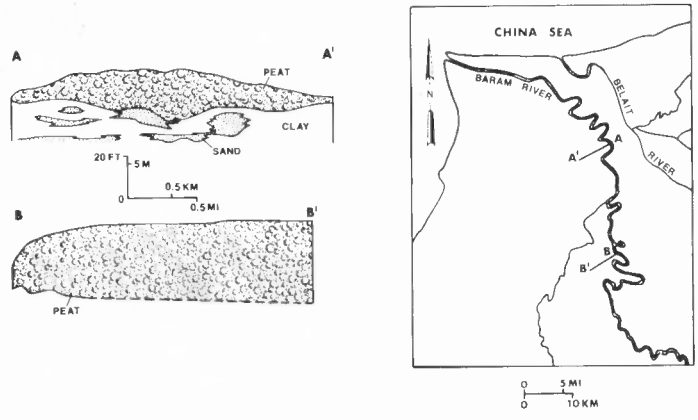


FIGURE 17. A profile of a raised swamp in the alluvial plain of the Baram River, Borneo. Modified from Anderson (1964).

vation upstream of the fluvial system (Fig. 17). The elevation of these interfluve raised bogs from adjoining drainages provides protection of the organic matter from mixing with suspended muds, especially the organics in the center of the swamp. The inundation of mineral-rich floodwaters along the swamp margin supplies nutrients only at the periphery. Thus, the central part of the swamp is transformed into nutrient-poor substrate that is sustained by rainfall and (or) ground water. The variation in the nutrient supply of the swamp, otherwise known as ombrotrophic swamp, imparts zonation of vegetation during maturity in which herbaceous plants grow in the central part and arborescent plants grow along the margin.

Elsewhere in the alluvial plain, peat swamps developed in detritus-free areas such as in abandoned meanderbelts and associated floodplains. These abandoned areas also may have acted as topographic "highs" where elevated swamps formed above floodwaters. Abandonment of a long course of meanderbelts and associated floodplains occurs when a stream avulses via a crevasse-splay channel. The diversion of discharge into the crevasse channel initiates a shift in the position of the stream. Complete shift is attained when the old stream channel is healed, shutting off detrital input downstream. The sediment cutoff permits colonization by plants in swamps formed on the abandoned area. These swamps are potential areas for peat development until a subsequent stream avulsion is diverted into this abandoned area.

SEDIMENTOLOGIC AND TECTONIC EVOLUTION OF THE BASIN AND SUMMARY

The Raton Basin records a sedimentologic and tectonic evolution from a foreland basin (Dickinson, 1974) during the Late Cretaceous to intermontane basin (Baltz, 1967) during the early Tertiary. During the Late Cretaceous and early Tertiary, the oceanic lithospheric plates of the Pacific Ocean were converged and subducted beneath the western margin of the North American plates. This gave rise to, from west to east, a foreland thrust foldbelt (Sevier orogenic belt) and a foreland basin. The Pierre Shale, Trinidad Sandstone and Vermejo Formation were deposited along the western coast of the Western Interior seaway which covered the foreland basin. During the Laramide orogeny, the foreland basin was transformed into numerous asymmetric, intermontane basins isolated by basement-cored uplifts and flanked by high-angle reverse and thrust faults. These intermontane basins were depocenters of lacustrine and through-flow fluvial systems, and the surrounding uplifts served as source areas. The Raton Basin at this time was filled with fluvial sediments that were derived from an uplift to the west (Baltz, 1967; Fassett, 1976).

The effects of tectonism on sedimentation are well displayed by syntectonic lithofacies of the Raton and Poison Canyon formations (Fig. 16). The syntectonic lithofacies include the conglomerate, conglomeratic sandstone and quartzose and arkosic sandstones. The conglomerate and conglomeratic sandstone, which contain limestone, chert, sandstone, schist and gneiss fragments, reflect unroofing of the sedimentary and metamorphic rocks of the uplifted source area. These syntectonic lithofacies are common in the sand-rich alluvial plain deposits of the Raton Formation. In the overlying Poison Canyon Formation, the arkosic sandstone is very common, indicating unroofing of the basement igneous-core through time. The abundance of feldspars in this sandstone was a function of cold or arid climate which retarded chemical decomposition of the mineral (Flores and Pillmore, in press). Flores and Tur (1982) and Flores and Pillmore (in press) suggested that the initial uplift of the source area may have occurred with deposition of the quartzose sandstone lithofacies at the base of the Raton Formation. The quartzose sandstone, which contains as much as 98% quartz, may have been derived from the quartzitic, Upper Cretaceous Dakota Sandstone.

Flores and Pillmore (in press) indicated that the response of sedimentary processes to tectonism in the Raton and Poison Canyon formations was reflected by the three megacyclic coarsening-upward intervals (Fig. 9) and downslope variations in fluvial systems. The coarsening-upward intervals represent recurring periods of basin subsidence outpaced by increased uplift of the source area. The fine-detritus-dominated facies reflects deposition during periods of increased basin subsidence and stable conditions in the source area. The overlying sand-dominated facies represents deposition during episodes of tectonic uplift in the source area and diminished basin subsidence. The vertical facies succession, in turn, records an evolution of fluvial systems from dominantly meandering and anastomosed streams in the fine-detritus-dominated facies to dominantly braided streams in the sand-dominated facies. These fluvial systems were probably a depositional continuum in which the braided streams are an upslope continuation of the meandering and anastomosed streams. However, during increased uplift and reduced basin subsidence, the braided streams prograded toward the basin center and capped deposits of the meandering and anastomosed streams.

Finally, the abundance of coals in the fine-detritus dominated facies of the Raton Formation indicates that, in addition to the autocyclic processes that accompany fluvial systems, rapid subsidence of the basin concurrent with quiescence of the source area were important factors controlling the accumulation of organic deposits. Finally, the absence of coals in the mud-rich facies of the Poison Canyon Formation in the central part of the basin may be more of a climatic control than tectonic control in the formation of organic deposits.

REFERENCES

Anderson, J. A. R., 1964, The structure and development of the peat swamps of Sarawak and Brunei: Journal of Tropical Geography, v. 18, pp. 7–16.

Anderson, J. A. R. and Muller, J., 1974, Palynological study of a Holocene peat and a Miocene coal deposit from NW Borneo: Review of Paleobotany and Palynology, v. 19, pp. 291–351.

Baltz, E. H., Jr., 1967, Stratigraphy and regional tectonic implications of part of Upper Cretaceous and Tertiary rocks, east-central San Juan Basin, New Mexico: U.S. Geological Survey, Professional Paper 552, 101 pp.

Billingsley, L. T., 1978, Stratigraphy of the Pierre Shale, Trinidad Sandstone, and Vermejo Formation, Walsenberg area, Colorado: a deltaic model for sandstone and coal deposition; *in* Hodgson, H. E., ed., Proceedings of the second symposium on the geology of Rocky Mountain coal: Colorado Geological Survey, Research Series 4, pp. 23–34.

Cohen, A. D., 1984, The Okefenokee swamp: a low sulphur end member of a shoreline-related depositional model for coastal plain coals; *in* Rahmani, R. A. and Flores, R. M., eds., Sedimentology of coal and coal-bearing sequences: International Association of Sedimentologists, Special Publication 7, pp. 231–240.

Dickinson, W. R., 1974, Plate tectonics and sedimentation; *in* Dickinson, W. R., ed., Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists, Special Publication 22, pp. 1–27.

Fassett, J. E., 1976, What happened during Late Cretaceous time in the Raton and San Juan Basins: with some thoughts about the area in between: New Mexico Geological Society, Guidebook 27, pp. 185–191.

Flores, R. M., 1984, Comparative analysis of coal accumulation in Cretaceous alluvial deposits, southern United States Rocky Mountain basins; *in* Stutt, D. F. and Glass, D., eds., The Mesozoic of middle North America: Canadian Society of Petroleum Geologists, Memoir 9, pp. 373–385.

Flores, R. M. and Danilchik, W., 1978, Sedimentary structures and interpretations of depositional environments of Pierre Shale, Trinidad Sandstone, and Vermejo Formation in the vicinity of Trinidad Dam, Las Animas County, Colorado: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Guidebook, pp. 1–8.

Flores, R. M. and Tur, S. M., 1982, Characteristics of deltaic deposits in the Cretaceous Pierre Shale, Trinidad Sandstone, and Vermejo Formation, Raton Basin, Colorado: Mountain Geologist, v. 19, pp. 25–40.

Flores, R. M., Pillmore, C. L. and Merewether, E. A., 1985, Overview of depositional systems and energy potential of Raton Basin, Colorado and New Mexico; *in* Macke, D. L. and Maughan, E. K., eds., Rocky Mountain Section, Field Trip Guide, 1985, pp. 41–73.

Flores, R. M. and Pillmore, C. L., in press, Tectonic control on alluvial paleoarchitecture of Cretaceous and Tertiary Raton Basin, Colorado and New Mexico; *in* Ethridge, F. G., Flores, R. M. and Harvey, M. D., eds., Recent developments in fluvial sedimentology: Society of Economic Paleontologists and Mineralogists, Special Publication 39.

Harms, J. C., Southard, J., Spearing, D. R. and Walker, R. G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists, Short Course 2, 161 pp.

Hayes, M. O. and Kana, T. W., eds., 1976, Terrigenous clastic depositional environments: University of South Carolina, Technical Report, no. 11-CRD, 184 pp.

Hills, R. C., 1888, The recently discovered Tertiary beds of the Huerfano River

basin, Colorado: Colorado Scientific Society, Proceedings, v. 3, pp. 148–164.

Johnson, R. B., Dixon, G. H. and Wanek, A. A., 1966, Late Cretaceous and Tertiary stratigraphy of the Raton Basin in New Mexico and Colorado: New Mexico Geological Society, Guidebook 7, pp. 88–98.

Koster, E. H., 1985, Channel processes, vertebrate taphonomy and architecture of an Upper Cretaceous coastal plain sequence—southeast Alberta: Third International Fluvial Sedimentology Conference, Colorado State University, Abstracts, p. 24.

Kosters, E. C., 1983, Louisiana peat resources: New Orleans, Department of Natural Resources, Louisiana Geological Survey, 63 pp.

Kruit, C., 1955, Sediments of the Rhone delta—grain size and microfauna: Nederlands Geologisch Mijnbouwkundig Genootschap (Koninklijk) Verhandelingen, v. 15, pp. 357–514.

Kumar, N. and Sanders, J. E., 1976, Characteristics of shoreface deposits—Modern and ancient: Journal of Sedimentary Petrology, v. 46, pp. 145–162.

Lee, W. T., 1917, Geology of the Raton Mesa and other regions in Colorado and New Mexico; *in* Lee, W. T. and Knowlton, F. H., Geology and paleontology of Raton Mesa and other regions in Colorado and New Mexico: U.S. Geological Survey, Professional Paper 101, 450 pp.

Leighton, V. L., 1980, Depositional environments and petrography of the Trinidad Sandstone and related formations, Raton area, New Mexico [M.S. thesis]: Fort Collins, Colorado State University, 97 pp.

Matuszczak, R. A., 1969, Trinidad Sandstone interpreted, evaluated in Raton Basin, Colorado-New Mexico: Mountain Geologist, v. 6, pp. 119–124.

McCabe, P. J., 1984, Depositional environments of coal and coal-bearing strata; *in* Rahmani, R. A. and Flores, R. M., Sedimentology of coal and coal-bearing sequences: International Association of Sedimentologists, Special Publication 7, pp. 13–42.

Obradovich, J. D. and Cobban, W. A., 1975, A time-scale for the Late Cretaceous of the western interior of North America: Geological Association of Canada, Special Paper, no. 13, pp. 31–54.

Oomkens, E., 1967, Depositional sequences and sand distribution in a deltaic complex: Geológie en Mijnbouw, v. 46, pp. 265–278.

Orth, C. L., Gilmore, J. S., Knight, J. D., Pillmore, C. L., Tschudy, R. H. and Fassett, J. E., 1981, An iridium abundance anomaly at the palynological Cretaceous-Tertiary boundary in northern New Mexico: Science, v. 214, pp. 1341–1343.

Pillmore, C. L. and Flores, R. M., 1984, Field guide and discussions of coal deposits, depositional environments, and the Cretaceous-Tertiary boundary, southern Raton Basin; *in* Lintz, J., Jr., ed., Western geological excursions: Geological Society of America, Annual Meeting Guidebook, v. 3, pp. 1–51.

Pillmore, C. L. and Maberry, J. O., 1976, The depositional environment and trace fossils of the Trinidad Sandstone, southern Raton Basin, New Mexico: New Mexico Geological Society, Guidebook 27, pp. 191–197.

Pillmore, C. L., Tschudy, R. H., Orth, C. L., Gilmore, J. S. and Knight, J. D., 1984, Geologic framework of nonmarine Cretaceous-Tertiary boundary sites, Raton Basin, New Mexico and Colorado: Science, v. 223, pp. 1180–1182.

Smith, D. G., 1983, Anastomosed fluvial deposits: modern examples from western Canada; *in* Collinson, J. D. and Lewin, J., eds., Modern and ancient fluvial systems: International Association of Sedimentologists, Special Publication 6, pp. 169–180.

Smith, D. G., 1985, Epsilon cross stratification (ECS) in modern and ancient lateral accretion channel (point bar) deposits: alluvial, deltaic and tidal systems compared: Third International Fluvial Sedimentology Conference, Colorado State University, Abstracts, p. 35.

Smith, D. G. and Smith, N. D., 1980, Sedimentation in anastomosed river systems: examples from alluvial valleys near Banff, Alberta: Journal of Sedimentary Petrology, v. 50, pp. 157–164.

Staub, J. R. and Cohen, A. D., 1979, The Snuggedy Swamp of South Carolina: a back-barrrier estuarine coal-forming environment: Journal of Sedimentary Petrology, v. 49, pp. 133–144.

Strum, S., 1985, Lithofacies and depositional environments of the Raton Formation (Upper Cretaceous-Paleocene) of northeastern New Mexico [M.S. thesis]: Raleigh, North Carolina State University, 81 pp.

Styan, W. B. and Bustin, R. M., 1984, Sedimentology of Fraser River delta peat deposits: a modern analogue for some deltaic coals; *in* Rahmani, R. D. and Flores, R. M., eds., Sedimentology of coal and coal-bearing sequences: International Association of Sedimentologists, Special Publication 7, pp. 241–271.

Straaten, L. M. J. U. van, 1959, Littoral and submarine morphology of the Rhone delta; *in* Russell, R. J., ed., Proceedings of the second coastal geography conference: Baton Rouge, Louisiana State University, National Academy of Science, National Research Council, pp. 223–264.

Wanek, A. A., 1963, Geology and fuel resources of the southwestern part of the Raton coal field, Colfax County, New Mexico: U.S. Geological Survey, Coal Investigations Map C-45.

Weimer, R. J. and Hoyt, J. H., 1964, Burrows of *Callianassa major* Say, geologic indicators of littoral and shallow neritic environments: Journal of Paleontology, v. 38, pp. 761–676.