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DEPOSITIONAL ARCHITECTURE OF CENOZOIC GULF COASTAL PLAIN FLUVIAL SYSTEMS[1]

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ABSTRACT

The depositional architecture of aggrading coastal plain fluvial sequences includes both the three-dimensional interrelationships and geometries of component framework sand bodies and the distribution of bedding and internal structures within the framework facies. Examination of late Quaternary and Oligo-Miocene fluvial systems of the Texas Coastal Plain illustrates the architectural variety inherent in aggradational coastal plain sequences and indicates common depositional styles.

1. Coastal plain sequences typically record deposition by multiple synchronous fluvial systems, ranging from large extrabasinal rivers to small streams draining the basin fringe and local intrabasinal streams. Identification and definition of the major systems and their component depositional elements (fluvial axes and interaxial streamplains, lacustrine basins, or aeolian plains) is the initial step in reconstruction of basin paleogeography.
2. Contemporaneous major as well as minor rivers may possess grossly differing load, discharge, and geometric characteristics. Consequently, deposits of each depositional element commonly differ greatly in terms of internal structure, mineralogical and textural composition, and sand-body geometry.
3. Major extrabasinal rivers typically enter the aggradational coastal plain at topographically or structurally stabilized points. Once on the coastal plain, the river will radiate from its point source in an attempt to aggrade the depositional surface as evenly as possible. Both nodal and random down-channel avulsions result in successive occupation of multiple channel trends. Facies maps of thick sequences of channel and associated deposits (i.e., sand isolith or percent maps) consequently show complex interweaving or distributing trends. Lateral spacing of major rivers determines the along-strike extent of distributary alluvial aprons. Long-term stability of the loci of sediment input favors vertical persistence of fluvial elements and systems.
4. Within fluvial axes, framework channel facies may form multilateral belts up to tens of miles in width, or may stack vertically. Dry climate and dominance of bedload or extremely flashy fluvial systems favor development of multilateral sand belts. Mixed-load fluvial systems are characterized by moderate to strong vertical stacking of framework sand bodies.
5. Significant vertical change in depositional style within major fluvial axes records the evolution of river pattern in response to extrinsic or intrinsic changes in the drainage or depositional basin. In the Texas Coastal Plain, mixed-load fluvial axes commonly exhibit evidence for upward decrease in river bedload content.

Because fluvially deposited stratigraphic units peripheral to large marine sedimentary basins most likely consist of a mosaic of individual depositional systems and component elements, accurate description and interpretation of coastal plain paleogeography necessitates a hierarchical, three-dimensional approach to analysis of alluvial stratigraphy.

INTRODUCTION

Temporal evolution of aggrading fluvial systems and the three-dimensional geometry of their deposits has been a subject of considerable speculation. Most published studies of fluvial sediments have, however, concentrated on limited segments of a single fluvial system, and have commonly been two-dimensional in scope because of outcrop or other data limitations. A few authors, for example Brown (1969) and Fisher and McGowen (1969), have presented combined surface and outcrop syntheses and discussed three-dimensional aspects of fluvial systems. Allen (1965) schematically illustrated fluvial basin-filling sequences. Allen (1978), Leeder (1978), and Bridge and Leeder (1979) presented quantitative geometric models of fluvial system aggradation and discussed some implications for interpretation of alluvial stratigraphy. The reports of Fisk (1944 and 1947) provide one of the best known and most complete three-dimensional studies of Holocene fluvial deposits.

Despite the limited literature, three-dimensional description of major alluvial sequences, including vertical and lateral changes in sand-body composition, internal structure, interconnectedness, trend, and dimensions is a useful and commonly necessary prelude to interpretation of and exploration for epigenetic mineral deposits (Galloway, 1978; Galloway et al, 1979b) and for evaluation of flow dynamics, hydrochemical evolution, and yield potential of alluvial aquifers (Freeze and Witherspoon, 1967; Galloway et al, 1980). In addition, such a description is the logical step beyond simple environmental classification of local stratigraphic sequences according to existing fluvial models. It is, in effect, the geological extension of systemic con-

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cepts of physical geography synthesized by Chorley and Kennedy (1971) and applied by Schumm (1977); as such, it becomes a powerful tool for interpretation of the evolving paleogeography of a depositional basin as well as of the peripheral source terranes.

This paper describes the three-dimensional architecture of several Tertiary and Quaternary fluvial systems of the Texas Coastal Plain, including (1) areal and vertical facies distributional patterns, (2) geometry and dimensions of component facies elements, (3) internal structure of the framework sand facies, and (4) relationship of principal fluvial systems to conventional stratigraphic subdivisions and to each other. The descriptions provide a basis for some potentially useful generalities about fluvial depositional style applicable to tectonically passive, aggrading coastal plains, and for detailed description of the paleogeography of the Tertiary Gulf Coastal Plain and associated hinterlands.

PHYSICAL SETTING

The post-Eocene Texas Gulf Coastal Plain consists of an aggradational veneer of fluvial, lacustrine, and aeolian sediments overlying a thick progradational deltaic and continental-slope platform. The basin has, through time, subsided to accept the deposition of tens of thousands of feet of debris eroded from the North American continent. Although fluvial deposits are a volumetrically minor part of the preserved basin fill, it is obvious that major rivers traversed the coastal plain and funneled sediment into the open Gulf of Mexico.

Modern climate of the coastal plain exhibits a pronounced gradient from humid in East Texas to semiarid in South Texas (Thornthwaite, 1948). To the south, annual pan evaporation exceeds average precipitation by a factor of four; along the eastern coastline, pan evaporation is only modestly greater than precipitation (Fig. 1). Significantly, sedimentological and mineralogical analyses indicate that this fundamental climatic gradient from dry in South Texas to relatively wet in East Texas had evolved by middle Tertiary time (Galloway, 1977). The abundance in South Texas of paleocaliche horizons within units ranging from Miocene through Pleistocene age suggests that this zonation persisted through the late Tertiary and into the Quaternary.

The modern coastal plain is a dissected low-relief surface, which dips gently gulfward. Average elevation of the inland coastal plain margin is typically higher in South Texas. The inner coastal plain physiographic province is underlain by outcrops of Late Cretaceous and early Tertiary terrigenous clastics and less abundant chalk and marl. Resistant strata, such as the Austin Chalk, form low strike-parallel cuestas or escarpments (Fig. 1). Across Central and South Texas, the province abuts abruptly against the periphery of the Edwards Plateau (Fig. 1), a relatively elevated, dissected province underlain by Lower Cretaceous limestones.

Structural elements of the post-Eocene coastal plain include the Rio Grande and Houston embayments and the intervening San Marcos arch (Fig. 1). The embayments, which have a history extending back into the Mesozoic, are broad sags separated by the relatively stable arch. These passive tectonic elements are reflected more in their influence on sedimentation than as obvious structures. Regional basin tectonics during the Cenozoic indicates primarily an isostatic response to sedimentary loading. Inland, early Tertiary and Mesozoic strata are broken by the generally strike-aligned Pearsall-Luling-Mexia fault system. The Balcones fault zone separates the coastal plain from the Edwards Plateau. Major belts of growth faults, rooted in Tertiary deltaic and slope systems, locally extend to the surface but exhibit only modest displacement of younger strata.

With some qualification, primarily imposed by increased incision of major river valleys during Pleistocene fluctuations in sea level, the post-Eocene Texas Coastal Plain has been characterized by a relatively constant structure, climate, and physiography. Examination of Holocene fluvial depositional style is therefore a logical starting point, but one that is limited by the short period of time available for rivers to adapt to gradient and load changes imposed by the most recent rise in sea level (approximately 6,000 years B.P.) and contemporaneous rapid climatic fluctuations (Looney and Baker, 1977). The well-mapped surficial facies of the late Quaternary coastal plain complex provides a better perspective of youngest aggrading coastal plain depositional style.

COASTAL PLAIN DEPOSITIONAL STYLE— LATE QUATERNARY PERSPECTIVE

Within the past decade, compilations of surficial geologic mapping of the Quaternary coastal plain have been completed as part of the Texas Coastal Zone Environmental Geologic Atlas, Land Resources, and Submerged Lands programs (Brown et al, in press; Brown et al, 1976; Brown et al, 1977; Fisher et al, 1973; Fisher et al, 1972; McGowen et al, 1976a; McGowen et al, 1976b; Kier et al, 1977; McGowen and Morton, 1979). Maps generated by these projects illustrate in unusual detail the areal geometry and depositional patterns of the shallow, exposed youngest fluvial and marginal marine sediments of the coastal plain. The latest Pleistocene Beaumont surface and superimposed Holocene fluvial sediments provide a well-preserved plan view of an aggradational, stable, high sea-level stand coastal plain. Subsurface mapping utilizing well sample and geophysical log data (e.g. Winker,

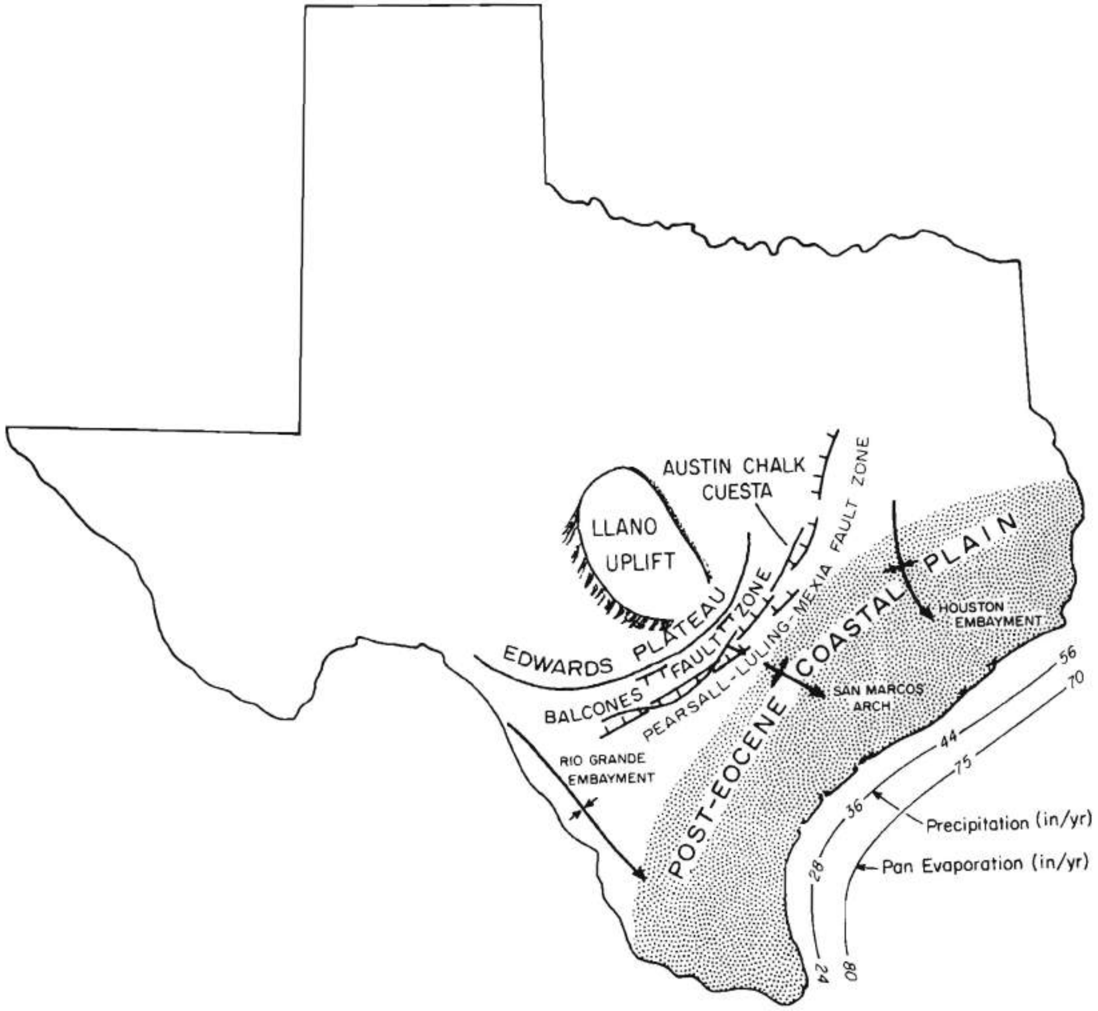


FIG. 1.—Location index and structural, climatic, and physiographic setting of the post-Eocene Texas Gulf Coastal Plain.

1979; Kreitler et al, 1977) indicate that the surficial facies patterns reflect the three-dimensional facies framework. Synthesis of the various maps (Fig. 2) illustrates the principal Quaternary depositional elements of the lower coastal plain Beaumont/Modern depositional surface. These elements include the Rio Grande, Nueces, San Antonio-Guadalupe, Colorado, Brazos, Trinity, and Neches River systems and their associated deltaic fringes and incised valley fills, and the South Texas aeolian sand sheet. Coastal margins of the late Pleistocene deltaic systems are covered by a veneer of transgressive bay, marsh, strandplain, barrier, and lagoonal deposits of Holocene age (undifferentiated on Fig. 2). Temporal relationships of the various late Pleistocene and Holocene depositional units are discussed in various Environmental Geologic Atlas volumes and are thoroughly reviewed by Winker (1979). For this discussion, the significant points that are readily apparent are (1) the persistence of depositional elements indicated by the superposition of Holocene rivers along axial parts of older fluvial and distributary aprons, and (2) the local extent of Holocene aggradational deposits in comparison to their late Pleistocene counterparts, which record a much longer period of unconfined alluvial deposition during stable, high-standing sea-level conditions. The composite late Quaternary facies patterns provide a much better analog in terms of scale to the older coastal plain systems than do modern deposits, which still retain a strong transgressive overprint.

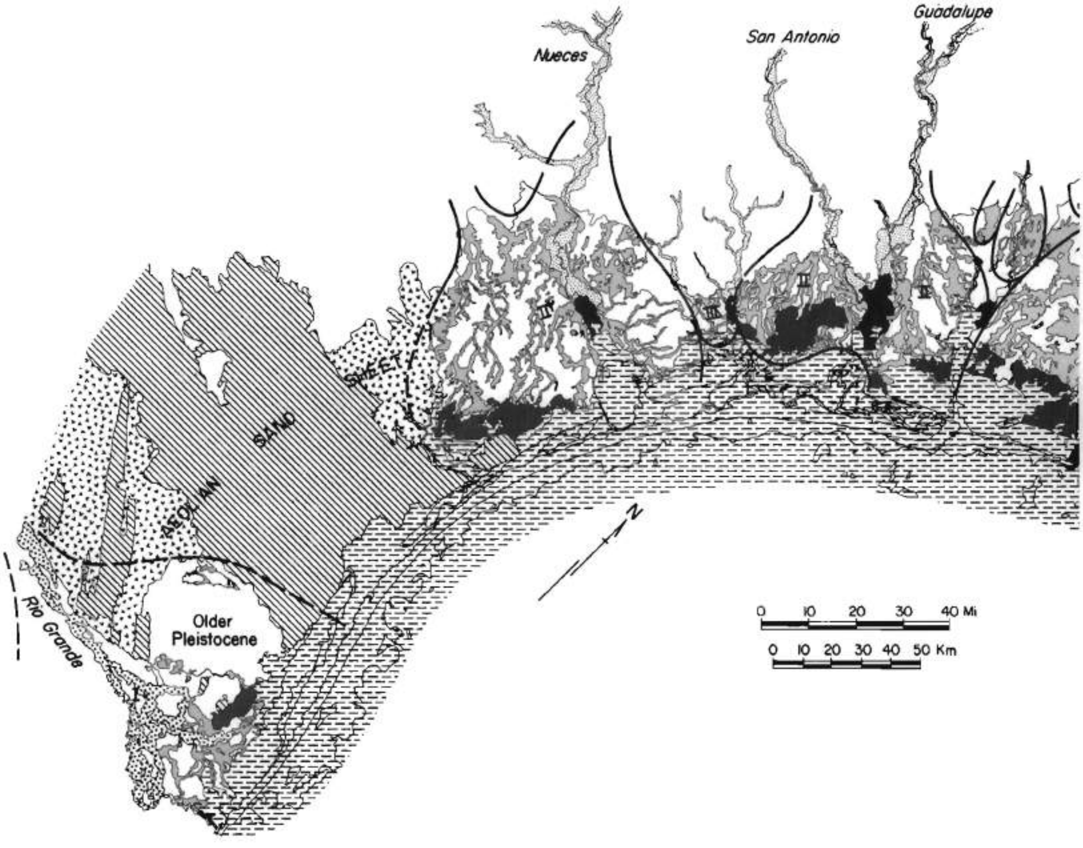


FIG. 2. — Late Quaternary depositional elements of the Texas Gulf Coastal Plain. Areal facies patterns of exposed late

QUATERNARY DEPOSITIONAL STYLES

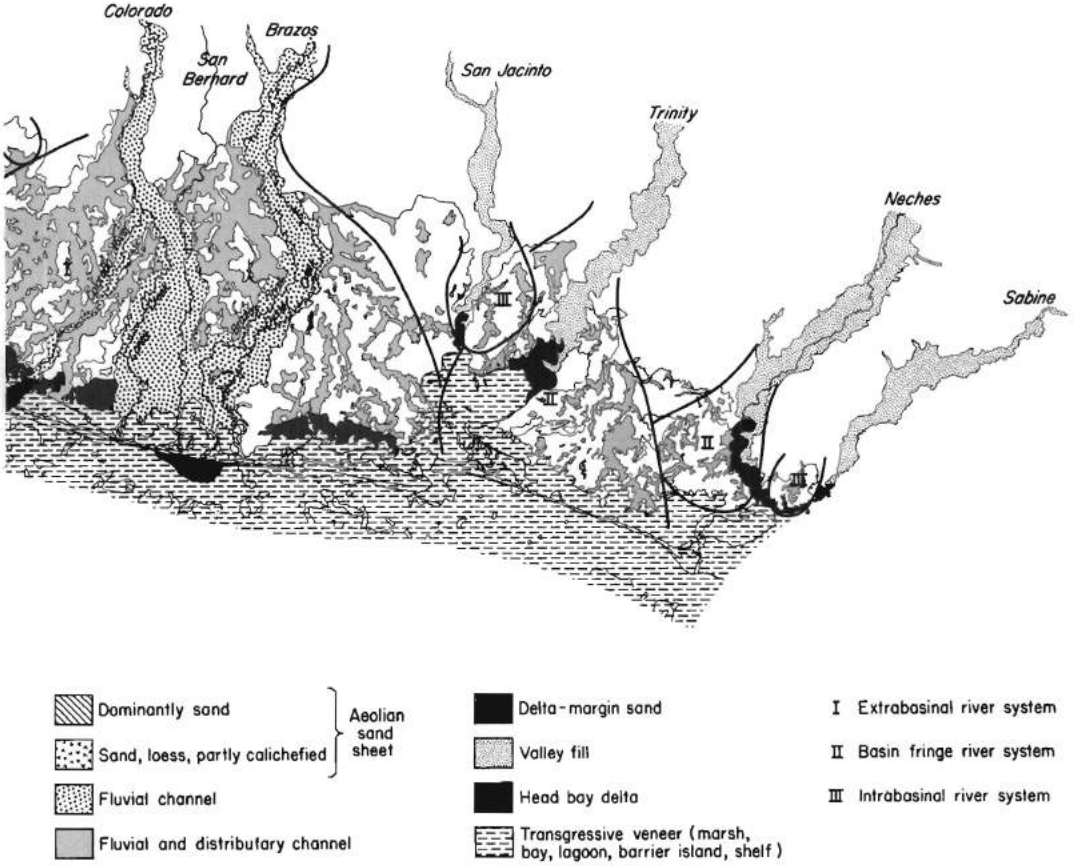
The later Quaternary deposits record the presence of a hierarchy of river systems draining across the coastal plain.

Major *extrabasinal rivers,* including the Colorado, Brazos, and Rio Grande, tap integrated drainage basins extending far beyond the coastal plain or its immediate environs. Only these largest rivers have filled their low-sea-level incised valleys and have begun to resume aggradation of the coastal plain.

Several *basin-fringe rivers,* including the Trinity, Neches, Guadalupe, San Antonio, and Nueces drain inland source areas, such as the Edwards Plateau, which lie on the periphery of the coastal plain. The modern rivers all remain confined within incised valleys and have prograded small bay-head deltas into the upper ends of their drowned valleys.

Numerous minor *intrabasinal streams* drain inland portions of the coastal plain. The San Jacinto and several small streams along the central coastal plain exemplify such minor drainage axes. All are incised and are building small bay-head deltas into flooded valley segments.

The Beaumont surface records development of broad alluvial aprons containing multiple channel courses radiating from the upper valleys of extrabasinal and basin-fringe rivers. These distributary-like patterns have been recognized by several authors, including Barton (1930), Metcalf (1940), Bernard and LeBlanc (1956), and Aronow (1971). The size of each late Pleistocene alluvial apron is commensurate with each associated river system (Fig. 2). The coalesced lower alluvial and upper deltaic plain of the Brazos and Colorado Rivers extends over 100 mi (160 km) along the coast. That of the Rio Grande is comparably large if extensions both into Mexico and below the aeolian veneer of the South Texas sand sheet are included (Winker, 1979). The local superposition of fluvial channel deposits upon thin delta plain and distributary sequences deposited along their downdip margins is also most apparent in the deposits of these large extrabasinal streams. Rivers draining the basin



Pleistocene and Holocene fluvial, deltaic, and aeolian deposits compiled from the Texas Coastal Zone Environmental Geologic Atlas, Texas Land Resources Map, and State Submerged Lands program maps.

fringe constructed moderate-sized alluvial aprons ranging from 25 (Neches) to 50 (Nueces) mi (40 to 80 km) wide. Probable lower deltaic plain distributary deposits are preserved around the margins of the alluvial apron (Fig. 2, eastern margin of the Nueces, for example). Intrabasinal streams commonly coincide with local Beaumont alluvial lobes; however, such small systems are more likely to be geologically short-lived and thus do not consistently coincide with Pleistocene precursors.

Areal patterns, combined with the published studies of the local stratigraphy of the shallow sediments, indicate several generalities about Quaternary fluvial depositional style:

1. The Quaternary coastal plain sequence is a mosaic of fluvial systems differing in channel types, sizes, and sediment compositions. Extrabasinal fluvial systems define the fundamental depositional elements of the coastal plain; they are separated by aprons of the larger basin-fringe rivers, by deposits of local, intrabasinal streams, and by aeolian sediments of the South Texas sand sheet (Fig. 2).

2. The point of entry of major extrabasinal and basin-fringe river systems onto the depositional coastal plain is stable for long periods of time. This stability is a natural consequence of continuous seaward tilting of the coastal plain, resulting in entrenchment updip from the hinge line (Winker, 1979). Shifting of such an entrenched locus requires large-scale drainage capture and geomorphic reorganization.

3. Upon reaching the aggradational, unconfined lower coastal plain environment, channel avulsion occurs repeatedly, resulting in construction of a fan-like apron of interspersed channel fill and overbank facies across the lower coastal plain. Large aprons spread laterally, coalescing with aprons produced by adjacent river systems (e.g., Colorado-Brazos, San Antonio-Guadalupe). A record of inland fluvial avulsion is preserved in the late Holocene deposits of the Colorado and Brazos Rivers. Oyster Creek (Fig. 2) is a former course of the Brazos in-

termittently occupied from approximately 4,000 to 1,000 years B.P. (Bernard et al, 1970). Nodal avulsion (terminology of Leeder, 1978) occurred far up the alluvial apron, near its apex. The Colorado River diverted to its present course across the lower two-thirds of its alluvial apron in relatively recent time and left a well-preserved, abandoned meanderbelt now occupied by underfit Caney Creek (Fig. 2). The point of diversion lies well down onto the alluvial apron and would be considered random avulsion (Leeder, 1978). The complex branching pattern of older channel courses indicates that both nodal and random avulsion have characterized aggradation of the Brazos-Colorado alluvial apron.

4. Successive channel trends may be intersecting, subparallel, or superimposed. The modern Colorado, for example, is coincident with a mapped older channel trend over much of its course (Fig. 2). Cross sections (Bernard et al, 1970; Winker, 1979) indicate common vertical amalgamation of successive fluvial channel-fill units in the Brazos apron. Resultant sand bodies are commonly two or more times thicker than original channel depth. Similar superposition of channel sequences probably characterized the upper alluvial apron of other major extrabasinal and basin-fringe rivers.

5. Various river systems show no consistent relationship to coastal plain climate. Most large modern rivers are mixed-load to suspended-load types on the coastal plain. The Colorado is the most bedload rich of the major rivers, a characteristic that is reflected in the relatively high proportion of its apron surface underlain by sandy channel and meanderbelt facies (Fig. 2). Three adjacent rivers, the Brazos, the small, intrabasinal San Bernard, and the Colorado, lie within the same climatic zone but exhibit typical fine-grained point bar, braided, and chute-modified coarse-grained point bar morphologies, respectively. In fact, classic localities for contrasting bedload channel (McGowen and Garner, 1970) and mixed-load channel (Bernard and others, 1970) point bar sequences lie within miles of each other. As shown by Schumm (1977), sediment load, not coastal climate, is obviously a primary control of local channel morphology.

OLIGOCENE-MIOCENE COASTAL PLAIN DEPOSITION

The paleogeography of the Oligo-Miocene Texas Coastal Plain closely resembled that of the late Quaternary. Average shoreline lay some miles inland of but parallel to the present shore, source terranes exposing older Tertiary and Mesozoic sediments flanked the coastal plain, and the regional climatic gradient was well established (Galloway, 1977). Explosive volcanic activity was especially pronounced in the southwestern U.S. and northern Mexico from Oligocene into early Miocene. A climax in uplift along the Balcones fault zone and probable concomitant increased elevation of the Edwards Plateau modified inland topography along the coastal plain margin (Weeks, 1945). Impacts on deposition of both events are evident in parts of the Oligo-Miocene sequence.

Studies of the physical and hydrostratigraphic setting of the South Texas uranium province have utilized an extensive surface and subsurface data base incorporating several hundred petroleum and uranium exploration electric logs, mine exposures, and cores to map and interpret depositional facies of the Oligo-Miocene section (Galloway, 1977; Galloway et al, 1980). Synthesis of the results of these studies across the southern two-thirds of the Texas Coastal Plain (Fig. 3) provides the basis of this discussion.

The Catahoula and Oakville Formations comprise two major Oligo-Miocene fluvial depositional episodes that are physically distinctive across much of the South Texas Coastal Plain (Fig. 4). The Catahoula Formation consists of fluvial systems that grade downdip into the thick progradational deltaic Frio Sandstone of subsurface terminology. It overlies barrier/lagoon and deltaic deposits of the Eocene Jackson Group (Fig. 4). The Catahoula is distinguished by the abundance of contained tuffaceous mud and silt produced by weathering of fluvially reworked airfall volcanic ash. The overlying Oakville Sandstone is recognized by its abundant limestone fragments and fossil debris reworked from the inland Cretaceous. Similar, but generally finer grained and less sand-rich fluvial deposits of the Fleming/Lagarto Formation overlie the Oakville. Together, the Oakville and Fleming/Lagarto comprise the updip fluvial equivalents of

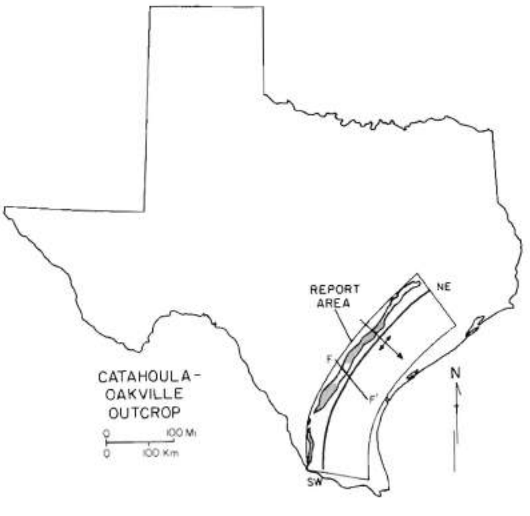


FIG. 3.—Index map showing location of the Oligo-Miocene study area, South and Central Texas Coastal Plain.

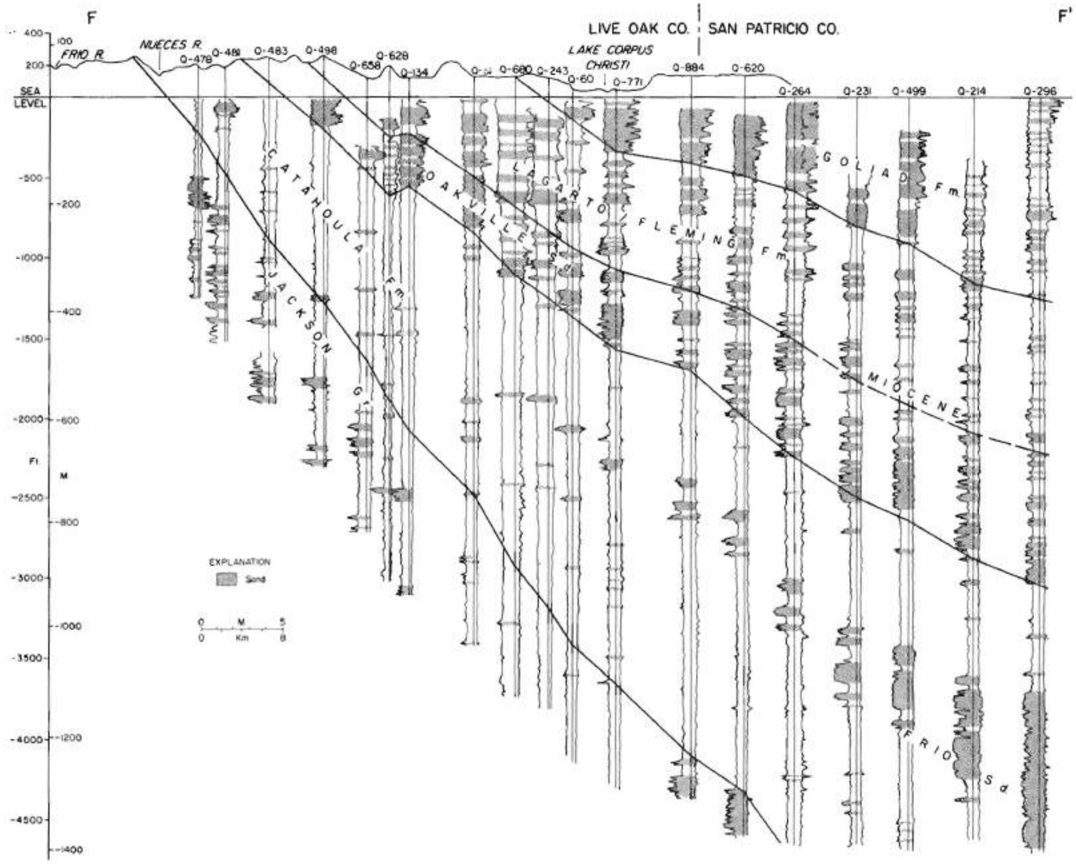


FIG. 4. — Representative dip-oriented cross section of the late Tertiary stratigraphic succession, South Texas Coastal Plain. Location of section (Fig. 3) is in an interfluvial, sand-poor area of the Catahoula, but parallels a major Oakville fluvial axis.

the major Miocene progradational deltaic complex of the deep subsurface (Fig. 4).

CLASSIFICATION OF PALEO-FLUVIAL SYSTEMS

For regional synthesis and description of complex fluvial sequences, classification by type models (such as braided, fine-grained meanderbelt, etc.) proves to be of limited use. First, the variety of channel fill deposits encountered typically includes many examples that show little resemblance to well-described modern analogs. Secondly, a variety of intergradational fluvial sequences typically occurs at the same stratigraphic horizon within a given local area. Similar limitations of descriptive models are noted by Jackson (1978). Thirdly, use of models requires detailed description of vertical or lateral textural and sedimentary structural sequences that cannot be obtained in the subsurface or in areas of poor exposure. Limitation of interpretation in the subsurface to availability of cores would, in the Gulf Coast Basin, as in most sedimentary basins, eliminate all but a fractional percent of the total available data base. As an alternative, a qualitative modification of Schumm's (1977) classification of aggrading alluvial channels has been adopted for use in interpretation and description of ancient fluvial systems (Galloway et al, 1979b). Salient characteristics of bedload, mixed-load, and suspended-load channel facies as used in this report are summarized in Figure 5. The classification is based upon empirical interrelationships among typical geometry, composition, and internal organization of channel fills desposited by rivers transporting texturally different sediment loads. A fluvial depositional system is classified according to the channel fill type most characteristic of the trunk stream or streams. After systems had been mapped and broadly classified, available exposures or cores were examined in greater detail in order to determine specific channel models that appear to be most characteristic of each system.

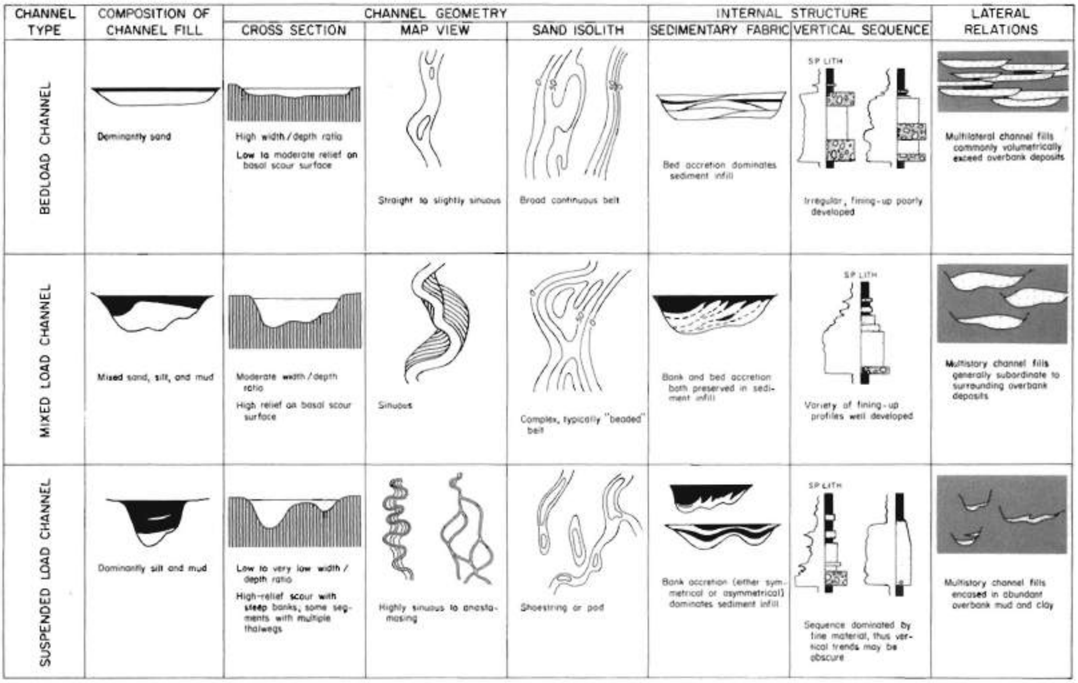


FIG. 5. —Geomorphic and sedimentary characteristics of bedload, mixed-load, and suspended-load stream channel segments. From Galloway (1977).

Principal Depositional Elements

Compositional differences allow regional mapping of both the Oakville and the Catahoula as separate intervals. Lithofacies maps, including both total sand thickness and sand percentage, form the basis for recognition of the principal fluvial depositional systems and their component depositional elements. The Catahoula consists of two major fluvial systems, the Gueydan bedload fluvial system of the Rio Grande embayment and the Chita-Corrigan mixed-load fluvial system of the Houston embayment (Fig. 6a). The Oakville Formation is most conveniently interpreted as a single large fluvial system extending from Washington County southward across the axis of the Rio Grande embayment (Fig. 6b), coincident with limits of outcrop recognition. East of the Brazos River, the entire Miocene section is mapped as undivided Fleming Formation and probably comprises a major mixed-load fluvial system. The southwestern margin of a Fleming fluvial axis extends into the mapped area (Fig. 6b). Depositional elements recognized within these three mapped fluvial systems include (1) the Gueydan bedload fluvial axis and its northeastern Karnes spur, (2) the Choke Canyon/Flatonia coastal lake/streamplain, (3) the Chita mixed-load fluvial axis, (4) the New Davy bedload fluvial axis, (5) the George West bedload fluvial axis, (6) the Hebbronville bedload fluvial axis, (7) the Moulton streamplain, and (8) the combined Burton/Penn mixed-load fluvial axes. Each element is labeled on Figure 6.

Fluvial axes consist of broad, commonly downdip-fanning sand-rich belts or aprons. Intervening broad areas of small dip-oriented sand trends and low overall sand content indicate parts of the coastal plain traversed by small, local streams or characterized by interfluvial lake basins. In plan view, facies distribution is similar to that developed in the later Quaternary; major extra-basinal rivers were located generally coincident with East and South Texas structural sags and a broad intervening stable area characterized by small- to medium-sized intrabasinal or basin-fringe streams. Regional three-dimensional relationships based on map (Fig. 6) and cross-sectional (Fig. 7) views illustrate the changing position as well as the vertical persistence of these depositional elements. Of particular importance is the fact that formational boundaries as well as time lines transect depositional elements. The necessary reliance on physical correlation somewhat unrealistically accentuates vertical separation of systems. Boundaries between the vertically superimposed Gueydan and Hebbronville axes and the Chita and Burton/Penn axes are locally transitional; the New Davy axis developed during deposi-

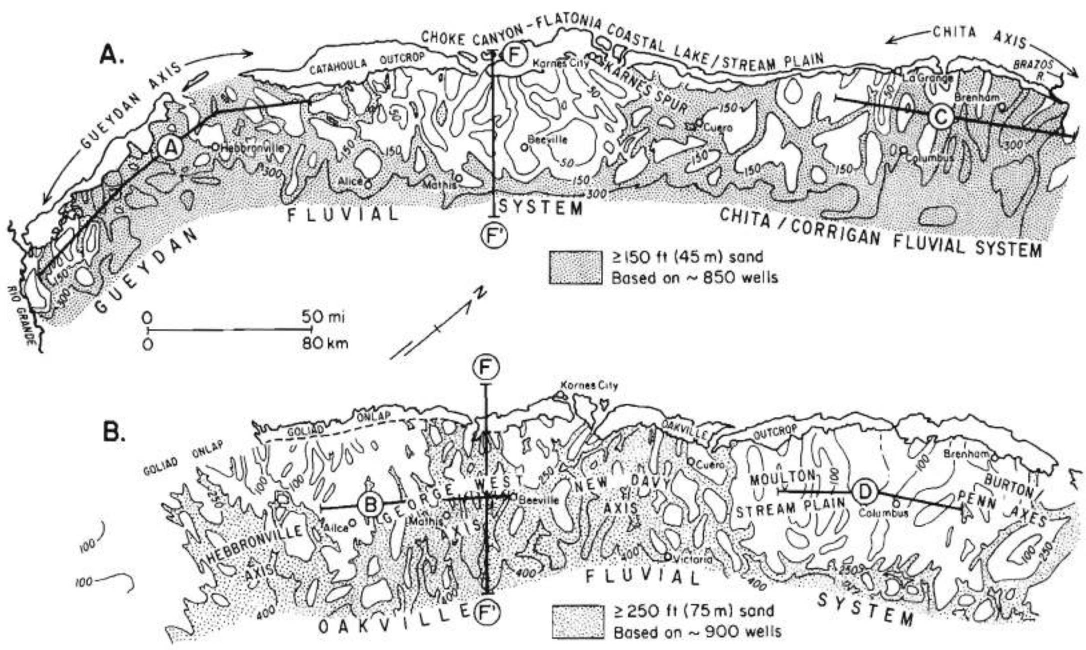


FIG. 6. —Simplified total net sand isolith maps of (A) Catahoula Formation and (B) Oakville Formation showing the location and extent of major fluvial depositional systems and their component depositional elements. Fluvial axes are outlined by broad, downdip-spreading sand-rich belts or aprons; intervening broad sand-poor areas define parts of the coastal plain characterized by local streams and inter-fluvial lake basins.

tion of uppermost Catahoula and must be arbitrarily subdivided in the subsurface. Abundance of volcanic ash in the Catahoula provides the best basis for approximating the regional physical correlations shown. Most significantly, the strike section emphasizes the fact that several contemporaneous major- and intermediate-scale rivers traversed the coastal plain, and that these rivers independently evolved in both size and location through geologic time.

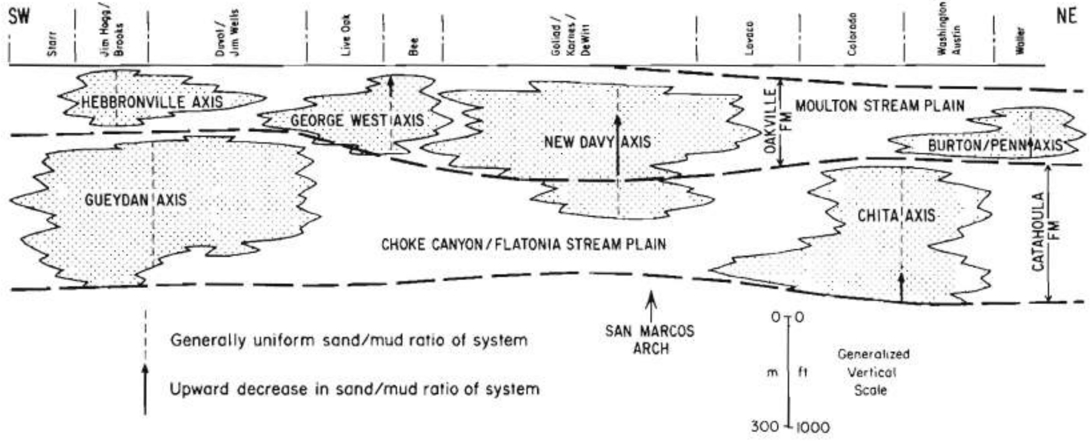
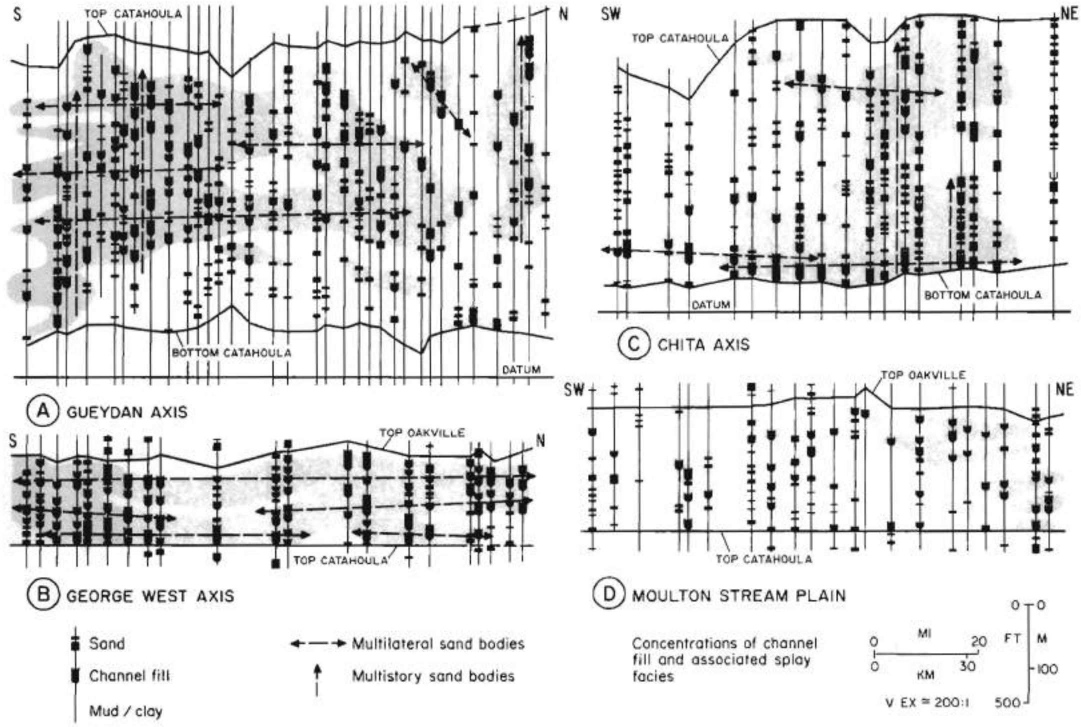


FIG. 7. —Generalized strike cross section of the Oligo-Miocene sequence illustrating the vertical and lateral position and extent of the principal depositional elements composing the Gueydan, Chita-Corrigan and Oakville fluvial systems. Major extra-basinal fluvial axes, such as the Gueydan-Hebbronville, tend toward long-term vertical persistance. The New Davy axis indicates the evolution of a newly developed basin-fringe river resulting from uplift of the adjacent Edwards Plateau (Fig. 1). For approximate line of section, see Figure 3.

TABLE 1.—COMPARATIVE FEATURES OF FOUR OLIGO-MIOCENE COASTAL PLAIN FLUVIAL DEPOSITIONAL ELEMENTS

	Gueydan Axis	George West Axis	Chita Axis	Moulton Streamplain
River Type	Extrabasinal	Extrabasinal	Large basin-fringe or extrabasinal (?)	Small basin-fringe and intrabasinal
System Classification	Bedload	Bedload	Mixed load	Mixed load and bedload
Discharge Characteristics	Moderately flashy	Flashy	Moderately flashy	Flashy to ephemeral
Typical Sand Percent	10–50%	50–90%	10–50%	10–40%
Internal Framework Architecture	Multistory and multilateral— No systematic vertical evolution	Multilateral— No systematic vertical evolution	Multistory and multilateral— Maximum channel fill abundance at base	Variable— No systematic vertical evolution
Areal Pattern	Distributary apron	Laterally constricted distributary apron	Anastomosing belt	Variable
Nature of Flood Deposits	Well-developed crevasse splays	Sheet splays	Well-developed crevasse splays	Sheet and crevasse splays
Composition	Volcanic rock fragment- and plagioclase-rich	Mixed volcanic and carbonate rock fragment-rich	Mixed lithic and feldspathic suite	Carbonate rock fragment-rich



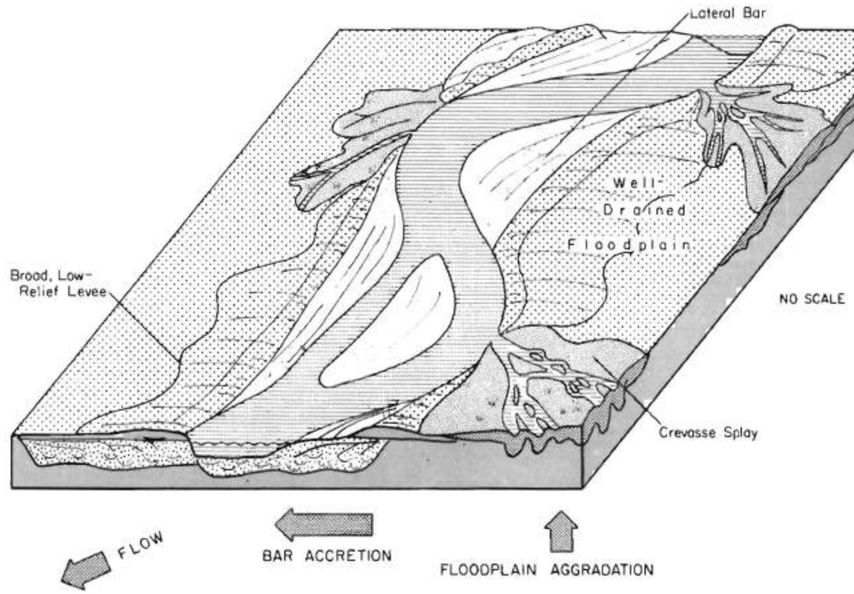


FIG. 9.—Schematic reconstruction of Gueydan depositional environments. High bedload, low sinuosity channels were flanked by extensive crevasse splays that funneled ash and sand into the surrounding floodplain environment. Abundance of volcanic ash transported by the river accentuated levee development and consequently, permanence of crevasse nodes. From Galloway (1977).

Four major depositional elements that are representative components of the Gueydan, Chita-Corrigan, and Oakville fluvial systems illustrate varieties of internal facies architecture characteristic of the Oligo-Miocene aggradational coastal plain. Salient features of these elements are summarized in Table 1 for comparison and contrast.

Gueydan Fluvial Axis.—The Gueydan fluvial axis covers approximately 9,000 mi² (23,000 km²) and consists of complexly interweaving, dip-oriented sand belts that diverge from a point source located northwest of the modern outcrop belt (Fig. 6a). Sand content ranges from a maximum of approximately 50 percent to less than 10 percent of the total Catahoula section. Multilateral sand bodies form broad composite belts several tens of miles wide (Fig. 8a). Thick sand bodies also tend to stack vertically; consequently, individual wells may intercept multiple sand units (Fig. 8a), and net sand maps provide a reasonable overview of sand-body geometries and trends, even though numerous genetic cycles are included within the mapped interval.

The Gueydan river system drained a large, lithologically diverse source terrane characterized by an abundance of extrusive volcanic rocks. Reworked volcanic debris forms a volumetrically dominant and distinctive sand and gravel component (Galloway, 1977; McBride et al, 1968). Compositionally similar volcanic deposits occur in Trans-Pecos Texas (McBride et al, 1968). The climate of the South Texas Coastal Plain was dry, as indicated by (1) development of tuffaceous paleosoil profiles rich in diagenetic montmorillonite and pedogenic calcite; (2) localization of vegetation (as evidenced by root traces) in channel, channel-margin, or lacustrine settings; and (3) the ubiquitous preservation of chemically unstable, reworked carbonate rock fragments (Creaser, 1977) and plagioclase feldspars in the sands.

Interpreted depositional environments are schematically reconstructed in Figure 9. Channels of the Gueydan system were wide, straight to slightly sinuous, and transported large volumes of medium sand to gravel. These features are typical of a bedload stream, but the Gueydan channel fills do not

FIG. 8.—Representative strike-parallel cross sections of major coastal plain fluvial depositional elements, including (A) the Gueydan extrabasinal bedload fluvial axis, (B) the George West extrabasinal bedload fluvial axis, (C) the Chita basin-fringe (?) mixed-load fluvial axis, and (D) the Moulton streamplain. Distribution of sand bodies interpreted from thickness and electric log character to be channel fill facies show various combinations of multilateral and multistory geometries. Additional thin or broken sand intervals may include splay, tributary, or local channel-fill deposits. Note the different proportions of sand and mud characteristic of each element. Location of sections on Figure 6.

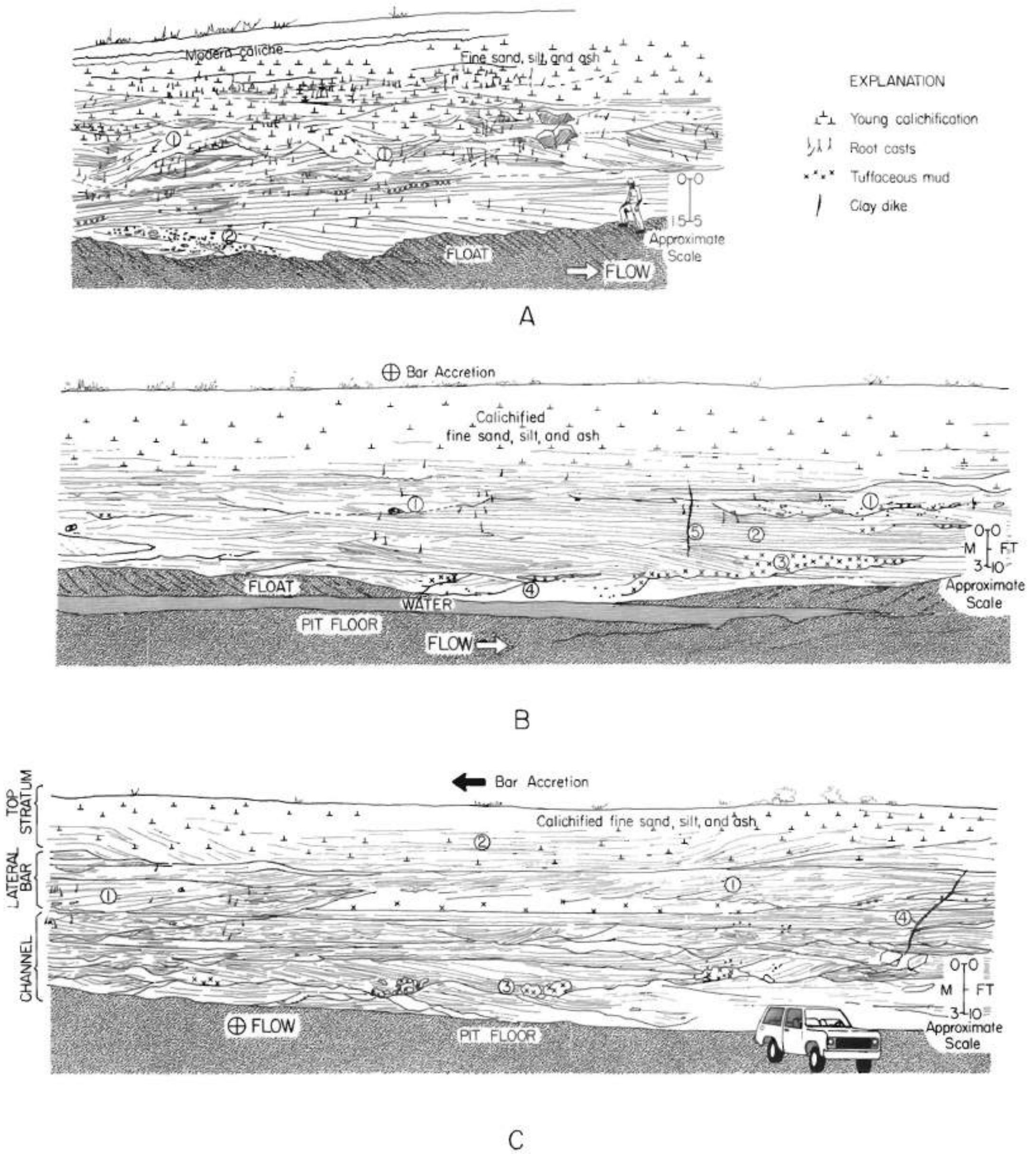


FIG. 10.—Internal structures of the Gueydan fluvial bedload channel fill in the Karnes spur. A and B parallel the paleocurrent direction (left to right). The base of the channel lies a few feet below the top of the float. C illustrates a section at right angles to the paleocurrent direction; channel, lateral bar, and top stratum deposits can be distinguished by grain size and internal structures. Significant features include: A. (1) Scour pool cross-stratification formed on the lee side of an obstruction, probably in situ brush or small trees (note abundance of root traces). (2) Abundant tuffaceous mud clasts incorporated in large-scale cross-stratified coarse to medium sand. B. (1) Broad, irregular scour-and-fill units displaying scalloped basal surfaces and containing abundant tuffaceous mud clasts of various sizes. (2) Thick, laterally continuous planar bed sets consisting of interlaminated medium and coarse sand. (3) Compacted ash pellet sand at toe of large scour trough. (4) Large-scale lenticular trough cross-stratification sets typical of the lower channel fill. (5) Intrastratal clay dike. C. (1) Low-angle accretionary bedding indicative of lateral bar migration from right to left into the channel. Note reactivation surfaces (2) Symmetrical swale fill in fine sand and silt of the top stratum. (3) Interchannel scour surface littered with large blocks of tuffaceous mudstone eroded from the channel banks. (4) Intrastratal clay dike. From Galloway (1977).

contain structures typical of conventional braided bedload stream models (Miall, 1978). Limited exposures indicate development of a few large latera or intra-channel bars capping trough cross stratified channel fills. The apparent degree of channel confinement was unusual for a bedload system; development of extensive crevasse splays and splay channels indicates the presence of permanent levees. The atypical channel stability as well as the relatively low preserved sand/mud ratio (for a bedload system) are probably explained by the abundance of silt and sand-sized vitric volcanic debris transported and deposited by Gueydan streams. Deposition of cohesive, rapidly altered ash accentuated bank stability, limiting lateral erosion of individual channels and localizing as crevasse splays the outpouring of flood waters and entrained sediment onto the floodplain. Further post-depositional argillation of vitric debris by pedogenic and meteoric diagenetic processes (Galloway and Kaiser, 1980) grossly modified the textural characteristics of the depositional sequence. Dramatic evidence for this textural evolution includes well-developed epigenetic uranium mineralization fronts (which required a permeable, well-integrated aquifer for their development) now encased in impervious mud-dominated splay sequences.

Sand-rich framework facies of the Gueydan axis include bedload channel fill and crevasse splay facies. Nonframework facies consist of tuffaceous floodplain mudstone and local tuffaceous lacustrine mudstone, claystone, and vitric ash.

Fluvial Channel Fill Facies. — Fluvial channel fill deposits are the dominant coarse clastic facies in the Gueydan system. Channel sand units average about 35 ft (10 m) thick, but single sand bodies more than 60 ft (20 m) thick are common. The base of the sand units is sharp (erosional) and is of low relief. Many of the thick sand bodies display an equally sharp top; others display the more typical transitional or fining-upward patterns. Width of individual sand bodies is difficult to determine with the well density used, but regional map patterns and examination of local areas of dense well control suggest widths of thousands of feet. Thus, width-to-thickness ratios of the channel fill units are high. Outcrop patterns and detailed subsurface mapping also indicate the development of multilateral sand belts up to several miles wide that are composed of numerous individual channel fill units.

Bedload channel fill sequences consist of coarse to medium sand with subordinate sandy cobble to granule conglomerate and very fine sand and silt. Tuffaceous mud clasts and sand-sized mud pellets are common. Initially, sands were moderately to well sorted, but subsequent diagenetic alteration of unstable volcanic rock fragments, clay authigenesis, and squashing of the mud pellets and clasts have typically produced a matrix-rich sand. Most sequences display at least a crude fining-upward trend, but grain size and sorting can vary widely within any part of the sand body.

Internal stratification types include common large-scale trough cross bedding or cut-and-fill structures, complex crosscutting scour surfaces, abundant planar and low-angle parallel stratification, and low-angle bar accretion bedding. Small-

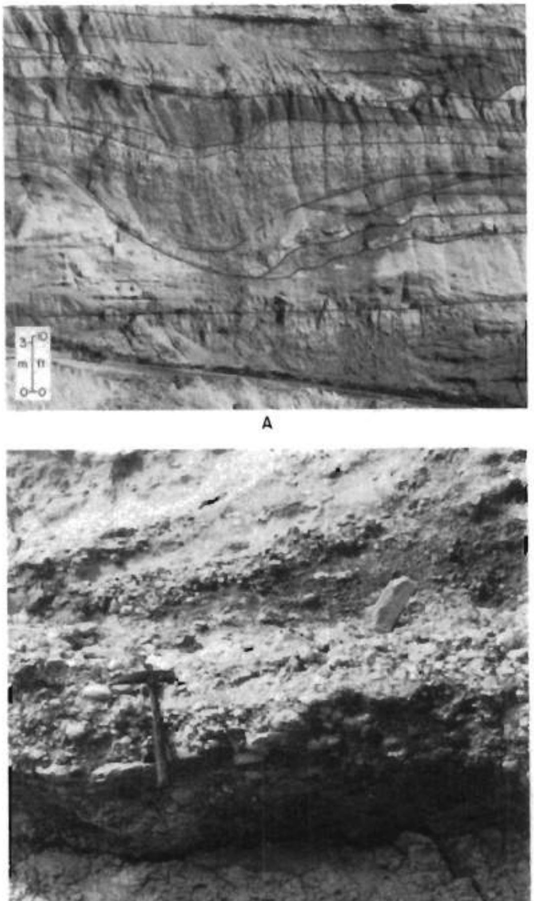


FIG. 11.—Sedimentary features of Gueydan crevasse splay facies. A. Lenticular, symmetrically filled suspended-load splay channel and laterally equivalent, horizontal interbedded splay mud, sandy mud, tuff, and muddy sand. Several lenticular splay channel units are crudely superimposed and overlie more evenly bedded to massive distal splay and floodplain tuff, silt, and mud. B. Weathered splay channel lag displaying abundant reworked, rounded to angular tuff and mud clasts eroded from the adjacent floodplain and older splay channels. Such sandy mud and tuff clast conglomerate, commonly with a matrix of diagenetic mud, is typical of the Gueydan splay facies.

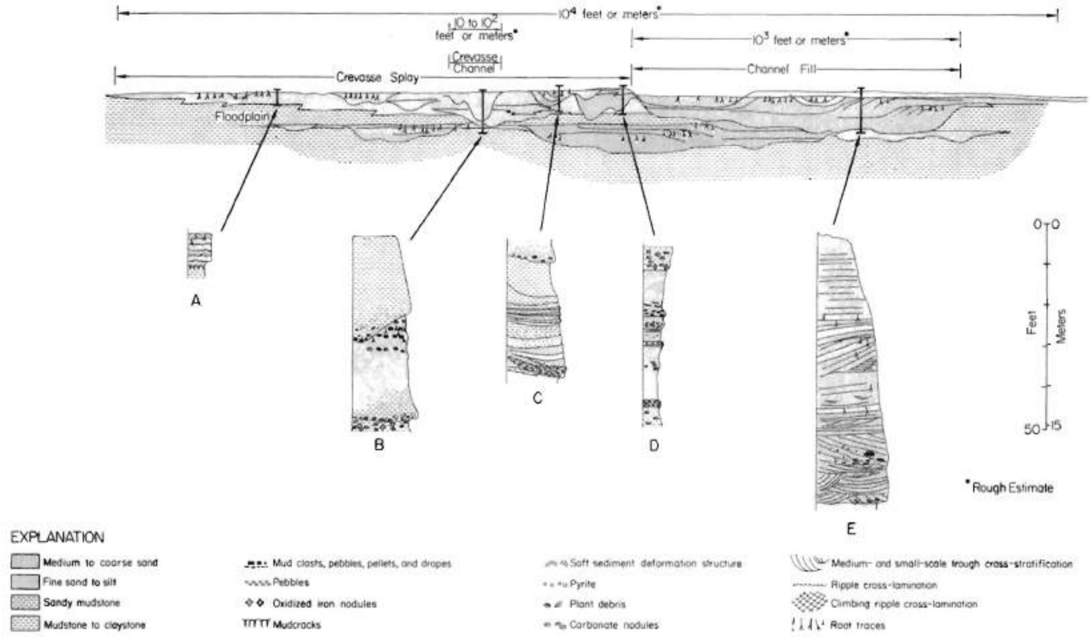


FIG. 12.—Schematic facies architecture of a composite Gueydan sand belt illustrating lateral relationships of the various facies. Channel-fill and crevasse deposits form the sand framework of the system. Measured sections illustrate typical sedimentary features of distal crevasse (A), proximal crevasse tuffaceous mudstone-filled channel (B), mixed sand and mudstone-filled channel (C), sand/silt-filled channel (D), and fluvial channel-fill deposits (E). Dimensions suggest order-of-magnitude widths of the channel complex and component facies. From Galloway (1977).

scale structures are uncommon, but include small-scale trough, ripple, and parallel lamination, vertical clay dikes, root casts, and armored tuffaceous mud balls. Spatial organization of sedimentary structures within channels is difficult to determine in the typically poor exposures or short cores available. In a well exposed, complete channel fill sequence in the Karnes spur (Fig. 10), a tripartite sequence consisting of (1) a lower zone of large-scale trough cross-stratified pebbly medium to coarse sand, (2) a middle zone dominated by localized scour fills, root zones, and large packages of horizontal to accretionary bedded medium to coarse sand, and (3) a top stratum of evenly bedded fine sand and silt.

Crevasse Splay Facies.—Floodwaters in the Gueydan fluvial system breached the broad, poorly developed natural levees, spread over interchannel areas, and deposited extensive aprons of ash-rich fine sand and silt along the flanks of major channels. These crevasse splays extend hundreds to thousands of feet beyond channel margins. Thickness is highly variable locally because of the complex internal structure of splays, which consist of narrow anastomosing channel fills as much as 30 ft (10 m) thick, separated by thinner sequences of irregularly bedded sheet flow and paleosoil deposits (Fig. 11a). Crevasse channel fills range from a few feet to a few hundred feet wide, which is narrow in contrast to the associated fluvial channel fills. Because floodwaters carried relatively fine sediment dominated by fine sand to silt-sized volcanic ash, crevasse channel fills are narrow, highly lenticular, symmetrically filled, and anastomosing suspended-load types (Fig. 11a). The constrast between Gueydan fluvial channel fill and crevasse channel fill graphically illustrates the extreme facies variation that may be produced by sediment-sorting mechanisms operating within the same fluvial system.

Crevasse splay deposits in the Gueydan contain a variety of sediment types, ranging from medium or fine sand and sandstone to mudstone, reflecting the varied depositional conditions typical of the crevasse environment (Coleman, 1969). Crevasse-channel fills range from tuffaceous fine to medium sand and sandstone to sandy tuffaceous mudstone and claystone. Crude fining-upward sequences are common. Weathering surfaces suggest that significant thicknesses of tuff-ball conglomerate filled some crevasse channels (Fig. 11b). Lenses of relatively unaltered ash also occur locally. Petrographic study indicates that the tuffaceous splay channel fill sediments were originally deposited as fine sand to silt-sized volcanic ash and ash pellets that have subsequently altered to montmorillonitic clay.

Facies Associations and Distribution.—Coarse sandy to conglomeratic channel fill lenses are both laterally and vertically amalgamated, commonly forming composite sand bodies several tens of feet thick and up to two to three miles wide. Vertical persistence of stacked channel margins is suggested by limited examination of closely spaced drill data. Marginal to and interbedded with channel fill deposits are comparably thick, internally complex crevasse splay sequences (Fig. 12). Amalgamated splays form a mosaic of small lenticular channel fills, crudely to well-bedded interchannel deposits, and more extensive paleosoil horizons that may extend several thousand feet beyond the channel margin. Together, splay and channel fills units form a sand-rich belt up to several miles wide (Fig. 12). Multiple belts occur within vertical sections through sand-rich parts of the Gueydan axis. Lateral juxtaposition of several belts produces multilateral sand units that may persist for tens of miles along depositional strike. Examples of both stacked and multilateral sand complexes are illustrated in Figure 8a.

George West Fluvial Axis.—The George West axis is a principal locus of entry of a single major river onto the Miocene coastal plain. This river was probably the Miocene descendant of the underlying Catahoula Gueydan fluvial system. It crossed the coastal plain along a broad swath in Live Oak County (Fig. 6), but may have periodically shifted nearly 90 mi (140 km) southward, traversing the coastal plain through Jim Hogg County along the Hebbronville axis. Regional strike sections indicate thickest sands of the Hebbronville axis are stratigraphically higher than most sand of the George West axis (Fig. 7). Compositional data as well as the southwesterly trend of the most proximal preserved sands of the George West axis (Fig. 6) support the inference of a single, large, extrabasinal paleo-Rio Grande river system shifting its location on the South Texas Coastal Plain through geologic time.

Total sand content of the George West axis commonly exceeds 250 ft (75 m) and is almost uniformly greater than 150 ft (45 m). Sand percentage is also high, averaging almost 60 percent and ranging to as much as 89 percent in the updip parts of the axis. As the total Oakville interval expands downdip, the absolute amount of sand increases along individual isolith thicks (Fig. 6); however, the ratio of sand to mud effectively decreases. Sand distribution along the axis is characterized by multiple dip-oriented, slightly sinuous, anastomosing or basinward bifurcating isolith thicks that form a broad belt nearly 70 mi (110 km) wide. Individual isolith thicks are generally less than 3 mi (5 km) wide. The high sand percentage, complexly intersecting sandbody trends, and broad areal dimensions of the belt are characteristic of a major bedload fluvial system (Galloway et al, 1979b; Schumm, 1977).

Internally, framework sands include three principal genetic facies: conglomeratic bedload channel fill, sandy bedload channel fill, and sheet splay. Figure 13 is a diagrammatic reconstruction of a sandy channel segment typical of the George West axis.

Conglomeratic Bedload Channel Fill Facies.—Although volumetrically minor within the preserved George West axis, conglomeratic channel fill deposits were probably a significant component of the upper coastal plain setting. The facies consists of interlensed medium to coarse sand and pebbly sand, sandy conglomerate and clast-supported conglomerate with subordinate amounts of fine sand to silt (Fig. 14). Grain size and texture vary randomly both vertically and laterally within sand bodies and within individual depositional units. Individual lenses of sand and gravel range from 3 to 15 ft thick

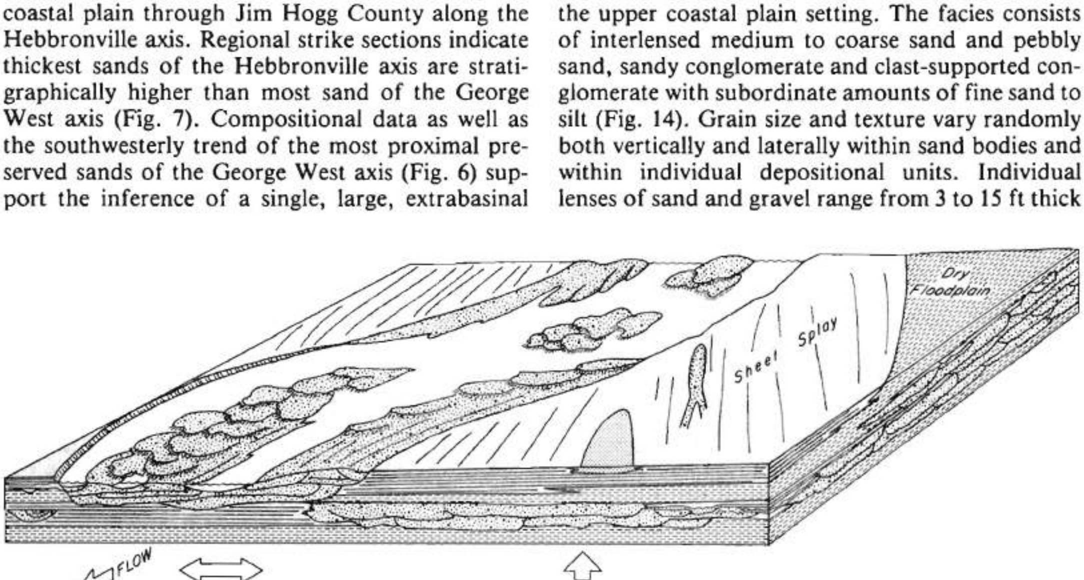


FIG. 13.—Schematic reconstruction of Oakville fluvial depositional environments. Braided bedload channels were flanked by extensive sheetflood-dominated crevasse splays, which grade laterally into interchannel floodplain deposits. From Galloway et al (1979a).

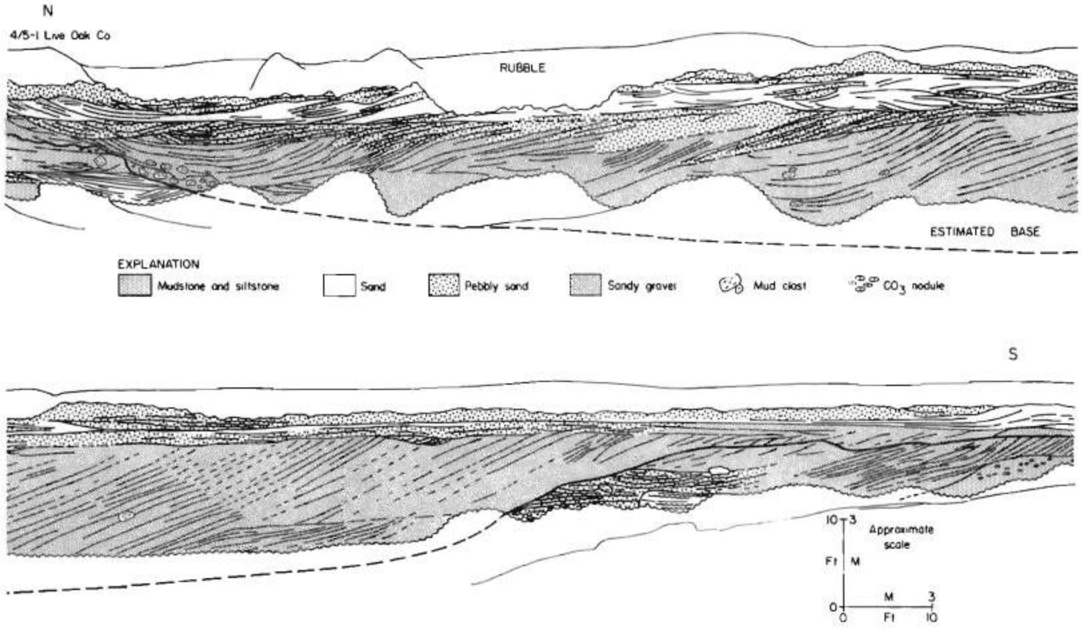


FIG. 14.—Line tracing of a photomosaic (gravel pit, Live Oak County) showing the internal structure and composition of a well-exposed conglomeratic braided channel fill of the Ray Point fluvial axis. Internal structure is dominated by large-scale gravel-bar accretionary bedding. Note abundance of reactivation surfaces. Unit is deposited on irregular scour surface lying directly on fine-grained overbank fine sand and floodplain mud, indicating deposition during major flooding. From Galloway et al (1979a).

(1 to 5 m). Internal structures are characterized by large-scale, low- to moderate-angle accretionary bed sets containing multiple reactivation surfaces, parallel and planar stratification, scour-and-fill structures, and medium- to small-scale trough cross-stratification (Fig. 14). Pebble sizes observed range up to 3 inches (7 cm) in diameter; common lithologies include jasper, chalcedony, silicified wood, volcanic rock fragments, chert, quartzite, and limestone. Clasts exhibit poor to fair imbrication. Intraformational clasts, including sandstone and mudstone grains, pebbles, and large blocks are common to abundant.

Sedimentary features indicate that various types of channel bars (probably including longitudinal, transverse, and marginal) interspersed with small braid channel lenses and flood channel bars were the primary depositional units (Galloway et al, 1979b).

Sandy Bedload Channel Fill Facies.—The principal component sediments of the George West fluvial axis are coarse to fine, locally conglomeratic, moderately sorted sands deposited as broad, tabular units separated by thin, laterally continuous beds of mud and clay. They contain interspersed, discontinuous lenses and beds of mud clast conglomerate, silt, and very fine sand. Individual channel fill sequences average between 10 and 20 ft (3 and 6 m) thick, have sharp erosional bases, and may be capped by a thin transition zone consisting of finely laminated to massive, root-disturbed fine sand, silt, and mud (Fig. 15). Internal structures consist of abundant planar and low-angle cross-stratified sand and broad lenses of trough and tabular cross-stratified sand (section B, Fig. 9). Common features include local scour-and-fill structures, laterally extensive, internal erosion surfaces, small to large mud clasts and blocks, deformed bedding (in finer sands), and possible antidune cross-stratification (Fig. 15). No consistent vertical sequence of grain size or internal structures is present. Local lenses of waxy, sparsely burrowed and finely ripple-laminated claystone indicate formation of local, temporary ponds within abandoned channel segments.

A variation of this facies (Fig. 16) consists of complexly interlensed, chaotically mixed mud clast conglomerate and moderately to poorly sorted sand. Structures are dominated by large accretionary, moderate-angle foreset stratification and horizontal stratification. Medium- to small-scale trough and tabular cross-stratification occurs locally within the sand bodies. Reactivation surfaces are abundant.

Interpreted paleochannel geometry, internal structures, and coarse overall texture indicate deposition in flashy, sandy, braided bedload fluvial channels dominated by high velocity, shallow to intermediate depths of flow. Principal depositional units included linguoid bars and various larger bar forms generated in and marginal to the low-water channel during major floods. Large gravel and mud clast conglomerate bars were deposited across proximal floodplain and stabilized interchannel islands by unusually high floods. Similar braided stream deposits of modern fluvial systems, including the Cimarron, Platte, and Saskatchewan Rivers, are reviewed by Shelton and Noble (1974), Miall (1978), and Rust (1978). Analogous sedimentary features are also found on the inland parts of the modern Nueces (Gustavson, 1978) and Pedernales Rivers, Central Texas.

Sheet Splay Facies. — Thin to thick sequences of moderately sorted coarse to fine sand and subordinate interbedded silt and sandy mud occur marginal to and interbedded with channel fill facies. Sheet splay units form laterally continuous sheet-like sand bodies; individual depositional units range from inches to over 15 ft (5 m) in thickness (Fig. 17). Internal structures are dominated by planar stratification. Bedding-plane parting lineation characterizes laminated sands. Less common structures include shallow symmetrically and asymmetrically filled scour channels and troughs, mud drapes, medium- to small-scale tabular cross-stratification, and ripple lamination. Mud clasts and blocks are

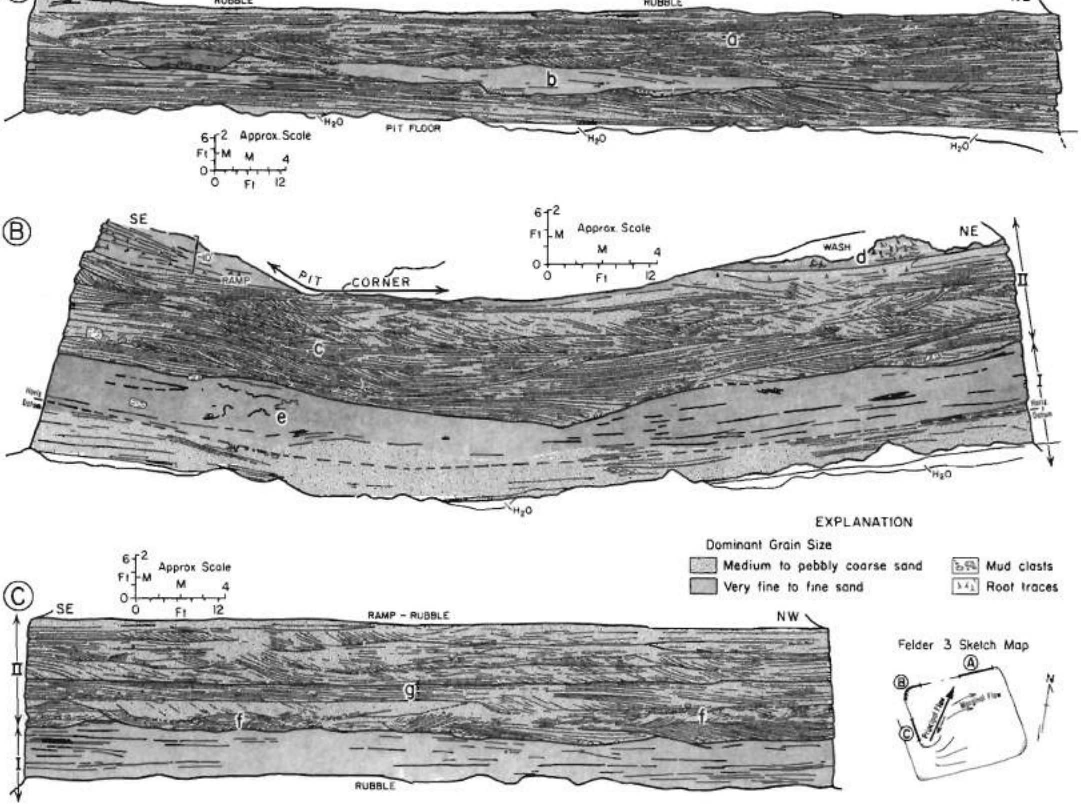


FIG. 15. — Line drawings from a series of photomosaics illustrating internal structures and textures characteristic of the George West sandy bedload channel facies. Sections A and C provide right-angle views oblique to the interpreted NNE paleocurrent direction. Approximately 6 m (20 ft) of additional sand lies below the pit floor. Two channel sequences (indicated by I and II) are separated by an extensive scour surface that can be traced across all sections. (a) Tabular cross-stratification produced by sand waves migrating up the channel margin during waning flow. (b) Small scour channels. (c) Well-developed tabular cross-stratification with multiple reactivation surfaces. (d) Root-disturbed channel top stratum. (e) Contorted bedding produced by sediment liquefaction. (f) Up-flow dipping trough cross-stratification possibly generated by antidune migration. (g) Planar stratification. From Galloway et al (1979a).

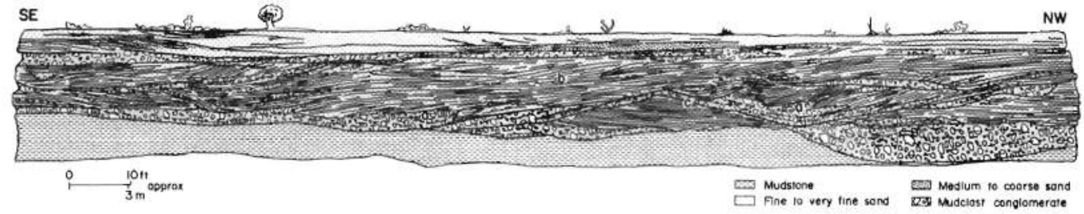


FIG. 16.—Variation of the sandy bedload channel fill facies consisting of complexly interstratified sand and mudclast conglomerate. Many large, lenticular depositional units show crude inverse grading with mud clasts and other unsorted coarse debris deposited at the toe of the large, low-angle accretionary foresets (a). Multiple reactivation surfaces (b) and cross-cutting scour and fill features (c) are also characteristic, as is horizontal stratification. Features indicate chaotic deposition during short periods of peak discharge. Felder uranium pit, Live Oak County.

common accessory components.

The abundant planar stratification, sheet geometry, and small-scale vertical cyclicity indicate pulsatory transitional and upper flow-regime conditions in a shallow, unconfined setting. Spatial association of the facies with channel fill units during suggests deposition of sheet splay units during periods of intense overbank flooding. Analogous flood sediments have been described by McKee et al (1967).

Facies Associations and Distributions.—Sandy channel fill and sheet splay units occur as intimately interbedded components of broad, tabular sand belts that are commonly several kilometers in width and 15 to 100 ft (5 to 30 m) in thickness (Fig. 18). Sand-rich cores of thicker belts contain vertically stacked, amalgamated sequences of several channel fills. Very little mud or clay is preserved except in lenses or lags of mud clast conglomerate. Presence of conglomerate channel fill deposits has been documented only in a limited area of the George West fluvial axis. Where present, however, they occur within the core of major sand belts (Fig. 18). and represent the most proximal fluvial facies preserved in the George West axis.

The composite fluvial belts grade laterally into interbedded sheet splay and floodplain facies, punctuated locally by isolated channel fills (Fig. 18). Sheet splay sands do not extend far beyond equivalent channel fills. As in the Gueydan axis, several bundles are stacked in areas of thickest sand and are less abundant in inter-axial areas where sand percentage is lower and less permeable floodplain deposits are more abundant and better preserved. However, the George West axis is characterized by extremely well developed multilateral sand belts that extend nearly unbroken for as much as 100 mi along strike (Fig. 8b), forming a fluvial sheet sand similar to that described by Campbell (1976).

Chita Fluvial Axis.—The Chita fluvial axis forms a broad, dip-oriented, sand-rich belt composed of several individual isolith thicks (Fig. 6). Width of the belt is about 40 mi (60 km), and, unlike the bedload Gueydan and George West axes to the south, downdip development of a distributing geometry is not pronounced. Individual sand-rich ribbons tend to bifurcate and intersect at oblique angles (Fig. 6a), but generally remain within the confines of a uniformly broad belt. This pattern characterizes other major axes mapped within the Chita-Corrigan fluvial system and overlying Oakville Burton/Penn axes.

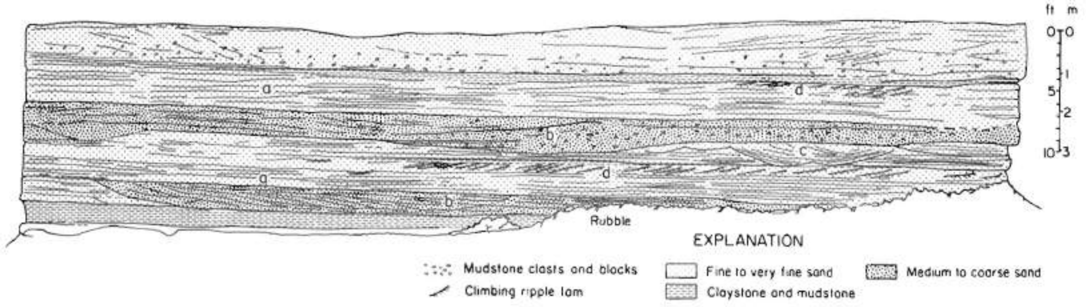


FIG. 17.—Sheet splay deposits interbedded with channel fills of the George West axis exposed in the Smith uranium mine (Live Oak County). Principal sedimentary features include well-developed horizontal bedding as well as internal planar stratification (a), local small scour channels commonly filled with coarser sand and mud clasts (b), small scour fills (c), and waning-flow sequences capped by climbing ripple lamination (d).

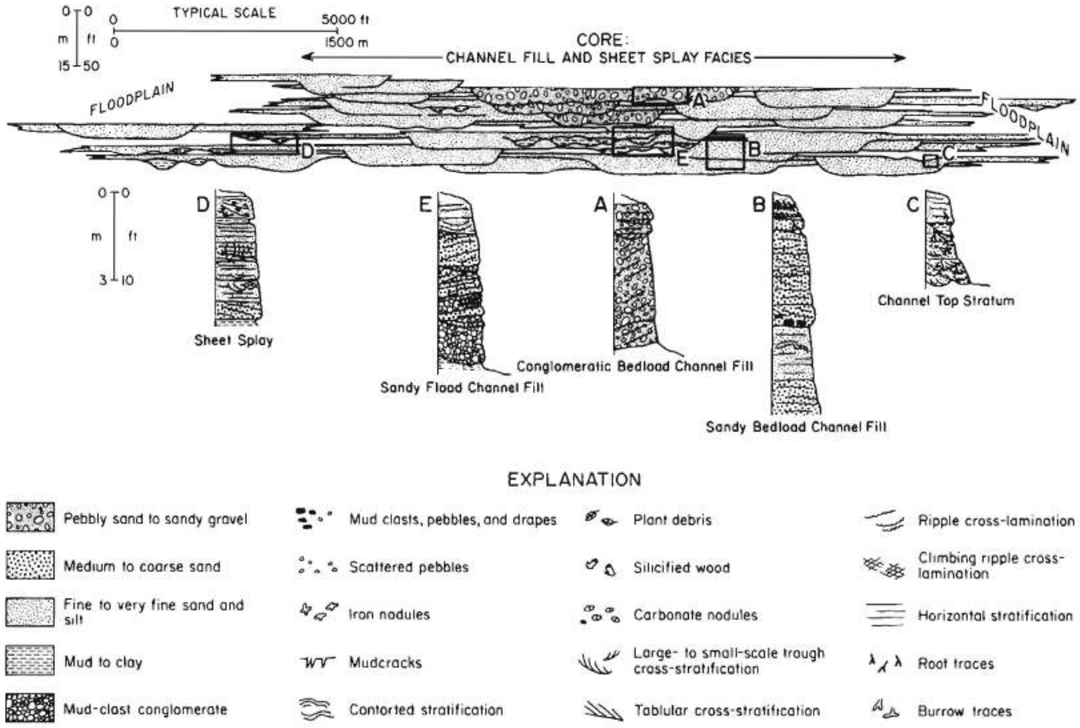


FIG. 18.—Schematic facies architecture of a composite sand belt typical of the George West fluvial axis. The sand body consists of amalgamated sandy and conglomeratic channel fill and sheet splay units interfingering laterally with floodplain deposits. Measured sections illustrate common internal features of component sand facies.

Chita sands consist of abundant quartz with subordinate mixed orthoclase and plagioclase grains. Chert, carbonate rock fragments, and volcanic rock fragments are common. The mixed composition suggests a complex source terrane, probably consisting primarily of older clastic sequences. Carbonate rock fragment content increases up-section into the transitionally overlying Burton/Penn axis, documenting increasing exposure of Cretaceous strata and culminating in a calclithic lithology unique to Miocene fluvial sands of the central coastal plain (Galloway, 1977; Galloway et al, 1980; Thomas, 1960; Ragsdale, 1960).

The Chita axis consists of stacked and multilateral sequences of channel fill and associated sands forming composite dip-oriented belts, which are separated by mud-rich facies containing thin, discontinuous sand units. Compositionally, the axis contains approximately 35 percent sand and minor conglomerate; locally, sand percent ranges from less than 10 to more than 50 percent. Up to 10 individual sand units (10 m or more thick) occur within a single vertical section; the number is generally proportional to the sand content of the section. Although different in detail, the overlying Burton/Penn fluvial deposits of the Oakville are grossly similar.

Framework facies of the Chita fluvial axis include mixed-load fluvial channel fill sand and laterally equivalent crevasse splay deposits, which can be differentiated into proximal and distal parts on the basis of sedimentary features and thickness. Nonframework facies include well-drained floodplain mud and silt and local interchannel lake clay, mud, and sand. Lacustrine deposits become especially prominent within the Catahoula farther eastward. They are not present in the overlying Burton/Penn axis, however.

A schematic reconstruction of a typical Chita channel fill is shown in Figure 19. Main channels appear to have been meandering and possessed moderate width to depth ratios typical of a mixed-load fluvial system. Lateral migration of channels resulted in accretion of point bars that were moderately to highly modified by development of chutes and chute bars during frequent floods. Vertical sequences resembling those of the modern Colorado and Amite Rivers (McGowen and Garner, 1970), Arkansas River (Reineck and Singh, 1975), Wabash River (Jackson, 1976), and Brazos

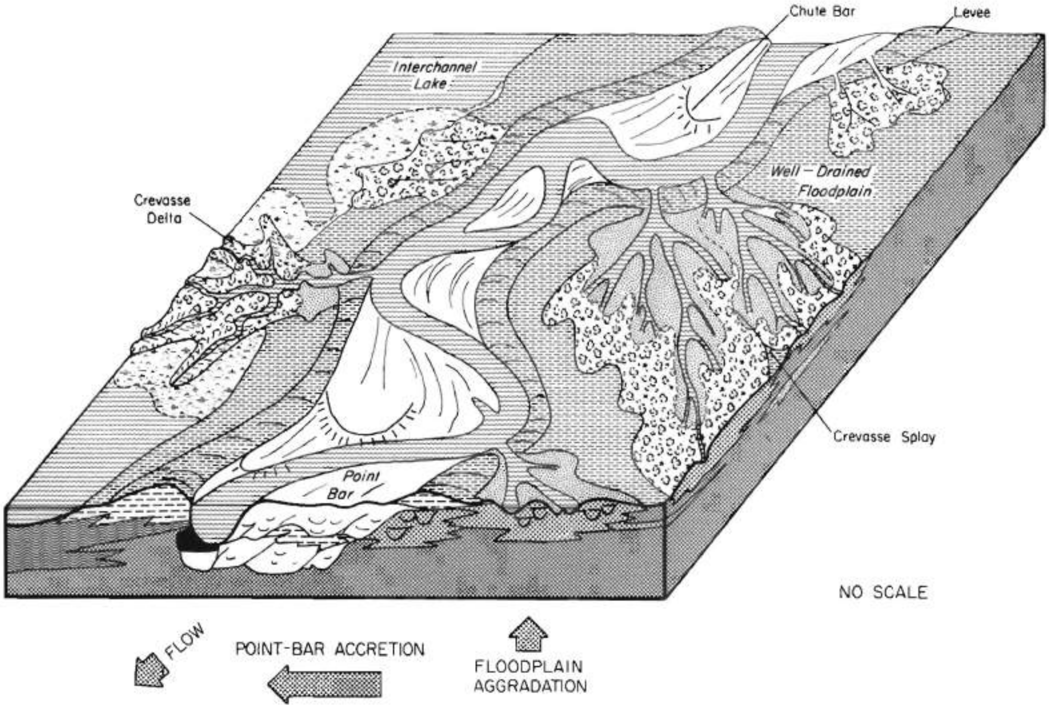


FIG. 19.—Schematic reconstruction of Chita-Corrigan depositional environments. Mixed-load, sinuous to meandering streams and associated levees and crevasse splays formed relatively high, well-drained belts separating vegetated floodplain, and in the upper Texas Coastal Plain, interchannel lakes. Crevasse splays were well developed and stabilized by tuffaceous, vegetated levees. From Galloway (1977).

River (Bernard et al, 1970) are all found. Such complexity and variety of vertical sequences suggests variable flow conditions typical of many modern basin-fringe rivers.

Crevasse splays were exceptionally well developed along the margins of the leveed channels (Fig. 19). Size of proximal crevasse channels, as well as the progradational nature of many crevasse sequences, indicated persistence of individual splays through many flood events. Abundance of vegetation as well as the presence of airfall ash accentuated levee and splay stability.

Fluvial Channel Fill Facies.—Fluvial channel fills form dip-oriented, sinuous sand units averaging 35 to 50 ft (10 to 15 m) thick. Approximately 5 percent of the sand bodies are over 75 ft (23 m) thick. Margins of the channel fill units are erosional.

Channel fill facies typically consist of subequal parts of medium to coarse sand (containing some sandy granule to small pebble gravel) and fine to very fine sand. Local lenses of mudstone and muddy sandstone, mud clast conglomerate, and muddy granule conglomerate occur in lower parts of the channel fill; clay pellets and chips are common in upper parts. Sands are moderately to well sorted. Ferruginous nodules and fragments of silicified wood are common accessories.

Channel fill deposits display a variety of sedimentary structures, including medium- to large-scale, low- to high-angle trough cross-stratification, scour and fill, planar stratification, and local avalanche cross-stratification. Laterally persistent cross-cutting scour surfaces floored by basal mud clast and gravel lags suggest complex histories of channel fill and reactivation. Small-scale structures are less common, but ripple and parallel lamination, local mud drapes, and root structures are present. Ripple lamination occurs internally within some large trough sets; the small structures are typically present in uppermost parts of the channel sequences. Lateral migration of point bars within river meanders is indicated by locally preserved large-scale accretionary bedding in the upper channel fill (Fig. 20).

Channel fill facies have a grossly lenticular cross-sectional geometry, but depth of basal scour and the extent of lateral accretion can vary considerably, resulting in a broad spectrum of channel shapes. Channel fills tend to fine upward, particularly within the upper parts. However, a local variant is a bipolar trend with coarser trough crossbedded sands at the base and one or more coarse avalanche sets capping the sequence. This latter sequence may be produced by migrating longitudinal bars (Jackson, 1976), spillover lobes (Bernard et al, 1970), or by chute-bar accretion (McGowen and Garner, 1970).

Top stratum deposits consist of very fine sand, silt, and mudstone, which may be rooted, finely laminated, or structureless.

Crevasse Splay Facies. — The crevasse splay facies consists of thin to thick, crudely bedded and lenticular sand and sandstone, siltstone, and mudstone deposited along the margins of the fluvial channels. Altered airfall ash is a dominant component of crevasse facies but is diluted by nonvolcanic silt and sand.

Crevasse splay facies form coalescing aprons that thin away from fluvial axes and interfinger with floodplain or lacustrine mudstone and siltstone. Individual crevasse sequences rarely exceed 30 ft (10 m) in thickness, but stacking of channels and their associated crevasse splay units results in superimposed facies tens of feet thick. Individual beds or lenses within the crevasse sequence typically are a few feet thick, though proximal crevasse channel fills may be 10 to 20 ft (3 to 6 m) thick.

Proximal crevasse deposits are characterized by their variety of structures, textures, and bedding features, which occur in close geographic and stratigraphic proximity. Lenticular crevasse channels range from a meter to over ten meters in thickness, and from a few meters to hundreds of meters in width (where lateral migration has occurred). Width/thickness ratios are moderate to low, and lenticularity and irregular basal scour are hallmarks of crevasse channels.

Proximal crevasse deposits contain abundant fine sand and silt, as well as local lenses of medium sand. Mud chip and mud clast conglomerate is diagnostic and may compose a volumetrically significant sediment type. Common accessory features include local zones of micrite nodules, scattered ferruginous nodules, and carbonaceous or silicified wood and plant debris. Ripple, climbing ripple, wavy, and parallel lamination, medium-scale trough cross-lamination, and dewatering structures are abundant. Rooted zones, clay and mud drapes, and mud cracks are also common. Crevasse channel fill units contain medium- to large-scale trough cross-stratification, planar lamination, and multiple crosscutting scour surfaces. Lateral accretion bedding formed locally as crevasse channels migrated.

Distal crevasse deposits consist of areally extensive, thin to thick, irregular beds of siliceous, tuffaceous, muddy siltstone to fine sandstone; local scour-and-fill lenses of poorly sorted medium sandstone also occur. The base of beds is sharp, and load structures are common. Primary structures were almost entirely destroyed by root and burrow churning or shrink-swell pedogenic processes typical of high-montmorillonite soils developed on the ashy sediments. Splay facies of the Burton/Penn axis exhibit a broad range of primary planar, ripple, and cross-lamination types.

Crevasse facies commonly form a progradational vertical sequence grading from massive floodplain mudstone and siltstone upward into interbedded floodplain and distal crevasse beds, capped in turn by lenticular or thick-bedded proximal crevasse units. Detailed core drilling illustrates the digitate fan-like geometry and depositional setting of a major splay developed along the margin of a trunk alluvial channel of the Chita axis (Fig. 21).

Facies Associations and Distribution. — Sand-rich facies trends consist of axial cores of amalgamated channel fill deposits up to several thousand feet wide. Multiple scour surfaces and lateral accretion bedding add complexity to this massive sand facies. Marginal crevasse splay sands and interbedded finer sediments form laterally extensive aprons marginal to the channel axis (Fig. 21). Together these sand facies compose depositional belts up to a

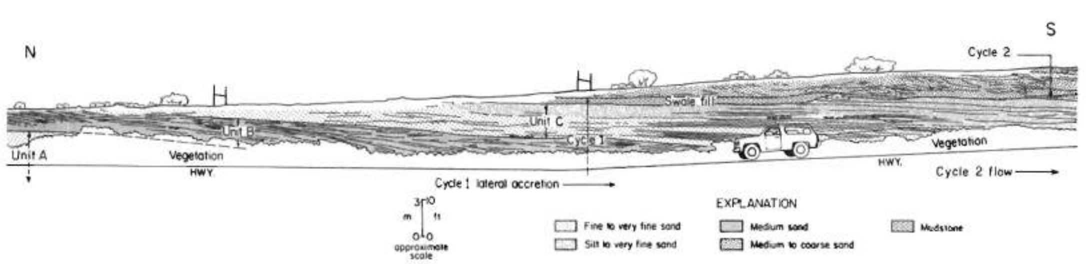


FIG. 20. — Road cut exposure (Grimes County) displays lateral accretion bedding typical of upper point bar deposits (units A, B, and C, cycle I) of a sinuous mixed-load channel of the Burton/Penn axis. Similar deposits are common in the underlying Chita axis. A second cycle (II) is stacked on the upper point bar and local swale fill deposits of cycle I. These lower point bar and channel lag deposits consist of medium to coarse sand, in contrast to the fine sand typical of the upper point bar. Internal features include abundant parallel and trough cross-stratification.

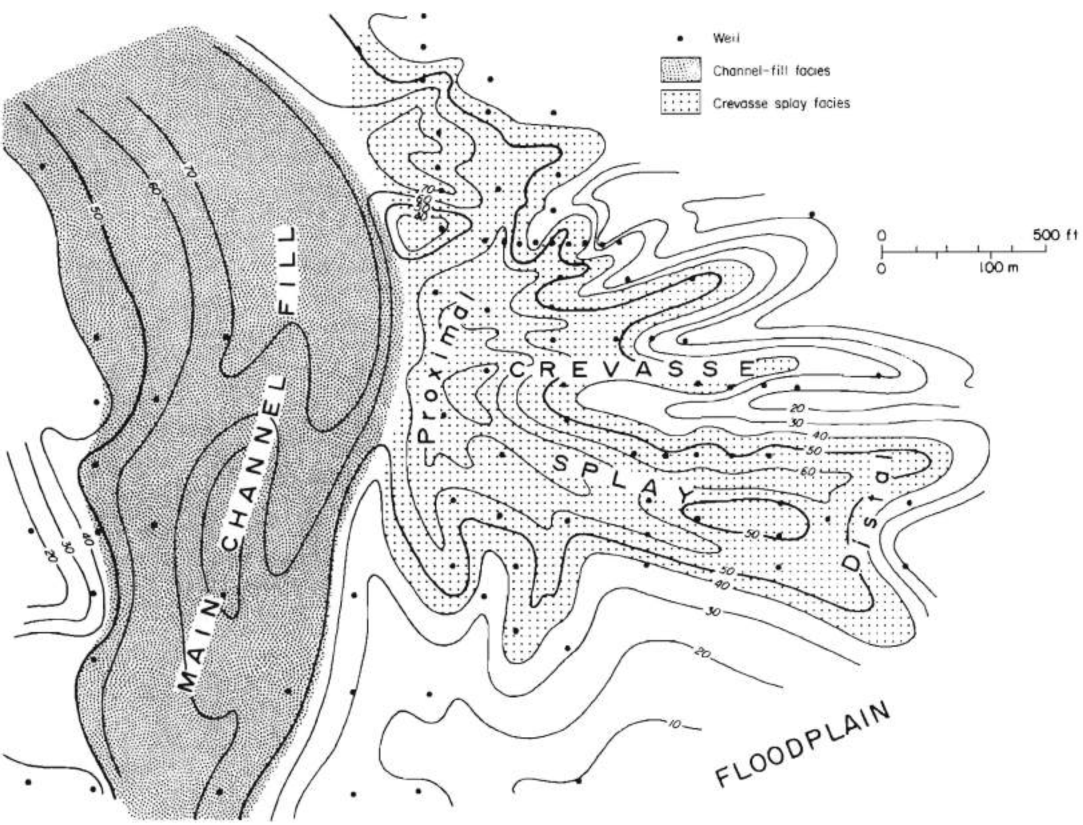


FIG. 21. — Detailed map of crevasse splay sands lying at the periphery of a major sinous channel of the Chita fluvial axis. The splay extends more than 2,000 ft (600 m) into the adjacent floodplain. The digitate isolith pattern reflects the presence of well-developed splay channels, particularly in proximal parts of the splay. Note that aggregate splay thickness is comparable to that of the associated channel fill.

few miles in width (Fig. 22). Composited multilateral belts are up to tens of miles in width, particularly at the base of the Catahoula section (Fig. 6c). Narrow belts exhibiting vertical stacking are more characteristic of the upper Chita section. Abundance of thin sand bodies within thick floodplain sequences far removed from main channel belts suggest the presence of numerous small tributary coastal plain streams.

Moulton Streamplain. — Between the New Davy and Burton/Penn fluvial axes, the Oakville fluvial system grades into a relatively sand-poor interval which contains several narrow, localized, dip-oriented sand trends (Fig. 6b). Within this area, total Oakville sand thickness rarely exceeds 150 ft (45 m), and sand content commonly ranges between 10 and 40 percent.

The limited lateral and vertical dimensions of sand bodies and relative abundance of fine-grained sediment indicate deposition in a part of the Miocene coastal plain characterized by small, locally sourced intrabasinal or basin-fringe streams most of which were of the bedload and mixed-load types. Small streams with local catchment basins would probably be flood-prone or ephemeral, a supposition supported by sedimentologic details of the framework sand facies.

Principal component facies of the Moulton streamplain include framework sands of the channel fill and sheet/crevasse splay facies as well as finer sediments of the Oakville floodplain facies.

Channel Fill Facies. — Moderate- to well-sorted coarse to very fine sand and sparse granule conglomerate and pebbly sand occur as lenticular channel fill units ranging from 10 to 25 ft (3 to 7 m) in thickness. Channel fills exhibit a sharp, irregular erosional base and crudely developed fining-upward textural sequence. Commonly a lower massive zone of medium- to large-scale, low-angle trough cross-stratified medium to pebbly coarse sand is overlain by several meters of planar laminated fine to medium sand, and capped in turn by interbedded very fine sand, silt, and sandy mud containing ripple, climbing ripple, wavy, and planar lamination, medium isolated trough bed sets, and sparse root traces (sections B, C, D, Fig. 23). A few channel sequences, particularly in the upper Oakville, display lateral accretion bedding in their upper part.

Although present in many channel fills of the Moulton streamplain facies, gravel is a minor component, consisting of granule to fine pebble-sized reworked Cretaceous fossils, carbonate rock fragments, and silicified wood. Mud clasts and chips occur in local concentrations within both cross-stratified and planar stratified units. Reworked, pedogenic micrite nodules are common in mud-clast-rich zones.

Both outcrop and log sections provide numerous examples of vertical nesting of several channel sequences. However, amalgamation of several such composite channel fill units is relatively rare; less than 10 percent of the shallow sand bodies sampled are more than 40 ft (12 m) thick.

Sheet/Crevasse Splay Facies. —Channel fills are interbedded with a great variety of sand and silt units deposited during flooding of the small coastal plain streams. Splay deposits include both sheets, up to 10 ft (3 m) thick, of planar stratified, well-sorted medium, fine, and coarse sand, and more discontinuous beds and lenses of well to moderately sorted medium to very fine sand, silt, and mud (sections E and F, Fig. 23). Sheet splays were produced by shallow, high-velocity flow of floodwaters along active channel margins and into adjacent floodplain areas during flash floods common to local streams with small drainage basins (McKee et al, 1967). Crevasse splays formed under flood conditions where flow was partially channelized as it topped stream channel margins and spread onto the floodplain. Variations in water depth, flow velocity, and sedimentation rate resulted in a great variety of structures. Pulsatory sedimentation is indicated by abundant clay drapes and lenses, reactivation surfaces, internal scours separating individual depositional units and waning-flow sequences of primary structures within units. Both types of splay sequences locally contain root traces and other evidence of subaerial exposure. Mud clasts and chips are common.

Splay deposits are similar to those of the New Davy axis. However, within the Moulton streamplain complex, they form a volumetrically large proportion of the total sand framework and may extend far into the interchannel floodplain environment, reflecting the extremely flashy to ephemeral nature of the associated streams.

Facies Associations and Distribution. —Multiple vertically stacked channel fill sand units produce distinct, mappable belts a few miles in width (Fig.

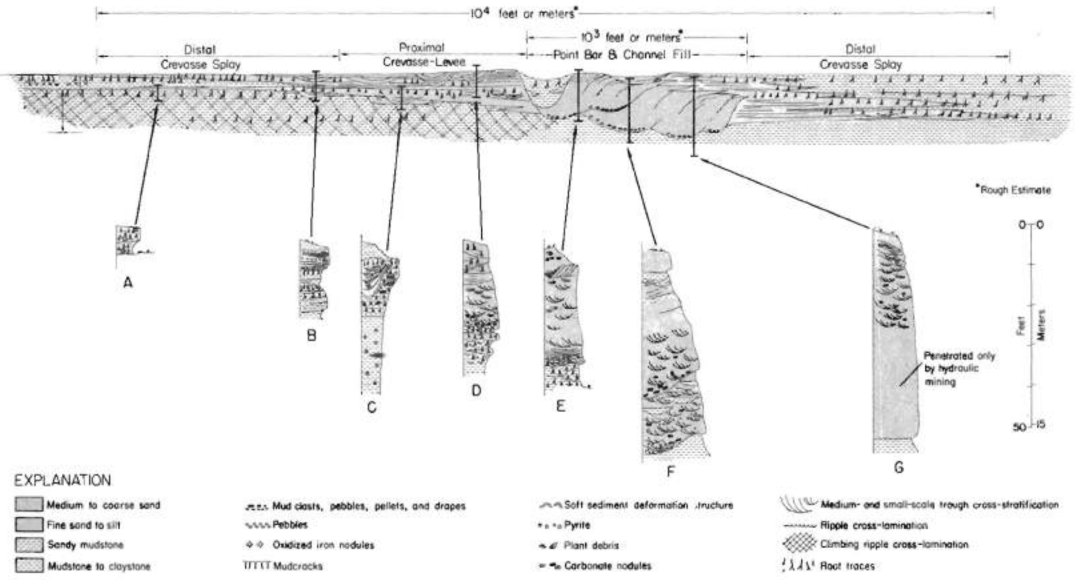


FIG. 22. —Composite cross section of a Chita-Corrigan system fluvial sand belt. The main channel-fill sand unit displays both simple and complex fining-upward sequences (F and G) as well as local coarse-grained chute deposits (E). Proximal crevasse deposits consist of lenticular, erosional channel fills (D) and coarsening-upward sequences capped by root-disturbed sands and small, lenticular distributary channel fills (C). Distal crevasse deposits include medium to thick beds displaying abundant small-scale primary structures (B) or intense pedogenic reworking (A). From Galloway (1977).

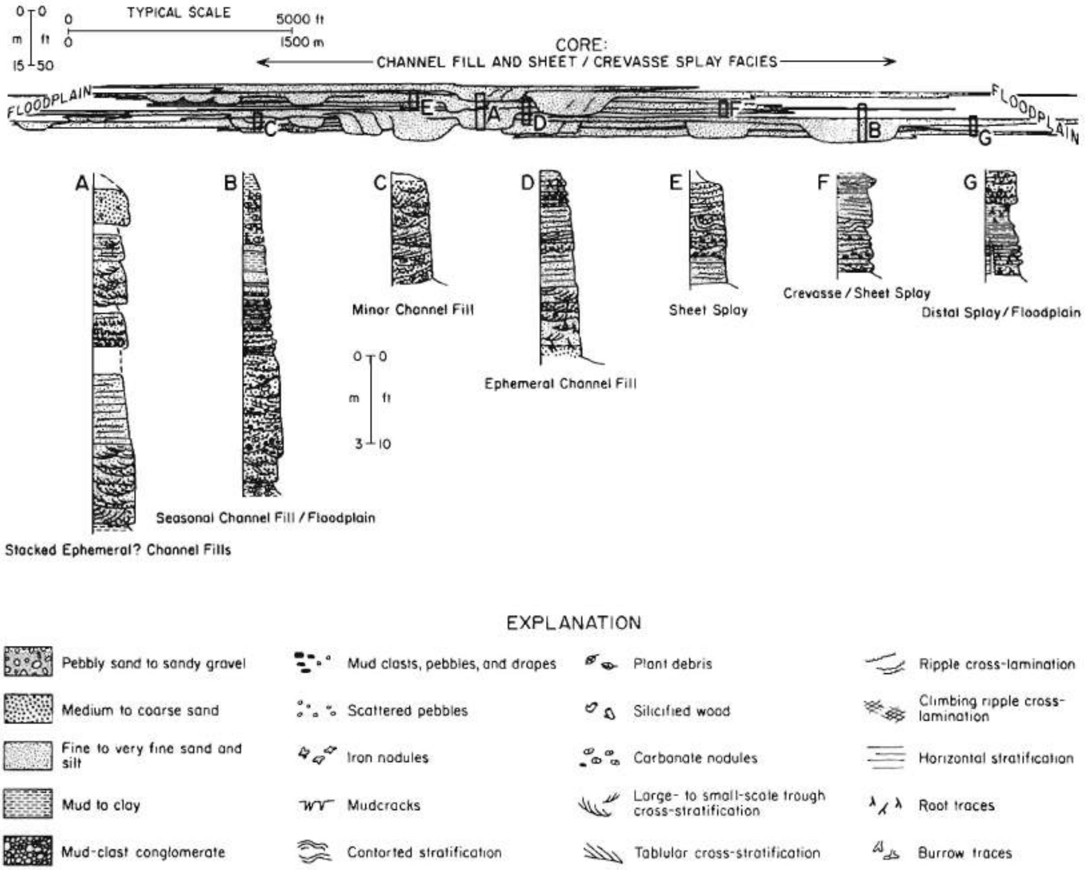


FIG. 23.—Schematic facies architecture of a composite sand belt within the Moulton streamplain. Numerous laterally and vertically amalgamated small channel fills and abundant sheet and crevasse splay units produce sand belts that are internally heterogeneous. Sedimentary features that indicate flashy or ephemeral flow conditions characterized the small drainage networks of the streamplain. Measured sections illustrate internal features of sand facies.

6b). Together with the genetically associated crevasse and sheet splay sands (Fig. 23), such composite channel assemblages form narrow basinward-trending belts that are laterally isolated within thick sections of muddy floodplain facies. Thickness of such composite sand belts rarely exceeds 50 ft (15 m), though several may be present within a single vertical section (Fig. 8d).

Evolution of Fluvial Depositional Axes

In addition to the general facies characterization and interrelationship exhibited by each depositional element, the six fluvial axes mapped exhibit three divergent trends of vertical evolution or changing depositional style. The Gueydan, Hebbronville, and George West fluvial axes are similar in that there is no regional, systematic vertical change in average textural or facies composition (Fig. 7). Channel fill units are equally abundant and texturally similar throughout the sequences (sections A and B, Fig. 8). In contrast, the Chita and Burton/Penn axes are characterized by a greater abundance of channel fill deposits and generally coarsest grain sizes at the base of the sequence (Fig. 8, section C). Stated more generally, the *apparent* bedload- to suspended-load ratio seems to have increased abruptly, initiating deposition along these individual axes, and then systematically decreased as the channel system evolved (Fig. 7). Variable proportions of preserved sand may also reflect variation in coastal plain subsidence rate; maximum percentage of channel fill and splay facies would be preserved during periods of slow subsidence or stability (Allen, 1978). A tectonic cause, manifested by altered channel load, subsidence rate, or both is indicated by the local development of low-angle unconformities at the base of proximal portions of many sand-rich fluvial axes (Galloway and Kaiser, 1980, Figure 18; Galloway et al, 1979b, Figure 10). Deposits composing the New Davy axis are characterized by a pronounced vertical gradation from bedload to mixed-load channel fills; however, maximum development of the bedload system is presaged by a transitional zone that extends well down into the Catahoula (Fig. 7). Appearance of this axis is most directly related to the uplift of and development of a well-integrated drainage basin on the Cretaceous cover of the Edwards Plateau.

General depositional patterns indicate a somewhat cyclic evolution of mixed-load axes that is not readily apparent in contemporaneous bedload systems of the Texas Coastal Plain. Causes of such evolutionary sequences are speculative. Schumm (1977) reviewed various responses of river systems to changes in controlling variables such as base level, climate, large-scale channel avulsion, and tectonism. Responses to regional or local changes are demonstrably complex and related to development of intrinsic geomorphic thresholds within individual drainage basins; thus, regional variations might modify deposits of different contemporaneous fluvial systems in different ways. Variation in regional coastal plain subsidence rate might explain the crude fining-upward patterns exhibited by both the Catahoula and Oakville/Fleming depositional cycles in the Central Texas coastal plain (Allen, 1978).

DISCUSSION

Comparison of Quaternary and Oligo-Miocene fluvial depositional patterns reveals several general regional geomorphic characteristics of aggrading coastal plain fluvial systems and attributes of the internal architecture (composition and structure) of their component depositional elements.

1. An aggrading coastal plain is the depositional product of multiple major and minor rivers. Each river or stream possesses its own characteristic morphology, size, textural and mineralogical composition, discharge characteristics, and evolutionary response to changing extrinsic conditions. Because these factors are determined by the interplay of regional geomorphology and tectonism, nature of the sediment load available to and transported by the river, climatic patterns, and size of the drainage basins, deposits of each river or stream commonly display characteristic facies relationships and internal structures.

Implications. —The initial goal of a sedimentologic study of a coastal plain sequence should be the recognition, and to the extent possible, mapping of the major fluvial depositional axes present. Discrete axes are defined by laterally restricted dip-oriented belts or aprons containing abundant channel fill facies, and may be further differentiated by variations in average textural and/or mineralogical composition. Until these principal depositional elements are recognized and mapped, establishing the basic paleogeomorphology of the coastal plain, detailed description of localized fluvial deposits is of limited utility. Further, extrapolations of detailed interpretations or descriptions across large parts of the basin margin are unwarranted at best, and completely erroneous at worst. Conversely, generalized description of the entire formation or depositional unit under the generalized category of fluvial deposits ignores the tremendous diversity of compositional, geometric, and internal features inherent in fluvial systems. These variables can and do produce great geographic variation in economically important attributes of fluvial deposits, such as groundwater transmissivity (Galloway et al, 1980) and potential for formation of epigenetic ore deposits (Galloway et al, 1979b).

2. Major rivers entering a broad coastal plain are point-source systems. The points of entry are controlled by regional structure and by upper coastal plain topography. In a tectonically stable coastal plain setting, subtle, passive depressions (such as the Rio Grande trough) become preferred sites of entry or focus for major extrabasinal rivers (Fig. 24) and may persist for extended periods of geologic time. More stable platform areas commonly coincide with inter-axial parts of the coastal plain characterized by small basin-fringe or intrabasinal streams (Fig. 24). Topographic features tending to influence drainage patterns include major incised valleys developed in upper coastal plain or basin margin strata and strike-parallel scarps or cuestas produced by differential erosion of more resistant strata or along fault zones (Fig. 24). Fluvial systems deflected along strike by structural or topographic features may develop multiple preferred axes of entry onto the coastal plain. The main channel may occupy the different gaps sequentially, or might oscillate between them. Evidence for such multiple channel evolution is seen in the Quaternary history of the upstream part of the Nueces River, which is inferred to have once drained into Baffin Bay, but is now trapped behind the Catahoula escarpment for over 50 mi (80 km) along strike (Duessen, 1924; Sayre, 1937) before turning coastward and draining into Corpus Christi Bay (Fig. 2).

Implications. —As in any setting where a broad terrigeneous clastic depositional platform must be constructed by a series of point sources of sediment input, geometric considerations favor the evolution of multiple contemporaneous distributaries or sequential channel alignments that spread incoming sediment as uniformly across the platform as possible. Areas of extended fluvial bypass become increasingly lower in relative elevation and, consequently, provide increasingly favored gradients. In the Texas Coastal Plain setting, Quaternary rivers spread extensively across the depositional surface by sequential avulsion of the major channel, both near the point of entry onto the coastal plain (nodal

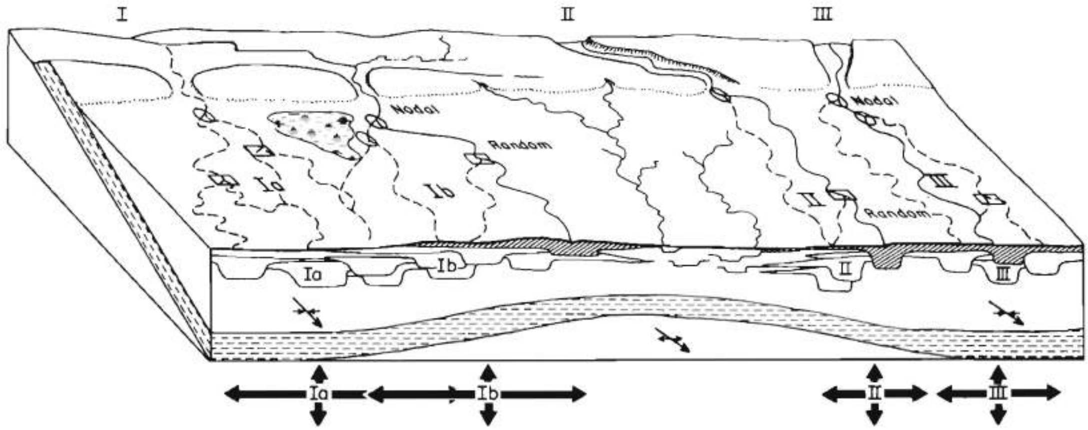


FIG. 24. — Schematic diagram generalizing fluvial depositional patterns and internal architecture of the Texas Coastal Plain. Major extrabasinal rivers (I, II, and III) enter from structurally or topographically stabilized point sources. Once on the aggradational coastal plain, channels sequentially occupy multiple positions in an attempt to aggrade the coastal plain surface as uniformly as possible. Both nodal and random avulsions are common. Resultant framework sand distributions produce either fan-like apron or broad, belted geometries. Bedload fluvial systems tend to produce multilateral as well as stacked sand bodies. Vertical stacking of channel sequences producing multistory sand bodies, is more typical of mixed-load systems.

avulsion) or at positions farther downflow (random avulsion). Map patterns of Oligo-Miocene fluvial systems indicate a similar pattern of ancient channel migration. Although resultant geometry of channel fill facies as seen on the depositional surface (late Quaternary) or in isolith maps (ancient) commonly resembles multi-axial belts or distributary patterns, development of individual channel trends was sequential. Where a single large river is the sole major sediment input for broad areas of the coastal plain, pronounced distributive sand-body geometries record the development through time of a large, very low gradient alluvial fan-like apron (Fig. 24; Gueydan fluvial axis). Where several large streams enter the coastal plain in proximity, less lateral dispersal of sediments is required to aggrade uniformly the depositional surface, and parallel interwoven belted geometries are produced (Fig. 24; Chita fluvial axis). Finally, because points of entry of major streams are influenced by major structural or topographic features, vertical superposition of large fluvial systems commonly occurs through extended periods of geologic time. The Rio Grande trough, for example, has been characterized by fluvial and deltaic deposition since Eocene time (Belcher and Galloway, 1977). To the east, the Mississippi Embayment has been a focus of fluvial sedimentation since Jurassic time (Mann and Thomas, 1968).

3. In contrast to major extrabasinal river systems, local basin-fringe and intrabasinal rivers are more subject to capture, structural modification, and local tectonics. They are therefore more irregular in their locus of entry and show great variation in composition, discharge characteristics and resultant channel morphologies, and localization.

Implications. — Smaller streams play a locally important part in coastal plain aggradation, and their deposits occur intermixed with and marginal to major fluvial axes. Where multiple small streams drain the coastal plain, the term streamplain is used in this report. Isolith and facies mapping of thick streamplain sequences typically shows only general trends because loci of channel development are less persistent vertically and because individual drainage axes are interspersed. Scale of individual channel sequences and that of all associated facies is reduced proportionally to the local drainage area of such streams.

ECONOMIC APPLICATIONS

Late Tertiary fluvial deposits of the Texas Coastal Plain contain a variety of extractable natural resources including fresh ground water, petroleum, and uranium. Quantitative delineation of three-dimensional sand-body architecture is of obvious utility in the exploration for and development of hydrocarbon and water-bearing reservoirs. In such studies, environmental description provides a means to an end — an improved interpretation of the geographic distribution, trend, and reservoir quality of porous, permeable facies. Because uranium deposits of the coastal plain are epigenetic, genetic facies mapping aids both reconstruction of ground-water paleoflow patterns responsible for mineralization and delineation of areas containing favorable host sands. However, facies architecture is only one of a number of variables that determine the presence and localization of economic resources. Consequently, facies mapping is necessary but insufficient to explain uniquely or predict resource distribution.

The distribution of known uranium deposits illustrates this dichotomy. All of the Catahoula and Oakville fluvial axes reviewed here contain ore-grade uranium occurrences. Largest reserves, totaling well 10^7 pounds of U_3O_8, occur in the Gueydan and George West bedload axes. The largest individual ore bodies occur within fluvial channel fill facies, but numerous small to medium deposits are localized in crevasse and sheet splay sands laterally associated with major channel belts (Galloway, 1977; Galloway and Kaiser, 1980; Galloway et al, 1979a). In contrast, small fluvial channel fills of the Moulton streamplain and mixed-load channel and splay deposits of the Chita axis contain only modest known reserves (estimated 10^6 pounds of U_3O_8) in numerous, scattered small deposits. Overall exploration favorability is thus a function of the size, composition, and fluvial architecture of each major depositional element. Actual abundance and localization of resultant uranium concentration depends on several additional factors, including structure, local groundwater flow history, availability of a source, and distribution of geochemical conditions both to efficiently solubilize and concentrate the uranium.

CONCLUSIONS

Surface and subsurface mapping of Tertiary and Quaternary fluvial systems of the Texas Gulf Coastal Plain reveals common sedimentary styles and internal architectures of alluvial sequences deposited on a tectonically passive continental margin. Because nearly all fluvial stratigraphic units peripheral to a large depositional basin consist of a mosaic of individual fluvial axes and interaxial depositional elements, adequate description of fluvial formations and interpretation of coastal plain paleogeography necessitates a hierarchical approach to their study.

1. Three-dimensional regional stratigraphic analysis must establish and locate major depositional elements that compose the sequence.
2. Comparison of textural and compositional variability between and within individual depositional elements contributes significantly to recognition of separate river axes, which commonly possess different source terranes.
3. Within each fluvial axis, internal geometry, structure, and compositional variations provide further detail about flow conditions and type of river channels that are characteristic of major as well as minor rivers. Generalizations about depositional style, composition, or postdepositional changes are extrapolated only within the associated depositional element.
4. Finally, paleogeographic reconstruction, examination of evolutionary changes in depositional style and of interrelationships between depositional and structural trends, and compilation of evidence for climatic, base level, or tectonic adjustments can be systematically attempted.

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