Geometry of Sandstone Reservoir Bodies[1]

RUFUS J. LeBLANC[2]
Houston, Texas 77001

Abstract Natural underground reservoirs capable of containing water, petroleum, and gases include sandstones, limestones, dolomites, and fractured rocks of various types. Comprehensive research and exploration efforts by the petroleum industry have revealed much about the character and distribution of carbonate rocks (limestones and dolomites) and sandstones. Porosity and permeability of the deposits are criteria for determining their efficiency as reservoirs for fluids. Trends of certain sandstones are predictable. Furthermore, sandstone reservoirs have been less affected than carbonate reservoirs by postdepositional cementation and compaction. Fracture porosity has received less concentrated study; hence, we know less about this type of reservoir. The discussions in this paper are confined to sandstone reservoirs.

The principal sandstone-generating environments are (1) fluvial environments such as alluvial fans, braided streams, and meandering streams; (2) distributary-channel and delta-front environments of various types of deltas; (3) coastal barrier islands, tidal channels, and chenier plains; (4) desert and coastal eolian plains; and (5) deeper marine environments, where the sands are distributed by both normal and density currents.

The alluvial-fan environment is characterized by flash floods and mudflows or debris flows which deposit the coarsest and most irregular sand bodies. Braided streams have numerous shallow channels separated by broad sandbars; lateral channel migration results in the deposition of thin, lenticular sand bodies. Meandering streams migrate within belts 20 times the channel width and deposit two very common types of sand bodies. The processes of bank-caving and point-bar accretion result in lateral channel migration and the formation of sand bodies (point bars) within each meander loop. Natural cut-offs and channel diversions result in the abandonment of individual meanders and long channel segments, respectively. Rapidly abandoned channels are filled with some sand but predominantly with fine-grained sediments (clay plugs), whereas gradually abandoned channels are filled mainly with sands and silts.

The most common sandstone reservoirs are of deltaic origin. They are laterally equivalent to fluvial sands and prodelta and marine clays, and they consist of two types: delta-front or fringe sands and abandoned distributary-channel sands. Fringe sands are sheetlike, and their landward margins are abrupt (against organic clays of the deltaic plain). Seaward, these sands grade into the finer prodelta and marine sediments. Distributary-channel sandstone bodies are narrow, they have abrupt basal contacts, and they decrease in grain size upward. They cut into, or completely through, the fringe sands, and also connect with the upstream fluvial sands or braided or meandering streams.

Some of the more porous and permeable sandstone reservoirs are deposited in the coastal interdeltaic realm of sedimentation. They consist of well-sorted beach and shoreface sands associated with barrier islands and tidal channels which occur between barriers. Barrier sand bodies are long and narrow, are aligned parallel with the coastline, and are characterized by an upward increase in grain size. They are flanked on the landward side by lagoonal clays and on the opposite side by marine clays. Tidal-channel sand bodies have abrupt basal contacts and range in grain size from coarse at the base to fine at the top. Laterally, they merge with barrier sands and grade into the finer sediments of tidal deltas and mud flats.

The most porous and permeable sandstone reservoirs are products of wind activity in coastal and desert regions. Wind-laid (eolian) sands are typically very well sorted and highly crossbedded, and they occur as extensive sheets.

Marine sandstones are those associated with normal-marine processes of the continental shelf, slope, and deep and those due to density-current origin (turbidites). An important type of normal-marine sand is formed during marine transgressions. Although these sands are extremely thin, they are very distinctive and widespread, have sharp updip limits, and grade seaward into marine shales. Delta-fringe and barrier-shoreface sands are two other types of shallow-marine sands.

Turbidites have been interpreted to be associated with submarine canyons. These sands are transported from nearshore environments seaward through canyons and are deposited on submarine fans in deep marine basins. Other turbidites form as a result of slumping of deltaic facies at shelf edges. Turbidite sands are usually associated with thick marine shales.

[1] Manuscript received, March 17, 1972.

[2] Shell Oil Company. This paper is based on the writer's 30 years of experience in studies of modern and ancient clastic sediments—from 1941 to 1948, with the Mississippi River Commission, under the guidance of H. N. Fisk, and, since August 1948, with Shell Development Company and Shell Oil Company.

The writer is grateful to Shell Oil Company for permission to publish this paper, and he is deeply indebted to Alan Thomson for his critical review of the manuscript; he is also grateful to Nick W. Kusakis, John Bush, Dave C. Fogt, Gil C. Flanagan, and George F. Korenek for assistance in the preparation of illustrations and reference material; to Aphrodite Mamoulides and Bernice Melde for their library assistance; to Darleen Vanderford for typing the manuscript, and to Judy Breeding for her editorial assistance.

Numerous stimulating discussions of models of clastic sedimentation and the relationship of sedimentary sequences to depositional processes were held with Hugh A. Bernard and Robert H. Nanz, Jr., during the late 1940s and 1950s, when we were closely associated with Shell's early exploration research effort. The writer is particularly indebted to these two men for their numerous contributions, many of which are included in this paper.

The writer also wishes to thank W. B. Bull, University of Arizona, for his valuable suggestions concerning the alluvial-fan model of clastic sedimentation.

Introduction

Important natural resources such as water, oil, gas, and brines are found in underground reservoirs which are composed principally of the following types of rocks: (1) porous sands, sandstones, and gravels; (2) porous limestones and dolomites; and (3) fractured rocks of various types. According to the 1971 American Petroleum Institute report on reserves of crude oil and natural gas, sandstones are the reservoirs for about 75 percent of the recoverable oil and 65 percent of the recoverable gas in the United States. It is also estimated that approximately 90 percent of our underground water supply comes from sand and gravel (Walton, 1970).

Sandstone and carbonate (limestone and dolomite) reservoirs have been intensively studied during the past 2 decades; consequently, the general characteristics and subsurface distribution of these two important types of reservoirs are relatively well known in numerous sedimentary basins. The factors which control the origin and occurrence of fracture porosity have received less attention; thus, our knowledge and understanding of this type of reservoir are more limited.

The detection of subsurface porosity trends within sedimentary basins was recognized by the petroleum industry as one of its most significant problems, and for the past 2 decades it has addressed itself to a solution through extensive research. Largely as a result of this research, which is summarized below, our ability to determine trends of porous sedimentary rocks has progressed noticeably, especially during the past 10 years.

The amount of porosity and permeability present within sedimentary rocks and the geometry of porous rock bodies are controlled mainly by two important factors: (1) the environmental conditions under which the sediments were deposited and (2) the postdepositional changes within the rocks as a result of burial, compaction, and cementation. Postdepositional diagenetic processes have less effect on the porosity and permeability of sands and sandstones than they have on carbonate sediments; consequently, porosity trends are significantly more predictable for sandstones than for limestones and dolomites.

Organization of paper—The following two parts of this paper give a brief historical summary of the early research on clastic sediments and present a classification of environments of deposition and models of clastic sedimentation. A résumé of significant studies of modern clastic sediments—mainly by the petroleum industry, government agencies, and universities—follows. The main part of the paper concerns the sedimentary processes, sequences, and geometry of sand bodies which characterize each of the following models of clastic sedimentation: alluvial fan, braided stream, meandering stream, deltaic (birdfoot-lobate and cuspate-arcuate), coastal interdeltaic (barrier island and chenier plain), and marine (transgressive, submarine canyon, and fan).

Historical Summary of Early Research on Modern Clastic Sediments

Geologists are now capable of interpreting the depositional environments of ancient sedimentary facies and of predicting clastic porosity trends with a reasonable degree of accuracy (Peterson and Osmond, 1961; Potter, 1967; Rigby and Hamblin, 1972; Shelton, 1972). This capability stems from the extensive research conducted on Holocene sediments by several groups of geologists during the past 3 decades. Conditions which led to this research, and the most significant studies of clastic sedimentation which provided the models, criteria, and concepts necessary to make environmental interpretations, are summarized below.

During the late 1930s and early 1940s, petroleum geologists became aware that improved methods of stratigraphic interpretations were badly needed, and that knowledge and geologic tools necessary to explore for stratigraphic traps were inadequate. A detailed study made by the Research Committee of The American Association of Petroleum Geologists on the research needs of the industry ultimately led to the establishment of geologic research departments by major oil companies. By 1948, exploration research by the oil industry was in its early stages, and expansion proceeded rapidly thereafter.

Meanwhile, some very significant developments were occurring at Louisiana State University. H. V. Howe and R. J. Russell, together with their graduate students, had already published several Louisiana Geological Survey bulletins summarizing their pioneer work on the late Quaternary geology of southern Louisiana (Howe and Moresi, 1931, 1933; Howe *et al.*, 1935; Russell, 1936). Their early work on the Mississippi deltaic plain and the chenier plain of southwestern Louisiana is considered to be the beginning of the modern environmental approach to stratigraphy. Fisk became fascinated with the Howe and Russell approach, and he applied results of their research to his study of Tertiary sediments. The work of Fisk (1940) in central Louisiana, which included a study of the lower Red River Valley and part of the Mississippi Valley, attracted the attention of General Max Tyler, president of the Mississippi River Commission in Vicksburg. General Tyler engaged Fisk as a consultant and provided him with a staff of geologists to conduct a geologic investigation of the lower Mississippi River alluvial valley.

The Fisk (1944) report on the Mississippi Valley, which now has become a classic geologic document, established the relations between alluvial environments, processes, and character of sediments. The AAPG, recognizing the significance of this contribution, retained Fisk as Distinguished Lecturer, and the results and significance of his work became widely known. One of his most significant contributions came when, as the petroleum industry was getting geologic research under way, he was selected by a major oil company to direct its geologic research effort in Houston.

By 1950, a few major oil companies were deeply involved in studies of recent sediments. However, the small companies did not have staff and facilities to conduct this type of research, and American Petroleum Institute Project 51 was established for the purpose of conducting research on recent sediments of the Gulf Coast. Scripps Institution of Oceanography was in charge of the project, which continued for 8 years. Results of this research were available to all companies (Shepard *et al.*, 1960).

While the petroleum industry was conducting "in-house" research and supporting the API project, some significant research was being done by the U.S. Waterways Experiment Station in Vicksburg, Mississippi, and by the new Coastal Studies Institute at Louisiana State University under the direction of R. J. Russell. These two groups conducted detailed studies of recent sediments for many years, and results were made available to the petroleum industry.

By 1955, a fairly good understanding of processes of sedimentation and character of related sediments in several depositional environments had been acquired. Although the application of this wealth of knowledge to operational problems was very difficult, some useful applications nevertheless had been made by the middle 1950s, and it was generally agreed that the initial research effort was successful.

Since 1955, geologists all over the world have become involved in studying recent sediments and applying the results to research on older rocks. Geologists with the U.S. Geological Survey and several universities have conducted studies of alluvial fans, braided streams, and eolian deposits; and the oceanographic institutions, such as Scripps, Woods Hole, and Lamont, have investigated deep-marine sediments on a worldwide basis. Publication of papers on clastic sedimentation has been increasing rapidly. The first textbook on the geology of recent sediments cites more than 700 references, 75 percent of which have appeared since 1955 (Kukal, 1971). Many of these contributions, considered to be most significant to the current understanding of clastic sediments, are cited in this paper.

Models and Environments of Clastic Sedimentation

The realm of clastic sedimentation can be divided into several conceptual models, each of which is characterized by certain depositional environments, sedimentary processes, sequences, and patterns. What are considered to be some of the most common and basic models and environments[3] of clastic sedimentation, arranged in order from the periphery to the center of a depositional basin, are listed below and are shown on Figures 1–4.

- Continental
  - Alluvial (fluvial) models
    - Alluvial fan
    - Braided stream
    - Meandering stream (includes flood basins between meander belts)
  - Eolian (can occur at various positions within continental and transitional models)
- Transitional
  - Deltaic models
    - Birdfoot-lobate (fluvial dominated)
    - Cuspate-arcuate (wave and current dominated)
    - Estuarine (with strong tidal influence)
  - Coastal-interdeltaic models
    - Barrier-island model (includes barrier islands, lagoons behind barriers, tidal channels, and tidal deltas)
    - Chenier-plain model (includes mud flats and cheniers)
- Marine
  - (Note: Sediments deposited in shallow-marine environments, such as deltas and barrier islands, are

[3] The classification of depositional environments presented herein was initially developed by the writer and his colleague, Hugh A. Bernard, during the early 1950s (LeBlanc and Bernard, 1954) and was recently modified (Bernard and LeBlanc, 1965). For other classifications, refer to Laporte (1968), Selley (1970), Crosby (1972), and Kukal (1971).

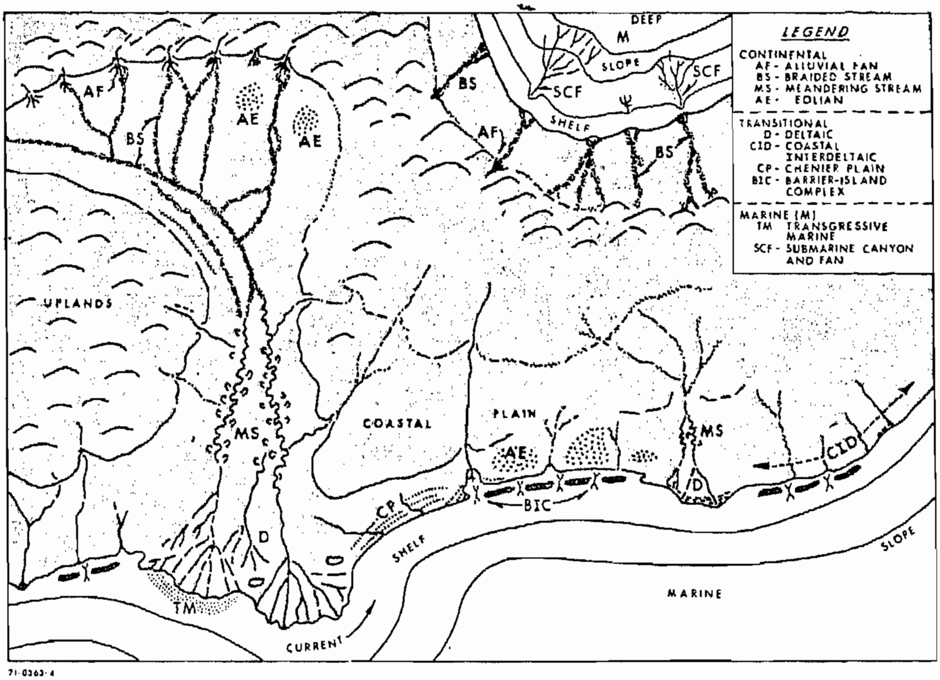


Fig. 1—Some common models of clastic sedimentation. See Figures 2–4 for details.

included under the transitional group of environments.)
Transgressive-marine model
Submarine-canyon and submarine-fan model

Résumé of Significant Studies of Modern Clastic Sedimentation

Alluvial Fans

Although much work has been done on alluvial fans, only a few papers discuss the relation of sedimentary sequences to depositional processes. Some of the more important contributions are by Rickmers (1913), Pack (1923), Blackwelder (1928), Eckis (1928), Blissenbach (1954), McKee (1957), Beaty (1963), Bull (1962, 1963, 1964, 1968, 1969, 1971), Hoppe and Ekman (1964), Winder (1965), Anstey (1965), Denny (1965, 1967), Legget *et al.* (1966), and Hooke (1967).

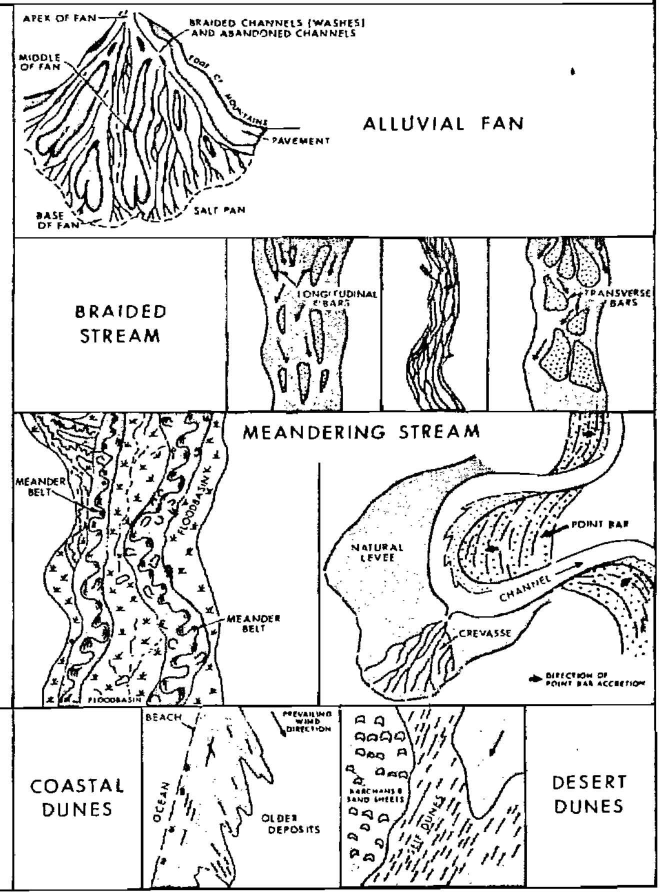
Braided Streams

Early papers on braided streams concerned channel patterns, origin of braiding, and physical characteristics of braided streams. Significant studies of this type were conducted by Lane (1957), Leopold and Wolman (1957), Chein (1961), Krigstrom (1962), Fahnestock (1963), and Brice (1964).

The relatively few papers on the relation of braided-stream deposits to depositional processes did not appear until the 1960s. Doeglas (1962) discussed braided-stream sequences of the Rhône River of France, and Ore (1963, 1965) presented some criteria for recognition of braided-stream deposits, based on the study of several braided streams in Wyoming, Colorado, and Nebraska. Fahnestock (1963) described braided streams associated with a glacial outwash plain in Washington. More recently, Williams and Rust (1969) discussed the sedimentology of a degrading braided river in the Yukon Territory, Canada. Coleman (1969) presented results of a study of the processes and sedimentary characteristics of one of the largest braided rivers, the Brahmaputra of Bangla Desh (formerly East Pakistan). N. Smith (1970) studied the Platte River from Denver, Colorado, to Omaha, Nebraska, and used the Platte model to interpret Silurian braided-stream deposits of the Appalachian region. Waechter (1970) has recently studied the braided Red River in the Texas Panhandle, and Kessler (1970, 1971) has investigated the Canadian River in Texas. Boothroyd (1970) studied braided streams associated with glacial outwash plains in Alaska.

ENVIRONMENTS				
CONTINENTAL	ALLUVIAL (FLUVIAL)	ALLUVIAL FANS (APEX, MIDDLE & BASE OF FAN)	STREAM FLOWS	CHANNELS
				SHEETFLOODS
				"SIEVE DEPOSITS"
			VISCOUS FLOWS	DEBRIS FLOWS
				MUDFLOWS
		BRAIDED STREAMS		CHANNELS (VARYING SIZES)
				BARS: LONGITUDINAL
				BARS: TRANSVERSE
		MEANDERING STREAMS (ALLUVIAL VALLEY)	MEANDER BELTS	CHANNELS
				NATURAL LEVEES
				POINT BARS
			FLOODBASINS	STREAMS, LAKES & SWAMPS
	EOLIAN	DUNES	COASTAL DUNES	TYPES: TRANSVERSE SEIF (LONGITUDINAL) BARCHAN PARABOLIC DOME-SHAPED
			DESERT DUNES	
			OTHER DUNES	

DEPOSITIONAL MODELS



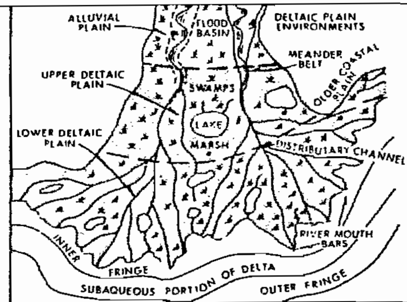
71-d363-1

Fig. 2—Alluvial (fluvial) and eolian environments and models of clastic sedimentation.

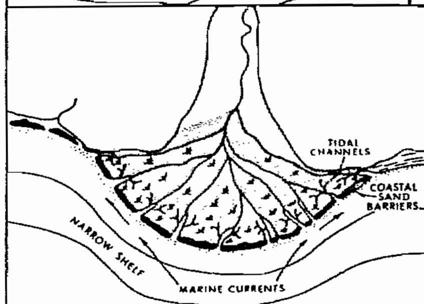
ENVIRONMENTS				
TRANSITIONAL	DELTAIC	UPPER DELTAIC PLAIN	MEANDER BELTS	CHANNELS
				NATURAL LEVEES
				POINT BARS
			FLOODBASINS	STREAMS, LAKES & SWAMPS
		LOWER DELTAIC PLAIN	DISTRIBUTARY CHANNELS	CHANNELS
				NATURAL LEVEES
			INTER-DISTRIBUTARY AREAS	MARSH, LAKES, TIDAL CHANNELS & TIDAL FLATS
		FRINGE	DELTA FRONT: INNER	RIVER-MOUTH BARS
				BEACHES & BEACH RIDGES
				TIDAL FLATS
			DELTA FRONT: OUTER	
		DISTAL		

DEPOSITIONAL MODELS

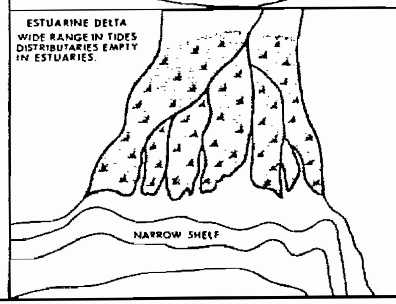
TYPES OF DELTAS



BIRDFOOT-LOBATE DELTA



CUSPATE-ARCUATE DELTA



ESTUARINE DELTA

71-0363-2

FIG. 3—Deltaic environments and models of clastic sedimentation.

Meandering Streams

H. N. Fisk's studies of the Mississippi alluvial valley, conducted for the Mississippi River Commission during the period 1941–48, represent the first significant contribution on meandering stream environments and deposits. This pioneer effort provided geologists with knowledge of the fundamental processes of alluvial-valley sedimentation. Another study of a meandering stream, the Connecticut River, and its valley was made by Jahns (1947). Important work on alluvial sediments deposited by meandering streams was also done by Sundborg (1956) in Sweden, and by Frazier and Osanik (1961), Bernard and Major (1963), and Harms *et al.* (1963) on the Mississippi, Brazos, and Red River point bars, respectively. Thus, by 1963 the general characteristics of point-bar sequences, and the closely related abandoned-channel and flood-basin sequences, were sufficiently well established to permit geologists to recognize this type of sedimentary deposit in outcrops and in the subsurface.

Other important contributions were made by Allen (1965a) on the origin and characteristics of alluvial sediments, by Simons *et al.* (1965) on the flow regime in alluvial channels, by Bernard *et al.* (1970) on the relation of sedimentary structures to bed form in the Brazos valley deposits, and by McGowen and Garner (1970) on coarse-grained point-bar deposits.

Deltas

The early work by W. Johnson (1921, 1922) on the Fraser delta, Russell (1936) on the Mississippi delta, Sykes (1937) on the Colorado delta, and Fisk (1944) on the Mississippi delta provided a firm basis for subsequent studies of more than 25 modern deltas during the late 1950s and the 1960s.

Fisk continued his studies of the Mississippi delta for more than 20 years. His greatest contributions were concerned with the delta framework, the origin and character of delta-front sheet sands, and the development of bar-finger sands by seaward-migrating rivermouth bars.

Scruton's (1960) paper on delta building and the deltaic sequence represents results of API Project 51 on the Mississippi delta. Additional research on Mississippi delta sedimentation, sedimentary structures, and mudlumps was reported by Welder (1959), Morgan (1961), Morgan *et al.* (1968), Coleman *et al.* (1964), Coleman (1966b), Coleman and Gagliano (1964, 1965), and also by Kolb and Van Lopik (1966). Coleman and Gagliano (1964) also discussed and illustrated processes of cyclic sedimentation. The most recent papers on the Mississippi delta are by Frazier (1967), Frazier and Osanik (1969), and Gould (1970).

Studies of three small birdfoot deltas of Texas—the Trinity, Colorado, and Guadalupe—were made by McEwen (1969), Kanes (1970), and Donaldson (1966), respectively. In addition, Donaldson *et al.* (1970) presented a summary paper on the Guadalupe delta. These four contributions are valuable because each one presents photographs and logs of cores of complete deltaic sequences.

European geologists associated with the petroleum industry and universities also have made valuable contributions to our understanding of deltas. Kruit (1955) and Lagaaij and Kopstein (1964) discussed their research on the Rhône delta of southern France, Allen (1965c, 1970) summarized the geology of the Niger delta of western Africa, and van Andel (1967) presented a résumé of the work done on the Orinoco delta of eastern Venezuela. More recently, the Po delta of Italy was studied by B. Nelson (1970) and the Rhône delta of southern France by Oomkens (1970).

Other recent contributions on modern deltas are by Coleman *et al.* (1970) on a Malaysian delta, by R. Thompson (1968) on the Colorado delta in Mexico, and by Bernard *et al.* (1970) on the Brazos delta of Texas.

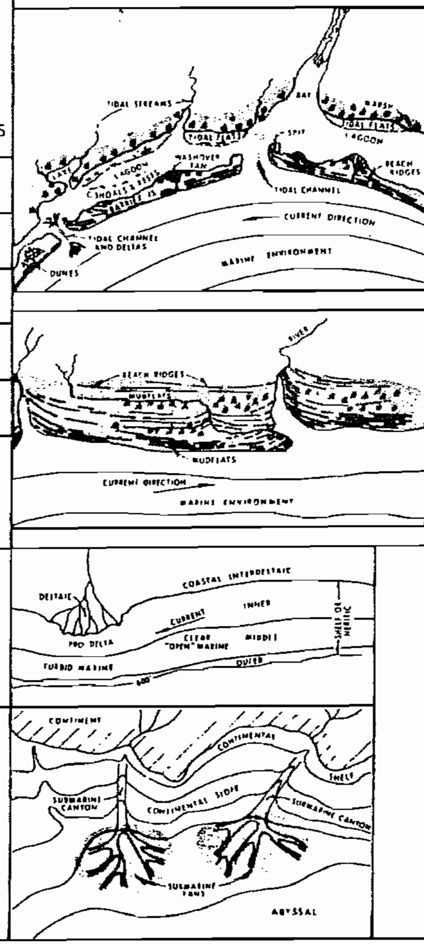
The deltaic model is probably the most complex of the clastic models. Although additional research is needed on this aspect of sedimentation, the studies listed have provided some valuable concepts and criteria for recognition of ancient deltaic facies.

Coastal-Interdeltaic Sediments

Valuable contributions to our knowledge of this important type of sedimentation have been made by several groups of geologists. In the Gulf Coast region, the extensive Padre Island–Laguna Madre complex was studied by Fisk (1959), and the chenier plain of southwestern Louisiana was studied by Gould and McFarlan (1959) and Byrne *et al.* (1959). The Galveston barrier-island complex of the upper Texas coast was investigated mainly by LeBlanc and Hodgson (1959), Bernard *et al.* (1959, 1962), and Bernard and LeBlanc (1965).

Among the impressive studies made by Europeans during the past 15 years are those by van Straaten (1954), who presented results of very

ENVIRONMENTS					DEPOSITIONAL MODELS
TRANSITIONAL	COASTAL INTER-DELTAIC	COASTAL PLAIN (SUBAERIAL)	BARRIER ISLANDS	BACK BAR, BARRIER, BEACH, BARRIER FACE, SPITS & FLATS, WASHOVER FANS	BARRIER IS. COMPLEX
			CHENIER PLAINS	BEACH & RIDGES	CHENIER PLAIN
				TIDAL FLATS	
			TIDAL	TIDAL FLATS	
				TIDAL DELTAS	
		SUBAQUEOUS	LAGOONS	SHOALS & REEFS	
			TIDAL CHANNELS		
			SMALL ESTUARIES		
MARINE	SHALLOW MARINE	SHELF (NERITIC)	INNER	SHOALS & BANKS	SHALLOW MARINE
			MIDDLE		
			OUTER		
	DEEP MARINE	CANYONS			DEEP MARINE
		FANS (DELTAS)			
		SLOPE & ABYSSAL			
		TRENCHES & TROUGHS			



71 0363-3

FIG. 4—Coastal-interdeltaic and marine environments and models of clastic sedimentation.

significant work on tidal flats, tidal channels, and tidal deltas of the northern Dutch coast, and by Horn (1965) and H. E. Reineck (1967), who reported on the barrier islands and tidal flats of northern Germany.

During the past several years, a group of geologists has conducted interesting research on the coastal-interdeltaic complexes which characterize much of the U.S. Atlantic Coast region. Hoyt and Henry (1965, 1967) published several papers on barriers and related features of Georgia. More recently, results of studies at the University of Massachusetts on recent coastal environments of New England were reported by Daboll (1969) and by the Coastal Research Group (1969).

In addition, Curray *et al.* (1969) described sediments associated with a strand-plain barrier in Mexico, and Potter (1967) summarized the characteristics of barrier-island sand bodies.

Eolian Sand Dunes

Prior to the middle 1950s, eolian depositional environments were studied principally by European geologists (Cooper, 1958). Since that time, the coastal sand dunes of the Pacific, Atlantic, and Gulf coasts of the United States, as well as the desert dunes of the United States and other countries, have been investigated by university professors and by geologists with the U.S. Geological Survey. Some of the most significant contributions, especially those concerned with dune stratification, are discussed in the section on the eolian model of clastic sedimentation.

Marine Sediments

Early work on modern marine sands, exclusive of those deposited adjacent to and related to interdeltaic and deltaic depositional environments, was conducted largely by scientists associated with Scripps, Woods Hole, and Lamont oceanographic departments. Several aspects of marine sediments were discussed by Trask *et al.* (1955), and the recent sands of the Pacific Ocean off California were studied by Revelle and Shepard (1939), Emery *et al.* (1952), and Emery (1960a). Stetson (1953) described the northwestern Gulf of Mexico sediments, and Ericson *et al.* (1952, 1955) and Heezen *et al.* (1959) investigated the Atlantic Ocean sediments. Later, Curray (1960), van Andel (1960), and van Andel and Curray (1960) reported results of the API project on the Gulf of Mexico. A few years later, results of the API project studies on the Gulf of California were reported by van Andel (1964) and van Andel and Shor (1964). Menard (1964) discussed sediments of the Pacific Ocean. For a more complete list of references to studies of recent marine sands, the reader is referred to Kuenen (1950), Guilcher (1958), Shepard *et al.* (1963), and Kukal (1971).

Much of the early research on modern marine environments was devoted to submarine canyons, fans, and basins considered by the investigators to be characterized mainly by turbidity-current sedimentation. Several scientists affiliated with Scripps and the University of Southern California published numerous papers on turbidites which occur in deep marine basins.

It is extremely difficult to observe the processes of turbidity-current sedimentation under natural conditions; consequently, the relations between sedimentary sequences and processes are still relatively poorly understood. Much of the research dealing with turbidity currents has been concerned with theory, laboratory models, and cores of deep-water sediments deposited by processes which have not been observed.

Alluvial-Fan Model of Clastic Sedimentation

Occurrence and General Characteristics

Alluvial fans occur throughout the world, adjacent to mountain ranges or high hills. Although they form under practically all types of climatic conditions, they are more common and best developed along mountains of bold relief in arid and semi-arid regions (Figs. 5, 6).

The alluvial-fan model has the following characteristics: (1) sediment transport occurs under some of the highest energy conditions within the entire realm of clastic sedimentation, (2) deposition of clastic sediment occurs directly adjacent to the areas of erosion which provide the sediments, and (3) deposits are of maximum possible range in size of clastic particles (from the largest boulders to clays) and are commonly very poorly sorted compared with other types of alluvial sediments (Fig. 5).

The size of individual alluvial fans is controlled by drainage-basin area, slope, climate, and character of rocks within the mountain range. Individual fans range in radius from several hundred feet to several tens of miles. Coalescing fans can occur in linear belts that are hundreds of miles long. Fan deposits usually attain their maximum thicknesses and grain size near the mountain base (apex of fan) and

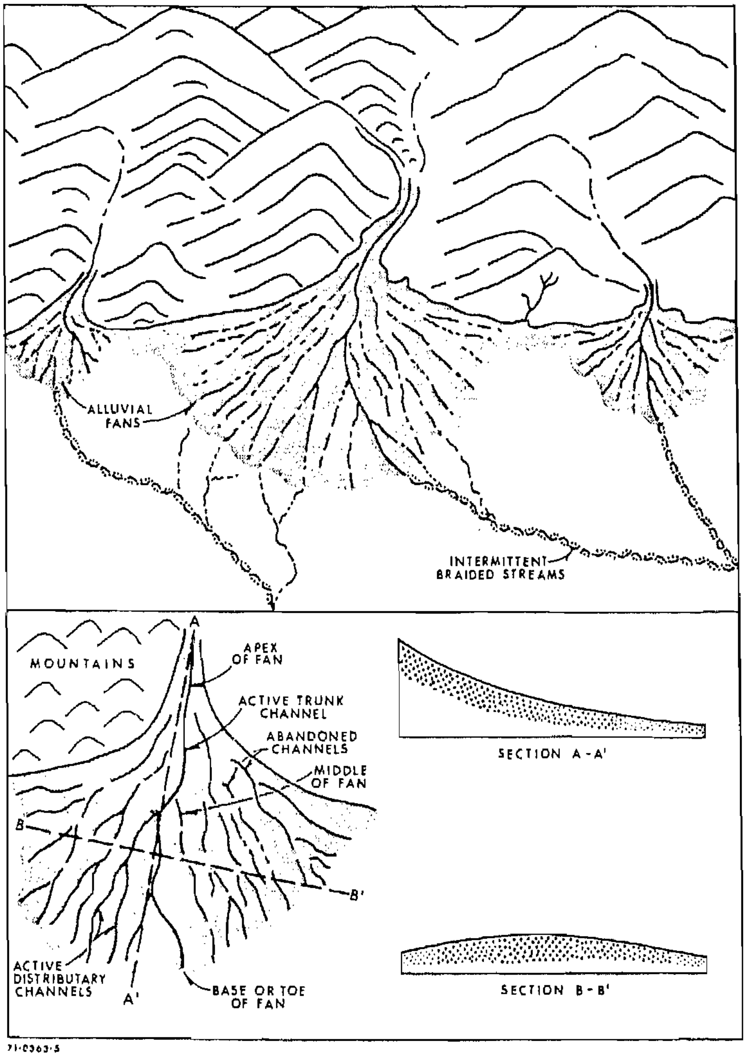


FIG. 5—Alluvial-fan model of clastic sedimentation.

gradually decrease in thickness away from the apex.

The alluvial-fan environments commonly grade downstream into braided-stream or playa-lake environments. In some areas, where mountains are adjacent to oceans or large inland lakes, alluvial fans are formed under both subaerial and submerged conditions. Such fans are now referred to as "Gilbert-type" deltas.

Alluvial-fan deposits form important reservoirs for groundwater in many areas, and adjacent groundwater basins are recharged through the fan deposits which fringe these basins.

Source, Transportation, and Deposition of Sediments

Tectonic activity and climate have a profound influence on the source, transportation, and deposition of alluvial-fan deposits. Uplift of mountain ranges results in very intensive erosion of rocks and development of a very high-gradient drainage system. The rate of weathering and production of clastic material is controlled mainly by rock characteristics and climate (temperature and rainfall).

Clastic materials are transported from source areas in mountains or high hills to alluvial fans by several types of flows: stream flows and sheetfloods and debris flows or mudflows. Sediment transport by streams is usually characteristic of large fans in regions of high to moderate rainfall. Mudflows or debris flows are more common on small fans in regions of low rainfall characterized by sudden and brief periods of heavy downpours.

Stream deposits—Streams which drain relatively small segments of steep mountain ranges have steep gradients; they may erode deep canyons and transport very large quantities of coarse debris. The typical overall stream gradient is concave upward, and the lowest gradient occurs at the toe of the fan (Fig. 5).

Hooke (1967) described a special type of stream-flow deposit, which he called "sieve deposits," on fans which are deficient in fine sediments. These gravel deposits are formed when water infiltrates completely into the fan. Bull (1969) described three types of water-laid sediments on alluvial fans: channel, sheetflood, and sieve deposits. Stream channels radiate outward from the fan apex and commonly are braided. The processes of channel migration, diversion, abandonment and filling, and development of new main channels and smaller distributary channels on the lower part of the fan surface are characteristic features. Most fan surfaces are characterized by one or a few active channels and numerous abandoned channels. Deposits on abandoned portions of gravelly and weathered fan surfaces are referred to as "pavement."

Alluvial-fan channel deposits have abrupt basal contacts and channel geometry; they are generally coarse. Bull (1972) described channel deposits as imbricated and massive or thick-bedded.

Heavy rainfall in mountainous source areas can result in floods on alluvial fans. The relatively shallow and wide fan channels are not capable of carrying the sudden influx of large volumes of water; consequently, the streams overtop their banks and flood part of the fan surface. The result is the deposition of thin layers of clastic material between channels. Bull (1969) reported sheetflood deposits to be finer grained than channel deposits, cross-bedded, and massive or thinly bedded.

Debris-flow deposits—Some workers refer to both fine-grained and coarse-grained types of plastic flowage in stream channels as mudflows, but others consider mudflows to be fine-grained debris flows. Examples of transportation and deposition of clastic sediments by mudflows

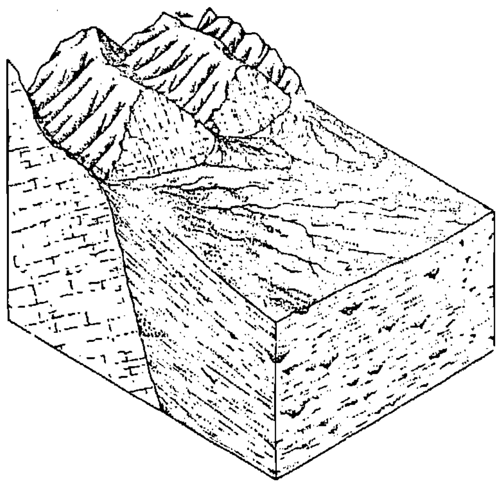


FIG. 6—Stratigraphic geometry of an alluvial fan. After Bull (1972).

were first described by Rickmers (1913) and Blackwelder (1928). The following conditions favor the development of mudflows: presence of unconsolidated material with enough clay to make it slippery when wet, steep gradients, short periods of abundant water, and sparse vegetation.

Pack (1923) discussed debris-flow deposition on alluvial-fan surfaces. Debris flows occur as a result of very sudden, severe flooding of short duration. Beaty (1963) described eyewitness accounts of debris flows on the west flank of the White Mountains of California and Nevada. Debris flows follow channels, overtop the channel banks, and form lobate tongues of debris along channels. Debris-flow deposits are very poorly sorted, fine- to coarse-grained, and unstratified; they have abrupt margins. This type of deposit is probably most common on the upper parts of the fans between the apex and midfan areas.

Summary: Character and Geometry of Alluvial-Fan Deposits

Most of the alluvial-fan studies conducted thus far have been concerned primarily with the origin and general characteristics of fans and the distribution of sediments on the surfaces of fans. An exception is Bull's excellent summary paper (Bull, 1972), which contains significant data on the geometry of channel, sheetflood, debris-flow, mudflow, and sieve deposits. The abstract of Bull's paper is quoted below:

Alluvial fans commonly are thick, oxidized, orogenic deposits whose geometry is influenced by the rate and duration of uplift of the adjacent mountains and by climatic factors.

Fans consist of water-laid sediments, debris-flow deposits, or both. Water-laid sediments occur as channel, sheetflood, or sieve deposits. Entrenched stream channels commonly are backfilled with gravel that may be imbricated, massive, or thick bedded. Braided sheets of finer-grained sediments deposited downslope from the channel may be cross-bedded, massive, laminated, or thick bedded. Sieve deposits are overlapping lobes of permeable gravel.

Debris-flow deposits generally consist of cobbles and boulders in a poorly sorted matrix. Mudflows are fine-grained debris flows. Fluid debris flows have graded bedding and horizontal orientation of tabular particles. Viscous flows have uniform particle distribution and vertical preferred orientation that may be normal to the flow direction.

Logarithmic plots of the coarsest one percentile versus median particle size may make patterns distinctive of depositional environments. Sinuous patterns indicate shallow ephemeral stream environments. Rectilinear patterns indicate debris flow environments.

Fans consist of lenticular sheets of debris (length/width ratio generally 5 to 20) and abundant channel fills near the apex. Adjacent beds commonly vary greatly in particle size, sorting, and thickness. Beds extend for long distances along radial sections and channel deposits are rare. Cross-fan sections reveal beds of limited extent that are interrupted by cut-and-fill structures.

Three longitudinal shapes are common in cross section. A fan may be lenticular, or a wedge that is either thickest, or thinnest, near the mountains.

Ancient Alluvial-Fan Deposits

Some examples of ancient alluvial-fan deposits which have been reported from the United States, Canada, Norway, and the British Isles are summarized in Table 1, together with other types of alluvial deposits.

Braided-Stream Model of Clastic Sedimentation

Occurrence and General Characteristics

Braided streams occur throughout the world under a very wide range of physiographic and climatic conditions. They are common features on extensive alluvial plains which occupy a position in the clastic realm of sedimentation between the high-gradient alluvial-fan environment at the base of mountain ranges and the low-gradient meandering-stream model of sedimentation (downstream). In physiographic provinces characterized by mountainous areas adjacent to the sea, the braided-stream environment can extend directly to the coastline and thus constitute the predominant environment of alluvial deposition. In this type of situation, meandering streams do not exist (Fig. 7). The braided stream is also a common feature of glacial outwash plains associated with the fluvioglacial environment.

The braided-stream model is characterized by extremely variable rates of sedimentation in multiple-channel streams (Fig. 8), the patterns of which vary widely compared with meandering channels. Braided channels are usually wide and shallow; they contain numerous bars, are slightly sinuous or straight, and migrate at rapid rates. Stream gradients are high, are quite variable, and are less than those of alluvial fans but generally greater than those of meandering streams. Large fluctuations in discharge occurring over short periods of time are also common. The combination of steep gradients and high discharge rates results in the transporta-

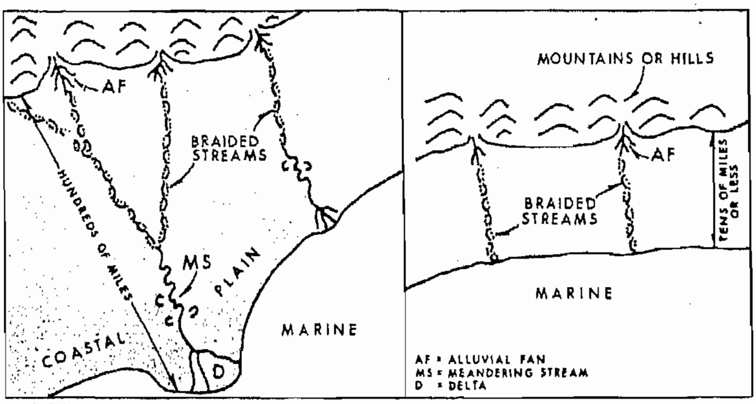


FIG. 7—Braided-stream model of clastic sedimentation.

tion and deposition of large amounts of coarse material, ranging from boulders to sand. Braided-stream deposits overall are finer than those of alluvial fans, coarser than those of meandering streams, and quite varied in stratification.

Source, Transportation, and Deposition of Sediments

Aggrading braided streams transport very large quantities of clastic material derived from a variety of sources, such as outwash plains, alluvial fans, mountainous areas, and broad plains. Unlike that of meandering streams, the bulk of the sedimentary load of most braided streams is transported as bed load. Rates of sediment transport and deposition are extremely variable, the maximum rate occurring during severe floods of short duration. High-gradient upstream segments of braided streams close to source areas are characterized by deposition of poorly sorted clastic sediments which

Table 1. Examples of Ancient Alluvial-Fan, Braided-Stream, and Meandering-Stream Deposits

Alluvial Fan	*Braided Stream*	*Meandering Stream*	*Composite*	*Author*
Arizona			Arizona	Melton, 1965
California				Crowell, 1954
California			California	Flemal, 1967
			California	Galehouse, 1967
Colorado				Boggs, 1966
			Colorado	Bolyard, 1959
		Colorado		Brady, 1969
			Colo. Plateau	Finch, 1959
			Colo. Plateau	Stokes, 1961
Colorado				Howard, 1966
Colorado				Hubert, 1960
Connecticut Valley				Klein, 1968
		Illinois		Hewitt *et al.*, 1965
		Illinois		Shelton, 1972
			Kansas	Lins, 1950
		Kansas		Shelton, 1971
	Llano Estacado			Bretz & Horberg, 1949
	Maryland	Maryland		Hansen, 1969
Massachusetts				Wessel, 1969
Massachusetts				Stanley, 1968
			Massachusetts	Mutch, 1968
		Michigan		Shideler, 1969
		Montana		Gwinn, 1964
	Mississippi	Mississippi		Berg & Cook, 1968
Montana	Montana			Gwinn & Mutch, 1965
			Montana	Shelton, 1967
Montana				Wilson, 1967, 1970
Montana				Beaty, 1961
			Nebraska	Exum & Harms, 1968
			Nebraska	Harms, 1966
	New York	New York		Buttner, 1968
	New Jersey, New York			Smith, 1970; Shelton, 1972
			North Dakota	Royse, 1970
			Oklahoma	Visher, 1965b
		Pennsylvania		Beutner *et al.*, 1967
	Pennsylvania			Smith, 1970
		Pennsylvania		Ryan, 1965
			Rhode Island	Mutch, 1968
S.W. USA				Bull, 1972
			Texas	Fisher & McGowen, 196[illegible]
Texas				McGowen & Groat, 197[illegible]
		Texas		McGowen & Garner, 19[illegible]; Shelton, 1971
		West Virginia		Beerbower, 1964, 1969
		Wyoming		Berg, 1968
Wyoming	Wyoming			Spearing, 1969
			Alberta	Byers, 1966
			Quebec	Dineley & Williams, 196[illegible]
Northeastern Canada				Klein, 1962
		Nova Scotia		Way, 1968
Northwest Territories	Northwest Territories	Northwest Territories		Miall, 1970
		England		Allen, 1964; Laming, 196[illegible]
Wales and Scotland				Bluck, 1965, 1967
		South Wales		Kelling, 1968
Norway				Nilsen, 1969
	Scotland			Williams, 1966, 1969
	Spain			Nagtegaal, 1966
	Spitsbergen	Spitsbergen		Moody-Stuart, 1966
		New South Wales		Conolly, 1965

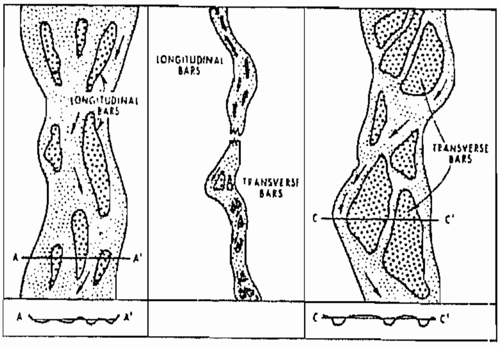


FIG. 8—Types of braided-stream channels and bars.

range in size from boulder to sand. Farther downstream, there is a gradual decrease in grain size and an increase in sorting.

The bed-load materials are transported under varying bed-form conditions, depending upon river stage. Coleman (1969) reported ripple and dune migration in the Brahmaputra River of Bangla Desh ranging from 100 ft to 2,000 ft (30–610 m) per day. Chein (1961) reported downstream movement of sandbars in the Yellow River of China to be as great as 180–360 ft (55–110 m) per day. (For comparison, the rate of bed-load movement in the meandering Mississippi is about 40 ft [12 m] per day.)

Process of channel division (braiding) by development of bars—The exact causes of channel division which results in the development of the braided pattern are not very well understood. Two methods in which channel division takes place have been described by Ore (1963) as follows:

> Leopold and Wolman (1957, p. 43–44), using results of both stream-table studies and observations of natural braided streams, discuss in some detail how channel division may take place. At any time, the stream is carrying coarser fractions along the channel center than at the margins, and due to some local hydraulic condition, part of the coarsest fraction is deposited. Finer material is, in part, trapped by coarser particles, initiating a central ridge in the channel. Progressive additions to the top and downstream end of the incipient bar build the surface toward water level. As progressively more water is forced into lateral channels beside the growing bar, the channels become unstable and widen. The bar may then emerge as an island due to downcutting in lateral channels, and eventually may become stabilized by vegetation. New bars may then form by the same process in lateral channels. These authors stress that braiding is not developed by the stream's inability to move the total quantity of sediment provided to it; as incapacity leads merely to aggradation without braiding. The condition requisite to braiding is that the stream cannot move certain sizes provided; that is, the stream is incompetent to transport the coarsest fraction furnished to a given reach. Observations for the present study substantiate the braiding process of Leopold and Wolman.
>
> Many features of streams, bars, and braided reaches result from changes in regimen (e.g., discharge, load, gradient), to a large extent representing seasonal fluctuations. Other features of bars result from normal evolution, and represent no change in regimen.
>
> The incipient longitudinal bar formed in a channel commonly has an asymmetric, downstream-pointing, crescentic shape. This coarse part is the "nucleus" of the bar, is coarser than successive additions to the downstream end, and largely retains its position and configuration as long as any part of the bar remains. During longitudinal bar evolution downstream of this incipient bar the water and its sediment load commonly sweep from one lateral channel diagonally across the downstream end of the bar, forming a wedge of sediment with an advancing front at its downstream edge. This wedge of sediment is higher at its downstream edge, both on the longitudinal bars described here, and where found as transverse bars to be considered later. The latter build up the channel floor, independent of longitudinal bar development, simply by moving downstream.
>
> After a certain evolutionary stage, bar height stops increasing because insufficient water for sediment transport is flowing over its surface, and deepening and widening of lateral channels slowly lower water level. From then on, the bar may be either stabilized by vegetation or dissected.
>
> Widening of a reach after bar deposition is in some cases associated with lateral dissection of the newly formed bar. Most erosion, however, apparently occurs on the outer channel margins. If water level remains essentially constant for long periods of time, lateral dissection may establish terraces along bar margins. A compound terrace effect may be established during falling water stages. The constant tendency of the stream to establish a cross-sectional profile of equilibrium is the basic cause of lateral cutting by the stream.
>
> Longitudinal bars which become awash during high-water stages may be dissected by small streams flowing transversely over their surfaces. In stream-table experiments, sediment added to a system eroding transverse channels on bar surfaces is first transported along lateral channels beside the bars. Eventually, these channels fill to an extent that sediment starts moving transversely over bar surfaces, and fills bar-top, transverse channels. The addition of sufficient sediment to fill lateral and bar-top channels often culminates in a transverse bar covering the whole bar surface evenly.
>
> Another process of braiding, in addition to that described by Leopold and Wolman, takes place in well sorted sediments, and involves dissection of transverse bars. This is in opposition to construction of longitudinal bars in poorly sorted sediment, the type of braiding discussed above. Both types may occur together geographically and temporally. During extended periods of high discharge, aggradation is by large tabular bodies of sediment with laterally sinuous fronts at the angle of repose migrating downstream. Stabilization of discharge or decrease in load after establishment of these transverse bars results in their dissection by anastomosing channels; bars in this case form as residual elements of the aggradational pattern.
>
> The transient nature of braided stream depositional surfaces is characteristic of the environment. The streams and depositional areas within the stream exhibit profound lateral-migration tendencies, especially during

periods of high discharge. Channel migration takes place on several scales. Individual channels erode laterally, removing previously deposited bars. They divide and coalesce, and several are usually flowing adjacent to one another concurrently within the main channel system. The whole channel system, composed of several flowing channels with bars between, also exhibits migrating tendencies.

Braided-stream deposits—Our knowledge of modern braided-stream deposits has increased substantially during the past several years as a result of studies of several rivers in Wyoming, Colorado, and Nebraska by Ore (1963, 1965); the Brahmaputra River of Bangla Desh (formerly East Pakistan) by Coleman (1969); the Platte River of Colorado and Nebraska by N. Smith (1970); the Red River of the Texas panhandle by Waechter (1970); the Canadian River of northwest Texas by Kessler (1970, 1971); and the Copper River of Alaska by Boothroyd (1970). These studies revealed that braided-stream deposits are laid down principally in channels as longitudinal bars and transverse bars. Abandoned-channel deposits (channel fills) have been reported by Doeglas (1962) and Williams and Rust (1969).

According to Ore (1963, 1965), longitudinal-bar deposits occur mainly in upstream channel segments and transverse bars are more common in downstream segments; however, in some places these two types of bars occur together (Fig. 8). Longitudinal-bar deposits are lens-shaped and elongated in the downstream direction. Grain size decreases downstream from coarse to fine in an individual bar; deposits are poorly sorted and mainly horizontally stratified but laterally discontinuous. Transverse-bar deposits occur as long thin wedges and are highly dissected by channels. The downstream edges of transverse bars migrate to produce planar cross-stratification and some festoon crossbedding. Sediments of transverse bars are generally finer and better sorted than those of longitudinal bars.

N. Smith (1970) described some very significant relations between types of bars, stratification, and grain size in the Platte River. In the upstream segment in Colorado, the deposits consist mainly of longitudinal bars characterized by low-relief stratification, generally horizontally bedded but including some festoon crossbedding. The downstream channel segment in Nebraska is characterized by transverse-bar deposits consisting of better sorted, fine-grained sand with abundant tabular cross-stratification and some festoon crossbedding.

The Red River braided-stream sediments of West Texas consist of longitudinal-bar deposits with low-angle or horizontal stratification; they are deposited during waning flood stages (Waechter, 1970). Low-river-stage deposits consist mainly of migrating transverse-bar deposits (in channels) with tabular cross-stratification and some festoon crossbedding. The migration of very shallow channels results in stratification sets that are horizontal, tabular or lenticular, and laterally discontinuous.

Kessler (1970) reported longitudinal-bar deposits consisting mainly of fine sand in upstream reaches of the Canadian River in West Texas. Transverse-bar deposits are predominant in the downstream part of the area studied. Kessler (1971) also discussed individual flood sequences of deposits which contain parallel bedding and tabular and small-ripple cross-laminations. These sequences are covered by clay drapes and are laterally discontinuous.

Coleman (1969) presented the results of a significant study of one of the largest braided rivers of the world, the Brahmaputra in Bangla Desh. This river is 2–6 mi (3–9.5 km) wide and migrates laterally as much as 2,600 ft (790 m) per year; deposition of sediments in its channels during a single flood occurs in a definite sequence of change, ranging from ripples up to 5 ft (1.5 m) high that migrate downstream 400 ft (120 m) per day to sand waves 50 ft (15 m) high that migrate up to 2,000 ft (610 m) per day.

Williams and Rust (1969) presented results of a very detailed study of a 4-mi (6.5 km) segment of a degrading braided stream, the Donjek River of the Yukon Territory, Canada. They divided the bar and channel deposits, which range from coarse gravels to clays, into seven facies. Ninety-five percent of the bar deposits are of the longitudinal type and consist of gravel, sand, and some finer sediments. Abandoned-channel deposits consist of gradational sequences of gravels, sand, and clays that become finer upward.

Summary: Braided-Stream Deposits

Most of the sediments of modern braided streams studied during the past decade have been referred to by authors as transverse- or longitudinal-bar deposits. These sediments were deposited within braided channels during varying discharge conditions ranging from low water to flood stage. Thus, all longitudinal and transverse bars should be considered as a special type of bed form occurring within active braided channels.

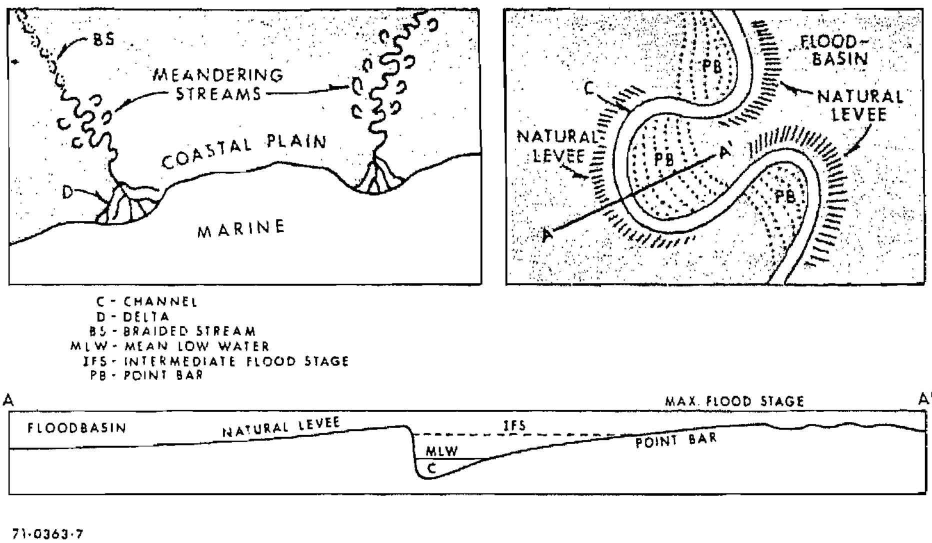


FIG. 9—Setting and general characteristics of meandering-stream model of clastic sedimentation.

Studies by Doeglas (1962) and Williams and Rust (1969) are significant because they describe abandoned-channel deposits. Doeglas discussed the methods of channel abandonment and described the channel-fill deposits as coarse grained, with channel or festoon laminations, in the upstream portions of abandoned channels, and as fine grained, silty, and rippled in the downstream portions of abandoned channels.

Ancient Braided-Stream Deposits

Some examples of ancient braided-stream deposits which have been reported from the United States, Spitsbergen, and Spain are summarized in Table 1.

Meandering-Stream Model of Clastic Sedimentation

Occurrence and General Characteristics

Meandering streams generally occur in coastal-plain areas updip from deltas and downdip from the braided streams. The axis of sedimentation is usually perpendicular to the shoreline (Fig. 9).

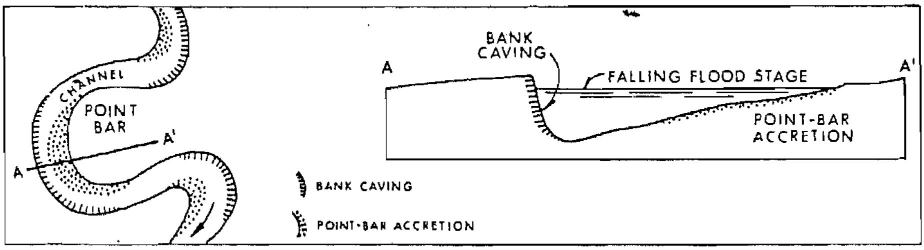
This model is characterized by a single-channel stream which is deeper than the multichannel braided stream. Meandering streams usually have a wide range in discharge (cu ft/sec) which varies from extended periods of low-water flow to flood stages of shorter duration. Flooding can occur one or more times per year and major flooding once every several years. The meandering channel is flanked by natural levees and point bars, and it migrates within a zone (meander belt) about 15 to 20 times the channel width. Channel segments are abandoned and filled with fines as new channels develop.

Source, Transportation, and Deposition of Sediments

Sediments are derived from whatever type of deposit occurs in the drainage area. Clays and fine silts are transported in suspension (suspended load), and coarser sediments such as sand, gravel, and pebbles are transported as bed load. Sediment transport and deposition during extended low-water stages are confined to the channel and can be nil or very slow. Maximum sediment transport occurs during rising flood stage when the bed of the channel is scoured.

The maximum rate of sediment deposition occurs during falling flood stages. Grain size depends on the type of sediment available to the channel; the coarsest sediments are deposited in the deepest part of the channel, and the finest sediments accumulate in floodbasins and in some parts of the abandoned channels.

Channel migration and deposition of point-bar sediments—The most important processes of sedimentation in the meandering-stream model are related to channel migration which occurs as a result of bank caving and point-bar accretion (Fig. 10). The process of bank caving occurs most rapidly during falling flood



71-0363-8

FIG. 10—Areas of bank caving and point-bar accretion along a meandering channel.

stage, when currents of maximum velocities are directed against the concave bank. Bank caving occurs at maximum rates in bends where the bed and bank materials are very sandy. Rates are much slower in areas where banks are characterized by clayey sediments (Fisk, 1947).

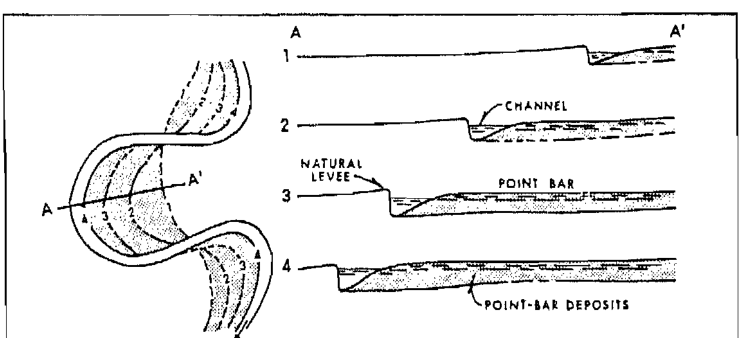
Deposition occurs on the convex bar (point bar) simultaneously with bank caving on the concave bank.

Bank caving and point-bar accretion result in channel migration and the development of the point-bar sequence of sediments (Fig. 11). The point bar is probably the most common and significant environment of sand deposition. The thickness of this sequence is governed by channel depths. Point-bar sequences along the Mississippi River attain thicknesses in excess of 150 ft (45 m). Medium-size rivers like the Brazos of Texas produce point-bar sequences that are 50 ft (15 m) thick (Bernard *et al.*, 1970).

Channel diversions and filling of abandoned channels—The process of channel diversion and channel abandonment is another characteristic feature of meandering streams. There are two basic types of diversion and abandonment: (1) the neck or chute cutoff of a single meander loop and (2) the abandonment of a long channel segment as a result of a major stream diversion (Fisk, 1947).

Meander loops which are abandoned as a result of neck or chute cutoffs become filled with sediment (Fig. 12A). The character of the channel fill depends on the orientation of the abandoned loop with respect to the direction of flow in the new channel. Meanders oriented with their cutoff ends pointing downstream (Fig. 12B) are filled predominantly with clays (clay plugs); those oriented with the cutoff ends pointing upstream are filled principally with sands and silts.

A major channel diversion is one which results in the abandonment of a long channel segment or meander belt, as shown in Figure 13. Channeling of flood water in a topographically low place along the bank of the active channel can rapidly erode unconsolidated sediments and create a new channel. This process can happen during a single flood or as a result of several floods. The newly established channel has a gradient advantage across the topographically lower floodbasin. A diversion can occur at any point along the channel.



71-0363-9

FIG. 11—Development of point-bar sequence of sediments.

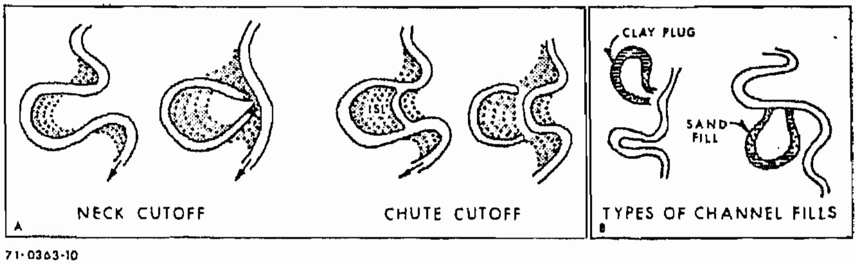


FIG. 12—Channel diversion, abandonment, and filling as a result of neck and chute cutoffs.

The character of the sediments which fill long channel segments is governed by the manner of channel diversion. Abrupt abandonment (during a single flood or a few floods) results in the very rapid filling of only the upstream end of the old channel, thus creating a long sinuous lake. These long, abandoned channels (lakes) fill very slowly with clays and silts transported by flood waters (Fig. 14, left).

Gradual channel abandonment (over a long period) results in very gradual channel deterioration. Diminishing flow transports and deposits progressively smaller amounts of finer sands and silts (Fig. 14, right).

Summary: Characteristics of Meander-Belt and Floodbasin Deposits

The meandering-stream model of sedimentation is characterized by four types of sediments: the point bar, abandoned channel, natural levee, and floodbasin. The nature of each of these four types of sediments and their interrelations are summarized in Figure 15.

Only two main types of sand bodies are associated with a meandering stream: the point-bar sands and the abandoned-channel fills. The former, which are much more abundant than the latter, occur in the lower portion of the point-bar sequence and constitute at least 75 percent of the sand deposited by a meandering stream. Coalescing point-bar sands can actually form a "blanketlike" sand body of very large regional extent. The continuity of sand is interrupted only by the "clay plugs" which occur in abandoned meander loops or in the last channel position of meander belts which have been abandoned abruptly.

Examples of ancient alluvial deposits of meandering-stream origin which have been reported in the literature are summarized in Table 1.

Deltaic Models of Clastic Sedimentation

Occurrence and General Characteristics

Deltaic sedimentation occurs in the transitional zone between continental and marine (or inland seas and lakes) realms of deposition. Deltas are formed under subaerial and subaqueous conditions by a combination of fluvial and marine processes which prevail in an area where a fluvial system introduces land-derived sediments into a standing body of water.

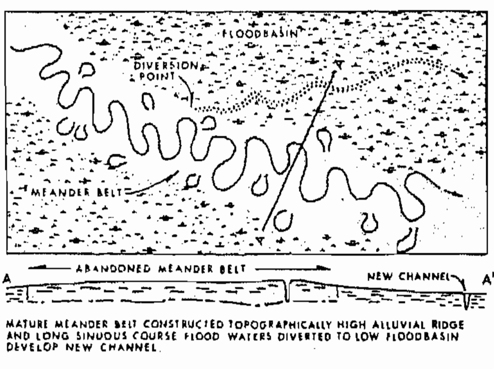


FIG. 13—Major channel diversion and abandonment of a meander belt.

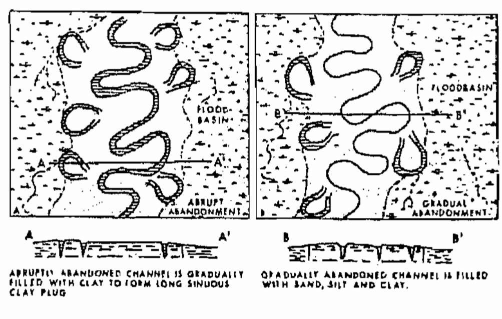
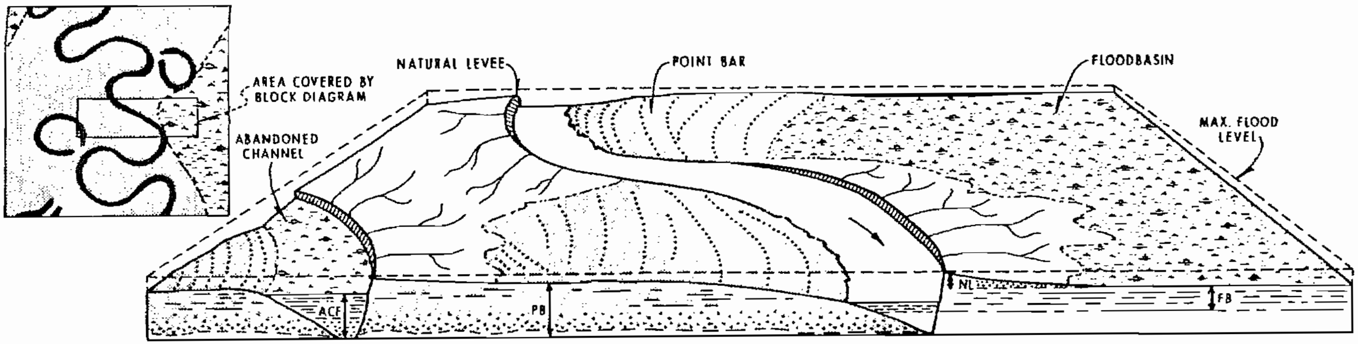


FIG. 14—Variations in character of abandoned channel fill typical of meander belts.



NATURAL LEVEE DEPOSITS (NL)

RELATIVELY THIN WEDGE OF SANDS, SILTS AND CLAYS DEPOSITED BY OVERBANK FLOOD WATERS. THICKEST SECTION OCCURS ADJACENT TO CHANNEL. DEPOSITS THIN AWAY FROM CHANNEL AND GRADE WITH FLOODBASIN CLAYS.

SEQUENCE CONSISTS OF THIN CYCLIC UNITS OF LIGHT COLORED, HORIZONTALLY-BEDDED SANDY SILTS (DEPOSITED DURING OVERBANK FLOOD) SEPARATED FROM EACH OTHER BY DARKER LAYERS OF ORGANIC RICH SILTY CLAYS AND INCIPIENT SOIL ZONES WHICH DEVELOP BETWEEN FLOOD SEASONS.

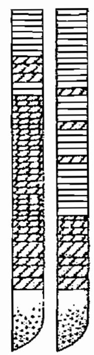
OVERALL SEQUENCE IS FINER NEAR BASE AND GRADES INTO SANDS AND SILTS UPWARDS. OVERLIES FLOODBASIN CLAYS OR OLDER POINT BAR DEPOSITS. THICKEST PORTION OF NATURAL LEVEES ARE REMOVED BY BANK CAVING PROCESS.

FLOODBASIN DEPOSITS (FB)

BLANKETLIKE ACCUMULATION OF CLAYS AND SILTY CLAYS WHICH ARE DEPOSITED FROM SUSPENDED LOAD OF FLOODWATERS INTO THE TOPOGRAPHICALLY LOWEST PORTION OF THE FLOODPLAIN. OVERLIES OLDER FLOODPLAIN DEPOSITS SUCH AS ABANDONED MEANDER BELT DEPOSITS AND FLOODBASIN CLAYS.

SEQUENCE CONSISTS OF CYCLIC LAYERS OF CLAYS AND SILTY CLAYS DEPOSITED DURING FLOODS WHICH ARE SEPARATED FROM EACH OTHER BY WEATHERED, OXIDIZED INCIPIENT SOIL ZONES WITH ABUNDANT PLANT MATERIAL AND FREQUENTLY DISTURBED BY ROOTS AND BURROWS. PEAT CAN ACCUMULATE LOCALLY UNDER SWAMP CONDITIONS.

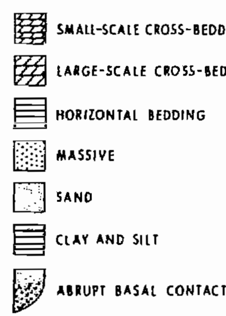
SIMILAR TO LOWER PART OF NATURAL LEVEE SEQUENCE.

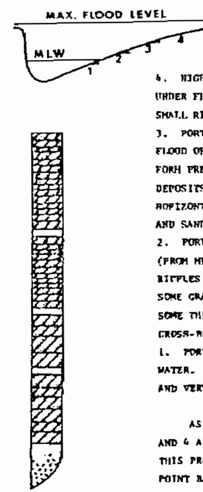


ABANDONED-CHANNEL DEPOSITS (AC)

ACCUMULATION OF ORGANIC RICH SEDIMENTS VARYING IN GRAIN SIZE BUT GENERALLY COARSE TO FINE UPWARDS. LOWER PART OF CHANNEL-FILL (ACTIVE CHANNEL-FILL) IS VERY SIMILAR TO THE LOWER PORTION OF THE POINT BAR SEQUENCE, CONSISTING OF MASSIVE SAND OVERLAIN BY FESTOON CROSS-BEDDED SAND. IN CHANNELS WHICH WERE ABANDONED GRADUALLY THIS LOWER SECTION IS OVERLAIN BY CROSS-BEDDED SANDY SILTS AND SILTS WHICH REPRESENT DEPOSITION DURING PARTIAL FLOW IN THE CHANNEL. THE UPPER MOST UNIT CONSISTS OF PREDOMINANTLY CLAYS AND SILTY CLAYS WITH ABUNDANT PLANT MATERIAL. THIS UNIT REPRESENTS THE ABANDONED STAGE OF THE CHANNEL.

IN ABRUPTLY ABANDONED CHANNELS THE BASAL SANDS UNIT (ACTIVE CHANNEL-FILL) IS DIRECTLY OVERLAIN BY A RELATIVELY THICK SECTION OF ORGANIC RICH CLAYS (OF THE ABANDONED STAGE). THIS UNIT IS VERY SIMILAR TO SOME PARTS OF THE FLOODBASIN DEPOSITS.





POINT-BAR DEPOSITS (PB)

COARSE TO FINE UPWARDS SEQUENCE OF SEDIMENTS DEPOSITED ON THE CONVEX BANK (BAR) OF MIGRATING CHANNEL.

DEPOSITIONAL PROFILE ACROSS POINT BAR (FROM DEEPEST PORTION OF CHANNEL TO THE HIGHEST PART OF THE BAR) IS CHARACTERIZED BY THE FOLLOWING FOUR ZONES:

4. HIGHEST PART OF BAR (SHALLOWEST PART OF CHANNEL UNDER FLOOD CONDITIONS). BED FORM CONSISTS MAINLY OF SMALL RIPPLES.

3. PORTION OF BAR (CHANNEL) COVERED BY WATER DURING FLOOD OF MAXIMUM AND INTERMEDIATE MAGNITUDES. BED FORM PREDOMINANTLY SMALL RIPPLES AND HORIZONTAL. DEPOSITS OF THIS ZONE CONSISTS OF CYCLIC UNITS OF HORIZONTALLY-BEDDED AND SMALL SCALE CROSS-BEDDED SILTS AND SANDY SILTS, WITH SOME CLAYS.

2. PORTION OF BAR MOST FREQUENTLY COVERED BY WATER (FROM MLW TO FLOODSTAGES). BED FORM CONSISTS OF LARGE RIPPLES (SCALLOPED). SEDIMENT ARE MAINLY SANDS WITH SOME GRAVELS THAT ARE FESTOON CROSS-BEDDED. CONTAINS SOME THIN UNITS OF HORIZONTALLY-BEDDED AND SMALL SCALE CROSS-BEDDED SANDS.

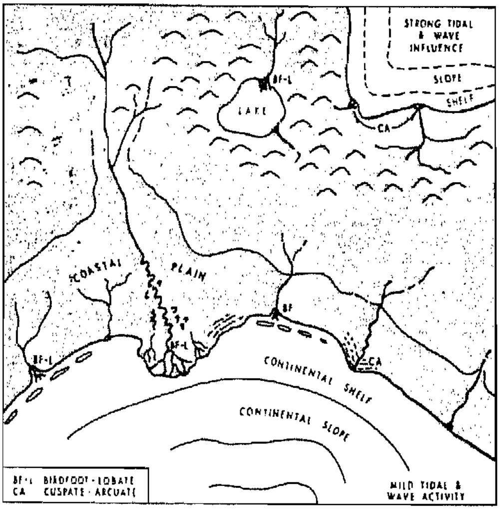
1. PORTION OF CHANNEL GENERALLY ALWAYS COVERED BY WATER. BED FORM NOT OBSERVED. SEDIMENTS ARE MASSIVE AND VERY POORLY SORTED, USUALLY CONTAINING CLAY BALLS.

AS BAR GROWS BY ACCRETION (OFFLAP) ZONES 2, 3, AND 4 ARE SUPERPOSED OVER ZONES 1, 2, AND 3 RESPECTIVELY. THIS PROCESS RESULTS IN THE DEVELOPMENT OF THE TYPICAL POINT BAR SEQUENCE SHOWN ON THE LEFT.

LAYERS OF CLAY (MUD) ARE DEPOSITED (FROM SUSPENSION) OVER PART OF THE BAR DURING WANING FLOOD STAGES WHEN VELOCITY IS NIL. THESE CLAY DRAPES ARE FREQUENTLY PRESERVED. THEY CAN OCCUR ANYWHERE IN THE SEQUENCE.

DURING MAJOR FLOOD THE INTERMEDIATE PARTS OF THE BAR (SHALLOW PART OF FLOOD CHANNEL) ACTS AS A SPECIAL TYPE OF BED FORM. HORIZONTALLY-BEDDED SANDS ARE DEPOSITED OVER THESE HIGH PARTS. SANDS WHICH SPILL OVER THE BAR EDGES ARE PRESERVED AS SPILL OVER BEDDING, USUALLY WITH VERY HIGH DIPS.

FIG. 15—Characteristics of meander-belt and floodplain deposits.



71-0363-15

FIG. 16—Occurrence of deltaic models of clastic sedimentation.

Large deltas usually are associated with extensive coastal plains; however, all coastal plains do not include large deltas. The deltaic environment occurs downstream from the meandering-stream environment and is directly adjacent to, and updip (landward) from, the marine environment; it is flanked by the coastal-interdeltaic environment. Most large deltas occur on the margins of marine basins, but smaller deltas also form in inland lakes, seas, and coastal lagoons and estuaries (Fig. 16).

That portion of a delta which is constructed under subaerial conditions is called the "deltaic plain"; that portion which forms under water is called the "delta front," "delta platform," and "prodelta." The bulk of the deltaic mass is deposited under water.

Deltas are considered to be extremely important because they are the sites of deposition of sand much father downdip than the interdeltaic environment, as well as being the sites where clastic deposition occurred at maximum rates.

Source and Transportation of Sediments

Sediments deposited in large deltas are derived from extensive continental regions which are usually composed of rock types of varied compositions and geologic ages. Thus, the composition of deltaic sediments can be quite varied.

The sediment load of rivers consists of two parts: (1) the clays and fine silts transported in suspension and (2) the coarser silts and sands, and in some cases gravels, transported as bed load. The ratio of suspended load to bed load varies considerably, depending upon the rock types and climatic conditions of the sediment-source areas. The suspended load is generally much greater than the bed load.

The transportation of sediment to a delta is an intermittent process. Most rivers transport the bulk of their sediments during flood stages. During extended periods of low discharge, rivers contribute very little sediment to their deltas.

The extent to which deltaic sediments are dispersed into the marine environment is dependent upon the magnitude of the marine processes during the period that a river is in flood stage. Maximum sediment dispersal occurs when a river with a large suspended load reaches flood stage at the time the marine environment is most active (season of maximum currents and wave action). Minimum dispersal occurs when a river with a small suspended load (high bed load) reaches flood stage at a time when the marine environment is relatively calm.

Size of deltas—There is an extremely wide range in the size of deltas;[4] modern deltas range in area from less than 1 sq mi (2.6 sq km) to several hundreds of square miles. Some large deltaic-plain complexes are several thousand square miles in area. Delta size is dependent upon several factors, but the three most important are the sediment load of the river; the intensity of marine currents, waves, and tides; and the rate of subsidence. For a given rate of subsidence, the ideal condition for the construction of a large delta is the sudden large influx of sediments in a calm body of water with a small tidal range. An equally large sediment influx into a highly disturbed body of water with a high tidal range results in the formation of a smaller delta, because a large amount of sediment is dispersed beyond the limits of what can reasonably be recognized as a delta. Rapid subsidence enhances the possibility for a large fluvial system to construct a large delta.

Types of deltas—A study of modern deltas of the world reveals numerous types. Bernard

[4] Published figures on areal extent of deltas are based on size of the deltaic plain and do not include submerged portions of the delta, which in many cases are as large as or larger than the deltaic plains.

(1965) summarized some of the factors which control delta types as follows:

> Deltas and deltaic sediments are produced by the rapid deposition of stream-borne materials in relatively still-standing bodies of water. Notwithstanding the effects of subsidence and water level movements, most deltaic sediments are deposited off the delta shoreline in the proximity of the river's mouth. As these materials build upward to the level of the still-standing body of water, the remainder of deltaic sediments are deposited onshore, within the delta's flood plains, lakes, bays, and channels.
>
> Nearly 2,500 years ago, Herodotus, using the Nile as an example, stated that the land area reclaimed from the sea by deposition of river sediments is generally deltoid in shape. The buildup and progradation of deltaic sediments produces a distinct change in stream gradient from the fluvial or alluvial plain to the deltaic plain. Near the point of gradient change the major courses of rivers generally begin to transport much finer materials, to bifurcate into major distributaries, and to form subaerial deltaic plains. The boundaries of the subaerial plain of an individual delta are the lateral-most distributaries, including their related sediments, and the coast line. Successively smaller distributaries form sub-deltas of progressively smaller magnitudes.
>
> Deltas may be classified on the basis of the nature of their associated water bodies, such as lake, bay, inland sea, and marine deltas. Other classifications may be based on the depth of the water bodies into which they prograde, or on basin structure.
>
> Many delta types have been described previously. Most of these have been related to the vicissitudes of sedimentary processes by which they form. Names were derived largely from the shapes of the delta shorelines. The configuration of the delta shores and many other depositional forms expressed by different sedimentary facies appear to be directly proportional to the relative relationship of the amount or rate of river sediment influx with the nature and energy of the coastal processes. The more common and better understood types, listed in order of decreasing sediment influx and increasing energy of coastal processes (waves, currents, and tides), are: birdfoot, lobate, cuspate, arcuate, and estuarine. The subdeltas of the Colorado River in Texas illustrate this relationship. During the first part of this century, the river, transporting approximately the same yearly load, built a birdfoot-lobate type delta in Matagorda Bay, a low-energy water body, and began to form a cuspate delta in the Gulf of Mexico, a comparatively high-energy water body. Many deltas are compounded; their subdeltas may be representative of two or more types of deltas, such as birdfoot, lobate, and arcuate. Less-known deltas, such as the Irrawaddy, Ganges, and Mekong, are probably mature estuarine types. Others, located very near major scarps, are referred to the "Gilbert type," which is similar to an alluvial fan.

Additional studies of modern deltas are required before a more suitable classification of delta types can be established. J. M. Coleman (personal commun.) and his associates, together with the Coastal Studies Institute at Louisiana State University, are presently conducting a comprehensive investigation of more than 40 modern deltas. Results of their studies undoubtedly will be a significant contribution toward the solution to this problem.

Only three types of deltas will be considered in this report: the birdfoot-lobate, the cuspate-arcuate, and the estuarine.

Sedimentary Processes and Deposits of the Birdfoot-Type Delta

The processes of sedimentation within a delta are much more complex and variable than those which occur in the meandering-stream and coastal-interdeltaic environment of sedimentation. It is impossible to discuss these deltaic processes in detail in a short summary paper such as this; therefore, only a brief summary of the following significant processes is presented.

1. Dispersal of sediment in the submerged parts of the delta (from river mouths seaward);
2. Formation of rivermouth bars, processes of channel bifurcation, and development of distributary channels;
3. Seaward progradation of delta, deposition of the deltaic sequence of sediments, and abandonment and filling of distributary channels; and
4. Major river diversions, abandonment of deltas, and development of new deltas.

Dispersal and deposition of sediments—Riverborne sediments which are introduced in a standing body of water (a marine body or inland lakes and seas) are transported in suspension (clays and fine silts) and as bed load (coarse silts, sands, and coarser sediments). Most of the sands and coarse silts are deposited in the immediate delta-front environment as rivermouth bars and slightly beyond the bar-front zone. The degree of sand dispersal is, of course, controlled by the level of marine energy; however, in most birdfoot deltas, sands are not transported beyond 50-ft (15 m) water depths. Fisk (1955) referred to the sands deposited around the margins of the subaerial deltaic plain as "delta-front sands," and they are called "delta-fringe sands" herein.

The finer sediments (clays and fine silts), which are transported in suspension, are dispersed over a much broader area than the fringe sands and silts. The degree of dispersal is governed by current intensity and behavior. Accumulations of clays seaward of the delta-fringe sands are referred to as "prodelta" or "distal clays" (Fig. 17).

Channel bifurcation and development of distributary channels—Some of the most significant deltaic processes are those which result in the origin and development of distributary

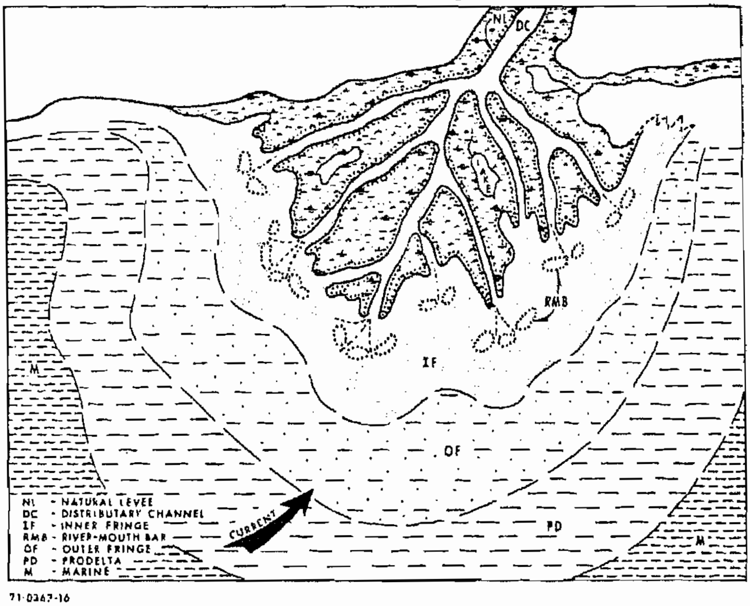


FIG. 17—Distribution of distributary-channel and fringe sands in a birdfoot-lobate delta.

channels. Welder (1959) conducted a detailed study of these processes in a part of the Mississippi delta, and Russell (1967a) summarized the origin of branching channels, as follows:

> The creation of branching channels is determined by the fact that threads of maximum turbulence and turbulent interchange (Austausch; 1.2.3; 3.5) lie deep and well toward the sides of channels, particularly if they have flat beds (typical of clay and fine sediments in many delta regions). These threads are associated with maximum scour and from them, sediment is expelled toward areas of less turbulence and Austausch. Significant load is propelled toward mid-channel, where shoals are most likely to form.

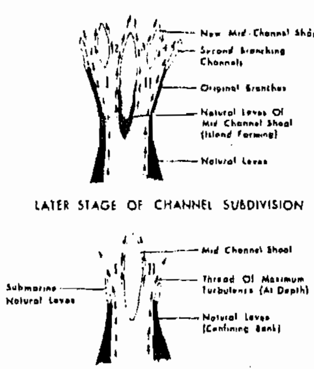


FIG. 18—Stages in development of channel bifurcation. After Russell (1967).

At its mouth, the current of a delta channel continues forward (as a result of momentum) and creates *jet flow* into the lake or sea it enters. After leaving the confinement imposed by fixed banks, however, the current flares marginally to some extent (widening the jet, reducing its velocity, and eventually dissipating its flow energy). Near the termination of confining banks the jet flow is concentrated and moves ahead into relatively quiet water. With flaring of jet flow comes an increase in spacing between threads of most intense turbulence and exchange. There is a tendency toward scour below each thread, but the exchange process sends most of the entrained material toward marginal quiet water on both sides (Fig. 8 [Fig. 18 of this paper]). Deposition creates a submarine natural levee on the outer side of each thread. Sediment is also attracted toward and deposited in the widening area of mid-channel water, where it builds a shoal. The channel divides around the shoal, creating two distributaries, each of which develops its own marginal threads of maximum turbulence, perpetuating conditions for other divisions below each new channel mouth. If not opposed by wave erosion and longshore currents, the subdivision continues in geometric progression (2, 4, 8, 16, etc.) as the delta deposit grows forward.

The marginal natural levees are submarine features at first and fish may swim across their crests. Later they grow upward, and for awhile become areas where logs and other flotsam accumulate and where birds walk with talons hardly submerged. Salt- or fresh-water-tolerant grasses invade the shallow water and newly created land, first along levee crests, later to widen as the levees grow larger. Salicornia and other plants become established pioneer trees such as willows, and eventually in the plant succession comes the whole complex characteristic of natural levees upstream. In tropical areas mangroves are likely to become the dominant trees.

A similar conversion exists in mid-channel, where the original shoal becomes land and either develops into a lenticular or irregular island or becomes the point of land at the head of two branching distributaries.

Progradation of delta and deposition of deltaic sequence—Fisk's discussion of the process of distributary-channel lengthening (progradation of delta seaward) is probably one of the most significant of his many contributions on deltaic sedimentation (Fisk, 1958). His description of this important aspect of delta development is presented below. (Stages in the development of a birdfoot-type delta are shown in Figure 19.)

Each of the pre-modern Mississippi River courses was initiated by an upstream diversion, similar to the one presently affecting the Mississippi as the Atchafalaya River enlarges (Fisk, 1952). Stream capture was a gradual process involving increasing flow through a diversional arm which offered a gradient advantage to the gulf. After capture was effected, each new course lengthened seaward by building a shallow-water delta and extending it gulfward. Successive stages in course lengthening are shown diagrammatically on Figure 2 [Fig. 19, this paper]. The onshore portion of the delta surface . . . is composed of distributaries which are flanked by low natural levees, and interdistributary troughs holding near-sea-level marshes and shallow water bodies. Channels of the principal distributaries extend for some distance across the gently sloping offshore surface of the delta to the inner margin of the steeper delta front where the distributary-mouth bars are situated. The offshore channels are bordered by submarine levees which rise slightly above the offshore extensions of the interdistributary troughs.

In the process of course lengthening, the river occupies a succession of distributaries, each of which is favorably aligned to receive increasing flow from upstream. . . . The favored distributary gradually widens and deepens to become the main stream . . . ; its natural levees increase in height and width and adjacent interdistributary troughs fill, permitting marshland development. Levees along the main channel are built largely during floodstage; along the distal ends of distributaries, however, levee construction is facilitated by crevasses . . . which breach the low levees and permit water and sediment to be discharged into adjacent troughs during intermediate river stages as well as during floodstage. Abnormally wide sections of the levee and of adjacent mudflats and marshes are created in this manner, and some of the crevasses continue to remain open and serve as minor distributaries while the levees increase in height. Crevasses also occur along the main stream during floodstages . . . and permit tongues of sediment to extend into the swamps and marshes for considerable distances beyond the normal toe position of the levee.

Distributaries with less favorable alignment are abandoned during the course-lengthening process, and their channels are filled with sandy sediment. Abandoned distributaries associated with the development of the present course below New Orleans vein the marshlands. . . . Above the birdfoot delta, the pattern is similar to that of the older courses . . . ; numerous long, branching distributaries diverge at a low angle.

Stream diversions, abandonment of deltas, and development of new deltas—Deltas prograde seaward but they do not migrate laterally, as a point bar does, for example. A delta *shifts position* laterally if a major stream diversion occurs upstream in the alluvial environment or in the upper deltaic-plain region (Fig. 20). Channel diversions were discussed in the section on the meandering-stream model.

Deltas, like meander belts, can be abandoned abruptly or gradually, depending upon the time required for channel diversion to occur. Once a delta is completely abandoned, all processes of deltaic sedimentation cease to exist in that particular delta. With a standing sea level, the sediments of the abandoned delta compact, and subsidence probably continues. The net result is the encroachment of the marine environment over the abandoned delta. This process has erroneously been referred to by some authors as "the destructive phase of deltaic sedimentation." The author maintains that the proper terminology for this process is "transgressive marine sedimentation." The two processes and their related sediments are significantly different, as the discussion of the transgressive marine model of sedimentation demonstrates (see the succeeding section on this model).

As the marine environment advances landward over an abandoned subaqueous delta front and the margins of the deltaic plain, the upper portion of the deltaic sequence of sediment is removed by wave action. The amount of sediment removed depends on the inland extent of the transgression and on the rate of subsidence. The front of the transgression is usually characterized by deposition of thin marine sand units. Seaward, sediments become finer and grade into clays. Thus, local marine transgressions which occur because of delta shifts result in the deposition of a very distinctive marine sedimentary sequence which is easily distinguished from the underlying deltaic sequence.

Concurrent with marine transgression over an abandoned delta, a new delta will develop on the flanks of the abandoned delta. Sedimentary processes in the new delta are similar to those described under the discussion of progradation of deltas.

Repeated occurrences of river diversions result in the deposition of several discrete deltaic masses which are separated by thin transgressive marine sequences (Fig. 20). Under ideal conditions, deltaic facies can attain thicknesses

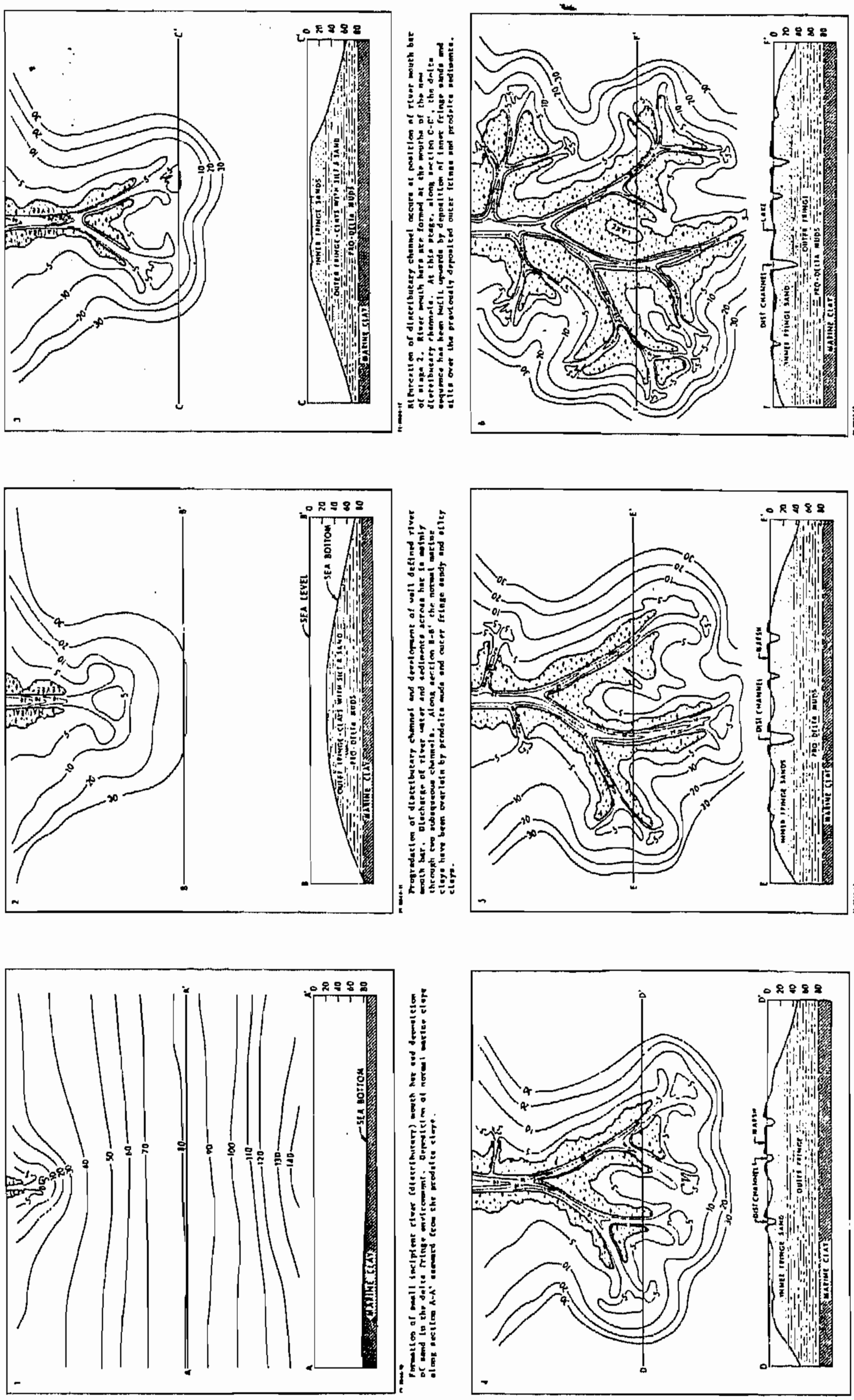


FIG. 19—Stages in development of birdfoot delta and deposition of deltaic sequence.

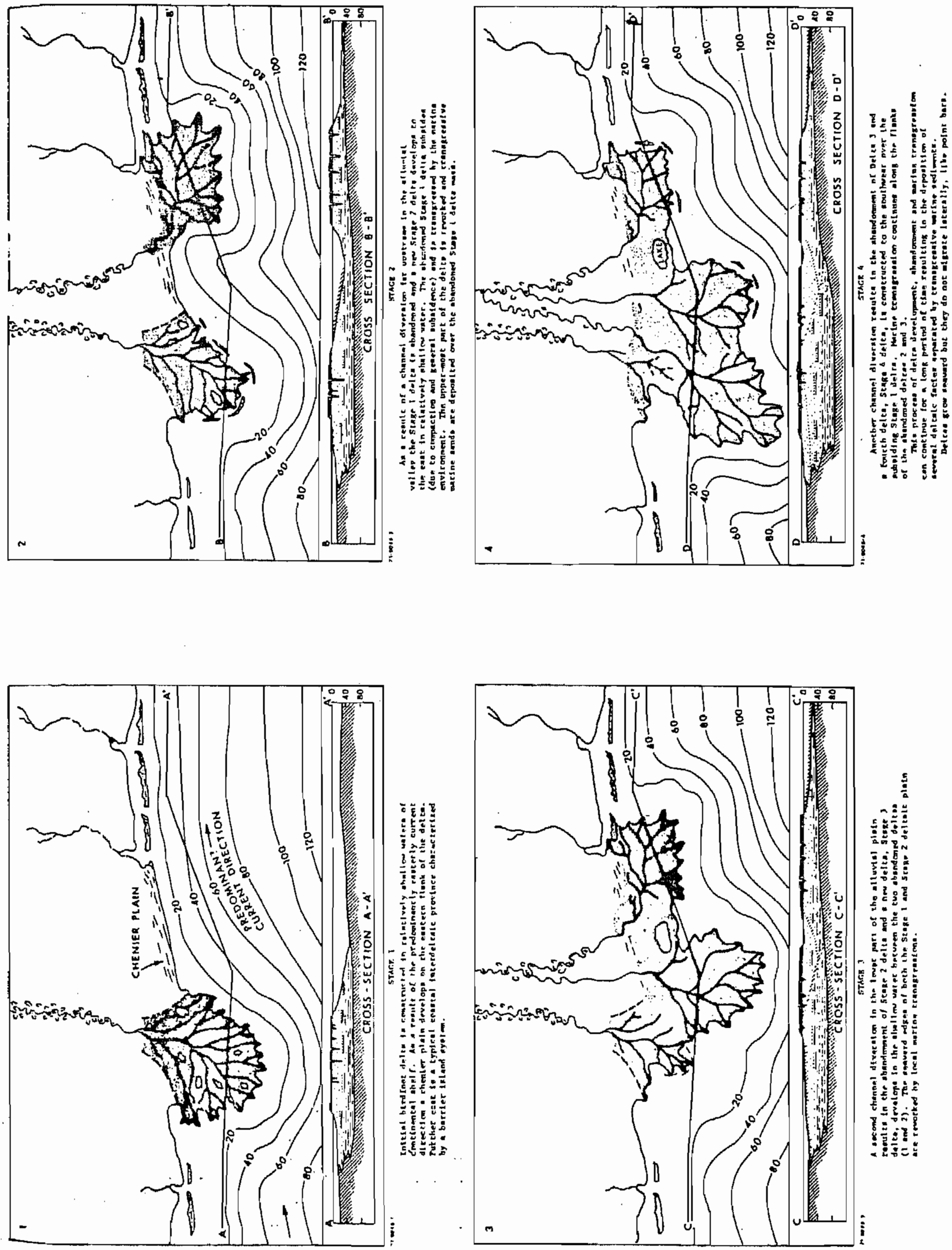


FIG. 20—Stages in development of a deltaic-plain complex and related deltaic facies.

of several hundreds of feet in a large sedimentary basin.

Sedimentary Processes and Deposits of the Cuspate-Arcuate Type of Delta

The shape of a delta is controlled by the influence of marine processes which are active against the delta front (Table 2). Russell (1967a) presented the following excellent summary of the modification of deltas by marine processes.

> The depositional processes characteristic of river mouths are opposed by marine processes that work toward removal of deposits. In a quiet sea or lake the geometric increase in number of distributaries is most closely approached. Below the most inland and earliest forking of the river, the delta builds out as a fan-shaped accumulation, with distributaries creating ribs with natural levees separating basins that widen and open toward the sea. The point deserving greatest emphasis is that the entire delta system originates underwater and only later becomes features visible as land.
>
> The ideal delta front is *arcuate* or has a *bird-foot* shape as viewed from the air or indicated on a chart. The latter pattern indicates a condition in which the deposition of load is dominant over the efforts of marine processes. It results from the forward growth of natural levees and the inability of longshore currents to carry away sediment about as rapidly as it is brought to the river mouth. The delta of the Mississippi is the largest and most typically cited example. Some talons of the foot extend out more than 20 miles and the basins between natural levees flank V-shaped marshes and bays up to about 1.5 fathoms deep. Many smaller bird-foot deltas occur in lakes and estuaries, where there is relatively little distance for fetch to generate high waves and where there are only feeble longshore currents.
>
> The arcuate-front deltas, such as those of the Nile and Niger, indicate sufficient wave action and removal of sediment by longshore currents to maintain relatively stable, smooth fronts. In some cases the momentum of jet flow is apparently sufficient to prevent much flaring, and a single pair of natural levees advances seaward to form a *cuspate* delta front, localized along a single channel. The Tiber, Italy, is the commonly cited example. The Sakayra River, on the Black Sea coast of Turkey has such a delta, but the reason is dominance of wave action. Ahead of it is a large area of shoal water with an extremely irregular system of channels and natural levees (changing so rapidly that a pilot keeps daily watch over them in order to guide boats back to the river mouth). Levees are prevented from growing up to sea level because wave erosion keeps them planed off to a depth of a few feet and because longshore currents entrain and transport sediment away effectively enough to prevent seaward growth of land area. This leaves but one channel mouth in a central position as a gently protruding single cusp.

The modern Brazos River delta of Texas (constructed since 1929) is a good example of a small modern arcuate delta which has been strongly influenced by marine processes. Bernard *et al.* (1970) discussed this small delta and its vertical sequence of sediments. Stages in the development of this type of delta are shown in Figure 21.

The modern Niger delta of western Africa is a classic example of a large arcuate-type delta that is highly influenced by marine processes and tidal currents. Allen (1965c, 1970) described the environments, processes, and sedimentary sequences of this interesting delta. On the basis of data presented by Allen, it is obvious that, although there are many similarities between the Niger delta and the birdfoot-type Mississippi delta, there are certainly some significant differences. For example, from the standpoint of sand bodies, the characteristics and geometry of the delta-fringe sands of the Niger are considerably different from those of the Mississippi. As indicated on Figure 22, a very large quantity of the sand that is contributed to rivermouth bars by the Niger is transported landward and deposited on the front of the deltaic plain as prominent beach ridges (this is a special form of delta-fringe sand according to the writer's deltaic classification). This process results in the development of a thick body of clean sands along the entire front of the deltaic plain.

Another important difference between the Niger and the Mississippi is the occurrence of a very extensive tidal-marsh and swamp environment on the Niger deltaic plain behind (landward of) the prominent beach ridges. This environment is characterized by a network of numerous small channels which connect with the main distributary channels. These channels, which are influenced by a wide tidal range, migrate rather freely and become abandoned to produce extensive point-bar deposits and many abandoned channel fills. In contrast, the Mississippi River distributary channels migrate very little and, hence, point-bar sands constitute only a small percentage of the deltaic deposits.

In summary, the Niger arcuate delta is characterized by prominent delta-fringe sands (which include the beach-ridge sands) occurring as a narrow belt along the entire front of the deltaic plain. Point-bar sand bodies are very common directly adjacent to and landward of the delta-fringe sands. The combination of high-level marine energy and strong tidal currents results in development of a relatively large quantity of distributary and point-bar (migrating channels) sands.

Table 2. Factors Which Influence Characteristics of Deltaic Deposits

Characteristics of Deltaic Deposits		Factors Which Influence Deltaic Sedimentation						
		Magnitude of Fluvial Processes (Sediment Influx)	Magnitude of Marine Processes (Wave Energy, Range in Tide & Currents)	Depth of Water	Subsidence Rate	Sea Level	Salinity of Water	Climate and Vegetation
Thickness of Deltaic Sequence		Large sediment influx required to produce thick sequence.	High wave and current energy tends to disperse sediments and reduce rate of sedimentation.	Water depths in basin controls max. thickness possible. Subsidence permits development of sequence thicker than depth.	Rapid subsidence produces thick sequence. Thin sequences occur in stable areas.	Rising sea level results in thicker sequences.		Abundant vegetation promotes development of thick organic rich layer in upper part of sequence.
Sand Content	Distributary Channel Fills	Percent of sand in channels depends on rapid or gradual diversion. Gradual abandonment produces more sand in fills.	Large tidal range can transport sand upstream near river mouths and increase sand content in fills.					
	Fringe	Amount of sand in fringe depends on sand load of river. Small for muddy rivers; large for rivers with high sand load.	Strong currents may transport sand along coast away from delta thus reducing sand content of fringe.					
Porosity and Permeability	Distributary Channel Fills		Large tidal range results in deposition of clays and silts in lower reaches of channels thus lowering porosity and permeability.					
	Fringe	High sand content. Rivers generally have best developed fringe sands.	Strong wave and current winnows fines and deposition of clean sand occurs. Dirty sands are deposited in areas of low marine energy.					
Geometry of Deltaic Mass			Strong marine currents can disperse sediment over extensive area to form broad subaqueous fringe and pro-delta mass.	Relatively thin blanket-like deltaic masses form in shallow water. Geometry influenced by bottom topography.	Thin blanket-like delta masses occur in stable areas. Local downwarps result in ladle-shape delta masses.	Rising sea level will produce on-lap fringe over marsh facies. Falling sea level causes strong off-lap of marsh over fringe.	Fine sediments in suspension flow over denser sea water and may be dispersed over broad areas by currents.	
Influence of Organisms on Sediments		Rapid influx of sediment and high turbidity greatly reduces organism population and degree of bioturbation.	Organisms have little influence on sediments in near shore zone with large wave energy.					
Number of Distributary Channel Fills			Strong wave and current action prevents normal development of river mouth bars necessary for bifurcation of channel.	Deltas constructed in shoal water have largest number of distributary channels.				
Thickness (Depth) of Dist. Channel Fills					Rapidly subsiding deltaic plain may result in thicker dist. channel fills.	Falling sea level may cause deepening of channels. Rising sea level causes shoaling.		
Rate of Sedimentation		Rates of sedimentation generally greatest in deltas of rivers with large sediment.	Strong currents can disperse sediments and reduce deposition rates.					Rapid growth of vegetation traps sediments and increases rate of deposition.
Thickness of Organic Rich Clays and Peats (Conc) in Upper Part of Sequence					Thick section of peat and organic clays can accumulate in a near sea level environment (with subsidence).	A rising sea level will result in thick section of organic material in upper portion of sequence.		Warm, wet deltas with dense vegetation are characterized by thick peats and organic rich clays.

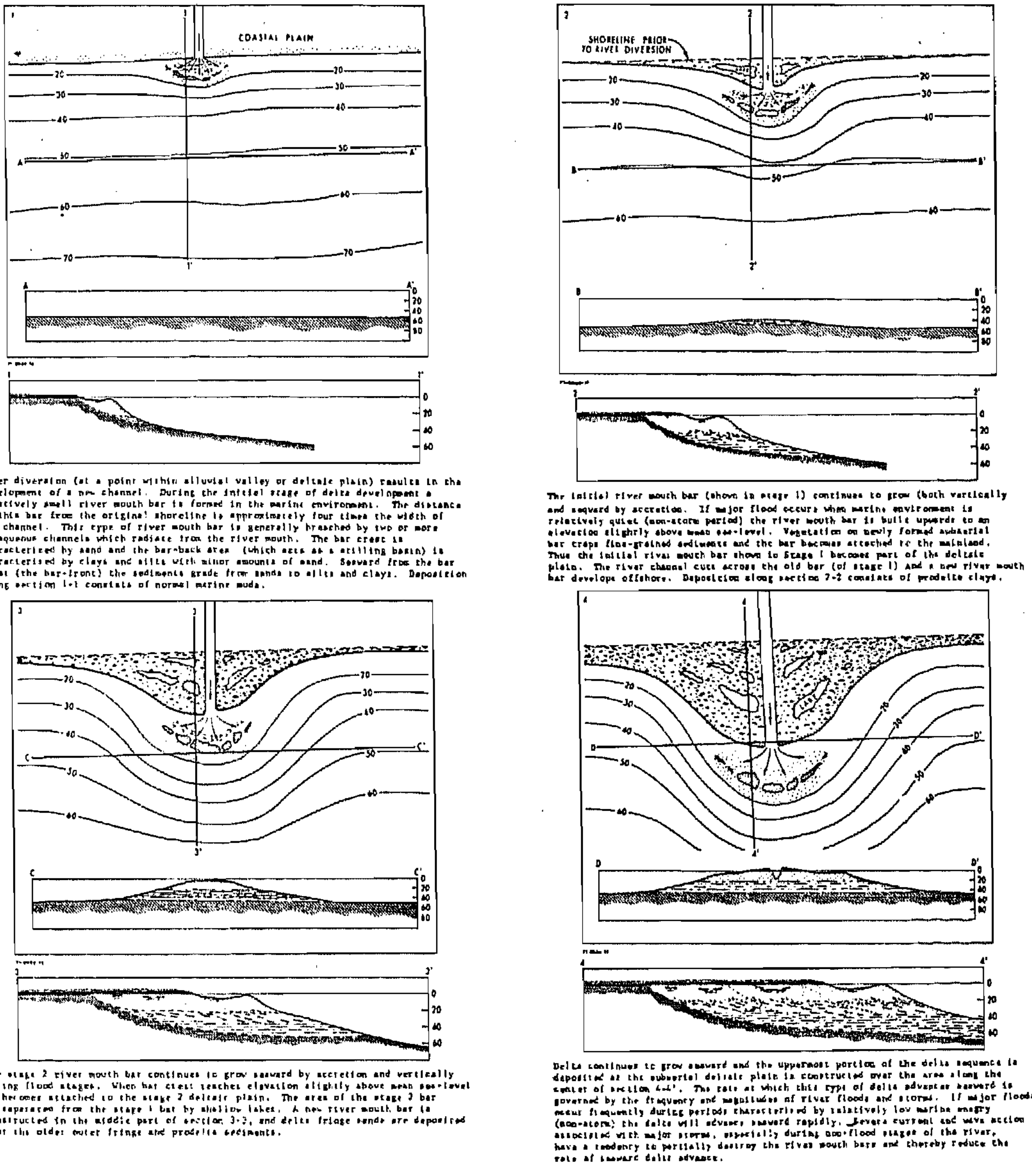
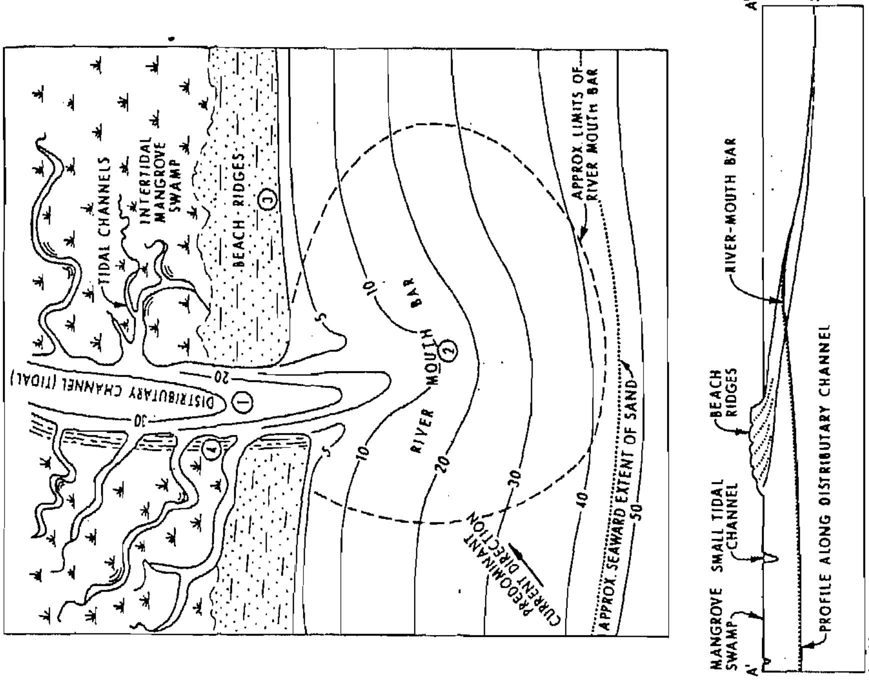


FIG. 21—Stages in development of a cuspate delta.

Sedimentary Processes and Deposits of Estuarine-Type Delta

Large deltas such as the Ganges, Amazon, and Colorado (in Gulf of California) are considered to be examples of estuarine-type deltas. Although our knowledge of these deltas is extremely limited, it is now reasonably well established that they are associated with extreme tidal conditions (up to 25 ft [8 m] at the mouth of the Colorado River). It is apparent that very strong tidal currents have a profound influence on the distribution of sediments. Sands are known to be transported for great distances in front of these deltas; however, the geometry of these sand bodies is unknown. Additional studies of this type delta are badly needed.

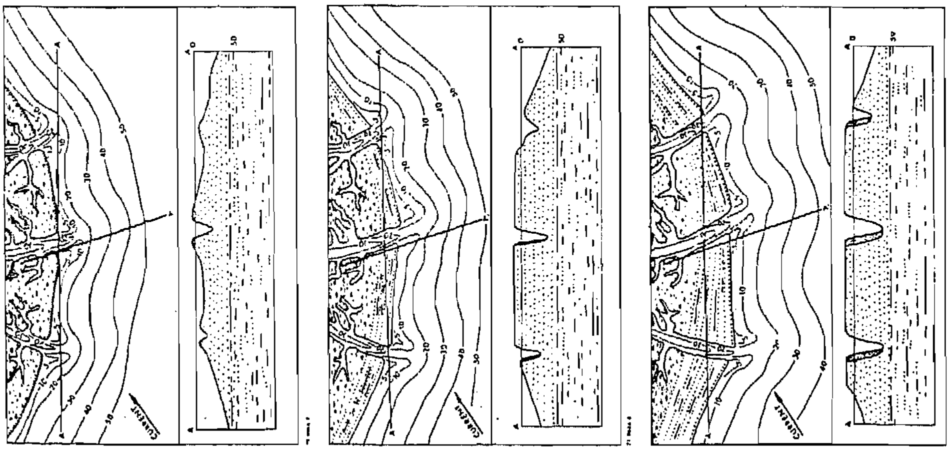


Arcuate deltas generally develop in areas where level of marine energy (currents, waves and tides) is very high as compared to the magnitude of the fluvial processes. Although river mouth bars develop as in other types of deltas, they are generally reworked and partially destroyed as rapidly as they are formed by strong marine currents and wave action, especially in situations where severe storm activity does not coincide with major flood periods. This situation precludes the full development of river mouth bars and resulting channel bifurcation.

Sands introduced to the marine environment by the distributary channel are initially deposited on or near the river mouth bars. These sands are subsequently transported to the beach environment by currents and waves. This leads to the development of prominent beach accretion ridges and the best developed delta fringe sands have the characteristics of beach deposits.

Strong littoral drift results in lateral migration (in same direction as marine current) of the lower ends of distributary channels. This lateral channel migration is accompanied by the deposition of sediments along the margins of the channel opposite the direction of migration (4).

If the tidal range is large the area behind the beaches of the delta front is generally characterized by a complex of tidal channels which empty into the main distributary channels. These channels are associated with marshes or swamps and they migrate to produce point bar sequences.



The three diagrams shown above illustrate stages in the development of a deltaic sequence which is characteristic of arcuate deltas. One of the most prominent features of this type of delta is the beach ridge complex on the delta front. This is a very special type of delta fringe sands. Note that as the delta advances seaward the subaqueous part of the delta sequence is locally replaced by distributary channels, which become deeper and wider as the delta advances seaward.

FIG. 22—Processes of deltaic sedimentation associated with an arcuate delta.

Table 3. Examples of Ancient Deltaic Deposits

Geographic Occurrence	Author
California	Todd and Monroe, 1968
Illinois	Lineback, 1968
	Swann *et al.*, 1965
Indiana	Hrabar and Potter, 1969
	Wier and Girdley, 1963
Iowa & Illinois	Laury, 1968
Kansas	Brown, 1967
	Hattin, 1965
Louisiana	Clark and Rouse, 1971
	Curtis, 1970
Michigan	Asseez, 1969
Miss., La. & Ala.	Galloway, 1968
Montana	Sims, 1967
Nebraska	Shelton, 1972
New Mexico	Schlee and Moench, 1961
New York	Friedman and Johnson, 1966
	Lumsden and Pelletier, 1969
New York & Ontario	Martini, 1971
New York	Wolff, 1967
North Dakota	Shelton, 1972
Ohio	Knight, 1969
	Lené and Owen, 1969
Oklahoma	Busch, 1953, 1971
	Shelton, 1972
	Visher *et al.*, 1971
Oregon	Dott, 1964, 1966
	Snavely *et al.*, 1964
Pa., W. Va., Ohio	Beerbower, 1961
	Ferm and Cavaroc, 1969
South Dakota	Pettyjohn, 1967
Texas	Brown, 1969
	Fisher and McGowen, 1969
	Gregory, 1966
	LeBlanc, 1971
	Nanz, 1954
	Shannon and Dahl, 1971
	Wermund and Jenkins, 1970
	Shelton, 1972
W. Va., Pa., Ohio	Donaldson, 1969
Wyoming	Barlow and Haun, 1966
	Dondanville, 1963
	Hale, 1961
	Paull, 1962
	Weimer, 1961b
Wyoming & Colorado	Weimer, 1965
Several states, U.S.A.	Fisher *et al.*, 1969
N. Appalachians	Ferm, 1970
Central Appalachians	Horowitz, 1966
Central Appalachians	Dennison, 1971
Upper Miss. embayment & Illinois basin	Pryor, 1960, 1961
Upper Miss. Valley	Swann, 1964
Okla., Iowa, Mo., Kans., Ill., Ind., Ky.	Manos, 1967
Okla. to Penn.	Wanless *et al.*, 1970
Central Gulf Coast	Mann and Thomas, 1968
Alberta, Canada	Carrigy, 1971
	Shawa, 1969
	Shepheard and Hills, 1970
	Thachuk, 1968
England	Allen, 1962
	Taylor, 1963
Ireland	Hubbard, 1967
Scotland	Greensmith, 1966

Summary: Deltaic Sand Bodies

There are three basic types of deltaic sand bodies: delta-fringe, abandoned distributary-channel, and point-bar sands. The relative abundance and general characteristics of these sand bodies in the three types of deltas considered herein are summarized below.

Birdfoot-type delta—The most common sands are those of the delta-fringe environment. These sands occur as relatively thin, widespread sheets, and they contain a substantial amount of clays and silts.

Abandoned distributary channels contain varied amounts of sand, probably composing less than 20 percent of the total delta sand content. These sand bodies are long and narrow, are only slightly sinuous, and are encased in the delta-fringe sands or prodelta clays, depending upon channel depths and the distance that the delta has prograded seaward.

Cuspate-arcuate type of delta—Delta-fringe sand complexes are wide (width of delta), though individual sand bodies are relatively narrow, and are generally much cleaner than delta-fringe sands of the birdfoot-type delta.

Distributary-channel sands and point-bar sands are much more common than in birdfoot-type deltas and can constitute up to 50 percent of the total sand content of the delta. These two types of sands are encased in delta-fringe and prodelta sediments.

Estuarine-type delta—Delta-fringe sands appear to be much more common than distributary and point-bar sands. They probably extend for great distances within the marine environment in front of the delta; however, their geometry remains unknown.

Ancient Deltaic Deposits

Deposits of deltaic origin have been reported from more than 40 states and from several foreign countries. Some examples are summarized in Table 3.

Coastal-Interdeltaic Model of Sedimentation

Setting and General Characteristics

This type of sedimentation occurs in long, narrow belts parallel with the coast where shoreline and nearshore processes of sedimentation predominate. The ideal interdeltaic deposit, as the name implies, occurs along the coast between deltas and comprises mud flats and cheniers (abandoned beach ridges) of the chenier-plain complex and the barrier-island–lagoon–tidal-channel complex (Fig. 23). It can also occur along the seaward edge of a coastal plain which is drained by numerous small streams and rivers but is devoid of any sizable deltas at the marine shoreline.

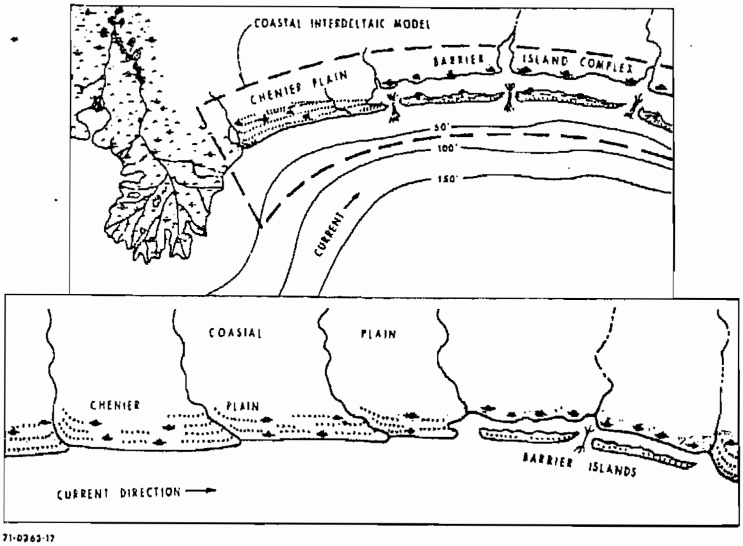


FIG. 23—General setting and characteristics of coastal-interdeltaic model of clastic sedimentation.

Source and Transportation of Sediments

Most of the sediments deposited are derived from land, but minor amounts come from the marine environment. A portion of the sediment transported to the marine shoreline by rivers and smaller streams is dispersed laterally by marine currents for great distances along the coast. Clays and fine silts are carried in suspension, and sand is transported mainly as bed load or by wave action in the beach and nearshore zone. The suspended silt and clay load is dispersed at a rapid rate and is most significant in the development of the mud flats of the chenier plain. Lateral movement of the sand bed load occurs at a relatively slow rate and is most significant in the development of the cheniers and the barrier-island complex.

A minor amount of sediment can also be derived from adjacent continental-shelf areas if erosion occurs in the marine environment.

Sedimentary processes and deposits of chenier plain—Major floods result in the sudden large influx of sediments at river mouths. Much of the suspended load introduced to the coastal-marine environment is rapidly dispersed laterally along the coast by the predominant longshore drift. A considerable portion of this suspended load is deposited along the shoreline (on the delta flank) as extensive mud flats. This period of regressive sedimentation (progradation or offlap) occurs in a relatively short period when rivers are at flood stages (Fig. 24).

During long periods when rivers are not flooding, the supply of sediment to the coast is reduced considerably or is nil. Coastal-marine currents and wave action rework the seaward edge of the newly formed mud flat, and a transgressive situation develops. A slight increase in

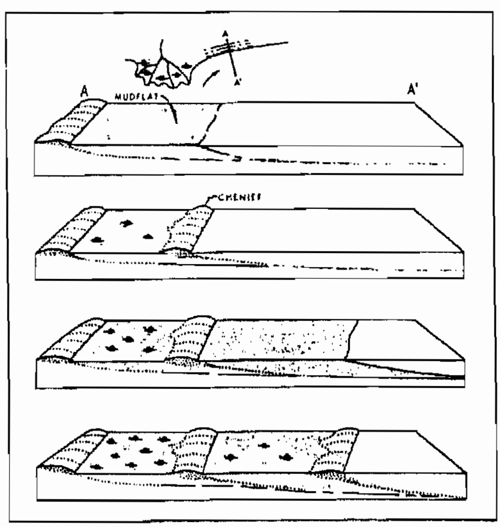


FIG. 24—Stages in development of a chenier plain.

sand supply can result in a regressive situation, and the initial transgressive beach accumulation will grow seaward by regressive beach accretion to form a long, narrow, well-defined chenier on the seaward edge of the extensive mud flat.

Another period of river flooding develops another mud flat on the seaward edge of the chenier. During the subsequent nonflood season, the coastal-transgressive processes produce another beach ridge. Thus, over a long period, a chenier plain consisting of mud flat and beach ridges is constructed.

The width of a mud flat is varied and is dependent on the magnitude and duration of a river flood. The size of the chenier (height and width) is determined by two factors: duration of the nonflood season (absence of muds) and magnitude of coastal-marine processes, including storm tides and waves.

Small streams which drain to the coastline across a chenier plain contribute little sediment to the chenier-plain environment. The mouths of these streams are generally deflected in the direction of the littoral drift.

Sedimentary processes and deposits of barrier-island complex—The typical barrier-island complex comprises three different but related depositional environments: the barrier island, the lagoon behind the barrier, and the tidal channel–tidal deltas between the barriers.

The seaward face of a barrier island is primarily an environment of sand deposition. Coastal-marine energy (currents and wave action) is usually much greater than in the chenier–mud-flat regions. Sediments are transported along the coast in the direction of the predominant littoral drift. Coarser sands are deposited mainly on the beach and upper shoreface, and finer sands are deposited in the lower shoreface areas. Silts and clays are deposited in the lower shoreface zones on the adjacent shelf bottom—at depths greater than 40–50 ft (12–15 m). Storm tides and waves usually construct beach ridges several feet above sea level, depending on the intensity of storms, and also transport sandy sediments across the barrier from the beach zone to the lagoon.

Under ideal conditions, a barrier grows seaward by a beach-shoreface accretion process to produce a typical barrier-island sequence of sediments which grades upward from fine to coarse (Figs. 25, 27). The various organisms which live in the beach, shoreface, and adjacent offshore areas usually have a significant influence on the character of sedimentary structures.

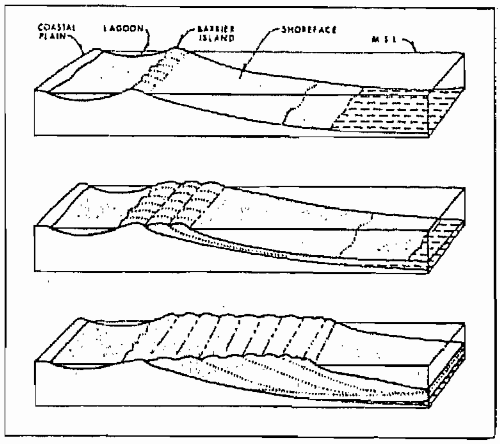
Dry beach sand can be transported inland by the wind and redeposited as dune sand on the barrier, in the lagoon, or on the mainland across the lagoon.

Tidal channel–tidal delta—Tidal action moves a large quantity of water in and out of lagoons and estuaries through the tidal channels which exist between barrier islands. These channels are relatively short and narrow and vary considerably in depth. Maximum channel depths occur where the tidal flow is confined between the ends of barriers. The channel cross section is asymmetric: one side of the channel merges with the tidal flats and spit; the opposite side of the channel has abrupt margins against the barrier (Fig. 26).

As marine waters enter the lagoon or estuary system during rising tides, the inflow attains its maximum velocity in the deepest part of the confined channel. The tidal flow is dispersed as it enters the lagoon, and current velocities are greatly reduced. The result is the deposition of sediment in the form of a tidal delta which consists of a shallow distributary channel separated by sand or silt shoals. Similar tidal deltas are also formed on the marine side of the system by similar processes associated with the falling or outgoing tide.

The depth of tidal channels and the extent of tidal deltas are dependent on the magnitude of the tidal currents. The deepest channels and the largest deltas are associated with large lagoons and estuaries affected by extreme tidal ranges.

Tidal channels migrate laterally in the direction of littoral drift by eroding the barrier head adjacent to the deep side of the channel and by spit and tidal-flat accretion on the opposite side.



71-0343-19

FIG. 25—Stages in development of a barrier island.

Lateral migration of the tidal system results in the deposition of the tidal-channel and tidal-delta sequences of sediments.

Summary: Characteristics of Coastal-Interdeltaic Deposits

The coastal-interdeltaic model of sedimentation is characterized by six distinct but related types of deposits: mud flat, chenier, barrier island, lagoon, tidal channel, and tidal delta. Characteristics of these deposits are summarized in Figure 27.

Three main types of sand bodies are associated with this model: barrier island, chenier, and tidal channel–tidal delta. The barrier-island sand body, which is the largest and most significant of the three, is long (usually tens of miles)and narrow (2–6 mi or 3–10 km), is oriented parallel with the coastline, and attains maximum thicknesses of 50–60 ft (15–18 m). The chenier sand bodies are very similar to those of the barriers; however, they are generally only about a third as thick. Tidal-channel sand bodies are oriented perpendicular to the barrier sands, and their thickness can vary considerably (less than, equal to, or greater than that of the barrier sands), depending on the depth of tidal channels.

Ancient Coastal-Interdeltaic Deposits

Examples of ancient coastal-interdeltaic deposits reported from 13 states are summarized in Table 4.

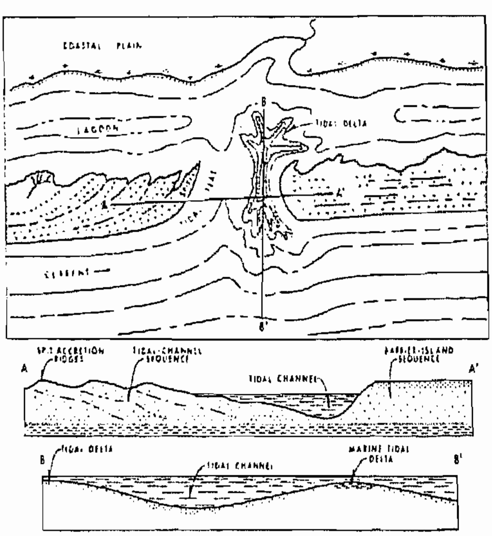


FIG. 26—Relation of tidal channels and tidal deltas to barrier islands.

Table 4. Examples of Ancient Coastal-Interdeltaic Deposits

Geographic Occurrence	*Author*
Colorado	Griffith, 1966
Florida	Gremillion *et al.*, 1964
Georgia	Hails and Hoyt, 1969
	MacNeil, 1950
Illinois	Rusnak, 1957
Louisiana	Sloane, 1958
Louisiana & Arkansas	Thomas and Mann, 1966
	Berg and Davies, 1968
Montana	Cannon, 1966
	Davies *et al.*, 1971
	Shelton, 1965
New Mexico	Sabins, 1963
New York	McCave, 1969
Oklahoma & Kansas	Bass *et al.*, 1937
	Boyd and Dyer, 1966
	Dodge, 1965
Texas	Fisher and McGowen, 1969
	Fisher *et al.*, 1970
	Shelton, 1972
	Harms *et al.*, 1965
	Jacka, 1965
Wyoming	Miller, 1962
	Paull, 1962
	Scruton, 1961
	Weimer, 1961a

EOLIAN MODEL OF SAND DEPOSITION

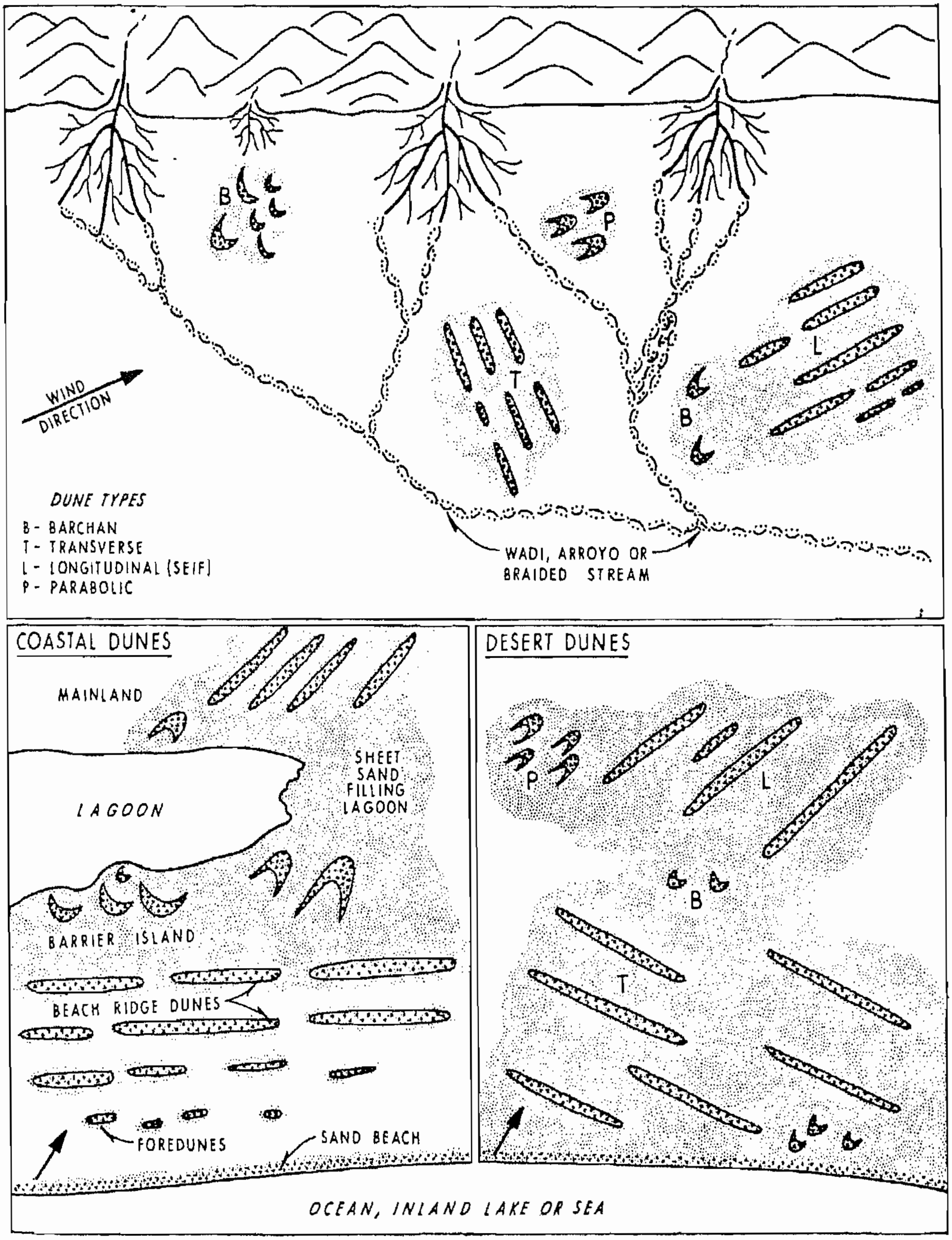
Occurrence and General Characteristics

A very common process of sedimentation is transportation and deposition of sand by the wind. Two basic conditions are necessary for the formation of windblown sand deposits: a large supply of dry sand and a sufficient wind velocity. These conditions are commonly present along coastlines characterized by sandy beaches and also in semiarid regions and deserts, where weathering and fluvial sedimentation produce a large quantitiy of sand (Fig. 28).

Under certain conditions, sands on the downstream parts of alluvial fans and along braided streams are transported and redeposited by the wind (Glennie, 1970). Sands originally deposited on point bars of meandering streams and along distributary channels of some deltas are also picked up by the wind and redeposited locally as dune sand. Similarly, sands deposited along beaches of the coastal-interdeltaic environments are redeposited by onshore winds as sand dunes on barrier islands or on the mainland. Thus, the eolian process of sand deposition is likely to occur within all models of clastic sedimentation discussed in the preceding sections.

Eolian Transport and Sedimentation

The complex processes of sand transport and deposition by the wind were studied and de-



71-0363-22

FIG. 28—Occurrences of eolian sands in coastal and desert regions.

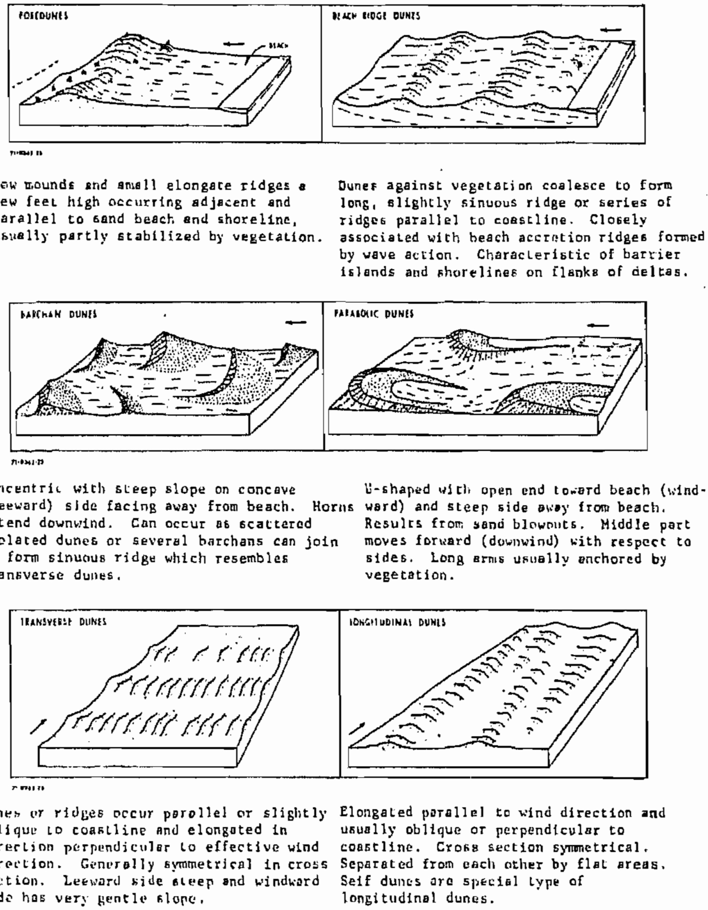


FIG. 29—Some common types of coastal dunes which also occur in deserts.

scribed by Bagnold (1941). Recently, Glennie (1970) summarized this type of sedimentation as observed under desert conditions.

The most common method of sand deposition is in the form of sand dunes. Many types of dunes have been recognized and described by numerous authors (Fig. 29). H. Smith (1954) presented the following classification and description of coastal dunes which can occur either under active or stabilized conditions.

1. Foredune ridges, or elongate mounds of sand up to a few tens of feet in height, adjacent and parallel with beaches.
2. U-shaped dunes, arcuate to hairpin-shaped sand ridges with the open end toward the beach.
3. Barchans, or crescentic dunes, with a steep lee slope on the concave side, which faces away from the beach.
4. Transverse dune ridges, trending parallel with or oblique to the shore, and elongated in a direction essentially perpendicular to the dominant winds. These dunes are asymmetric in cross profile, having a gentle slope on the windward side and a steep slope on the leeward side.
5. Longitudinal dunes, elongated parallel with wind direction and extending perpendicular or oblique to the shoreline; cross profile is typically symmetric.
6. Blowouts, comprising a wide variety of pits, troughs, channels, and chute-shaped forms cutting into or across other types of dunes or sand hills. The larger ones are marked by conspicuous heaps of sand on the landward side, assuming the form of a fan, mound, or ridge, commonly with a slope as steep as 32° facing away from the shore.
7. Attached dunes, comprising accumulations of sand trapped by various types of topographic obstacles.

McKee (1966) described an additional type, the dome-shaped dune, from White Sands National Monument, and Glennie (1970) described the seif dune of Oman, which is a special type of longitudinal dune. Many other dune types have been described; however, the above types appear to be the most common.

Studies of modern eolian sand bodies—Cooper (1958) reviewed the early studies of sand dunes, mainly by Europeans, and summarized the status of dune reseach in North America. Additional sand-dune studies in the United States since 1959 were made in Alaska by Black (1961), on the Texas coast by McBride and Hayes (1962), on the Georgia coast by Land (1964), in the Imperial Valley of California by Norris (1966), in coastal California by Cooper (1967), and in the San Luis Valley of Colorado by R. Johnson (1967). Additional studies outside the United States were made in southern Peru by Finkel (1959), in Baja California by Inman *et al.* (1966), in Libya by McKee and Tibbitts (1964), in Russia by Zenkovich (1967), and in Australia by Folk (1971).

During the past several years, some very important studies on eolian sands, which included detailed observations of internal dune structure and stratification in deep trenches cut through dunes, were made along the Texas coast by McBride and Hayes (1962), in White Sands National Monument by McKee (1966), along the Dutch coast by Jelgersma *et al.* (1970), and in the deserts of the Middle East by Glennie (1970). These authors presented photographs and sketches of various types of sedimentary structures exposed in trench walls and described their relations to dune types, wind regime, and grain-size distribution. These studies have provided some badly needed criteria for recognition of ancient eolian sands. The following summary of the geometry and general characteristics of modern eolian sand bodies was prepared largely from the references cited above.

Summary: Coastal Eolian Sand Bodies

Coastal eolian sand bodies, consisting of several types of dunes, are very long and quite narrow; they range in thickness from a few feet to a few hundreds of feet, and are aligned parallel with or oblique to the coastline. Because these sands are derived from beach deposits and form in vegetated areas, they commonly contain fragments of both shells and plants. They are characterized by high-angle crossbedding and are usually well sorted. The adjacent and laterally equivalent beach deposits are generally horizontally bedded and have some low-angle crossbedding.

Summary: Eolian Sand Bodies of Desert Regions

Desert eolian sand bodies differ from coastal eolian sands mainly in their distribution. The internal sedimentary structures and their relations to dune types are similar (Bigarella *et al.*, 1969). Seif dunes are products of two wind directions and appear to occur more commonly in desert areas. These dunes are characterized by high-angle crossbedding in two directions.

Ancient Eolian Deposits

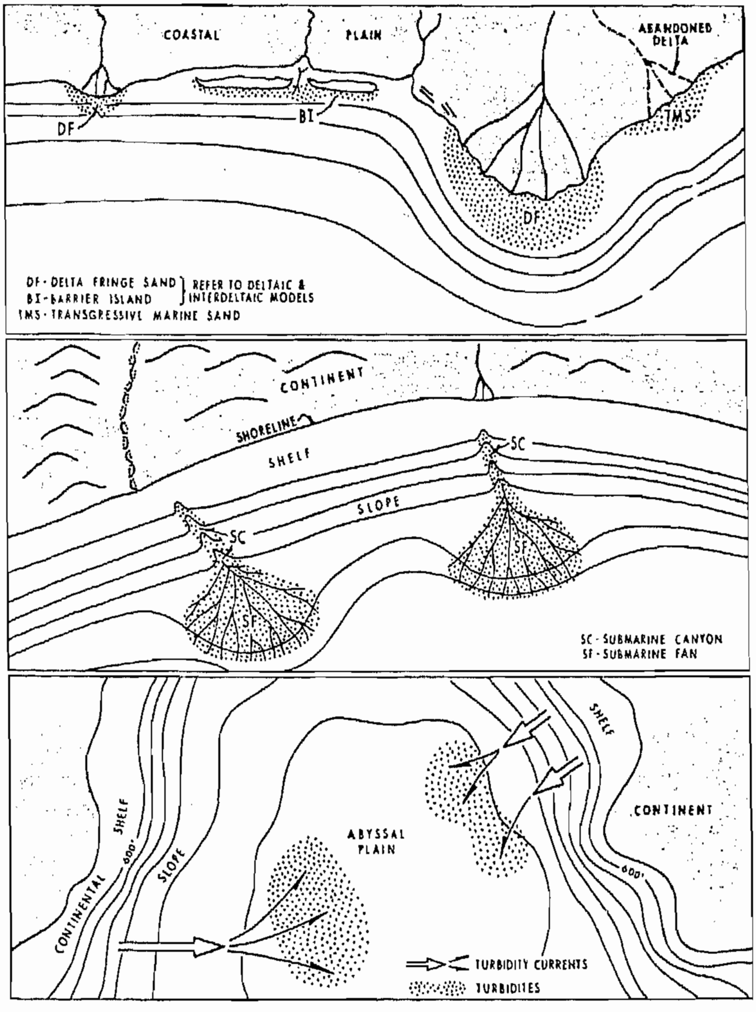
Ancient eolian deposits have been reported from the Colorado Plateau by Baars (1961) and Stokes (1961, 1964, 1968), from the southwestern United States by McKee (1934), from England by Laming (1966), and from Brazil and Uruguay by Bigarella and Salamuni (1961). Criteria for recognition of eolian deposits have been summarized by Bigarella (1972).

Marine Clastic Sedimentation

Transportation and deposition of sand in the marine environment occur under a wide range of geologic and hydrologic conditions, ranging from those of the coastal shallow-marine environments to the deeper water environments of the outer continental shelves, the slopes, and the abyssal plains (Fig. 30).

As indicated in the Introduction, sands deposited under regressive (progradational) conditions within the coastal shallow-marine environments are considered herein as products of either the coastal-interdeltaic or the deltaic model of sedimentation. Other important shallow-marine sand bodies are produced as a result of marine transgressions.

During the past several years, studies made principally by the major oceanographic institutions on the modern deep-marine environments and research by petroleum geologists, university professors, and graduate students on ancient clastic sediments of various geologic ages have revealed that sand bodies of deep-marine origin are rather common throughout the world. Although most geologists now accept the fact that some sands are of deep-marine origin, our understanding of the various geologic processes which produce these sand bodies is relatively poor. The writer's personal experience with this type of clastic sedimentation is limited; however, on the basis of familiarity with the literature on marine sediments, it appears that most deep-marine sands are depos-



71-0363-71

FIG. 30—Deposition of sand in marine environments.

ited under three principal types of environmental conditions: (1) on the outer shelf, the slope, and the continental rise, as a result of slumping, sliding, and tectonic activity such as earthquakes; (2) in abyssal plains, by density (turbidity) and bottom currents; and (3) in submarine canyons, fan valleys, and fans, by both bottom and density currents.

Only two of these several types of marine sands are discussed in this paper: (1) the shallow-marine sands deposited as a result of trangressive-marine sedimentation associated with the shifting of deltas and (2) the deep-marine sands deposited in submarine canyons, fan valleys, and fans.

Transgressive-Marine Model of Clastic Sedimentation

Setting and general characteristics—Deposition of clastic sediments during periods of marine transgressions (onlap) is a common process of sedimentation in most basins. There are two basic types of marine transgression: that which is associated with the shifting of deltas as a result of major river diversions during a period of standing sea level, and that which occurs as a result of a relative rise in sea level (due to subsidence of a coastal plain or eustatic rise in sea level). The inland and lateral extents of marine transgressions resulting from delta shifts are limited in size, depending on the dimensions of the abandoned deltaic plains. Marine transgressions resulting from relative changes in sea level extend over much broader regions and are commonly referred to as regional transgressions. Their dimensions are governed mainly by the topography of the coastal plain being transgressed and by the amount of relative rise in sea level. Thus, transgressive-marine deposition can occur locally over abandoned deltas or regionally over eolian, alluvial, interdeltaic, and deltaic deposits of a large part of a coastal plain.

Modern marine transgressions resulting from major changes in drainage and delta shifts have been described by several authors: Russell, 1936; Russell and Russell, 1939; Kruit, 1955; van Straaten, 1959; Scruton, 1960; Curray, 1964; Coleman and Gagliano, 1964; Rainwater, 1964; Coleman, 1966b; Scott and Fisher, 1969; L. Brown, 1969; and Oomkens, 1970.

Sources, transportation, and deposition of sediments—After a delta is abandoned because of upstream channel diversion, a very significant change occurs in conditions of sedimentation. The abandoned deltaic plain and subaqueous delta front no longer receive sediment and gradually subside owing to the compaction of the deltaic deposits. The seaward edge of the abandoned delta is attacked by marine wave and current action and recedes landward at relatively slow rates. As marine processes erode the upper part of the deltaic sequence, the sandy sediments within the sequence are winnowed and deposited along the advancing shoreline as barrier islands, beaches, and shallow-marine sands; finer sediments are deposited farther offshore. Thus, the transgressive-marine depositional profile is characterized by sands and shell material nearshore and by progressively finer sediments offshore. Over a period of time, as the transgression proceeds inland, the thin veneer of shallow-marine sands which are deposited over the underlying delta sediments is in turn overlain by marine silts and clays. Stages in the development of such a trangressive-marine sand body are illustrated in Figure 31.

Character of sediments—This type of sedimentation, although largely restricted in extent to abandoned deltas and adjacent and laterally

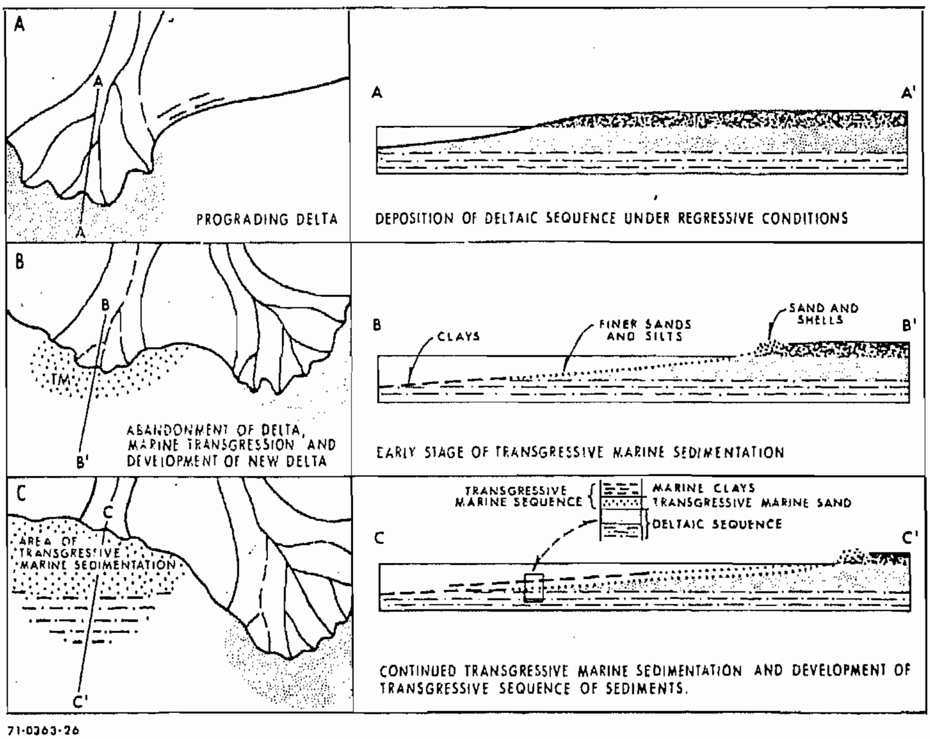


FIG. 31—Transgressive-marine sedimentation resulting from delta shifts.

equivalent interdeltaic and offshore-marine environments, is significant because it produces very diagnostic blanketlike layers of marine sediments (thin shallow-marine sand overlain by clays) which separate the individual deltaic units (Fig. 31). These layers usually provide the only good correlations within thick deltaic facies, and the marine shales act as impervious seals between deltaic sand bodies. The transgressive-marine sands containing calcareous shell material usually become cemented and thus do not form very efficient reservoirs.

Submarine Canyon-Fan Model of Clastic Sedimentation

Occurrence and general characteristics—The occurrence of modern and Pleistocene sands in deep-marine environments of the world is well documented as a result of numerous deep-sea investigations by oceanographic institutions during the past 20 years. Although there is much controversy regarding the origin of these sands, it is certain that such sands do exist. An analysis of the literature reveals that some of the most common deep-sea sands are those associated with submarine canyons and fans. (For a discussion of types of submarine canyons, troughs, and valleys, the reader is referred to Shepard and Dill, 1966.)

Submarine canyons and fans are common features associated with continental shelves, slopes, and rises. The canyons and fans off the Pacific Coast of the United States and Canada have received the most attention. Significant papers on these features off the coasts of Washington, Oregon, California, and Baja California, and off the Gulf and Atlantic coasts, are listed in the selected references. Also included are references to papers on canyons and fans in the Mediterranean, the Atlantic Ocean off Africa, and the Indian Ocean off Pakistan.

Characteristics and origin of submarine canyons have been discussed by numerous authors (for summary, see Shepard and Dill, 1966). Although it is still uncertain how some deep-sea canyons and valleys originated, it is now reasonably well established that a large number of canyons and fans are related to rivers, and that they were formed during stages of low sea level of the Quaternary Period (Figs. 32, 33). For

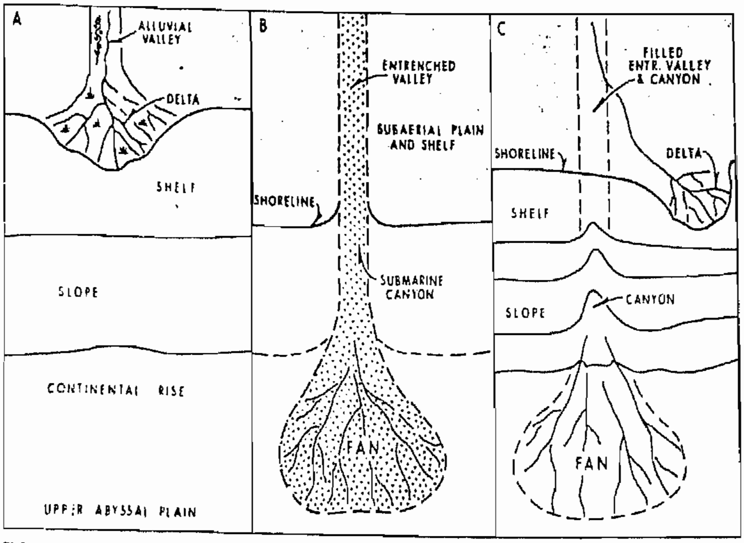


FIG. 32—Stages in development of submarine canyon and fan.

Stage A: Standing sea-level situation. Development of alluvial valley and delta and deposition of marine clays on shelf and slope. Base of aggrading river is well below sea level.

Stage B: Falling and low-sea-level situation. Development of entrenched-valley system on coastal plain and of submarine canyon offshore. Bases of entrenched valley (near coast) and of canyon are well below sea level. Rates of sedimentation are very high. Material removed by canyon-cutting and sediments flowing through canyon while it formed are deposited as extensive submarine fan.

Stage C: Rising and standing sea-level situation. Alluviation of entrenched-valley system and partial filling of canyon. Rates of sedimentation are greatly reduced after sea level reaches a stand. Slight modification of fan by normal-marine processes occurs.

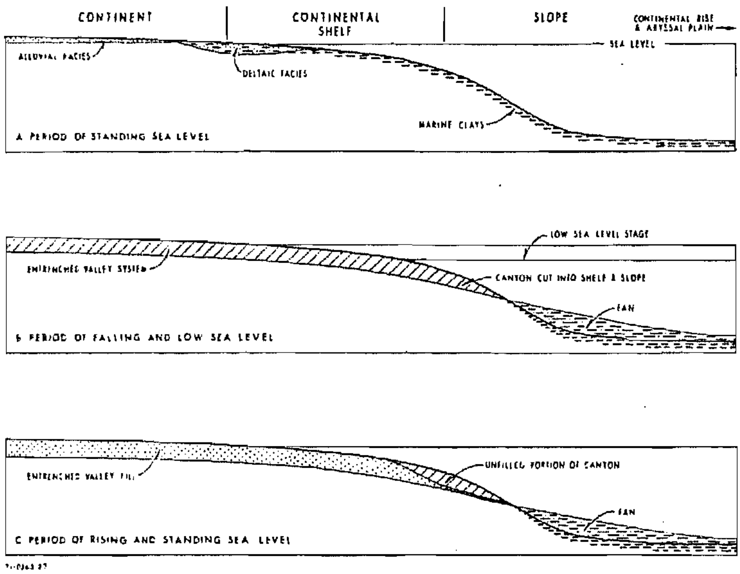


FIG. 33—Relation of submarine-fan deposits to submarine-canyon and entrenched-valley system.

example, the Mississippi Canyon off southern Louisiana is a continuation of the late Pleistocene Mississippi entrenched valley system (Fisk, 1944; Osterhoudt, 1946; Fish and McFarlan, 1955; and Bergantino, 1971). Also, the Astoria canyon and fan off Oregon are related to the Columbia River (Duncan and Kulm, 1970); the Newport Canyon is related to the Santa Ana River of California (Felix and Gorsline, 1971); the Congo Canyon connects with the Congo River (Heezen *et al.*, 1964); the Monterey and Soquel canyons and fans occur off the Great Valley of California (Martin and Emery, 1967); the Bengal deep-sea fan and the "Swatch-of-No-Ground" canyon occur off the Ganges River delta (Curray and Moore, 1971); and the Inguri canyon is related to a river flowing in the Caspian Sea (Trimonis and Shimkus, 1970). The *National Geographic* magazine maps of the Indian and Atlantic Ocean floors (Heezen and Tharp, 1967, 1969) show large fans off the Indus and Amazon Rivers and also off the Laurentian Trough, and the Hudson Canyon is associated with the Hudson River. Seismic reflection surveys between canyon heads (on shelves) and the coastline most probably will reveal more examples of canyons related to entrenched river valleys on land.

There is an extremely wide variation in the size of submarine canyon-fan systems. Some of the small ones off California studied by Gorsline and Emery (1959) include short canyons 5–10 mi (8–16 km) long and fan areas of about 50 sq mi (130 sq km). The largest canyon-fan systems studied thus far are those of the Congo, Ganges, and Rhône Rivers. The Bengal fan is 2,600 km long and 1,100 km wide; the Congo fan is more than 520 km long and 185 km wide; and one of the largest fans off the Pacific coast of the United States, the Delgade fan, is 300 km long and 330 km wide (Normark, 1970). Menard (1960) discussed the dimensions of several other fans.

Some very significant studies of deep-sea sands associated with canyons and fans—based on core, seismic reflection, and bathymetric data, and bottom observations and photography by divers—have been made during the past 3 years (Winterer *et al.*, 1968; Carlson and Nelson, 1969; Shepard *et al.*, 1969; Curray and Moore, 1971; Normark, 1970; Nelson *et al.*, 1970; Piper, 1970; Duncan and Kulm, 1970; and Felix and Gorsline, 1971).

Physiographic features.—Detailed bathymetric surveys over several canyons and fans of various sizes have revealed that these submarine features are characterized by physiographic features very similar to those of subaerial alluvial fans. The canyons are V-shaped and have steep walls and gradients. The surfaces of the fans are characterized by lower gradient distributary channels with natural levees and by topographically low interchannel areas. Some fans are crossed by relatively large fan valleys

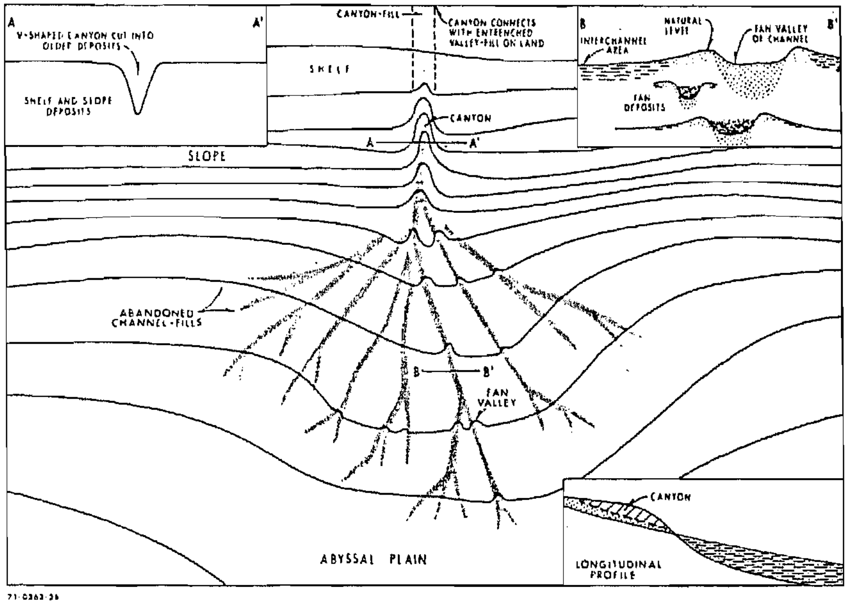


FIG. 34—Submarine-canyon and fan model of clastic sedimentation.

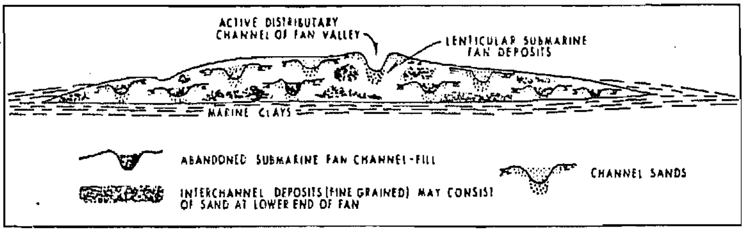
which also have natural levees. The principal physiographic features of a typical canyon and fan are illustrated in a generalized fashion in Figure 34.

The overall shape of a submarine fan can either be symmetrical or asymmetrical, depending on strong current directions and on the presence of high topographic features on the abyssal plains. Sizes of the distributary channels and natural levees are widely varied; the larger channels usually have the highest and broadest natural levees. The lower parts of fans merge with the abyssal plains. Channels on fan surfaces were probably formed by depositional processes. Erosional channels that have been reported probably represent an entrenchment stage, as is the case with subaerial alluvial fans.

Many canyons were cut across continental shelves and slopes, and the fans were constructed at the base of the slopes or on the continental rises. Some canyons presently do not extend landward across the continental shelves (*e.g.*, the Mississippi Canyon) because they have been filled with sediments. Seismic surveys reveal that this type of canyon was once connected with inland entrenched valley systems.

Longitudinal profiles of canyons and fans are concave upward. The steepest gradients occur in the upper (landward) portions of canyons, and the lowest gradients occur on the outer or lower portions of fans.

Depositional processes and character of sediments—It is absolutely certain that large quantities of sediment, including a significant amount of sand, have been transported through submarine canyons and deposited as submarine fans in deep-sea environments. The manner in which these sediments were transported, especially the sands, is much less certain. Nearly 2 decades ago, some very strong statements were made by oceanographers regarding the turbidity-current origin of both the canyons and the fan deposits. Although no one had actually seen or measured a turbidity current in a canyon or over a submarine fan, the turbidity-current concept was very popular with most oceanographers during the early 1950s. During the past 20 years, numerous additional observations have been made, but no one has yet seen a live turbidity current in a natural marine environment. On the basis of direct observations of the ocean bottom and sedimentary structures in cores, many oceanographers now believe that some submarine-fan sand deposits were transported mainly by normal bottom currents, especially during low stages of sea level of the Pleistocene. A typical example is the origin of the sand associated with the Mississippi cone in



71-0343-29

FIG. 35—Generalized distribution of submarine-fan deposits.

the Gulf of Mexico off southern Louisiana. Greenman and LeBlanc (1956) did not consider these sands to be of turbidity-current origin, but Ewing *et al.* (1958) were certain that the sands were transported and deposited by turbidity currents. Twelve years later, Huang and Goodell (1970) concluded, on the basis of detailed studies of sedimentary structures observed in numerous cores, that the sands are not of turbidity-current origin, but that the mechanisms of transport are bottom currents, differential pelagic settling, and mass movement by sliding and slumping. Walker and Massingill (1970) reported that part of the Mississippi cone sediments were recently involved in large-scale slumps. They presented evidence that one slump moved from near the mouth of the Mississippi Canyon southeastward for at least 160 n. mi. Thus, the origin of these deep-sea sands and many others remains a problem.

Regardless of the mechanisms of sediment transport through submarine canyons and of deposition of fans, the general nature and distribution of fan deposits have been determined for several fans. The coarsest and most poorly sorted sediments occur in canyons. Sands are common in distributary channels and fan valleys and on the lower parts of the open fan. Sandy sediments also occur on natural levees, but the interchannel areas are characterized by fine-grained sediments (Fig. 35). Core data from several fans indicate that sand bodies are usually thin and very lenticular, and are interbedded with fine-grained sediments.

For details concerning the sedimentary structures which characterize submarine-canyon and fan deposits, the reader is referred to Carlson and Nelson (1969); Shepard *et al.* (1969); Stanley (1969); Huang and Goodell (1970); and Haner (1971).

Horn *et al.* (1971) described the characteristics of sediments related to submarine canyons, fans, and adjacent abyssal plains of the northeast Pacific Ocean off Alaska, Canada, Washington, Oregon, and northern California. They interpreted sediments with a wide range in layer thickness, with graded and nongraded layers, and with sand in the basal parts of graded units to be proximal turbidites related to main routes followed by turbidity currents (probably channels). The finer grained sediments, mainly graded silts and clays, were interpreted as distal turbidites deposited beyond the main avenues of turbidite flows.

It is the opinion of the writer that many of the submarine canyons and related fans which now are found off rivers are the products of entrenchment (canyons) and deposition (fans) during stages of low sea level of the Pleistocene. Oceanographers who have studied several of these fan deposits have concluded that they are of Miocene to Pleistocene age. The geologic-age determinations were made on the basis of present sediment load of the related rivers and known thickness of fan deposits. This writer suggests that rates of sedimentation were probably several times greater during Pleistocene low-sea-level stages than at the present time (period of higher and standing sea level) and, consequently, that the fan deposits are probably chiefly of Pleistocene age.

Ancient examples of submarine canyon and fan deposits—Some examples of ancient deposits of submarine canyon and fan origin have been described from the Gulf coast by Osterhoudt (1946), Bornhauser (1948, 1960), Hoyt (1959), Paine (1966), and Sabate (1968); from California by Sullwold (1960), Martin (1963), Bartow (1966), Dickas and Payne (1967), Normark and Piper (1969), Piper and Normark (1971), Davis (1971), Fischer (1971), and Shelton (1972); from Canada by Hubert *et al.* (1970); from Europe by Walker (1966), Stanley (1967, 1969), and Kelling and Woollands (1969); and from Australia by Conolly (1968).

Selected References

Al-Habeeb, K. H., 1970, Sedimentology of the flood-plain sediments of the middle Euphrates River, Iraq: Baghdad Univ., MS thesis.

Allen, J. R. L., 1962, Petrology, origin, and deposition of the highest lower Old Red Sandstone of Shropshire, England: Jour. Sed. Petrology, v. 32, p. 657–697.

——— 1964, Studies in fluviatile sedimentation: six cyclothems from the lower Old Red Sandstones, Anglo-Welsh basin: Sedimentology, v. 3, p. 163–198.

——— 1965a, A review of the origin and characteristics of Recent alluvial sediments: Sedimentology, v. 5, p. 89–191.

——— 1965b, Coastal geomorphology of eastern Nigeria: beach-ridge barrier-islands and vegetated tidal flats: Geologie en Mijnbouw, v. 44, p. 1–21.

——— 1965c, Late Quaternary Niger delta and adjacent areas: sedimentary environments and lithofacies: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 5, p. 547–600.

——— 1970, Sediments of the modern Niger delta, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 138–151.

American Petroleum Institute, 1971: Petroleum facts and figures.

Anderson, G. S., and K. M. Hussey, 1962, Alluvial fan development at Franklin Bluff, Alaska: Iowa Acad. Sci. Proc., v. 69, p. 310–322.

Andrews, P. B., 1970, Facies and genesis of a hurricane washover fan, St. Joseph Island, central Texas: Texas Univ. Bur. Econ. Geology Rept. Inv. 67, 147 p.

Anstey, R. L., 1965, Physical characteristics of alluvial fans: U.S. Army Quartermaster Research and Eng. Command, Earth Sci. Div. Tech. Rept. ES-20, 109 p.

Arnborg, L. E., 1948, The delta of the Angerman River: Geog. Annaler, v. 30, p. 673–690.

Asseez, L. O., 1969, Paleogeography of Lower Mississippian rocks of Michigan basin: Am. Assoc. Petroleum Geologists Bull., v. 53, no. 1, p. 127–135.

Attia, M. I., 1954, Deposits in the Nile Valley and the delta: Cairo, Egypt Geol. Survey, 356 p.

Axelson, V., 1967, The Laitaure delta, a study of deltaic morphology and processes: Geog. Annaler, v. 49, p. 1–127.

Baars, D. L., 1961, Permian blanket sandstones of Colorado Plateau, *in* J. A. Peterson and J. C. Osmond, eds., Geometry of sandstone bodies: Am. Assoc. Petroleum Geologists, p. 179–219.

Bagchi, K., 1944, The Ganges delta: Calcutta, Calcutta Univ. Press, 157 p.

Bagnold, R. A., 1941, The physics of blown sand and desert dunes: New York, W. Morrow and Co., 265 p.

Bakker, W. T. J. N. P., and T. Edelman, 1965, The coast line of river-deltas: 9th Conf. on Coastal Engineering Proc., p. 199–218.

Barlow, J. A., Jr., and J. D. Haun, 1966, Regional stratigraphy of Frontier Formation and relation to Salt Creek field, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 2185–2196.

Bartow, J. A., 1966, Deep submarine channel in upper Miocene, Orange County, California: Jour. Sed. Petrology, v. 36, no. 3, p. 700–705.

Bass, N. W., *et al.*, 1937, Origin and distribution of Bartlesville and Burbank shoestring oil sands in parts of Oklahoma and Kansas: Am. Assoc. Petroleum Geologists Bull., v. 21, p. 30–66.

Bates, C. C., 1953, Rational theory of delta formation: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2119–2162.

Beall, A. O., Jr., 1968, Sedimentary processes operative along the western Louisiana shoreline: Jour. Sed. Petrology, v. 38, p. 869–877.

Beaty, C. B., 1961, Boulder deposit in Flint Creek Valley, western Montana: Geol. Soc. America Bull., v. 72, p. 1015–1020.

——— 1963, Origin of alluvial fans, White Mountains, California and Nevada: Assoc. Am. Geographers Annals, v. 53, p. 516–535.

Beerbower, J. R., 1961, Origin of cyclothems of the Dunkard Group (Upper Pennsylvanian-Lower Permian) in Pennsylvania, West Virginia, and Ohio: Geol. Soc. America Bull., v. 72, p. 1029–1050.

——— 1964, Cyclothems and cyclic depositional mechanisms in alluvial plain sedimentation: Kansas Geol. Survey Bull. 169, v. 1, p. 31–42.

——— 1969, Interpretation of cyclic Permo-Carboniferous deposition in alluvial plain sediments in West Virginia: Geol. Soc. America Bull., v. 80, p. 1843–1848.

Berg, R. R., 1968, Point bar origin of Fall River sandstone reservoirs, northeastern Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 52, no. 11, p. 2116–2122.

——— and B. C. Cook, 1968, Petrography and origin of lower Tuscaloosa sandstones, Mallalieu field, Lincoln County, Mississippi: Gulf Coast Assoc. Geol. Socs. Trans., v. 18, p. 242–255.

——— and D. K. Davies, 1968, Origin of Lower Cretaceous Muddy Sandstone at Bell Creek field, Montana: Am. Assoc. Petroleum Geologists Bull., v. 52, no. 10, p. 1888–1898.

Bergantino, R. N., 1971, Submarine regional geomorphology of the Gulf of Mexico: Geol. Soc. America Bull., v. 82, p. 741–752.

Bernard, H. A., 1965, A resume of river delta types: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 334–335.

——— and R. J. LeBlanc, 1965, Resume of Quaternary geology of the northwestern Gulf of Mexico province, *in* Quaternary of the United States, Review volume for 7th Cong., Internat. Assoc. for Quaternary Research: Princeton, New Jersey, Princeton Univ. Press, p. 137–185.

——— and C. F. Major, 1963, Recent meander belt deposits of the Brazos River: an alluvial "sand" model: Am. Assoc. Petroleum Geologists Bull., v. 47, no. 2, p. 350.

——— R. J. LeBlanc, and C. F. Major, 1962, Recent and Pleistocene geology of southeast Texas, *in* Geology of the Gulf Coast and central Texas and guidebook of excursions, Geol. Soc. America 1962 Ann. Mtg.: Houston Geol. Soc., p. 175–224.

——— C. F. Major, and B. S. Parrott, 1959, The Galveston barrier island and environs—a model for predicting reservoir occurrence and trend: Gulf Coast Assoc. Geol. Socs. Trans., v. 9, p. 221–224.

——— *et al.*, 1970, Recent sediments of southeast Texas; a field guide to the Brazos alluvial and deltaic plains and the Galveston barrier island complex: Texas Univ. Bur. Econ. Geology Guidebook No. 11.

Beutner, E. C., *et al.*, 1967, Bedding geometry in a Pennsylvanian channel sandstone: Geol. Soc. America Bull., v. 78, no. 7, p. 911–916.

Bigarella, J. J., 1972, Eolian deposits—their characteristics, recognition, and importance, *in* J. K. Rigby and W. K. Hamblin, eds., Recognition of ancient

sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.
——— and R. Salamuni, 1961, Early Mesozoic wind patterns as suggested by dune bedding in the Botucatu Sandstone of Brazil and Uruguay: Geol. Soc. America Bull., v. 72, p. 1089–1106.
——— *et al.*, 1969, Coastal dune structure from Parana, Brazil: Marine Geology, v. 7, p. 5–55.
Bird, E. C. F., 1961, The coastal barriers of East Gippsland, Australia: Jour. Geology, v. 127, p. 460–468.
——— 1962, The river deltas of the Gippsland lakes: Royal Soc. Victoria Proc., v. 75, pt. 1, p. 65–74.
Black, R. F., 1961, Eolian deposits of Alaska: Arctic, v. 4, no. 2, p. 89–111.
Blackwelder, E., 1928, Mudflow as a geologic agent in semi-arid mountains: Geol. Soc. America Bull., v. 39, p. 465–483.
——— 1931, Desert plains: Jour. Geology, v. 39, p. 133–140.
Blissenbach, E., 1952, Relation of surface angle distribution to particle size distribution on alluvial fans: Jour. Sed. Petrology, v. 22, p. 25–28.
——— 1954, Geology of alluvial fans in semi-arid regions: Geol. Soc. America Bull., v. 65, p. 175–189.
Bluck, B. J., 1964, Sedimentation of an alluvial fan in southern Nevada: Jour. Sed. Petrology, v. 34, no. 2, p. 395–400.
——— 1965, The sedimentary history of some Triassic conglomerates in The Vale of Glamorgan, South Wales: Sedimentology, v. 4, p. 225–246.
——— 1967, Deposition of some upper Old Red Sandstone conglomerates in the Clyde area: a study in the significance of bedding: Scottish Jour. Geology, v. 3, no. 8, pt. 2, p. 139–167.
Boggs, S., Jr., 1966, Petrology of Minturn Formation, east-central Eagle County, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 7, p. 1399–1422.
Bolyard, D. W., 1959, Pennsylvanian and Permian stratigraphy in Sangre De Cristo Mountains between La Veta Pass and Westcliffe, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 1896–1939.
Bonham-Carter, G. F., and A. J. Sutherland, 1967, Diffusion and settling of sediments at river mouths: a computer simulation model: Gulf Coast Assoc. Geol. Socs. Trans., v. 17, p. 326–338.
Boothroyd, J. C., 1970, Recent braided stream sedimentation, south-central Alaska (abs.): Am. Assoc. Petroleum Geologists Bull., v. 54, no. 5, p. 836.
Bornhauser, M., 1948, Possible ancient submarine canyon in southwestern Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 2287–2290.
——— 1960, Depositional and structural history of northwest Hartburg field, Newton County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 44, p. 458–470.
Bouma, A. H., 1965, Sedimentary characteristics of samples collected from some submarine canyons: Marine Geology, v. 3, no. 4, p. 291–320.
Boyd, D. R., and B. F. Dyer, 1966, Frio barrier bar system of south Texas: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 170–178.
Brady, L. L., 1969, Stratigraphy and petrology of the Morrison Formation (Jurassic) of the Canon City, Colorado area: Jour. Sed. Petrology, v. 39, no. 2, p. 632–648.
Bretz, J. H., and L. Horberg, 1949, The Ogallala Formation west of the Llano Estacado: Jour. Geology, v. 57, no. 5, p. 477–490.
Brice, J. C., 1964, Channel pattern and terraces of the Loup Rivers in Nebraska: U.S. Geol. Survey Prof. Paper 422-D, 41 p.
Brickman, R., and L. J. Pons, 1968, A pedo-geomorphological classification and map of the Holocene sediments in the coastal plain of the three Guianas: Wageningen, Netherlands, Soil Survey Institute, 40 p.
Brown, L. F., Jr., 1969, North Texas (eastern shelf) Pennsylvanian delta systems, *in* Delta systems in exploration for oil and gas: Texas Univ. Bur. Econ. Geology, p. 40–53.
Brown, S. L., 1967, Stratigraphy and depositional environment of the Elgin Sandstone (Pennsylvanian) in south-central Kansas: Kansas Geol. Survey Bull. 187, pt. 3, 9 p.
Buffington, E. C., 1952, Submarine "natural levees": Jour. Geology, v. 60, p. 473–479.
Bull, W. B., 1960, Types of deposition on alluvial fans in western Fresno County, California (abs.): Geol. Soc. America Bull., v. 71, p. 2052.
——— 1962, Relation of textural (cm) patterns to depositional environment of alluvial fan deposits: Jour. Sed. Petrology, v. 32, p. 211–216.
——— 1963, Alluvial fan deposits in western Fresno County, California: Jour. Geology, v. 71, p. 243–251.
——— 1964, Geomorphology of segmented alluvial fans in western Fresno County, California: U.S. Geol. Survey Prof. Paper 352-E, p. 59–129.
——— 1968, Alluvial fans: Jour. Geol. Education, v. 16, p. 101–106.
——— 1969, Recognition of alluvial-fan environments in stratigraphic record (abs.): Am. Assoc. Petroleum Geologists Bull., v. 53, p. 710.
——— 1972, Recognition of alluvial-fan deposits in the stratigraphic record, *in* J. K. Rigby and W. K. Hamblin, eds., Recognition of ancient sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.
Busch, D. A., 1953, The significance of deltas in subsurface exploration: Tulsa Geol. Soc. Digest, v. 21, p. 71–80.
——— 1971, Genetic units in delta prospecting: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 1137–1154.
Buttner, P. J. R., 1968, Proximal continental rhythmic sequences in the Genesee Group (lower Upper Devonian): Geol. Soc. America Spec. Paper 106, p. 109–126.
Byers, P. R., 1966, Mineralogy and origin of the Eastend and Whitemud Formations of south-central and southwestern Saskatchewan and southeastern Alberta: Kingston, Ontario, Queen's University, Master's thesis.
Byrne, J. V., *et al.*, 1959, The chenier plain and its stratigraphy, southwestern Louisiana: Gulf Coast Assoc. Geol. Socs. Trans., v. 9, p. 237–260.
Cadwell, D. H., and J. H. Moss, 1969, Floodplain sediments and their movement during a high discharge, near Manheim, Pennsylvania: Pennsylvania Acad. Sci. Proc., v. 43, p. 185–186.
Cannon, J. L., 1966, Outcrop examination and interpretation of paleocurrent patterns of the Blackleaf Formation near Great Falls, Montana: Billings Geol. Soc. 17th Field Conf. Guidebook, p. 71–111.
Carlson, P. R., and C. H. Nelson, 1969, Sediments and sedimentary structures of the Astoria submarine canyon-fan system, northeast Pacific: Jour. Sed. Petrology, v. 39, p. 1269–1282.
Carrigy, M. A., 1971, Deltaic sedimentation in Atha-

basca tar sands: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 1155–1169.

Casey, S. R., and R. B. Cantrell, 1941, Davis sand lens, Hardin field, Liberty County, Texas, *in* A. I. Levorsen, ed., Stratigraphic type oil fields: Am. Assoc. Petroleum Geologists, p. 564–599.

Cavaroc, V. V., 1969, Delineation of some outer deltaic plain subenvironments based on sedimentary properties in vertical section (abs.): Am. Assoc. Petroleum Geologists Bull., v. 53, no. 3, p. 710–711.

Challinor, J., 1946, Two contrasted types of alluvial deposits: Geol. Mag., v. 83, p. 162–164.

Chamberlin, T. K., 1964, Mass transport of sediment in the heads of Scripps submarine canyon, California, *in* R. L. Miller, ed., Papers in marine geology: New York, The Macmillan Co., p. 42–64.

Chawner, W. D., 1935, Alluvial fan flooding: the Montrose, California flood of 1934: Geog. Rev., v. 25, p. 255–263.

Chein, C., 1961, The braided river of the lower Yellow River: Sci. Sinica, v. 10, no. 6, p. 734–754.

Clark, R. H., and J. T. Rouse, 1971, A closed system for generation and entrapment of hydrocarbons in Cenozoic deltas, Louisiana Gulf Coast: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 1170–1178.

Coastal Research Group, 1969, Field trip guidebook, coastal environments of northeastern Massachusetts and New Hampshire: Massachusetts Univ. Geol. Dept. Contr. 1-CRG, 462 p.

Coleman, J. M., 1966a, Ecological changes in the massive fresh-water clay sequence: Gulf Coast Assoc. Geol. Socs. Trans., v. 16, p. 159–174.

——— 1966b, Recent coastal sedimentation: central Louisiana coast: Louisiana State Univ. Coastal Studies Inst. Tech. Rept. 29, p. 1–73.

——— 1969, Brahmaputra River: channel processes and sedimentation: Sed. Geology, v. 3, no. 2–3, p. 129–239.

——— and S. M. Gagliano, 1964, Cyclic sedimentation in the Mississippi River deltaic plain: Louisiana State Univ. Coastal Studies Inst. Tech. Rept. 16, pt. G; also in Gulf Coast Assoc. Geol. Socs. Trans., v. 14.

——— and ——— 1965, Sedimentary structures: Mississippi River deltaic plain, *in* Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, p. 133–148.

——— *et al.*, 1964, Minor sedimentary structures in a prograding distributary: Marine Geology, v. 1, p. 240–258.

——— *et al.*, 1970, Sedimentation in a Malaysian high tide tropical delta, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 185–197.

Collinson, J. D., 1968, Deltaic sedimentation units in the Upper Carboniferous of northern England: Sedimentology, v. 10. no. 4, p. 233–254.

——— 1968, The sedimentology of the Grindslow shales and the Kinderscant grit: a deltaic complex in the Namurian of northern England: Jour. Sed. Petrology, v. 39, no. 1, p. 194–221.

Conolly, J. R., 1965, Petrology and origin of the Hervey Group, Upper Devonian, central New South Wales: Geology Soc. Australia Jour., v. 12, pt. 1, p. 123–166.

——— 1968, Submarine canyons of the continental margin, East Bass Strait (Australia): Marine Geology, v. 6, p. 449–461.

——— and W. J. Cleary, 1971, Braided deep sea deltas and the origin of turbidite sands (abs.): Am. Geophys. Union Trans., v. 52, p. 244.

Cooper, W. S., 1958, Coastal sand dunes of Oregon and Washington: Geol. Soc. America Mem. 72, p. 1–169.

——— 1967, Coastal dunes of California: Geol. Soc. America Mem. 104, 131 p.

Corbeille, R. L., 1962, New Orleans barrier island, New Orleans area: Gulf Coast Assoc. Geol. Socs. Trans., v. 12, p. 223–229.

Credner, G. R., 1878, The deltas: Petermanns Geog. Mitt., v. 56, 74 p. (in German).

Cressey, C. B., 1928, The Indiana sand dunes and shorelines of the Lake Michigan basin: Geol. Soc. Chicago Bull. 8, p. 37.

Crickmay, C. H., 1955, Delta formation: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 107–114.

——— 1960, Lateral activity in a river of northwestern Canada: Jour. Geology, v. 68, p. 377–391.

Croft, A., 1962, Some sedimentation phenomena along the Wasatch Mountain front: Jour. Geophys. Research, v. 67, p. 1511–1524.

Crosby, E. J., 1972, Classification of sedimentary environments, *in* J. K. Rigby and W. K. Hamblin, eds., Recognition of sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.

Crowell, J. C., 1952, Submarine canyons bordering central and southern California: Jour. Geology, v. 60, p. 58–83.

——— 1954, Geology of the Ridge Basin area: California Div. Mines Bull. 170, Map Sheet No. 7.

Culbertson, J. K., and D. R. Dawdy, 1964, A study of fluvial characteristics and hydraulic variables, middle Rio Grande, New Mexico: U.S. Geol. Survey Water-Supply Paper 1498-F, 74 p.

Curray, J. R., 1960, Sediments and history of Holocene transgression, continental shelf, northwest Gulf of Mexico, *in* F. P. Shepard *et al.*, eds., Recent sediments, northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, p. 221–266.

——— 1964, Transgressions and regressions, *in* Papers in marine geology: New York, The Macmillan Co., p. 175–203.

——— 1969a, Estuaries, lagoons, tidal flats and deltas, *in* New concepts of continental margin sedimentation: Am. Geol. Inst. Short Course Notes, Nov. 7–9, p. III-1 to III-30.

——— 1969b, Shore zone sand bodies: barriers, cheniers and beach ridges, *in* New concepts of continental margin sedimentation: Am. Geol. Inst. Short Course Notes, Nov. 7–9, p. II-1 to II-18.

——— and D. G. Moore, 1963, Facies delineation by acoustic-reflection: northern Gulf of Mexico: Sedimentology, v. 2, p. 130–148.

——— and ——— 1964, Holocene regressive littoral sand, Costa de Nayarit, Mexico, *in* Deltaic and shallow marine deposits: New York, Elsevier Publishing Co., p. 176–182.

——— and ——— 1971, Growth of the Bengal deep-sea fan and denudation in the Himalayas: Geol. Soc. America Bull., v. 82, p. 563–572.

——— *et al.*, 1969, Holocene history of a strand plain, lagoonal coast, Nayarit, Mexico, *in* Coastal lagoons, a symposium: Internat. Symposium on Coastal Lagoons Mem., Mexico, D. F., p. 63–100.

——— *et al.*, 1970, Late Quaternary sea-level studies in Micronesia: Carmarse expedition: Geol. Soc. America Bull., v. 81, p. 1865–1880.

Curtis, D. M., 1970, Miocene deltaic sedimentation,

Louisiana Gulf Coast, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 293–308.
Daboll, J. M., 1969, Holocene sediments of the Parker estuary, Massachusetts: Massachusetts Univ. Dept. Geology Contr. No. 3-CRG, 138 p.
Damuth, J. E., and R. W. Fairbridge, 1970, Equatorial Atlantic deep-sea arkosic sands and ice-age aridity in tropical South America: Geol. Soc. America Bull., v. 81, p. 189–206.
Davies, D. K., 1966, Sedimentary structures and subfacies of a Mississippi River point bar: Jour. Geology, v. 74, no. 2, p. 234–239.
——— *et al.*, 1971, Recognition of barrier environments: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 550–565.
Davis, J. R., 1971, Sedimentation of Pliocene sandstones in Santa Barbara Channel, California (abs.): Am. Assoc. Petroleum Geologists Bull., v. 55, p. 335.
Davis, W. M., 1938, Sheetfloods and streamfloods: Geol. Soc. America Bull., v. 49, p. 1337–1416.
Dennison, J. M., 1971, Petroleum related to Middle and Upper Devonian deltaic facies in central Appalachia: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 1179–1193.
Denny, C. S., 1965, Alluvial fans in the Death Valley region, California, Nevada: U.S. Geol. Survey Prof. Paper 466, 62 p.
——— 1967, Fans and pediments: Am. Jour. Sci., v. 265, p. 81–105.
Dickas, A. B., and J. L. Payne, 1967, Upper Paleocene buried channel in Sacramento Valley, California: Am. Assoc. Petroleum Geologists Bull., v. 51, no. 6, p. 873–882.
Dickinson, K. A., *et al.*, 1972, Criteria for recognizing ancient barrier coastlines, *in* J. K. Rigby and W. K. Hamblin, eds., Recognition of sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.
Dietz, R. J., and H. J. Knebel, 1971, Thou Sans Fond submarine canyon, Ivory Coast, Africa: Deep-Sea Research, v. 18, p. 441–447.
Dill, R. F., *et al.*, 1954, Deep-sea channels and deltas of the Monterey submarine canyon: Geol. Soc. America Bull., v. 65, p. 191–194.
Dillon, W. P., 1970, Submergence effects on a Rhode Island barrier and lagoon and inferences on migration of barriers: Jour. Geology, v. 78, no. 1, p. 94–106.
Dineley, D. L., and B. P. J. Williams, 1968, Sedimentation and paleoecology of the Devonian Escuminac Formation and related strata, Escuminac Bay, Quebec: Geol. Soc. America Spec. Paper 106, p. 241–264.
Dobby, E. H. G., 1936, The Ebro delta: Geog. Jour., v. 87, p. 455–469.
Dodge, C. F., 1965, Genesis of an Upper Cretaceous offshore bar near Arlington, Texas: Jour. Sed. Petrology, v. 35, no. 1, p. 22–35.
Doeglas, D. J., 1962, The structure of sedimentary deposits of braided rivers: Sedimentology, v. 1, p. 167–190.
Donaldson, A. C., 1966, Deltaic sands and sandstones, *in* Symposium on recently developed geologic principles and sedimentation of the Permo-Pennsylvanian of the Rocky Mountains: Wyoming Geol. Assoc. 20th Ann. Field Conf. Guidebook, p. 31–62.
——— 1969, Ancient deltaic sedimentation (Pennsylvanian) and its control on the distribution, thickness and quality of coals, *in* A. C. Donaldson, ed., Some Appalachian coals and carbonates: models of ancient shallow-water deposition: West Virginia Geol. and Econ. Survey, p. 93–123.
——— *et al.*, 1970, Holocene Guadalupe delta of Texas Gulf Coast, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 107–137.
Dondanville, R. R., 1963, The Fall River Formation, northwestern Black Hills, lithology and geologic history: Wyoming Geol. Assoc.–Billings Geol. Soc. Joint Field Conf. Guidebook, p. 87–99.
Dott, R. H., Jr., 1964, Ancient deltaic sedimentation in eugeosynclinal belts, *in* Deltaic and shallow marine deposits: Amsterdam, Elsevier Pub. Co., p. 105–113.
——— 1966, Eocene deltaic sedimentation at Coos Bay, Oregon: Jour. Geology, v. 74, p. 373–420.
Duncan, J. R., and L. D. Kulm, 1970, Mineralogy, provenance and dispersal history of late Quaternary deep-sea sands in Cascadia basin and Blanco fracture zone of Oregon: Jour. Sed. Petrology, v. 40, p. 874–887.
Eckis, R., 1928, Alluvial fans of the Cucamonga district, southern California: Jour. Geology, v. 36, p. 224–247.
Emery, K. O., 1960a, Basin plains and aprons off southern California: Jour. Geology, v. 68, p. 464–479.
——— 1960b, The sea off southern California: New York, John Wiley and Sons, Inc.
——— *et al.*, 1952, Submarine geology off San Diego, California: Jour. Geology, v. 60, no. 6, p. 511–548.
Ericson, D. B., M. Ewing, and B. C. Heezen, 1951, Deep-sea sands and submarine canyons: Geol. Soc. America Bull., v. 62, p. 961–965.
——— ——— and ——— 1952, Turbidity currents and sediments in the North Atlantic: Am. Assoc. Petroleum Geologists Bull., v. 36, p. 489–511.
——— *et al.*, 1955, Sediment deposition in deep Atlantic, p. 205–220, *in* Arie Poldervaart, ed., Crust of the earth: Geol. Soc. America Spec. Paper 62, 762 p.
——— *et al.*, 1961, Atlantic deep-sea cores: Geol. Soc. America Bull., v. 72, p. 193–285.
Evans, G., 1965, Intertidal flat sediments and their environments of deposition in the Wash: Geol. Soc. London Quart. Jour., v. 121, p. 209–245.
Ewing, M., *et al.*, 1958, Sediments and topography of the Gulf of Mexico, *in* L. G. Weeks, ed., Habitat of oil: Am. Assoc. Petroleum Geologists, p. 995–1053.
Exum, F. A., and J. C. Harms, 1968, Comparison of marine-bar with valley-fill stratigraphic traps, western Nebraska: Am. Assoc. Petroleum Geologists Bull., v. 52, no. 10, p. 1851–1868.
Eymann, J. L., 1953, A study of sand dunes in the Colorado and Mojave Deserts: Los Angeles, Univ. Southern California, MS thesis, 91 p.
Fahnestock, R. K., 1963, Morphology and hydrology of a glacial stream—White River, Mount Rainier, Washington: U.S. Geol. Survey Prof. Paper 422-A, 70 p.
Felix, D. W., and D. S. Gorsline, 1971, Newport submarine canyon, California: an example of the effects of shifting loci of sand supply upon canyon position: Marine Geology, v. 10, p. 177–198.
Ferguson, J., 1863, Delta of the Ganges: Geol. Soc. London Quart. Jour., v. 19, p. 321–354.
Ferm, J. C., 1970, Allegheny deltaic deposits, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 246–255.
——— and V. V. Cavaroc, Jr., 1969, A field guide to Allegheny deltaic deposits in the upper Ohio Valley:

Ohio Geol. Soc. and Pittsburgh Geol. Soc.
Field, M. E., and O. H. Pilkey, 1971, Deposition of deep-sea sands: comparison of two areas of the Carolina continental rise: Jour. Sed. Petrology, v. 41, p. 526–536.
Finch, W. I., 1959, Geology of uranium deposits in Triassic rocks of the Colorado Plateau region: U.S. Geol. Survey Bull. 1074-D, 164 p.
Finkel, H. J., 1959, The barchans of southern Peru: Jour. Geology, v. 67, p. 614–647.
Fischer, P. J., 1971, An ancient (upper Paleocene) submarine canyon and fan: the Meganos Channel, Sacramento Valley, California (abs.): 67th Ann. Geol. Soc. America Cordilleran Section Mtg. Prog., v. 3, no. 2, p. 120.
Fisher, W. L., 1969, Gulf Coast Basin Tertiary delta systems, *in* Delta systems in exploration for oil and gas: Texas Univ. Bur. Econ. Geology, p. 30–39.
——— and L. F. Brown, Jr., 1969, Delta systems and oil and gas occurrence, *in* Delta systems in exploration for oil and gas: Texas Univ. Bur. Econ. Geology, p. 54–66.
——— and J. H. McGowen, 1969, Depositional systems in Wilcox Group (Eocene) of Texas and their relationship to occurrence of oil and gas: Am. Assoc. Petroleum Geologists Bull., v. 53, no. 1, p. 30–54.
——— *et al.*, 1969, Delta systems in the exploration for oil and gas: Texas Univ. Bur. Econ. Geology, 78 p.
——— *et al.*, 1970, Depositional systems in the Jackson Group of Texas—their relationship to oil, gas and uranium: Texas Univ. Bur. Econ. Geology Geol. Circ. 70-4.
Fisk, H. N., 1940, Geology of Avoyelles and Rapides Parishes, Louisiana: Louisiana Geol. Survey Geol. Bull. No. 18.
——— 1944, Geological investigation of the alluvial valley of the lower Mississippi River: Mississippi River Commission, Vicksburg, Mississippi.
——— 1947, Fine-grained alluvial deposits and their effects on Mississippi River activity: Mississippi River Commission, Vicksburg, Mississippi.
——— 1952, Geological investigation of the Atchafalaya basin and problems of Mississippi River diversion: Mississippi River Commission, Vicksburg, Mississippi, p. 1–145.
——— 1955, Sand facies of Recent Mississippi delta deposits: 4th World Petroleum Cong. Proc., Sec. 1/C, p. 1–21.
——— 1958, Recent Mississippi River sedimentation and peat accumulation, *in* Ernest Van Aelst, ed., 4th Congres pour l'avancement des etudes de stratigraphie et de geologie du Carbonifere, Heerlen, 1958: Compte Rendu, v. 1, p. 187–199.
——— 1959, Padre Island and the Laguna Madre flats, coastal south Texas, *in* 2d Coastal Geog. Conf., April 6-9: Natl. Acad. Sci.-Natl. Research Council Pub., p. 103–151.
——— 1961, Bar-finger sands of the Mississippi delta, *in* J. A. Peterson and J. C. Osmond, eds., Geometry of sandstone bodies: Am. Assoc. Petroleum Geologists, p. 29–52.
——— and E. McFarlan, Jr., 1955, Late Quaternary deltaic deposits of the Mississippi River, *in* A. Poldervaart, ed., The crust of the earth: Geol. Soc. America Spec. Paper 62, p. 279–302.
——— *et al.*, 1954, Sedimentary framework of the modern Mississippi delta: Jour. Sed. Petrology, v. 24, no. 2, p. 76–99.
Flemal, R. C., 1967, Sedimentology of the Sespe Formation, southwestern California: Princeton, New Jersey, Princeton Univ., PhD thesis, 258 p.
Folk, R. L., 1971, Longitudinal dunes of the northwestern edge of the Simpson Desert, Northern Territory, Australia, Part 1, Geomorphology and grain size relationships: Sedimentology, v. 16, p. 5–54.
——— and W. C. Ward, 1957, Brazos River bar—a study of the significance of grain size parameters: Jour. Sed. Petrology, v. 27, p. 3–26.
Frazier, D. E., 1967, Recent deltaic deposits of the Mississippi River: their development and chronology: Gulf Coast Assoc. Geol. Socs. Trans., v. 17, p. 287–315.
——— and A. Osanik, 1961, Point-bar deposits, Old River locksite, Louisiana: Gulf Coast Assoc. Geol. Socs. Trans., v. 11, p. 121–137.
——— and ——— 1969, Recent peat deposits, Louisiana coastal plain: Geol. Soc. America Spec. Paper 114, p. 63–85.
Freeman, J. C., 1949, Strand-line accumulation of petroleum, Jim Hogg County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 33, no. 7, p. 1260–1270.
Friedkin, J. F., 1945, A laboratory study of the meandering of alluvial rivers: U.S. Waterways Experiment Sta., Vicksburg, Mississippi, May.
Friedman, G. M., and K. G. Johnson, 1966, The Devonian Catskill deltaic complex of New York, type example of a "teutonic delta complex," *in* Deltas in their geologic framework: Houston Geol. Soc.
Galehouse, J. J., 1967, Provenance and paleocurrents of the Paso Robles Formation, California: Geol. Soc. America Bull., v. 78, p. 951–978.
Galloway, W. E., 1968, Depositional systems of lower Wilcox Group, north-central Gulf Coast basin: Gulf Coast Assoc. Geol. Socs. Trans., v. 18, p. 275–289.
Geijskes, D. C., 1952, On the structure and origin of the sandy ridges in the coastal zone of Surinam: Koninkl. Nederlandsch Aardrijksk. Genoot. Tijdschr., v. 69, no. 2, p. 225–237.
Gellert, J. F., 1968, The Yangtze River mouth and delta: Warsaw, Przeglad Geog., v. 40, p. 413–418 (in German).
Giddings, J. L., 1947, Mackenzie River delta chronology: Tree Ring Bull., v. 13, p. 26–29.
Gilbert, G. K., 1914, The transportation of debris by running water: U.S. Geol. Survey Prof. Paper 86.
Giles, R. T., and O. H. Pilkey, 1965, Atlantic beach and dune sediments of the southern United States: Jour. Sed. Petrology, v. 35, no. 4, p. 900–910.
Gilluly, J., 1927, Physiography of the Ajo region, Arizona: Geol. Soc. America Bull., v. 48, p. 323–348.
Glenn, J. L., and A. R. Dahl, 1959, Characteristics and distribution of some Missouri River deposits: Iowa Acad. Sci. Proc., v. 66, p. 302–311.
Glennie, K. W., 1970, Desert sedimentary environments—Developments in sedimentology, no. 14: Amsterdam, Elsevier Pub. Co., 222 p.
Gorsline, D. S., 1967, Sedimentologic studies of the Colorado delta: Southern California Univ. Geol. Rept. 67-1, 121 p.
——— and K. O. Emery, 1959, Turbidity-current deposits in San Pedro and Santa Monica basins off southern California: Geol. Soc. America Bull., v. 70, p. 279–290.
——— *et al.*, 1967, Studies of submarine canyons and fans off southern California: Southern Calif. Univ. Geol. Rept. 67-3, 27 p.
Gould, H. R., 1970, The Mississippi delta complex, *in* Deltaic sedimentation—modern and ancient: Soc.

Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 3–30.
——— and E. McFarlan, Jr., 1959, Geologic history of the chenier plain, southwestern Louisiana: Gulf Coast Assoc. Geol. Socs. Trans., v. 9, p. 261–270.
Gourou, P., 1967, The Zambezi River delta: Acta Geog. Lovaniensia, v. 5, p. 31–36 (in French).
Greenman, N. N., and R. J. LeBlanc, 1956, Recent marine sediments and environments of northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 813–847.
Greensmith, J. T., 1966, Carboniferous deltaic sedimentation in eastern Scotland, a review and reappraisal, *in* Deltas in their geologic framework: Houston Geol. Soc.
——— and E. V. Tucker, 1969, The origin of the Holocene shell deposits in the chenier plain facies of Essex (Great Britain): Marine Geology, v. 7, p. 403–425.
Gregory, J. L., 1966, A lower Oligocene delta in the subsurface of southeast Texas: Gulf Coast Assoc. Geol. Socs. Trans., v. 16, p. 227–241.
Gremillion, L. R., *et al.*, 1964, Barrier and lagoonal sets on high terraces in the Florida panhandle: Southeastern Geology, v. 6, p. 31–36.
Griffith, E. G., 1966, Geology of Saber bar, Logan and Weld Counties, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 2112–2118.
Griggs, G. B., and L. D. Kulm, 1970, Sedimentation in Cascadia deep-sea channel: Geol. Soc. America Bull., v. 81, p. 1361–1384.
Guilcher, A., 1958, Coastal and submarine morphology: London, Methuen & Co., Ltd.: New York, John Wiley and Sons, Inc., 274 p.
——— 1959, Coastal sand ridges and marshes and their continental environment near Grand Popo and Ouidah, Dahomey: 2d Coastal Geog. Conf., U.S. Office Naval Research–Natl. Acad. Sci., Washington, D.C., p. 189–212.
Guy, H. P., *et al.*, 1966, Summary of alluvial channel data from flume experiments, 1956–1961: U.S. Geol. Survey Prof. Paper 462-I, p. 1–96.
Gwinn, V. E., 1964, Deduction of flow regime from bedding character in conglomerates and sandstones: Jour. Sed. Petrology, v. 34, no. 3, p. 656–658.
——— and T. A. Mutch, 1965, Intertongued Upper Cretaceous volcanic and nonvolcanic rocks, central-western Montana: Geol. Soc. America Bull., v. 76, p. 1125–1144.
Hack, J. T., 1941, Dunes of the western Navajo country: Geog. Rev., v. 31, p. 240–263.
Hails, J. R., 1964, The coastal depositional features of southeastern Queensland: Australia Geog., v. 9, p. 208–217.
——— and J. H. Hoyt, 1969, The significance and limitations of statistical parameters for distinguishing ancient and modern sedimentary environments of the lower Georgia coastal plain: Jour. Sed. Petrology, v. 39, no. 2, p. 559–580.
Hale, L. A., 1961, Late Cretaceous (Montanan) stratigraphy, eastern Washakie basin, Carbon County, Wyoming: Wyoming Geol. Assoc. 16th Field Conf. Guidebook, p. 129–137.
Hamilton, E. L., 1967, Marine geology of the abyssal plains in the Gulf of Alaska: Jour. Geophys. Research, v. 72, p. 4189–4213.
Haner, B. E., 1971, Morphology and sediments of Redondo submarine fan, southern California: Geol. Soc. America Bull., v. 82, p. 2413–2432.
Hansen, H. J., 1969, Depositional environments of subsurface Potomac Group in southern Maryland: Am. Assoc. Petroleum Geologists Bull., v. 53, no. 9, p. 1923–1937.
Hantzschel, W., 1939, Tidal flat deposits (Wattenschlick), *in* P. D. Trask, ed., Recent marine sediments: Am. Assoc. Petroleum Geologists, p. 195–206.
Happ, S. C., *et al.*, 1940, Some aspects of accelerated stream and valley sedimentation: U.S. Dept. Agriculture Tech. Bull., v. 695, 134 p.
Harms, J. C., 1966, Stratigraphic traps in a valley fill, western Nebraska: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 2119–2149.
——— and R. K. Fahnestock, 1965, Stratification bed forms and flow phenomena (with an example from the Rio Grande), *in* Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, p. 84–115.
——— *et al.*, 1963, Stratification in modern sands of the Red River, Louisiana: Jour. Geology, v. 71, p. 566–580.
——— *et al.*, 1965, Depositional environment of the Fox Hills sandstones near Rock Springs uplift, Wyoming: Wyoming Geol. Assoc. 19th Field Conf. Guidebook, p. 113–130.
Hattin, D. E., 1965, Stratigraphy of the Graneros shale (Upper Cretaceous) in central Kansas: Kansas Geol. Survey Bull. 178.
Heezen, B. C., and Marie Tharp, 1967, Indian Ocean floor: Natl. Geog. Mag., October.
——— and ——— 1969, Atlantic Ocean floor: Natl. Geog. Mag., June.
——— *et al.*, 1959, The floors of the oceans: Geol. Soc. America Spec. Paper 65, 122 p.
——— *et al.*, 1964, Congo submarine canyon: Am. Assoc. Petroleum Geologists Bull., v. 48, p. 1126–1149.
Hewitt, C. H., *et al.*, 1965, The Frye in situ combustion test—reservoir characteristics: Soc. Petroleum Engineers AIME Petroleum Trans., March, p. 337–342.
Holeman, J. N., 1970, The sediment yield of major rivers of the world: Water Resources Research, v. 4, no. 4, p. 737–747.
Hooke, R. L., 1967, Processes of arid-regional alluvial fans: Jour. Geology, v. 75, no. 4, p. 438–460.
Hoover, R. A., 1968, Physiography and surface sediment facies of a recent tidal delta, Harbor Island, central Texas coast: Austin, Texas, Texas Univ., PhD thesis, 223 p.
Hoppe, G., and S. R. Ekman, 1964, A note on the alluvial fans of Ladtjouagge, Swedish Lappland: Geog. Annaler, v. 46, p. 338–342.
Horn, D., 1965, Zur Geologischen entwicklung der sudlichen schleimundung in Holozan: Meyniana, v. 15, p. 41–58.
Horn, D. R., *et al.*, 1971, Turbidites of the northeast Pacific: Sedimentology, v. 16, p. 55–69.
Horowitz, D. H., 1966, Evidence for deltaic origin of an Upper Ordovician sequence in the central Appalachians, *in* Deltas in their geologic framework: Houston Geol. Soc., p. 159–169.
Houbolt, J. J. H. C., and J. B. M. Jonker, 1968, Recent sediments in the eastern part of the Lake of Geneva (Lac Leman): Geologie en Mijnbouw, v. 47, p. 131–148.
Howard, J. D., 1966, Patterns of sediment dispersal in the Fountain Formation of Colorado: Mtn. Geologist, v. 3, p. 147–153.
Howe, H. V., and C. K. Moresi, 1931, Geology of

Iberia Parish: Louisiana Geol. Survey Geol. Bull. No. 1.
——— and ——— 1933, Geology of Lafayette and St. Martin Parishes: Louisiana Geol. Survey Geol. Bull. No. 3, 238 p.
——— *et al.*, 1935, Reports on the geology of Cameron and Vermilion Parishes: Louisiana Geol. Survey Geol. Bull. No. 6, 242 p.
Hoyt, J. H., 1964, High angle beach stratification, Sapelo Island, Georgia: Jour. Sed. Petrology, v. 32, p. 309–311.
——— 1967, Barrier island formation: Geol. Soc. America Bull., v. 78, p. 1125–1136.
——— 1969, Chenier versus barrier, genetic and stratigraphic distinction: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 299–306.
——— and V. J. Henry, Jr., 1965, Significance of inlet sedimentation in the recognition of ancient barrier islands, *in* Sedimentation of Late Cretaceous and Tertiary outcrops, Rock Springs uplift: Wyoming Geol. Assoc. 19th Field Conf. Guidebook, p. 190–194.
——— and ——— 1967, Influence of island migration on barrier island sedimentation: Geol. Soc. America Bull., v. 78, p. 77–86.
——— and ——— 1971, Origin of capes and shores along the southeastern coast of the United States: Geol. Soc. America Bull., v. 82, p. 59–66.
——— and R. J. Weimer, 1963, Comparison of modern and ancient beaches, central Georgia coast: Am. Assoc. Petroleum Geologists Bull., v. 47, p. 529–531.
——— *et al.*, 1964, Late Pleistocene and Recent sedimentation on Georgia coast, *in* Deltaic and shallow marine deposits: New York, Elsevier Publishing Co., p. 170–176.
Hoyt, W. V., 1959, Erosional channel in the middle Wilcox near Yoakum, Lavaca County, Texas: Gulf Coast Assoc. Geol. Socs. Trans., v. 9, p. 41–50.
Hrabar, S. V., and P. E. Potter, 1969, Lower west Badeu (Mississippian) sandstone body of Owen and Green Counties, Indiana: Am. Assoc. Petroleum Geologists Bull., v. 53, no. 10, p. 2150–2160.
Huang, T., and H. G. Goodell, 1970, Sediments and sedimentary processes of eastern Mississippi cone, Gulf of Mexico: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 2070–2100.
Hubbard, J. A. E. B., 1967, Facies patterns in the Carrowmoran Sandstone (Visean) of western County Sligo, Ireland: Geol. Assoc. Proc., v. 77, pt. 2, p. 233–254.
Hubert, C., *et al.*, 1970, Deep-sea sediments in the lower Paleozoic Quebec supergroup: Geol. Assoc. Canada Spec. Paper 7, p. 103–125.
Hubert, J. F., 1960, Petrology of the Fountain and Lyons Formations, Front Range, Colorado: Colorado School Mines Quart., v. 55, p. 1–242.
——— 1964, Textural evidence for deposition of many western Atlantic deep-sea sands by ocean-bottom currents rather than turbidity currents: Jour. Geology, v. 72, p. 757–785.
Inman, D. L., and R. A. Bagnold, 1963, Littoral processes, *in* The sea, v. 2, chap. 2: New York, John Wiley and Sons, p. 529–553.
——— *et al.*, 1966, Coastal sand dunes of Guerrero Negro, Baja California, Mexico: Geol. Soc. America Bull., v. 77, no. 8, p. 787–802.
Ives, R. L., 1936, Desert floods in Sonoyta Valley: Am. Jour. Sci., v. 32, p. 349–360.
Jacka, A. D., 1965, Depositional dynamics of the Almond Formation, Rock Springs uplift, Wyoming: Wyoming Geol. Assoc. 19th Field Conf. Guidebook, p. 81–100.
Jahns, R. H., 1947, Geological features of the Connecticut Valley, Massachusetts as related to recent floods: U.S. Geol. Survey Water-Supply Paper 996, 157 p.
Jelgersma, S., J. de Jong, and W. H. Zagwijn, 1970, The coastal dunes of the western Netherlands; geology, vegetational history and archeology: Geol. Stichting Med., new ser., no. 21, p. 93–154.
Johnson, A., 1965, A model for debris flow: University Park, Pennsylvania, Pennsylvania State Univ., PhD thesis, 233 p.
Johnson, R. B., 1967, The great sand dunes of southern Colorado: U.S. Geol. Survey Prof. Paper 575-C, p. C177–C183.
Johnson, W. A., 1921, Sedimentation of the Fraser River delta: Canada Geol. Survey Mem. 125, 46 p.
——— 1922, The character of the stratification of the sediments of the Recent delta of the Fraser River, British Columbia, Canada: Jour. Geology, v. 30, p. 115–129.
Kanes, W., 1969, Tidal inlets, tidal deltas, and barrier islands versus alluvial deposits: a discussion of sedimentary criteria, *in* A. C. Donaldson, ed., Some Appalachian coals and carbonates: models of ancient shallow water deposition: West Virginia Geol. and Econ. Survey, p. 259–263.
——— 1970, Facies and development of the Colorado River delta in Texas, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 78–106.
Kelling, G., 1968, Patterns of sedimentation in Rhondda Beds of South Wales: Am. Assoc. Petroleum Geologists Bull., v. 52, no. 12, p. 2369–2386.
——— and D. J. Stanley, 1970, Morphology and structure of Wilmington and Baltimore submarine canyons, eastern United States: Jour. Geology, v. 78, p. 637–660.
——— and M. A. Woollands, 1969, The stratigraphy and sedimentation of the Llandoverian rocks of the Rhoyader district, *in* A. Woods, ed., The Precambrian and lower Paleozoic rocks of Wales: Univ. Wales Press, p. 255–282.
Kessler, L. G., II, 1970, Bar development and aggradational sequences in the braided portions of the Canadian River, Hutchinson, Roberts and Hemphill Counties, Texas (abs.): 23d Ann. Rocky Mountain Sec. Geol. Soc. America Mtg. Prog., v. 2, no. 5, p. 338.
——— 1971, Characteristics of the braided stream depositional environment with examples from the South Canadian River, Texas: Earth Sci. Bull., v. 4, no. 1, p. 25–35.
King, C. A. M., 1959, Beaches and coasts: London, Edward Arnold Publications, Ltd., 403 p.
Klein, G. deV., 1962, Triassic sedimentation, Maritime Provinces, Canada: Geol. Soc. America Bull., v. 73, p. 1127–1146.
——— 1967, Comparison of Recent and ancient tidal flat and estuarine sediments, *in* Estuaries: Am. Assoc. Adv. Sci. Pub. 83, p. 207–218.
——— 1968, Sedimentology of Triassic rocks in the lower Connecticut Valley, *in* Guidebook for field trips in Connecticut, New England Internat. Collegiate Geol. Conf.: Connecticut Geol. and Nat. History Survey Guidebook 2, p. (c-1) 1–19.
——— 1970, Depositional and dispersal dynamics of intertidal sand bars: Jour. Sed. Petrology, v. 40, p. 1095–1127.

——— 1971, A sedimentary model for determining paleotidal range: Geol. Soc. America Bull., v. 82, p. 2585–2592.
——— and J. E. Sanders, 1964, Comparison of sediments from Bay of Fundy and Dutch Wadden Sea tidal flats: Jour. Sed. Petrology, v. 34, no. 1, p. 18–24.
Knight, W. V., 1969, Historical and economic geology of Silurian Clinton Sandstone of northwestern Ohio: Am. Assoc. Petroleum Geologists Bull., v. 53, no. 7, p. 1421–1452.
Kolb, C. R., 1962, Distribution of soils bordering the Mississippi River from Donaldsonville to Head of Passes: U.S. Army Corps Engineers, Waterways Expt. Sta. Tech. Rept. 3–601, p. 1–61.
——— 1963, Sediments forming the bed and banks of the lower Mississippi River and their effect on river migration: Sedimentology, v. 2, p. 227–234.
——— and R. I. Kaufman, 1967, Prodelta clays of southeast Louisiana: Internat. Marine Geotech. Research Conf. Proc., Monticello, Illinois, p. 3–21.
——— and J. R. Van Lopik, 1966, Depositional environments of the Mississippi River deltaic plain, southeastern Louisiana, *in* Deltas in their geological framework: Houston Geol. Soc., p. 17–61.
——— *et al.*, 1968, Geological investigation of the Yazoo basin, lower Mississippi Valley: U.S. Army Corps Engineers, Waterways Expt. Sta. Tech. Rept. 3–480.
Komar, P. D., 1969, The channelized flow of turbidity currents with application to Monterey deep-sea channel: Jour. Geophys. Research, v. 74, p. 4544–4558.
——— 1970, The competence of turbidity current flow: Geol. Soc. America Bull., v. 81, p. 1555–1562.
Krause, D. C., *et al.*, 1970, Turbidity currents and cable breaks in the western New Britain trench: Geol. Soc. America Bull., v. 81, p. 2153–2160.
Krigstrom, A., 1962, Geomorphological studies of Sandur plains and their braided river in Iceland: Geog. Annals, v. 44, p. 328–346.
Kruit, C., 1955, Sediments of the Rhône delta; I, Grain size and microfauna: Koninkl. Nederlandse Geol. Mijnb. Genoot. Verh., Geol. Ser., v. 15, p. 357–514.
Kuenen, Ph. H., 1950, Marine geology: New York, John Wiley and Sons, Inc., 568 p.
Kukal, Z., 1964, Diagnostic features of Paleozoic deltaic sediments of central Bohemia: Sedimentology, v. 3, p. 109–113.
——— 1971, Geology of Recent sediments: New York, Academic Press, 490 p.
Lagaaij, R., and F. P. H. W. Kopstein, 1964, Typical features on a fluvio-marine offlap sequence, *in* Developments in sedimentology, v. 1, Deltaic and shallow marine deposits: Amsterdam, Elsevier Publishing Co., p. 216–226.
Laming, D. J. C., 1966, Imbrication, paleocurrents, and other sedimentary features in the lower New Red Sandstone, Devonshire, England: Jour. Sed. Petrology, v. 36, no. 4, p. 940–959.
Land, L. S., 1964, Eolian cross bedding in the beach dune environment, Sapelo Island, Georgia: Jour. Sed. Petrology, v. 34, no. 2, p. 389–394.
Lane, E. W., 1957, A study of the shape of channels formed by natural streams flowing in erodible material: U.S. Army Corps Engineers, Missouri River Div., Omaha, Nebraska, Sediment Ser. 9, 106 p.
——— 1963, Cross-stratification in San Bernard River, Texas, point bar deposits: Jour. Sed. Petrology, v. 33, p. 350–354.
——— and E. W. Eden, 1940, Sand waves in the lower Mississippi River: Western Soc. Engineers Jour., v. 45, no. 6, p. 281–291.
Laporte, L. F., 1968, Ancient environments: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 116 p.
Laury, R. L., 1968, Sedimentology of the Pleasantview Sandstone, southern Iowa and western Illinois: Jour. Sed. Petrology, v. 38, no. 2, p. 568–599.
Lawson, A. C., 1913, The petrographic description of alluvial fan deposits: California Univ. Pubs. Geol. Sci., v. 7, p. 325–334.
LeBlanc, R. J., and H. A. Bernard, 1954, Resume of late Recent geological history of the Gulf Coast: Geologie en Mijnbouw, new series, v. 16c, p. 185–194.
——— and W. D. Hodgson, 1959, Origin and development of the Texas shoreline: Louisiana State Univ. Coastal Studies Inst., 2d Coastal Geog. Conf., p. 57–101; EPR Pub. 219, Shell E&P Research, Houston.
LeBlanc, R. J., Jr., 1971, Environments of deposition of the Yegua Formation (Eocene), Brazos County, Texas: Corpus Christi Geol. Soc. Bull., v. 11, no. 6, 70 p.
Legget, R. F., R. J. E. Brown, and G. H. Johnston, 1966, Alluvial fan formation near Aklavik, Northwest Territories, Canada: Geol. Soc. America Bull., v. 77, p. 15–30.
Lené, G. W., and D. E. Owen, 1969, Grain orientation in a Berea Sandstone channel at south Amherst, Ohio: Jour. Sed. Petrology, v. 39, no. 2, p. 737–743.
Leopold, L. B., and M. G. Wolman, 1957, River channel patterns: braided, meandering and straight: U.S. Geol. Survey Prof. Paper 282-B, 85 p.
——— and ——— 1960, River meanders: Geol. Soc. America Bull., v. 71, p. 769–794.
——— *et al.*, 1966, Channel and hillslope processes in a semi-arid area, New Mexico: U.S. Geol. Survey Prof. Paper 352-G.
Lineback, J. A., 1968, Turbidites and other sandstone bodies in the Borden Siltstone (Mississippian) in Illinois: Illinois Geol. Survey Circ. 425, p. 1–29.
Lins, T. W., 1950, Origin and environment of the Tonganoxie Sandstone in northeastern Kansas: Kansas Geol. Survey Bull., v. 86, p. 107–140.
Liteanu, E., and A. Pricajan, 1963, The geological structure of the Danube delta: Bucharest, Hidrobiologia, v. 4, p. 57–82 (in Rumanian).
Logvinenko, N. V., and I. N. Remizov, 1964, Sedimentology of beaches on the north coast of the Sea of Azov, *in* Deltaic and shallow marine deposits, developments in sedimentology, v. 1: Amsterdam, Elsevier Publishing Co., p. 244–252.
Lucke, J. B., 1934, A study of Barnegat Inlet, New Jersey and related shoreline phenomena: Shore and Beach, v. 2, p. 45–93.
Lum, D., and H. T. Stearns, 1970, Pleistocene stratigraphy and eustatic history based on cores at Waimanalo, Oahu, Hawaii: Geol. Soc. America Bull., v. 81, p. 1–16.
Lumsden, D. N., and B. R. Pelletier, 1969, Petrology of the Grimsby Sandstone (Lower Silurian) of Ontario and New York: Jour. Sed. Petrology, v. 39, no. 2, p. 521–530.
Lustig, L. K., 1963, Competence of transport in alluvial fans: U.S. Geol. Survey Prof. Paper 475-C, p. 126–129.
——— 1965, Clastic sedimentation in the Deep Springs Valley, California: U.S. Geol. Survey Prof. Paper 352-F.
MacIntyre, I. G., and J. D. Milliman, 1970, Physio-

graphic features on the outer shelf and upper slope, Atlantic continental margin, southeastern United States: Geol. Soc. America Bull., v. 81, p. 2577–2589.

MacNeil, F. S., 1950, Pleistocene shore lines in Florida and Georgia: U.S. Geol. Survey Prof. Paper 221-F.

Mammerickx, J., 1970, Morphology of the Aleutian abyssal plain: Geol. Soc. America Bull., v. 81, p. 3457–3464.

Mann, C. J., and W. A. Thomas, 1968, Ancient Mississippi River: Gulf Coast Assoc. Geol. Socs. Trans., v. 18, p. 187–204.

Manos, C., 1967, Depositional environment of Sparland cyclothem (Pennsylvanian), Illinois and Forest City basins: Am. Assoc. Petroleum Geologists Bull., v. 51, no. 9, p. 1843–1861.

Martin, B. D., 1963, Rosedale channel—evidence for late Miocene submarine erosion in Great Valley of California: Am. Assoc. Petroleum Geologists Bull., v. 47, p. 441–456.

——— and K. O. Emery, 1967, Geology of the Monterey Canyon, California: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 2281–2304.

Martini, I. P., 1971, Regional analysis of sedimentology of Medina Formation (Silurian), Ontario and New York: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 1249–1261.

Mathews, W. H., and F. P. Shepard, 1962, Sedimentation of Fraser River delta, British Columbia: Am. Assoc. Petroleum Geologists Bull., v. 48, no. 8, p. 1416–1444.

Matthews, J. L., 1966, Sedimentation of the coastal dunes at Oceano, California: Univ. California at Los Angeles, PhD thesis, 138 p.

McBride, E. F., and M. O. Hayes, 1962, Dune cross bedding on Mustang Island, Texas: Am. Assoc. Petroleum Geologists Bull., v. 46, p. 546–552.

McCave, I. N., 1969, Correlation using a sedimentological model of part of the Hamilton group (Middle Devonian), New York State: Am. Jour. Sci., v. 267, no. 5, p. 567–591.

McCloy, J. L., 1969, Morphologic characteristics of the Blow River delta, Yukon Territory, Canada: Baton Rouge, Louisiana, Louisiana State Univ., PhD thesis, 161 p.

McEwen, M. C., 1969, Sedimentary facies of the modern Trinity delta, *in* Galveston Bay geology: Houston Geol. Soc., p. 53–77.

McGee, W. J., 1897, Sheetflood erosion: Geol. Soc. America Bull., v. 8, p. 87–112.

McGowen, J. H., and L. E. Garner, 1969, Comparison of Recent and ancient coarse-grained point bars (abs.): Am. Assoc. Petroleum Geologists Bull., v. 53, no. 3, p. 731–732.

——— and ——— 1970, Physiographic features and stratification types of coarse-grained point bars: modern and ancient examples: Sedimentology, v. 14, p. 77–111.

——— and C. G. Groat, 1971, Van Horn Sandstone, West Texas—an alluvial fan model for mineral exploration: Texas Univ. Bur. Econ. Geology, 57 p.

McKee, E. D., 1934, The Coconino Sandstone—its history and origin: Carnegie Inst. Washington Pub. 440, Contr. Paleontology, p. 77–115.

——— 1939, Some types of bedding in the Colorado River delta: Jour. Geology, v. 47, p. 64–81.

——— 1957, Primary structures of some Recent sediments: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 1704–1747.

——— 1966, Structures of dunes at White Sands National Monument, New Mexico: Sedimentology, v. 7, no. 1, 69 p.

——— and G. C. Tibbitts, 1964, Primary structures of a seif dune and associated deposits of Libya: Jour. Sed. Petrology, v. 34, no. 1, p. 5–17.

McKenzie, P., 1958, The development of sand beach ridges: Australian Jour. Sci., v. 20, p. 213–214.

Melton, M. A., 1965, The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona: Jour. Geology, v. 73, p. 1–38.

Menard, H. W., 1955, Deep-sea channels, topography, and sedimentation: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 236–255.

——— 1960, Possible pre-Pleistocene deep-sea fans off central California: Geol. Soc. America Bull., v. 71, p. 1271–1278.

——— 1964, Marine geology of the Pacific: New York, McGraw-Hill Book Co., Inc., 271 p.

——— *et al.*, 1965, The Rhône deep-sea fan, *in* Submarine geology and geophysics: London, Butterworth, p. 271–286.

Miall, A. D., 1970, Continental marine transition in the Devonian of Prince of Wales Island, Northwest Territories: Canadian Jour. Earth Sci., v. 7, p. 125–144.

Miller, D. N., 1962, Patterns of barrier bar sedimentation and its similarity to Lower Cretaceous Fall River stratigraphy, *in* Symposium on Early Cretaceous rocks: Wyoming Geol. Assoc. 17th Field Conf. Guidebook, p. 232–247.

Milling, M. E., and E. W. Behrens, 1966, Sedimentary structures of beach and dune deposits: Mustang Island, Texas: Inst. Marine Sci. Pub., v. 11, p. 135–148.

Moody-Stuart, M., 1966, High and low sinuosity stream deposits, with examples from the Devonian of Spitsbergen: Jour. Sed. Petrology, v. 36, no. 4, p. 1102–1117.

Moore, D., 1966, Deltaic sedimentation: Earth Sci. Rev., v. 1, p. 87–104, Amsterdam, Elsevier Publishing Co.

Moore, D. G., 1970, Reflection profiling studies of the California borderland: structure and Quaternary turbidite basins: Geol. Soc. America Spec. Paper 107.

Moore, G. T., and D. O. Asquith, 1971, Delta: term and concept: Geol. Soc. America Bull., v. 82, p. 2563–2568.

Morgan, J. P., 1961, Mudlumps at the mouths of the Mississippi River, *in* Genesis and paleontology of the Mississippi River mudlumps: Louisiana Geol. Survey Geol. Bull. No. 35.

——— 1970, Depositional processes and products in the deltaic environment, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 31–47.

——— *et al.*, 1953, Occurrence and development of mud flats along the western Louisiana coast: Louisiana State Univ. Coastal Studies Inst. Tech. Rept. No. 2.

——— *et al.*, 1968, Mudlumps: diapiric structures in Mississippi delta sediments, *in* J. Braunstein and G. D. O'Brien, eds., Diapirism and diapirs: Am. Assoc. Petroleum Geologists Mem. 8, p. 145–161.

Muehlberger, F. B., 1955, Pismo beach–Point Sal dune field, California: Lawrence, Kansas, Univ. Kansas, Master's thesis, 106 p.

Muller, G., 1966, The new Rhine delta in Lake Constance, *in* M. L. Shirley, ed., Deltas in their geologic framework: Houston Geol. Soc., p. 107–124.

Mutch, T. A., 1968, Pennsylvanian non-marine sediments of the Narragansett Basin, Massachusetts and

Rhode Island: Geol. Soc. America Spec. Paper 106, p. 177–209.

Nagtegaal, P. J. C., 1966, Scour-and-fill structures from a fluvial piedmont environment: Geologie en Mijnbouw, v. 45, no. 10, p. 342–354.

Nanz, R. H., 1954, Genesis of Oligocene sandstone reservoir, Seeligson field, Jim Wells and Kleberg Counties, Texas: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 96–117.

Nelson, B. W., 1970, Hydrography, sediment dispersal, and recent historical development of the Po River delta, Italy. *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 152–184.

Nelson, C. H., 1968, Marine geology of Astoria deep-sea fan: Corvallis, Oregon, Oregon State Univ., PhD thesis, 287 p.

——— *et al.*, 1970, Development of the Astoria canyon-fan physiography and comparison with similar systems: Marine Geology, v. 8, p. 259–291.

Nichols, M. M., 1964, Characteristics of sedimentary environments in Moriches Bay, *in* Papers in marine geology: New York, The Macmillan Co., p. 363–383.

Nilsen, T. H., 1969, Old Red sedimentation in the Buelandet-Vaerlandet Devonian district, western Norway: Sed. Geology, v. 3, no. 1.

Normark, W. R., 1970, Growth patterns of deep sea fans: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 2170–2195.

——— and D. J. W. Piper, 1969, Deep-sea fan-valleys, past and present: Geol. Soc. America Bull., v. 80, p. 1859–1866.

Norris, R. M., 1966, Barchan dunes of Imperial Valley, California: Jour. Geology, v. 74, p. 292–306.

Nossin, J. J., 1965, The geomorphic history of the northern Padang delta: Jour. Tropical Geog., v. 20, p. 54–64.

Nunnally, N. R., 1967, Definition and identification of channel and overbank deposits and their respective roles in flood plain formation: Prof. Geographer, v. 19, no. 1, p. 1–4.

Odem, W. I., 1953, Subaerial growth of the delta of the diverted Brazos River, Texas: Compass, v. 30, p. 172–178.

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

——— 1970, Depositional sequences and sand distribution in the post-glacial Rhone delta complex, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 198–212.

Ore, H. T., 1963, Some criteria for recognition of braided stream deposits: Contr. Geology, v. 3, no. 1, p. 1–14.

——— 1965, Characteristic deposits of rapidly aggrading streams, *in* Sedimentation of Late Cretaceous and Tertiary outcrops, Rock Springs uplift: Wyoming Geological Assoc. 19th Field Conf. Guidebook, p. 195–201.

Osterhoudt, W. J., 1946, The seismograph discovery of an ancient Mississippi River channel (abs.): Geophysics, v. 11, p. 417.

Otvos, E. G., Jr., 1970, Development and migration of barrier islands, northern Gulf of Mexico: Geol. Soc. America Bull., v. 81, p. 241–246.

Pack, F. J., 1923, Torrential potential of desert waters: Pan-Am. Geologist, v. 40, p. 349–356.

Paine, W. R., 1966, Stratigraphy and sedimentation of Hackberry shale and associated beds of southwestern Louisiana: Gulf Coast Assoc. Geol. Socs. Trans., v. 16.

Paull, R. A., 1962, Depositional history of the Muddy Sandstone, Bighorn basin, Wyoming: Wyoming Geol. Assoc. 17th Field Conf. Guidebook, p. 102–117.

Peterson, J. A., and J. C. Osmond, eds., 1961, Geometry of sandstone bodies: Am. Assoc. Petroleum Geologists, 240 p.

Petrescu, G., 1948, Le delta maritime du Danube; son evolution physico-geographique et les problems qui s'y posent: Rumania, Univ. Iaşi Ann. Sci., 2d sec. (Sc. Nat.), v. 31, p. 254-303.

Pettyjohn, W. A., 1967, New members of Upper Cretaceous Fox Hills Formation in South Dakota, representing delta deposits: Am. Assoc. Petroleum Geologists Bull., v. 51, no. 7, p. 1361–1367.

Pezzetta, J. R., 1968, The St. Clair River delta: Univ. Michigan, PhD thesis, 168 p.

Phleger, F. B, 1965, Sedimentology of Guerrero Negro Lagoon, Baja California, Mexico, *in* 17th Submarine geology and geophysics—Colston Research Society Symposium Proc.; Bristol, England, Paper 171, p. 205–237: London, Butterworths.

——— 1969, Some general features of coastal lagoons, *in* Coastal lagoons, a symposium: Internat. Symposium on Coastal Lagoons Mem., Mexico, D F., p. 2–25.

——— and G. C. Ewing, 1962, Sedimentology and oceanography of coastal lagoons in Baja California, Mexico: Geol. Soc. America Bull., v. 73, p. 145–182.

Pierce, J. W., 1970, Tidal inlets and washover fans: Jour. Geology, v. 78, no. 2, p. 230–234.

——— and D. J. Colquhoun, 1970, Holocene evolution of a portion of the North Carolina coast: Geol. Soc. America Bull., v. 81, no. 12, p. 3697–3714.

Piper, D. J. W., 1970, Transport and deposition of Holocene sediment of La Jolla deep sea fan, California: Marine Geology, v. 8, p. 211–227.

——— and W. R. Normark, 1971, Re-examination of a Miocene deep-sea fan and fan valley, southern California: Geol. Soc. America Bull., v. 82, p. 1823–1830.

Potter, P. E., 1967, Sand bodies and sedimentary environments, a review: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 337–365.

Price, W. A., 1947, Equilibrium of form and forces in tidal basins of coast of Texas and Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 9, p. 1619–1663.

——— 1954, Environment and formation of the chenier plain: Texas A&M Research Found. Proj. 63, Dept. Oceanography, Texas A&M College.

——— 1963, Patterns of flow and channeling in tidal inlets: Jour. Sed. Petrology, v. 33, no. 2, p. 279–290.

Priddy, R. R., *et al.*, 1955, Sediments of Mississippi Sound and inshore waters: Mississippi Geol. Survey Bull. 82.

Pryor, W. A., 1960, Cretaceous sedimentation in Upper Mississippi embayment: Am. Assoc. Petroleum Geologists Bull., v. 44, p. 1473–1504.

——— 1961, Sand trends and paleoslope in Illinois basin and Mississippi embayment, *in* J. A. Peterson and J. C. Osmond, Geometry of sandstone bodies: Am. Assoc. Petroleum Geologists, p. 119–133.

——— 1967, Biogenic directional features on several point bars: Sed. Geology, v. 1, p. 235–245.

Psuty, N. P., 1965, The geomorphology of beach ridges

in Tabasco, Mexico: Louisiana State Univ. Coastal Studies Inst. Tech. Rept. 30, p. 1–51.
Pugh, J. C., 1953, The Porto Novo-Badagri sand ridge complex: Nigeria, Univ. College of Ibadan Dept. Geography, Research Notes, no. 3, p. 1–14.
Rahn, P. H., 1967, Sheetflood, streamfloods, and the formation of pediments: Assoc. Am. Geographers Annals, v. 57, p. 593–604.
Rainwater, E. H., 1964, Transgressions and regressions in the Gulf Coast Tertiary: Gulf Coast Assoc. Geol. Socs. Trans., v. 14, p. 217–230.
Rapp, A., 1959, Avalanche boulder tongues in Lappland: Geog. Annaler, v. 41, p. 34–48.
Reineck, H. E., 1963, Sedimentgefuge im bereich der sudlichen Nordsee: Abhandl. Senckenberg: Naturf Gesell. 505, p. 1–136.
——— 1967, Layered sediments in tidal flats, beaches, and shelf bottoms of the North Sea, *in* Estuaries: Am. Assoc. Adv. Sci. Pub. 83, p. 191–206.
——— and I. B. Singh, 1967, Primary sedimentary structures in the Recent sediments of the Jade, North Sea: Marine Geology, v. 5, p. 227–235.
Reineck, H. R., 1972, Tidal flats, *in* J. K. Rigby and W. K. Hamblin, eds., Recognition of sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.
Revelle, R., and F. P. Shepard, 1939, Sediments off the California coast, *in* F. P. Shepard *et al.*, eds., Recent marine sediments: Am. Assoc. Petroleum Geologists, p. 245–282.
Rex, R. W., 1964, Arctic beaches, Barrow, Alaska, *in* Papers in marine geology: New York, The Macmillan Co., p. 384–400.
Rickmers, W. R., 1913, The Duab of Turkestan: New York, Cambridge Univ. Press, 563 p.
Rigby, J. K., and W. K. Hamblin, eds., 1972, Recognition of sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.
Rona, P. A., 1970, Submarine canyon origin on upper continental slope off Cape Hatteras: Jour. Geology, v. 78, p. 141–152.
Royse, C. F., Jr., 1970, A sedimentologic analysis of the Tongue River–Sentinel Butte interval (Paleocene) of the Williston basin, western North Dakota: Sed. Geology, v. 4, p. 19–80.
Ruhe, R. U., 1964, Landscape morphology and alluvial deposits in southern New Mexico: Assoc. Am. Geographers Annals, v. 54, p. 147–159.
Rusnak, G. A., 1957, A fabric and petrographic study of the Pleasantview Sandstone: Jour. Sed. Petrology, v. 27, no. 1, p. 41–55.
——— 1960, Sediments of Laguna Madre, Texas, *in* Recent sediments, northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, p. 153–196.
Russell, R. J., 1936, Physiography of lower Mississippi River delta, *in* Lower Mississippi River delta: Louisiana Geol. Survey Geol. Bull. 8, p. 1–199.
——— 1942, Geomorphology of the Rhône delta: Assoc. Am. Geographers Annals, v. 32, p. 149–254.
——— 1967a, River and delta morphology: Louisiana State Univ. Coastal Studies Inst. Tech. Rept. 52, 49 p.
——— 1967b, Aspects of coastal morphology: Geog. Annaler, v. 49, ser. A, p. 299–309.
——— and H. V. Howe, 1935, Cheniers of southwestern Louisiana: Geog. Rev., v. 25, no. 3, p. 449–461.
——— and R. D. Russell, 1939, Mississippi River delta sedimentation, *in* P. D. Trask, ed., Recent marine sediments: Am. Assoc. Petroleum Geologists, p. 153–177.
Ryan, D. J., 1965, Cross-bedding formed by lateral accretion in the Catskill Formation near Jim Thorpe, Pennsylvania: Pennsylvania Acad. Sci. Proc., v. 38, no. 2, p. 154–156.
Ryder, J. M., 1971, The stratigraphy and morphology of para-glacial alluvial fans in south-central British Columbia: Canadian Jour. Earth Sci., v. 8, p. 279–298.
Sabate, R. W., 1968, Pleistocene oil and gas in coastal Louisiana: Gulf Coast Assoc. Geol. Socs. Trans., v. 18, p. 373–386.
Sabins, F. F., Jr., 1963, Anatomy of stratigraphic trap, Bisti field, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 47, p. 193–228.
Saucier, R. T., 1964, Geological investigation of the St. Francis basin: U.S. Army Corps Engineers, Waterways Expt. Sta. Tech. Rept. 3–659.
——— 1967, Geological investigation of the Boeuf-Tensas basin, lower Mississippi Valley: U.S. Army Corps Engineers, Waterways Expt. Sta. Tech. Rept. 3–757.
Schlee, J. S., and R. H. Moench, 1961, Properties and genesis of "Jackpile" Sandstone, Laguna, New Mexico, *in* J. A. Peterson and J. C. Osmond, eds., Geometry of sandstone bodies: Am. Assoc. Petroleum Geologists, p. 134–150.
Scholl, D. W., *et al.*, 1970, The structure and origin of the large submarine canyons of the Bering Sea: Marine Geology, v. 8, p. 187–210.
Schumm, S. A., 1963, Sinuosity of alluvial rivers on the great plains: Geol. Soc. America Bull., v. 74, p. 1089–1100.
——— 1971, Fluvial paleochannels, *in* J. K. Rigby and W. K. Hamblin, eds., Recognition of sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.
Schwartz, M. L., 1971, The multiple causality of barrier islands: Jour. Geology, v. 79, no. 1, p. 91–94.
Scott, A. J., and W. L. Fisher, 1969, Delta systems and deltaic deposition, *in* Delta systems in exploration for oil and gas: Texas Univ. Bur. Econ. Geology, p. 10–39.
Scruton, P. C., 1960, Delta building and the deltaic sequence, *in* F. P. Shepard *et al.*, eds., Recent sediments, northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, p. 82–102.
——— 1961, Rocky Mountain Cretaceous stratigraphy and regressive sandstones: Wyoming Geological Assoc. 16th Field Conf. Guidebook, p. 241–249.
Selley, R. C., 1970, Ancient sedimentary environments: Ithaca, New York, Cornell Univ. Press, 237 p.
Shannon, J. P., Jr., and A. R. Dahl, 1971, Deltaic stratigraphic traps in West Tuscola field, Taylor County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 1194–1205.
Sharp, R. P., 1942, Mudflow levees: Jour. Geomorphology, v. 5, p. 222–227.
——— and L. H. Nobles, 1953, Mudflow in 1941 at Wrightwood, southern California: Geol. Soc. America Bull., v. 64, p. 547–560.
Shawa, M. S., 1969, Sedimentary history of the Gilwood Sandstone (Devonian), Utikuma Lake area, Alberta, Canada: Bull. Canadian Petroleum Geology, v. 17, p. 392–409.
Shelton, J. W., 1965, Trend and genesis of lowermost sandstone unit of Eagle Sandstone at Billings, Montana: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 1385–1397.
——— 1967, Stratigraphic models and general criteria for recognition of alluvial, barrier-bar, and turbidity-

current sand deposits: Am. Assoc. Petroleum Geologists Bull., v. 51, no. 12, p. 2441–2461; also *in* Billings Geol. Soc. 17th Field Conf. Guidebook, p. 1–17.

——— 1972, Models of sand and sandstone deposits: Oklahoma Geol. Survey Bull. (in press).

Shepard, F. P., 1960, Gulf Coast barriers, *in* F. P. Shepard *et al.*, eds., Recent sediments, northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, p. 197–220.

——— F. B Phleger, and Tj. H. van Andel, 1960, Recent sediments, northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, 394 p.

——— 1965, Importance of submarine valleys in funneling sediments to the deep sea, *in* Progress in oceanography, v. 3: New York, The Macmillan Co., p. 321–332.

——— and E. C. Buffington, 1968, La Jolla submarine fan-valley: Marine Geology, v. 6, p. 107–143.

——— and R. F. Dill, 1966, Submarine canyons and other sea valleys: Chicago, Rand McNally, 381 p.

——— and D. G. Moore, 1955, Sediment zones bordering the barrier islands of central Texas coast, *in* Finding ancient shorelines: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 3, p. 78–96.

——— and ——— 1960, Bays of central Texas coast, *in* F. P. Shepard *et al.*, eds., Recent sediments, northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, p. 117–152.

——— *et al.*, eds., 1960, Recent sediments, northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, 394 p.

——— *et al.*, 1963, Submarine geology: New York, Harper and Row, 557 p.

——— *et al.*, 1969, Physiography and sedimentary process of La Jolla submarine fan and fan-valley, California: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 390–420.

Shepheard, W. W., and L. V. Hills, 1970, Depositional environments, Bearpaw-Horseshoe Canyon (Upper Cretaceous) transition zone, Drumheller "Badlands," Alberta: Bull. Canadian Petroleum Geology, v. 18, p. 166–215.

Shideler, G. L., 1969, Dispersal patterns of Pennsylvanian sandstones in the Michigan basin: Jour. Sed. Petrology, v. 39, no. 3, p. 1229–1237.

Shirley, M. L., ed., 1966, Deltas: Houston Geol. Soc., 251 p.

Shuiyak, B. A., and V. L. Boldyrev, 1966, The processes of beach ridge formation: Oceanology (Engl. ed.), v. 6, no. 1, p. 88–94.

Siebold, E., 1963, Geological investigation of nearshore sand transport—examples of methods and problems from Baltic and North Seas, *in* Progress in oceanography, v. 1: New York, The Macmillan Co., p. 3–70.

Simons, D. B., and E. V. Richardson, 1961, Forms of bed roughness in alluvial channels: Am. Soc. Civil Engineers Proc., Jour. Hydraulics Div., v. 87, no. HY 3, May, p. 87–105.

——— 1962, The effect of bed roughness on depth-discharge relations in alluvial channels: U.S. Geol. Survey Water-Supply Paper 1498-E.

——— 1966, Resistance to flow in alluvial channels: U.S. Geol. Survey Prof. Paper 422-J, 69 p.

——— *et al.*, 1965, Sedimentary structures generated by flow in alluvial channels, *in* Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, p. 34–52.

Sims, J. D., 1967, Geology and sedimentology of the Livingston Group, northern Crazy Mountains, Montana: Evanston, Illinois, Northwestern Univ., PhD thesis, 109 p.

Sioli, H., 1966, General features of the delta of the Amazon, *in* Scientific problems of the humid tropic zone deltas and their implications: UNESCO, Dacca Symposium Proc., p. 381–390.

Sloane, B. J., Jr., 1958, The subsurface Jurassic Bodcaw sand in Louisiana: Louisiana Geol. Survey Geol. Bull. 33.

Smith, A. E., Jr., 1971, Deltas of the world—modern and ancient, bibliography: Houston Geol. Soc. Delta Study Group, 42 p.

Smith, A. J., 1966, Modern deltas: comparison maps, *in* Deltas in their geologic framework: Houston Geol. Soc., p. 233–251.

Smith, H. T. U., 1954, Coastal dunes: Coastal Geog. Conf., February, U.S. Office Naval Research, p. 51–56.

Smith, N. D., 1970, The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north central Appalachians: Geol. Soc. America Bull., v. 81, p. 2993–3014.

Snavely, P. D., Jr., *et al.*, 1964, Rhythmic-bedded eugeosynclinal deposits of the Tyee Formation, Oregon Coast Range, *in* Symposium on cyclic sedimentation: Kansas Geol. Survey Bull. 169, p. 461–480.

Spearing, D. R., 1969, Stratigraphy, sedimentation, and tectonic history of the Paleocene-Eocene Hoback Formation of western Wyoming: Ann Arbor, Michigan, Univ. Michigan, PhD thesis, 179 p.

Stanley, D. J., 1967, Comparing patterns of sedimentation in some modern and ancient submarine canyons: Earth and Planetary Sci. Letters, v. 3, p. 371–380.

——— 1968, Graded bedding-sole marking-graywacke assemblage and related sedimentary structures in some Carboniferous flood deposits, eastern Massachusetts: Geol. Soc. America Spec. Paper 106, p. 211–239.

——— 1969, Submarine channel deposits and their fossil analogs ("fluxoturbidites"), *in* New concepts of continental margin sedimentation: Am. Geol. Inst. Short Course Notes, Nov. 7–9, p. DJS-9-1–DJS-9-17.

——— 1970, Flyschoid sedimentation on the outer Atlantic margin off northeast North America, *in* Flysch sedimentology in North America: Geol. Assoc. Canada Spec. Paper No. 7, p. 179–210.

——— 1972, Submarine channel deposits, fluxoturbidites and other indicators of slope and base-of-slope environments in modern and ancient marine basins, *in* J. K. Rigby and W. K. Hamblin, eds., Recognition of sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.

——— and N. Silverberg, 1969, Recent slumping on the continental slope off Sable Island bank, southeast Canada: Earth and Planetary Sci. Letters, v. 6, p. 123–133.

——— *et al.*, 1971, Lower continental rise east of the middle Atlantic states: predominant sediment dispersal perpendicular to isobaths: Geol. Soc. America Bull., v. 82, p. 1831–1840.

Stetson, H. C., 1953, The sediments of the northwestern Gulf of Mexico—Part 1. The continental terrace of the western Gulf of Mexico: its surface sediments, origin and development, *in* Papers in physical oceanography and meteorology: Massachusetts Inst. Tech. Abs. Theses, v. 12, no. 4, p. 5–45.

Stokes, W. L., 1961, Fluvial and eolian sandstone bodies in Colorado Plateau, *in* J. A. Peterson and J. C. Osmond, eds., Geometry of sandstone bodies: Am. Assoc. Petroleum Geologists, p. 151–178.

——— 1964, Eolian varving in the Colorado Plateau: Jour. Sed. Petrology, v. 34, no. 2, p. 429–433.

——— 1968, Multiple parallel-truncation bedding planes—a feature of wind-deposited sandstone formations: Jour. Sed. Petrology, v. 38, no. 2, p. 510–515.

Sullwold, H. H., Jr., 1960, Tarzana fan, deep submarine fan of late Miocene age, Los Angeles County, California: Am. Assoc. Petroleum Geologists Bull., v. 44, p. 433–457.

Sundborg, A., 1956, The river Klarälven. A study of fluvial processes: Geog. Annaler, v. 38, p. 127–316.

Swann, D. H., 1964, Late Mississippian rhythmic sediments of Mississippi Valley: Am. Assoc. Petroleum Geologists Bull., v. 48, no. 5, p. 637–658.

——— *et al.*, 1965, The Borden Siltstone (Mississippian) delta in southwestern Illinois: Illinois Geol. Survey Circ. 386, 20 p.

Swift, D. J. P., 1969, Inner shelf sedimentation: processes and products, *in* New concepts of continental margin sedimentation: Am. Geol. Inst. Short Course Notes, Nov. 7–9, p. DS-4-1–DS-4-46.

——— and R. M. McMullen, 1968, Preliminary studies of intertidal sand bodies in the Minas Basin, Bay of Fundy, Nova Scotia: Canadian Jour. Earth Sci., v. 5, no. 2, p. 175–183.

Sykes, G., 1937, The Colorado delta: Carnegie Inst. Washington Pub. 460, 193 p.

Taylor, J. H., 1963, Sedimentary features of an ancient deltaic complex: the Wealden rocks of southeastern England: Sedimentology, v. 2, p. 2–28.

Thachuk, N. M., 1968, Geological study of the Middle Devonian Gilwood arkoses in the Nipisi area, Alberta: Petroleum Soc. of Canadian Inst. Mining and Metallurgy, 19th Ann. Tech. Mtg., Preprint No. 6828, 17 p.

Thom, B. G., 1967, Mangrove ecology and deltaic geomorphology: Tabasco, Mexico: Jour. Ecology, v. 55, p. 301–343.

Thomas, W. A., and C. J. Mann, 1966, Late Jurassic depositional environments, Louisiana and Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 178–182.

Thompson, R. W., 1968, Tidal flat sedimentation on the Colorado River delta, northwestern Gulf of California: Geol. Soc. America Mem. 107, 133 p.

Thompson, W. O., 1937, Original structures of beaches, bars, and dunes: Geol. Soc. America Bull., v. 48, p. 723–752.

Todd, T. W., 1968, Dynamic diversion: influence of longshore current-tidal flow interaction on chenier and barrier island plains: Jour. Sed. Petrology, v. 38, p. 734–746.

——— and W. A. Monroe, 1968, Petrology of Domengine Formation (Eocene) at Potrero Hills and Rio Vista, California: Jour. Sed. Petrology, v. 38, p. 1024–1039.

Trask, P. D., *et al.*, 1955, Recent marine sediments—a symposium: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 4, 736 p.

Treadwell, R. C., 1955, Sedimentology and ecology of southeast coastal Louisiana: Baton Rouge, Louisiana, Louisiana State Univ., unpub. thesis, p. 1–176.

Trimonis, E. S., and K. M. Shimkus, 1970, Sedimentation at the head of a submarine canyon: Acad. Sci. USSR, Oceanology (Engl. ed.), v. 10, p. 74–85.

Trowbridge, A. C., 1911, The terrestrial deposits of Owens Valley, California: Jour. Geology, v. 19, p. 709–[illegible]

——— 1930, Building of Mississippi delta: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 867–901.

van Andel, Tj. H., 1960, Sources and dispersion of Holocene sediments, northern Gulf of Mexico, *in* F. P. Shepard *et al.*, Recent sediments, northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, p. 34–[illegible]

——— 1964, Recent marine sediments of Gulf of California, *in* Tj. H. van Andel and G. C. Shor, Jr., eds., Marine geology of the Gulf of California: Am. Assoc. Petroleum Geologists Mem. 3, p. 216–310.

——— 1967, The Orinoco delta: Jour. Sed. Petrology, v. 37, no. 2, p. 297–310.

——— and J. R. Curray, 1960, Regional aspects of modern sedimentation in northern Gulf of Mexico and similar basins and paleogeographic significance, *in* F. P. Shepard *et al.*, eds., Recent sediments of northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, p. 345–364.

——— and G. C. Shor, Jr., eds., 1964, Marine geology of the Gulf of California: Am. Assoc. Petroleum Geologists Mem. 3, 408 p.

Van Lopik, J. R., 1955, Recent geology and geomorphic history of central coastal Louisiana: Louisiana State Univ. Coastal Studies Inst. Tech. Rept. 7, [illegible]

Vann, J. H., 1959, The geomorphology of the Guiana coast: Louisiana State Univ. Coastal Studies Inst., 2d Coastal Geog. Conf. Proc., p. 153–187.

van Straaten, L. M. J. U., 1951, Texture and genesis of Dutch Wadden Sea sediments: 3d Internat. Cong. Sedimentology Proc., Netherlands, p. 225–244.

——— 1954a, Composition and structure of Recent marine sediments in the Netherlands: Leidsche Geol. Meded., pt. 19, p. 1–110.

——— 1954b, Sedimentology of Recent tidal flat deposits and the Psammites du Condroz (Devonian): Geologie en Mijnbouw, v. 16, p. 25–47.

——— 1959, Littoral and submarine morphology of the Rhone delta: Louisiana State Univ. Coastal Studies Inst., 2d Coastal Geog. Conf. Proc., p. 233–[illegible]

——— 1961, Sedimentation in tidal flat areas: Alberta Soc. Petroleum Geologists Jour., v. 9, p. 203–226.

——— 1965, Coastal barrier deposits in south- and north-Holland [illegible] Netherlands, Geol. Sticht. Meded., new series, no. 17, p. 41–75.

Venkatarathnam, K., 1970, Formation of the barrier spit and other sand ridges near Chilka Lake on the east coast of India: Marine Geology, v. 9, no. 2, p. [illegible]

Visher, G. S., 1965a, Use of vertical profile in environmental reconstruction: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 1, p. 41–61.

——— 1965b, Fluvial processes as interpreted from ancient and Recent fluvial deposits, *in* Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, p. 116–131.

——— 1965, Depositional framework of the Bluejacket-Bartlesville sandstone, *in* Guidebook to geology of the Bluejacket-Bartlesville sandstone, Oklahoma: Oklahoma City Geol. Soc., p. 32–51.

——— 1972, Physical characteristics of fluvial deposits, *in* J. K. Rigby and W. K. Hamblin, eds., Recognition of ancient sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.

——— *et al.*, 1971, Pennsylvanian delta patterns and petroleum occurrences in eastern Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 1206–1230.

Volker, A., 1966, The deltaic area of the Irrawaddy River in Burma, *in* Scientific problems of the humid tropic zone delta and their implications: UNESCO, Dacca Symposium Proc., p. 373–379.

Waechter, N. D., 1970, Braided stream deposits of the Red River, Texas panhandle (abs.): Geol. Soc. America Abs. with Programs, v. 2, no. 7, p. 713.

Walker, J. R., and J. V. Massingill, 1970, Slump features on the Mississippi fan, northeastern Gulf of Mexico: Geol. Soc. America Bull., v. 81, p. 3101–3108.

Walker, K. R., 1962, Lithofacies maps of Lower Mississippian clastics of eastern and east-central United States: Am. Assoc. Petroleum Geologists Bull., v. 46, p. 105–111.

Walker, R. G., 1966, Deep channels in turbidite-bearing formations: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 1899–1917.

Walton, W. C., 1970, Groundwater resource evaluation: New York, McGraw-Hill Co., 664 p.

Wanless, H. R., *et al.*, 1970, Late Paleozoic deltas in the central and eastern United States, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 215–245.

Warme, J. E., 1966, Geology of Mugu Lagoon: Univ. California at Los Angeles, PhD dissert.

——— 1971, Paleoecological aspects of a modern coastal lagoon: California Univ. Pubs. Geol. Soc., v. 87, 134 p.

Way, J. H., Jr., 1968, Bed thickness analysis of some Carboniferous fluvial sedimentary rocks near Joggins, Nova Scotia: Jour. Sed. Petrology, v. 38, no. 2, p. 424–433.

Weidie, A. E., 1968, Bar and barrier-island sands: Gulf Coast Assoc. Geol. Socs. Trans., v. 18, p. 405–415.

Weimer, R. J., 1961a, Spatial dimensions of Upper Cretaceous sandstones, Rocky Mountain area, *in* J. A. Peterson and J. C. Osmond, eds., Geometry of sandstone bodies: Am. Assoc. Petroleum Geologists.

——— 1961b, Upper Cretaceous delta on tectonic foreland, northern Colorado and southern Wyoming (abs.): Am. Assoc. Petroleum Geologists Bull., v. 45, p. 417.

——— 1965, Late Cretaceous deltas, Rocky Mountain region (abs.): Am. Assoc. Petroleum Geologists Bull., v. 49, p. 363.

Welder, F. A., 1959, Processes of deltaic sedimentation in the lower Mississippi River: Louisiana State Univ. Coastal Studies Inst. Tech. Rept. No. 12, p. 1–90.

Wermund, E. G., and W. A. Jenkins, Jr., 1970, Recognition of deltas by fitting trend surfaces to Upper Pennsylvanian sandstones in north-central Texas, *in* Deltaic sedimentation—modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 156–269.

Wessel, J. M., 1969, Sedimentary history of Upper Triassic alluvial fan complexes in north-central Massachusetts: Massachusetts Univ. Dept. Geology Contr. No. 2, 157 p.

Wier, C. E., and W. A. Girdley, 1963, Distribution of the Inglefield and Dicksburg Hills Sandstone members in Posey and Vanderburgh Counties, Indiana: Indiana Acad. Sci. Proc., v. 72, p. 212–217.

Wilde, P., 1965, Recent sediments of the Monterey deep-sea fan: Cambridge, Massachusetts, Harvard Univ., PhD dissert., 153 p.

Williams, G. E., 1966, Paleogeography of the Torridonian Applecross Group: Nature, v. 209, no. 5030, p. 1303–1306.

——— 1969, Characteristics and origin of a Pre-Cambrian pediment: Jour. Geology, v. 77, p. 183–207.

Williams, P. F., and B. R. Rust, 1969, The sedimentology of a braided river: Jour. Sed. Petrology, v. 39, no. 2, p. 649–679.

Wilson, M. D., 1967, The stratigraphy of the Beaverhead Group in the Lima area, southwestern Montana: Evanston, Illinois, Northwestern Univ., PhD dissert., 183 p.

——— 1970, Upper Cretaceous-Paleocene synorogenic conglomerates of southwestern Montana: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 1843–1867.

Winder, C. G., 1965, Alluvial cone construction by alpine mudflow in a humid temperate region: Canadian Jour. Earth Sci., v. 2, p. 270–277.

Winterer, E. L., *et al.*, 1968, Geological history of the pioneer fracture zone with the Delgada deep-sea fan northeast Pacific: Deep-Sea Research, v. 15, no. 5, p. 509–520.

Wolff, M. P., 1967, Deltaic sedimentation of the Middle Devonian Marcellus Formation in southeastern New York: Ithaca, New York, Cornell Univ., PhD dissert., 231 p.

Wolman, M. G., and L. M. Brush, 1961, Factors controlling the size and shape of stream channels in coarse noncohesive sands: U.S. Geol. Survey Prof. Paper 282-G, p. 183–210.

——— and L. B. Leopold, 1957, River flood plains: some observations on their formation: U.S. Geol. Survey Prof. Paper 282-C, p. 87–107.

Wurster, P., 1964, Delta sedimentation in the German Keuper Basin, *in* Deltaic and shallow marine deposition: Amsterdam, Elsevier Publishing Co., p. 436–446.

Zenkovich, V. P., 1964, Formation and burial of accumulative forms in littoral and nearshore marine environments: Marine Geology, v. 1, p. 175–180.

——— 1967, Processes of coastal development: New York, Interscience Publishers—Division of John Wiley and Sons, Inc.