Coastal Sedimentary Environments

Edited by Richard A. Davis, Jr.

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Introduction

Richard A. Davis

The zone where land and sea meet is composed of a variety of complex environments. The coastal areas of the world contain a large percentage of its population and are therefore of extreme economic importance. Industrial, residential, and recreational developments, as well as large urban complexes, occupy much of the coastal margin of most highly developed countries. Undoubtedly future expansion in many undeveloped maritime countries will also be concentrated on coastal areas. Accompanying our occupation of coasts in this age of technology is a dependence on coastal environments for transportation, food, water, defense, and recreation. In order to utilize the coastal zone to its capacity, and yet not plunder its resources, we must have extensive knowledge of the complex environments contained along the coasts.

The many environments within the coastal zone include bays, estuaries, deltas, marshes, dunes, and beaches. A tremendously broad range of conditions is represented by these environments. Salinity may range from essentially fresh water in estuaries, such as along the east coast of the United States, to extreme hypersaline lagoons, such as Laguna Madre in Texas. Coastal environments may be in excess of a hundred meters deep (fjords) or may extend several meters above sea level in the form of dunes. Some coastal environments are well protected and are not subjected to high physical energy except for occasional storms, whereas beaches and tidal inlets are continuously modified by waves and currents.

Because of their location near terrestrial sources, coastal environments contain large amounts of nutrients. The combination of this nutrient supply with generally shallow water gives rise to a diverse and large fauna and flora. Coastal areas also serve as the spawning and nursery grounds for many open-ocean organisms. Many species in coastal environments are of great commercial importance, such as clams, oysters, shrimp, and many varieties of fish. It is certain that we need better management of these resources. We also need to develop more and improved methods of cultivating these environments.

All of the above examples point out the need for a fundamental knowledge of modern coastal environments. An almost equally important aspect of coastal environments is their role in the geologic record. In order to properly interpret the relationships and depositional environments among various facies preserved in the rock record it is necessary to have a thorough understanding of modern environments (Law of Uniformitarianism). There is a great deal of economic significance to ancient coastal environments. Water, oil, and gas occur in large quantities in various reservoir sands of beach and dune complexes of ancient barrier island and inner shelf sands. The huge clastic wedge deposits of ancient deltaic environments are also a source of petroleum materials and coal.

All of the above examples indicate various reasons that a comprehensive knowledge of coastal environments is necessary for a geologist, engineer, oceanographer, or coastal manager, or for other persons involved in the coastal zone. This book is designed to provide such a background. Most of the important coastal environments are included. The discussions contain such descriptive aspects as morphology and sediment distribution but also emphasize physical processes and their interactions with the sediments and sediment body morphology. Primary consideration is given to the principles involved and to general considerations but numerous case history examples are included.

Our efforts here represent an unusual attempt to produce a text for student use in that each chapter is authored by a different individual or individuals. The subject matter makes this approach a practical one in that the discussion of each of the coastal environments is presented by a specialist who has considerable experience in the environment being discussed.

Each of the chapters that covers one of the coastal environments can stand alone. As a result these chapters can be ordered to suit the reader or the instructor. The depth of treatment for each of these chapters shows some variation, in part because of the existing literature. For example, there are many volumes devoted to beaches, estuaries, and deltas in addition to the journal literature. Such coastal environments as dunes and marshes, in contrast, have not received the same coverage in the literature, especially by way of thorough summaries. These environments therefore have been treated in more detail than other environments. The chapters on dunes and marshes are probably the most comprehensive summaries available in the literature.

The last two chapters both involve applications of basic principles to the study of coastal environments or coastal systems. The chapter on sequences, especially Holocene stratigraphic sequences, provides an excellent framework for the reader to gain an understanding of Walther's Law as well as coastal systems. Application of computer techniques to coastal sedimentation has been an important and valuable tool. The discussion of this topic considers various approaches to modeling, including conceptual, simulation, and predictor types. No consideration is given to programming or computer language; only the principles of modeling and various examples are discussed.

Authors

Each of the contributors is an active researcher in the coastal zone, with specialization in the environment for which he is responsible in the book. The authors represent a rather broad spectrum of backgrounds, with research experience being concentrated on the Atlantic and Gulf coasts of the United States, although most have some foreign experience as well.

Dr. Paul B. Basan is an expert in sediment–organism relationships. He conducted his doctoral research on sedimentation in salt marshes under the supervision of his co-author, Dr. R. G. Frey, at the University of Georgia. In addition to his research in salt marshes, Dr. Basan has authored several research articles on trace fossils.

Dr. Robert B. Biggs serves as Assistant Dean in the College of Marine Studies, University of Delaware; in addition, he conducts a research program in coastal estuaries. His work has primarily been in Chesapeake Bay and more recently in Delaware Bay.

Already in his short career, Dr. Jon C. Boothroyd has established himself as an outstanding coastal sedimentologist. Most of his efforts have been concentrated on inlets and periglacial coasts. His many published papers have included the coasts of Alaska and Iceland as well as New England. Most of Dr. Boothroyd's research has been supported by the Office of Naval Research, Geography Programs and the United States Army Corps of Engineers, Coastal Engineering Research Center.

The editor, Dr. Richard A. Davis, Jr., is primarily interested in beach and nearshore sedimentation. He has published numerous research articles with W. T. Fox and has written a text, *Principles of Oceanography,* and edited *Beach and Nearshore Sedimentation* for the SEPM. Most of his research has been supported by the Office of Naval Research, Geography Programs and the Coastal Engineering Research Center, United States Army Corps of Engineers. Dr. Davis has investigated beaches throughout the United States and in Australia.

Dr. William T. Fox combines outstanding expertise in computer modeling with considerable experience in beach and nearshore environments. Included are the Atlantic, Pacific, and Gulf coasts of the United States. Much of his work has been with R. A. Davis and has been funded by the Office of Naval Research.

Although Dr. Robert G. Frey is primarily a paleontologist he has had much experience in sediment–organism relationships. In addition to his many research articles Dr. Frey edited a comprehensive volume, *Trace Fossils.* Much of his marsh research has been funded by the National Science Foundation.

Dr. Victor Goldsmith has considerable experience in dune and shelf sedimentation. His research has been concentrated on the Atlantic coast of the United States, although he has also studied other areas, including the coast of Israel. Dr. Goldsmith's research on dunes was largely supported by the Coastal Engineering Research Center, United States Army Corps of Engineers.

Holocene coastal sequences have been studied by Dr. John C. Kraft for more than a decade. Although most of his research has been along the North Atlantic coast of the United States other areas have also been included with recent emphasis in the eastern Mediterranean Sea. Much of his research has been funded by the National Science Foundation and the Office of Naval Research.

Dr. L. D. Wright visited and investigated nearly every major delta in the world during his association with the Coastal Studies Institute of Louisiana State University. He is continuing deltaic studies but is also investigating beach and nearshore dynamics on the east coast of Australia. Most of Dr. Wright's delta research has been funded by the Office of Naval Research.

Chapter 1
River Deltas

L. D. Wright

Introduction

Deltas are the "gifts" of rivers to the sea. They result from, and are molded by, interacting fluvial and marine forces. Since ancient times river deltas have been of fundamental importance to civilization. Owing to their early significance as agricultural lands, deltas received considerable attention from such scholars as Homer, Herodotus, Plato, and Aristotle. Today deltaic accumulations play a paramount role in accommodating the world's energy needs: Ancient deltaic sediments provide source beds and reservoirs for a large fraction of the known petroleum reserves.

The term "delta" was first applied by the Greek historian Herodotus, circa 450 b.c., to the triangular alluvial deposit at the mouth of the Nile River. For the purposes of this discussion, deltas are defined more broadly as coastal accumulations, both subaqueous and subaerial, of river-derived sediments adjacent to, or in close proximity to, the source stream, including the deposits that have been secondarily molded by various marine agents, such as waves, currents, or tides. According to this definition, deltas include all delta plains, regardless of plan-view shape or of the suite of individual landforms present. Because the different processes that control delta development vary appreciably in relative intensity on a global scale, delta-plain landforms span nearly the entire spectrum of coastal features and include distributary channels, river-mouth bars, open and closed interdistributary bays, tidal flats, tidal ridges, beaches, beach ridges, dunes and dune fields, and swamps and marshes.

The range of deltaic environments is equally broad. Some deltas occur along coasts that experience negligible tides and minimal wave energy; others have formed in the presence of extreme tide ranges or against the opposing forces of huge waves. Deltas may accumulate in the humid tropics, where vegetation is abundant and biologic and chemical processes are of prime importance, or they may form in arid or arctic environments, where biologic activity is subdued. Despite these pronounced environmental contrasts, all actively forming deltas have, by definition, at least one common attribute: A river supplies clastic sediment to the coast and inner shelf more rapidly than it can be removed by marine processes.

Occurrence and Distribution of Deltas

Deltas occur wherever a stream debouches into a receiving basin. This statement holds true whether the receiving basin is an ocean, gulf, inland sea, bay, estuary, or lake. Consequently, deltas of various sizes can be found throughout the world. Figure 1 and Table 1 show the locations of some of the world's largest modern deltas. In addition to these major deltas, literally thousands of minor deltas are distributed over all the world's coasts.

Although major deltas occur on the shores of virtually all seas and at all latitudes except at the poles, there are certain requirements for their occurrence that are not met in many parts of the world. The first prerequisite for a significant deltaic accumulation is the existence of a major river system that carries substantial quantities of clastic sediment. For such a system to exist, there must be a large drainage basin within which precipitation accumulates, sediments are supplied by erosion, and individual tributaries coalesce to create a larger trunk stream. The sediment–water discharge from the drainage basin is then transported to the coast by way of the alluvial valley that confines the trunk stream. The general spatial relationships between the drainage basin, alluvial valley, and delta are illustrated diagramatically in Figure 2.

Whether or not a river is sufficiently large and transports sufficient quantities of sediment to produce a major delta depends largely on the nature of the drainage basin. Drainage basin climate, geology, relief, and area are all critical determinants of river discharge. Unless the drainage basin experiences significant precipi-

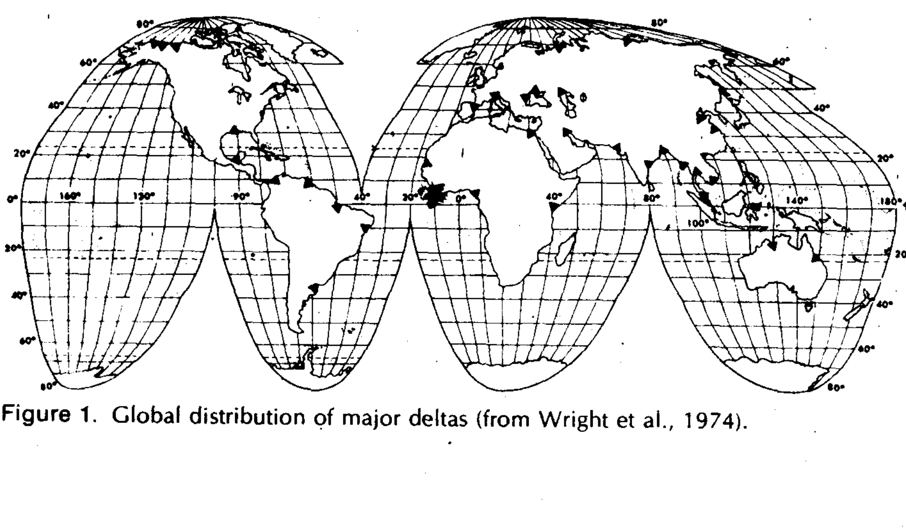

Figure 1. Global distribution of major deltas (from Wright et al., 1974).

Table 1. Major Deltas and Their Locations

River	Continent	Receiving body of water	Coordinates	
			Lat.	Long.
Amazon	South America	Atlantic Ocean	0	52°W
Burdekin	Australia	Coral Sea	19°S	147°E
Chao Phraya	Asia	Gulf of Siam	13°N	101°E
Colville	North America	Beaufort Sea	71°N	151°W
Danube	Europe	Black Sea	43°N	28°E
Dneiper	Asia	Black Sea	47°N	32°E
Ebro	Europe	Mediterranean Sea	41°N	02°E
Ganges–Brahmaputra	Asia	Bay of Bengal	32°N	90°E
Grijalva	North America	Gulf of Mexico	18°N	93°W
Hwang Ho	Asia	Yellow Sea	37°N	118°E
Indus	Asia	Arabian Sea	24°N	67°E
Irrawaddy	Asia	Bay of Bengal	16°N	94°E
Klang	Asia	Straits of Malacca	3°N	101°E
Lena	Asia	Laptev Sea	73°N	125°E
Mackenzie	North America	Beaufort Sea	68°N	139°W
Magdalena	South America	Caribbean Sea	12°N	69°W
Mekong	Asia	South China Sea	10°N	107°E
Mississippi	North America	Gulf of Mexico	30°N	90°W
Niger	Africa	Gulf of Guinea	4°N	7°E
Nile	Africa	Mediterranean Sea	32°N	31°E
Ord	Australia	Timor Sea	16°S	120°E
Orinoco	South America	Atlantic Ocean	8°N	62°W
Paraná	South America	Atlantic Ocean	33°S	58°W
Pechora	Europe	Barents Sea	68°N	54°E
Po	Europe	Adriatic Sea	44°N	12°E
Red	Asia	Gulf of Tonkin	21°N	107°E
Sagavanirktok	North America	Beaufort Sea	70°N	148°W
São Francisco	South America	Atlantic Ocean	11°S	37°W
Senegal	Africa	Atlantic Ocean	17°N	16°W
Shatt-al-Arab	Asia	Persian Gulf	30°N	49°E
Tana	Africa	Indian Ocean	2°S	42°E
Volga	Europe	Caspian Sea	47°N	48°E
Yangtze–Kiang	Asia	East China Sea	32°N	122°E

tation for at least part of the year, no river can arise. Lithologic resistance, combined with drainage basin pedology and vegetation, determines the rate at which sediments can be eroded from the basin to be supplied to the river. Through gravity vertical relief provides the energy to erode the underlying rocks and transport the resulting sediment to the water accumulating in the streams and rivers of the basin.

Of all the requisites for the occurrence of a major river system, probably the most restrictive is the necessity for a large catchment area. The mean basin area of the rivers listed in Table 1 is only slightly less than 10^6 km². The drainage basin of

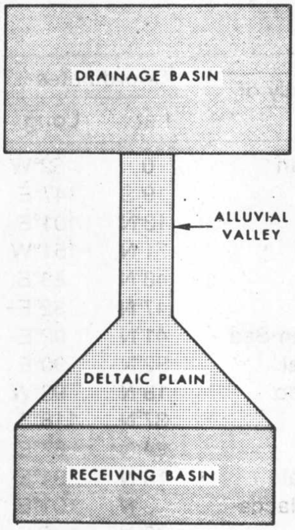

Figure 2. Major components of a river system (from Coleman and Wright, 1971).

the Mississippi, for example, covers 41% of the continental United States, or an area of 3.3×10^6 km², and the Amazon (Brazil) arises from a basin 5.9×10^6 km² in area. Large, high-order drainage basins of this type consist of numerous smaller, low-order basins and result when tributaries join downstream to form a single large stream. Because the process of tributary joining requires both relatively long periods of time and moderately long distances, large river deltas normally are not present along coasts that are highly active tectonically or that are in very close proximity to drainage divides. Accordingly, the occurrence of major river systems is also closely dependent on global tectonics. Inman and Nordstrom (1971) have produced a macroscale classification of the world's coasts in which they distinguish between the following tectonic classes and subclasses (Inman and Nordstrom, 1971, p. 9):

1. Collision coasts
   a. *Continental collision coasts,* that is, collision coasts involving the margins of continents, where a thick plate collides with a thin plate (e.g., west coasts of the Americas)
   b. *Island arc collision coasts,* that is, collision coasts along island arcs, where a thin plate collides with another thin plate (e.g., the Philippines, and the Indonesian and Aleutian island arcs)
2. Trailing-edge coasts
   a. *Neo-trailing-edge coasts,* that is, new trailing-edge coasts formed near beginning separation centers and rifts (e.g., the Red Sea and Gulf of California)
   b. *Afro-trailing-edge coasts,* that is, the opposite coast of the continent is also trailing, so that the potential for terrestrial erosion and deposition at the coast is low (e.g., Atlantic and Indian Ocean coasts of Africa)
   c. *Amero-training-edge coasts,* that is, the trailing-edge of a continent with a collision coast; and therefore "actively" modified by the depositional

products and erosional effects from an extensive area of high interior mountains (e.g., east coasts of the Americas)

3. Marginal sea coasts, that is, coasts fronting on marginal seas and protected from the open ocean by island arcs (e.g., Vietnam, southern China, and Korea)

In connection with their classification, Inman and Nordstrom assembled data on 58 major rivers having drainage areas in excess of 10^5 km^2. Of these, 46.6% were found to debouch along Amero-training-edge coasts (class 2 c), 34.5% along marginal seacoasts (class 3), 8.6% along Afro-trailing-edge coasts (class 2 b), and 1.7% along neo-trailing-edge coasts (class 2 a). Only 8.6% of the rivers examined [the Columbia (United States), Colorado (United States), Frazer (Canada), Ebro (Spain), and Po (Italy) Rivers] enter the sea along collision coasts, where tectonic activity is high and drainage divides are characteristically close to the sea.

General Characteristics of Deltas and Deltaic Environments

Deltas vary immensely in terms of morphologic suites, overall geometry, sediment properties, and dynamic environment. Consequently, with regard to these factors very few generalizations can be made until the causes and scope of the variability are considered in the sections to follow. Nevertheless, there are a few general features that are almost universal among deltas and a few general processes that all deltas experience, although in varying intensities. These common denominators are the subjects of this section; in the following sections the processes of deltaic development and the causes of deltaic variability are considered in more detail.

Delta Components

On a gross scale, delta plains can be subdivided into the basic physiographic zones illustrated in Figure 3. Generally, every delta consists of a subaqueous delta and a subaerial delta, even though the relative areas of these may vary considerably. The subaqueous delta is that portion of the delta plain which lies below the low-tide water level; it is the foundation on which progradation of the subaerial delta must proceed. In general, the subaqueous delta is characterized by seaward fining of sediments, sand being deposited nearest the river mouths and fine silts and clays settling farther offshore from suspension in the water column. The seawardmost portion of the subaqueous delta is composed of the finest material deposited from suspension (primarily clays) and is referred to as the prodelta. The prodelta clays grade upward and landward into the coarser silts and sands of the delta front. The latter are deposited at least in part from traction load. The depositional features of the delta front are nearly as varied as deltas themselves and depend on the associated dynamic environments. In addition to a variety of types of distributary-mouth accumulations, the delta front may include such features as linear tidal ridges or shoreface beach deposits.