DELTAS

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Summary

The world's river deltas are among the most important natural environments on Earth because they support large human populations that live on the subaerial parts of the delta and an even larger population that relies on their enormous productivity in agriculture, fisheries, and oil and gas production. Deltas are composed of a complex set of sub-environments at the land-ocean interface that are susceptible to rapid migration or degradation with environmental change or ocean processes, such as waves, tides and coastal currents. As we enter the twenty-first century, many deltas are imperiled by a host of natural and human-induced environmental problems including concentration of pollutants from upland and local sources, land loss due to local subsidence and sea level rise, and conversion of habitat.

1. Introduction

The term "delta" was originally coined by the ancient Greeks, who recognized that the land area at the mouth of the Nile (Fig. 1) and other Mediterranean rivers resembled the Greek letter (Δ). Deltas are depositional landforms, derived from sediment particles and

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dissolved ions delivered by rivers to a basin. In most cases this basin is the marine environment, although deltas can form along lake margins or even in inland basin areas, such as the Okavango (Botswana). Deceleration of the unidirectional river flow entering the ocean results in a reduced ability to carry sediments, causing rapid deposition on the continental shelf adjacent to the river mouth. River discharge points into the ocean often remain stable for millions of years, resulting in sediment accumulations that can reach 15 to 20 km in thickness. These enormous volumes of material are accommodated on the margin because the great weight of sediments deforms the underlying crust of the Earth and generates internal sediment compaction. The resulting subsidence in deltaic areas partially balances the input of new sediments. Deltas are among the most *dynamic* of Earth's environments, as the zone of active sediment deposition migrates in response to changing sea level, subsidence, and the interplay between constructive processes, such as river sediment supply, and destructive processes (e.g. tidal currents, ocean waves) that erode the delta front.

Figure1. U.S. Space Shuttle photograph of the Nile delta in Egypt showing the river channel and floodplain entering the delta from the upper left. The vegetated area of the delta (dark blue) contrasts sharply with the desert sands (yellow) of adjacent areas of Egypt. The Mediterranean Sea is located in the lower right of the image. *Photo provided by NASA.*

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Deltas have served as the cradle for many of the world's great civilizations, including the Egyptian (Nile), Sumerian (Tigris-Euphrates), Indian (Indus), and Chinese (Yangtze and Huang-ho). This concentration of populations resulted from the enormous ecological resources of deltas. The provision of dissolved and particulate nutrients by the associated river supports a complex food web that provided early peoples with game and shallow water fisheries (fin and shell). Higher-elevation inland areas subjected to cyclic inputs of fine-grained sediment with the river flood are some of the richest and most self-sustaining (i.e. no artificial fertilizers) agricultural soils on Earth. Although many deltas continue to support a large human population, the lesson of the twentieth century are that deltas are also among the most *fragile* of Earth's environments. Deltas are part of a larger dispersal system (see Figure 2), and can experience profound change with human alteration of the drainage basin (e.g. deforestation, dams). They also concentrate chemical (toxins, fertilizers) input into the drainage basin with deleterious effect on the deltaic food web. Drilling for oil and gas deposits and overfishing have environmental consequences for offshore deltaic areas. In addition to the increasing direct pressures of modern civilization, global warming threatens to raise sea level rapidly, inundating large areas of the world's deltas. The new millennium brings with it many challenges to maintain, protect, and restore one of the most precious life support systems for mankind and other living things.

2. Subenvironments

Recent studies have shown that most of the world's deltas began to form in their present location at about 8500 to 7000 cal yBP. This also marks the time that humans began to settle into communities and to grow crops. It was at this time that the post-glacial rise in sea level generated by melting of high-latitude ice sheets began to slow. Prior to this period, river discharge points retreated across the rapidly flooding continental shelf surface.

Except in areas experiencing regional subsidence or uplift of the continental margin relative to worldwide (eustatic) sea level, sea level has remained within about 2 m of present levels since about 7000 cal yBP. This has permitted seaward growth of deltas driven by the supply of new sediment discharged by the rivers. The present interglacial period of sea level highstand resembles the magnitude of earlier sea level events in the Quaternary. This new deltaic sediment is deposited on top of earlier highstand deltaic units, resulting in kms thick sedimentary sections.

Deltas have been recognized by the scientific community to be composed of several subenvironments (Figure 2) that have distinct landforms, ecology, and sediment deposits. The boundaries between these subenvironments migrate laterally through time. Migration of deltaic environments is a natural process driven by the competing effects of river sediment deposition and destruction by waves, tides, subsidence, and rising or falling eustatic sea level.As the delta front decays in an area, inland regions are subjected to increased soil salinities that results in displacement of the plant and animal community with a saline-tolerant ecology. Offshore growth of the delta (progradation) results in accretion of the land surface elevation, thus reversing this process. As discussed in Section 4, anthropogenic effects can greatly accelerate this natural migration of environments. There are four main subenvironments in deltas (see Figure

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2).

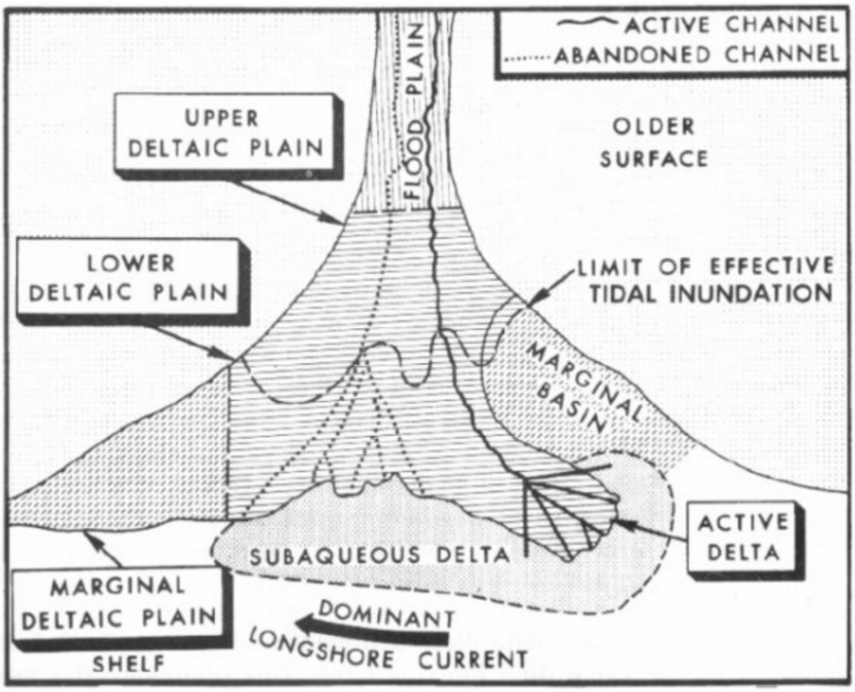

Figure 2. Principle components of a delta system (from Coleman and Prior, 1982)

The *upper* and *lower delta plains* are subaerial portions of the delta that differ mainly in their proximity to the ocean and exposure to saline waters. As a result, lower delta plains tend to be dominated by a saline marsh or mangrove community while, further inland, upper delta plain areas show a gradation from freshwater marsh grasses to swamps (tree-dominated wetlands). The inland boundary of the latter subenvironment merges with the lowland floodplain of the river's alluvial valley. The *river channel* and its distributary channels form a third, laterally migrating subenvironment on the subaerial delta. Much of the delta's active sediment deposition takes place subaqueously: a fourth subenvironment that is found on the inner continental shelf.

2.1. Upper Delta Plain

The alluvial valley of a river is the land area adjacent to the river channel that has been occupied in the past by the river channel and is underlain by river-deposited sediment (alluvium) from old channel deposits and from overbank flooding. This area is variable in width, dependent on the degree of confinement of the river channel by higher elevation landforms. In most deltas, as the river approaches the coast, the alluvial valley spreads laterally with the disappearance of confining hills.

Often, this also marks the point at which sediment deposits of deltaic origin are found at depth, e.g. sediments deposition influenced by marine, as well as riverine, processes. This *upper deltaic plain* is low-elevation (usually less than 10 m above sea level) and slopes seaward. As river water spills out onto this plain, water velocity decreases in the channel, causing increased lateral meandering of the river channel (see section 2.3) and a tendency to bifurcate into distributary channels. The extent of the upper delta plain is dependent on factors such as local topography, magnitude of the river sediment load, and age of the river, but it can be enormous. The Ganges-Brahmaputra upper deltaic plain for example encompasses virtually all of Bangladesh and large adjacent areas of India.

While the bulk of the active delta building takes place nearer to the river-ocean interface, the upper delta plain remains an area of river sediment deposition by overbank flooding. Channel migration and avulsion erodes older deltaic deposits from the upper delta plain and reintroduces these sediments to the river-ocean interface. In pristine deltas, the upper delta tends to be an area dominated by swamp vegetation capable of surviving inundation by river and rainwater flooding, except where climatic extremes such as high-latitude or extreme aridity preclude colonization by trees.

The frequency and depth of inundation are controlled by subtle differences in elevation and proximity to river distributaries. This, in turn, creates a patchwork of wetland environments including freshwater marshes and lakes. Inundation affects soil type as well. Poorly drained wetlands, where river and rainwater flooding may remain for all or most of the year are organic-rich, because the high influx of leaf litter and other particulate organic matter cannot breakdown in waters that rapidly become anoxic with bacterial consumption of oxygen. Peats can be found associated with freshwater marshes, where leaf litter supply and organic preservation reach their highest levels.

These deposits are analogues for some types of coals found in older strata. In higher elevations areas, swamps dry out during the low discharge period of the river, depending on its coincidence with local seasonality of rainfall. Well-drained swamp soils are oxygenated and tend to have low (<1%) organic content.

The physiography and ecology of upper delta plain areas are similar to the alluvial valley (i.e. floodplain) of rivers. They differ in that the upper deltaic plain is underlain by a sequence of deltaic strata that may reach kms in thickness. Hence, subsidence plays a role in the evolution of these environments.

In the Mississippi delta for example, a cycle has been described that occurs on 1000 year timescales, where proximity to a river distributary and the sediment it provides by overbank flooding is critical for landform evolution. Areas proximal to the distributary tend to be relatively high, well-drained swamps due to the influx of riverine sediments that counteracts the effects of subsidence by compaction and crustal flexure. As a distributary is isolated by avulsion from the river discharge, this natural levee begins to subside at rates up to 1 cm/yr.

With time, reduction in elevation results in increased flooding by rainwater and regions transition to poorly drained swamp and finally lakes, before reoccupation of that part of the upper delta plain by a river distributary begins to increase elevation with a new influx of sediments. Low-elevation, interdistributary areas are the most vulnerable to natural or anthropogenically generated saline water intrusion. Well-drained areas comprise some of the most productive agricultural soils on Earth because of the regular influx of nutrient-rich riverine sediments.

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Biographical Sketch

Mead Allison is an Associate Professor in the Department of Earth and Environmental Sciences at Tulane University in New Orleans, Louisiana, USA, and a specialist in sediment transport and accumulation in deltaic settings. He has conducted research and authored scientific publications on deltas in North and South America, South Asia, and Europe and presently lives on one of the world's largest deltas (the Mississippi).

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