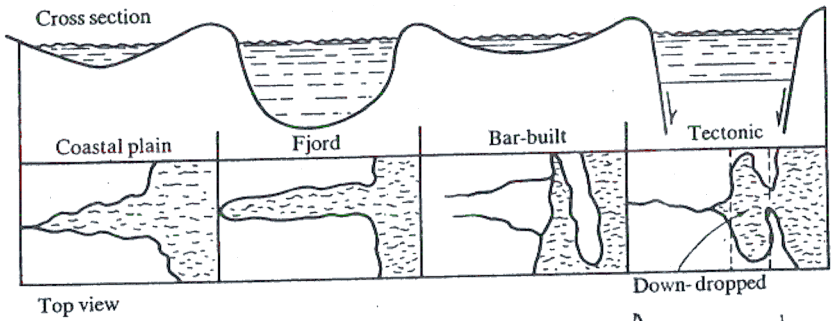


From: The World Ocean, by Ankouchine and Sternberg

10.2 THE ESTUARINE ENVIRONMENT

Men have always lived closed to estuaries, that is, at the mouths of rivers, because these bodies of water provide large quantities of food and give shelter to industrial activity and commerce. Furthermore, estuaries used to provide an easy means of waste disposal. It has been only recently that men have realized the vulnerability of river mouths and, indeed, the entire watershed of a river.

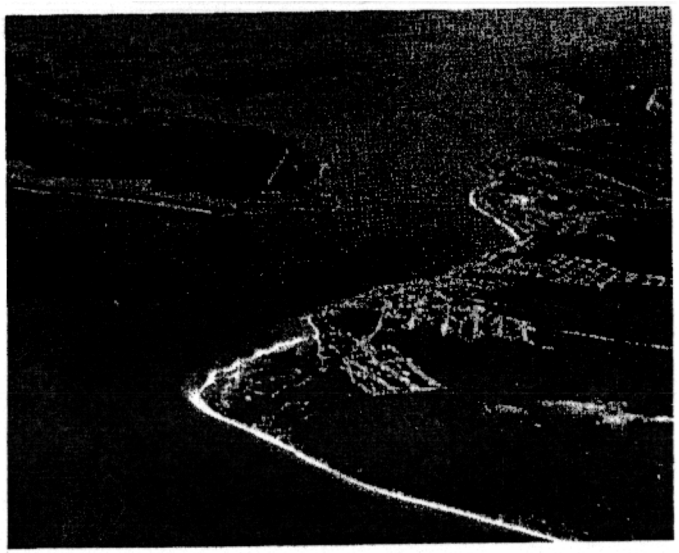
Prior to the mid-19th century, abuses of the estuarine environment were limited to silt erosion from agriculture, overgrazing, and deforestation. Since the industrial revolution, cities, factories, and great transportation facilities have centered around the protection and water afforded by coastal embayments. Today, seven out of the ten largest metropolitan areas of the world have grown up around estuaries. It has been estimated that one-third of the population of the United States lives or works adjacent to its major estuaries. As a result, many coastal bodies of water are suffering from the contaminating effects of industrial and human waste products. An understanding of estuarine processes, therefore, is necessary and critical if men are to use these natural bodies of water without ruining them to the point of irreversible damage.

TYPES OF ESTUARIES

An estuary can be defined as a "semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage." From a geomorphological standpoint, estuaries can be divided into four basic types. These are: (1) coastal plain estuaries, or drowned river valleys, (2) fjords, (3) bar-built estuaries, and (4) estuaries produced by tectonic processes. Each of these types has certain attributes associated with its geography, geometry, catchment basin, bathymetry, and offshore oceanic characteristics.

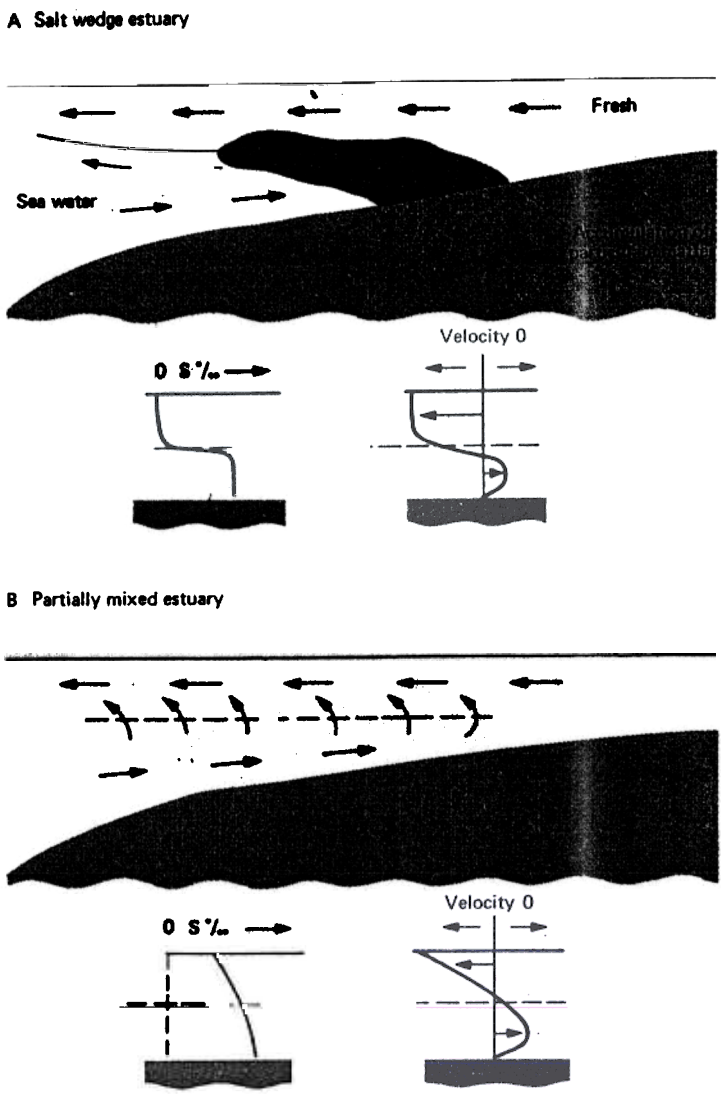
Coastal Plain Estuaries. The rise in sea level at the end of the Pleistocene epoch caused extensive flooding of lowland areas throughout the world. On broad coastal plains, seawater extended up Pleistocene river valleys to form what are called *coastal plain estuaries*. The shoreline of such drowned river valleys follows the drainage pattern of the lower reaches of the river (Fig. 10-28).

Figure 10-28
The rising sea level of the Holocene marine transgression caused seawater to fill the lower portions of existing river valleys.



The circulation within a coastal plain estuary is related to the river flow and the tidal currents. Seawater flows inward along the bottom while the river flows outward at the surface. Mixing occurs in the region of density change between the two layers (Fig. 10-29). The extent of salt-water intrusion is controlled by the tide. The Mississippi River is a prominent example of a *salt-wedge estuary*, in which the river flow is so strong that it obscures the tidal influence on the incursion of seawater along the bottom. The river flow seaward and the seawater intrusion at the river bottom maintain a salinity distribution in the estuary, so that a

FIGURE 10-29
Representation of longitudinal profiles of coastal plain estuaries showing the salt wedge type (A); and the partially mixed type (B).



balance exists between the salt transported inward at the bottom and the salt swept seaward by the river. The salt balance tends to be maintained, because a change in the flow pattern is countered by a change in the salinity distribution in the estuary.

Sedimentation within a salt-wedge estuary is controlled by the water circulation pattern. Fine sediments (clay) that are dispersed in the river-water tend to form aggregates when introduced into seawater. This process, called *flocculation*, occurs in water whose salinity is as low as 8 parts per thousand. The flocculated aggregates sink rapidly and tend to accumulate in the saline wedge above the river bed. Accumulation of sediment in the upper reaches of the estuary is also increased by fine silt carried upstream within the saline wedge (Fig. 10-29A).

During the seasons of low river flow, the tidal currents may become dominant in an estuary and tidal mixing occurs at all depths. Under these circumstances, the vertical gradient of salinity is very small. The estuary is, therefore, considered *vertically homogeneous*. However, a horizontal salinity gradient exists, and the salinity increases toward the sea. The pattern of estuarine circulation shown in Fig. 10-29A almost disappears, and accumulation of suspended sediment within the estuary is retarded.

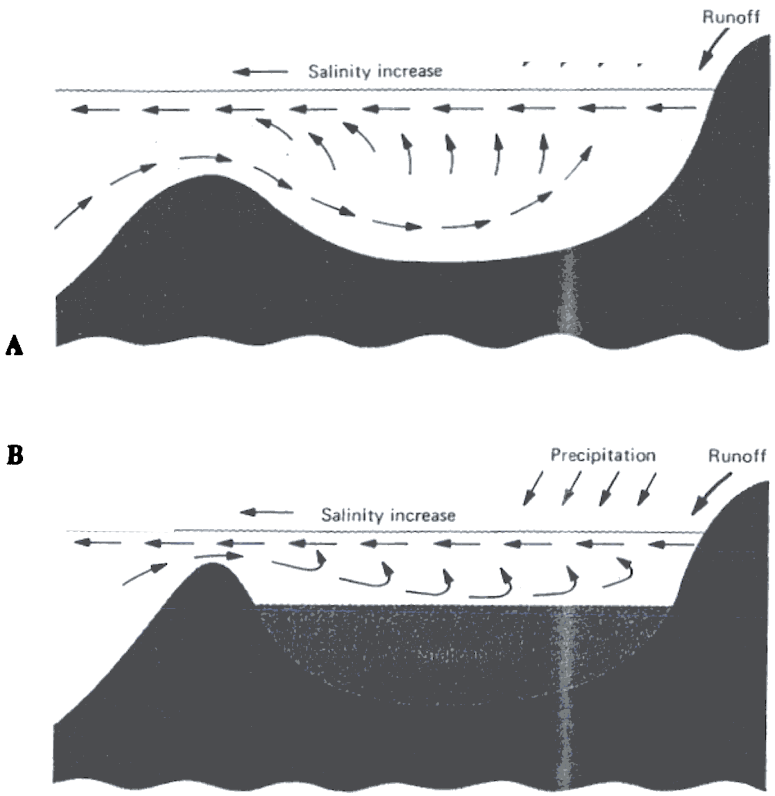
These two conditions (i.e., river-dominated and tide-dominated circulation) simply represent the ends of a continuous spectrum of possible circulation patterns. The ratio of tidal amplitude to river flow determines the pattern that will exist. In most estuaries, the circulation is mixed, falling somewhere between the salt-wedge and the vertically homogeneous cases (Fig. 10-29B). Where river flow changes significantly between seasons, the estuarine circulation changes accordingly. As a result, a given estuary may be closer to the salt-wedge type during peak river runoff and may be well-mixed during low runoff.

A knowledge of circulation is important in the design of waste discharge systems for municipalities and industries located on coastal plain estuaries. An effluent discharged near the bottom of a salt-wedge estuary would migrate upstream and so, may not be dispersed quickly by mixing processes.

FJORDS. Fjords are inlets in the coastal reaches of formerly glaciated valleys. They occur at latitudes above 38 degrees, usually on the western side of continents or large islands where Pleistocene glaciers carved their way to the sea. We find them, therefore, in Greenland, Norway, western Siberia, Scotland, British Columbia, Chile, and New Zealand.

Fjords are characterized by steep walls, a U-shaped cross section, and a sill built of glacial drift deposited near the seaward entrance (Fig. 10-30). The almost vertical walls of many fjords are some of the few places in the world where beaches do not exist (Fig. 10-31). Because the sill and the narrow mouth restrict the entrance, the circulation of water within a fjord is often unique, being controlled by its geometry.

An example of the circulation within a relatively deep-silled fjord is shown in Fig. 10-32. Most fjords exist in temperate and polar regions where the runoff of fresh water is large. We find, consequently, the estuarine features shown in Fig. 10-32A. Biological productivity in mixed estuaries of this sort is generally kept high because mixing and runoff add nutrients to the surface water layers.



Many fjords have extremely shallow sills and great depth (300 to 400 m). These basins tend to become stagnant, because tidal mixing is not sufficient to recirculate deep-water layers. Bottom water becomes *anoxic* when the rate of consumption of oxygen during breakdown of organic detritus settling from the surface layers exceeds the rate of oxygen replenishment. Anoxic water, although rich in the nutrients produced in the decomposition process, is devoid of organisms other than anaerobic bacteria.

The dense bottom water in an anoxic basin can be replaced with oxygenated seawater. Occasionally, when either the runoff of fresh water becomes very low or upwelling brings uncommonly dense water above the sill depth, the body of anoxic water is displaced and kills many marine organisms as it circulates outward. After such an episode of overturning, the process of oxygen depletion in the basin repeats itself. Although it is not a fjord, the Black Sea provides an illustration of this phenomenon.

BAR-BUILT ESTUARIES. On broad, gently sloping continental shelves, sand carried by wave action accumulates in offshore bars aligned parallel to the coast. These bars become barrier islands as they are built upward and shoreward by storm waves that move sand from offshore areas and from sediment sources upcoast. The barrier islands enclose coastal water and form shallow estuaries (Fig. 10-33).

Bar-built estuaries are found on lowland coasts throughout the world. The eastern and gulf coasts of the United States have many good examples. There are several types of circulation and mixing processes within these estuaries. The lower valley of the river that discharges into such an estuary exhibits the characteristics of a salt-wedge estuary. The main part of the bar-built estuary is shallow, with restricted entrances between the barrier islands. As a result, the influence of tides (except within the entrance channels) is minimized. Wind, on the other hand, is an important source of energy for mixing and circulation.

In dry climates where river flow fluctuates dramatically with rainfall, the salinity within the estuary can vary from essentially fresh during high runoff to highly saline (greater than 40 parts per thousand) when net evaporation is excessive.

ESTUARIES PRODUCED BY TECTONIC PROCESSES. In some coastal areas, earth movement by faulting, folding, or local subsidence produces marine basins that receive river discharges. The entrance to these tectonically produced estuaries is often restricted (as in San Francisco Bay). Hence, the circulation and mixing processes can be dominated by either river or tidal flows. In areas having an excess supply of fresh water, the circulation can follow the examples shown in Fig. 10-32.

In regions characterized by net evaporation, the circulation might be reversed, as illustrated in Fig. 10-33. Here, seawater enters the basin on the surface, becomes more dense because of evaporation, sinks, and flows out along the bottom. Biological productivity within an estuary of this sort is relatively low, because the water comes from oceanic surface water already depleted in nutrients. Some nutrients are introduced into the estuary by runoff but not in sufficient quantities to promote phytoplankton growth. Estuaries and larger restricted basins that exhibit a surface inflow of water are found in arid regions. The upper Gulf of California, the Red Sea, and the Mediterranean Sea are examples.