CHAPTER 6 TIDAL FLATS AND ESTUARIES

Excerpt from: "Waves, Tides & Shallow-Water Processes" (Pergamon Press)

'All the rivers run into the sea; yet the sea is not full.'
Ecclesiastes, I, 7.

Wherever wave power is relatively low along a stretch of coastline, and the tidal range is moderate to large, then **tidal flats**, rather than beaches, are likely to develop. Tidal flats usually have very low gradients, in the order of 1:1000 at the landwards edge, and are composed predominantly of silts and clays, instead of sands. The large tidal range and shallow gradients mean that waves do not break on any one part of the flats for a long time and, consequently, the flood and ebb tidal currents are more effective at sediment transport than is wave action.

QUESTION 6.1 With the aid of an atlas, can you suggest why tidal flats are well developed around the Wash on the east coast of England, along the north coast of the Netherlands and along the coastline of the United Arab Emirates?

There are some exceptions where tidal flats occur on coasts facing the open sea, e.g. Surinam on the north-east coast of South America. In such cases, tidal-flat development is encouraged by a combination of exceptionally high concentrations of fine-grained, suspended sediments in the coastal waters and a very gentle offshore slope. Elsewhere, tidal flats are usually restricted to regions in the shelter of features such as spits (e.g. Orford Ness on the Suffolk coast), barrier islands (like the Friesian Islands), and coastal embayments or estuaries.

In the first part of this Chapter, we look at the processes leading to sediment transport and deposition on tidal flats. In the second part, we turn our attention specifically to estuaries where, although the same general principles apply, the interaction of tidal currents and river flow modifies the pattern of sediment transport.

6.1 SEDIMENT TRANSPORT AND DEPOSITION ON TIDAL FLATS

Tidal flats are flat and almost featureless areas which occur along some stretches of coastline and within estuaries. They are often backed by areas of salt-marsh and dissected by a network of tidal channels (Figure 6.1). Seawater enters the tidal channels on the flood tide, gradually filling them as the tide rises until the water spills over and floods the adjacent flats. After the slack water of high tide, the water drains back off the flats and through the tidal channels until the entire tidal flat is exposed once more. This pattern of water movement, and the interaction between tidal currents and wave action, has important consequences for the transport and distribution of sediment on the tidal flat.

6.1.1 SEDIMENT DISTRIBUTION ON TIDAL FLATS

In the simplest situation (e.g. the tidal flats of the Netherlands), there is a seawards progression in grain size from mud-dominated sediments at the

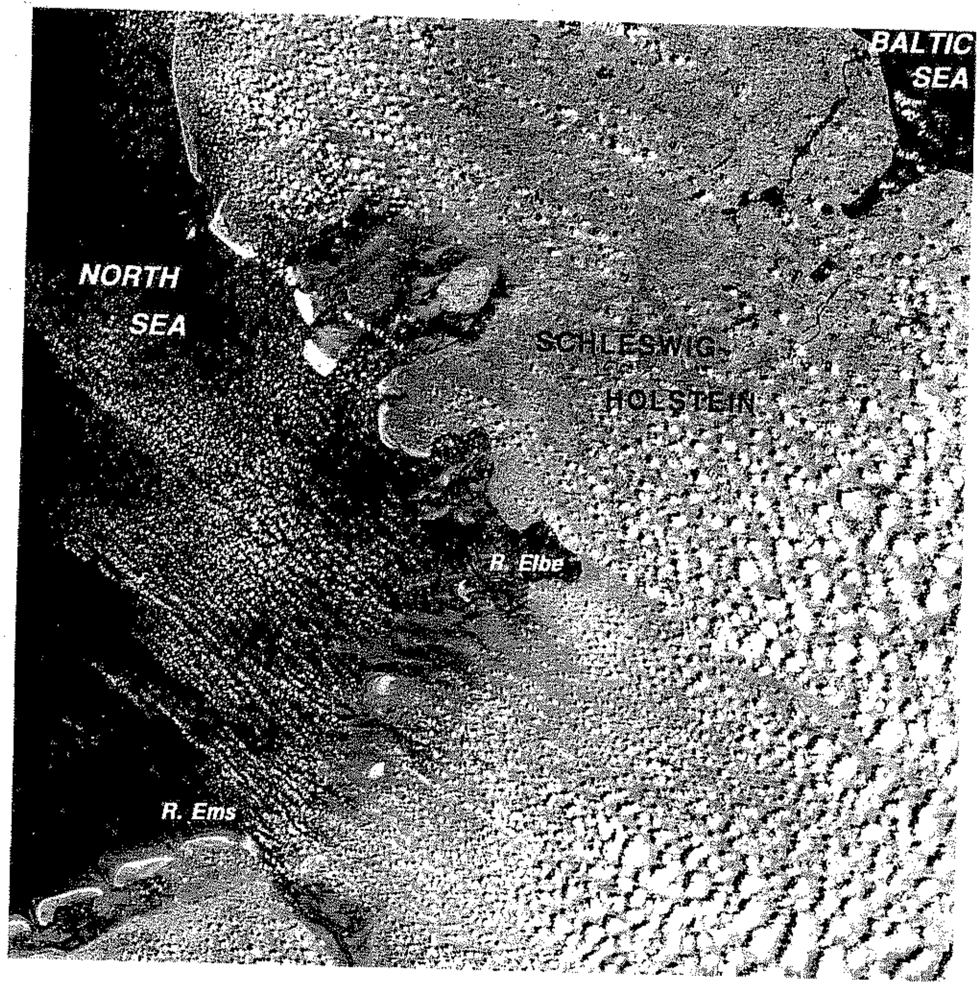

Figure 6.1 Landsat Multispectral Scanner image of part of the German North Sea Coast. Islands and exposed sand bars are shown in white, tidal flats are grey and tidal channels, estuaries and sea areas are black.

landwards end to sand-dominated sediments at the seawards end (Figure 6.2(a)). However, there are departures from this trend (e.g. sediment zonation in the Wash is more complicated due to more extensive wave action in the intertidal zone).

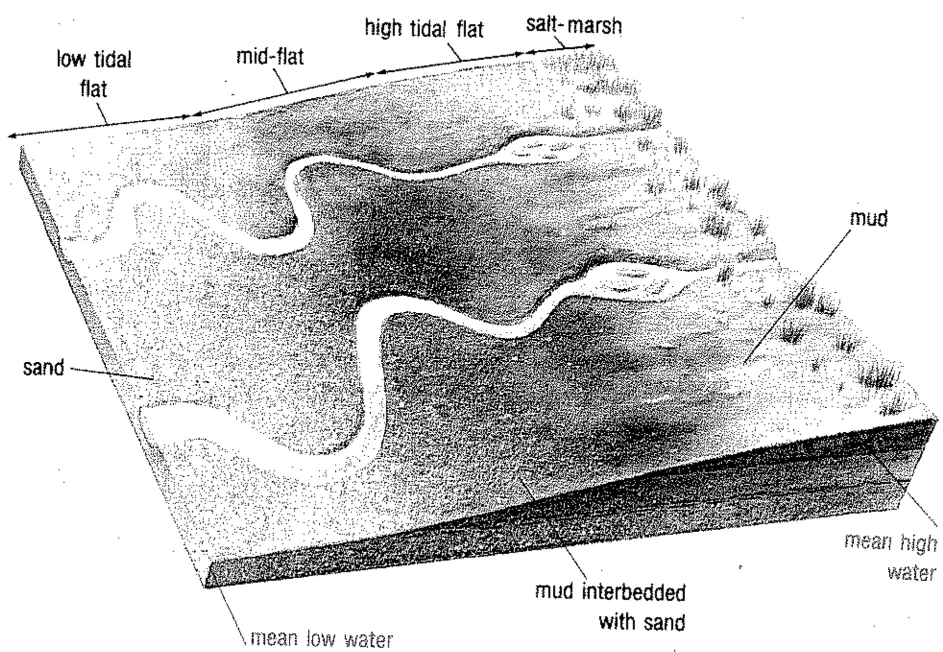

Figure 6.2(a) A simple model for sediment zonation on tidal flats. Note that the vertical scale has been exaggerated.

Figure 6.2(b) Photograph of a typical estuarine tidal mud-flat.

The **low tidal flats** are submerged for most of the tidal cycle and are subjected to strong tidal currents and minor wave action during this period. Even at the slack water of low and high tide, there is some sediment disturbance by waves. Consequently, muds are kept in suspension and sediments are deposited only from the bedload. These consist of well-winnowed sands.

QUESTION 6.2 What sort of bed forms might you expect to see on the low tidal flat?

The **mid-flats** are submerged and exposed for roughly similar periods. They are usually submerged during the mid-tidal cycle when tidal currents may reach their maximum speeds and so the sediment may be affected by these strong tidal currents, although wave action is very weak. Bedload transport and deposition of sands are again dominant, accompanied by the development of current-formed ripples. However, during the period of slack high water, fine muds held in suspension are able to settle out, forming characteristic mud drapes over the surfaces of the previously formed ripples.

The **high tidal flats** are submerged only at high tide when current speeds fall to zero. No bedload transport or deposition occurs but during the slack water period muds settle out of suspension to form the mud-flats (Figure 6.2(b)). When the tide turns, these muds will be eroded only if the ebb current generates a shear stress at the bed which is greater than the critical shear stress required to erode the sediment. Because muds are cohesive sediments, they are difficult to erode after deposition (Section 4.2.2). In laboratory experiments using muds from the Wadden Sea, currents of 0.4–$0.5\,\mathrm{m\,s^{-1}}$ were required to resuspend muds that had been allowed to settle for 16 hours, whereas redeposition did not occur until current speeds had decreased to between 0.1 and $0.2\,\mathrm{m\,s^{-1}}$.

The deposition of fine-grained silts and clays on the high tidal flats is also encouraged by their settling lag (Section 4.4.2). As the flood tide inundates the tidal flats and the current begins to slacken, these grains begin to settle from suspension as soon as the critical depositional shear velocity is reached. However, they do not settle vertically through the water, but are carried landwards as they sink, by the still-moving current. Eventually, they are deposited at some distance inland of the point at which the critical depositional shear velocity was reached. Assuming that the ebb tide and flood tide current speeds are equal, when the tide turns the deposited sediments will not be resuspended until much later in the flow. This effect is enhanced by the cohesive properties of the sediment. As a result, on the ebb tide the sediment grains will be suspended for a shorter period than on the flood tide and will not move back offshore as far as they moved inshore. Thus, the high tidal flat is a zone of rapid sediment accretion, and, as its level is raised with fresh accumulations of mud, the degree and duration of submergence during high water decreases.

Ultimately, the flat is exposed for sufficiently long periods for colonization by land plants to begin. The most common pioneering salt-tolerant plants in Western Europe are *Salicornia* (the fleshy marsh samphire) and *Spartina* (the tough marsh cord grass—Figure 6.3). The plant roots help to bind the sediment and prevent further erosion. More significantly, the plant stems retard the flow, encouraging still further the deposition of silts and clays. Total colonization of the muds of the high tidal flat leads to the development of a salt-marsh, flooded normally only during high spring tides. Thus the salt-marsh (and the other zones of the tidal flat) gradually extends seawards, and the older, landwards regions are flooded less frequently. However, the deep drainage channels persist long after the marsh has become dry land.

(a)

(b)

Figure 6.3(a) The binding of muds by *Spartina* grass roots in a salt-marsh.

(b) The aerial roots of mangrove trees help to trap muds and bind sediments.

6.1.2 LOW-LATITUDE TIDAL FLATS

In humid tropical regions, mud-flats are often colonized by mangrove trees whose aerial root systems tend to trap muds. Consequently, mangrove swamps develop above mean high tide level in place of salt-marsh. Mangrove swamps are particularly extensive on the tidal flats in between the tidal channels of the Niger delta, for example.

In low latitudes, wherever little terrigenous sediment is supplied to coastal regions, carbonate sediments are able to accumulate. Here, the sediments of the intertidal region are dominantly carbonate muds (Section 5.4.1) containing a high proportion of faecal pellets. These muds are colonized by blue–green algae which trap and bind the sediments, in the same way that salt-marsh plants do, to form algal mats. Along arid coastlines, such as that of the United Arab Emirates which borders the Persian Gulf, the seawards accretion of sediments leaves the older areas of algal mat stranded above sea-level. They are subject to intense surface evaporation, particularly after they have been flooded by seawater during occasional storms and extra-high tides.

QUESTION 6.3(a) If water is lost at the surface of the mats by evaporation, what is likely to happen at their base, which is still below mean sea-level?

(b) What will happen to the salts dissolved in the seawater?

This process is referred to as 'evaporative pumping'; the environment resulting from the sequence of carbonate sediments and evaporites is known as a **sabkha**, the Arabic word for a salt-flat.

6.2 ESTUARIES

The word estuary is derived from the Latin word *aestus*, meaning tide, and the adjective *aestuarium*, meaning tidal. Most people would recognize an estuary as the region where a river meets an inlet of the sea (Figures 6.4(a) and 6.5). As an everyday definition, this may seem perfectly satisfactory, but it gives no indication of how far up-river an estuary extends or of the interaction between the fresh river water and the saline seawater. In order to answer these points, the following catch-all definition has been proposed:

> An estuary is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors: (a) a marine or lower estuary, in free connection with the open sea; (b) a middle estuary, subject to strong salt and freshwater mixing; and (c) an upper or fluvial estuary, characterized by freshwater but subject to daily tidal action.
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> (R. W. Fairbridge (1980) in E. Olausson and I. Cato (eds.) *Chemistry and Biogeochemistry of Estuaries*, John Wiley.)

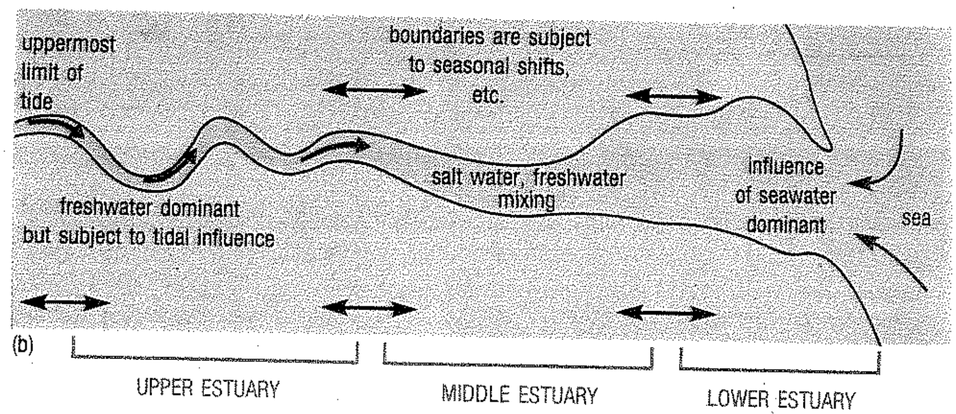
Figure 6.4(b) illustrates this description.

Most estuaries are geologically very young; they have developed since the latest post-glacial rise in sea-level inundated coastlines and drowned the mouths of river valleys. They are now being progressively infilled with sediment. Today, only those rivers which transport small amounts of sediment and discharge it into coastal waters (where wave and tidal current action are sufficiently strong to disperse the sediment) have open estuaries of the type seen round the British Isles. However, where the sediment discharge is high and there is limited wave and tidal current action, then the open estuary rapidly fills in and a delta grows seawards at the expense of the estuary (see Chapter 7).

6.2.1 ESTUARINE TYPES

Estuaries are far from uniform in character and the differences are mainly due to variations in tidal range and river discharge, which affect the

(a)



(b)

Figure 6.4(a) Aerial view of the seawards end of an estuary at low tide. The main river channel hugs the left-hand side (looking landwards).

(b) A schematic map of a typical estuary showing the divisions into lower, middle and upper estuary based on the definition by Fairbridge. The boundaries are transition zones that shift according to the seasons, the weather and the tides.

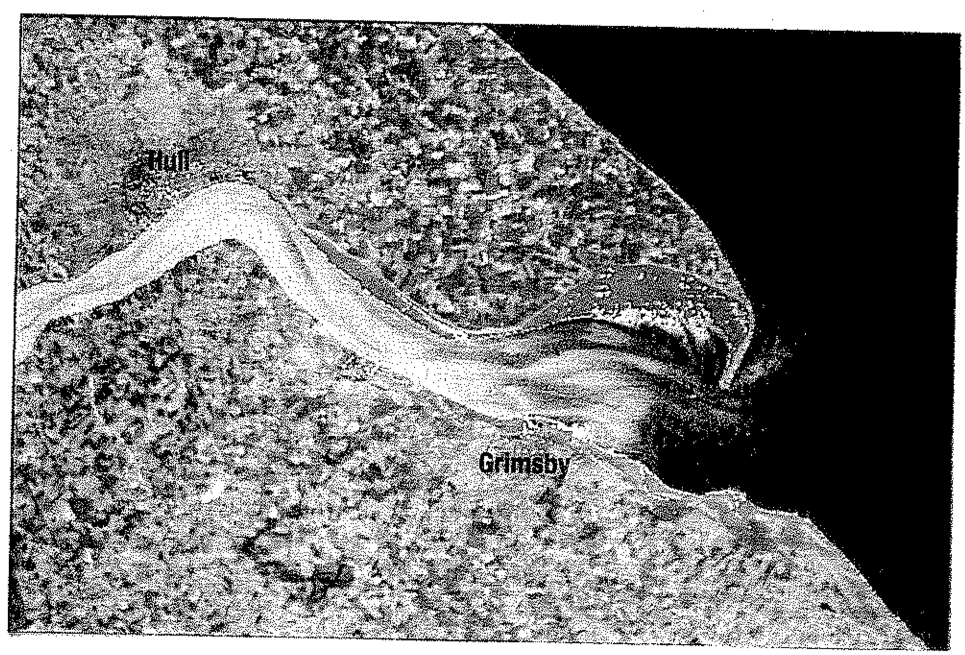


Figure 6.5 Landsat Multispectral Scanner image of the Humber estuary, north-eastern England approximately two hours before low water (taken in 1976 before the building of the Humber Bridge). Seawater and river water are black. The yellow coloration in the estuary is due to high concentrations of suspended sediment and so shows the pattern of sediment distribution and movement in the estuary. Although most of the blue colour represents built-up areas, the blue bands bordering the north bank of the Humber as far as the spit at the mouth, and extending southwards from the estuary mouth along the coast, are intertidal mud.