Tidal range

The height difference between high water and low water during the tidal cycle is known as the **tidal range**. As discussed earlier, tidal range increases with distance from an amphidromic point, so that a coastline located near an amphidromic point experiences a small tidal range, whilst a coast on the periphery of an amphidromic system will experience a much greater tidal range. In addition, a number of other factors contribute to the great variety of tidal ranges experienced on the world's coasts. These include:

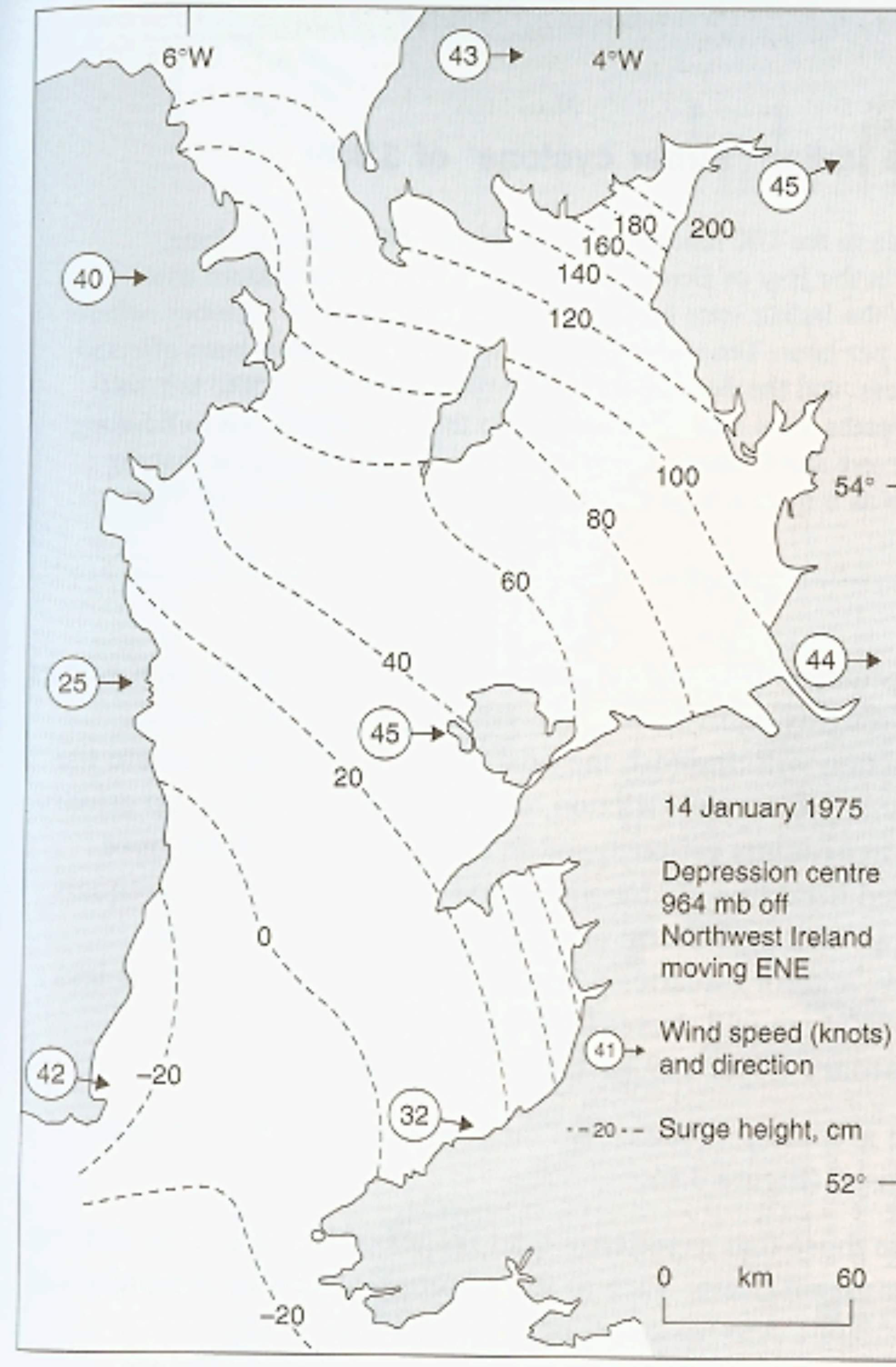


Figure 3.5 ***A storm surge in the Irish Sea (British Isles) resulting from a deep depression in January 1975.***
Source: from Briggs *et al.* (1997) (Figure 17.5, p. 305)

- **Bathymetry** – because of the enormous wavelength of the tidal wave it can be considered everywhere as a shallow water wave. Therefore, it can undergo refraction like all waves and become focused on particular stretches of coastline, where tidal energy, height and range are increased.
- **Width of continental shelf** – the very shallow waters encountered by a tidal wave on a continental shelf reduce celerity and increase the wave height. The slowing of the front of an approaching tidal wave allows the back of the wave to catch up, so increasing wave height further. Therefore, wider continental shelves allow more time for the broad tidal wave crest to concentrate into a narrower but higher wave, increasing tidal height at the coast.
- **Coastal configuration** – tidal waves entering coastlines which are restricted in some way, such as embayments, gulfs and estuaries, will become compressed as they progress, increasing tidal height and range. This is most marked in funnel-shaped estuaries where the estuary width decreases incrementally upstream, such as the Severn Estuary in southwest Britain where the tidal range is in excess of 14 m. Conversely, open ocean coasts, often coupled with a narrow continental shelf, tend to reflect the tidal wave, resulting in minimal tidal ranges. Nichols and Biggs (1985) examined the influence of configuration on tidal range in estuaries. They state that variations in tidal range along an estuary are determined by the relationship between the upstream

Box 3.1

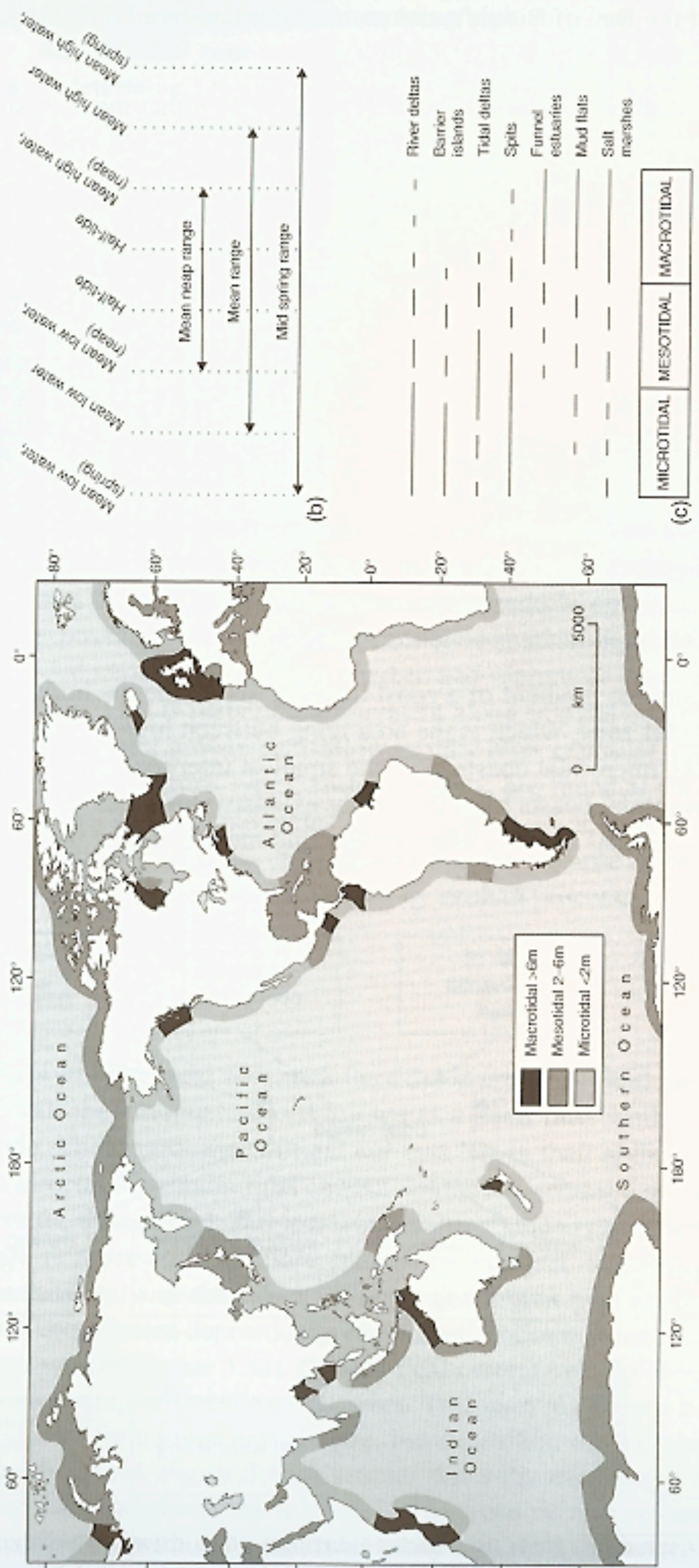
Storm surge – the Indian 'Super cyclone' of 1999

The Meteorological Office in the UK report that in October 1999 a deep cyclone, labelled 05B, developed in the Bay of Bengal and tracked towards the eastern coast of India. It made landfall in the Indian state of Orissa in the morning of 29 October, where winds peaked at 255 km per hour. Ten million people are thought to have been affected, one million made homeless, and the death toll as of 10 November was 7,500, but was expected to rise. These deaths were not due, however, to the high winds, but to flooding from heavy rain and a severe storm surge. Some unconfirmed reports suggest that the storm surge was as much as 6 metres high and inundated the coast to up to 14.5 km inland.

convergence of the estuary sides and the friction created between the tidal waters and the estuary bed (roughly equivalent to the surface area of the estuary), because increased friction will diminish the tidal range. For estuaries where the effect of convergence is greater than friction, tidal range will increase up estuary, producing a **hypersynchronous estuary**, and in these estuaries a **tidal bore** wave may be produced heralding the incoming tide. Where convergence equals friction then tidal range will be uniform along the length of the so-called **synchronous estuary**; and for estuaries where the effect of convergence is less than friction, then tidal range will decrease up the estuary to produce a **hyposynchronous estuary** (Dyer 1997).

Coasts can be classified according to their tidal range (Davies 1964), with three categories being recognised (Figure 3.6):

1 **Microtidal** coasts are those that experience tidal ranges of less than 2 m and are characteristic of open ocean coasts, such as the eastern seaboard of Australia and the majority of the Atlantic African coastline, for example.
2 **Mesotidal** coasts possess tidal ranges between 2–4 m according to Davies (1964). Some authors, however, consider mesotidal coasts to have tidal ranges between 2–6 m (e.g. Briggs *et al.* 1997). However, the majority of texts adopt Davies' definition (e.g. Pethick 1984; Carter 1988; Summerfield 1991; Viles and Spencer 1995; French 1997). Examples of mesotidal coasts include much of the Malaysian and Indonesian coastline, and along the eastern seaboard of Africa.
3 **Macrotidal** coasts experience tidal ranges in excess of 4 m according to Davies (1964) and most other authors, but defined as greater than 6 m by Briggs *et al.* (1997), a range considered by some authors to indicate hypertidal conditions. Macrotidal coasts occur where the continental shelf is wide allowing the shoaling tidal wave to increase in height, and where the coastal configuration amplifies the tidal height. Examples include most of the northwest European coastal seas (e.g. Celtic Sea (including the Severn Estuary), the North Sea, the English



ure 3.6 **(a) The distribution of tidal ranges around the global coastline; (b) the variation of tidal range during monthly tidal cycles; and (c) stal geomorphological features associated with the various tidal range categories.**
ce: from Briggs et al. (1997) (Figure 17.17, p. 318)

Channel, and the Bay of Biscay), and parts of northeastern North America (e.g. Hudson Bay and the Bay of Fundy).

Macrotidal coasts are considered to be tide-dominated, in that most erosional, transport and depositional processes operating here are driven by tidal forces. Mesotidal coasts are considered mixed with wave and tide processes being equally important. Microtidal coasts however, are wave dominated, and many of the coastal systems discussed in Chapter 2 are of this type. Overall, there is a close relationship between tidal range and the type of coastal landforms encountered along any given coastline, and therefore, an appreciation of tidal range is essential in understanding coastal systems' diversity. For example, estuaries with their component tidal flats (whether sand or mud flats), salt marshes or mangroves, and characteristic ecosystems are typical of coasts with high tidal ranges, whereas at the other end of the spectrum barrier islands (as discussed on pp. 45–49) are commonest along microtidal coasts.

Tidal range is particularly important for coastal geomorphology because it influences the operation of physical processes (Figure 3.7). There are a number of reasons why such importance is attached to tidal range:

- Tidal range and the gradient of a coast together determine the horizontal extent of the **intertidal zone**, which is the area lying between high and low water. High-gradient, microtidal coasts have the smallest intertidal zones, whilst low-gradient, macrotidal coasts have extremely extensive intertidal areas. Ecological diversity in intertidal zones is often greater and more complex on macrotidal

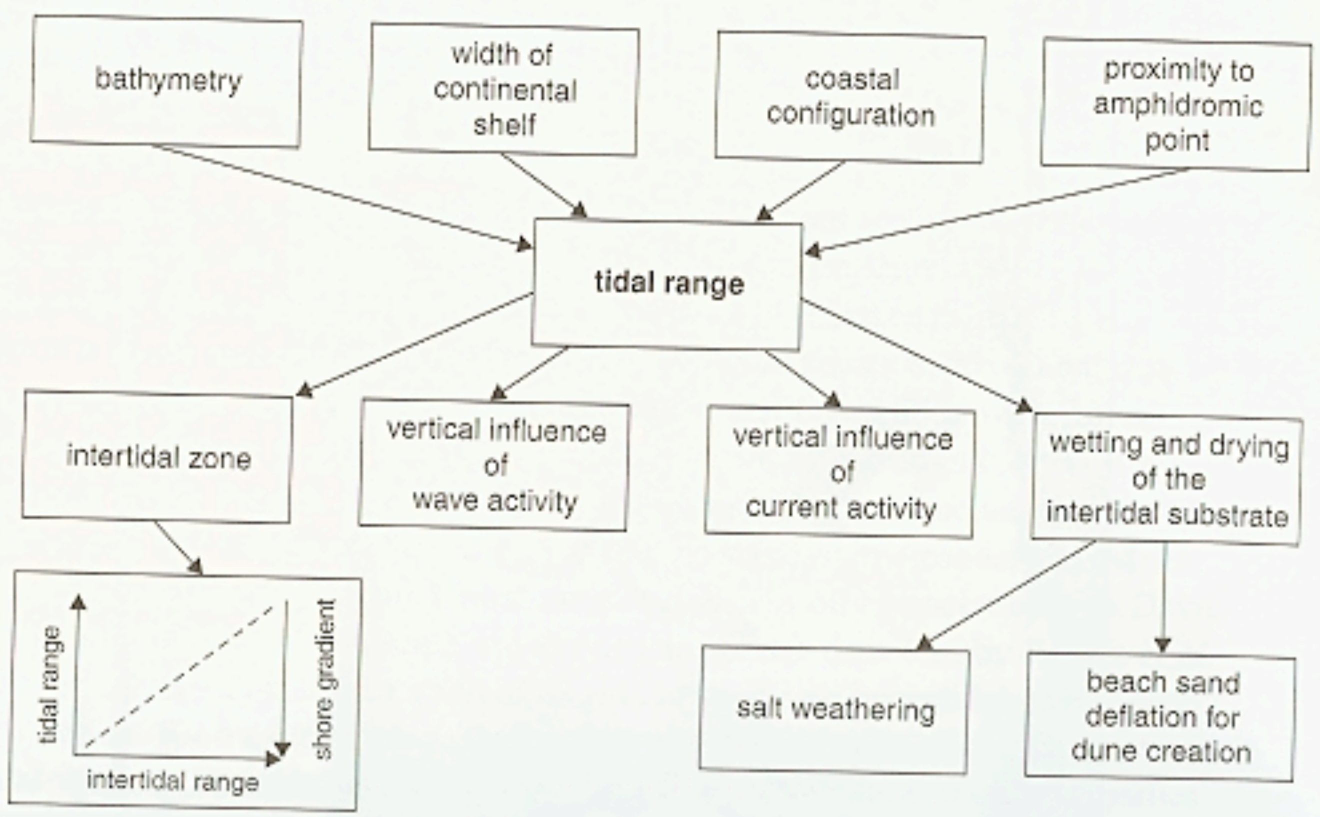


Figure 3.7 *The geomorphological signficance of tidal range.*

coasts, with salt marshes occurring high and unvegetated tidal flats low within the intertidal zone.
- It determines the extent of the vertical distance over which coastal processes operate, especially wave activity. On microtidal coasts wave breaking is concentrated within a very narrow vertical zone throughout the tidal cycle, and it is under these conditions that well-defined erosional features such as wave-cut notches are preferentially formed. However, wave energy on macrotidal coasts can be distributed over many metres throughout the tidal cycle, so that its erosional capacity is relatively diminished, but it does mean that wave activity influences a wider area. The same is also true for the operation of tidal currents (see pp. 83–86), with a greater tidal range subjecting a wider area to their activity.
- The periodic rise and fall of the tides causes wetting and drying of the substrate within the intertidal zone. Generally, the greater the tidal range, the more substrate is exposed or submerged at different states of the tide. This is important for a number of processes, including salt weathering, where seawater invading hard crystalline or laminated rocks submerged at high tide is evaporated when exposed at low tide. Salt crystals grow within minute voids in the rocks producing stresses which weaken and ultimately lead to the disintegration of the rock. This is particularly prevalent along tropical coasts, where evaporation and salt crystal growth can follow rapidly after exposure, and where especially susceptible rock types, such as granite, are found at the coast. Also, as discussed on pp. 64–71, sand dunes are more likely to develop on coasts with a relatively high tidal range, as this provides a wider expanse of beach sand for drying and subsequent landward transport by aeolian processes.

Tidal Currents

As water rises and falls with the tides it produces **tidal currents**. A rising tide that floods the intertidal zone is known as a **flood tide**, whilst a falling tide is the **ebb tide**. The significance of tidal currents lies in their ability to entrain and transport sediment. Maximum tidal current velocity is achieved at the flood and ebb tide mid-points, then at high and low water current velocity decreases to zero (slackwater) before reversing. Therefore, maximum sediment transport occurs at the mid-points in the flood and ebb tides (i.e. midway between high and low water and vice versa), whilst sediment deposition predominantly occurs around slackwater (i.e. at high and low water) (Figure 3.8a). Critical tidal current velocity thresholds exist for transporting different particle sizes. Transport may occur at and above the threshold velocity for a given particle size, but deposition occurs where velocity is less than the threshold. Figure 3.8b illustrates this with reference to mud and sand-sized particles and shows the relationship between current velocity and sediment size distribution within the intertidal zone, with mud characterising the low-energy low and high intertidal areas, whilst sand shoals occur in the high-energy mid-intertidal

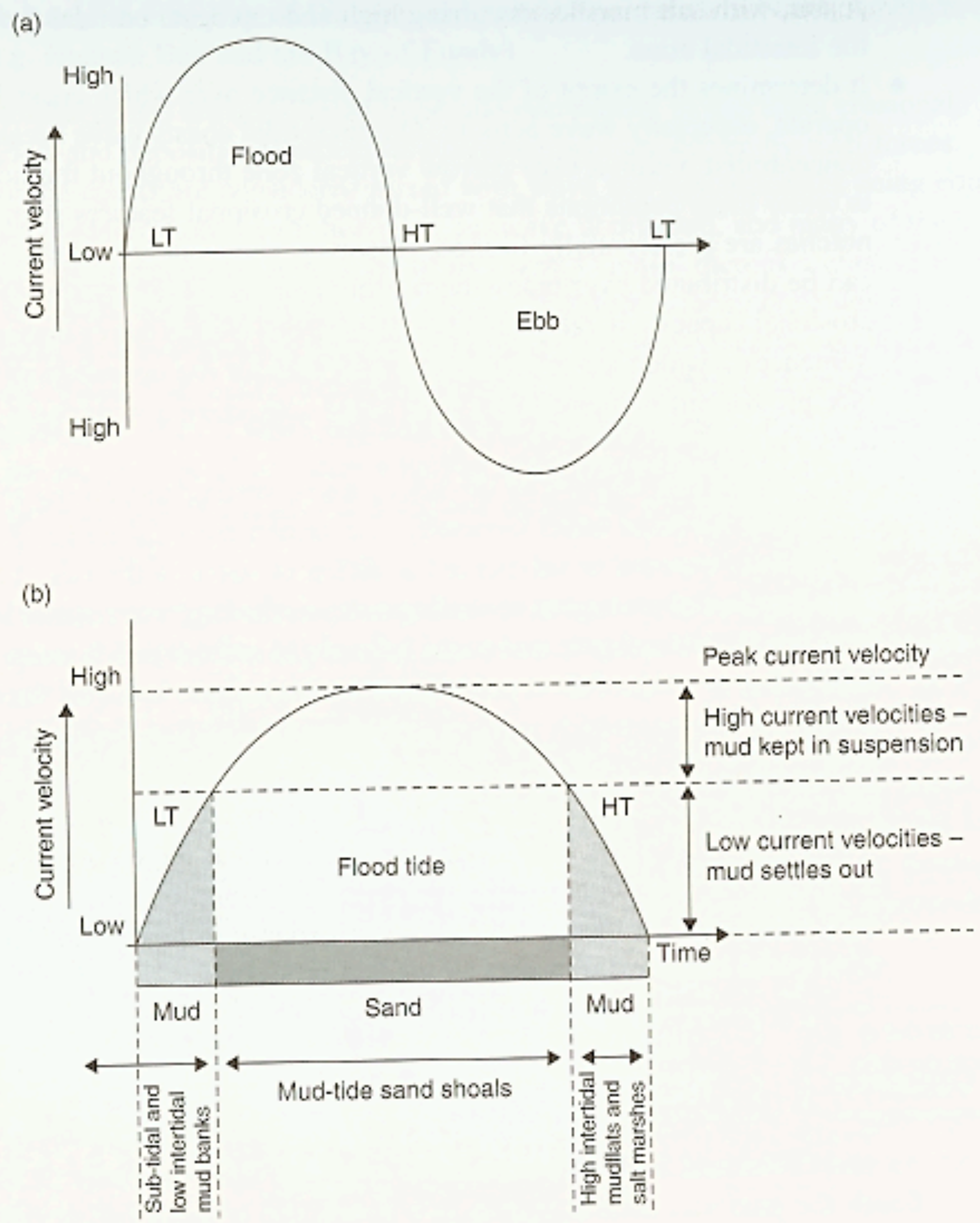


Figure 3.8 ***Tidal current activity and sediment deposition: (a) changes in current velocity and direction through a tidal cycle; and (b) the relationship between flood tide current velocity and the distribution of different sediment types in the intertidal zone (HT, high tide; LT, low tide).***
Source: from French (1997) (Figure 2.10, p. 45)

zone. Overall much sediment is transported in, out and within the intertidal zone during every ebb–flood tidal cycle.

Quite often a **sediment couplet** may be deposited (Plate 3.1), where sand deposited during tidal current deceleration is overlain by mud deposited at slackwater. If an additional couplet is deposited during each cycle then stacks of couplets may be preserved as **tidal rhythmites**. These have been used to reconstruct past tidal

Plate 3.1 ***A salt marsh cliff in the Baie de Mont St Michel (Normandy, France) showing distinct sediment couplets. Note coin for scale (c. 2cm diameter) near top of the cliff.***

regimes, with the thickness of sand layers indicating spring to neap tide variations, with the thicker sand layers representing the higher current velocity associated with spring tides. Indeed, if neap tide current velocities fail to exceed the sand transport threshold then the neap couplets will be dominated almost exclusively by mud (Reading and Collinson 1996).

In many instances, due to factors similar to those discussed on pp. 74–76, the ebb–flood tidal cycle is asymmetrical, with either the flood or ebb tide taking longer than the other. For example, a twelve-hour symmetrical tide consists of 5.5 hours per flood and ebb tide element, with one hour slackwater at high tide; however, an asymmetrical tide might comprise a flood tide lasting 3.5 hours and an ebb of 7.5 hours (French 1997), with one hour at high water. This is of great significance for tidal geomorphology because a fixed volume of water or **tidal prism** must come in and go out each ebb–flood tidal cycle, which means that during the shortest tidal element, which in the above example is the flood tide, the tide must flow faster. The faster tidal velocity associated with the flood tide, in the above example, means that more and coarser sediment can be transported during the flood, which becomes the **dominant current**. The ebb tide, however, becomes the **subordinate current**. A tidal coast may be referred to as flood- or ebb-dominated, depending upon which tidal element provides the dominant current. Extending this to sediment transport suggests that there is a net landward transport of sediment in flood-dominated systems (tidal inlets and estuaries may silt up as a consequence) and net seaward transport in ebb-dominated systems.