Geofile for AQA

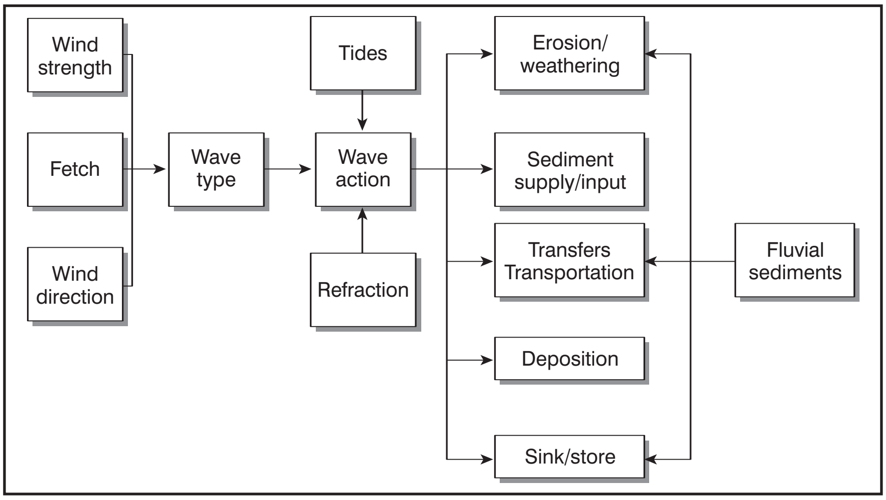
September 2008 575

Lucy Prentice

Coastal Systems: waves, tides, sediments, cells

The narrow strip where the sea and land interact is shaped and influenced by both natural and human variables within a powerful system. The action of waves, tides and currents provides an input of energy which is then used through the processes of erosion, weathering, transportation and deposition to produce the morphology of the coastal zone above and below the waves. The coastal system is driven by wave energy within the nearshore (breaker zone) and foreshore (intertidal) zones. Figure 1 shows how the components of the system are related and interact. The processes within the system and the appearance of the coastline will be controlled by a number of physical variables and possibly influenced by human activity.

Figure 1: The coastal system



Physical variables

- Climate/weather patterns/seasons
- Wave type and strength
- Wind direction
- Fetch length and direction
- Tidal range/flow
- Currents
- Geology of coastline
- Concordant/discordant
- Availability of sediment from marine, coastal and fluvial sources
- Erosional and weathering processes.

Human influences

- Coastal engineering and management
  - Groynes
  - Sea walls
- Disruption of sediment supply
  - Dredging
  - River dams
  - Cliff protection
- Non-management
  - Blocking structures
  - Jetties
  - Harbour walls.

Waves

Waves are caused by the surface of the sea exerting frictional drag on the lowest layer of the wind. Higher layers of the wind then move faster over the lower levels and fall forward, pushing down on the sea surface, creating a wave. As the wind blows on the back of the small ripple, the wave grows. In the open sea there is no actual movement of water, just a movement of energy.

An imaginary particle would move in a clockwise direction between wave crest, trough, then back to the crest of the wave, but would not move forward in the ocean; these are called oscillation waves. The orbit of the particle varies from circular to eliptical; the base of the orbit is called the wave base (Figure 2).

The height of the wave is an indication of energy and depends on the fetch (the distance over which the wind blows), the strength of the wind, duration of the wind, and sea depth. Strong winds will create steep waves which, when the winds ease, will decrease in height and increase in wavelength. These waves are called swell. Swell waves effect the Atlantic coasts of Britain even in the quieter summer months.

Wave refraction occurs where the undersea topography causes the wave fronts to slow, bend and aim to break parallel to shore. This effect is most often seen in a headland and bay coastline. Wave energy tends to be concentrated on the headlands hence more erosion, with lower energy levels occurring within the bays and deposition occurring. If the waves break at an angle within the bays, then longshore drift occurs.

Types of wave

As a wave approaches the shore, and the water depth decreases, the wave length becomes shorter and the wave height increases to compensate. The circular motion of the wave becomes more elliptical as the wave base drags on the sea bed and the wave velocity decreases (Figure 2a). The wave steepens further, until the ratio of height to length is 1:7. Eventually the body of the wave collapses forward, or breaks, and rushes up the beach. Movement of water up the beach is called swash. Movement of water down the beach is called backwash (Figure 2b).

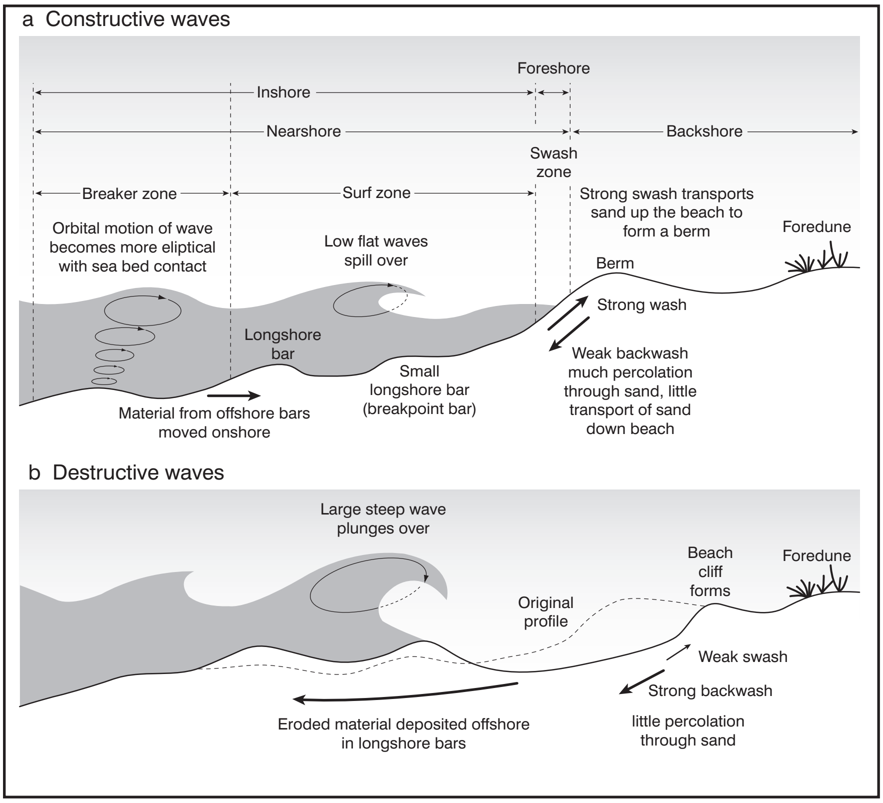
Sea bed topography can also influence how a wave breaks. A sudden reduction in water depth over a steeper shingle profile will produce a taller, steeper wave which is more likely to plunge. A gently shelving sea bed, with a long run up, is more likely to encourage lower-profile waves.

There are two types of wave: constructive and destructive, which shape beaches by the removal, addition and movement of sediment. Figure 3 shows their characteristics and how they shape beaches.

Constructive/spilling waves

- Long wavelength
- Low in height
- Strong swash pushes sediment up the beach
- Backwash soaks into beach on return. Sediment not pulled back
- Lower energy waves , commonly swell waves

Figure 2: Constructive/destructive waves



Source: Guinness and Nagle, 2000, p. 116

- 6–10/minute
- Most effective over a gentle shelving sea bed.

Destructive/plunging waves

- Short wave length
- Steep wave faces and high wave height
- Wave crashes downwards into the trough of the wave with little swash
- Backwash is very strong and drags material back down the beach
- Backwash interferes with swash of next wave
- Higher energy waves generate localised storm conditions
- 11–15/minute
- Most effective over a steeply shelving sea bed which causes a rapid increase in friction and a steep wave front.

Influence of waves and sediment on beach morphology

Beach morphology is dependent on several factors: wave type, energy, sediment type and sea bed morphology. It is a complex relationship, but some key relationships can be found:

- Sand forms wide, gentle gradient beaches, whereas shingle beaches are narrower and have a steeper angle of rest due to their larger particle size (Figure 3).
- Constructive waves have a stronger swash and a weaker backwash, carrying material up the beach but not having enough energy to carry it back down.
- Destructive or plunging waves have a weak swash, with a small swash distance, and a strong high energy backwash which draws material back down the beach.
- Swash, whether from constructive or destructive waves, will tend to be stronger and backwash weaker on a shingle beach due to high percolation rates.
- Sandy beaches will tend to have strong swash with a long run up due to the flat profile and a similar strength backwash due to low percolation rates on compressed sand. Material will be combed back down the beach, but returned with the next wave.
- Sediment will be moved up a shingle beach. High percolation rates on the backwash will be too weak to remove sediment.
- Finer sediments do not require so much energy to be eroded and transported. Higher energy environments therefore are characterised by coarser sediment sizes.
- Most changes in beach morphology occur within the sweep zone between high and low tide. Above the high tide mark a storm beach or berm may form when material is flung to the top of the beach (Figure 3).

Most British beaches will be subject to both types of wave during the year, with higher-energy destructive waves dominating during the stormier winter months and constructive lower-energy waves during the calmer summer months (Figure 3).

These points may explain why sandy beaches are eroded so badly during the winter when high-energy destructive waves are combined with a gentle sandy profile. The percolation rate on the backwash is low and therefore material can be dragged from the beach. As smaller particle sizes do not require much energy to be transported, beaches can be depleted quickly. During stormy conditions, sand and larger material is thrown up the beach to create a storm beach of larger pebbles. During lower-energy conditions with constructive waves the sandy beach can be replenished by the strong swash of constructive waves. Figure 3 shows typical characteristics of beaches on the south coast of England and how they are dependent on seasons and sediment size.

Tides

The ocean's tides are controlled by the gravitational pull of the Moon, and to a lesser extent the Sun. The Moon pulls the water in the ocean towards it, creating a bulge of water; a high tide. The Moon not only pulls the water but also pulls the Earth towards it, this creates a second bulge of water and the second high tide on the other side of the Earth.

Twice a month the Earth, Moon and Sun are aligned: this puts an extra gravitational pull on the tidal bulge, to produce an extra high tide called a spring tide. When the Sun and Moon are at right angles to each other, neap tides occur, when the tidal range is lowest.

Figure 4 shows the influence of the Moon and Sun on the Earth's tides. When a spring tide coincides with an onshore gale, a storm surge can occur, which can lead to exceptionally high seas and flooding, as in the East coast floods of 1953 and the 'near miss' of November 2007.

The tidal range is the vertical distance between high tide and low tide, and this coincides with the sweep zone for the beach (Figure 3). The slope of the shoreline and the tidal range determine the amount of shore exposed to wave action A low tidal range tends to produce a narrower beach, which is prone to higher erosion; such beaches are found on the shores of seas such as the Mediterranean, rather than oceans. Higher tidal ranges are found on ocean coasts, such as the Atlantic coasts of Britain and Canada.

Sediments and sediment cells

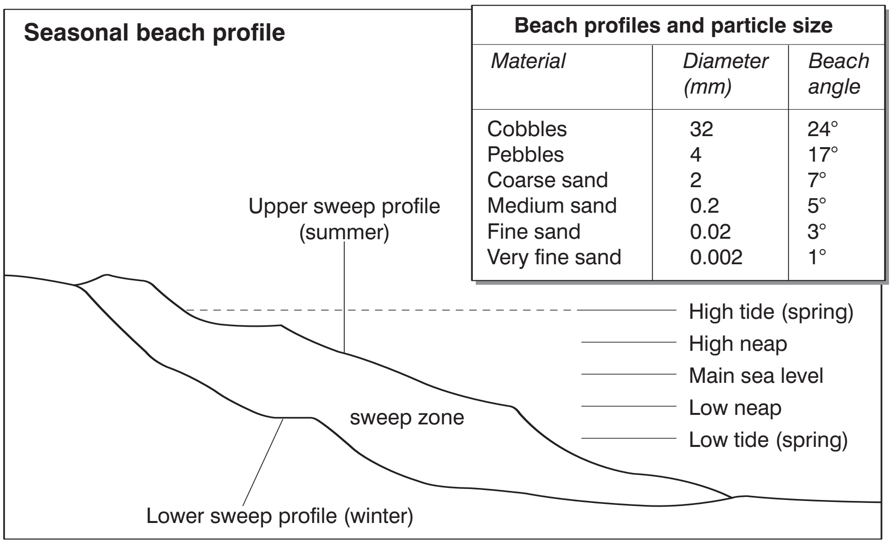
One of the main activities of the coastal system is the sourcing, transfer and deposition of sediment along a stretch of coastline called a sediment or littoral cell.

DEFRA (the Department for Environment, Farming and Rural Affairs) defines a sediment cell as:

> 'A length of coastline and its associated nearshore area within which the movement of coarse sediment (sand and shingle) is largely self-contained. Interruptions to the movement of sand and shingle within one cell should not affect beaches in a neighbouring sediment cell.'

The English and Welsh coastlines are divided into 11 cells, which are then divided into subcells or management units. Sediment cell theory is a key component of shoreline management plans, which determine future strategies (see **Geofile** no. 537). Figure 5 shows the main inputs, transfers and stores within a sediment cell.

Figure 3: Beach morphology and sediment type

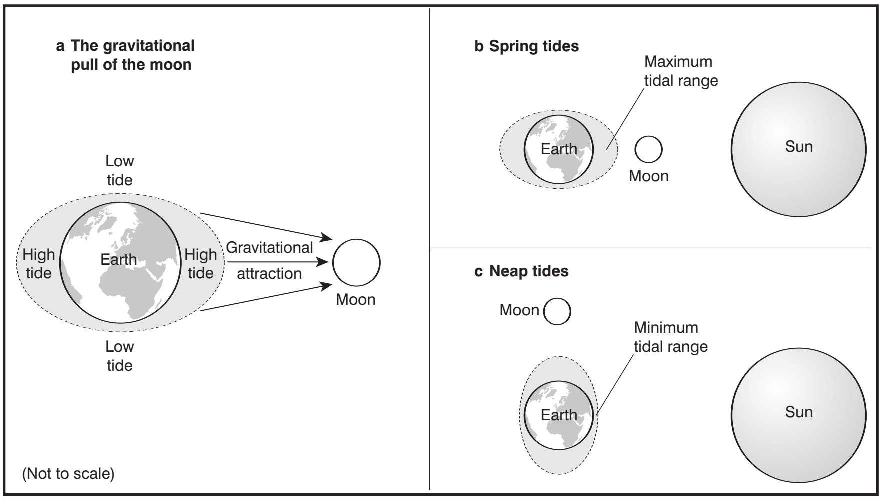


Beach profiles and particle size

Material	*Diameter (mm)*	*Beach angle*
Cobbles	32	24°
Pebbles	4	17°
Coarse sand	2	7°
Medium sand	0.2	5°
Fine sand	0.02	3°
Very fine sand	0.002	1°

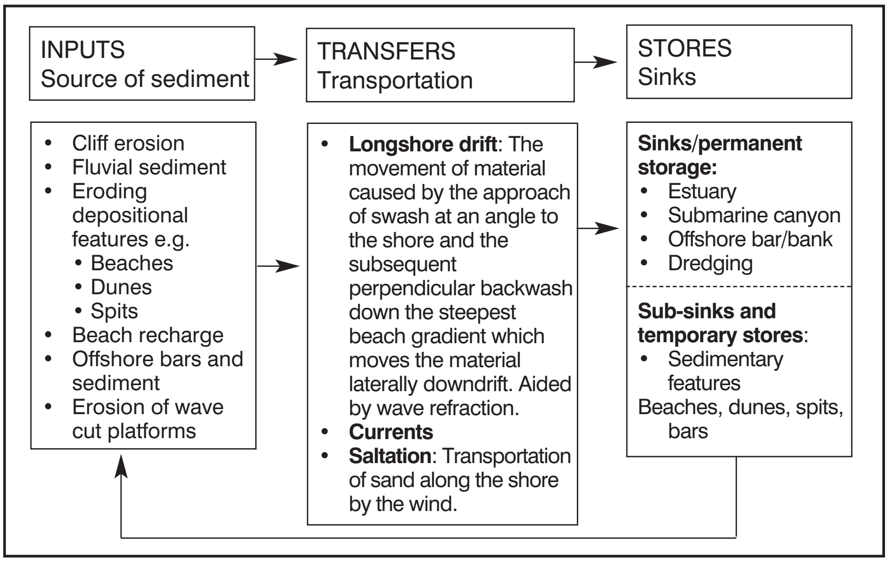
Source: Guinness and Nagle, 2000

Figure 4: Causes of tides



Source: Waugh 1995, p. 130

Figure 5: Sources of sediment, transfers and sediment sinks and stores within sediment cells



The key characteristics of sediment cells are as follows.

- Cells are discreet and function separately from each other. The sediment cells are geographically bounded by significant disruptions to the coastline, such as headlands, estuaries or a convergence of currents or longshore drift direction.
- Within the cell, sediment is sourced, transferred and stored. Coarse sediments are not exchanged between cells, but finer sediment in suspension can be.
- Over time, sub-sinks will erode and the sediment will re-enter the cell's system.
- The sediment in the sink is away from wave action and longshore drift, it becomes essentially an output, as it is no longer being worked by the processes within the cell.
- The amount of sediment available to the sediment cell is called the sediment budget. The sediment cell will produce depositional features which are in equilibrium with the amount of sediment available. If the budget is decreased then the waves will continue to move sediment, causing erosion in some areas. If the budget increases, then more deposition is likely.

Human activity and sediment cells

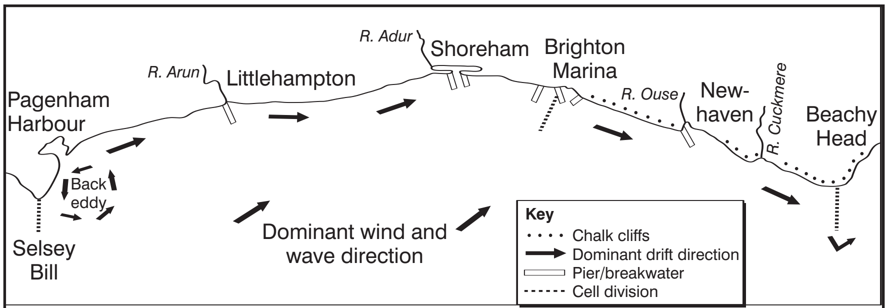
Human activity can interfere with the processes within a sediment cell by disrupting the supply of sediment and therefore the sediment budget of the cell. Groynes, jetties and harbour walls will block the movement of sediment, which can lead to beach erosion further downdrift. Groynes are used to trap sediment in areas where a beach is considered essential, either for the protection of cliffs, defences, leisure amenity or economic prosperity. More built-up coastal areas tend to have more groynes than more rural coastlines, and these areas often have problems of beach erosion.

Sediment input supply can also be disrupted by river dams, which cut down on the amount of fluvial sediment entering the coastal system. Protecting soft cliffs can prevent cliff falls and reduce the amount of sediment entering the system.

The South Downs sediment cell

The South Downs Shoreline Management Plan occupies sub-cell 4d along the Sussex coast of England between the cliff headlands of Selsey Bill and Beachy Head. The shoreline management plan further splits the cell in half to the east and west of Brighton Marina, forming two further subcells. The subcell beaches are heavily defenced with rock reefs, wooden and rock groynes along all urban sections. Beaches are composed of pebbles swept onshore at the end of the last ice age, as sea levels rose to give an extensive fossil beach with sand exposed at low tide. To the east of Brighton Marina the chalk cliffs continue to Beachy Head and include the famous Seven Sisters Cliffs. Figure 6 outlines the key features of the cell.

Figure 6: South Downs Sediment Cell 4d:Selsey Bill to Beechy Head



- Dominant drift and transport direction west to east (48%)
  From E/SE 28%
  From south 16% .
- The tidal range increases and floods from west to east. The falling ebb tide flows to the west.
- Onshore shingle movement or shingle creep in water of 15m or less and kelp rafted sediment (10,000m^3).
- The tidal inlet of Pagham Harbour and the rivers Adur (2800m^3) and Arun provide fluvial sediments into the cell to the west of Brighton Marina.
- Dredging Shoreham Harbour (32000m^3), Brighton Marina (5000m^3), Newhaven Harbour.
- Bypassing of breakwaters pushes sediment offshore.
- Up to 5000m^3 gravel and sand lost round Beachy Head to Eastbourne beaches.
- Major store of gravel at Birling Gap is being depleted.
- A back eddy in the lee of Beachy Head deposits sediment to the south of Pagham Harbour.
- The rivers Ouse and Cuckmere (5000m^3) provide sediment to the east of Brighton Marina.
- Of the 22km of cliff in the cell 8km is protected; this affects the quantities of flints entering the cell from cliff erosion. Possible input of 5000 m^3.
- Rottingdean, Saltdean and Seaford have become seriously depleted and have been artificially replenished.
- The construction of the breakwater at Newhaven undoubtedly helped starve Seaford beach.
- Wave cut platform erosion may contribute 400m^3 of sediment.
- Where the rivers enter the sea they block the eastwards movement of long shore drift and spits/beaches build-up to the west of the channel outlet.
- Abraded and recently eroded finer particles of sand and chalk are transported by suspension past beaches,barriers and headlands. To next subcell or offshore stores.

(Source: SDCG and SCOPAC, figures are estimates)

Conclusion

The coastal system is a complex and dynamic system which will adapt according to wave energy levels and sediment supply. A change in one part of the system will cause the whole system to work harder to compensate for the change and achieve equilibrium. This can be inconvenient for the millions of people who live along the world's coastlines as they may find they no longer have a beach, a safe harbour, or even a home. With global warming and the predicted rise in sea levels, familiar coastlines will change as tidal ranges, weather patterns , sediment supplies and wave energy all change.

References

SCOPAC: Standing Conference on problems associated with the coastline: www.stream.port.ac.uk
South Downs Coastal Goup: www.sdcg.org.uk
BERM project: www.geog.sussex.ac.uk/BERM
Bishop and Prosser (2003), *Landform Systems*, Collins
Guinness and Nagle (2000), *AS Geography Concepts*, Hodder and Stoughton
Waugh (1995), *Geography: an Integrated approach*, Nelson Thornes
DEFRA: www.DEFRA.gov.uk
Google Earth: Close-up aerial views of the British coastline

Focus Questions

1 Describe how the action of the sea interacts with the coastline through the coastal system.

2 How do wave type and sediment size affect beach morphology?

3 (a) Define the term sediment cell.
(b) What are the three main components of a sediment cell, and how do they interact?
(c) How can people affect the equilibrium of a sediment cell?

4 (a) Identify the sources, transfers and sinks within the South Downs sediment cell 4d from the information provided.
(b) Suggest how and why human activity has affected this cell.