

Topic: Coastal Systems

3.1.3.2 Geomorphological & coastal processes

What you need to know
How weathering and mass movement affects the coastline
How erosion, transportation and deposition affect the coastline

Introduction:

Coastlines differ according to their orientation and geology. Coastlines which protrude out into the sea and are formed from less resistant sedimentary deposits are more likely to be modified by a range of coastal processes than a less exposed hard rock cliff face.

Where wave energy is strong, erosion and transportation is more likely to take place and conversely, where wave energy is weaker, deposition will occur. As well as wave energy, other geomorphological processes can modify the coastline. Chemical, mechanical and biological weathering loosen rocks, in advance of their removal by waves and mass movement also provides loose material.

Geomorphological processes: These include marine, atmospheric and terrestrial processes.

Subaerial weathering:

Mechanical weathering:

There are two main types of mechanical weathering which occur at the coast.

- **Freeze-thaw** weathering occurs when the daytime temperature is different than the night-time temperature either side of freezing point on rock faces. During the day, water enters cracks in the rock and at night when the temperature drops the water expands as it freezes. The increase in the volume of ice exerts pressure on fissures in the rock and weakens it internally. During the day, when the temperature rises again, the ice melts. The process reoccurs repeatedly until the rock breaks apart. The material is then loose to fall onto the shore.
- The other type of mechanical weathering is **exfoliation**. This occurs when the daytime and night-time temperatures are distinctively different on dry rock. During the day, the sun heats up the surface of the rock and at night the outer layers cool down. This repeated expansion and contraction of the surface layers results in the gradual disintegration of the top layers.

Biological weathering:

This type of weathering occurs when plants or animals break down the rock.

- On cliff faces, both animal and plant action can loosen large amounts of rock material. Trees and plant roots can prise apart rocks by growing in between the bedding planes and joints enlarging them as they increase in size. Equally damaging is when small animals burrow underground and loosen rocks such as sand martins. Microorganisms in the soil are also able to break down the rocks; particularly carbonate rocks.

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- Below high tide level, seaweed will often attach itself to rocks and when waves crash on the shore, seaweed will be subject to powerful currents and forces that will pull pieces of the rock away with it.

Chemical weathering:

The chemistry that makes up coastal rocks can be affected by rain and sea water leading to the gradual disintegration of solid rocks.

- **Hydrolysis** occurs in certain rocks with minerals that are reactive to water or chemicals in the water. This is where particular minerals break down due to their contact with water leading to loss of rock coherence and structure.
- **Oxidation** can also occur on cliff faces and shoreline rocks where iron elements are present within rocks. The 'rusting' of the iron content may cause rocks to disintegrate.

Mass movement:

There are several types of mass movement that occur along a coastline and involve significant quantities of material being released and falling under gravity, usually onto the shore.

- **Rockfall:** when rocks are broken down by freeze-thaw weathering, this loosened material is vulnerable to the elements. If the rock is at the top of a steep cliff face, it can fall directly to the shore. This can occur more so when a wave cut notch is created at the foot of the cliff by wave action, causing the overhanging rock to be unsupported and more likely to fall.
- **Soil creep:** this is a process operating at the granular scale. It happens on gentle slopes and is noticeable from the wavy surface it produces. Damp soil moves very slowly down the slope as the weight of water pushes it forwards. Rain splash may release soil grains that fall further downslope.
- **Landslide:** rocks and unconsolidated material on the cliff face are saturated with water (rain or wave-splash). Eventually the material slips down the slope. Landslides occur more often on soft rock coastlines where there are natural joints in the rock, into which water can get. They occur on steep gradient slopes and are very similar to slumps, although slumps occur on shallower, concave slopes.
- **Rotational slumping:** heavy rain is absorbed by unconsolidated material making up the cliff (often glacial till, or boulder clay). The cliff face becomes heavier and eventually it separates from the material behind at a rain-lubricated slip plane. Slumping occurs on a concave cliff face and contributes to this shape as successive slumps accumulate. Material at the slump foot (toe) has to be removed by wave action before more slumping can replace it.
- **Mudflows:** these occur on very steep slopes along the coastline. Where there is limited vegetation to bind the soil together and the ground is very saturated

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heavy rain can produce sheet flow over the upper cliff surface. The soil continues to be lubricated and it eventually flows over the cliff face and down onto the shore at a fast speed.

Marine coastal processes:

The processes of erosion, transportation and deposition occur as a result of differing wave and current energy. Where marine energy is high, erosion, removal and transportation is more likely to take place. Where energy is reduced, deposition of transported material is more of a feature. It is important to recognise that the wave type affects the process that occur.

Erosion:

- **Hydraulic action** – this process occurs where the power of the waves hits the cliff face directly and loosens the interior of joints and bedding planes. Cavitation is a similar process. As the wave smashes into a crevice, it compresses air bubbles that effervesce (fizz) powerfully as the wave (and pressure) begins to recede, and creates a mini explosion. Rock within the crack will be loosened and over time this process will widen the opening further.
- **Wave quarrying** – when high energy, tall waves hit the cliff face they have the power to enlarge joints and remove large chunks of rock in one go through vibration. This occurs due to the intense force of these waves.
- **Corrasion / abrasion** – this process occurs when high energy waves have the energy to be able to carry pebbles with force. As the wave breaks at the foot of the cliff, material is thrown at the cliff face and wears it away by chipping fragments off.
- **Solution** – this process occurs when weak carbonic acid in seawater dissolves rock at the coastline and breaks it down (particularly that containing calcium carbonate such as limestone and chalk).
- **Attrition** – this is when rocks and boulders which have already been loosened from the coastline are ground over each other in the water – usually by repeated swash and backwash - and over time the angular edges become smoothed and rounded and boulders/fragments become pebbles, pebbles become shingle, and shingle may become sand.
- **Run-off** – this is when rivers & streams erode away their channel as they approach the mouth. Increased erosion of coastal landscapes can occur because of this. However, runoff can interfere with other process. Often, at river estuaries there is an increase in coastal deposition as the river current entering the sea increases turbulence and friction with marine currents, reduces the energy of both, resulting in deposition of fluvial and marine sediment.

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Transportation:

Most material is moved along the coastline by a process called longshore drift (littoral drift). This occurs when the waves approach the coastline at an oblique angle as a result of the wind driving them onwards at the same angle. The waves push material at an angle up the beach via the swash and it is then deposited on the beach. The backwash will then collect the material and pull it down the beach in a vertical direction back out to sea. Another wave will then collect that material and carry it obliquely towards shore again. The process continues until material is moved along the coastline in a zig-zag movement. Some of this material is held within the water itself as *suspension*. When waves are predominantly constructive it is this process that creates and enlarges beaches. Larger material which has not been reduced down by attrition is unlikely to be picked up and carried by the waves, unless there are storm conditions and the waves are high energy. This material will be moved along the sea bed by the power of the current. This is called *traction*.

Deposition:

This process occurs when wave energy is reduced and friction overcomes the available energy. The wave has to drop material at this point. This can occur in a number of circumstances. Firstly, during the process of longshore drift, where the coastline changes and longshore drift continues to move material, energy will reduce and the transportation will stop, depositing material offshore as a spit. Sometimes when the coastline changes, there is a river estuary. The flow of water from the river into the sea can further reduce the energy of the waves; hence deposition may occur – requiring constant dredging to keep port routes open.

At a headland, wave energy is intensified at the promontory due to refraction and low energy waves then splay out into the bays either side. Material is then deposited in the bays due to reduced wave energy.

The formation of constructive waves also leads to deposition. *Constructive* waves have a low frequency, a long wavelength and a low amplitude. When they break on a beach, they have a strong swash and a weak backwash. This means they deposit more material on a beach as the strength in the swash allows the wave to travel far up the beach before deposition takes place. When they have deposited material on the beach, the energy in the wave is lost and much of the water percolates into the beach material and therefore the backwash is weak. This means material will be left on the beach with a net accumulation. The repeated action of pushing material up a beach eventually leads to the development of ridges, or *berms* on a beach.

The Holderness coast: geomorphological and coastal processes

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Case study: The Holderness Coastline

The Holderness Coastline is a dynamic coastline, continually changing as a result of a range of geomorphological and coastal processes. Since Roman times the coastline has retreated by approximately 5km and at least 23 settlements have been lost to the sea.

Marine processes are both eroding and depositing material along this coastline. The coastline stretches from Flamborough Head in the north, a headland of resistant chalk, to Spurn Head - a spit in the south, at the mouth of the Humber Estuary.

Erosion is greatest between the south of Flamborough Head to the area north of Spurn Head. This occurs primarily due to the powerful destructive waves hitting the coastline in combination with the soft glacial tills that form the Plain of Holderness.

The waves along this coastline are impacted upon by a range of factors:

- Firstly, the fetch - which helps generate large waves - enables destructive waves to be driven by prevailing north easterly winds across the North Sea. Combined with this is the impact of the Coriolis Force which directs the waves at the coastline from a north easterly direction. This force can result in successive days of powerful destructive waves along the coastline which can remove metres of land at a time.
- Storm conditions within the North Sea, particularly during the winter months when Arctic maritime air pushes down towards the UK, creates bigger storm waves, which further erode the coastline due to the high energy they contain. These waves can be up to four metres in height.
- There is a large tidal range along the coastline: up to seven metres at certain times of the year. Scouring and abrasion at the sub-tidal foreshore leads to basal cliff erosion resulting in cliff retreat of, on average, 1.5 metres per year.

The wave energy combines with the lithology of the coastline to produce its distinctive coastal landscape. The hard rock coastline known as Flamborough Head is an exposed chalk headland with caves, arches and stacks that have been created from wave action over time. Waves hitting directly at the headland refract around it, directing the wave energy at the sides of the headland. Weaknesses (natural fault lines due to previous earth movement, together with fissures and joints in the chalk) are eroded rapidly by hydraulic action caused by storm waves forcing air into cracks (cavitation). Storm waves hurl material at the cliff face which chips off solid rock (abrasion/corrasion) to form caves and arches. Sub-aerial weathering processes (freeze thaw particularly, and chemical solution) then weaken rocks at the top of the arch until it collapses under gravity. This leaves a stack, later reduced to a stump. The fact that Flamborough Head absorbs the wave energy would normally mean that areas next to a headland would be protected from high energy waves. However, the long fetch and regular storm waves, together with the lithology (rock type) of the coastline to the south of Flamborough Head means that the rate of erosion is still substantial.

South of the hard chalk rock at Flamborough Head lies a vast area composed of boulder clay. Deposited at the end of the last ice age, the unconsolidated material is soft and easily removed by the destructive waves which directly hit the clay cliffs. In front of the cliffs lie sandy beaches which do little to reduce the energy in the waves. The cliffs are very steep which means that the destructive waves hit directly at the foot of the cliff and weaken it. The base of the cliff is undercut, allowing the overhang to slump

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down onto the beach below. This happens more so with boulder clay than many other rock types due to the large number of pore spaces in the unconsolidated material which absorb rainfall, making the material heavier and lubricating a slip plane. The structural failure of the cliff leaves large amounts of material at the base of the cliff, which should act as protection against the wave action, however, longshore drift quickly removes the material southwards, leaving the cliffs once again vulnerable to further wave action.

The human use of this land has contributed to these unstable cliffs. Foundations for houses and water / gas pipes along with agricultural field-drainage pipes have weakened the structure of the ground leading to an increased rate of erosion.

Sub-aerial geomorphological processes also impact upon the rate of erosion. Storm conditions, which regularly affect this coastline, bring strong winds and heavy rain which can destabilise slopes, prior to their removal by the waves. Heavy rain soaks into fissures in the clay and makes the cliffs more unstable than just from the waves themselves. The boulder clay acts as a sponge and, fully saturated, the weakened material slumps down, bringing vegetation, farm buildings and houses with it.

Physical weathering processes can also affect this coastline, leaving the cliffs more vulnerable to wave action. During the winter months freeze-thaw weathering can occur. The fractures in the boulder clay allow water to enter during the day and at night when temperatures drop it freezes and expands. This process of expansion and contraction, when the ice melts again, will weaken the cliff structure and make it fracture further. The cliffs are then more vulnerable than before. The east coast suffers some of the lowest winter temperatures in the UK due to Arctic maritime air masses bringing cold stormy weather, so this type of weathering is not uncommon.

The Holderness Coastline is also affected by littoral movement and subsequent deposition. When material has been eroded from the boulder clay cliffs it is then moved southwards along the coast by north easterly waves by the process of longshore drift. This process of zig-zag material transportation repeats until it reaches a coastline change, to the east of Hull, where the River Humber reaches the sea. There, the material is deposited as turbulence between the North Sea current and the River Humber current causes movement to slow. This deposited material has formed Spurn Head, a spit composed of sand and gravel.

The process of longshore drift leading to deposition occurs as a result of energy loss. Where the coastline changes direction and the River Humber enters the sea, the energy in the currents are reduced due to friction. This leads to deposition as the waves have less energy to carry the material along. Spurn Head has grown and been washed away at several times in its history in a cyclical process of about 350 years. However, for the past 100 years it has been fixed in position by coastal defences. These defences have now failed and while the southern tip is stable, held in place by vegetation, the narrow spit neck in the northern section is being eroded by the waves and has recently been breached. The cost of repairing the spit neck is too high so at this point, nothing is being done to protect the northern section of the spit in the hope that sediment 'wash-over' will gradually move the entire spit westwards as a whole. The implications of the spit being entirely eroded has major consequences for the silting up of the Humber Estuary – one of the main trade estuaries of the UK containing the ports of Hull, Grimsby, Immingham and Goole.

Exam style question:

1. Explain how a variety of coastal features may form to create a distinctive coastal landscape. (9 marks)
2. Describe and comment on the issues associated with coastal erosion (6 marks)

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1. Explain how a variety of coastal features may form to create a distinctive coastal landscape. (9 marks)

By focusing on the Holderness coastline, both erosional and depositional processes occur here leading a variety of erosional and depositional features.

Focus needs to be on how destructive waves affect the Holderness Coast. Mention fetch, Coriolis force, strong winds and tidal range resulting in storm surges. Explanation is required about the formation of caves, arches and stacks at Flamborough Head as a result of direct wave action and refraction.

Description then needs to be given about how the waves undercut the base of the boulder clay cliffs to the south of Flamborough Head and result in slumping of cliffs. Wave action then removes the material out to sea and transports it along the coast via longshore drift.

Further south along the Holderness coast the focus will be on depositional landforms so therefore Spurn Head and the formation of a spit is needed here. The process of longshore drift needs to be described along with what happens when the coastline changes direction and friction increases. The Humber Estuary and its emergence into the North Sea allows deposition to take place and for the spit to develop over time.

Level 1 will focus on describing different landforms but won't link this to the processes of formation.

Level 2 will focus on the link between feature and process and begin to distinguish between different categories of feature.

Level 3 – Detailed explanation of how erosional and depositional features are formed and the key processes operating to form a distinctive coastal landscape.

Whilst the question doesn't specify that a case study is needed, for the highest level it is easier to develop the answer around a place as the locational detail is likely to improve the answer.

2. Describe and comment on the issues associated with coastal erosion (6 marks)

Answers will refer to some of the following:

- Cliff collapse – impact on houses, businesses, transport networks, local government, tourism etc.
- Reduction in beach size – impact on tourism, increased coastal erosion rate and impact on houses as a result of this.
- Planned hard engineering and likely costs; political consequences of decisions not to protect vulnerable coastlines; and – when constructed – the impact of hard defences on areas further down the coast which might experience increased coastal erosion as a result.

Level 1 (1-3 marks) will only focus on one issue in detail but may have other issues stated. The responses will be largely descriptive.

Level 2 (4-6 marks) a range of issues focused on in detail. There will be commentary evident of how the issue may develop in the long-term with links and/or ranking the issues, either by seriousness or urgency.

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Q1	Match the terms with their process description		
A	Repeated heating & cooling of rock leading to expansion & contraction		
B	Tree roots widening fissures at the top of a cliff		
C	Cliff faces being chipped as storm waves fling material at rock faces		
D	Smoothing, rounding & reducing of beach material by swash/backwash		
E	Powerful effervescence of compressed air as waves recede from joints		
Corrasion/abrasion cavitation attrition exfoliation biological action			

Q2	Tick whether these involve Erosion or Weathering processes	Erosion	Weathering
A	Freeze thaw action		
B	Hydraulic action		
C	Dissolving action by acid rain		
D	Quarrying		
E	Attrition		
F	Corrasion		
G	Oxidation of ferrous minerals within coastal rocks		

Q3	Tick the 2 factors out of each trio that will be most influential in the following processes			
A	Freeze-thaw action	Diurnal temp. range	Predominant wave direction	Degree of jointing of rock
B	Cliff slumping	Offshore currents	Nature of cliff material	Intensity of rainfall
C	Spit formation	Change in angle of coastline	Longshore drift	Concordant coast
D	Longshore drift	Predominant wave direction	Predominant wind direction	Tidal range
E	Cliff retreat	Nature of cliff material	High energy coast	Length of ocean fetch

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Q4	How would geomorphological & coastal processes be different along the Holderness coast if these variables were changed?	
Development of stacks		Retreat of the Holderness coast
If the coastal rock at Flamborough Head was granite.....		If the boulder clay cliffs were twice the height....
Growth of Spurn Point		The East Yorkshire coastal landscape
If coastal erosion protection methods were put in place along the full Holderness coast....		If it was an entirely concordant coastline....

Q5	Compare and contrast the roles played by Weathering and Erosion processes at the coast.
Weathering:	
Erosion:	

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ANSWERS

Q1	Match the terms with their process description		
A	Repeated heating & cooling of rock leading to expansion & contraction	Exfoliation	
B	Tree roots widening fissures at the top of a cliff	Biological action	
C	Cliff faces being chipped as storm waves fling material at rock faces	Corrasion/abrasion	
D	Smoothing, rounding & reducing of beach material by swash/backwash	Attrition	
E	Powerful effervescence of compressed air as waves recede from joints	Cavitation	
Corrasion/abrasion cavitation attrition exfoliation biological action			

Q2	Tick whether these involve Erosion or Weathering processes	Erosion	Weathering
A	Freeze thaw action		✓
B	Hydraulic action	✓	
C	Dissolving action by acid rain		✓
D	Quarrying	✓	
E	Attrition	✓	
F	Corrasion	✓	
G	Oxidation of ferrous minerals within coastal rocks		✓

Q3	Tick the 2 factors out of each trio that will be most influential in the following processes			
A	Freeze-thaw action	Diurnal temp. range	Predominant wave direction	Degree of jointing of rock
		✓		✓
Joints & fractures are required for water to penetrate (day), freeze (night) & expand in to widen				
B	Cliff slumping	Offshore currents	Nature of cliff material	Intensity of rainfall
			✓	✓
Softer cliff material that is made heavier & lubricated by rainfall is more likely to slump				
C	Spit formation	Change in angle of coastline	Longshore drift	Concordant coast
		✓	✓	
L/drift provides the material that is deposited as wave energy declines at changes of coast orientation. It can extend across a discordant coastline irrespective of changes in the rock type.				
D	Longshore drift	Predominant wave direction	Predominant wind direction	Tidal range
		✓	✓	
Predominant wind direction will drive the predominant wave direction at an angle to the beach for swash to be driven up at an angle irrespective of tidal range.				
E	Cliff retreat	Nature of cliff material	High energy coast	Length of ocean fetch
		✓	✓	
Cliffs of softer material will retreat faster at a high energy coast. It's not always the longest fetch that creates high energy conditions; the N. Sea has a shorter fetch than the Atlantic but the Holderness coast is the fastest eroding coast in the country when high energy conditions prevail.				

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ANSWERS

Q4	How would geomorphological & coastal processes be different along the Holderness coast if these variables were changed?	
Development of stacks		Retreat of the Holderness coast
If the coastal rock at Flamborough Head was granite..... <i>Unlikely that stacks would develop. The hardness of granite compared with chalk means it is far more resistant to erosion. The structure of granite lacks the fissures, joints and bedding planes that facilitate the development of caves to erode into arches and stacks. The nature and structure of an igneous rock means far longer is required for caves to develop and the landforms, if they did occur, would take longer, and last longer.</i>		If the boulder clay cliffs were twice the height.... <i>Higher cliffs would slump a greater quantity of material onto the beach in mass movement. This needs removing by wave action before a new wave-cut notch can develop in the new cliff position and lead to further cliff slumping. The rate of retreat would slow down considerably, although it would continue.</i>
Growth of Spurn Point		The East Yorkshire coastal landscape
If coastal erosion protection methods were put in place along the full Holderness coast.... <i>Spurn point requires a continuous provisioning of eroded material from upcoast to be deposited along its length by longshore drift. If this supply was interrupted by coastal protection, the spit would no longer grow southwards and it would begin to erode more rapidly at its vulnerable neck. A breach is more likely and the entire spit could be rapidly eroded as the balance of erosion/deposition is tipped in favour of sediment loss.</i>		If it was an entirely concordant coastline.... <i>The Holderness coastal landscape is defined by its discordant nature: a chalk headland at Flamborough and glacial deposits of boulder clay along the majority of the coastline. This gives rise to different processes and sediment inputs into the sub-cell. If the coast was all chalk, or all boulder clay the range of erosion features would be reduced as would the nature of depositional features.</i>

Q5	Compare and contrast the roles played by Weathering and Erosion processes at the coast.	
Weathering:		
<i>This causes the loss of internal coherence of solid rock and eventual disintegration in situ. The debris from weathering is often removed by agents of erosion. This may present a fresh rock surface for further weathering to take place. Similar to erosion, there are physical (mechanical), chemical and biological forms of weathering. However, it often takes place well above direct wave action, affecting rock that is not directly subject to erosion by marine erosional processes, but may take place all the way down to the sea bed.</i>		
Erosion:		
<i>This causes rock to break down and be removed from its location. Marine erosion is often confined to the intertidal zone between low and high tide, although wave action in storm conditions may affect cliff faces at some height above high tide. Erosion processes can operate on their own, or upon the results of weathering, removing rock debris and acting on weaknesses that weathering has initiated/exploited. Erosion involves transportation of rock debris, unlike weathering.</i>		