Geography AS
Unit 1 – Dynamic Landscapes
Coastal Landscapes and Change
Summer Work (Mrs Ellis)

Unit 1 Dynamic Landscapes

1) **Tectonic Processes and Hazards** – This unit looks at natural hazards (their frequency, distribution and trends), and how to manage them.
2) **Coastal Landscapes and Change** – This unit looks at coastal processes, landforms and landscapes, coastal risk and how to manage them.

Over the summer, I would like you to do some work on coastal landscapes and change

Coastal Landscapes – Research

Do some research on the different types of coastal landscape. Consider the following points:

- Erosional v depositional
- Cliff v sandy v estuarine
- Different types of geology
- Emergent v submergent
- Land use
- Tidal range
- Wave energy
- Concordant and discordant

Present your findings in an interesting way to share with the class. This can be a PowerPoint, video, colourful mind map etc. Use pictures and maps in your work.

Coastal Landscapes – The Players/Stakeholders

There are a number of groups (players/stake holders) who are involved in coastal management

- DEFRA (UK)
- Ministry of defence
- Local councils
- Lands owners
- Local people
- Environmental groups
- Other organisations e.g. RAMSAR, UNESCO, NNR
- Large companies e.g. oil companies

Find at least one example of each of these. How have been involved in managing coasts. Used named locations in your answers

This work should be presented as a table. (headings – Player/ responsibilities/ possible conflicts/ located name example with details/sources).

Example headings for task 2.

Player/ Stakeholder	Responsibilities	Possible conflicts/ issues with other stake holders	**Detailed** located example involving this player	Sources e.g. websites/ books /articles
Eg Defra				

Useful Websites and clips

https://www.s-cool.co.uk/a-level/geography/coastal-processes

https://www.bbc.co.uk/programmes/b006mvlc (BBC coasts)

https://www.bbc.co.uk/programmes/b006w6xh/clips (short clips)

https://www.geography-fieldwork.org/a-level/coasts/

https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs

https://coast.noaa.gov/czm/

Useful reading

Geofactsheet 141 – The Holderness Coastlines

Geofactsheet 356 – coastal erosion Landforms on the Gower Peninsula

Geofile 491 – Coastal erosion – East Yorkshire

Geofile 537 – North Norfolk coast Shoreline Management Plan

Geofile 575 – Coastal Systems

Geofile 585 – Pressures on the Coastline

Geofile 600 – Sea level change: Causes and coastal landforms

Geoactive 510 – Managing conflicts in Poole harbour

Geoactive 542 – Sand Dune Management, Merseyside

Useful Unit Guide:

https://www.amazon.co.uk/Edexcel-level-Geography-Student-Guide/dp/1471863158/ref=pd_sbs_14_3/259-9953827-8091026?_encoding=UTF8&pd_rd_i=1471863158&pd_rd_r=100690a3-9759-11e9-9696-83bafaaed3b7&pd_rd_w=JQfwV&pd_rd_wg=JxZ9M&pf_rd_p=18edf98b-139a-41ee-bb40-d725dd59d1d3&pf_rd_r=C50R8YMGNMTKNDZ9WPHE&psc=1&refRID=C50R8YMGNMTKNDZ9WPHE

For each piece of work please credit your sources – those above and any of your own. Try not to use Wikipedia but stick to websites run by governments, academic sites, appropriate charities and organisations, and quality news sites

And finally

Over the holidays read a good quality newspaper or check the BBC website for news on the environment and/ or Science. Make a collection of articles that are related to Geography. Keep these in a folder.

Geofile Online
JANUARY 2005
491

Mike Wynn

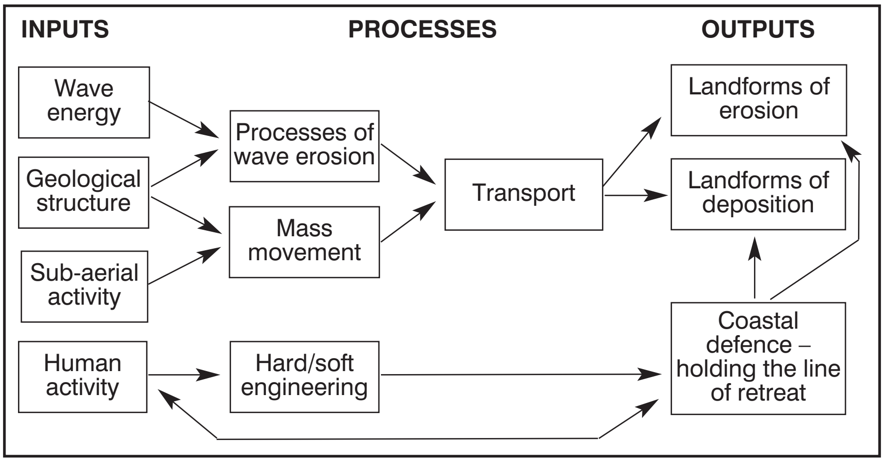
Landforms of Coastal Erosion: Examples from East Yorkshire

Introduction

The coast – the interface between land and sea – is a worldwide linear zone, often only a matter of a few metres wide. In Britain we often think of the coast as being formed by the energy of the waves, largely due to their ubiquity and power; however, sub-aerial processes are also significant; sometimes climatic regimes are important and also vegetational processes on some coasts.

The coastal zone can also be viewed as a **system**, with **inputs**, **processes** and **outputs**) (Figure 1).

Figure 1: Coastal systems



Wave Energy

Waves are pockets of energy generated by the wind; consequently the **fetch** of a wave is significant. In the North Sea, wind can blow from the Arctic directly southwards, generating storm waves that attack north-facing sections of the East Coast such as Whitby, Flamborough Head, and the north Norfolk coast. On a global scale, winds blow across the Atlantic Ocean from the south west, creating **swell** that reaches the Cornish coast.

Depending upon preceding weather conditions over the surrounding sea area, waves arrive at the coast with a number of characteristics: wave height, wave period, wavelength, wave velocity and wave steepness. The combination of length and height determine the amount of energy: $E = LH^2$, so a small increase in height gives a large increase in energy.

As waves approach shallow water, friction with the sea bed increases, so the height and steepness increase, causing the crest of the wave to 'fall over'; this is when the wave breaks, water rushes up the beach as the **swash** and returns by gravity as the **backwash**. Under calm conditions the frequency of waves (**wave period**) ranges from 6 to 8 per minute, but under storm conditions this increases to 10 to 14 per minute, with a commensurate increase in the amount of energy expended on erosion.

The Processes of Coastal Erosion

Waves are affected by friction as the body of water moves forward and the energy within becomes a major erosional process.

- **Abrasion** (Corrasion) Waves throw loose sand and shingle and even boulders at the cliff; this is one of the most effective methods of erosion. A hard cliff face becomes smoothed and even undercut to create a notch; a cliff face of alternating hard and soft rock becomes indented (differential erosion).
- **Attrition** This is where all movement of the water turns rocks, boulders and gravel into smooth, rounded, smaller rocks, usually between high and low tide.
- **Solution** (corrosion) This takes place where carbonic acid in sea water reacts with $CaCO_3$ in limestones, or the salt in sea water and spray corrodes rocks, especially if salt crystals grow and cause rocks to disintegrate.
- **Biological activity** Secretions from algae attack rocks, and some molluscs can bore holes in rock.
- **Wave pounding** (Waugh), **wave quarrying** (Knapp) Waves impact the rock face with pressures of up to $50 kg/cm^2$ (cf. car tyre $2 kg/cm^2$) (Knapp). The effect of this is to loosen blocks of rock along any weakness. This process can eventually destroy sea walls.
- **Hydraulic pressure** This is often unseen, but very effective. Waves enter a tiny crevice or large cave and air is trapped, then forced into all the weaknesses, time after time, so that the rock can eventually collapse.
- **Subaerial weathering** This occurs most notably by rain leading to the saturation of cliff material and then the failure of the cliff by **mass movement**. This mass movement can range from soil creep, to slumping, to landslides. This is an important process on the upper part of the cliff and in softer material.

Factors Affecting Coastal Erosion

Geological structure
All rock has degrees of hardness or softness. Boulder clay is much softer than chalk, so the former will erode to form a bay, the latter will be resistant and form a headland. However, the same features will result with two similar rocks eg limestone, providing one is harder than the other.

Within the rock it is necessary to recognise some common structural features. All sedimentary rocks are laid down in layers called **beds** or **strata**, one layer being separated from the next by the **bedding plane**. Within beds are **joints**, the result of **lithification** (soft sediment turning into hard rock). Bedding planes and joints are weaknesses within the rock and are likely to be exploited by processes of weathering and erosion (Figure 2).

Figure 2: Some structural terminology

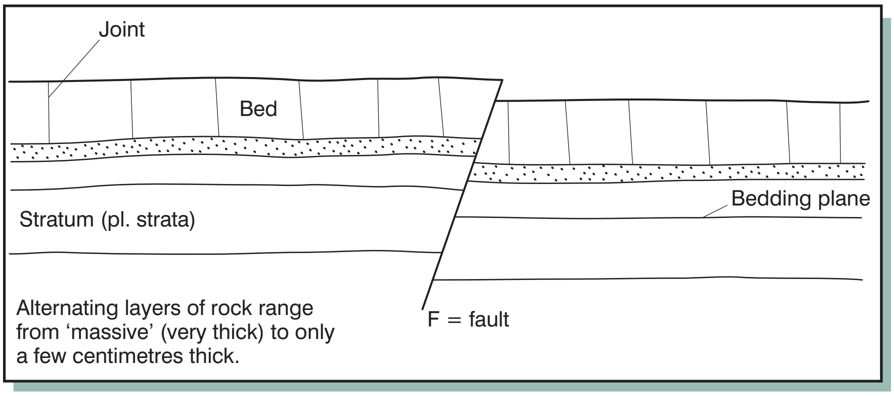
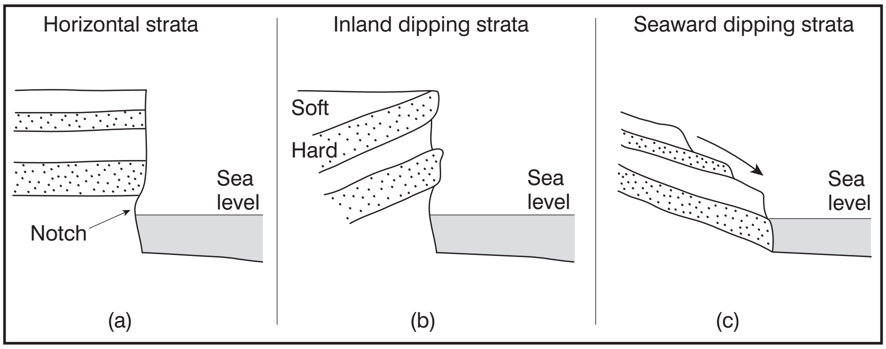


Figure 3: Cliff profiles



Igneous rocks also exhibit joint patterns, as in the hexagonal columns of basalt seen widely throughout Iceland and on the Giant's Causeway in Antrim, Northern Ireland.

Metamorphic rocks exhibit banding or lineation formed in the process of metamorphism as minerals are realigned with their long axes parallel to each other; schistosity is one of the best examples.

The cliff profile can be influenced by the dip of the rocks (Figure 3).

Folding and faulting

As a result of earth movements all rocks exhibit some degree of folding which can become weaknesses. Faulting does not have to be a major movement, but merely a few millimetres, which is sufficient to dislocate the beds and create a line of weakness for the processes of weathering and erosion to exploit.

Coastal morphology

On an indented coastline, headlands and the offshore topography concentrate wave attack on that headland by the process of **wave refraction**. Many headlands have a wave-cut platform between high and low tide which can cause friction for the wave, but due to their solid nature they do not absorb energy, as a sandy beach would do, so waves can break at the foot of the cliff, causing maximum erosion. Some waves at high tide may cross the wave-cut platform and not be much affected by friction and then refracted by the cliff, having minimal erosional impact.

In a bay, waves have to travel further, and a beach absorbs wave energy and reduces the power of the wave before it reaches the cliff. Where there is a wide, deep, sandy beach, waves may not even reach the cliff at all.

Flamborough Head and Holderness Coast

Flamborough Head in East Yorkshire is a chalk headland exhibiting classic features of coastal erosion, but also some unique features (Figures 4, 5 and 6).

The Lower Chalk zones form the highest cliffs of the headland north of Thornwick and are inaccessible. The Middle Chalk forms Thornwick Bay and the North Landing area, whilst the Upper Chalk can be seen at Selwicks Bay. Chalk in northern England is harder than that in southern England due to a higher calcite content. The Lower and Middle Chalk also contain varying amounts of flint, a secondary deposit which is very hard and brittle. The layers of chalk dip in a southerly direction at 4°; they are well jointed and criss-crossed by minor faulting – all the necessary ingredients for erosion.

Geological history

The recent geological history of the area is important. Pre-glacially the cliffs were only made out of chalk and were about half their present height. The sea eroded caves, arches and stacks and a wave-cut platform. During the Ice Age the whole of this area was covered in ice; post-glacially, as the ice retreated, a vast deposit of Boulder Clay was left over all the area, masking pre-existing features: the caves were plugged with Boulder Clay and the bays were infilled. As the North Sea basin filled up and the waves rolled in, their first job was to excavate the Boulder Clay, to reveal many of the original features.

Selwicks Bay

In Selwicks Bay, most easily eroded by the sea are the faults, which enlarge into **caves**. In places, two caves erode back to back to form a through-cave, or a cave can erode through a small headland into a pre-existing bay, both of which are called **arches**. Some arches are so small it is only possible to crawl through them, others are large enough to sail a yacht through. Arches themselves eventually collapse; the upstanding tower of rock is a **stack** and they also eventually collapse, to leave a **stump**, only slightly proud of the **wave-cut platform**. All this erosion results in the slow, inexorable retreat of the cliff line, leaving a foundation of chalk as the wave-cut platform, one of which occupies the majority of Selwicks Bay (Figure 4).

There are two unique features. Part of Selwicks Bay is composed of a wide 'line of disturbance' where the chalk has been subjected to and contorted by severe earth movements, the friction reconstituting some of the minerals into calcite which has hardened this section of cliff, so as to form a small headland within the bay, Also at Selwicks Bay is a **blow hole**, not unique in itself, but it reflects the glaciological history of the headland. Pre-glacially it was created as a blow hole that was then infilled and covered by Boulder Clay, only to be post-glacially re-excavated and enlarged so that today, even though the water rushes in, it does not blow. The weaker clay surrounding it is actively slumping into the blow hole and forms a huge amphitheatre

Figure 4: Sketch map of features at Selwicks Bay

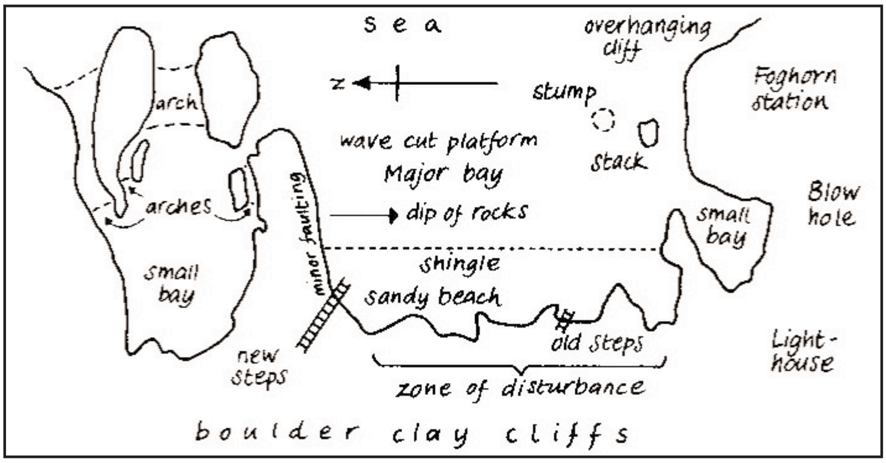


Figure 5: Sketch diagram of the west side of North Landing, Flamborough Head (pre-1984)

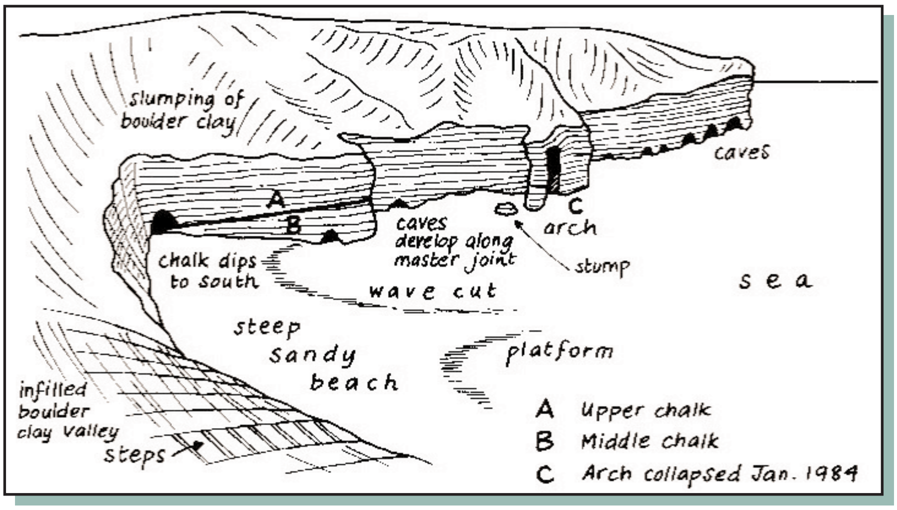
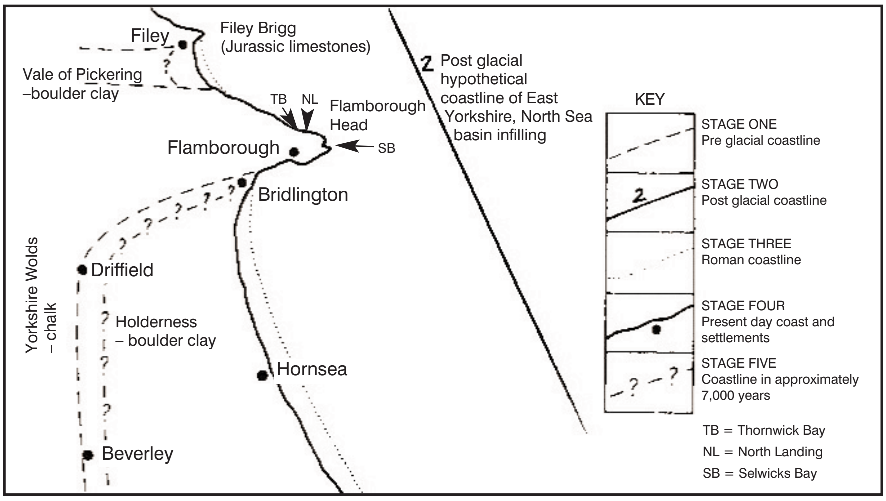


Figure 6: The sequence of East Yorkshire coastlines in pre- and post-glacial times



around the blow hole, an example of the subaerial weathering of the cliffs (Figure 7).

North Landing

At North Landing in the Middle Chalk, the layers of chalk are much thinner, there is a lot of flint, the jointing is very close so the whole rock is highly fragmented, there is a lot of faulting and the bay, being open to the north, is subjected to attack by the storm waves from the Arctic. Caves abound and one fault has been enlarged into a long narrow inlet, called a **geo**. On the west side of the bay there was once a series of arches. Figure 8 shows an arch that is no longer there – it collapsed one night in January 1984. Two to three metres from the base it was quite narrow and it is tempting to suggest that storm waves battered it to bits, but the roof of the arch had been under pressure for many years, with two major right-angled cracks and overhead pressure bending the layers of chalk. The overlying weight of saturated Boulder Clay caused the eventual collapse, a result of sub-aerial processes; marine erosion removed most of the collapsed debris within about three months (Figure 9). Currently there are two stumps being abraded, one from a pre-existing arch that collapsed long ago and a second stump from the 1984 arch collapse. They both now form part of the wave cut platform.

A retreating coastline

The Holderness coast is well known as one of the most rapidly eroding coasts in the world. As shown in Figure 6, Holderness did not exist pre-glacially and the chalk formed a coastline that stretched from Sewerby (just north of Bridlington) to Driffield and south to Beverley (Stage One). At the last onset of the ice, glaciers rode over the existing cliff and pushed their way up the Vale of Pickering, over Flamborough Head and up the lower slopes of the Yorkshire Wolds. As they melted and retreated they covered the landscape in a thick layer of Boulder Clay (Stage Two). The North Sea Basin became the North Sea and waves began to attack the clay deposits, rolling the cliff line westwards. The offshore gradient of Bridlington Bay is very gentle, but the beach sand near Holderness cliffs is very thin and underlain by a platform of impermeable Boulder Clay; most tides except summer neap tides, reach the base of the cliffs and in storm conditions waves break on the soft clay of the cliff. It is estimated that the coastline has retreated by 4 km since Roman times (Stages Three and Four).

Villages are still under threat, such as Mappleton, which at great expense has been protected. The cost of protection for rural areas is just too high – saving farmland that is valued at a few thousand pounds per acre with protection that costs millions of pounds. The storm surge of January 31/February 1 1953 was of such ferocity that the concrete promenades at Hornsea and Withernsea were smashed to bits. All our engineering ability may combat 'normal' waves or even some storm surges, but if we are to continue to experience sea level rise and further storm surges, then coastal defences as they exist will not suffice; managed retreat is the only option, but what about towns like Hornsea and Withernsea? In the past few years both have had their coastal protection substantially upgraded, but what will happen when a whole village is next threatened? (Stage Five).

Conclusion

Throughout the world, coastal features are ubiquitous and the sea relentlessly erodes the edge of the land, but where waves attack upstanding coasts the resultant features can be impressive.

Wave energy, geological structure and sub-aerial activity are the major inputs influencing cliff formation. These cliffs are attacked by the processes of wave erosion and modified by the processes of mass movement which result in a variety of coastal landforms, both depositional and erosional.

Human activity is cyclical. As soon as hard or soft engineering is used, especially the former, it has an interruptive effect on the processes. Coastal defences often have to be modified in the light of experience.

Bibliography

Clowes, A. and Comfort, P. (1982) *Process and Landform*, Oliver & Boyd.
Goudie, A. (1984) *The Nature of the Environment*, Blackwell.
Waugh, D. (2000) *Geography: An Integrated Approach*, 3rd edn, Nelson.
See also **Geofile** No. 388, September 2000, N. Punnett: 'Coastal Erosion – Back to Nature'.

Figure 7: The blow hole at Flamborough Head, adjacent to the Lighthouse and Selwicks Bay

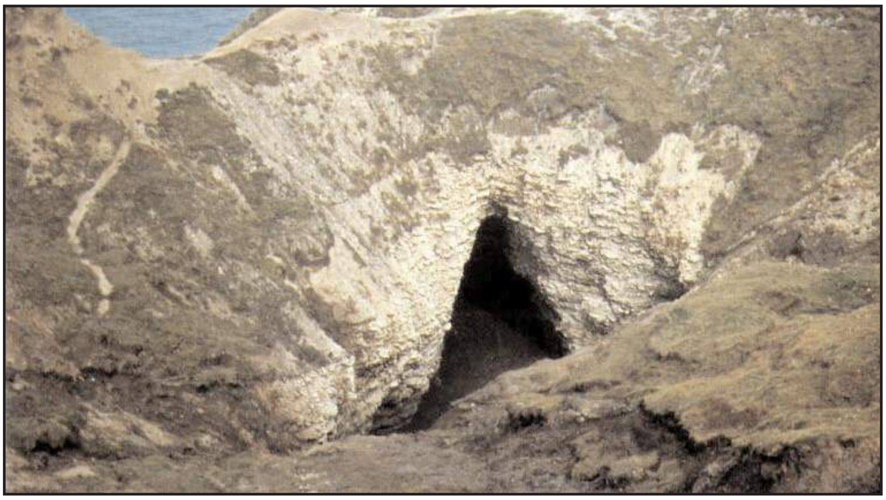


Figure 8: Arch at North Landing, prior to collapse. Note not only the narrowing of the column, but more importantly the weakness at the top of the arch caused by the overlying weight

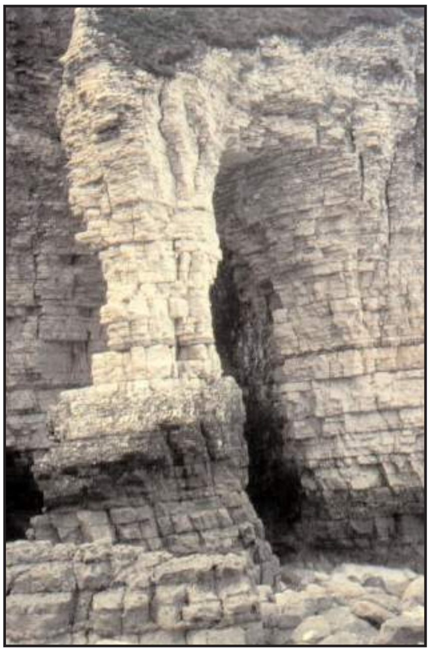


Figure 9: Taken only three months after the arch collapsed in 1984. Most of the debris has already disappeared

Focus Questions

1. How can a coastline demonstrate the inter-relationship between process, structure and stage of development?

2. Develop arguments for and against protecting coastlines subject to rapid erosion referring to hard and soft engineering techniques

3. Discuss the assertion that it is not possible to understand the present day landscape without reference to past geomorphological processes.

Geo Factsheet

www.curriculumpress.co.uk Number 141

Coastal Management – An Update

Case Study of The Holderness Coast, Yorkshire

Introduction

A range of classic coastal features stretch over 50km, from the chalk cliffs of Flamborough, through the plain of Holderness, to Spurn Head where a large spit guards the entrance to the Humber estuary. The combination of clay geology and a high-energy environment has helped make this part of the Yorkshire coast one of the most rapidly eroding coastlines in Europe. Historical records show that some twenty-nine villages have fallen into the sea since Roman times *(Fig. 1)*. This problem continues to challenge coastal engineers and as the pressure from population growth, economic development and recreation grows, choosing an appropriate management strategy is proving to be an increasingly difficult task.

What physical factors are at work along this coastline?

A wide range of contributory factors is shown in *Fig. 1*, and three of the most important are outlined below:

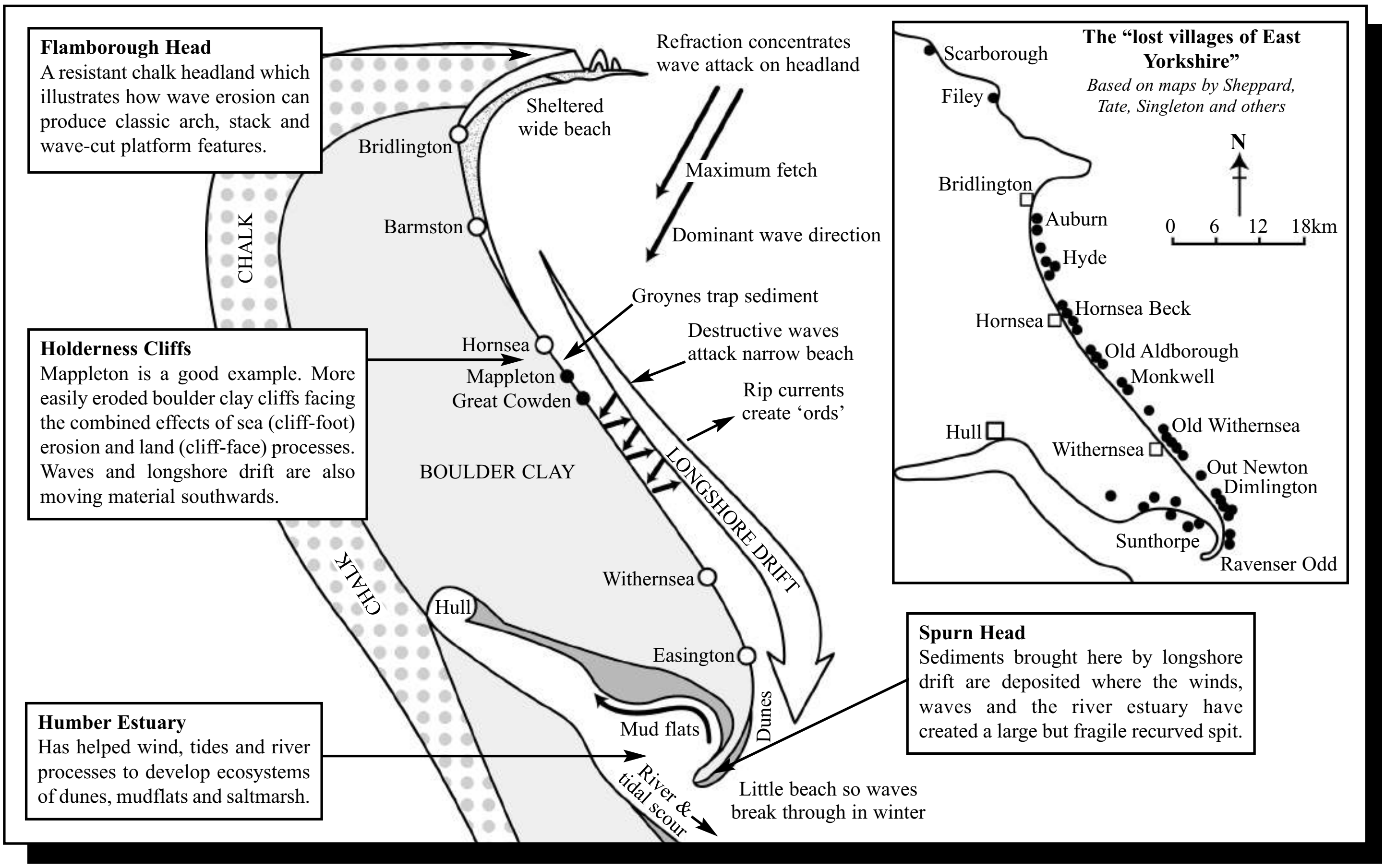
- **Weather** – Winter storms produce stronger waves and higher sea levels (surge). In addition, the rain they bring intensifies land-based (sub aerial) processes. The saturated clay cliffs suffer increased runoff leading to slumping and other forms of mass-movement.
- **Waves** – The dominant waves are from the north east which is also the direction of the largest fetch. Destructive waves erode the beaches and attack the foot of the cliffs, removing the clay in suspension. Longshore drift then carries this material southward. Tides and the lower energy environment of the Humber estuary allow sediments to collect forming a spit, mudflats and sand dunes near to Spurn Head.
- **Geology** - The two main types of rock found along the coast are chalk and boulder clay. The more resistant chalk has survived large-scale erosion and this has created the classic features of Flamborough Head *(see Fig. 2, page 2)*. The boulder clay cliffs to the south are more easily eroded and their retreat has formed the sweeping bay of Holderness. It is this **differential rate** of erosion that has given the coastline its distinctive shape.

What features and processes make this coastline so distinctive?

Three distinctive features stand out along this coastline:

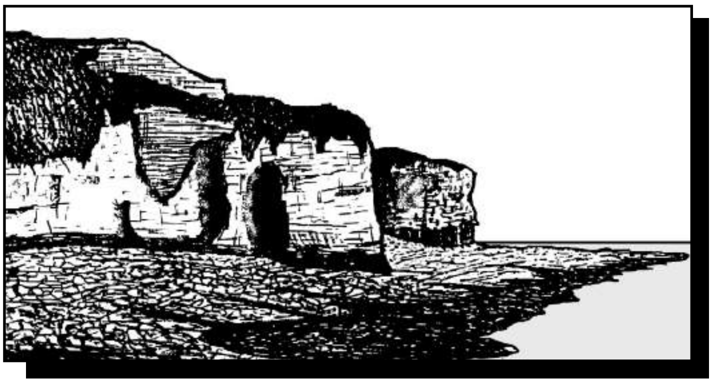
- the impressive chalk headland and cliffs near Flamborough
- the retreating clay cliffs of the Holderness Bay
- the 6km spit at Spurn Point

Fig. 1 Physical factors that help create features along the Holderness Coast.



Flamborough Head
This headland *(see Fig. 2)* illustrates how wave erosion can produce the classic arch, stack and wave-cut platform features, often associated with chalk rock. The chalk is resistant to erosion and has a distinctive lithology. The horizontal bedding planes are seen in cliffs at Flamborough Head and North Landing where they assist in the development of **wave-cut platforms**. These form close to high tide levels when shingle carried in the waves increases **abrasion**.

Fig. 2 The features of Flamborough Head.



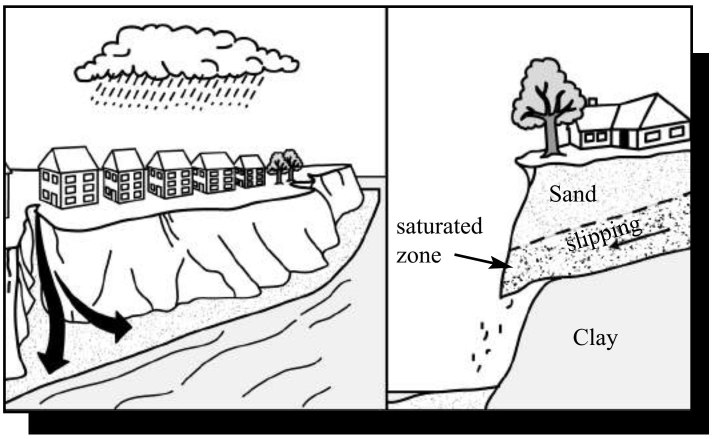
As the cliffs retreat a noticeable **notch** indicates how powerful wave energy can be. Vertical joints allow waves to penetrate the cliffs and together with faults these can lead to the formation of caves and geos. **Wave quarrying** can result from the sheer weight of the waves striking the cliffs (hydraulic pressure) or from air being trapped in faults and acting pneumatically as waves break. **Wave refraction** further concentrates waves on headlands allowing caves to develop progressively into **arches**, **sea stacks** and **stumps** *(see Geo Factsheet number 129 The impact of structure on coastal landforms).*

It should not be forgotten that cliff-face (sub-aerial) processes like **rock falls** are also important here and work together with cliff-foot (sea) processes to create these headland features.

The Holderness cliffs
These boulder clay cliffs are formed from material left by ice sheets. They are retreating at an average rate of 1.8 metres per year (ten times the rate in the chalk cliffs). This results from the combined effects of land (cliff-face) processes and sea (cliff-foot) erosion.

On land, rainwater enters the clay and the weight of water causes material to slide seawards. This may occur along natural **slip planes** in the cliffs or the saturated clay may **slump** forwards onto the beach. Removal of vegetation, and increasing urbanisation can accelerate these effects. Cliff-top housing or hotels may make matters worse *(see Fig. 3)*.

Fig. 3 Processes at work on the Holderness cliffs.



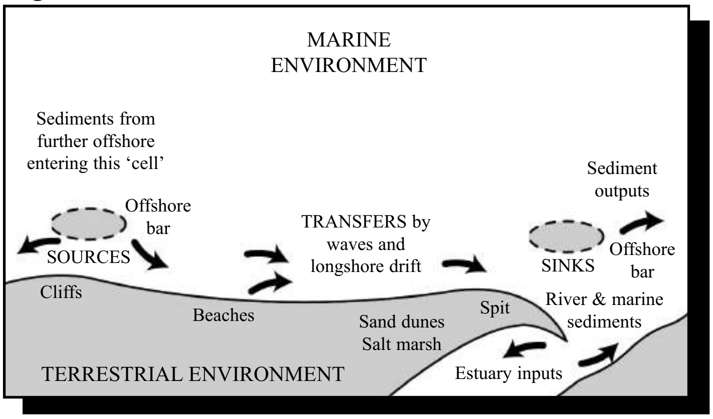
At the cliff-foot the fine clay is easily removed by waves and it is estimated that **longshore drift** carries half a million tonnes of sediment southwards each year in **suspension**. There is therefore little material left to form beaches and protect the cliffs from winter storms and high tides. At particular places along this coast strong **rip currents** may excavate **'ords'**, or deep hollows, which can lead to catastrophic rates of cliff erosion. Recent examples have been documented at Great Cowden and Easington, with cliffs retreating locally at rates of over ten metres per year.

Building groynes to encourage beach deposition in one location may lead to erosion further along the coast. This may well be the case downdrift of holiday resorts like Hornsea, Mappleton and Withernsea, where they have sought to protect their beaches from erosion.

Spurn Head
Sediments are deposited here where the winds, waves and river estuary have created a large but fragile **recurved spit**. Whilst the spit is currently growing at around 10cm each year winter storms periodically threaten to cut through the narrow neck and detach it from the mainland. Historical evidence suggests that changes in erosion and deposition happen in cycles. The spit is also the site of sand dune and saltmarsh ecosystems *(see Geo Factsheet 119 on sand dunes and salt marshes)*.

Small sections of the coastline such as this running from Flamborough to the Humber estuary are referred to as **littoral cells**. They are open systems with inputs, transfers and outputs of water and sediment *(see Fig. 4)*.

Fig. 4 The Holderness littoral cell.



What human factors play a part along this coast?
There are three human influences at work here:

- **The presence of people along the coast** turns physical processes into hazards and threatens life and property. Increasing population levels due to retirement and the development of leisure and holiday facilities have occurred around Bridlington and Hornsea. Caravan parks are a particular feature of this area. The risks from erosion have been much publicised at Easington where the gas terminal has been under threat.

- **Interfering with natural processes** such as longshore drift or implementing unsuitable defence strategies can have adverse effects. The downdrift impacts of groynes at Hornsea, Mappleton and Withernsea mean that sediment is being prevented from building beaches elsewhere. Rapid erosion rates at sites like Great Cowden may be due to this sediment starvation effect.

- Finally **global warming** and short-term changes in climate, an indirect human impact, are creating a rise in sea level and increasing storminess. Areas like Spurn Head and the shoreline of the Humber Estuary are at great risk in such conditions, from both coastal flooding and erosion.

Coastal management – What are the options?

Our thoughts about the suitability of different types of coastal management have changed over time. The full spectrum of options is listed in *Table 1*, together with some examples. **Hard engineering** (e.g. seawalls) with its high construction and maintenance costs is only used where there is no choice but to protect valuable buildings or business.

So-called **soft engineering** tries to cope with coastal processes using techniques like beach nourishment. It has lower costs and often some environmental benefits. Very few strategies are truly **sustainable** or future-proof, and currently tend to be small scale or only tried where land values are low.

Table 1 The spectrum of Coastal Management options.

Strategy	Purpose or description	Strengths	Weaknesses	Yorkshire coast examples
HARD ENGINEERING	***This approach involves CONTROL . Traditionally (Victorian) used to overcome natural processes***			
1. Cliff-foot strategies	**To protect the beach from sea erosion**			
Sea walls	Massive, made of rocks or concrete, used to absorb waves. Some types can act as Baffles	Traditional solution to protect valuable resources, high-risk property or densely populated areas	Very costly, foundations easily undermined of built on beaches, or where LSD operates	Holiday resorts, e.g. Hornsea and Withernsea
Revetments	Massive, made of concrete, used to reflect rather than resist waves	As above though relatively cheaper	Costly and do not cope well with very strong waves	Easington gas terminal
Gabions	Wire cages holding smaller rocks	Cheaper version of above	Relatively lightweight and small scale solution	Skipsea
Groynes	Rock or wooden types, hold beach material threatened by LSD erosion	Low capital costs and repaired relatively easily	Need regular maintenance. Cause scour downdrift and have wider impacts	Hornsea, Withernsea and (famously) at Mappleton
Offshore bars (artificial reefs)	Reduce power of waves offshore	Mimic natural bars and reefs. Can be built of waste material	Possible ecological impacts and may not work at large scale	Only used as small scale pilot study so far
Rip-rap (rock armour)	Very large rocks in front of sea walls or cliffs to absorb waves	Effective and prevents large-scale undermining	No longer a relatively cheap option. May move in severe weather.	Withernsea and Easington
2. Cliff-face strategies	**To reduce damage from sub-aerial erosion**			
Cliff drainage	Removal of water prevents landslides and slumping	Cost effective	Drained cliffs can dry out and lead to collapse (rockfalls)	Small scale project at Easington
Cliff regrading	Lower the angle of cliffs to stabilise ground	Works on clay or loose rock where little else will	Retreat of cliff line uses up valuable land	Mappleton
SOFT ENGINEERING	***This approach involves ACCOMMODATION, working with natural processes***			
Beach nourishment	Sand pumped or transported to replace losses by LSD	Appears 'natural looking' process	Expensive and may soon erode. Possible ecological effects	Hornsea and Mappleton
'Do nothing'	Land no longer worth defending	Saves expenditure on defence	May allow problems to get worse.	Neck of Spurn head
'Red-lining' or zone management	Withdrawal or prevention of planning permission for new development	Cost effective in long term	Unpopular with residents and business. Politically tough	
SUSTAINABLE MANAGEMENT	***This approach involves ADJUSTMENT, working to secure the future of a coastline***			
'Managed retreat'	Incentives given through grants/buyouts to encourage re-location and 'set-back' schemes	Cost effective (as it saves construction costs) in longer term. May help reduce tides in estuary environments	Difficult to argue politically if residents involved	Suggested in 1994 for Hornsea but not implemented. Ideal for estuary around Sunk Island.
Coastal resilience (ecosystems)	Partial flooding allows salt marsh and wetlands to adjust to sea.water. Allowing erosion in some places helps sand dunes develop in others	Very cost effective and environmentally valuable. Allows conservation of bird life especially	Loss of agriculturally productive land. Does this work on a large scale?	Plans to flood Sunk Island and plant in sand dunes south of Hornsea
Shoreline management plans	Detailed consultation getting local groups to work together to find best solution for each littoral sub-cell	Solutions tailored to specific places and particular needs of local community	May be seen as delaying tactic by those who want action now	Applied to coast further north in the Scarborough and Whitby areas

How are coastal management decisions made?

Decisions about how to defend each section of a coast can be taken using various types of assessments:

- **Cost-benefit analysis** considers the social and economic aspects of a strategy. The benefits of a scheme (new businesses or jobs and savings in lives and property) are divided by the costs of building and maintaining it.

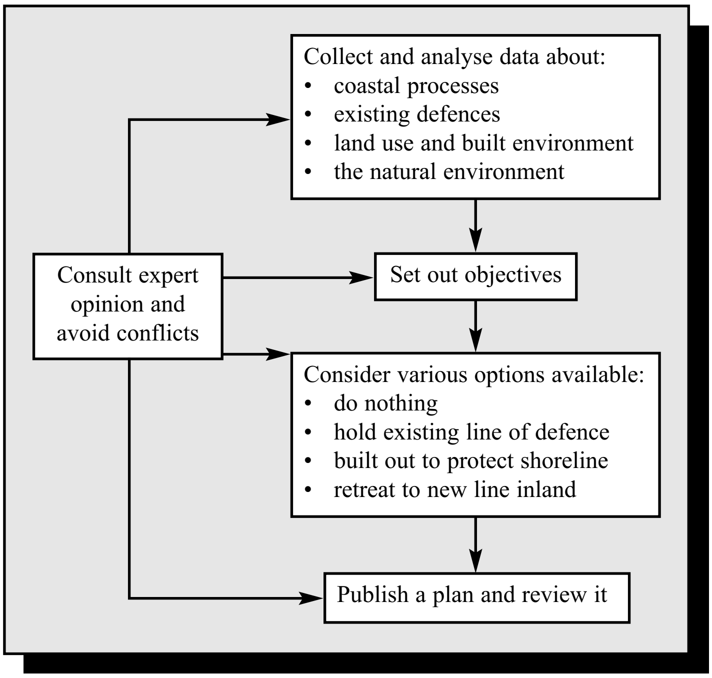
- **Environmental impact assessments** try to assess the effects any strategy will have upon an area. It is especially important along coastlines as attractive scenery and ecosystems are valuable tourist assets.

- **Feasibility studies** look at the technical merits of a particular scheme and site. Is the engineering planned suited to the local geology or coastal processes?

- **Risk assessment** involves taking decisions in the light of the likely recurrence interval and what is at risk. Insurance and legal claims will make this an important consideration in the future.

- **Shoreline management plans** *(see Table 1, page 3)* try to decide upon the most appropriate scheme for each part of a littoral cell, in discussion with all parties. The mechanism is set out below *(Fig. 5)*.

Fig. 5 Setting up a Shoreline Management Plan.



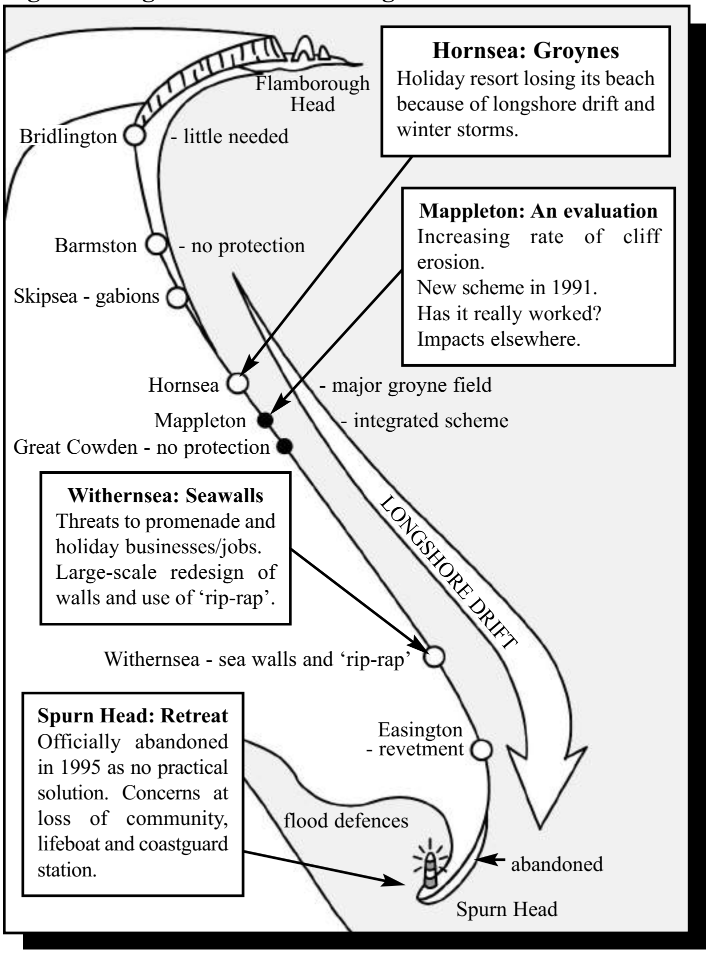
Defence strategies used along the Holderness coast *(see Fig. 6)*:

In the northern part of the Holderness coast there is little need to protect the shore as much of the beach material is relatively stable, though removal of aggregate should be banned. Erosion increases southwards though there is still a balance between the rate of cliff erosion and sea removal. Beyond Hornsea the loss of sediment by longshore drift is considerable.

The coast at **Skipsea** has a series of **Gabion cages** built by the local landowner, though areas either side of his caravan and leisure site are still eroding.

Barmston today has little protection with some dumping of rock waste being the only defence.

Fig. 6 Management schemes along the Holderness coast.



Exam Hint: *Practice drawing a very simple Holderness outline and then design three separate maps to mark on:*
- *physical features of erosion and deposition*
- *physical factors influencing coastal processes*
- *management strategies*

Hornsea however is a holiday resort with a promenade and hotel frontage. Here the beach is of great importance both as a tourist feature and a means of protecting the seawall from wave erosion and winter flooding. **Groynes** have been repaired and new ones built at a cost of over £5.2 million. In addition steel 'doors' guard the entrance to the beach and the old seawall has been raised slightly. Sand dunes in the south beach are being planted with trees.
- ***Advantages*** – groynes seem locally effective, they are relatively low cost, they are acceptable visually and development of low-lying land has now been possible
- ***Disadvantages*** – this trapping of sand may have caused scour at Mappleton. Groynes rarely work on their own, maintenance is continual and groynes do not hold mud.

Withernsea is another resort further south. Here there are also groynes and a sea wall, though the emphasis has been on a more comprehensive approach. To prevent wave erosion a new wave **return wall** has been built. The wall is further protected by **rip-rap** or rock armour and some **beach nourishment**. The natural beach has all but disappeared leaving a wave-cut platform in the clay beneath. At £ 6.3 million this appears good value if it can halt the fall in local property prices.
- ***Advantages*** – this will hold the line, calm concerns of local residents and hoteliers and save seasonal jobs in the resort
- ***Disadvantages*** – costs have limited the length of the sea wall, the rocks have reduced access to the beach and views are restricted. There is a problem of wave noise.

Easington is the latest location to receive help. A **revetment** of rock armour has been placed at the foot of the cliffs to protect this natural gas terminal which handles 25% of North Sea production. This recent £4.5 million scheme remains untested. Though the site qualified for protection as 'being in the national interest', the scheme fails to protect the actual village despite a public enquiry. There are important SSSI sites to the south and there is considerable conflict with environmental groups.

Spurn Head is a rather different environment from the rest of the coastline though here again the problem is one of erosion. The management strategy here is perhaps best described as **'abandonment'**. Following successive winters when storms enabled the sea to wash over the neck of the spit, Holderness Borough Council decided that it could no longer afford to repair the damage. It was officially abandoned in 1995.

- ***Advantages*** – the growing annual costs of protection were saved, some evidence suggests that it may repair itself, and not all environmental groups were against it becoming an island. There may be no other long term solution.
- ***Disadvantages*** – the community of lifeboat men and coastguards and their families may have to move elsewhere. There may be loss of a 'heritage coast' site and an important bird habitat (Yorkshire Wildlife Trust)

In the **Humber estuary** the problem is one of flooding. The predicted rise in sea level threatens the half a million or so people who live less than two metres above current sea level. In addition the decreasing supplies of sediment from the Holderness cell and the Humber catchment are reducing the formation of new land. More sustainable solutions such as **managed retreat** near Sunk Island and selective breaching of saltmarsh embankments will be needed to reverse recent increases in erosion, salinity and pollution.

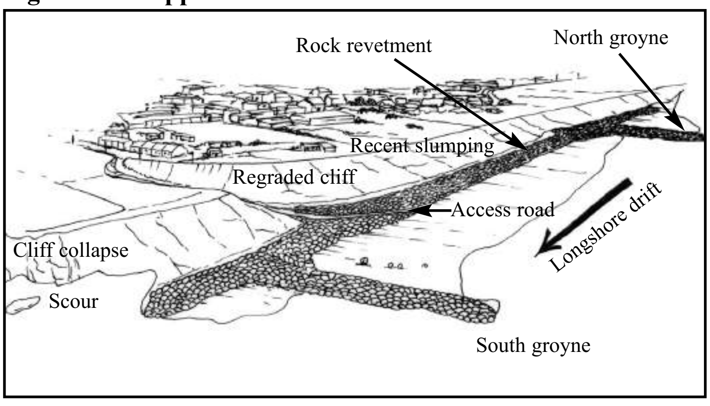
How successful are these schemes?

Mappleton provides a useful case study of the costs and benefits of coastal defence. Whilst this scheme was not traditional hard engineering it nevertheless raises a number of issues regarding the wisdom of interrupting the natural processes along a coastline.

Erosion rates at Mappleton have long been recorded, and in 1786 the village was 3.5 kms from the sea. By 1988 the sea was on its doorstep, access to the beach was impossible and houses in Cliff Road were quite literally falling into the sea. There was tremendous pressure from local residents to save the village, though in the end it was the threat to the coast road that won the day. In 1991 a scheme was implemented at a cost of £2.1 million supported by EU funding.

Features of the scheme included two rock groynes designed to trap beach sediment, a rock revetment to prevent erosion of the cliffs. The cliffs themselves were **re-graded** to reduce slumping and there was some **nourishment** of the beach to encourage deposition. In addition a new access road was built and a car park and toilets for visitors.

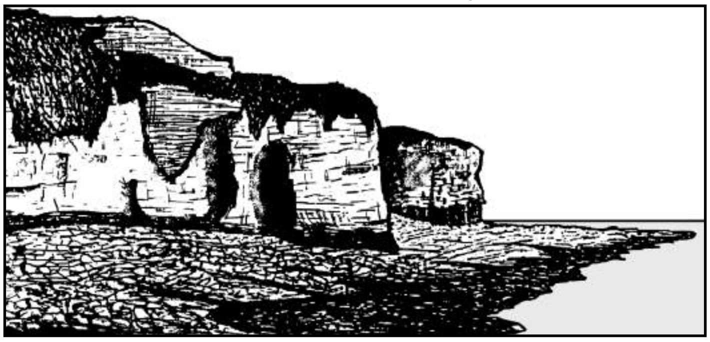
Fig. 7 The Mappleton sea defences.



In 2002 all is not well. The houses and the beach looks secure, but the re-garded cliffs behind are showing early signs of slumping. Beyond the second groyne the large rocks are being undermined and the cliff face below the car park has begun to erode (**terminal scour**). More worrying is the very rapid erosion of beaches, cliffs and farm buildings at Great Cowden 3 km to the south which may be linked to Mappleton's growing beach. Evidence for this is not conclusive however.

Practice Exam Question

Below is a sketch of the coastline at Flamborough.



(a) Identify three of the (landforms) features of coastal erosion shown. *(3 marks)*

(b) Explain how each of these may have formed. *(9 marks)*

(c) Define the term 'cost-benefit analysis' and explain how it is used in decisions about coastal management. *(8 marks)*

(d) Answer one of these questions: *(10 marks)*

Either (1): For a named coastal management scheme which you have studied, evaluate its success.

Or (2): Referring to named examples, suggest what factors influence the choice of coastal defence strategy.

Answer Guide

(a) Wave-cut platform, sea stack, cave and cliff are obvious choices.

(b) Ensure that you include a full range of technical terms such as explanation of processes such as abrasion, hydraulic action and differential erosion.

(c) Look at benefits – especially the adjacent land use and environmental quality, and costs – especially economic costs of the types of defences.

(d) *Either* – use Mappleton framework as a guideline
Or – use the section on Coastal Management options.

Further Research

Bishop and Prosser (1997) Landform Systems. Collins.
Cook et al.(2000) Geography in Focus (chapter 11). Causeway Press.
Manuel et al.(1995) Coastal Conflicts. CUP.
Hordern, R. (1995) Geography of Yorkshire. Hodder.
Geo Active – Mappleton,unit 30, Mary Glasgow 1991
Geography Review articles - Philip Allan Updates
February 1993, September 1995, and March 2002
Geo Factsheets – Numbers 100 (Coastal management at Selsey), 119 (Geography of coastal sand dunes), 124 (Salt Marshes), 129 (Impact of structure and lithology on coastal landforms).
Edexcel Geography B GCSE - A decision-making Exercise based on Easington set in May 2000

Useful websites

www.learn.co.uk - lots of ideas inc. coastal erosion
www.geography.learnontheinternet.co.uk
www.bennett.karoo.net - excellent photo gallery
www.pml.ac.uk/lois/Education - basics plus photos

Acknowledgements
This Factsheet was researched by Bob Hordern, a Principal Examiner and well-known author.
Curriculum Press. *Unit 305B, The Big Peg, 120 Vyse Street, Birmingham B18 6NF.*
 ISSN 1351-5136

Geo Factsheet

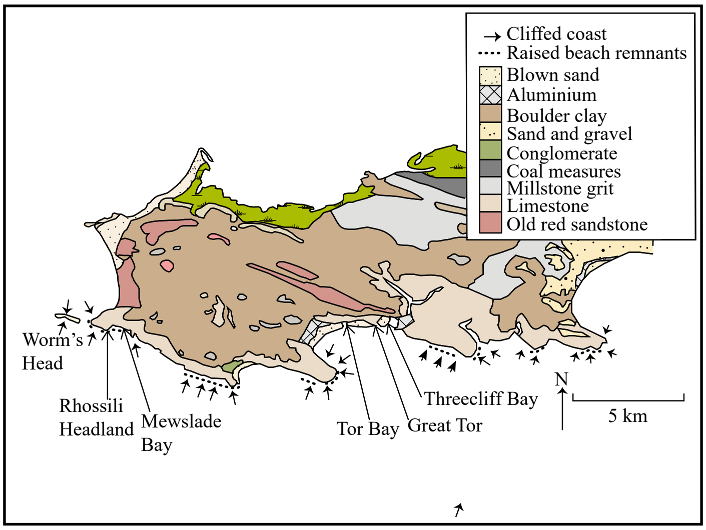
www.curriculum-press.co.uk Number 356

Coastal Erosion Landforms on the Gower Peninsula

The Gower

The rocky southern coast of the Gower Peninsula in South Wales is home to long stretches of limestone cliffs, many of which are fronted by shore platforms. The form of both the cliffs and shore platforms is the result of the interrelationship between marine and subaerial processes and the geological structure and lithology of the coastline. **Figure 1** provides a geological overview of the Gower.

Figure 1. Geology of the Gower Peninsula



What Are Cliffs and Shore Platforms?

Cliffs such as the limestone cliffs found on much of the southern coast of the Gower are common features on rocky coastlines. They are steep or vertical slopes rising from the sea or a shore platform which mark a clear break in slope between coastal hinterlands and the shore. Strictly speaking, a break in slope at the coast is referred to as a cliff if the slope angle exceeds 40°. **Shore platforms** are relatively flat or gently sloping surfaces (between 0 and 3°) that extend seaward from the base of a cliff. Many shore platforms are **intertidal** meaning that they are covered at high tide and exposed at low tide. Cliff and shore platform morphologies vary immensely due to the interaction of a number of factors affecting their development, including the balance between marine and subaerial processes, how these processes are influenced by rock lithology and structure, and fluctuations in sea-level.

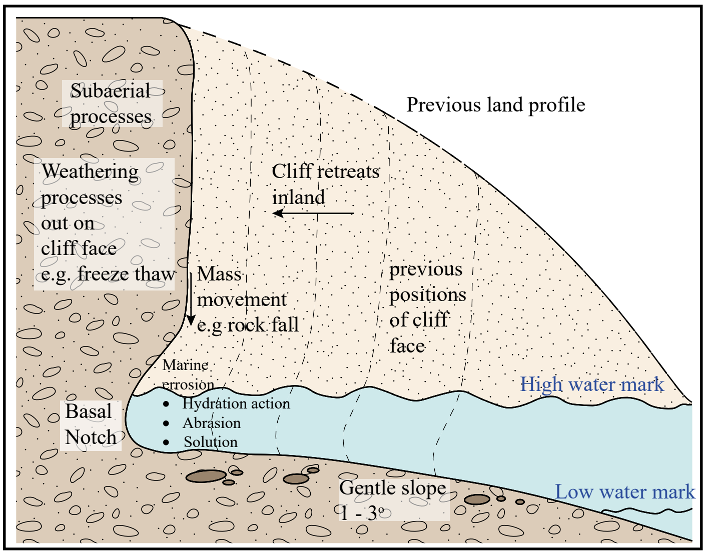
How Are Cliffs and Shore Platforms Formed?

A combination of **marine erosion**, **weathering**, and **mass movement** processes create and shape cliffs and shore platforms. Cliff formation is initiated as waves undercut coastal slopes by hydraulic action and abrasion, creating a **basal notch**. Basal notches cover 1-2 metres vertically and can be up to 3 metres deep, with more pronounced notches being created in resistant rocks that can support and sustain the overhang as it recesses into the cliff base. The rocks overhanging the notch will eventually collapse, aided by gravity, as the notch increases in size, presenting a steeper 'new' cliff face as they do so. The limestone cliffs of the Gower recede by **rock fall**, a mass movement process that is common on steep, bare rock faces, by which small blocks of rock detach and fall from the cliff face.

The pieces of rock are loosened by weathering processes such as freeze-thaw attacking joints within the rock. The **rate** at which cliffs erode and recede is determined by local geology and wave energy.

Continued cliff recession will take place providing that any eroded material is broken down and removed rather than being allowed to accumulate. Continued recession creates shore platforms, which are the base of the rock mass that is 'left behind' as the cliff recedes in a landward direction (**Figure 2**).

Figure 2. The Formation of Cliffs and Shore Platforms



Shore platforms dissipate wave energy and so are self-limiting in terms of the distance they can extend inland (around 500 metres maximum).

As the platform increases in size, waves have further to travel to reach the base of the cliff, meaning that the extent to which they can erode the cliff base is greatly reduced. Erosion then gives way to deposition, allowing beaches to form at the foot of cliffs, whilst the cliff face takes on a more gently-sloping profile as weathering and mass movement take over. Some shore platforms are temporarily or permanently covered by beach material.

Exposed rock platforms may be quite smooth, but more often they are uneven surfaces with many protrusions and indentations or **marine potholes**, which may be filled with saltwater or beach material. Salt and biological weathering help to shape the platform.

Micro-features such as **caves**, **sea arches**, and **blowholes** may form due to differential erosion as cliffs recede (**Figure 3**, **Table 1**, and **Example 1**).

Figure 3. Micro-features

Example 1. Threecliff Bay (see Figure 9).
Threecliff Bay acquires its name from the three linked, pointed peaks that have been created in the rock face due to the steep dip of the rock strata and faults which have created lines of weakness. At one point a cave has eroded through the rock outcrop creating a natural arch created by fracturing along a diagonal fault. The arch is large enough to walk through at low tide.

Example 2. Worm's Head (see Figure 8).

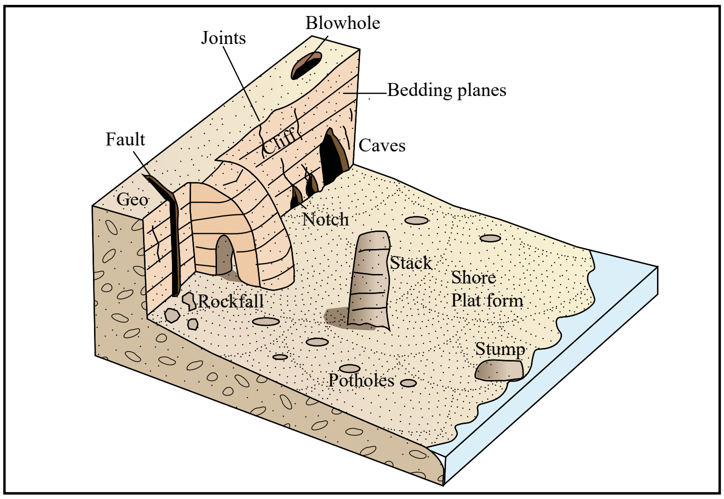


Table 1.

Micro-Feature	Description and Formation
Notches and nips	Wave-cut-**notches**, found at the bases of cliffs, are created through the processes of abrasion, solution (*corrosion*), and hydraulic action as waves repeatedly attack the base of a cliff. A small notch is sometimes called a **nip**. The formation of a notch is the starting point and an ongoing indicator for active cliff recession and shore platform formation.
Marine potholes	When shore platforms are ground into by the abrasive power of rock fragments, small depressions may form. These become filled, in part at least, with sand, shingle and pebbles. This material is swirled around as the water, driven by tides, advances and retreats. This swirling of material and abrasion of the platform can form cylindrical, bowl-shaped **potholes**.
Gorges / geos	**Gorges** or **geos** are narrow, steep-sided clefts within cliffs formed by differential erosion aided by the presence of vertical fault planes.
Caves	A **cave** is a depression formed in a cliff face in which the depression depth has become greater than its width. The depression is initiated and enlarged often at the site of a structural weakness in the cliff face where a fault, joint or bedding plane is present.
Blowholes	A **blowhole** may form via the hydraulic and pneumatic action of waves crashing onto the 'ceiling' of the cave, eroding upwards to the point where the land above collapses and falls through.
Sea arches	When two caves form back-to-back on a coastal promontory and deepen over time along a line of geological weakness, which is likely to follow through the promontory, they may eventually meet, creating a **sea arch**.
Stacks and stumps	When the 'roof' of a sea arch collapses, it can leave behind an isolated pillar of rock known as a sea **stack**. The stack is attached to the same sub-marine base as the promontory it was once a part of. Small stacks, which can be inundated by high tides yet revealed at low tide, are known as **stumps**.

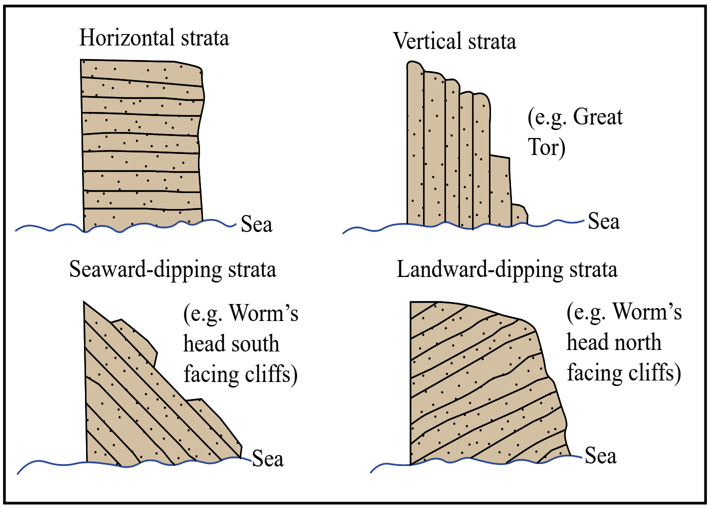
The Importance of Geology

The geology of a coastline is an important factor in determining the rate of cliff recession and the **morphology** of cliffs and shore platforms. The term **structure** refers to the physical characteristics of rocks including faults, joints, bedding, folding, and dip. **Lithology** refers to the chemical and physical composition of a rock, determining how resistant a rock will be to erosion and breakdown by chemical or mechanical processes.

More resistant rocks produce steeper cliffs whereas softer rocks produce more gently-sloping profiles. Most cliffs of the Gower are formed of limestone, which is a relatively resistant sedimentary rock comprised of layers. Cliff morphology is also determined by dip, joints, folds, and faults. **Folding** is when the Earth's crust bends and flexes due to compressional tectonic forces.

Folding usually takes place as part of mountain building processes and can alter the angle of dip. The dip of a bedding plane is the angle that it makes with a horizontal plane. Different dips result in different cliff profiles (Figure 4) whilst structural weaknesses such as joints (fractures within rock along which no displacement can be observed) and faults (a fracture where displacement within the rock is observable) provide zones of weakness at which differential erosion can be initiated, creating micro-features. Compressional earth movements have tightly folded the limestone beds in the south of the Gower peninsula. The angle of dip of the limestone strata ranges from almost horizontal to vertical, creating a variety of cliff profiles (Example 2).

Figure 4. The Influence of Dip on Cliff Profiles



The angle of dip can also influence the form of shore platforms. The intertidal platform, which periodically connects Worm's Head (see later) to the mainland, has a very jagged 'corrugated' appearance due to the heavily tilted beds of limestone, although the jagged layers have been smoothed in part by abrasion, solution, and salt weathering as the limestone has reacted with seawater (Figure 5a and b).

Figure 5a. Uneven 'Corrugated' Platform Surface

Figure 5b. Marine Erosion and Chemical Weathering Have Smoothed the Surface

Sea-level Fluctuations: Relict Cliffs and Shore Platforms

Shore platforms, and the beaches that may be situated on top of them, can become isolated from the action of the sea, separated due to a fall in mean sea level. These raised platforms and fossil beaches create coastal flats, stranded high above present-day sea-level, like that on Rhossili Headland and Inner Worm's Head, sometimes backed by inactive relict cliffs, like those situated at Mewslade Bay. Relict cliffs, no longer subjected to the action to waves, can be identified by their gently sloping, convex profiles, and sometimes vegetated slopes. All evidence of such emergent features on the Gower is found on the rocky south coast where raised beaches made up of pebbles, shells, and sand, which have been cemented together by calcium carbonate, are exposed within cliffs (Figure 6).

Example 2. Great Tor

The almost vertically dipping limestone strata, which creates the headland 'Great Tor', marks a division between Tor Bay and Three Cliffs Bay, separating the two bays at high tide.

The vertical beds, tilted upright from their original horizontal position by folding processes, have created a sheer rock face. The bedding planes (the surface which separates one layer of the sedimentary rock from the next) provide a surface along which the layers can 'slide' away from the rock mass. It is worth noting that movement planes can be marked by faults and joints as well as bedding planes.

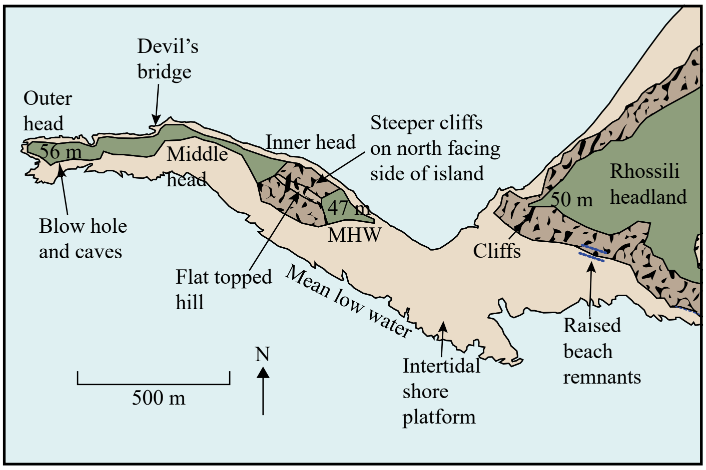
Remnants of a shore platform can just be made out at the base of a cliff, but these cliffs are affected by marine erosion to a much lesser extent than they were in the past. A sandy beach is permanently present on the shore platform. The cliffs of the south coast, situated between Worm's Head and Mumbles Head, presently experience little effect from marine erosion. They are instead subjected to modification by subaerial processes. This is evidenced on the landward side of Great Tor, where the slope angle is less steep than the seaward face and has become vegetated.

Figure 6. Raised Beach Material Exposed on the Rhossili Headland

Worm's Head

Worm's Head is a tidal island, separated from the Gower Peninsula by a shore platform. It is only exposed for 2 ½ hours before and after low tide (see Figure 8b and c). It takes around fifteen minutes to walk across, over the uneven platform, to reach the first of the three sections of the island, the Inner Head (Figure 7). Worm's Head is part of one of the two headlands positioned to the north and south of Rhossili Bay, which was created by the differential erosion of softer Old Red Sandstone situated between harder limestone outcrops.

Figure 7. Worm's Head

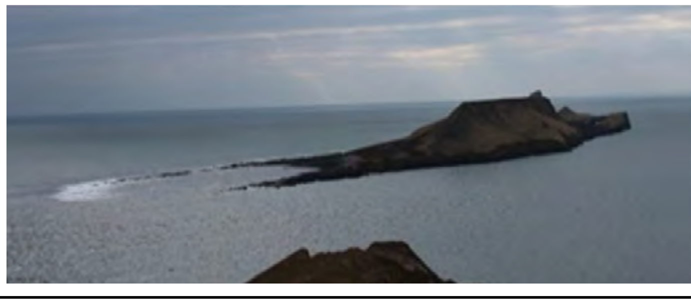


The strata making up the platform connecting the mainland and Worm's Head dips at angles of around 30-45°, creating a 'corrugated' surface (see Figure 5a and b). The platform is full of small faults that have weakened it, meaning that it has been worn down at a faster rate than Rhossili Headland on the mainland and Worm's Head, thus creating the tidal island, which once was attached to the mainland at both high and low tide. The cliffs on the most westerly tip of the island are 56 metres high and the top of the Inner Head is flat, which suggest that it was once a shore platform – part of the same flat area on Rhossili Headland. The cliffs on the north-facing side of the island have a much steeper profile than those on the south side. This is due to the southward direction in which the limestone layers dip (see Figure 4). Differential erosion has taken place as the limestone has retreated; waves have exploited weaknesses in its layers: Devil's Bridge is a natural rock bridge created from a collapsed sea cave within the Middle Head (Figure 8a). Caves and a blowhole are present on the Outer Head. When waves are exceptionally large, water can be seen shooting into the air from the mainland. Remnants of raised beaches, which date to the Ipswichian interglacial (125,000 years BP) when sea levels rose to 6-9 metres higher than present, can be seen exposed on both the Inner and Outer Head (Figure 6b).

Figure 8a. The Middle and Outer Head and Devil's Bridge, Worm's Head. Note the wave-cut platform made of tilted layers of limestone. The high tide mark is clear.

Figure 8b. Worm's Head at Low Tide

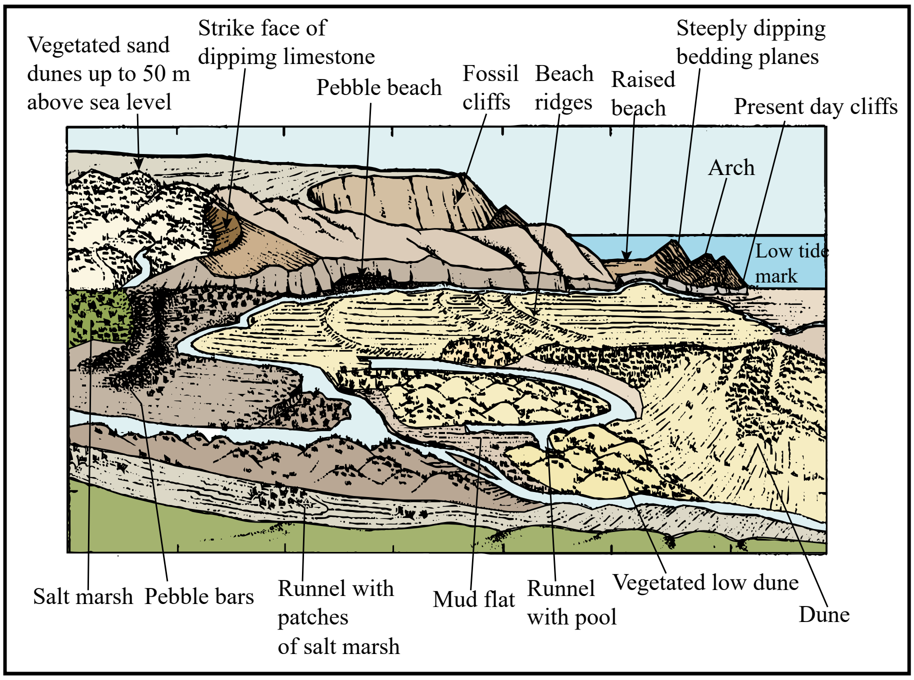
Figure 8c. Worm's Head at High Tide



Summary and Conclusions

Cliffs and shore platforms are formed as coastlines are subjected to marine and subaerial processes and retreat over time. The morphology of these features is influenced by the interaction of, and balance between, marine and subaerial processes, sea-level change, and geological factors. The south coast of the Gower peninsula has many outcrops of dipping limestone strata from which a variety of cliff profiles, shore platforms, and their associated micro-features have been created.

Figure 9. Three Cliffs Bay



Exam Question

(See Figure 9.)

Study Figure 9;
Assess the relative importance of the geomorphological processes that are operating at present and those that have occurred in the past in regards to shaping the landforms shown.

Guidance:
- Use a colour coding system to categorise which landform's occurred when sea-levels were higher (e.g., raised beaches, fossil cliffs, fossil dunes) and those which are being formed by present day processes.
- As this is an assessment question, you need to try to work out the relative importance of the two sets of landforms in creating the landscape.
- The tariff is likely to be between 12 and 16 marks and therefore requires a planned essay, as in A-Level.

Bibliography and Further Reading

- Bird, E. (2008) *Coastal Geomorphology: An Introduction* Wiley
- Bridges, E. M. (1997) *Classic Landforms of the Gower Coast* The Geographical Association
- Davidson-Arnott, R. (2012) *An Introduction to Coastal Processes and Geomorphology* Cambridge University Press
- Davies, A. (2012) *Walking on Gower* Cicerone
- Huggett, R.J. (2011) *Fundamentals of Geomorphology* (3rd Edition) Routledge
- Masselink, G. Hughes, M. G. & Knight, J. (2011) *Introduction to Coastal Processes and Geomorphology* (2nd Edition) Routledge
- Pethick, J. (1988) *An Introduction to Coastal Geomorphology* (3rd Edition) Arnold
- Small, R.J. (1972) *The Study of Landforms: A Textbook of Geomorphology* Cambridge University Press

***Acknowledgements:** This **Geo Factsheet** was researched and written by **Kate Cowan** (a Teacher of Geography at King Edward VI High School for Girls, Birmingham) and published in January 2017 by **Curriculum Press**, Bank House, 105 King Street, Wellington, TF1 1NU.*
ISSN 1351-5136

GeoActive Online 510

MANAGING CONFLICTS IN POOLE HARBOUR, DORSET

by Lindsay Frost

POOLE HARBOUR IS a large, shallow bay (38 km^2) just to the west of Bournemouth on the south coast of England. It is sheltered from the sea by two spits (Studland and Sandbanks) on either side of a narrow entrance (300 metres) which is kept open by the flow of four rivers (Figure 1). There is a wide variety of natural water and land based environments along the 100 km shoreline of the bay (Figure 2), especially in the southern part of the Harbour, which makes it a sensitive marine area.

One consequence of the wide variety and importance of natural areas in and around the Harbour is that it has received many national and international conservation designations (Figure 3).

As well as this wide range of natural areas, archaeological investigations show that people have used the area since pre-Iron Age times. Today a number of diverse human activities are found in and around Poole Harbour:

- Urbanisation has taken place on the northern shore, with the settlement of Poole (population 147,600 in 2011) now merging with Bournemouth (Figure 1). As well as housing there are roads and railways, and light industries such as building luxury watercraft and pottery-making. Some redevelopment has taken place (e.g. Twin Sails Bridge).
- There is a small port (24 ha) with regular ferry services to France and the Channel Islands (Figure 1). Cargo ships carry imports of steel, timber and grain, and exports of clay, grain and gravel. In 2010/11 the port handled 991,000 tonnes of cargo.
- There is a small commercial fishing fleet of 100 boats, including shellfish cultivation within the Harbour (e.g. oysters, clams, cockles).

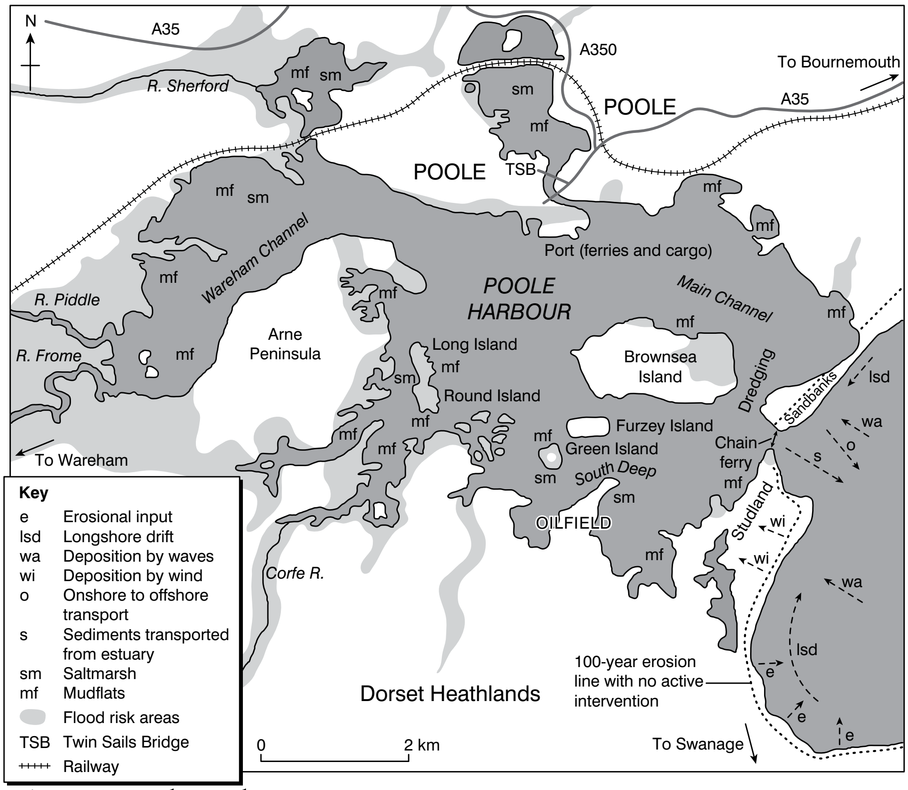


Figure 1: **Poole Harbour**

Type of natural habitat	Features
Tidal mudflats	Make up 55% of the Harbour area. Many invertebrates, e.g. sea squirts, provide food for 60 different species of wader.
Saltmarshes	Make up 21% of the Harbour area. 20,000 migratory birds, e.g. redshank, pied avocet (1+% of British population), black-tailed godwit.
Reed beds	Many birds such as the Dartford warbler.
Eelgrass beds	Two types of seahorse (spiny and short-snouted) discovered in 2005 (see Figure 7).
Freshwater marshes and lagoons	Make up 23% of the Harbour area. Brownsea Island and the Little Sea provide overwintering areas for birds, and a habitat for dragonflies and damselflies.
Sand dunes	Mature succession (600 years old) from lyme grass to pine forest (Studland spit).
Heathland	Six British native reptiles (e.g. sand lizard) found in the same place.
Pine woodland	Red squirrels on three islands in the Harbour.
Shallow waters	Nursery area for sea bass.

Figure 2: **Natural areas found in and around Poole Harbour**

- There is a Ministry of Defence site on the northern shore (Hamworthy Royal Marine base).
- Most controversially, Europe's largest onshore oilfield (Wytch Farm) started production in 1979, with oilwells on Furzey Island (1,700 metres deep) and on the southern shore. At the peak in the 1990s, 111,000 barrels of oil a day were produced, which

has declined to 15,000 barrels now. Production is due to continue until 2037.

- The catchment area of the four rivers draining into the bay supports a lot of agriculture.
- Coastal defences (e.g. seawalls, embankments) are found in a number of places within the Harbour and on the Sandbanks and Studland spits.

Tourism and recreation are significant in the area, given the warm climate of southern England and the close proximity to London and its commuter belt, which allows day trips to the Harbour area. Water-based activities include yachting, waterskiing, windsurfing, kitesurfing (Whitley Lake), swimming in the sea, sub-aqua diving, and the use of personal watercraft (canoes, rowing-boats, jetskis). There are many marinas (e.g. at Poole and Wareham) and yacht clubs, as the warm, shallow waters are ideal for water-based recreation. Land-based activities include walking, horse-riding, bird watching, wildfowling, camping and caravanning, and use of beaches (sunbathing, naturists, barbecues). Studland peninsula (a 5 km sand spit) is a tourist honeypot, attracting up to 25,000 people on a sunny summer day.

Designation	Year	Purpose
National Nature Reserve (NNR)	1946	Protect significant habitat or geological formation areas, e.g. Studland and Godlingston Heaths
Area of Outstanding Natural Beauty (AONB), Dorset	1956	Conserve and enhance natural beauty of the landscape
Heritage Coast (Purbeck)	1970	Manage and conserve the natural beauty of undeveloped coastline, e.g. Studland sand cliffs
Site of Special Scientific Interest (SSSI)	1987 and 1991	Protect and allow people to enjoy the best wildlife and geological sites, e.g. Ham Common and Poole Harbour
Ramsar	1999	Conservation and wise use of wetlands
European Marine Site (EMS): Special Protection Area (SPA) or Special Area of Conservation (SAC)	1999	Strictly protected sites of high-quality habitats and species, including reducing the impacts of recreational and other uses on waterfowl and waders, e.g. Dorset heathlands, Poole Harbour
World Heritage Site (UNESCO)	2001	Identify natural features of world importance, such as geology and geomorphology, e.g. Old Harry rocks

Figure 3: **Conservation designations for the Poole Harbour area**

Issues affecting future development

A number of issues and concerns affect Poole Harbour's future.

Climate change

- Sea level in and around the Harbour is predicted to rise by 34 cm by 2055 and 1 metre by 2105, flooding low-lying areas. By 2102, 5,000 properties will be at risk in the north of Poole Harbour, including some of the UK's most expensive houses, along with large areas of saltmarsh and land in river valleys (Figure 1).
- There will be increased storm activity, with destructive waves, putting pressure on coastal defences (150 metre recession at Sandbanks and 60 metres at Studland spit).
- Temperatures and precipitation levels are likely to increase, changing the growing conditions in natural habitats.
- A Mediterranean climate may develop, encouraging more tourism and recreational activities.

Physical processes

- Coastal erosion will include disruption to sediment movements and deposition (breach of Sandbanks with 37 properties at risk in the next 100 years; Studland has no properties at risk), partly due to dredging of Main Channel (deepened by 1.5 metres and widened to 100 metres in 2006) – see Figure 1.
- The poor 'flushing' ability of the Harbour increases its vulnerability to water pollution (e.g. from oil and agrochemicals).
- Invasion by 'alien' species (e.g. Pacific oyster) brought in by boats and ships could threaten the natural areas in and around the Harbour.

Commercial activity

- Drilling for oil carries the risk of oilspill, and decommissioning to return areas to a natural state could also involve a risk of pollution.
- Wastes enter the Harbour from various sources: sewage disposal, agrochemicals, oil, anti-fouling paints on boats.
- Any oil or chemical spill in the English Channel could find its way into the Harbour, settling in the mudflats and polluting shellfish.
- Illegal fishing or shellfish dredging could create an imbalance in the local food webs.
- Some buildings close to the shoreline are unsightly.
- Port activities are limited by the size of vessels that can use it; alternative uses could include a wind farm, or facilities for specialised marine cargo.
- Ferry traffic is in decline (passenger numbers halved between 1998 and 2011).
- There is a loss of underwater archaeological remains due to dredging of Main Channel.

Urbanisation and redevelopment

- There is increasing demand for housing, especially along the northern shore (Figure 4), and this could have an impact on some habitats.
- Redevelopment of inner urban areas of Poole may affect the shoreline and intertidal areas, particularly through disposal of sewage and other wastes.
- Poole has an ageing population (in 2011, 20.5% of the population was over 65 – that is 4% above the national average), which puts pressure on support services such as hospitals.

Tourism and recreation

- There are conflicts between different users of land and water in and around the Harbour.

Year	Population
1991	138,300
1994	137,000
2001	140,000
2006	140,000
2011	147,600

Figure 4: **Population change in Poole**

- There are conflicts between people and natural environments (e.g. disturbance of nesting birds in May and June).
- Often there are too many people in one place at the same time at specific 'honeypot' areas such as Studland (SSSI) and Godlington Heaths (NNR), which received a million visitors in 2005/06.
- Large numbers of people damage land areas, for example by dune destabilisation, erosion due to trampling (blowouts), fire (natural areas take six years to recover), disturbance of wildlife, litter and other waste, and car parking.
- Too many people on the water cause damage, for example by boat anchors dragging, litter, antifouling paints on watercraft, moorings and marinas, disturbance of species (e.g. wildfowl), and excessive bait digging (e.g. at Holes Bay).

Management

Poole Harbour Commissioners have managed the area for over a hundred years, and today an Integrated Coastal Zone Management (ICZM) approach (e.g. Dorset Coast Forum) is necessary because all human activities and natural processes are interlinked. There is wide consultation among a number of organisations including Natural England, Dorset County Council, Wessex Water and the National Trust. In 1994 the first Aquatic Management Plan (AMP) was introduced with guidelines and byelaws, and was followed by a recreational zoning scheme in 1995. A revised version of the AMP was produced in 2006 by the Poole Harbour Steering Group using the 1998 Poole Harbour Management Policies, and it was reviewed again in 2011.

Objective area	Specific objective
Archaeology	Ensure that dredging does not damage archaeological sites
Commerce	Ensure that oil operations are screened and the areas are returned to a natural state after use
Conservancy and marine safety	Ensure that dredging does not result in loss of important marine habitats
Emergency planning	Review and practise an oilspill contingency plan
Fisheries	Manage conflicts between shellfishing, bait digging or bait dragging, and monitor their impact on the European Marine Site
Managing the shoreline	Respond to rising sea level in the most sustainable way
Nature conservation	Ensure that any development can demonstrate no adverse impacts on nature
Recreation	Manage access and use of the Harbour, and minimise conflicts between users and wildlife
Transport	Ensure that transport developments (e.g. Twin Sails Bridge) do not have negative impacts on nature or natural processes
Water quality and pollution	Encourage the use of more environmentally sensitive farming techniques

Figure 5: **Examples of specific objectives of the Aquatic Management Plan**

The aim of the AMP is:

> *To provide the safe and sustainable use of Poole Harbour, balancing the demands on its natural resources, minimising risk, and resolving conflicts of interest.*

Essentially the AMP tries to separate conflicting uses, and to keep people away from the most sensitive natural areas (Figure 5). It does this by zoning the water areas (including a quiet area), setting speed limits for watercraft (8 knots near bathing beaches), and providing information on, and enforcing, regulations (e.g. Conservation Regulations No.34 1994).

The National Trust (NT) plays an important management role on Brownsea Island, and at Studland (Figures 1 and 5). It has provided large car parks (four car parks with 2,300 spaces), educational materials, signage and displays, barbecue areas, fencing for fragile areas of dunes, boardwalks, replanting of dune grasses (e.g. marram), litter collection on a daily basis in the summer (4,000 kilos a day), beach zoning (e.g. for naturists), swim safety zones, and patrols by wardens and rangers. The NT has also adopted a 'managed retreat' policy in terms of coastal defences, which has resulted in the repair of existing gabions, dune building, and the moving of beach huts and hire shops under threat.

There is a wide range of other management tools, including the 1998 Oil Spill Contingency Plan ('Poolspill'), an Environmental Impact Assessment for Wytch Farm oilfield, European Union directives (2000) on monitoring cleanliness of coastal waters, a Navigational Safety Management Plan using a radar and automatic identification system and a 24-hour watch by the Harbour Control Centre, a Moorings Policy (2008) which will phase out boat moorings in environmentally sensitive areas, the control of sea bed leasing for cultivation of shellfish through the Poole Fishery Order (1985), and a byelaw to prohibit bait digging in Holes Bay (PHC Master Plan 2011).

Summary

Poole Harbour is a beautiful, thriving and often overcrowded area that needs careful management and a coherent plan for the future in the face of both natural and human threats.

Activities

1 Describe the location and main features of Poole Harbour.

2 Study the data in Figure 6.
(a) How could this information be best presented?
(b) What issues are raised by the trends shown in Figure 6?
(c) Are these trends a benefit or a problem for the natural areas of Poole Harbour? Explain your answer.

Figure 6: **Cargo and passenger data for the port of Poole, 1990–2011**

Year	Cargo (thousand tonnes)	Ferry passengers (thousands)
1990/91	2,353	781
1993/94	2,302	611
2000/01	1,953	555
2005/06	1,766	440
2010/11	991	258

Source: Dorset County Council

3 Why can Poole Harbour be considered to be a sensitive marine ecosystem?

4 Study the list of issues affecting future development in and around Poole Harbour. Which *two* issues do you think are the most serious? Explain your answer.

5 Study Figure 7. Describe and explain the issues and consequences of the situation shown.

6 Study Figure 8.
(a) Describe the location of zones and designated areas within the Aquatic Management Plan.
(b) Explain why certain uses of Poole Harbour have been separated.

7 Consider all of the information provided about the AMP (text and Figures 5 and 8). Identify, and write about, three strengths and three weaknesses of this plan (this is called an **evaluation**).

8 (a) Which issue affecting Poole Harbour does each designation in Figure 8 try to tackle?

Figure 7: **Marine life in an 'anchorage sensitive area'**

(b) Which issues are not tackled by any of the designations given in Figure 8?
(c) Write three of your own objectives for a revised Aquatic Management Plan, and for each objective identify what would need to be done by people in practical terms.

9 What is a likely problem when trying to manage a coastal area, such as Poole Harbour, when it involves a large number of organisations?

Extension activity

10 (a) Why is the Shoreline Management Plan (SMP) for Sandbanks 'hold the line', while the Studland SMP is 'limited intervention'?
(b) What do you think would be the most *sustainable* way of managing Poole Harbour as the sea level rises?

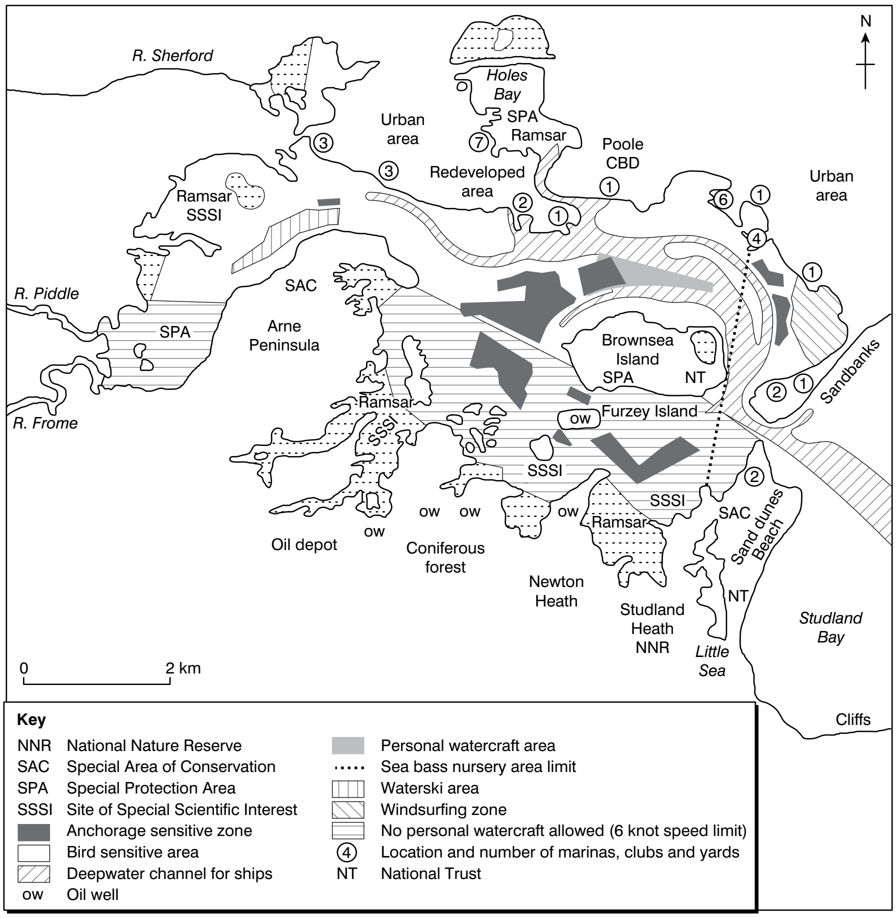


Figure 8: **Poole Harbour AMP, land uses and conservation designations**

GEOACTIVE 542

Sand dune management: Ainsdale, Merseyside

By Rob Morris

A case study about the management of sand dunes

This case study looks at the Ainsdale Sand Dunes National Nature Reserve, which is one of the most important wildlife sites in England. The site was established in 1965 to protect the best example of sand dunes on the northwest coast.

Today the reserve has many rare species which are allowed to flourish, and it provides a place for visitors to get close to and to enjoy the magnificent scenery of dunes, pine woodland and golden sandy beaches. It occupies the central part of the Sefton Coast Site of Special Scientific Interest (SSSI), an unspoilt sand dune system which stretches from Liverpool to Southport (21 km long).

The dunes of the Sefton Coast have been formed over hundreds of years, with sand blown inland from the wide, sandy beaches at low tide and then trapped by specialist coastal plants, such as marram grass, which can tolerate the dry, salty conditions.

Ainsdale Reserve is a distinct place that requires specific management to allow wildlife to thrive and to permit visitors to enjoy their experience.

Key vocabulary

ecosystem, psammosere, conflict, dune scrub, myxomatosis, honeypot site, invasive species, management strategy

Learning outcome

At the end of this case study you will have learned how fragile ecosystems such as sand dunes are managed to minimise conflicts between nature and the needs of people.

Relevance to specifications

AQA A	Unit 1: Physical Geography, Section B, The Coastal Zone, page 15 http://filestore.aqa.org.uk/subjects/AQA-9030-W-SP-14.PDF
AQA B	Unit 1: Managing places in the 21st century, The coastal environment, pages 8–10 http://filestore.aqa.org.uk/subjects/AQA-9035-W-SP-14.PDF
Edexcel A	Unit 2: The Natural Environment, Section A, The Physical World, Topic 1, Coastal Landscapes, pages 19 and 20 http://www.edexcel.com/migrationdocuments/GCSE%20New%20GCSE/9781446911907_GCSE_Lin_Geog_A_Issue_5.pdf
Edexcel B	Unit 1: Dynamic Planet, Section B, Small-scale Dynamic Planet, Topic 5, Coastal Change and Conflict, page 16 http://www.edexcel.com/migrationdocuments/GCSE%20New%20GCSE/9781446911914_GCSE_Lin_Geog_B_Issue_5.pdf
OCR B	Unit B563: Key Geographical Themes, Theme 1: Coastal Management, page 13 http://www.ocr.org.uk/Images/82581-specification.pdf
WJEC A	Unit 2: Options, Physical Options, Theme 7, Our Changing Coastline, page 18 http://www.wjec.co.uk/qualifications/geography/geography-gcse/16128.pdf?language_id=1
WJEC B	Unit 1: Challenges and Interactions in Geography, Theme 2: Physical Processes & Relationships Between People and Environments, Coastal processes and coastal management, page 19 http://www.wjec.co.uk/uploads/publications/17213.pdf?language_id=1
CCEA	Unit 1: Understanding Our Natural World, Theme A: The Dynamic Landscape, page 9; a copy of the specification can be downloaded from: http://www.rewardinglearning.org.uk/microsites/geography/gcse/index.asp
Cambridge IGCSE	Theme 2: The Natural Environment, page 17 http://www.cie.org.uk/images/150857-2016-syllabus.pdf
Edexcel IGCSE	Section A, The Natural Environment, Topic 2, Coastal environments, page 7 https://www.edexcel.com/migrationdocuments/IGCSE%20New%20IGCSE/IGCSE2009_Geography_(4GE0)_Specification.pdf

Sand dune management: Ainsdale, Merseyside

The Sefton Coast, north of Liverpool, is one of Britain's largest dune systems (Figure 1). One part of this dune system that is under extreme pressure from humans is the Ainsdale Sand Dunes National Nature Reserve (NNR). The area covers 508 hectares of the 22 km long Sefton Coast dune system. To the north of the Ainsdale Dunes is the Ainsdale and Birkdale Sandhills Local Nature Reserve (LNR). The NNR is managed by Natural England, a government-financed agency that looks after the natural environment of England. It manages sites all over the country for the public to enjoy.

The Ainsdale Dunes form a delicate ecosystem with many rare species of plants and wildlife. Together these create a typical example of a psammosere, a sequence of changes in vegetation types across the sand dunes with increasing distance from the sea. The dune system lies close to one of the most densely populated parts of the country, with over 5 million people living within an hour's drive. The dunes face a number of pressures as a result of human use. As a result, there is a need for careful management to minimise conflict between the various demands on the dunes, and to conserve the fragile nature of the area.

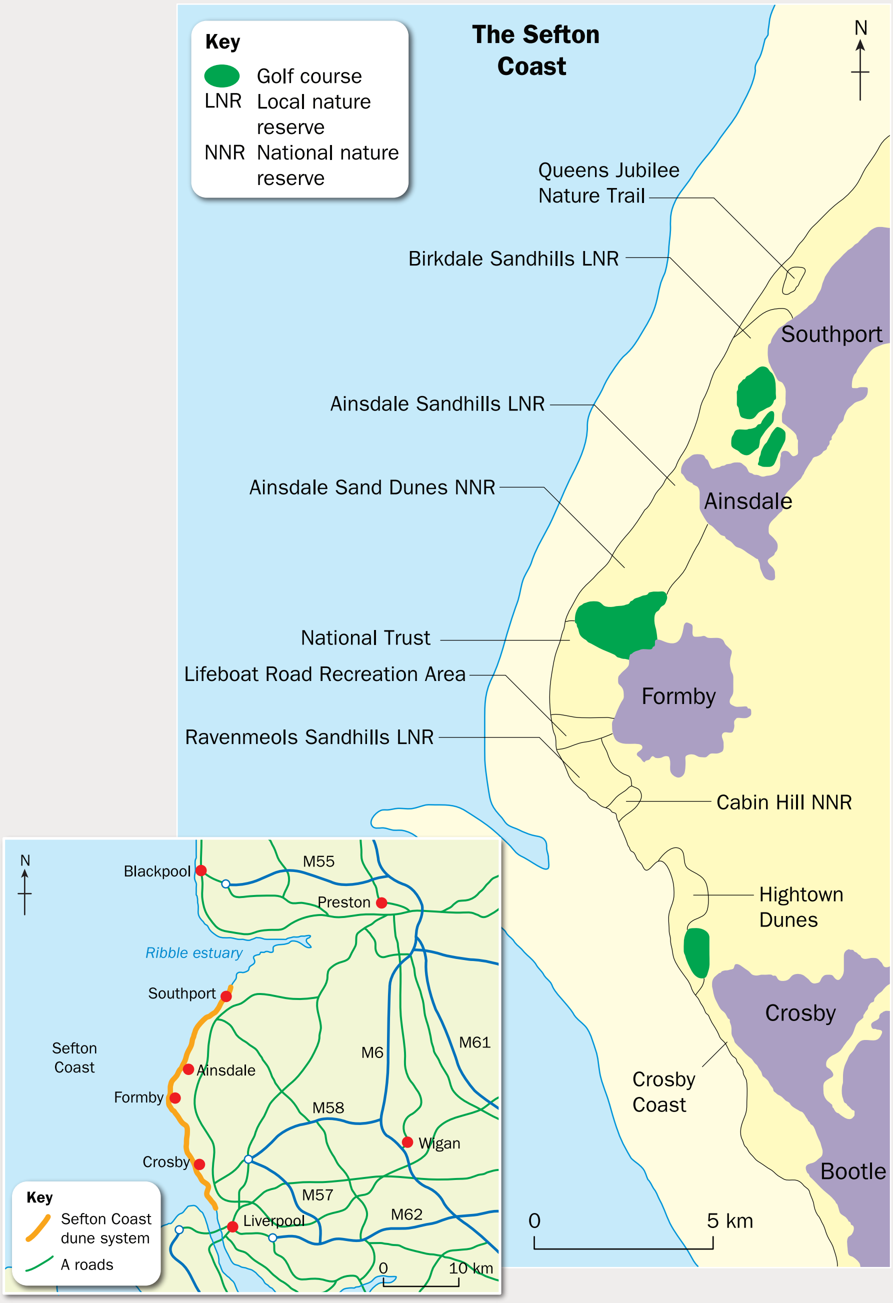


Figure 1 The Sefton Coast and its dune system

The environment of the Ainsdale Dunes

The Ainsdale Dunes are typical of a sand dune system, with high dune ridges, fixed dunes, and valleys between the dunes known as dune slacks (Figure 2). The slacks are hollows, which are usually flooded in winter and form ponds, providing a habitat for many rare plants and animals. Sand dunes also provide an example of plant succession, in which the nature of the vegetation changes with distance away from the sea.

Close to the sea, the dunes are dominated by species like marram grass and sand twitch, which are adapted to the lack of soil, strong winds and the high salt content of the sand. The areas of dune slack support common species like creeping willow and flag irises. On the inland side of the dune system, the vegetation changes gradually to trees, especially pine trees. In Ainsdale, much of the vegetation is dune scrub – a mixture of shrubs and grasses, particularly brambles. The dunes are also home to many rare plant species such as helleborines and orchids.

> **"Psammosere: a sequence of changes in vegetation types across the sand dunes with increasing distance from the sea."**

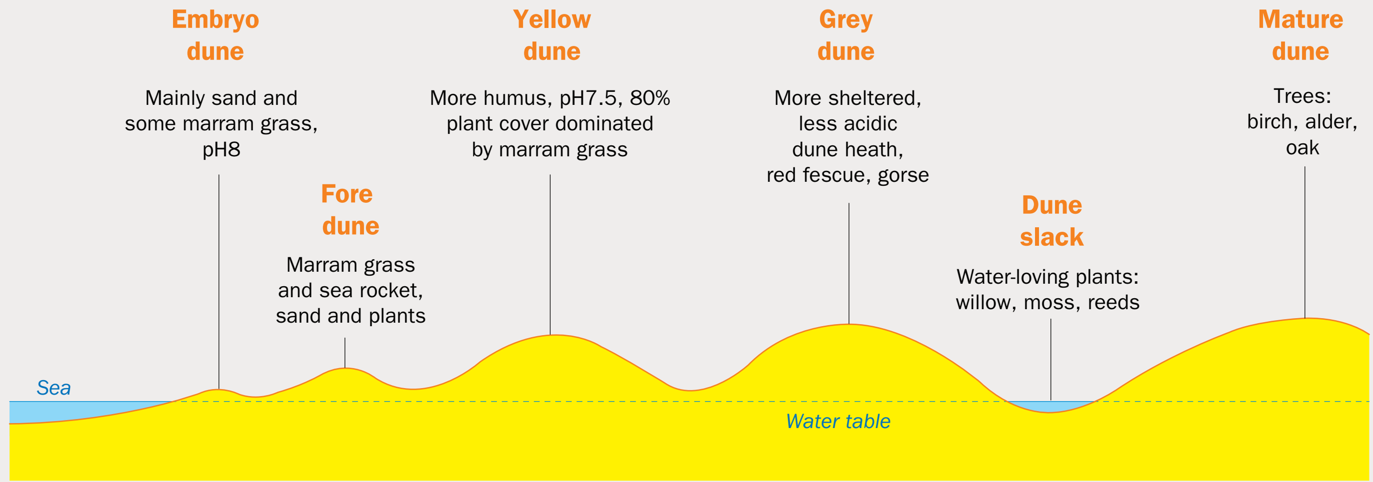


Figure 2 Cross-section of a dune system

Fauna (wildlife)

The Ainsdale Dunes have for many years been recognised as an outstanding area of wildlife interest, including reptiles such as sand lizards. The dune slacks are also the breeding ground of the rare and protected natterjack toad, the loudest amphibian in Europe. There are also rabbits, red squirrels in the woodland, and various bird species.

Pressures on the dunes

The fragile dunes ecosystem and traditional uses of the area, such as grazing, are under threat from a number of pressures.

1 The growth of dune scrub vegetation

The spread of scrub vegetation leads to soil development and the drying-out of the dune slacks. This allows the establishment of tree and shrub species including the native sea buckthorn and birches, and non-natives such as pine and sycamore.

This leads to the development of scrub woodland, a semi-natural habitat (Figure 3) but one that results in a loss of valuable shrubs that create an open dune habitat, such as creeping willow. Brambles produce dense undergrowth that means many rare dune plants are crowded out and unable to survive. The decline of rabbit numbers due to myxomatosis since the mid-1950s has also contributed to this.

2 Tourism

The Sefton Coast is close to cities like Liverpool and Manchester, both of which are part of larger conurbations, and to towns like Southport and Warrington. Most visitors are attracted to Ainsdale by the wide, flat beaches and expanses of sand at low tide, and many people enjoy walking in the dunes. Some like to walk their dogs here, while others come for the solitude, to experience the wild landscape and to observe the wildlife.

Large numbers of visitors inevitably create pressures on habitats and species, including dune erosion and a loss of habitat quality. Activities such as dropping litter, riding quad bikes, driving 4x4 vehicles, lighting fires and collecting rare species can cause a lot of damage. This can take up much of the wardens' time, which could be better spent on management. Allowing free access to the dunes encourages footpath erosion, and while this can help keep the grass short, it can also create bare patches of sand.

“Large numbers of visitors inevitably create pressures on habitats and species.”

Figure 3 Scrub vegetation on the dunes

Source: Photo by Rob Morris

3 Management strategies

The dunes are managed in order to conserve open sand dune habitats and the species for which the area is famous, while allowing public access and providing information for visitors.

- Management of the NNR is undertaken by Natural England, the statutory wildlife agency for England, while that of the LNR is by Sefton Council. Each of these organisations has produced a management plan for their site.
- Visitor numbers at Ainsdale are controlled at Ainsdale itself as it is a honeypot site. This has the advantage of encouraging the majority of people who come to the coast for the beach and associated facilities to be concentrated in limited areas where intensive management can be arranged to accommodate them.
- Access to Ainsdale Dunes is also carefully controlled. Large numbers of visitors are allowed on the beach at Shore Road to the north of the NNR, while fewer visitors are allowed onto the NNR, so providing a wildlife sanctuary – access there is allowed only by permit.
- Little human intervention is allowed here, but it does include small information boards, guided walks and illustrated talks by the site warden.
- Access to the NNR is only by the three main public-permitted paths, and this has kept visitor numbers down. The adjacent LNR has open access to visitors and includes several permitted paths, as well as many informal footpaths, particularly towards the beach.
- On the beach, visitor access is more formal, with car parking on the beach itself and with the type of facilities usually found on a busy resort beach. Paths are covered by boardwalks to reduce the impact to the dune and beach area, while boards inform and encourage visitors to discover more about the natural life of the area. Wardens are important for visitor management and the protection of rare species.
- In recent years, Sefton Council has restricted parking on the beach during spring tides. This has led to protests from beach users and traders, such as ice cream vans. In order to limit vehicle access to the dunes, Sefton Council has erected wooden posts at the top of the beach and adjacent to the dunes. The gaps between the posts are too narrow for cars to get through but quad bikes can be lifted over them. However, the posts are only found for a kilometre south of the access road at Ainsdale, and any determined 4x4 driver is able to drive to a point where a vehicle can enter the dune system.

The management strategies used on the NNR and LNR minimise undesirable impacts on the delicate ecosystem, and also need to be sustainable.

4 Clearance of invasive species

Removing the dune scrub vegetation used to be carried out by volunteers using hand tools, but only small areas could be cleared in this way, and it was expensive. The use of weedkillers is not environmentally sound as it can affect other species. Recently, scrub clearance using tractors with specialised rakes has allowed large areas to be cleared, and this is often more successful than scrub cutting because the roots are removed. However, this is expensive and causes some damage to the dunes themselves.

Mowing was used in the 1980s to control the creeping willow in the dune slacks, where it was taking over these areas. Cuttings were hand-raked and removed off-site by tractor and trailer.

Cut material can be used to surface paths, or be rotted down to make compost that can be used elsewhere. Surveys have shown that mowing in the slacks increases the range of species found. It does, though, need careful management. Mowing can damage soil as it compacts it, making it harder for plants to grow. Raking cut vegetation can be very time-consuming for the wardens.

5 Grazing

For centuries, rabbits were an important influence on the Ainsdale Dunes. Following the outbreak of myxomatosis in the mid-1950s which killed many rabbits, the dunes became overgrown, resulting in the loss of some plant species.

Grazing by farm animals was introduced on the dunes by English Nature (the predecessor of Natural England) in the 1990s.

Today, grazing by Herdwick sheep and Belted Galloway cattle has proved to be the most successful and appropriate form of vegetation management. These particular breeds eat most things but are particularly useful as they eat plants such as creeping willow. This has also encouraged resurgence in the rabbit population.

Grazing does require the support of dog walkers as they are obliged to keep their pets on a lead.

6 Blowouts

A natural process that often occurs at high tides is the blowout (Figure 4). These create new sandy habitats within the fixed dunes, and strip away vegetation that is especially important for annual plants, invertebrates, natterjack toads and sand lizards. Recreational activities can cause such erosion and if property or infrastructure is

Figure 4 Formation of a blowout

Figure 5 A dune slack provides a good habitat for natterjack toads

Source: Photo by Rob Morris

threatened, diggers are called in to stabilise the dunes. At Ainsdale, this has had to be done close to the coast road near a Pontins holiday camp, and to prevent sand blowing onto the Southport to Liverpool railway line.

7 Species management

Three important species in the Ainsdale Dunes area are protected by both European and national legislation: the natterjack toad, sand lizard, and petalwort (a plant). To ensure their survival, special measures are taken for each species.

- Natterjack toads have specific breeding pools, and their management includes the deepening of pools which gives more open conditions, and to provide water in drought years (Figure 5). In popular areas the pools are fenced off and information boards explain the importance of this toad.
- Sand lizards are most frequent in the area closer to the beach and are more likely to be disturbed by visitors. Again, fencing is erected to protect the most sensitive sites and paths are re-routed.
- Petalwort is type of plant that favours conditions found in and around dune slacks. It is found in fewer than 20 places in the UK. Grazing, light trampling and disturbance actually helps this species thrive, and a management strategy has been developed to encourage its survival.

Conclusions

The Ainsdale Dunes have experienced more than 30 years of conservation management, which has gradually modified and improved the dunes. However, since 2010, Sefton Council has cut back on the amount of money it spends in the area, so fewer wardens are employed to patrol the area, and there are fewer repairs to fences and boardwalks. As a result, more vehicles are driving into the dunes, leading to more damage.

The challenge remains: how can managers achieve a balance between conserving the valuable habitats and wildlife, and allowing visitors access into such an attractive area?

> **"The challenge remains: how can managers achieve a balance between conserving the valuable habitats and wildlife, and allowing visitors access into such an attractive area?"**

Activities

1 Describe the location of the Sefton Coast.

2 Explain why the wardens at Ainsdale need to employ management methods such as the removal of dune scrub, mowing, and the removal of invasive species.

3 Study Figure 2 and suggest reasons why the vegetation changes with greater distance from the sea.

4 a Referring to Figure 4, describe how a 'blowout' occurs.

b Why is a blowout good for the management of the sand dune system?.

5 This part of the coast is also known as England's Golf Coast. Use the internet to research why sand dunes make good golf courses.

6 Referring to Figure 6, describe how visitor numbers are managed at Ainsdale.

7 Design a poster to encourage dog walkers to keep their dogs on leads while they are in the areas where there are grazing sheep and cattle.

8 You are a local resident from Ainsdale and like to walk your dog in the dunes. You are unhappy about the decision to graze cattle there. Write a letter to the warden at the Ainsdale NNR expressing your displeasure, and suggest some alternative strategies the warden might employ.

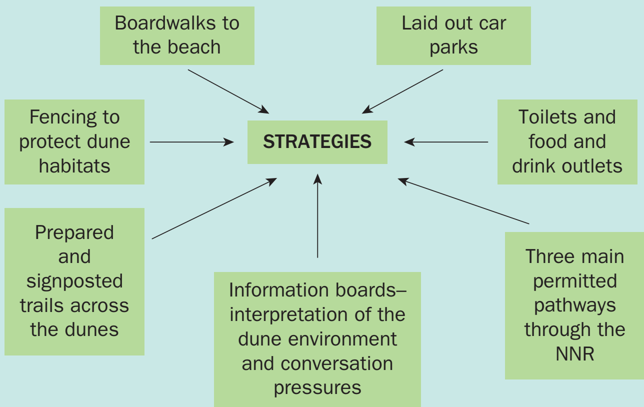


Figure 6 Strategies used to manage visitor numbers at Ainsdale

Learning checkpoint

- The Ainsdale Dunes is a delicate ecosystem with many rare species of plants and animals. It is a typical example of a psammosere.
- The NNR is under extreme pressure from human use which conflicts with the fragility of the ecosystem.
- Natural England has a number of management strategies aimed at conserving the valuable habitats and wildlife and still allowing visitor access.

Glossary task

Write glossary definitions for these terms:

conflict	**invasive species**
dune scrub	**management strategy**
ecosystem	**myxomatosis**
honeypot site	**psammosere**

Remember this case study

To help you remember this case study, make notes under the following headings:

What are the Ainsdale dunes?

Where are they?

Why are they important?

What are the implications/impacts of people's use of the NNR?

How are the dunes being managed?

Try to make your notes fit a single sheet of A4.

Geofile Online

JANUARY 2009
585

Kim Adams

Pressures on the Coastline

According to the United Nations Environment Programme (UNEP), the population density in coastal areas is now twice as high as the global average, with more than 50% of the global population living less than 60km from a coastline, in 180 coastal countries. Of the world's 33 mega-cities, 21 are in coastal areas, with 14 of the largest 15 on low-lying vulnerable areas, ranging from older world cities like London to newer mega-cities like Shanghai (Figure 1).

The coast and its river estuaries and deltas has always been a focus for trade, communications, industrial sites but also for natural goods and services. Fishing, aquaculture, tourism and recreation and even biomedicine depend on coastal biodiversity and landforms. Although 'nature's services' cannot easily be quantified, their economic value is critical, as shown even in the USA, where its largest commercial and recreational fishery, the Gulf of Mexico, is presently threatened by an oxygen-depleted 'dead zone' as large as the country of Belize. The 2005 Millennium Ecosystem Assessment highlighted that for millions of the world's poorest people, healthy coastal ecosystems are a matter of survival. The United Nations FAO states that one critical ecosystem for many tropical/subtropical coasts, the mangrove swamp, was reduced in extent by 25% between 1980 and 2003. Increasing pressures may ironically also result from setting up conservation zones.

The 2004 Indian Ocean tsunami and 2005 Hurricane Katrina in New Orleans highlighted another issue to be faced by coastlines: that of flood risk. The UN Hyogo Framework for Action on Disaster 2005–2015 highlighted the problem of vulnerable populations being juxtaposed with increased flood risk, exacerbated by loss of coastal sediments and ecosystems and their 'buffering capacity' against natural hazards. Over 200 million people are at risk, with about a half of these living in areas no more than one metre above sea level. Vulnerability hot spots range from the Thames Gateway and the Netherlands, to the Bay of Bengal, much of East Asia, as well as large areas of the Caribbean and USA.

The coast is the interface between fluvial and marine systems which both creates highly productive ecosystems in its estuaries and near shore waters and also creates its main threat: some 80% of pollution in oceans originates from land-based activities. These activities destroy and contaminate habitats, and about half of all the world's coasts are threatened in some aspect from human activity, as shown in Figure 2.

The driving force is population pressure, from sheer numbers increasingly wanting to live along the coast, and their increased personal wealth and consumerist demands. Not only are new areas being developed in coastal zones, but major redevelopments are being undertaken in existing coastal settlements as they compete in an increasingly globalised world, for example Brooklyn and Queens in New York, London's Thames Gateway and Shanghai's Bund.

Only in the last few decades has any concerted effort been made to reconcile the many conflicting uses on coastlines, so now the pressures being tackled are at differing scales: locally, regionally, nationally and internationally. Traditionally, coastal pressures have been managed by a focus on single issues, for example over-fishing or erosion or pollution incidents. The more holistic and sustainable strategy of integrated coastal zone management (ICZM) has long had widespread support in the USA and UK, and even in Belize in Central America, but is a relatively new concept in many growth economies, such as China.

The one pressure which is uniting countries in a concerted international effort is that of the pressures associated with climate change (Figure 3). Paradoxically, many of

Figure 1: Coastal populations

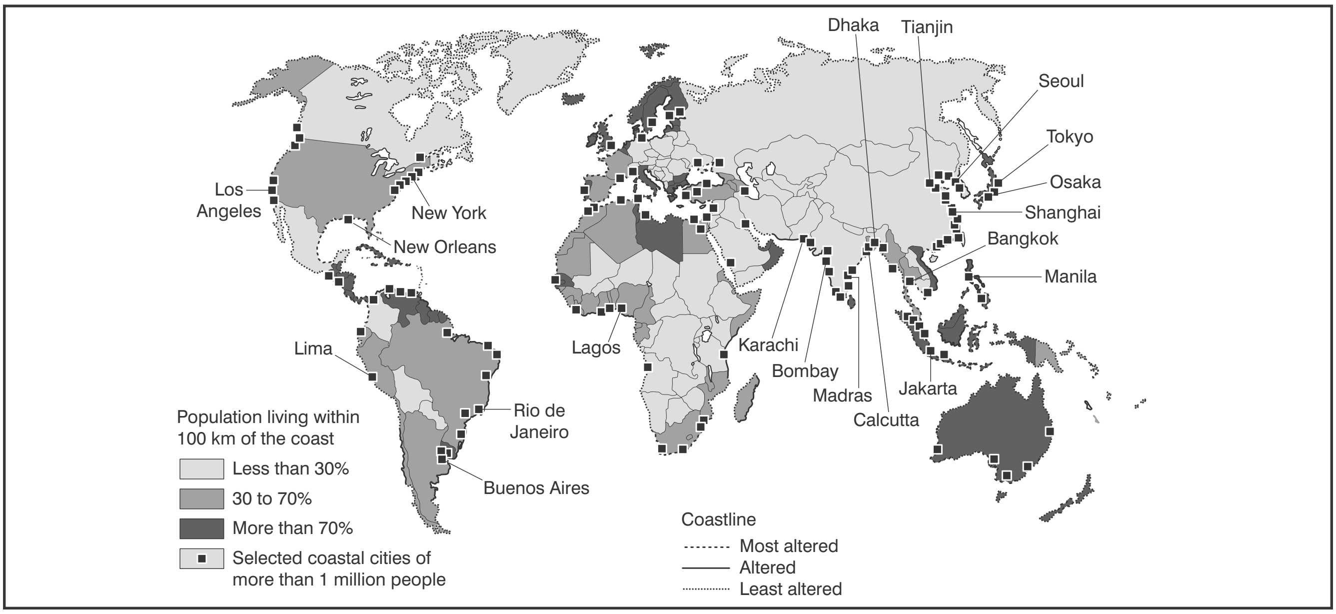


Figure 2: Sources of pressures on coastlines

Pressures	Major impacts
Climate change	Sea level rise, increased risk of storm surges, flooding and erosion, increased sea temperature, biodiversity change and often loss.
Urbanisation	Coastal squeeze, habitat disruption and destruction, eutrophication and pollution, artificial management of coastal processes e.g. sea walls, nourishment, water demand from rivers and aquifers resulting in salt water intrusion.
Tourism and recreation	As in urbanisation, plus seasonal demands and spatial hotspots. Increasing influence as the growth industry of the 21st century and as the pleasure periphery for holiday makers expands to encompass 'new' locations.
Manufacturing industry	Coastal squeeze, pollution, biodiversity and habitat loss, landscape change, bio-product exploitation.
Primary industry – agriculture and forestry	Eutrophication, pollution, biodiversity and habitat loss and fragmentation, salinisation, altered sediment inputs, increased water demand resulting in less fresh water input to coasts.
Primary industry – fisheries	Over-exploitation of fish stocks, by catch of non-targeted species, destruction of bottom species' habitats, large scale disruption to food webs.
Primary industry – aquaculture	Eutrophication from overuse of nutrients and pollution, genetic alterations and alien species invasions, diseases and parasitic spread to indigenous fish.
Infrastructure including shipping	Operational and accidental spillages, pollution.
Energy: exploration, exploitation and distribution of raw materials	Alteration to habitats and landscapes, subsidence, contamination, pollution (noise, light, substances, altered sediment flows), sea bed and shore disturbance.

NB these pressures may not be local to the coast but may be felt quite some way inland, as rivers act as corridors for pollution and changed freshwater and sediment input to coastal zones

Adapted from the EU Marine Strategy Directive, 2005

these coastal cities vulnerable to increased sea levels, storms and surges are themselves partly responsible for increasing the greenhouse gas levels globally, because of their large and growing 'climate footprint'! They face growing economic disruption and increased regulation of production systems, energy resources, and standards for health and environment to combat their impact on the environment.

Case studies of pressures

Case study 1: Country-scale pressures and management options: China

With 18,000 km of continental coastline, China can be viewed as a 'marine nation' with its future development increasingly tied to coastal areas and resources. Its coastline is facing several growing major issues, including rising sea levels threatening low-lying areas, pollution of inshore waters and loss of biodiversity, together with growing, increasing pressures to increase conservation. A recent report by China's State Oceanic Administration estimates the percentage of 'unsalvageable' eco-systems is 73% for mangroves, 80% for coral reefs and 57% for wetlands.

Some 73% of China's GDP originates from the coastal zone, the location for all the country's 14 'economic free zones' and five 'special economic zones'. Over 56% of the country's population, 677 million, live in the 13 south-eastern and coastal provinces and two mega-cities, Shanghai and Tianjin. Guangdong Province, including the Pearl River Delta, has had one of the fastest economic growth rates in East Asia over the past decade; similar to Hong Kong and Singapore. Now a new coastal growth centre is being developed at the China-Vietnam border, called the Beibu Gulf Economic Rim.

Environmentally, China's coastal zone has a rich variety of marine life, with many unique species such as the Dugong sea lions, Yangtze river dolphin, and Chinese white dolphin. Over-fishing, rapid urbanisation, and lack of pollution controls on agriculture and industry have degraded river and coastal water quality, which in turn has destroyed much of the marine habitat and reduced marine ecosystem stability and biodiversity. Indeed, over-fishing and growing trans-boundary water pollution from China are two issues that underlie political tensions in NE Asia. China dominates fish farming (70% globally). Decreased sediment flow to the coast, because of large-scale dam projects, is leading to accelerated coastal erosion, compounded by sand mining for the construction boom. Rising sea levels, and salt water intrusion, especially in the Yangtze and Pearl River delta zones, are being felt especially by Shanghai and Tianjin, port city for Beijing, both key to the country's economic wellbeing. They have had relative sea level rises of up to 19cm over the past 30 years, due to natural and human exacerbated subsidence from over-building, ground water abstraction and huge reclamation projects such as Shanghai's new Pudong business and residential zone, and Dongtan ecocity. Also threatened is the key industrial zone of the Pearl River Delta, a huge cluster of cities and provinces about the size of the Netherlands, with 30 million official residents and some 12 million migrant workers. 2004 and 2006 were critical years showing the effects of rising sea levels, coupled with storm surges, coastal erosion, and saline water intrusion. By 2050 an estimated 1,153 of its 41,698 km^2 will be flooded.

There are many blocks to effective management and conservation in China:

- conflicts of long-term conservation with shorter-term goals of industrialisation and demand for rising living standards;
- arguments between central and provincial governments;
- few laws and enforcement in place;
- Communist rulers quash any voices of dissent, major organised protests are rare, and there is no

Figure 3: Bio-physical effects of climate change on coastal areas

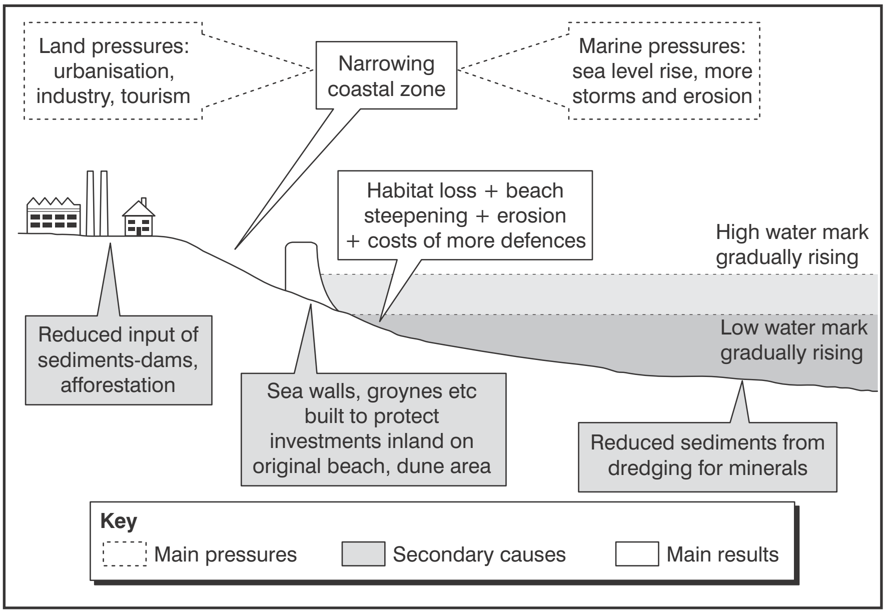
Type of change	Direction of change	Effects and pressures created
Global sea level	Increase – by 9–88 cm by 2100, 2–4 times the rate of that measured in the 20th century. Regional variations – some areas little rise, others huge!	Storm surges-coastal inundation, displacement of wetlands, coastal erosion, increased storm flooding and damage, loss of ecosystems: from estuary to sand dune, mangrove to salt marsh, salt water intrusion, rising water tables, impeded drainage.
Sea water temperature	Increase	Effects on ecosystems, rates of productivity and growth. Coral bleaching is a negative effect.
Precipitation intensity	Increase	Effects on ecosystems, runoff, sediment movement into coastal areas, erosion.
Waves	Uncertain	Changed longshore drift and onshore drift patterns.
Storm frequency	Regional variations	Changed frequency and intensity of storm flooding and damage.
River runoff	Regional variations	Changed sediment supply from rivers to coast – if more floods then more sediment.
Atmospheric CO_2	Increase	Increased productivity in coastal ecosystems.

culture of pressure groups. There are, however, signs of a growing environmental movement, as shown in 2007 by the use of 1million mobile texts to the local government to halt a billion-dollar petrochemical plant (to make paraxylene, linked to cancer), in the major port of Xiamen.

The main management solution to rising sea levels will be by adaptation, for example by higher sea walls, and 'water gates' like the Thames barrier, e.g. Wu Song Kou Wai, on the Yangtze estuary. China is now fully involved in the post-Kyoto–Bali Roadmap, which attempts to address global warming at the source by reducing emissions. Attempts in the 1960s to reduce the level of groundwater exploitation and recharge the aquifers reduced subsidence in the Shanghai zone to a few millimetres annually, but this has not been maintained in the current economic expansion with growing land reclamation. A combination of building and water abstraction conservation plus recharge wells and basins, will be needed to protect fresh water supplies at the coast, where salt water intrusion is a growing pressure.

Whilst 'Coastal Environmental Stewardship' is apparently now a national priority, China faces even greater political, social, and economic issues. China is facing many development problems at a level unknown to most of the world, and it may be argued that the nature of the challenges to their coastal waters is no different than many others – but perhaps the rate and scale of change are larger!

Figure 4: The term 'coastal squeeze' is applied to the situation where the coastal margin is squeezed between the fixed landward boundary (artificial or otherwise) and the rising sea level



Case study 2: Meso scale pressures: the Mediterranean coastal squeeze

'Coastal squeeze' has serious implications for wildlife, particularly birds which need beaches and mudflats to feed, and for farmers and property owners who are losing land. This is a global pressure – and it is well illustrated around the Mediterranean. Development along the Mediterranean has created the so called 'Med Wall' where over 50% of the coast is dominated by concrete. Two-thirds of Europe's wetlands, most of which are coastal, have been destroyed over the past 100 years. Population densities along Europe's coast are higher and continue to grow faster than those inland, especially in Portugal, Ireland, Spain, France, Italy and Greece. This pressure is from spontaneous tourism and from EU subsidies designed to help economic restructuring in the form of new roads, which subsequently has attracted residential sprawl. Some 9% of all European coastal zones lie below 5 metres, especially in the Netherlands and Belgium, and are vulnerable to rises in sea level and related storm surges. Localised hotspots exist, especially the highly developed Venice area.

A recent feature of many Mediterranean coastlines is the huge growth of 'urbanisacions', a Spanish term for self-contained clusters of apartments and villas catering for affluent retired foreigners and holiday makers, facilitated by cheap flights. One of the largest is La Marina near

Figure 5: Students studying the microcosm of pressures on coastal Belize: Caye Caulker

Source: Stephen Carville

Alicante on the Spanish Costa Blanca. Development began in 1985 and has pressurised the low-lying coastline and sand dunes, with issues ranging from water supply to lack of social integration with the local population.

The influential 1995 Dobris report provided the first major assessment of the state of coastlines and seas in Europe, but a review in 2007 suggested pressures on the seas and coasts continues to be high, despite all efforts at management such as the 'blue corridor' network of reserves and attempts at 'integrated coastal zone management' linked to the wider context of ecosystems and human well-being set up by the Millennium Ecosystem Assessment. Amazingly, management is still hindered in such an affluent area by the lack of a systematic GIS database for the European coast! Pollution has improved from reductions of nutrient pollution from industry and waste water, but agricultural run-off remains a problem.

Case study 3: Belize a small, middle-income country attempting integrated coastline management

Belize, in Central America, has a complex, dynamic physical coastal system made up of the world's second largest barrier reef, a UNESCO World Heritage Site, offshore atolls, hundreds of patch reefs, extensive seagrass beds, mangrove forests, and more than 1,000 offshore islands called cayes. The latter dominate the tourism industry because of their natural attractions, with the first hotel built on Ambergris Caye in 1965. The pressures originate from:

- Concentration of people: over 45% of Belize's 314,000 population (2007) lives at the coast.
- 33% of the population live below the poverty line, despite Belize being classed in 2006 as an upper-middle income country by the World Bank (China is classed as lower-middle income). To meet its reduction in poverty goals as part of the 2000 Millennium Development Goals, its coastal natural resources are essential.
- The economy is dominated by tourism and fisheries. In 1970 there were under 30,000 tourists, but by 2007 over 400,000 a year.
- The rise of cruise ships, both visiting the country (over 500% increase since 2000, with about 200 visits per year now) and passing by on Caribbean routes, add another concentrated dimension to tourism pressures, discharging not just swimmers to 'reef walk', but their sewage, called 'black water'!
- Growth of aquaculture, especially shrimp farming, is increasing in economic importance and physical impact.
- Increasing intensification of sugar and citrus production inland results in chemicals being washed into the relatively pristine coastal waters with fragile ecosystems.
- Rise in pharmaceutical companies wishing to carry out bio-prospecting for new products from the reef, creating more disturbance and potential damage to a vulnerable ecosystem already adjusting to global warming and sea level and temperature changes.
- Low investment and fragmented management

As a result, certain species have become endangered: the West Indian manatee, American crocodile, marine turtles and several types of birds.

However, since the late 1980s an attempt at Coastal Zone Management has been making some progress, funded mainly by the Global Environment Facility and United Nations Development Programme, helped as well by the EU, and operated by the Belizean government's Ministry of Fisheries, Research and Monitoring. 2000 is taken as a base line for data collection, although measuring changes in the marine environment is obviously difficult! Education is seen as a prime role for Coastal Zone Management. The coast is split into nine planning zones, with various 'roadmaps' for planning aquaculture and demand for new facilities like hotels. Ecotourism is encouraged by the government, with organisations like the Belizean Ecotourism Association and Programme for Belize which work with the government to try and control the worst effects of tourist pressures. By the 21st century, marine reserves covered 11% of the coastal mainland, but only 1% of the ocean/ atolls and cayes.

Conclusion

The pressures on all coastlines are increasing rapidly, both from physical and human causes. There is an increased determination to plan the coastline in an integrated, long-term holistic manner, involving all stakeholders in an attempt to balance the needs of development with protection of the very resources that sustain coastal economies. However, lack of reliable data and often government effectiveness has meant the ideals of integrated coastal management are a long way from being met on a large scale.

Focus Questions

1. How do the types and scales of changes at coastlines create different pressures? (What are the categories causing change: human e.g. tourism, industrial, and physical e.g. rising sea level.)

2. Why is coastal squeeze a complex issue? (Consider the variety of direct and indirect causes and consequences.)

3. What factors make coastal pressures difficult to manage effectively? (Categorise the barriers e.g. under funding, institutional capacity political will, scale of pressure, need to coordinate so many organisations involved, lack of data e.g. on destruction rates, lack of cohesive lobbying.)

4. Why is integrated coastal zone management seen as the ideal strategy in all these case studies? (Think of the scale, the complexity and the range of the pressures experienced in the case studies.)

The Chiapas earthquake, Mexico 2017

By Philippa Simmons

Synopsis

This **Geofile** will explore the causes and impacts of, and the responses to the Chiapas earthquake that occurred in Mexico September 2017. Mexico is situated where the Cocos plate converges with the North American plate – one of the most tectonically active regions in the world, with up to 40 earthquakes a day. At 23.49 local time on 7 September 2017 an earthquake of magnitude 8.2 struck off the coast of Mexico. This was the strongest earthquake to be recorded globally in 2017, and the second strongest to ever happen in Mexico.

This event shows that, whilst Mexico's responses to tectonic events have improved since the partial destruction of Mexico City in 1985, there is still a long way to go.

Key terms

Tectonic: movement of the plates of the earth's crust and resulting events

Tectonic hotspot: an area of intense earthquake or volcanic activity

Plate boundary: the place where two plates converge

Convergent boundary: a plate margin where two plates are moving towards each other

Aftershocks: smaller earthquakes following the main event

Magnitude: the scale of an earthquake, measured by either the Richter or Mercalli scales

Tsunami: a large wave at sea, moving onshore, usually generated by an earthquake

Vulnerability: the degree to which people are at risk from a hazardous event.

Learning objectives

By the end of this **Geofile** you will have improved your understanding of:

- the causes of the Chiapas earthquake
- the impact of the earthquake, particularly focusing on the people in Chiapas
- the nature of the responses to the earthquake from the Mexican government
- the work Mexico still needs to do to improve its earthquake preparedness.

Links

Exam board	Link to specification
AQA	
AS	Component 1 Physical Geography 3.3.1.4 Seismic hazards p18 pdf version Click here
A2	Component 1 Physical Geography 3.1.5.4 Seismic hazards p15 pdf version Click here
Edexcel	
AS	1.4c and 1.5c Social and economic impacts of tectonic hazards p18 pdf version Click here
A2	1.4c and 1.5c Social and economic impacts of tectonic hazards p15 pdf version Click here
OCR	
AS	Topic 2.5 Hazardous Earth 4b Range of impacts on people as a result of earthquake activity – case studies + 5b Strategies – case studies p39 pdf version Click here
A2	Topic 3.5 Hazardous Earth 4b There is a range of impacts people experience as a result of earthquake activity – case studies + 5b There are various strategies to manage hazards from earthquakes – case studies p51 pdf version Click here
Eduqas A2	3.1.3 Earthquakes, processes, hazards and their impacts 3.1.4 Human factors affecting risk and vulnerability 3.1.5 Responses to tectonic hazards P30 of pdf version Click here
WJEC	
AS	1.3.3 Earthquakes, processes, hazards and their impacts 1.3.4 Human factors affecting risk and vulnerability 1.3.5 Responses to tectonic hazards P20 pdf version Click here
A2	4.1.3 Earthquakes, processes, hazards and their impacts 4.1.4 Human factors affecting risk and vulnerability 4.1.6 Responses to earthquakes P35 pdf version Click here

The Chiapas earthquake, Mexico 2017

Mexico – a tectonic hotspot

Mexico is situated in a tectonically active area and its inhabitants are used to regular seismic activity, such as the devastating earthquake that struck Mexico City in 1985 (8.1 on the Richter Scale). It caused the destruction of 100,000 buildings, killed over 5,000 people and left millions without electricity or water.

The 1985 earthquake was so catastrophic because Mexico City is built on a former lake-bed, resulting in amplification of earthquake waves by the soft sediments on which the city is built. Also, the lack of earthquake-resistant buildings, particularly in the informal settlements, compounded the damage. This event resulted in the Mexican government putting a lot of its resources into earthquake-resistant buildings in their main cities, but there is still some way to go in the rural and poorer areas.

The region of Chiapas lies on the boundary of the Cocos and North American plates. At this convergent plate boundary, the oceanic Cocos plate is being forced below the continental North American plate. This creates a subduction zone due to the oceanic plate being denser than the continental plate. Convergent plate boundaries can produce very large earthquakes; the two plates may lock, resulting in pressure building up. Eventually it reaches a breaking point whereby the upper plate will spring back, with it lifting the ocean floor. Consequently the region of Chiapas is at risk of large earthquakes and related tsunamis.

The causes of the Chiapas earthquake

On 7 September 2017 an earthquake with a magnitude of 8.2 M_w, as recorded by the United States Geological Survey (USGS), hit at 23.49 CDT off the southern coast of Mexico, 100 miles (160 km) from the region of Chiapas (Figure 1). This caused huge amounts of damage to the coastal areas around the epicentre and led to mass evacuations due to initial tsunami warnings; approximately 90 people were killed. The intensity was so great that it was stated that nearly half of Mexico's population of 120 million people felt the earthquake, and it even caused buildings to sway as far away as Mexico City (Figure 1).

Earthquakes in Mexico are a common occurrence (Figure 2), but the causes behind this earthquake were complex. The Cocos plate is made up of crust beneath the Pacific Plate and it is sinking deeper into the earth under

Figure 1 The Chiapas earthquake

Date	Affected Area	Magnitude	Deaths	Injuries
23 September 2017	Oaxaca	6.1 M_w	6	7
19 September 2017	Mexico City, Morelos, Puebla	7.1 M_w	370	6,011
7 September 2017	Chiapas, Oaxaca	8.2 M_w	98	300

Figure 2 Notable earthquakes in Mexico, 2017

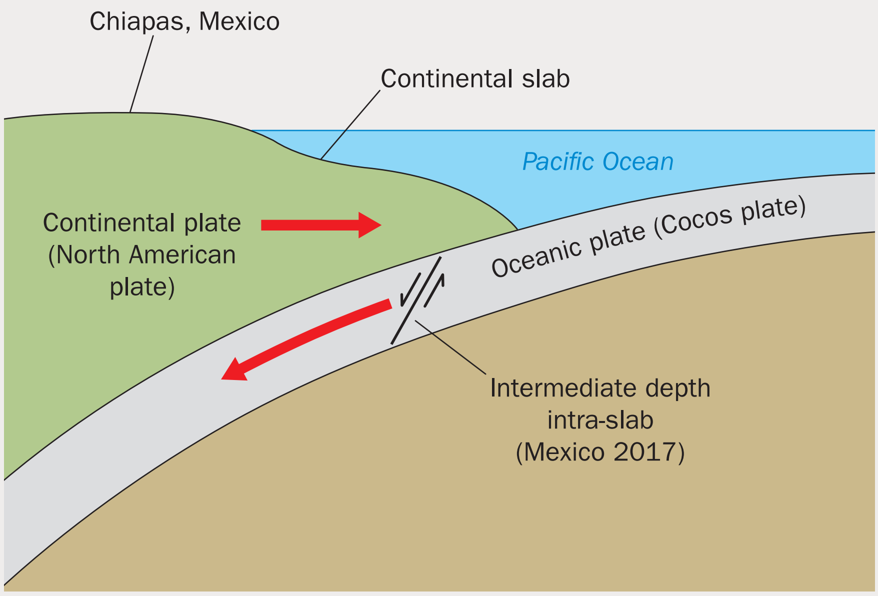


Figure 3 Section across the Cocos oceanic plate

its own weight. It would seem that this action is causing fractures inside the crust (Figure 3) which geologists believe could be the cause of the 2017 earthquake. There is still a lot of research to be done into these tectonic plates which is due to the complexity of the tectonic zone around Mexico.

Tsunami hazard

As shown by the 2011 Tohuku (Japan) event, earthquakes can cause secondary impacts, the most devastating of these often being a tsunami. Tsunamis are mostly commonly created at subduction zones due to the amount of pressure that can build up between the two plates. When this pressure is released it is often in the form of the overriding plate snapping back which displaces the water above it creating a tsunami. The Chiapas earthquake was different as it created a tsunami due to it being on a fault (Figure 3).

The Mexican tsunami was relatively small because it occurred in shallower water – generally, larger tsunamis occur when they are created in deeper ocean water and move to shallower shorelines. Following the Chiapas earthquake the Pacific Tsunami Warning Centre issued a warning for the whole of the Central American Pacific coast. The warning allowed time for some coastal communities to evacuate as a precaution; eventually the warnings were lifted once the lower threat was realised.

Following the tsunami warning there were a number of aftershocks from the initial earthquake. Aftershocks are smaller earthquakes which usually only last a few seconds but they can be surprisingly powerful. In the hour after the Mexico earthquake at least 12 aftershocks that were recorded by the USGS, and in the week following the earthquake a further 1800 aftershocks occurred, some having a magnitude of up to 6.1 on the Richter scale. Aftershocks can often be an issue because they can cause buildings that have already been weakened by the initial earthquake to collapse.

Other impacts

The main areas affected were the neighbouring states of Chiapas, Oaxaca and Tabasco, which surrounded the epicentre. The main initial (primary) impacts were:

- In total 1.5 million people were affected.
- In the state of Chiapas 41,000 homes were damaged.
- Approximately 90 people were killed: 71 in Oaxaca, four in Tabasco and 15 in Chiapas.
- At least one million people were left without electricity following the earthquake.
- Schools were closed in 11 different states to check the safety of the buildings.
- The states of Chiapas and Oaxaca are two of the poorest states in Mexico. Many buildings collapsed due to the houses being made out of flimsy material.

Responses to the earthquake

Public officials were quick to give guidance following the earthquake, which had been one of the biggest since the 1985 Mexico City earthquake. The Mexican government

Figure 4 President Enrique Pena Nieto climbs over rubble to view a destroyed school
Source: Presidenciamx/Alamy

had learnt a lot from the 1985 experience after many residents were trapped under rubble, left to fend for themselves while the authorities struggled to provide emergency services and aid for people. In 2017, determined to do things differently, President Enrique Pena Nieto and several of his cabinet members visited the state of Chiapas to help bring confidence to the people and lead the government relief efforts (Figure 4).

1. Access to stricken areas

One of the main problems following the Chiapas earthquake was that it occurred in some of Mexico's poorest states and in isolated and mountainous regions of the country. Rescue workers struggled to reach the most isolated communities and had to work hard to remove fallen rubble from some of the mountain roads to restore access to communities.

2. Reconstruction

Following the earthquake systems were put in place to support people in rebuilding what was damaged. These included:

- In the states of Chiapas and Oaxaca 73,000 families received support to help rebuild their houses.
- Reconstruction of schools – five months after the earthquake most children had returned to school.
- Mexican construction companies lent their support; Cemex (a Mexican cement producer) donated $1million worth of aid to support in the relief efforts.

This shows huge progress since 1985, when almost all aid came from the USA and the rest of the world. Nevertheless, despite rations being delivered to some of the worst hit states, there were still complaints of the relief being slow.

Although response times were fast following the Chiapas earthquake, it would seem it has still taken a long time for people to get back to normal in the regions that were most badly affected. The biggest challenge was removal of rubble from roads and getting the machinery up to the affected areas.

The future for Mexico

Twelve days after the strongest earthquake of 2017 hit Mexico, another one hit 123km from Mexico City with a magnitude of 7.1 M_w. This again demonstrated how vulnerable Mexico's population is to earthquakes and how much more the government need to do to protect their people and infrastructure.

This earthquake killed approximately 220 people and happened on the 32nd anniversary of the 1985 Mexico City earthquake. Although there was not as much damage, this earthquake, alongside the Chiapas earthquake, highlighted how much more Mexico's government need to do to ensure their buildings are resistant to earthquakes. Problems remaining include:

- Following the 1985 earthquake, new laws were put in place to ensure building regulations were followed to meet earthquake standards and that new buildings were monitored. The problem is that building regulations are often not followed or corners are cut when constructing buildings.

- Moreover, many of the settlements are informal or pre-date 1985 and have not been updated to withstand earthquakes.
- In Mexico City itself approximately 60% of the buildings are informal and unregulated where residents build their own homes out of whatever materials they can find, meaning that building codes are irrelevant.

New initiatives

In terms of reducing the vulnerability of Mexico's population, there have been positive moves to reduce the effects of earthquake activity. The government has implemented initiatives in major cities, for example:

- In 2002 the government launched a partnership with Fundacion del Centro Historico de la Cuidad de Mexico, a non-governmental organisation (NGO) which puts money into supporting the downtown area of Mexico City.
- Money being invested into monitoring systems to try and detect earthquakes
- There are emergency plans to prepare the city in the event of an earthquake.

These strategies are very much focused on places like Mexico City and particularly the city centre, which ignores many of the rural settlements and therefore does not tackle the vulnerability of the poorest people in Mexico. With each of the earthquakes mentioned, there is a common theme that highlights the vulnerability of Mexico's poorest communities and the government's difficulties addressing all these issues.

Conclusion

Inevitably Mexico will continue to be affected by tectonic hazards. Even though there has been much progress since the 1985 earthquake, there is still much further to go to support the urban poor and rural communities following severe earthquakes. Nevertheless, Mexico is moving in the right direction in reducing its people's vulnerability to earthquakes.

Figure 5 Rescue work on 20 September 2017 in Mexico City following the 7.1 M_w earthquake, in which about 225 people died
Source: SOPA Images Ltd/ Alamy

Focus questions

1. Explain the causes of the Chiapas earthquake. Include an annotated diagram with information from this **Geofile**.
2. Using the Chiapas case study and one you have studied yourself explain the impacts of tectonic hazards in two contrasting locations of the world. Why are they different? To what extent are physical and human factors responsible?
3. Essay question: Evaluate the importance of governance in managing the impacts of an earthquake. (Think not only about the importance of governance but also what other factors influence the impacts of an earthquake.)

Learning checkpoint

1. Why is Mexico such a tectonically active area? Research the causes of the Chiapas 2017 earthquake.
2. Using an annotated diagram, explain the causes of a tsunami.
3. Why is it difficult to reach rural communities following an earthquake?
4. What were the successes of Mexican government in their response to the Chiapas earthquake?
5. Following seismic activity, the worst affected in Mexico are the urban poor and rural communities. What does this suggest about Mexico as a country?
6. How can the government reduce Mexico's vulnerability to earthquakes?

Useful websites - news report and video

Wikipedia report on the Chiapas earthquake - Click here

BBC report on the earthquake - Click here

Guardian report on the 1985 earthquake - Click here

USGS report on the earthquake - Click here

GEOACTIVE 572

The Italian earthquakes of 2016

By John Rutter

A case study about the causes and effects of the earthquakes in Italy in 2016

In the second half of 2016 Italy was rocked by two major earthquakes. The first killed almost 300 people while the second, larger 'quake caused similar damage but there were relatively few casualties and only two deaths.

The differences can be explained by a complex mix of human and physical geography.

Key vocabulary

seismic, earthquake, tectonic, fault line, Richter Scale, magnitude, seismologist, geophysics

Learning outcome

At the end of this case study you will:

- have detailed knowledge, facts and figures about specific earthquake examples
- know how to compare and contrast different events
- be able to explain the reasons behind different levels of injury and damage
- be able to answer in detail questions about earthquakes and tectonic activity.

Relevance to specifications

Exam board	Link to specification
AQA	Paper 1: Living with the physical environment, Section A: The challenge of natural hazards, see pages 10–11. Click here
Edexcel B	Component 1: Global geographical issues, Topic 1: Hazardous Earth, see page 11. Click here
OCR B	Component 1: Our natural world, Topic 1: Global hazards, 1.2 How do plate tectonics shape our world?, see page 7. Click here
Eduqas A	Component 1: Changing physical and human landscapes, Theme 3: Tectonic landscapes and hazards, Key idea 3.2: Vulnerability and hazard reduction, see page 12. Click here
WJEC A	Unit 1: The core, A: The physical world, Theme 3: Living in an active zone, see page 15. Click here
Cambridge IGCSE	Theme 2: The natural environment, Topic 2.1: Earthquakes and volcanoes, see page 9. Click here
Edexcel IGCSE	Section A: The natural environment, Topic 3: Hazardous environments, see page 8. Click here

The Italian earthquakes of 2016

> "The year 2016 was a particularly active time for seismic activity in Italy."

The year 2016 was a particularly active time for **seismic** activity in Italy. The country and its inhabitants are no strangers to **earthquakes** or volcanoes – think back to stories of Pompeii and Mount Vesuvius from Roman times. However, there had been no major 'quakes since 2009 so people had, perhaps, started to become a little complacent. In 2009 a 6.3 magnitude earthquake had struck close to the town of L'Aquila in the central Italian district of Abruzzo. Up to 10 000 buildings were damaged, 308 people were killed and 65 000 were left homeless.

Knowing the country's history (Figure 1), perhaps people should have been better prepared for the disasters of 2016. However, memories are often short where tragedy is concerned and the more recent 'quakes initially caught many people by surprise.

Date	Location	Magnitude	Deaths	Injuries	Damage level
30 October 2016	Umbria	6.6	2 (indirect)	28	Extensive
24 August 2016	Lazio, Umbria, Marche	6.2	299	>400	Extensive
6 April 2009	L'Aquila	6.3	308	>1500	Severe
13 December 1990	Sicily	5.6	19	20	Severe
23 November 1980	Campania, Basilicata	6.9	2500	7700	Extreme
15 January 1968	Western Sicily	5.5	400	1000	Sequence of earthquakes
13 January 1915	L'Aquila	6.7	32 000	Unknown	Extreme
28 December 1908	Strait of Messina	7.1	200 000	Unknown	Extreme/ Tsunami
11 January 1693	Sicily, Malta	7.4	60 000	Unknown	Unknown
4 January 1169	Sicily	Unknown	20 000	Unknown	Severe/ Tsunami

Figure 1 Ten historic Italian earthquakes
Sources: National Geophysical Data Center, NOAA and United States Geological Survey

Tectonic shift

Earthquakes are caused by the movement of the Earth's **tectonic** plates. These rub against each other along **fault lines** – the cracks in the Earth's crust where the plates meet. Friction between the plates as they move causes them to stick and this creates a build-up of pressure. When this pressure is released an earthquake occurs. These are measured on the **Richter Scale** and are scored on a **magnitude** of 1 to 10. Each whole number of magnitude measures 10 times stronger than the previous one – so an 8.0 'quake is 10 times stronger than a 7.0 'quake.

> "Earthquakes are caused by the movement of the Earth's tectonic plates."

Italy has a fault line running along the whole length of the country where the Eurasian and African tectonic plates meet. It is this fault line that is responsible for the creation of the Alps mountain range and also makes Italy one of the most seismically active countries in Europe. Several different tectonic movements are taking place at the same time, and this is why seismic activity in Italy is so unpredictable.

Italy has had its fair share of loss but the 'quakes of 2016 still came as a major shock to the country and caused significant loss of life, injury and economic damage.

24 August 2016

On 24 August 2016 at 3.36 am local time, a 6.2 magnitude earthquake occurred on a shallow fault line on a northwest–southeast fault in the Central Apennine mountain range in central

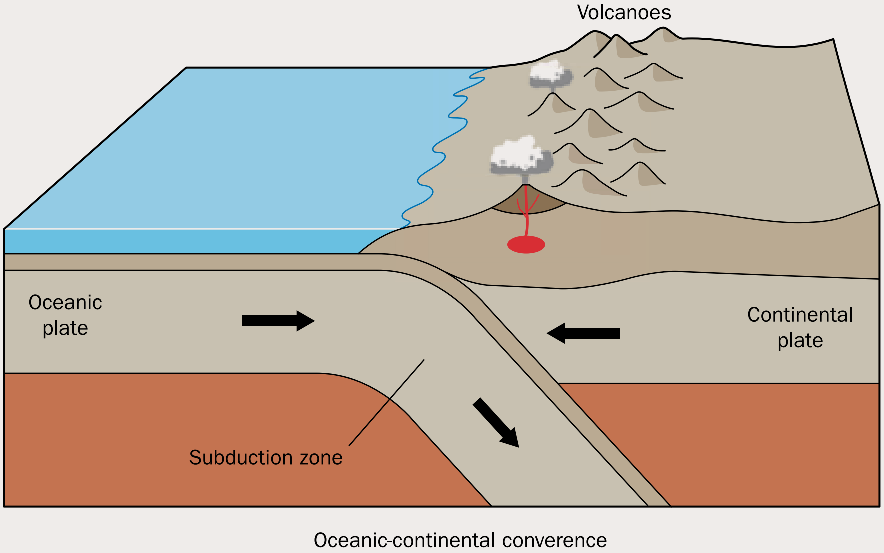


Figure 2 Activity at an earthquake subduction zone

Italy. The area is one of the most seismically active regions in Italy, formed as a result of the Adriatic plate being forced underneath the Eurasian plate (Figure 2) in a process known as subduction. The Eurasian plate is moving towards Africa at an average rate of 24 mm per year. The epicentre of the 'quake was relatively close to the surface at only around 4 km, approximately 75 km southeast of Perugia and 45 km north of L'Aquila in an area near to the borders of the Umbria, Lazio, Abruzzo and Marche regions (Figure 3).

Figure 3 Location of Italy's fault lines and the earthquakes of 2016

The earthquake caused widespread destruction in the town of Amatrice (Figure 4), located close to the epicentre. The local mayor stated in the aftermath that the town '…is not here anymore, half of the town is destroyed'. Other severely affected towns included Accumoli and Pescara del Tronto. Almost 300 people were killed across the region and at least 400 were injured. There were also estimated economic losses of up to £9 million. The monetary value, however, took little account of the widespread destruction of important cultural buildings.

In the days following the 'quake a massive rescue operation took place to search for survivors. However, attempts to find missing people were hampered by the hundreds of aftershocks that occurred for days following the event. By 30 August there were estimated to have been at least 2500 aftershocks including some approaching a magnitude of 5.0. These caused extra stress for people, and further damage.

Despite aid of £42 million promised by the Italian Prime Minister Matteo Renzi, there was considerable criticism following the disaster. Given the history of tectonic activity in the area, many people seemed unprepared. The media in particular were quick to point the blame at building regulations, or the lack of them, for some historic areas of Italy.

Figure 4 Destruction of the historic city of Amatrice, 24 August 2016
Source: Shutterstock/Antonio Nardelli

However, given the relative strength of the earthquake compared with that in August, the damage and loss of life was much less. To discover the reasons for this we have to look at both geological and social aspects of all of these events.

> "It may not just be poor countries that experience high levels of property damage."

30 October 2016

The press continued its criticism into the autumn when, once more, Italy was shaken by a further series of major 'quakes:

- At 7.11pm on 26 October a magnitude 5.5 earthquake struck 8 km southeast of Sellano at a depth of 10 km.
- Just over two hours later a magnitude 6.1 'quake hit 3 km west of Visso (only 30 km to the northwest of the epicentre of the August disaster).
- On 30 October a magnitude 6.6 'quake struck 6 km north of Norcia at a depth of 9.4 km (see Figure 3).

Despite the high magnitude of the final earthquake, only two deaths were recorded, and these were of elderly people who suffered heart attacks. There were around a dozen reported injuries and three people were pulled from the rubble by rescuers in the town of Tolentino. Damage to property and infrastructure was slightly more extensive (Figure 5). Main roads to the affected areas were closed and some were made impassable by large boulders falling from hillsides in the mountainous areas. There was considerable damage to property, with up to 100 000 residents being temporarily displaced.

Different events, different effects

The widespread damage was the subject of much discussion in the Italian press and media. Some blamed the poor construction and lack of building control in many of the country's historic towns. **Seismologist** Leonardo Seeber, who was born in Florence, said in the *Washington Post* newspaper

Figure 5 The church of San Benedetto destroyed in the Norcia earthquake
Source: Shutterstock/Paolo Bona

that 'Italy is an old country and the houses are made of stone', pointing out that such medieval buildings, in closely packed narrow streets, are more vulnerable to shaking and collapse. He outlined a similar magnitude earthquake in Virginia, USA which occurred in a remote area with mainly wooden buildings yet which caused much less damage than that experienced by the Italians. It is worth considering these differences when comparing earthquakes from different parts of the world: it may not just be poor countries that experience high levels of property damage.

However, while the destruction was on a similar scale in both the August and October 'quakes, we have to look beyond the construction of the buildings to discover why the loss of life was so much greater in the first event.

Time breeds complacency

The magnitude 6.6 earthquake in Norcia in October was significantly stronger than the 6.2 'quake recorded three months earlier. So why was the death toll in the first almost 300 people and, in the second, just two elderly people died, their deaths an indirect result of the event? According to Gianluca Valensise, from Italy's National Institute of **Geophysics** and Vulcanology, who was interviewed at the time of the disaster by the BBC, the answer is a mix of memory and fear. 'It is clear now that vulnerability greatly increases with the time that passes since the last earthquake. In Amatrice, the memory was lost. It had been long enough for people not to be concerned about earthquakes – and that brings trouble for the next one.' So while people who live in a hurricane zone or in the shadow of an active volcano, for example, are constantly living with the threat of an imminent crisis, those who live on seismic faults – where earthquakes are very difficult to predict – are quick to forget the threat that they pose.

> "Those who live on seismic faults ... are quick to forget the threat that they pose."

When the August earthquake struck, it was unexpected and people were caught unawares. Many were trapped inside their dangerous old homes and could not escape. By October, however, with the relentless news coverage of the previous few months, people were much more anxious. On 30 October residents had already experienced four more minor shocks, two of them in the previous week. Many had fled to relatives' homes, beds had been made available in hotels on the coast (which were empty at the end of the summer tourist season) and a large number had moved their families to sleep in their cars. Some of these people actually watched their own homes collapse from the safety of their cars, knowing they could have died if they had not moved.

An unpredictable business

The differences in the effects of the two Italian earthquakes – and comparisons with other events around the world – show just how unpredictable the world's tectonic activity can be. Geologists investigating the 'quakes have also stated that it may just be that they were very different in nature: at different depths and possibly involving a different pace of movement between the different plates involved. Larger events can cause less shaking and less damage. It is clear, though, that much more research needs to be done in order to predict earthquakes and to protect people from the destruction that they can cause.

Activities

1 For *one* of the Italian earthquakes of 2016 mentioned in the text, answer the following questions:

a When did the earthquake take place?

b Where was the location of the epicentre of the earthquake?

c What magnitude was the earthquake?

2 Write out the following paragraph, filling in the blanks.

Earthquakes are caused by the movement of ___________ plates. They are measured using the ___________ Scale and scored according to their ___________. In August 2016 a 'quake with a magnitude of ___________ hit central Italy with its ___________ 45 km north of L'Aquila. This was followed in October by a magnitude ___________ earthquake near ___________. Both earthquakes caused major property damage but only the event in ___________ caused severe loss of life.

3 Using Figure 3 and an atlas, draw a sketch map of central Italy. Include details of the major towns and cities, the epicentres of the two major earthquakes of 2016 and the fault lines that run across the country. You should annotate your map with details of the deaths, injuries and damage which each of the earthquakes caused.

4 Use the information in Figure 6.

a Leaving out the Haiti and China 2008 earthquakes, draw a scattergraph of earthquake magnitude against the number of deaths.

b Can you see any patterns in your graph?

Location (year)	Magnitude	Deaths
Nepal (2015)	7.8	8000
China (2014)	6.2	700
Pakistan (2013)	7.7	825
Japan (2011)	9.0	16 000
Chile (2010)	8.8	700
Haiti (2010)	7.0	316 000
Indonesia (2009)	7.5	1100
China (2008)	7.9	90 000
Peru (2007)	8.0	500
Indonesia (2006)	6.3	5700

Figure 6 The ten most recent major earthquakes around the world

5 ICT exercise

Use the internet to research designs for earthquake-proof housing. Look for different examples from around the world, from both rich and poor countries.

Now, either using computer-aided design software or your own imagination and pencil and paper, come up with your own design for a house that would withstand an earthquake in your own home town.

Learning checkpoint

- Italy is one of the most tectonically active countries in Europe.
- Earthquakes are caused by sudden movements between the Earth's tectonic plates.
- After several years with no major disasters, 2016 was a year in which Italy suffered two major 'quakes in a period of only three months.
- Similar earthquakes have different effects due to a mix of both human and physical geographical factors.

Glossary task

Write glossary definitions for these terms:

earthquake	**Richter Scale**
fault line	**seismic**
geophysics	**seismologist**
magnitude	**tectonic**

Remember this case study

To help you remember this case study, make notes under the following headings:

The location of the earthquakes and their causes

The social, economic and environmental effects of the two earthquakes

The response of emergency services and others

The reasons for the different effects between the two events

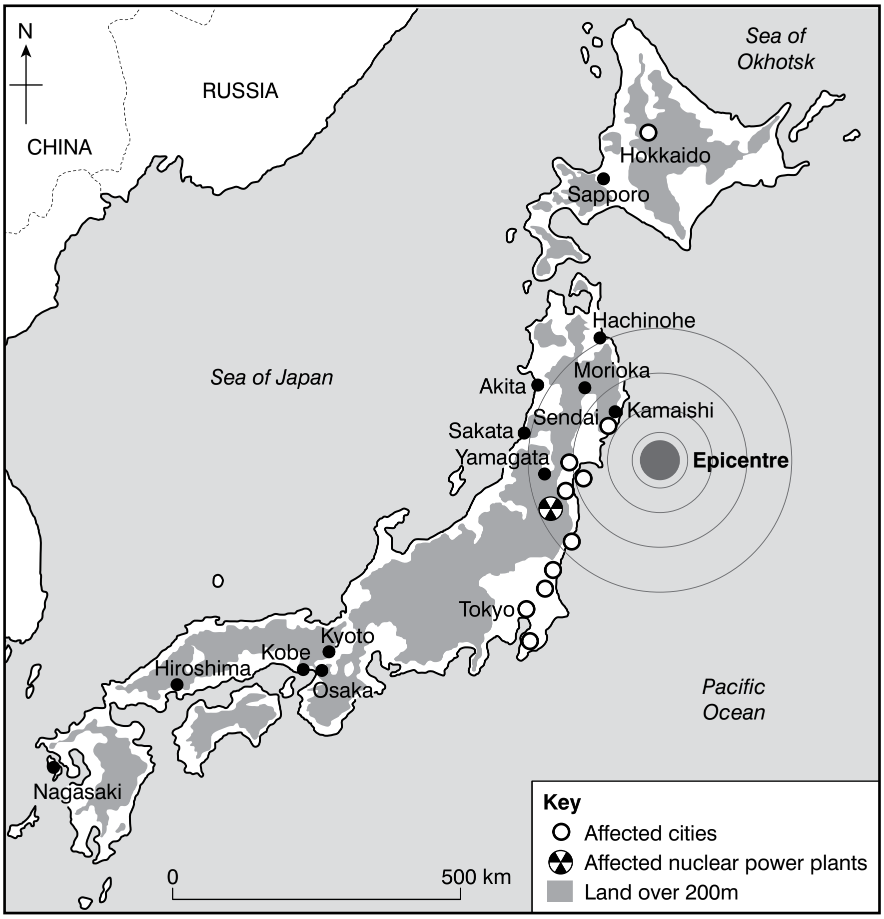
Try to make your notes fit a single sheet of A4. Remember to include specific facts and figures.

Geofile Online
JANUARY 2012
654

Alison Rae

Japan 2011: Earthquake, Tsunami, Nuclear Crisis ...

Figure 2: The earthquake epicentre, showing the affected cities

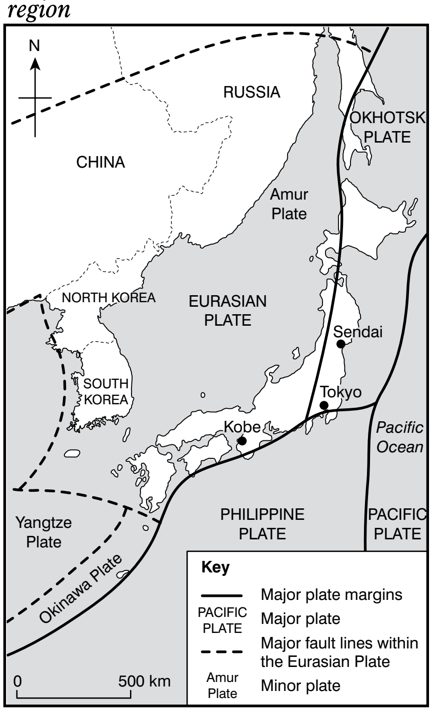


The series of hazardous events that hit Japan in March 2011 involved a set of complex and interrelated factors, some physical and some of human origin. The result was perhaps the worst disaster to befall Japan since the Second World War.

The seabed off the eastern coast of Japan is a highly seismologically active section of the earth's crust (Figure 1). The Eurasian, Pacific and Philippine plates meet here, making it an extremely complex boundary. Japan experiences 20% of the world's earthquakes of Richter Scale magnitude 6 or greater. On average, an earthquake – usually of low intensity – occurs every five minutes. Local people expect a larger tectonic event on average every 40 years, but the sheer scale of last March's earthquake shocked the population and emergency services.

Japan is located on the eastern edge of the Eurasian plate, adjacent to the huge, very solid Pacific plate. The Pacific plate is moving westwards, towards the Eurasian. As the denser of the two, the Pacific plate dips beneath Japan, rather like an escalator. The rate of movement is 7.6–10.2 cm per year. The situation is complicated by two things. First, there are two other plates in the equation: the Okhotsk to the north and the Philippine to the south; secondly the make-up of the eastern part of the Eurasian plate is complex in itself, as it includes several large fault lines. Some geologists see these as true plate margins (Figure 1).

Figure 1: Plate boundaries in the Japan region



Wednesday 9 March 2011 saw a 7.2 (Richter Scale) earthquake on this plate boundary. This level of event is not unusual, but, on this occasion, the knock-on effects were particularly serious, as the push of the Pacific plate as it went under Japan put extra strain on an area of existing pressure build-up along the margin. This led directly to a 480-km stretch of the Pacific plate breaking free and surging underneath Japan. At the same time, the Eurasian plate (on which Japan is situated) shifted 2.4m eastwards and was simultaneously lifted upwards by over 9m. The consequence was the 9.0 (Richter Scale) Tohoku earthquake on 11 March, rated as the fifth most powerful ever recorded globally (Figure 2). People do not always perceive the massive variations in the strength of Richter scale readings. Each point on the scale has 10 times the energy of the point below. Therefore, this second earthquake released around 1000 times the energy of the event along the margin two days previously, equivalent to around 600 of the Hiroshima atomic bombs dropped at the end of World War II. This would have been an epic disaster on its own, but then the tsunami hit!

The tsunami event

Japan experiences more tsunamis than any other country. The word means 'harbour wave', and has been adopted worldwide for such events. Several factors determine the height and therefore the destructiveness of a tsunami:

- the scale of the earthquake
- the volume of displaced water
- the topography of the sea floor
- whether there are any natural obstacles that dampen the shock and absorb some of the energy.

Ultimately, the tsunami was concentrated on a limited stretch of coastline around Sendai.

Since the epicentre was located under the ocean floor, all the water above this point was suddenly pushed up vertically, and therefore surged away in all directions at a speed of 800 kph (500 mph), the speed of a jet aircraft, across the Pacific in all directions. It took a mere 10 minutes for the wall of water to reach the coast of Japan. The speed and height of a tsunami wave are determined by the depth of the ocean. The shallower the water, the slower but higher is the wave. Where, as in this part of Japan, the offshore area is particularly shallow, friction between the moving water and the seabed slows down the lower part of the wave. The following water is then held back, so a sort of 'traffic jam' of water develops, causing the tsunami wave to build up higher and higher; in this case it was believed to have reached 40m in some places, completely overwhelming for people and for both natural and built environments. Whole settlements on the coast were simply erased in a few moments, as water flowed 10km inland. Sendai airport was rendered unusable within minutes, limiting future aid accessibility (Figure 3).

Source 1: Japan's disaster in figures – the impacts of the tsunami and subsequent crisis at the Fukushima nuclear power plant

- Japan's National Police Agency confirmed 15,676 deaths, 5,712 injured, and 4,832 missing.
- Victims aged 60 or older accounted for 65.2% of the deaths; 24% of victims were in their 70s.
- 45,700 buildings destroyed and 144,300 damaged. 300 hospitals damaged, with 11 completely destroyed. An estimated 24–25 million tons of rubble and debris.
- Around 1.5 million households without water supplies and 4.4 million without electricity.
- People within a 20-km zone around the Fukushima nuclear plant ordered to leave, those living between 20 km and 30 km from the site requested to stay indoors and subject to voluntary evacuation: >200,000 evacuated.

Evacuation and coping strategies

Finding those who needed rescuing was an extremely difficult challenge. Landline telephone connections were immediately lost at the point of the earthquake jolt, which also disabled most mobile phone masts. Electricity was also cut off, so those mobile phones which could get a signal soon had spent batteries. When homes and other buildings collapsed, people on the upper floors fared better, but often their only way out was to be rescued through the roof. An extensive area of north-eastern Japan was affected and there were simply not enough emergency workers to cope. Local police were usually the first on hand, but rarely had access to large equipment.

The frustrations of the rescuers

The chaos of the early hours and days of the rescue process are well illustrated by the reports directly from the rescuers themselves. They had come from the south of the country, Nagasaki and other cities, to find there were very few supplies of any kind for them to work with. Instead of administering medicines they were reduced to trying to ensure people washed their hands as often as possible to prevent colitis, enteritis and diarrhoea. The risk of flu passing between the elderly and weak was huge.

Within 10 days of the earthquake, an estimated 452,000 people were living in evacuation facilities, most of which were inadequate, leading to huge numbers suffering from hypothermia. Accommodation for those who had lost their homes was largely in schools and other public buildings, whose heating and other services were cut off. Often damp from floodwater, people had to cope with the bitter cold with a few blankets if they were lucky. In one residential home alone, 11 elderly people had died of this within a few days due to night-time temperatures as low as -4ºC. Dampness made the impact of the cold much worse. Bronchitis, pneumonia (both of which require antibiotics) and asthma (which needs sprays and other equipment) made the lives of hundreds even more difficult. Many chronically ill people, such as those with diabetes, could not get the medicines they needed. Even amongst the fitter of the population, hardly anyone directly affected by either the earthquake or the tsunami got away without broken bones, cuts or bruises.

The likelihood of epidemics breaking out, especially amongst the most vulnerable groups (the elderly, children and those already suffering from illness or infirmity) was high. Doctors and hospitals did all they could to care for those who required

Figure 3: Sendai airport, two days after the tsunami

Source: Wikimedia Commons

it, but they were short of medicines and personnel. Even emergency workers brought in from elsewhere in Japan were not always able to help as much as many people expected.

Cases of enteritis, colitis, diarrhoea and vomiting grew rapidly. Any epidemic would be most dangerous to the elderly survivors, already vulnerable by dint of age, and much affected by the experience of the disaster.

Damage to roads, railways and airports severely impeded transport following the disaster. For quite some time it was very difficult, even with military help, to deliver medicines and food to the affected area. Homeless survivors of the tsunami, temporarily housed in hospitals and schools, were given only very meagre supplies of rice and tea for some time. In some cases, they were driven to scavenge in the wreckage of their townships, picking among debris for provisions that had been swept away from shops by the tsunami, taking a chance that it was not contaminated – behaviour that would normally have been unthinkable and shameful. Shame plays an important role in Japanese society. Natural disasters strip away the dignity of both the living and the dead, but in a country as polite and formal as Japan this is particularly poignant.

In the town of Ichinomaki one supermarket remained open, but the queue was 2 to 3 hours long, people were allowed only 10 items or fewer, and they had to pay in cash. Most people had lost their cash and debit/credit cards when they lost their home.

Japanese pride

People were scavenging in the streets to try to find food for their families. They took what seemed like waste food from devastated supermarkets even though there were health risks from thawed frozen and out of date products. People found themselves without money, food and other resources, and their homes had been washed away and the cash machines were out of order. You too would probably have done the same as them in equivalent circumstances.

The extra difficulty for the Japanese in this awful situation was their culture of pride. Your reputation in society is very important to the Japanese. Just to be caught taking food or other crucial resources could blacken your name and diminish your family. Yet, even in an MEDC like Japan, many people had to become looters to stay fed, even at a limited level. Even those lucky enough to be in rescue centres were not necessarily fed enough in terms of quantity, calories or nutrition. People felt genuine shame at what they were doing and, whilst some did speak to foreign press, they refused to give their names or to have their photographs taken.

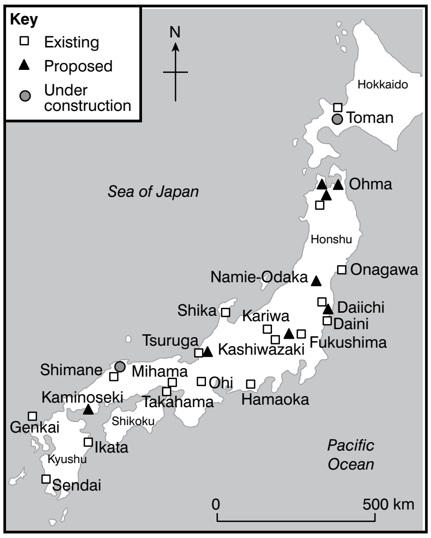
The local authorities found themselves under massive strain. The rules on burial procedures had to be relaxed to permit the burial of bodies without prior cremation, not the normal ritual in Japan, but essential on health grounds. Emergency workers coming to the affected north-eastern part of the country had insufficient knowledge of the situation, inadequate equipment and basic supplies like food, clean water and medicines. Whilst many roads in the north-east region were devastated, quite a few remained open, but only emergency vehicles were allowed to use the roads, so preventing food supplies, fuel and other aid from being driven from Tokyo. Finding petrol and diesel became impossible; people siphoned it from vehicles damaged in the tsunami and tried to find lost bicycles in the piles of wreckage. People struggled to find missing friends and relatives in any way they could (Figure 4).

Nevertheless, many people refuse to criticize the local or national authorities, realizing that the sheer scale of the destruction had made delivering aid a truly mammoth task.

The nuclear power station crisis

'Japan hails the heroic "Fukushima 50",' read a headline from Japanese newspapers, referring to the 50 volunteer nuclear power station and other engineering workers who remained within the stricken Fukushima site (Figure 4) battling to cool down the system and avert widespread radioactive leakage. They were likely to have been exposed to doses of radiation 12 times the legal limit in the UK, which in the short term should

Figure 4: Nuclear power plants in Japan



cause little harm. In the longer term, however, there is an increased likelihood of cancer.

Nevertheless, the Fukushima Daiichi nuclear plant disaster brought on by tsunami damage was one of the most serious civil nuclear accidents to date. Key safety systems failed, causing serial explosions and increasing releases of radiation. Four of the plant's six reactors were in trouble; higher than normal radiation levels were registered as far away as Tokyo (220km) but were not considered serious. Caesium and iodine isotopes have been found near the plant, and water and crops were prevented from entering the food chain. Local people (within 20km of the plant) were evacuated, and others left of their own accord. Compared with Chernobyl's disaster in 1986 (Ukraine), only 10% as much radiation was released.

It was not until November 2011 that reporters were allowed inside the Fukushima nuclear power plant. Fully protective clothing was essential. Requests for such visits had previously been refused on the grounds that radiation levels were simply too high and that the presence of visitors might limit the progress of the clearing up operation. The intention of allowing a tour at this stage was to show that the plant is indeed becoming more stable. Visitor reaction was mixed and you would expect journalists to be naturally suspicious. There were reports that some badly damaged buildings and piles of rubble had

Source 2: The Japan Tsunami Appeal

- The Japanese Red Cross opened its appeal for aid funds within hours of the disaster taking place. British people could donate via the British Red Cross. The aims were:
- First aid and emergency healthcare
- Distributing relief items
- Fitting out 70,000 temporary prefabricated homes with key appliances and domestic items (rice cookers, microwaves, kettles, etc. for 280,000 people in the hardest hit prefectures of Miyage, Fukushima and Iwate.

not yet been cleared, nor had all the damaged vehicles.

A report published in the Proceedings of the National Academy of Sciences in November 2011 stated that radioactivity levels across much of the North Eastern region of Japan remained higher than that considered safe for farming, despite the fact that earlier testing had showed that harvested crops contained levels of radiation well below the safety limit for human consumption. The source of the radiation was the radioactive isotopes (in particular caesium) that were blown across this area and offshore when the Fukushima plant melted down. Waves continued to wash some of this radiation back onshore in the east over the following months and scientists are uncertain as to how long this might continue. The western coastal plain region measures safe levels; it was largely protected from the worst of the radioactive fallout by the intervening mountain ranges.

The Japanese will continue to monitor this problem thoroughly. Whilst it seems certain that the Fukushima region remains contaminated, detailed checks need to be carried out in the neighbouring prefectures of Iwate, Miyagi, Ibaraki, Chiba, Yamagata and Niigata. Rice exports from this region to the rest of Japan have been banned, though some may have been consumed locally. Scares over radiation levels in green tea, mushrooms and beef have occurred.

Only time will tell the true consequences of this event.

All other nuclear plants will be strength-tested for tectonic movement. Moreover, the Japanese authorities have been made to think about the country's future energy mix. Current policy is to increase from 30% of power being nuclear-generated to 50%, but now the likely future trend is away from nuclear, perhaps even to go nuclear-free in such an active tectonic zone. Strategies for energy conservation and development of renewables will grow. There is even a plan to construct a 400-km wide belt of solar panels around the moon's equator, and beam the energy back to Japan using laser-guided microwaves.

The current Japanese tectonic situation

Japan is used to earthquakes. In March 2011 the greater crisis was the tsunami and, in particular, the proximity of the epicentre to the Japanese coastline. Japan has experienced earthquakes and their consequences throughout recorded history (and, clearly, before). It will continue to do so, due to the highly active tectonic nature of the region, on a quadruple tectonic junction. The area of greatest concern is currently Tokyo, sitting right on top of a triple junction and with over 20 million people in the city. The last earthquake to hit Tokyo (in 1923) killed 142,000 people in what was then a much less populous zone. Moreover, geologists and seismologists believe this area to be overdue for an earthquake. Pressure is building up underground. Just as the magnitude 7 earthquake of 9.3.11 increased the strain under the plates, leading to the magnitude 9 event two days later, so the level 9 'quake could have built up extra pressure under Tokyo.

Conclusion

When studying hazards and their impacts on countries at varying levels of economic development, we tend to make the assumption that LEDCs are affected much more than MEDCs. This is largely true. The 1989 Loma Prieta earthquake in California (around 7 on the Richter Scale) killed only 62 people and damaged relatively few buildings seriously. Yet the cleaning-up operation after the 1995 Kobe earthquake is still not complete and there are people suffering financial losses from which they can never recover, due largely to their lack of insurance. The Sendai earthquake event, along with its tsunami, was even more devastating than Kobe. Not every building, even in an MEDC, can be earthquake-proof, and no technology to date can protect against such a severe tsunami. Neither can the wealthiest and most organized governments cope with all that is required on such a short timescale: 'I thought we were a wealthy country, but now I don't know what to think', was a typical Japanese citizen's reaction. The Japanese refused much external aid that was offered, though some was accepted (Source 2).

Focus Questions

Using Figure 1:
(a) Describe the pattern of plate margins in the Japan region.
(b) Explain why the region is so hazard-prone. (Hint: remember there are human factors as well as the more obvious physical ones.)

2. Using Figure 2:
(a) Briefly describe the settlement pattern in Japan and explain the pattern you have identified in terms of the physical landscape. (The map has enough information on it to allow you to do this.)
(b) Explain why Sendai was particularly badly affected. Use map evidence to support your points.

3. Essay: Discuss the extent to which the Japanese people both help and hinder themselves in hazard prevention and in coping after a disaster such as the Sendai event of March 2011. (You should include references to other relevant tectonic events such as Kobe (1995) and to volcano/earthquake precaution methods and warning systems.)

Geography AS
Unit 1 – Dynamic Landscapes
Topic 1 – Tectonic Processes and Hazards
Summer Work (Mr Lever)

Unit 1 Dynamic Landscapes

1) **Tectonic Processes and Hazards** – This unit looks at natural hazards (their frequency, distribution and trends), and how to manage them.
2) **Coastal Landscapes and Change** – This unit looks at coastal processes, landforms and landscapes, coastal risk and how to manage them.

Task 1

On the following pages, use websites and your own research to draw and explain the different plate boundaries.

http://www.alevelgeography.com/

https://www.s-cool.co.uk/a-level/geography

https://pmt.physicsandmathstutor.com/download/Geography/A-level/Notes/Edexcel/1-Tectonic-Processes-and-Hazards/Essential%20Notes%20-%20Tectonics%20-%20Edexcel%20Geography%20A-level.pdf

Divergent (Constructive) Plate Boundary

……

……

……

……

……

……

……

……

……

……

……

Convergent (Destructive) Plate Boundary

………

………

………

………

………

………

………

………

………

………

………

Conservative Plate Boundary

………

………

………

………

………

………

………

………

………

………

………

Task 2

Research the following primary hazards created by a volcano. Complete the table below using the various website links below and your own research.

http://www.alevelgeography.com/type-and-frequency-of-volcanic-activity/

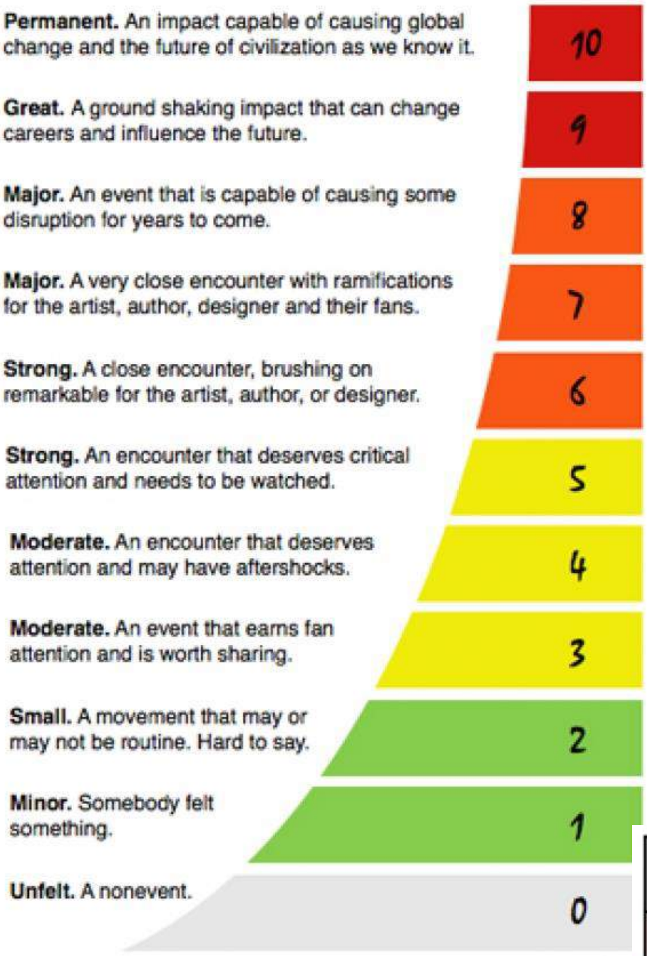
https://s-cool.co.uk/a-level/geography/natural-hazards/revise-it/volcanic-hazards

Volcanic Hazard	**What are they?**	**Impacts**	**Picture**
Pyroclastic Flow			
Tephra			
Lava Flows			
Volcanic Gases			
Lahars			
Jökulhlaups			

Task 3

There are several different tools and techniques used to measure the magnitude and intensity of tectonic hazards.

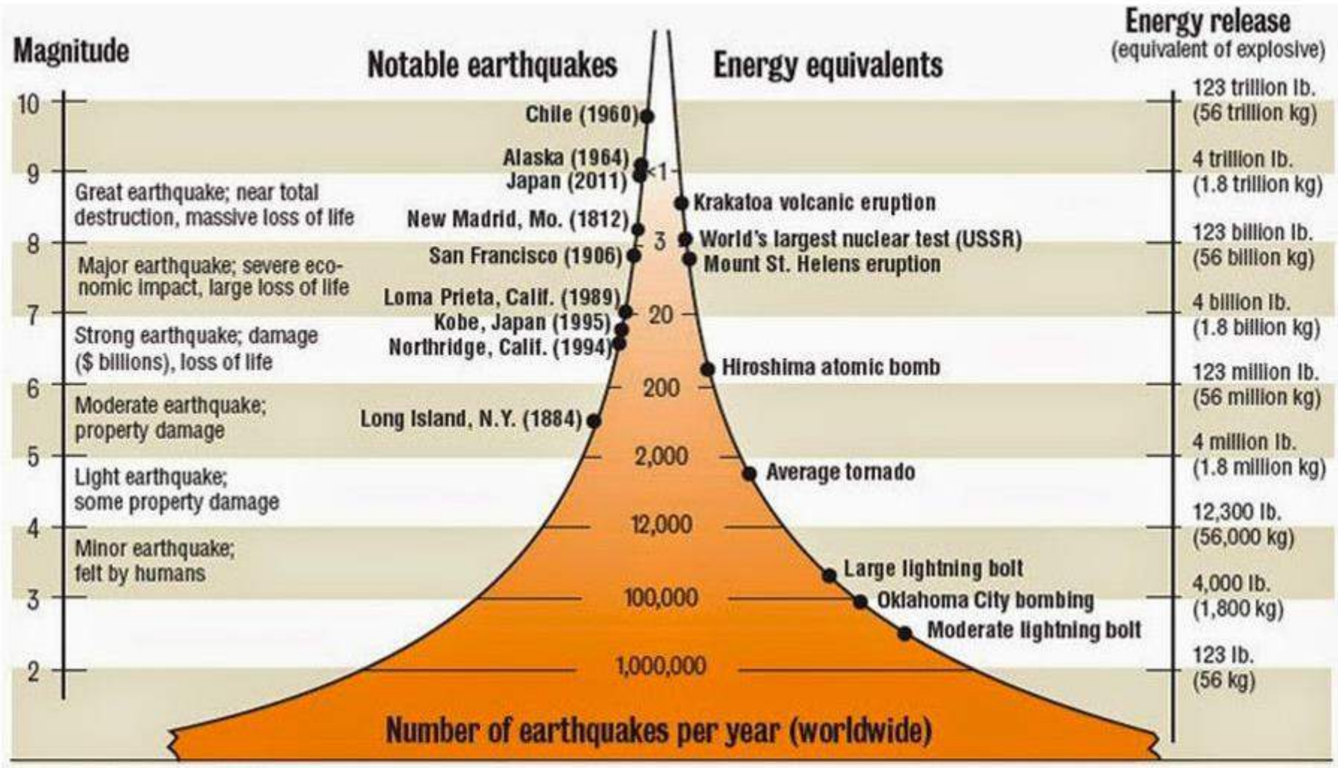
Below are different methods to measure both earthquakes and volcanic eruptions.



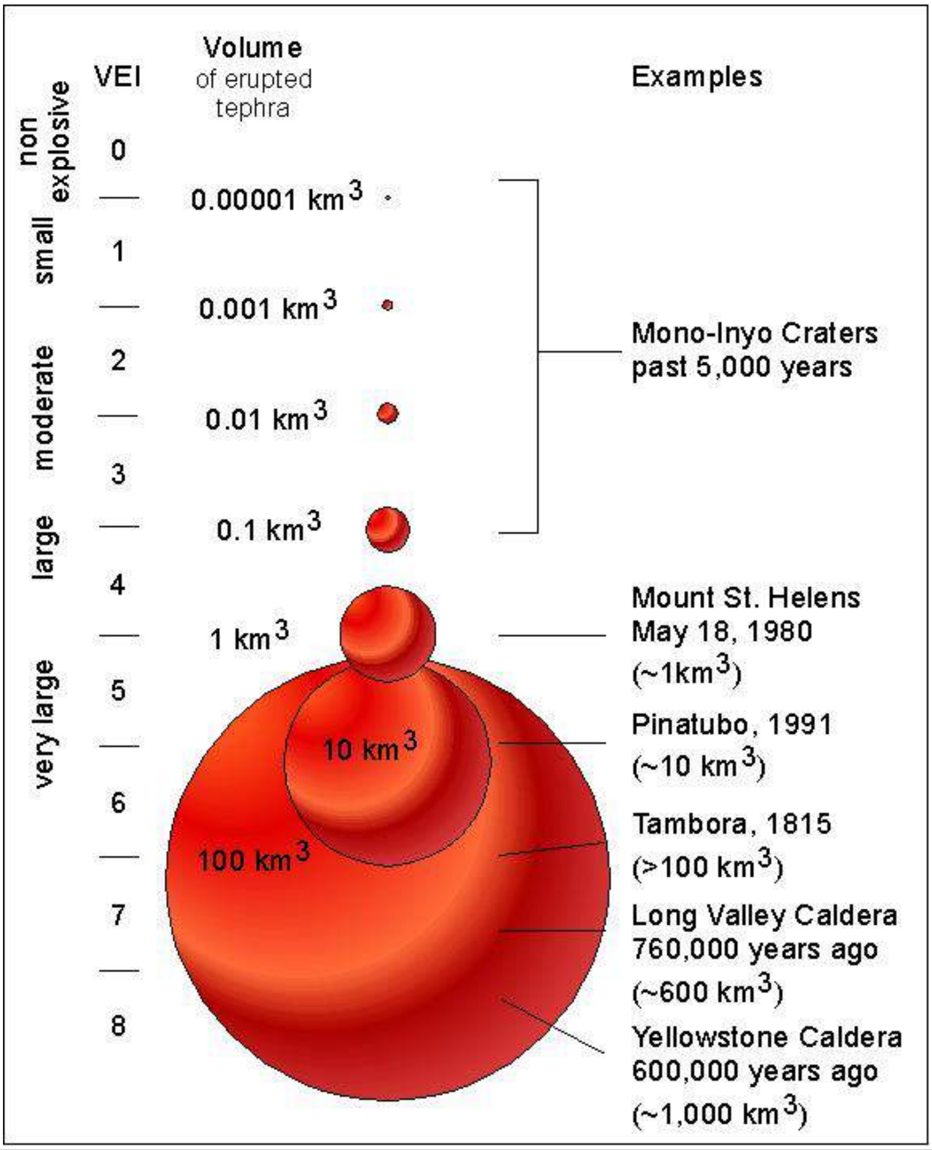
Richter Scale – Used to measure the height of waves produced by an earthquake.

Mercalli Scale – Used to measure the experienced impacts of an earthquake, based on people's experience and responses.

I. Instrumental	Not felt by many people unless in favourable conditions.
II. Weak	Felt only by a few people at best, especially on the upper floors of buildings. Delicately suspended objects may swing.
III. Slight	Felt quite noticeably by people indoors, especially on the upper floors of buildings. Many to do not recognise it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
IV. Moderate	Felt indoors by many people, outdoors by a few people during the day. At night, some awakened.
V. Rather Strong	Felt outside by most, may not be felt by some people in non-favourable conditions. Dishes and windows may break and large bells will ring. Vibrations like train passing close to house.
VI. Strong	Felt by all; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight.
VII. Very Strong	Difficult to stand; furniture broken; damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by people driving motor cars.
VIII. Destructive	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture moved.
IX. Violent	General panic; damage considerable in poorly designed structures, well designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X. Intense	Some well build wooden structures destroyed; most masonry and frame structures destroyed with foundation. Rails bent.
XI. Extreme	Few, if any masonry structures remain standing. Bridges destroyed. Rails bent greatly.
XII. Cataclysmic	Total destruction – everything is destroyed. Lines of sight and level distorted. Objects thrown into the air. The ground moves in waves or ripples. Large amounts of rock move position. Landscape altered, or leveled by several meters. In some cases, even the routes of rivers are changed.



Moment Magnitude Scale – Used by seismologists to scribe earthquakes in terms of energy released.



Volcanic Explosivity Index – Used to measure explosiveness of a volcanic eruption, which is calculated from the volume of products ejected.

Complete the table below, giving the advantages and disadvantages of each means of measuring tectonic hazards. Use the information above and your own research to complete the table, include at least 2 points for each scale, then rank them in order of effectiveness.

Scale for different tectonic hazard	**Advantages**	**Disadvantages**	**Rank (1-4) in terms of effectiveness.**
Richter Scale			
Mercalli Scale			
Moment Magnitude Scale			
Volcanic Explosivity Index			

Further Readings

Geofile 477 – Geological Slant on Plates

Geofile 654 – Japan 2011: Earthquake, Tsunami, Nuclear Crisis …

Geofile 694 – Living on a plate margin: Economic opportunities and reducing risk

Geofile 781 – The Chlapas earthquake, Mexico 2017

GeoActive 572 – The Italian earthquakes of 2016

Research/google the above readings and make notes below:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

Geofile Online
SEPTEMBER 2013
694
Jane Dove

Living on a plate margin: economic opportunities and reducing risk

Mount Merapi in Indonesia is one of the most dangerous volcanoes in the world. Periodic eruptions cause devastating pyroclastic flows and lahars, yet thousands of people live on its slopes. This article explores the sometimes literally fatal attraction between people and active plate margins. Following a brief consideration of the main tectonic hazards associated with plate margins and why people live there, this **Geofile** examines how hazardous environments are utilised to make a living and the strategies employed to limit the risks posed by volcanoes and earthquakes.

A dangerous place to live

Plate margins are inherently dangerous places to live. Natural hazards posing potentially the greatest threats to life and property include:

- **pyroclastic flows**, i.e. hot mixtures of gas, pumice, ash and hot lava which move rapidly downslope, killing all in their path
- **lahars**, or volcanic mudflows, which bury settlements and cause extensive flooding
- powerful **earthquakes** which cause buildings to collapse and trigger landslides
- **tsunamis**, generated by earthquakes and occasionally volcanic eruptions, which flood coastal settlements.

Heavy ash-fall also:

- prevents use of airspace, runways, roads and railways
- leads to crop failure where ash falls on leaves preventing photosynthesis
- contaminates pasture, making it unpalatable to livestock
- corrodes machinery
- causes respiratory illness.

Crops are also damaged by acid rain when sulphur dioxide, which is emitted during eruptions, mixes with rainwater.

Several world cities are located near active faults and volcanoes (Figure 1). Seattle, for example, on the US Pacific North West coast is close to Mount Rainier, a volcano which, if it erupted, would produce dangerous lahars. Cities near destructive margins i.e. those where plates collide, face the greatest risk because these locations produce powerful earthquakes and highly explosive types of volcanic eruptions. Movement along conservative margins those where plates move laterally past each other with no subduction, can also produce strong earthquakes. Constructive margins i.e. those where plates diverge, also generate earthquakes and volcanic eruptions, but these tend to be less powerful than those produced at other types of margin.

Figure 1: Examples of world cities near plate margins at risk from tectonic hazards

City	Tectonic hazards	Type of margin
Seattle	Rainier volcano/earthquakes	destructive
San Francisco	San Andreas fault earthquakes	conservative
Mexico City	Popocatépetl volcano/earthquakes	destructive
Guatemala City	Pacaya volcano/earthquakes	destructive
Managua	Masaya volcano/earthquakes	destructive
Quito	Guagua Pichincha volcano/earthquakes	destructive
Arequipa	El Misti volcano/earthquakes	destructive
Yogyakarta	Merapi volcano/earthquakes	destructive
Kagoshima	Sakurajima volcano/earthquakes	destructive
Shimabara	Unzen volcano/earthquakes	destructive
Tokyo	Earthquakes	destructive
Istanbul	North Anatolia fault - earthquakes	conservative
Tehran	earthquakes	collision zone
Naples	Vesuvius volcano	collision zone

Why people live on plate margins

Despite the risks, people often live near dangerous volcanoes such as Mount Merapi because ash weathers to produce fertile soils. Coastal areas are prone to tsunamis, but nevertheless offer fishing and trading opportunities. A detailed discussion of the ways people utilise hazardous environments on plate margins is set out later.

Many people live on plate margins through necessity, rather than choice. This is especially so where land is scarce and the population is rising. Some people are also unaware of the dangers, believing, for example, that deeply-weathered volcanoes covered by lush vegetation in the tropics pose no threat. Moreover, many without any past experience of a volcanic eruption or earthquake, are unlikely to comprehend the devastation such events might cause. Yet others may be in denial, or believe that a past event was a one-off event, not to be repeated.

People choosing to live on plate margins are likely to have weighed up the risks of a disaster occurring. Risk assessments calculate the probability that a particular hazard will occur, multiplied by the number of people affected and damage caused, less the mitigation measures taken to reduce the impact. Such objective assessments, however, ignore personal perceptions of risk.

Utilising volcanic resources on plate margins

Economic opportunities generated by volcanic and geothermal activity include agriculture, tourism, geothermal energy production and mining.

Agriculture

Volcanic soils cover 1% of the earth's surface, but support 10% of the world's population. Soils derived from volcanic ash and other volcanic ejecta are called andisols. They are characteristically light and fluffy


Figure 2: Crater Lake, Oregon

Source: Jane Dove


Figure 3: Mount Rainier, Cascades Mountains

Source: Jane Dove

and contain volcanic glass and clay minerals such as allophane.

Crops grow well because the soils have large pores which facilitate root development and drainage, as well as small pores which retain water for plant use. Additionally allophane forms strong bonds with organic matter which encourages humus to accumulate on the surface. Furthermore the soils are relatively young which means there has been little time for nutrients to have been lost through leaching.

Volcanic soils support rice cultivation in Japan, Indonesia and Philippines, coffee plantations in Central and South America and sugar cane and tropical fruit production in the Caribbean. Orchards and vineyards in temperate climates, such as those in Oregon, also thrive on volcanic soils.

Tourism

Volcanic and geothermal areas have long attracted visitors, but in recent decades tourism has increased. Mount Fuji, for example, is climbed by 300,000 people a year. Volcanoes of course are not exclusive to plate margins; many instead occur over hot spots e.g. Hawaii, and as such are beyond the scope of this **Geofile**.

Improvements in air travel have turned once inaccessible volcanoes, such as Yasur in Vanuatu, into tourist attractions. Cruise ships also now offer excursions, during ports of call, to nearby volcanoes such as Masaya in Nicaragua. Climbing a volcano has also become easier, for example a paved road leads to the crater rim of Poás in Costa Rica and gondolas carry visitors to the summit of Mount Usu in Japan.

The global reporting of eruptions, as they happen, has also increased visitation, particularly since the eruption of Mount St Helens in the USA in 1980. Designation as a Geopark, or World Heritage Site (WHS) has also raised the profile of volcanic attractions. Jeju Island in South Korea for example, famed for its lava tubes, experienced a significant increase in tourism after its designation as a WHS in 2007.

Marketing has also increased visitation. Packages often combine a visit to a volcano with other attractions such skiing on Mount Ruapehu in New Zealand, or bathing in hot springs in Japan. Some specialised adventure tourism companies offer opportunities to hike in remote areas where volcanoes are erupting, or to ‘sand-board’ down cinder cones as on Cerro Negro in Nicaragua.

Landscapes created by past volcanic activity, such as Crater Lake in Oregon, also attract visitors (Figure 2). Mountain areas, which often incorporate active and dormant volcanoes, are also important tourist attractions in their own right such as the Cascades in the USA (Figure 3). The mountains themselves have been created by past tectonic activity at destructive margins.

Geysers, hot springs, mud pools and fumaroles are tourist attractions in locations such as New Zealand, Iceland and Chile. Those on North Island, New Zealand are located in the Taupo Volcanic Zone within a back arc basin, an area of crustal extension developed behind a volcanic arc on the landward side of a subducting margin. The geysers in Iceland are the product of a constructive margin and a tectonic hot spot.

Settlements buried by ash during eruptions and later excavated are another type of volcano-related tourist attraction. Pompeii and Herculaneum are the best known examples, but they are not unique. The Meso-American village of Joya de Cerén in El Salvador and the Datei houses buried by Eldfell ash in 1973 (Heimaey, Iceland) also have considerable tourist potential.

Managing the sustainable development of tourism in volcanic areas poses challenges. Eruptions often draw large crowds, placing pressure on accommodation and infrastructure. Excluding tourists on the grounds of safety from erupting volcanoes would result in loss of income. Rebuilding tourist facilities after eruptions can be very expensive. The Spirit Lake Memorial Highway, for example, constructed after Mount St Helens erupted in 1980, cost $165 million.

Popular locations, such as the rim drive around Crater Lake in Oregon, can become very crowded in summer. Interpretative trails, such as those near Mount St Helens, often suffer from trampling pressure. Tourists sometimes damage volcanic features, by, for example, throwing things into geysers, or removing lava stalagmites as souvenirs. Managing safety in active volcanic areas as mass tourism increases is a growing concern, particularly where visitors ignore warning signs or stray into prohibited areas.

Geothermal energy

Heat and hot water extracted from geyser basins provides energy for electricity production. Hot water is also used for heating homes and commercial buildings. New Zealand is a world leader in geothermal energy production. Iceland derives 55% of its electricity from geothermal sources, based on its location on a constructive plate boundary and on a tectonic hot spot. In Chile the El Tatio geothermal area has considerable potential, but transporting electricity over long distances remains a problem.

Developing geothermal energy is an attractive option as fossil fuels decline and concerns about global warming grow. It does, however, have disadvantages in that removal of, or alterations to, groundwater in circulation causes geysers to decline or stop erupting. This, in turn, has led to conflicts between the tourism and geothermal energy production in New Zealand and Iceland.

Minerals

Volcanic rocks have a wide variety of economic uses, for example pumice is used as an abrasive and cinder for road construction. In Arequipa, Peru, the volcanic rock, 'sillar', a type of ignimbrite or lithified pyroclastic flow, is used as building stone.

Rich veins of copper, zinc, silver and gold are mined in volcanic areas. They form where hot liquids concentrate trace elements in magmas, or in the surrounding rocks, which are later re-deposited as rich mineral veins. The world's largest reserves of copper are mined in Chile, while large gold deposits are extracted from the Grasberg Mine in Indonesia. The Grasberg Mine employs many workers, but there are concerns that profits from the mine are not benefiting local people and that mine tailings are contaminating water supplies, and many of the profits go outside the area.

Sulphur, precipitated around volcanic vents, is mined, for example, at Ijen volcano in Java, Indonesia. Here workers are exposed daily to high concentrations of volcanic gases. The sulphur is mined to bleach sugar, vulcanise rubber and make matches and fertiliser. Former mines, such as those on White Island in New Zealand, have become tourist attractions.

Mineral deposits currently forming on the sea-floor at mid-ocean ridges and in back-arc basins may one day become economically viable. Mining for these massive sulphide deposits which are rich in copper, silver, zinc and gold is at the exploratory stage in the Bismarck Sea off Papua New Guinea.

Earthquake benefits

Earthquakes create faults which can trap oil and gas reserves. Faults can also sometimes help to bring water to the surface. Several Iranian cities for example, located on thrust faults created by movement between the Arabian and Eurasian plates, exploit such water supplies. Water-tables are often elevated here because rocks, ground down by the movement of the fault, create 'fault gouge', a type of impermeable clay which traps water. Irrigation schemes known as 'ganats' often tap into such underground changes in the water-table at faults, supplying water for crops on desert margins. The attraction between faults and settlements can, however, sometimes prove fatal, as for example when a major earthquake devastated Bam in 2003.

Case Study: Utilising a plate margin for agriculture and tourism – Costa Rica

Costa Rica is located on a destructive plate boundary, where the Cocos Plate subducts under the Caribbean Plate (Figure 4). This creates a line of active volcanoes which periodically erupt in the north and central part of the country. Volcanoes tend to be absent in southern Costa Rica because the Cocos Ridge disrupts normal subduction here. The country is also affected by occasional earthquakes, such as that which affected Cinchona in 2009.

Rich volcanic soils and a favourable climate support crops such as coffee, an important Costa Rican export. Most coffee is grown in the 'Central Valley' which in reality is a high intermontane plateau, 3,000-4,000 m above sea-level. The soils in the Central Valley are derived from ash produced by past eruptions of volcanoes such as Poás and Irazú. The plantations themselves are also tourist attractions, e.g. Britt Coffee offers tours of its estate which explain how the crop is grown and processed.

Volcanic eruptions are, however, a mixed blessing because heavy ash-fall and acid rain damage native vegetation and crops. An eruption of Poás, which has a highly acidic crater lake, produces sulphurous gases which mix with rainfall creating acid rain which periodically destroys coffee plantations downwind of the volcano.

Volcanoes, as well as rainforests, are a major tourist attraction in Costa Rica.

La Fortuna, a settlement of 6,000 people, at the base of the Arenal volcano is almost entirely dependent on tourism. Formerly considered extinct, the volcano came to life in 1968. Damaging pyroclastic flows flowed down the sides of the volcano destroying the villages of Tabacón, Pueblo Nuevo and San Luis killing 87 people. Arenal remained highly active until 2010. Tourists flocked to see volcanic gases and pyroclastics exploding from its crater summit and lava flowing down its sides. Its dangers, however, were demonstrated in 2000 when a pyroclastic flow killed a tourist and a guide who had strayed into a restricted area. Although the volcano is now quiet, its imposing symmetrical profile still draws visitors. Thermal hot springs on its flanks, e.g. at Tabacón, also attract tourists.

Poás and Irazú, both highly accessible from the capital San José, also attract tourists. From the summit of Poás, tourists view turquoise-coloured crater lakes and take in a visitor centre. Poás, like many other volcanoes in Costa Rica, is located in a National Park, which means income is derived from park fees.

Minimising risk on plate margins

Reducing risks which natural hazards pose on plate margins are achieved through a combination of structural controls, vulnerability modifications and post-disaster relief.

Structural controls

Structural mitigation measures include:

- earthquake-resistant buildings
- steep roofs to shed heavy ash-fall
- barriers to deflect lava flows and lahars
- draining crater lakes to reduce lahars.

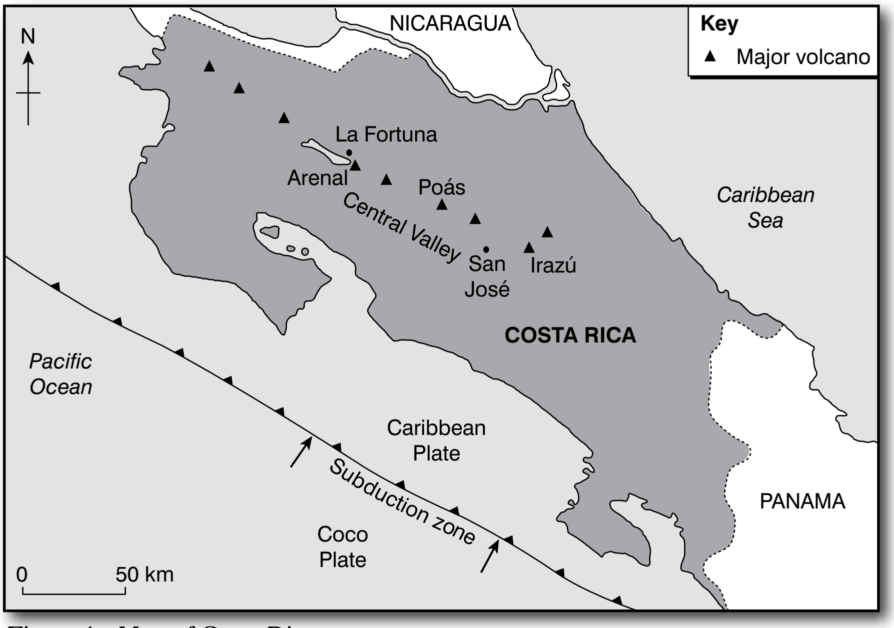


Figure 4: Map of Costa Rica

In Japan, for example, the impacts of lahars are reduced by: natural and artificial channels which confine flows; check dams which impound debris; together with large grates which intercept boulders. Such measures are, however, expensive and periodically have to be strengthened. Reliance on barriers can also lead to over-confidence in building down-slope, storing up trouble when a future disaster occurs.

Vulnerability modifications
Modifications include:

- hazard monitoring
- practising drills and designing evacuation routes
- issuing warnings
- land use planning.

Seismic monitoring is valuable because an increase in activity is one of the earliest indications of a pending earthquake or volcanic eruption. Ground deformation, changes in groundwater levels and alterations in volcanic gas and magma compositions also suggest an eruption may be imminent.

Accurate warnings and prompt evacuation can save many lives. This was demonstrated in 2010, when Mount Merapi erupted and evacuations saved an estimated 10,000 to 20,000 people. Issuing warnings can, however, be problematic because people may grow accustomed to false alarms, pre-eruptive events and earthquake foreshocks. Many may also be reticent to evacuate for fear their homes will be looted.

New building projects which avoid active fault lines, sediments prone to soil liquefaction and likely routes of lahars and pyroclastic flows can also save lives, as can the positioning of schools and hospitals on high ground on tsunami-prone coasts.

Insurance and post-relief assistance
Insurance and post-relief assistance helps to spread the financial burden when a disaster occurs. Insurance is, however, expensive and may not be available in areas deemed high risk. It can also lead to a false sense of security. Post-relief assistance, is in some cases misused or can lead to dependence.

Conclusion

This article has addressed how people exploit the resources of plate margins and limit the impacts when a natural hazard is realised. It is important to remember that natural hazards also occur within plates. The Tangshan earthquake for example, which killed at least 255,000 in 1976, occurred well away from a plate boundary. Nevertheless several major world cities are located near fault zones and active volcanoes which make a future disaster almost inevitable.

The negative impact of natural hazards has tended to obscure their beneficial effects. Moreover, technological and scientific advances are likely to reveal new economic opportunities. In geothermal areas for example, thermophilic organisms have been shown to produce heat-stable enzymes which can be used in a number of processes including DNA testing in the biotechnology industry.

Mitigation measures can reduce the impacts of natural hazards. Improvements, particularly in communications, now save many lives when volcanic eruptions and tsunamis occur. Nevertheless, plate margins still remain dangerous places to live, especially for the poor.

References

Blaikie, P. et al. (2003) *At Risk: Natural Hazards People's Vulnerability and Disasters*, Routledge, London.

Dove, J. (2012) 'Volcanic Tourism: Lessons from Mt St Helens', *Geography Review*, 26(2), 10-13.

Focus Questions

1. Why are plate margins dangerous places to live?
2. How can humans utilise hazardous environments to make a living?
3. Essay: Critically evaluate measures to reduce risk on plate margins. Use case studies to exemplify your answer.

Geofile Online

SEPTEMBER 2004
477

LUCY NEWSTEAD

GEOLOGICAL SLANT ON PLATES

Alfred Wegener, a German meteorologist born in 1880, is not a name that most people would think of if they had to name a scientific pioneer. People are more likely to say Darwin, Newton, Da Vinci or Galileo, but like these famous names he had a brilliant idea which seemed so far-fetched and revolutionary as to be considered ludicrous by his fellow scientists. His idea of **continental drift** suggested that continents moved around the Earth like giant rafts. He is now considered the father of the theory of what we call **plate tectonics**, the key to modern geological science. Although part of his theory of continental drift, that the continents ploughed through the ocean floor, has now been discounted, there is certain evidence for the break-up and movement of continents over the surface of the Earth.

The evidence for continental movement

- Evidence of an Upper Carboniferous glaciation (300 million years ago (Ma)) is found in the Southern Hemisphere continents from when they were part of a supercontinent called **Gondwanaland** near the South Pole at the time.
- The continental shelf outlines of the world's continents, if pieced together, fit near perfectly with very little overlap to form a supercontinent called **Pangaea,** which we now know was in existence 200 Ma. For instance, a glance at any world atlas will show that the eastern coastline of South America mirrors that of Western Africa.
- Fossil remains of a small freshwater reptile called **Mesosaurus** have been found in both South America and Africa. It seems very unlikely either that they could have crossed thousands of miles of ocean or evolved identically on separate continents.
- Fossils of **Glossopteris,** a seed fern, from 270Ma are found across the southern continents.
- Coal is found in Antarctica; coal is unlikely to have formed at its current latitude, as it requires tropical climates and dense vegetation to form.
- Basalt lava flows are located where continents tear apart. When Africa and South America rifted apart large volumes of flood basalt were erupted. This occurred over the Walvis Hot Spot which today is marked by the island of Tristan de Cunha.

Evolution of plate tectonic theory

Continental drift theory evolved into plate tectonic theory in the 1960s when extensive maps were made of the ocean floor. A mid-Atlantic ridge of mountains 1000 miles wide and 2500m high was discovered, as were deep ocean trenches at the edges of some continents, the deepest being the 11km-deep Marianas Trench off the Philippines. Echo sounders were used to probe the crust, and the ocean floors were found to be thinner than the continents. The layer below the crust was termed the mantle. Oceanographers towed magnetometers (instruments which measure the strength of the Earth's magnetic field) behind survey ships and a stripy pattern of **magnetic anomalies** related to the reversal of the Earth's poles was found. In 1963 it was eventually deduced by a Cambridge geologist, Fred Vine, that lavas erupting at mid-ocean ridges recorded the Earth's polarity at the time of their formation (Figure 1).

But if new ocean floor was being created, why was the planet not getting bigger? Ocean trenches held the answer. Hugo Benioff, a seismologist, observed that there was a zone of earthquakes and an arc of volcanoes close to these trenches. The depth of the earthquakes got progressively greater away from the trenches and disappeared at about 700km. Benioff suggested that this was due to oceanic crust sinking underneath the overlying plate, and named this area the **Benioff zone**. Figure 2 shows the main plates and their key characteristics.

The Structure of the Earth

The structure of the Earth can be likened to three concentric spheres of increasing diameter encasing one another. The centre of the Earth, the core, is divided into inner and outer sections. The **outer core** (at 2900 km depth) is liquid and composed mostly of iron with a temperature of 4000–6000ºC. We know it is liquid, as seismic waves cannot pass through it. The **inner core** is under intense pressure and, although very hot, is solid and made of iron with possibly around 20% nickel content. The **mantle** is 2300km thick and consists of silicate minerals, it surrounds the core and makes up 68% of the bulk of the Earth and can also be divided into two divisions. The lower mantle, also known as the **asthenosphere**, is largely solid with a temperature of 1000–1200ºC. Although solid, it is able to flow very slowly, like plastic, due to convection currents caused by heating from the core. The upper mantle is more brittle and is welded to the overlying crust. Together they form a layer called the **lithosphere** which is around 50km thick. Although the upper and lower mantle are effectively welded together, there is nevertheless a sharp division between the two called the **Moho** (**Mohorovicic discontinuity**), defined by differences in seismic wave speed.

The **crust** of the Earth is divided into two types, **continental crust** and **oceanic crust**. **Oceanic crust** covers 65% of the Earth's surface and is on average 6km thick; throughout its thickness it has the same basic composition, similar to basalt lava flows on its surface. **Continental crust** forms the Earth's continents and can be up to 70km thick. It is less dense then oceanic crust due to its high silica content (60%).

Plate tectonic theory

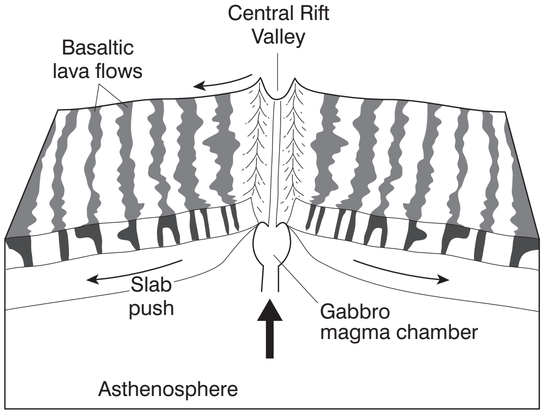
If we plot a world map of volcanic and earthquake activity, elongated bands can be picked out. These are the boundaries of the tectonic plates along which most activity occurs. Each plate consists of a section of lithosphere comprising of upper mantle, continental and oceanic or sometimes just oceanic crust. The plates move very slowly (5–20cm/year) over the lower mantle due to convection currents which originate from the intense heat given out by the core. Along these plate boundaries most of the world's earthquake and volcanic activity occur Crust is created,

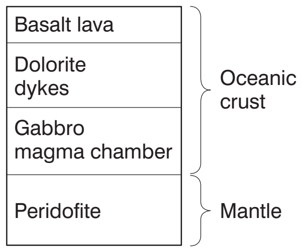
Figure 1: Plate tectonic boundaries and intra-plate volcanism

Constructive: Where oceanic crust is created
Mid-ocean spreading ridges.

Examples:
Mid-Atlantic Ridge

Oceanic crust is created along **mid-ocean ridges** with chains of submarine volcanoes. The oceans grow wider through sea floor spreading as more lava is erupted. As they widen a magnetic record is held within the iron rich minerals such as magnetite, which records changes in the Earth's magnetic field. This gives a stripy magnetic anomaly pattern. As the plates pull apart magma is produced by decompression of the underlying zone (70–110km down) to produce a mafic magma. The magma is added to the edges of the plates as an igneous rock called gabbro, which has crystallised in a magma chamber. If magma erupts on to surface of the sea floor it is then termed a basaltic lava flow.





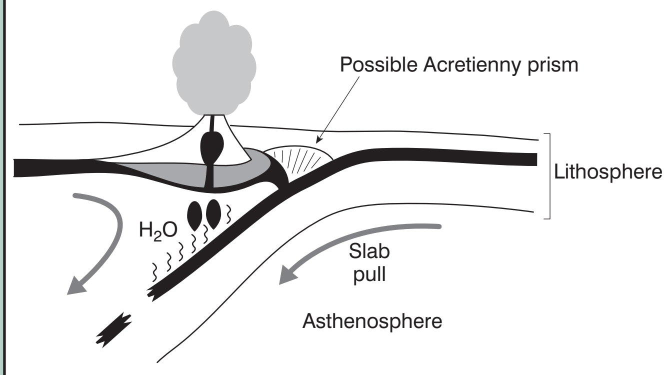
Magnetic anomalies of polar reversal are recorded in the magnetic minerals as 'stripes' Ridge is uplifted doe to buoyancy of crust before cooling and upswelling of magma, eg Mid-Atlantic Ridge

East Pacific Rise

Destructive: Where oceanic crust is destroyed and returned to the Earth's interior.
(including collision in some classifications)
(a) Oceanic crust subducts under oceanic crust.
(b) Oceanic crust subducts under continental crust

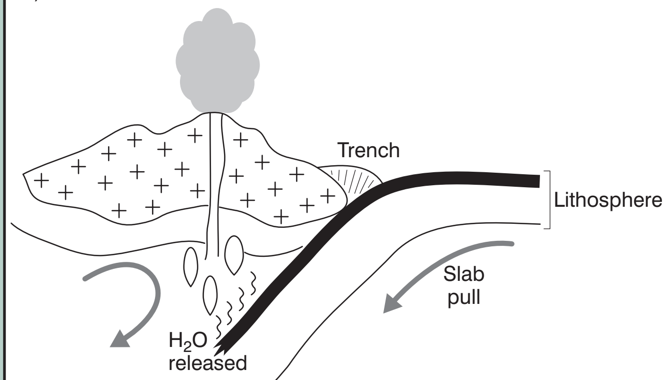
Old, cold and dense oceanic crust sinks or is subducted beneath a neighbouring plate and forms a deep ocean trench at a destructive boundary or **subduction zone**. The path of the subducting plate is indicated by a zone of dipping earthquakes called a Benioff zone. Above the subducting plate a **volcanic arc or chain** forms caused by melting. As the plate subducts temperature and pressure changes cause it to change to a rock type called eclogite which contains the minerals garnet and pyroxene. The type of volcanism produced is called intermediate or calc-alkaline. A variety of volcanic rocks can be produced from basalt to rhyolite. Volcanism is explosive due to the high silica content which increases the **viscosity** of the magma and volatile content (water). The crust above the subduction zone is uplifted due to the volumes of rising magma. Oceanic sediments are scraped from the descending oceanic plate to form an **accretionary prism.**

a) Ocean ⟶ Ocean subduction



Eg, Antilles Arc Caribbean: N. American plate subducting beneath Caribbean

b) Ocean ⟶ Continent subduction



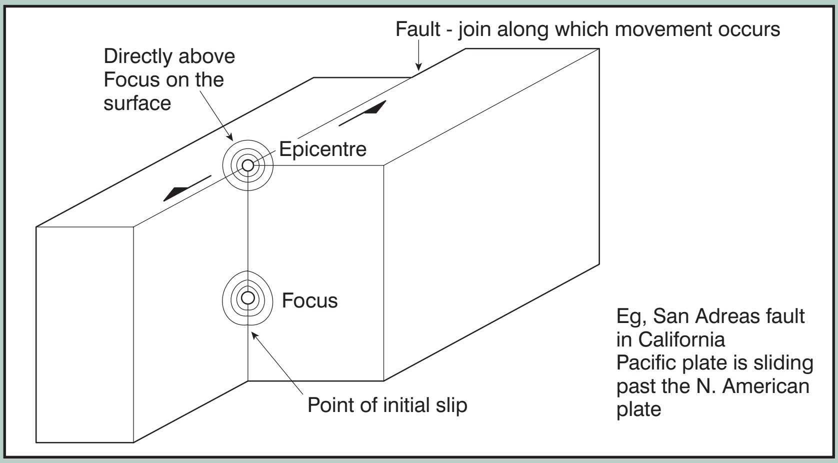
Eg, Andean volcanic arc S. American plate subducting beneath S. America
Age temperature and rate of subduction will affect the angle of the subducting plate

(a) Antilles Island Arc: Caribbean
(b) Cascade Range: USA Pacific North West

Figure 1 continued

Conservative: Where crust is neither created nor destroyed
Strike slip
Transform

At conservative margins there are no volcanoes but strong earthquakes occur. Here two plates or parts of plate slide past each other. Also known as a strike slip boundary, the most famous land example is the San Andreas Fault in California but the ocean ridges are split by many such faults caused by different rates of spreading at the ocean ridge. Friction causes the plates to become locked, when the fault breaks because a critical level has been reached seismic waves travel through the surrounding crust as an earthquake.

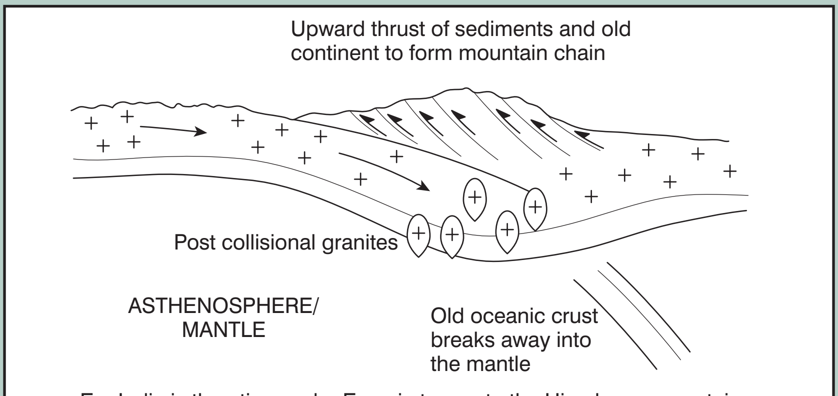


E.g. San Andreas Fault: California: USA

Collision: Where two continents collide – orogenic belt

E.g. India colliding with Asia to form the Himalayas

Where continents are pulled towards each other across a shrinking ocean by **slab pull** eventually collision will take place and large fold mountain ranges such as the Himalayas are formed. The "pulled" continent cannot be subducted like oceanic crust as it is too buoyant due to its low density. The continent is **thrust** under the leading edge of the other plate uplifting fold mountains made of oceanic sediments. Occasionally a segment of oceanic crust called an **ophiolite** is scraped off giving an insight into the geology of the ocean floors. Post collision al **granites** are intruded into the base of the mountain chain. Crustal shortening and thickening (70km) takes place.

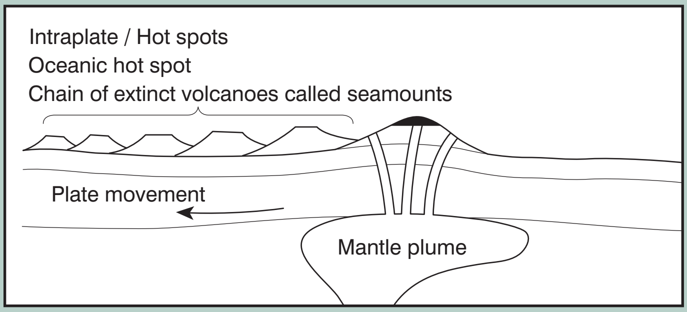


Eg, India is thrusting under Eurasia to create the Himalayan mountain chain. Mt Everest consists of marine sediments such as limestone!

Africa moving towards Europe to form the Alps

Intra-plate volcanism
Volcanic activity away from plate boundaries

"Jets" of hot mantle or **mantle plumes** called hot spots can pierce the crust away from the plate boundaries and cause intra-plate volcanoes such as those at Hawaii. They also occur in **continental rift zones** and aid the splitting of continents, erupting large volumes of basalt lava in the process. As the plate moves over the stationary hotspot a line of extinct volcanoes is created. Basaltic lava flows are indicative of this type of volcanic plate setting and form extensive flood basalts or **shield volcanoes**.



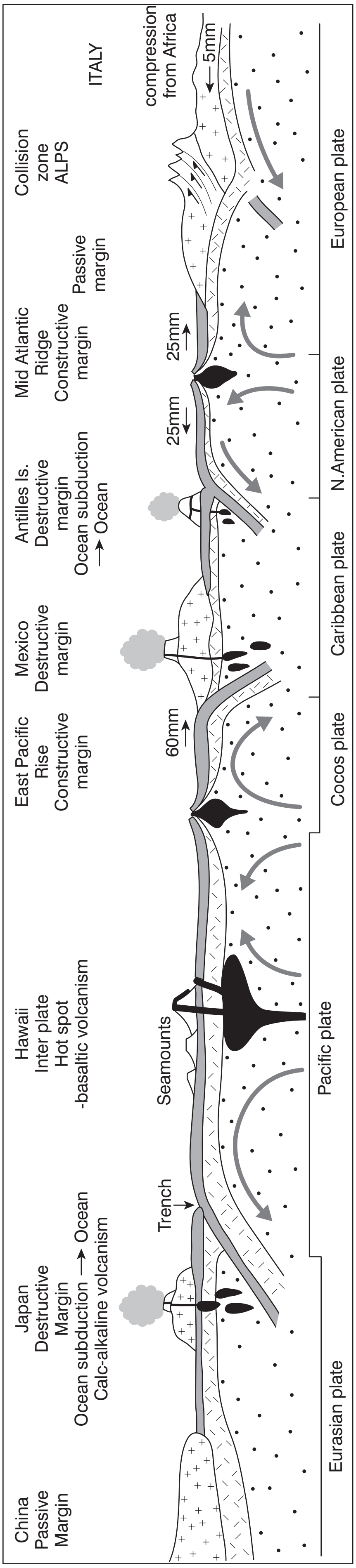
E.g. Hawaii Hot Spot
Yellowstone National Park

destroyed, torn apart and thrust up into fold mountain ranges. Plate movements can be said to be constructive, destructive or conservative.

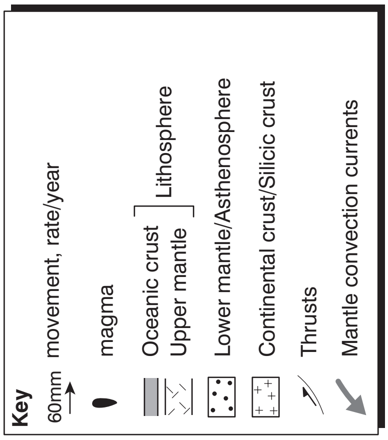
Constructive, destructive and collisional plate margin relationships

The estimated age of the oldest piece of oceanic crust on the Earth is 200Ma; all older crust has been subducted back into the mantle. For an ocean to form, a continental mass must split or rift. This is thought to be due to increased heat flow from the mantle on the base of the continental crust such as a

Figure 2: Global cross-section of interrelationships between plates and margins



mantle plume. The crust thins as it stretches and extension takes place forming a rift valley. This is thought to be happening in the East African Rift Valley. Volcanism will occur as the crust is stretched. Eventually the continent will rift into two and a new ocean basin and constructive margin will form. As the ocean grows the continental margins will become passive and will move away from the constructive margin. Geologists think that after 200Ma the oceanic crust next to the passive margin will become cold and dense enough to be subducted and the margin will transform into a destructive margin. Once the process of subduction has started it is impossible to stop and the weight and momentum of the descending slab will start to close the ocean if the rate of subduction is faster than the rate of spreading at the constructive margin. Eventually the constructive margin itself will be subducted, as is happening along Pacific North West coast as the last remaining segments of the Juan De Fuca plate are subducted. The two continents will travel towards each other and eventually collide to form a new continent. The complete cycle of ocean opening and closing probably takes around 400Ma.



India was originally attached to Madagascar 65Ma. Rifting and extension caused enormous volumes of continental flood basalts called the Deccan traps to erupt. The rifting was triggered by the Reunion Island hot spot to the east of Madagascar. At one time attached to Madagascar, India has since moved rapidly northwards and collided with Asia to form the Himalayas.

Conclusion

In comparison to the life span of a human being, plate tectonic processes happen impossibly slowly. However, if we consider that the Earth is probably 4.5 billion years old, in that context continents are positively "whizzing" around the planet, splitting apart, forming oceans and then colliding with other continents to form mountain ranges. In Britain we have a while to wait until the North Atlantic starts to subduct underneath Ireland and creates a new chain of volcanoes.

Focus Questions

1 (a) What is the evidence for plate tectonic theory?
(b) In what ways does modern plate tectonic theory differ from Wegener's theory of continental drift?

2 (a) With the aid of a diagram describe and explain the processes involved at each plate tectonic boundary.
(b). Explain the role of hot spots in continental break-up and intra-plate volcanism.

3. Summarise the way in which plate tectonics accounts for the opening and closing of oceans.

4. Research an example of each of the main types of plate boundary. How do the processes happening affect people? Produce your own plate map and add detailed labels of these examples.

5. Using this article and a geographical/geological dictionary create a glossary of the key terminology highlighted in bold.

Geofile Online
JANUARY 2007
537
Lucy Prentice

North Norfolk Coast Shoreline Management Plan DME

The communities of the North Norfolk coast have battled with the sea for hundreds of years and land has been lost as cliffs crumble and low lying marshes flood. With the predicted threat from rising sea levels due to **global warming** starting to loom large on the coastal management horizon, planners and coastal geomorphologists are beginning to suggest that after years of holding back the sea it is time to let nature take its course and stop '**Holding the Line**'. Figure 1 outlines the area's main geographical features including cliff lines, lower lying land, management responsibilities and management units mentioned in this **Geofile**.

Physical background

The cliffs along the North Norfolk coast are composed of sands and clays deposited by ice sheets during the last ice age. The cliffs' material is soft and crumbly in texture and can absorb rainwater which then percolates through the cliffs. This leaves the cliffs prone to **rotational slumping** and the fallen material then provides sediment for the beach and transportation by wave action within the **sediment cell** (Figure 2). At Happisburgh the cliffs are also under direct wave attack as there is not enough beach to protect the base of the cliffs and undercutting occurs with subsequent cliff falls. The low-lying marshlands to the west of Weybourne are caused by the deposition of sediment by **longshore drift**, largely from the east. Blakeney Point is a spit across the Glaven Estuary and has grown westwards from the shingle ridge at Salthouse and Cley. The ridge is mostly composed of shingle and protects the low-lying salt and freshwater marshes behind (Figure 1).

2004 Shoreline Management Plan

In 2004 a new **Shoreline Management Plan or SMP** (Figure 2) was proposed for the North Norfolk Coast, which at the time of writing was still not confirmed as policy. The plan was controversial in that it suggested a move towards retreating the present day coastline over the next 100 years. In the previous 1996 plan it was mostly smaller villages and farm land which were allowed to succumb to the sea but in the 2004 plan the future of substantial settlements, which had previously relied on protection ,were put on the line as they were assigned to the '**managed realignment**' policy.

Some of the main reasons for adopting a managed realignment policy strategy are as follows.

1. providing sustainable and effective flood and coastal defence
2. coping with sea level rise in the long term
3. habitat creation
4. reducing costs of defences.

The plan was written from three viewpoints:

- Firstly that economically it would become unviable to maintain and renew sea defences due to unfavourable **cost/benefit analysis**.
- Secondly that in the future as sea levels rose and the promontory effect changed the natural coastal processes, the **sediment cell** would become completely disrupted if even more defences altered the sediment budget.
- Thirdly that under **European Directives, habitats** needed to be protected or recreated elsewhere.

Public opinion has been strong and there has been much discussion over cost/benefit analysis figures which dismiss some settlements as not worth saving and designate some that are. What should happen to the towns, villages and beaches of the North Norfolk Coast? Should we be trying to save established communities? Or should we let them slide under the waves?

Responsibility and policy

The coastline is divided into **management units** based on the physical processes of the sediment cell and land use (Figure 1). Responsibility for managing these units is split between local councils, i.e. North Norfolk District Council (cliff/ beach protection) and the Environment Agency (flood protection). Policy is then integrated and coordinated through the **Shoreline Management Plan** (Figure 2), which looks at the coastline as a whole. Most of the funding for projects comes from **DEFRA** (Department for the Environment, Food and Rural Affairs) and units are given a points score when applying, based on their worth. Cost benefit analysis will look at whether the cost of the scheme can be justified against the worth of the property protected. This is often controversial as estimates in property may be straightforward but the future worth of tourist income and businesses is subjective. Figure 2 gives further detail on the main processes and policies that influence the coastline.

Policy decision case studies

The three settlements of Salthouse, Mundesley and Happisburgh have had mixed fortunes under previous management schemes (Figure 3). Salthouse village was flooded by the sea in the 1953 floods and again in 1996 (Figure 4). Mundesley has benefited

Figure 1: The North Norfolk coast

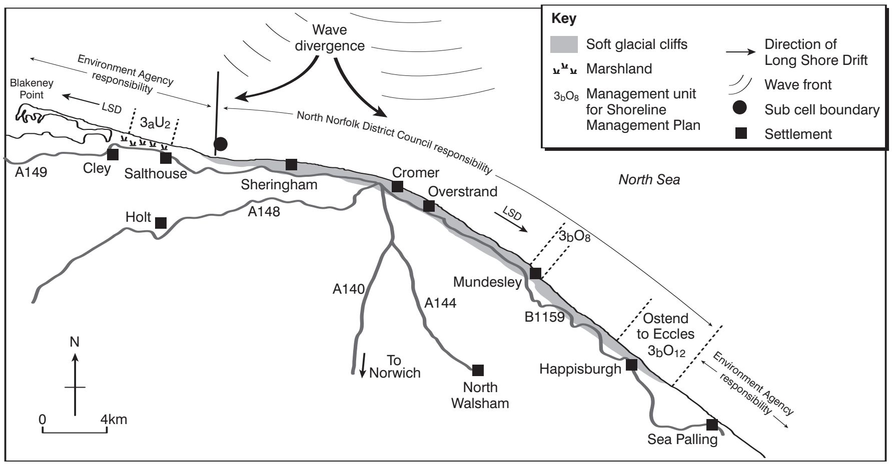


Figure 2: Processes, terms and policy

Sediment cell: (littoral cell)

- A section of coastline from within which sediment is **sourced**, **transferred** and **deposited** in sediment sinks.
- The cell may receive INPUTS of sediment from coastal (e.g. cliffs or eroding beaches) and land derived sources (e.g. river sediment) but only small amounts from other cells.
- The sediment is transported or TRANSFERED along the coastline by processes such as Long shore drift and currents to be stored in depositional features or traps These may be short term i.e. beach or long term a submarine canyon.
- The sediment may still remain geographically within the cell but once it is not transferred any more it is effectively OUTPUT from the cell.
- Natural boundaries of sediment cells include estuaries, submarine canyons, headlands or current/LSD changes in direction.
- Coastal defences can disrupt the flow of sediment in the cell causing erosion down drift and the loss of beaches and due to the drop in sediment supply.

Shoreline management plan

- A strategy document drawn up for managing the coastal defence of a defined stretch of coastline based on the boundary of a major sediment cell. (North Norfolk plan 1996 and proposed plan in 2004)
- The coastline is split into smaller management units based on landuse and DEFRA management policy is assigned.
- The plan aims to coordinate the interests and actions of all the bodies responsible for the coastline. ie, Local Councils, Environment Agency, Nature Conservation Groups.
- The coastal system is looked at as a whole so that action taken in one unit is not detrimental to another section of coastline. Sediment transfer is important to the health of beaches which are the best defence.
- The plan must accommodate the European Directives on habitat protection.

Cost/benefit analysis: Where the cost of implementing defence works is compared to the value or benefit of assets protected. The benefit must be greater than the cost for any scheme to be considered.

New Costs /km for:

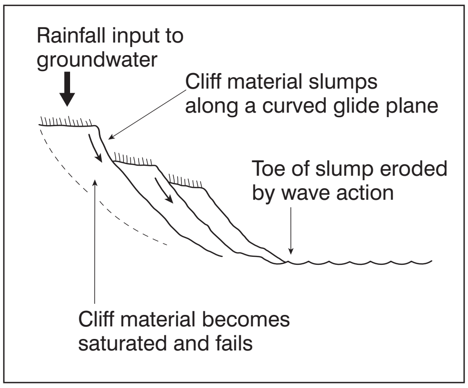
Revetements/seawalls = £2.7 millions/km (replace every 100 years)
Groynes = £ 0.6 millions/km (replace every 30 years)
Beach management = £5.1 millions/km

Maintenance
Revetements/groynes = £10,000/km

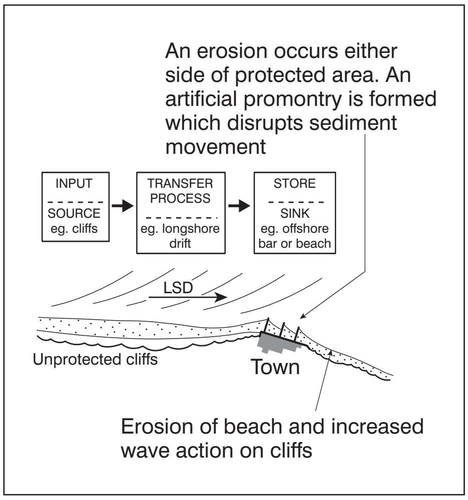
The initial review of the North Norfolk Shoreline Management plan only considered the value of property and not the worth of roads, recreational facilities and the impact on the local economy.

Coastal squeeze: Where the area a coastal habitat takes up is under pressure from a fixed landward boundary on one side and encroaching sea levels on the other. Most commonly used to illustrate the loss of saltmarsh due to erosion and flooding.

Cliffs: Rotational Slumping



Promontory effect: Sea defences, which protect against erosion, maintain the position of the current coastline whilst unprotected or less well protected areas retreat. This creates promontories or slight headlands along the coastline. As with a headland and bays coastline erosion is concentrated at the promontory resulting in the eventual loss of beaches. The promontories act like groynes inhibiting the movement of sediment down drift. As the cliffs erode either side of the promontory and retreat erosion will occur laterally towards the defended area. Cromer and Sheringham are examples of artificial promontories on the North Norfolk Coast which will become more pronounced in the future.



DEFRA Management Options: There are 4 policy options for the management units within a Shoreline management plan.

- **Hold the line:** the coastline is to be held at its present position through sea defence maintenance and upgrades
- **Advance the line:** build new defences seaward of the current coastline
- **Managed realignment (retreat):** Conscientiously allow the coastline to retreat including the removal of dilapidated defences
- **No Active Intervention (Do Nothing):** No action taken including maintenance and removal of defences.

DEFRA Points scheme: Coastal defence and protection works are costly and large schemes must apply for funding from DEFRA under a point scheme.

- **Priority/10** (given to urban areas)
- **Urgency/10** (failure within 5 years)
- **Cost/benefit ratio/10** (ratio 1:2 to score)

Total 30

Rural areas stand little chance of passing points threshold for funding (i.e. in 2003 20 points)

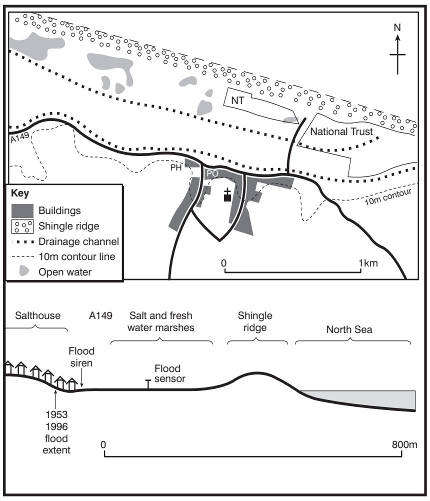
Conservation Legislation and Status

1971 Ramsar Convention: An international voluntary agreement which recognises Wetlands of International Importance and aims to protect them. The UK is a member.
1981 Wildlife and Countryside Act: Established SSSI s (Sites of Special Scientific Interest) to protect against the destruction habitats.
1994 European Union Habitats Directive
This established the Natura 2000 Network which includes **Special Areas of Conservation (SAC)** and **Special Protection Areas (SPA)** specially aimed at protecting the habitats of wild birds. Designated areas must be protected from pollution, deterioration or habitat disturbance. Habitats may need to be recreated elsewhere to ensure habitat

Figure 3: Data table for Salthouse, Mundesley and Happisburgh

	Salthouse	Mundesley	Happisburgh
Responsibility	Environment Agency	North Norfolk District Council	North Norfolk District Council
Unit label	3a02	3b08	3b012
Unit summary	Shingle ridge separates marshland from the sea. Salthouse lies 800 m from sea on small rise next to the main road.	Sand and shingle beach is backed by cliffs of glacial sand and clays (30 m). Mundesley lies on the cliff tops.	A poor beach allows wave attack at high tide onto weak clay cliffs (10 m). A string of homes lies along beach road which is rapidly eroding. The main village lies 50-100 m inland.
1996 SMP Policy	Long-term retreat	Hold the line	Hold the line (but has largely failed to win funding under the DEFRA points scheme)
Population No of households Average house price spring 2006 Second home %	250 130 £280,500 n/a	1800 902 £181,500 12%	850 209 £171,500 32%
History of erosion/flooding	• 1953 North Sea Storm Surge breached shingle ridge: 30 properties destroyed. • Breach occurred again in 1996 – main A149 road flooded.	Erosion halted during Victorian era with building of tall sea walls and groynes. Defences maintained and revetements added in C20th. Cliff retreat is largely due to rotational slumping rather than direct wave attack.	Rapid erosion since 1996 when failing revetements along one section to the south of the slipway were removed. Rapid erosion inland and laterally along the coastline resulted creating a bay. Numerous homes lost to erosion. Slipway access lost. Cliff retreat is due to undercutting by wave attack.
Defences in place to date	Shingle ridge which is natural but regraded by bulldozing.	Tall sea walls protect the cliffs, groynes and revetements. Estimated maintenance/replacement cost over next 100 years: £7.2 m.	Line of old revetements and groynes to north of slipway access. Some rip-rap (rock armour) in place added in 2002.
Economic activity and land use	Mostly housing in village with a pub, shop.	Housing, tourist facilities, shops, cafes, hotels.	Main village is inland of eroding area at present. Housing, café under imminent threat. Agricultural land. Tourist car park.
Ecological importance and status	• The Wash & North Norfolk SAC. • North Norfolk Coast **SPA**. (European designated site of importance to wild birds). • **AONB** (Area of Outstanding Natural Beauty). • **RAMSAR** site. • **Heritage Coastline**. • 66 ha of Bird Reserve managed by the Norfolk Wildlife Trust. Salt, brackish and freshwater marsh habitats. • The **GEESE** project is a partnership between the Norfolk Wildlife Trust, the National Trust and the Environment Agency costing £2.5 m.	• **AONB** (Area of Outstanding Natural Beauty).	• **AONB** (Area of Outstanding Natural Beauty). • Small cliffs at Happisburgh give way to lower-lying agricultural land and eventually the Norfolk Broads National Park. • Cliffs are **SSSI** for glacial history.
Consequences if nothing is done over the next 100 years (including no maintenance).	Shingle ridge will roll back (1 m/year) reducing area of marshland. Ridge breach will be more frequent damaging or destroying habitats. Main road will flood more frequently and Salthouse village will be prone to destructive storm surge.	Cliff behind the revetments will retreat at approximately 10 m/year but more rapidly once the revetements fail. Sea walls will create a promontory but will breach and collapse by 2105 due to erosion. Beach will gradually disappear until promontory is smoothed by the sea. Possibly £21 million on property lost by 2105. Main road, lifeboat access, museum and library lost.	Defences are already failing. Over the next 20 years rapid erosion of possibly 100 m. Small beach may remain. By 2105 up to 200 m. Up to 50 homes lost by 2105. Possibly £6 million value on property lost by 2105. Caravan park, lifeboat access lost.

Figure 4: Salthouse (Unit 3aO2) map and cross-section



from maintained cliff defences to protect its population but Happisburgh in contrast has suffered dramatic erosion and property loss over the last 10 years as its defences failed (Figure 5). Salthouse is under the North Norfolk Shoreline Management Plan whereas Mundesley and Happisburgh are under the Sheringham to Lowestoft Management Plan.

Figure 3 gives detailed information on each of the three settlements. Figure 4 is a map of Salthouse and includes a cross-section from the sea to Salthouse village which shows how the village is protected from flooding by the shingle ridge and the marshes.
Figures 5 and 6 show maps of Mundesley and Happisburgh including the possible positions of the coastline in 2105 if nothing is done to prevent erosion.

Figure 5: Mundesley (Unit 3bO8)

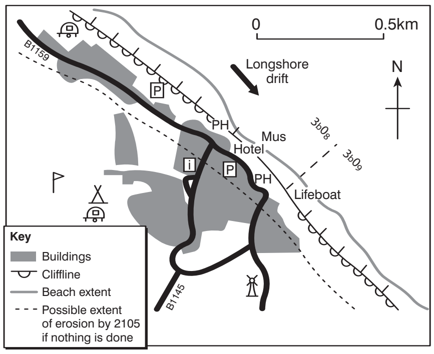
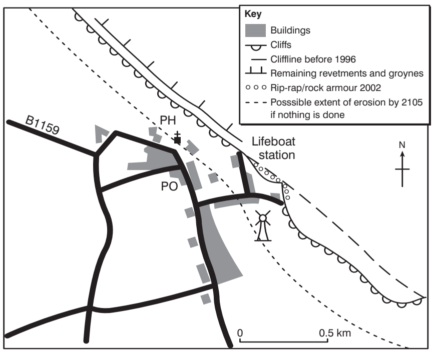


Figure 6: Happisburgh (Unit 3bO12)



Decision-making exercise

Objective: To decide on which policy should be adopted for each of the three Norfolk Coastal Management Units and the justification for this policy.

There are essentially four motivating reasons to manage the North Norfolk Coastline:

1. economic
2. social
3. sediment cell/coastal system health
4. ecological and environmental.

All interested parties will agree that something has to be done. For some this is to defend against the sea and preserve the present day coastline; for others it is to allow the coastal system to behave more naturally. In the short term people want to be protected but in the long term is this viable?

Resources (includes sources of information used in this Geofile)

- Figures 1-5
- Website resources:
  www.Happisburgh.org.uk: campaign site for Happisburgh, aerial photographs, plus other settlements
  www.edp24.co.uk: newspaper article search and property section
  www.north-norfolk.gov.uk: SMP information
  www.defra.gov.uk: coastal defence flood and coastal erosion risk management fact sheet plus links
  www.environment-agency.gov.uk: coastal flooding
  www.salthousehistory.co.uk: photographs of floods including 1953
  www.northnorfolk.org: data and profiles of settlements
  www.upmystreet.co.uk: data on settlements
  www.streetmap.co.uk Maps of settlements
- Maps: OS NE Norfolk Explorer 24 and 25

1. (a) Complete an enlarged version of the table on the right in bullet points to show the importance of each place under the headings.
(b) Decide on your final policy for each place and summarise the main justification for your decision.

	Happisburgh	Mundesley	Salthouse
Economic			
Social			
Sediment Cell Importance			
Environmental and Ecological			
Policy Decision			
Justification			

Policy statements are in Figure 1.
(c) Write a half page summary stating the case for your policy decision.

2. What could be the possible consequences on sediment cell processes of:
(a) defending all settlements
(b) defending only the main settlements along the Norfolk coast.
Key words: Sediment supply, promontory effect, beach health, sediment supply, erosion, deposition, wave action, long shore drift, beach replenishment.

3. Investigate some of the other settlements along the coastline. What may the future hold for these settlements? Issues to consider: cliff retreat – Overstrand, Sidestrand; flooding – Sea Palling, Weybourne.

4. Choose one of the bullet points below and present both sides of the debate in a short statement:

- The European Habitats Directive states that coastal habitats need to be recreated if they are lost to the sea. Should the same apply to settlements for people?
- It has been suggested in the proposed SMP that in the future, communities may be relocated. Is it viable to recreate and relocate communities which have been lost to the sea? If so can the cost be justified?
- People receive no compenstion for the loss of their homes and land. They may even have to pay to have their homes dismantled and destroyed before they collapse and become a danger. What justification and reasons can the authorities have for this policy?

5. Use the DEFRA website to investigate:
(a) the policy of 'making space for water'
(b) 'Futurecoast'.

Geofile Online

SEPTEMBER 2009
600

Jane Dove

Sea-level change: causes and coastal landforms

Introduction

A rise in sea-level, or a fall in the land surface, encourages sea-water to transgress inland, thereby flooding river outlets. A fall in sea-level, or a rise in the land, exposes the ocean floor and leaves old beach deposits abandoned above high tide. The term 'relative sea-level' refers to the combined effects of changes in both land and sea surface.

There are many causes of sea-level change, and several ways in which these changes can be classified. A distinction is often made between changes which affect sea-levels worldwide, and those which are felt more regionally or locally. Relative sea-levels have fluctuated over geological time, but some of the most dramatic changes occurred during the last Ice Age, or Pleistocene and early post-glacial or Holocene periods. Human activities increasingly are influencing sea-levels and altering coastal configurations (Figure 1). A wide variety of coastal landforms have been created by relative changes in sea-level.

Global changes

Any alteration of the volume of water held within the oceans produces what is known as a eustatic change in sea-level. As most ocean basins are interconnected, such absolute changes in sea-level tend to be felt worldwide, although some evidence now suggests that these changes can also be regional. The most common cause of eustatic sea-level change has been the growth and melting of continental glaciers, which occurred during, and immediately after, the Pleistocene. Today, global warming is melting continental ice caps, which in turn is contributing to a rise in sea-level.

Fluctuations in the volume of water held in the ocean can also be brought about by changes in sea temperatures, salinities and atmospheric pressures. Rising sea temperatures for example, brought about by global warming, cause oceans to expand and sea-levels to rise. An increase in the volume of freshwater flowing into oceans lowers their salinity and causes sea-level to rise. A fall in atmospheric pressure, brought about, for example, by a deep atmospheric depression passing over a sea surface, also produces a rise in sea-level.

Major changes in the configuration of land and sea areas, as a result of plate movements, increase or decrease ocean basin capacity. An increase in ocean basin capacity could lower sea-levels worldwide.

The gradual deposition of sediment in the world's oceans, from weathering and erosion of the land, reduces their capacity and will lead to an increase in world sea-levels, albeit over a very long time scale.

Regional and local changes

The earth's crust and uppermost part of the mantle form tectonic or lithospheric plates, which float on an underlying, denser asthenosphere. When in equilibrium the weight of the plates is counterbalanced by their buoyancy, but the addition of a load in the form of ice, water or sediment can upset this isostatic balance. That part of the lithospheric plate under the weight of the load becomes compressed, but this is compensated by a rise elsewhere. After the weight is removed, the land directly below the load begins to rise, while towards the margins, where the weight was absent, the crust sinks. Glacio-isostatic subsidence occurred during the Pleistocene when the crust was depressed by ice sheets. Sediment-isostatic subsidence occurs when sediments accumulating in large deltas, such as the Mississippi, depress the underlying crust. Hydro-isostatic subsidence occurs when the weight of water depresses the ocean floor. This occurred for example when Pleistocene ice sheets melted and water flowed into the oceans. Although the mechanisms are complex, the net effect of hydro-isostatic subsidence, some geomorphologists suggest, is a seaward tilting of the continental margin which produces a fall in relative sea-level on the coast, as for example seen around the coast of Australia.

Mountain-building activity, tectonic movements and earthquakes all lead to relative changes in sea-level by uplifting or down-faulting land or sea areas. The elevated shore platforms near Wellington in New Zealand, for example, are believed to have been created by tectonic activity. Volcanic eruptions can also alter relative sea-

Figure 1: The North Norfolk coast is threatened by rising sea-levels

levels, as for example occurred at Pozzuoli near Naples in Italy.

The compaction of deltaic sediments which contain lots of water by the weight of overlying accumulating material causes the land surface to become lower. This in turn leads to a relative rise in sea-level. Many of the world's major deltas such as the Mississippi are threatened by sea-level rise as the result of such compaction and also sediment isostasy.

Glacial and post-glacial sea-level change

During cold phases in the Pleistocene, sea-water was progressively lost via precipitation as snow to create glaciers and ice fields. Abstraction of water from the hydrological cycle in this way caused an absolute fall in sea-level (glacio-eustasy). There were several cold periods during the Pleistocene, each lasting 100,000 years, and each time the sea-level fell. At the same time, the reduced temperature of the sea water caused it to contract, which further lowered sea-levels. During warmer phases, or inter-glacials, each of which lasted about 10,000 years, glacial melting caused the sea-level to rise to approximately current levels. Rising sea temperatures also caused the sea to expand, further increasing sea-levels. The last cold glacial period peaked at 18,000 BP, and at this time sea-level was about 140 m below its present position. After this the glaciers began to melt, causing sea-level to rise. Melting continued into the post-glacial or Holocene period. The rise in sea-level is known as the Flandrian transgression, and ended about 6,000 BP.

During the Pleistocene, continents were depressed under the weight of the ice. The greatest depression occurred where the ice was thickest. When the glaciers melted, the land rebounded and shorelines located near formerly ice-covered areas in Canada, Scandinavia and Scotland rose (glacio-isostasy). Readjustment to the removal of the ice has, however, been slow and over an extended period because the lithospheric plate is rigid, and consequently parts of north-west Scotland are still experiencing uplift of about 2 mm per year.

Figure 2: Slope-over-wall cliff

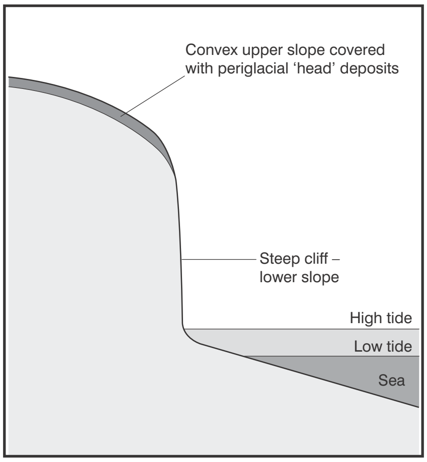
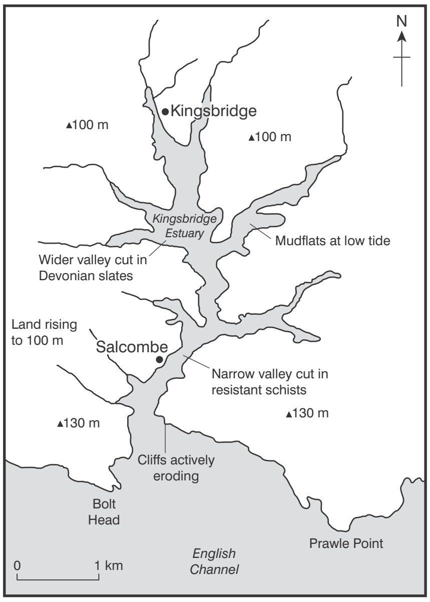


Figure 3: Kingsbridge Ria



While the lithospheric plate was depressed under the weight of thick ice sheets, at the margins of the depressed land area a forebulge developed, causing the land to rise slightly. When the land rebounded, the forebulge flattened, resulting in a rise in sea-level. This effect is still being felt in south-east Britain today, producing a 2 mm rise in sea-level annually (Figure 1).

Coastal landforms and sea-level change

Changes in relative sea-level have produced a variety of coastal landforms. Broadly these are grouped into submerged and emerged coastlines, although in reality many coastal areas have experienced both rises and falls in relative sea-level at different periods in their history. One example of a coastal landform formed in this way is a slope-over-wall cliff.

The cliff has a steep lower face and a gentler, convex upper profile (Figure 2). During interglacial periods in the Pleistocene, high sea-levels undercut the base of cliffs, creating a vertical face. In a succeeding cold phase the sea-level fell, so the cliff-line was not eroded by the sea. The cliff-line was, however, degraded by intense frost-shattering under periglacial conditions, and solifluction deposits or head moved downslope. Then a post-glacial rise in sea-level attacked the cliff again, producing the vertical lower face.

Submerged coastlines
(i) Rias
A ria is a sea inlet in an area of rugged relief where the lower reaches of a river valley and its tributaries have been drowned by a rise in sea-level (Figure 3). Many were created as the result of the Flandrian transgression, although, as a pre-cursor to this event, lower sea-levels during the Pleistocene would have encouraged rivers to cut deeply into their valley floors. Rias are common in Pembrokeshire, Devon and Cornwall in Britain, Brittany in France and in north-west Spain.

The shape of a ria is controlled by the form of its pre-existing river valley, which in turn is controlled by factors such as rock type and structure. In south-west Ireland, long, narrow inlets such as Bantry Bay have been created by the flooding of former river valleys. The river valleys were cut into shales which had been downfolded into synclines, while the surrounding hills were made of more resistant sandstone rocks upfolded into anticlines. In contrast, rias in South Devon, such as that at Kingsbridge, tend to be more branching than those in Ireland (Figure 3). Evidence from a 1:50,000 map that submergence has occurred include a number of finger-like inlets which become shallow inland, submarine contours marking the position of the former river channel, and cliffs at the outlet suggesting present day undercutting.

Rias vary in the amount of subsequent infilling after flooding. Some are fringed with salt-marsh and mudflats, while others end in rocky embayments. In some cases, estuaries may quickly fill with sediment, or keep pace with the rising sea-level so that no ria forms, e.g. Cuckmere Haven, East Sussex.

(ii) Drowned lowland estuaries
The Flandrian transgression also drowned lowland coastal valleys, creating broad, open estuaries and extensive mudflats, such as the Blackwater Estuary in Essex, and Pagham Harbour in West Sussex.

(iii) Dalmatian coastlines
In areas where mountain ranges lie parallel to the coast, a rise of sea-level produces a range of long, narrow islands separated by sounds. A good example where this has occurred is the Croatian coastline, where the outer ranges of the Dinaric Mountains are now islands, and coastal valleys between the ranges are occupied by the Adriatic Sea.

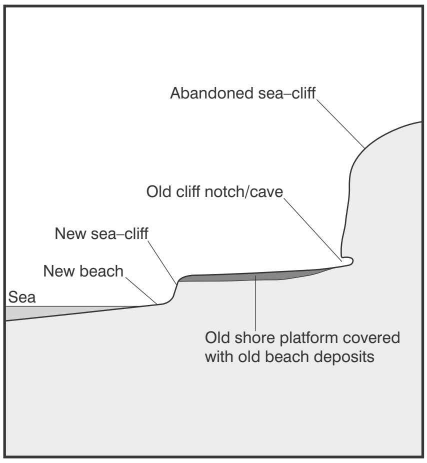
(iv) Submerged forests
Tree trunks and peat layers exposed at or below present day sea-level, such as that on the coast at Formby in Lancashire and Borth in Wales, represent forests which were submerged by the Flandrian transgression.

(v) Buried river channels
Buried channels can be found in the mouths of many river valleys. During cold phases in the Pleistocene, when sea-levels were low, rivers cut down into their channels to maintain their base levels. A subsequent rise of sea-level infilled the buried channels.

(vi) Offshore submerged benches and notches
Wave-cut platforms now just offshore mark the position of former coastlines which developed when sea-levels were much lower than they are today during cold phases in the Pleistocene. A subsequent post-glacial rise in sea-level has meant that these platforms now lie offshore, some hidden beneath marine sediments.

(vii) Other changes
The post-glacial rise in sea-level was responsible for severing the land link between Britain and continental Europe by 8,600 BP. Flooding also created the Isle of Wight and the Solent in southern Britain, and the Frisian Islands off the coast of the Netherlands. The Flandrian transgression also reworked sediment on the continental shelf, pushing it towards the coast, which ultimately led to the formation of large shingle complexes, such as the cuspate foreland at Dungeness, the spit at Orford Ness, and the tombolo at Chesil Beach.

Figure 4: An emerged/raised beach



Fjords, or glacial troughs, which are partly inundated by the sea, largely owe their origin to powerful glaciers which over-deepened their valley floors well below current day sea-level. A post-glacial rise in sea-level of perhaps 100 m added to the depth of water in the fjord, but in comparison with the glacial erosion, the sea-level rise was of minor importance in creating this landform. Sognefjord, for example, is over 4,000 m deep. Moreover, after glaciation the land would have risen isostatically, offsetting the effects of sea-level rise. Fjords occur on the western sides of continents at about 60 degrees north and south of the equator, for example in Norway, British Columbia in Canada, southern Chile, and South Island in New Zealand.

Emerged coastlines

Most emerged coastlines are Quaternary in age, although some formed earlier during the Tertiary period. Evidence of emerged coastlines include:

(i) Widening areas of salt-marsh and mangrove
As sea-levels fall, the area under salt-marsh and mangrove swamp increases. Rejuvenated streams incise into the marsh or swamp to reach new base levels.

(ii) Emerged or raised beaches
These are beaches of sand, shingle and shell deposits which stand well above the present sea-level (see Figure 4). The sediments often rest on old wave-cut platforms which are sometimes backed by abandoned caves, arches and stumps. On the Isle of Arran, for example, fossil cliffs and caves occur at the back of an old wave-cut platform.

Raised beaches are created by an uplift of the land, or a fall in sea-level. Repeated uplifts of the land or drops in sea-level produce a series of raised beaches, which can be radiometrically dated from the shell material they contain. Raised beaches which fringe the shores of Hudson Bay in Canada rise to 315 m above sea-level, and those around the Gulf of Bothnia in northern Europe were created as the result of isostatic readjustment following the removal of ice at the end of the Pleistocene. Some Scottish raised beaches were also created in this way when ice was removed from the Scottish Highlands. So called 'raised beaches' are also found in Southern Britain in Cornwall, Devon and Pembrokeshire, many being between 5 and 8 m above present mean sea-level. These platforms, which are known as 'emerged beaches', because they were not created by an uplift of land, were cut by high sea-levels during interglacial periods in the Pleistocene. Examples can be found at Portland Bill in Dorset where sand, pebbles and shelly material overlay periglacial head deposits.

Human causes of sea-level change

Human actions can also bring about alterations in relative sea-levels. The abstraction of groundwater from coastal aquifers, such as has occurred in Venice and Bangkok, causes the land surface to subside, which in turn leads to a relative rise in sea-level. The extraction of oil and gas reserves from rocks south of Los Angeles in California has similarly caused overlying sediments to subside and the sea to transgress inland. Drainage of salt-marsh causes the land surface to shrink, and the weight of industrial and port developments compacts sediments which lowers land levels and leads to a relative rise in sea-level.

Global warming is currently causing sea-levels to rise. This is partly because continental ice sheets and glaciers, such as those which overlay Greenland, are melting, and partly because the oceans are warming and therefore expanding. If all the remaining land-borne ice sheets, glaciers and snowfields were to melt on the continents, sea-level would rise by on average 60 m. It should, however, be noted that melting of sea ice in the Arctic Ocean and the ice shelves bordering Antarctica would not cause an increase in the volume of water in the oceans. This is because floating ice is already displacing water of a weight equal to its own.

Future changes

The Intergovernmental Panel on Climate Change (IPCC) in 2001 predicted that by the year 2100, sea-level will be rising on average at least 5 mm per year. This will lead to major changes in the configuration of coastlines such as the North Norfolk coast (Figure 1).

Specific changes to coastlines as the result of sea-level rise are:

(i) Cliffs, especially those composed of weak unconsolidated materials, will experience accelerated rates of erosion. Deeper water will encourage more powerful waves to attack the cliffs, leading to slope failures, while existing shore platforms will disappear below the sea. On drift-aligned coasts, however, the increased supply of sediment created by erosion is likely to be transported by longshore drift, to augment beaches elsewhere.

(ii) Sandy beaches will be eroded and sea-walls will be increasingly overtopped by waves. Beaches in front of sea-walls will become lower and narrower. Faced with increasing coastal erosion, the management options include holding the line by strengthening hard and soft defences; managed retreat, or abandonment to the sea.

(iii) Sand dunes will be eroded on their seaward faces and mobile dunes will migrate inland. In areas where dunes have been reclaimed, however, migration will not be possible. Slacks between dune ridges will become increasingly brackish, leading to changes in plant communities. In low-lying countries such as the Netherlands, where much of the coast is protected by sand dunes, defences will have to be strengthened.

(iv) Estuaries and inlets will become larger and deeper and salt-water will penetrate further inland, altering wetland habitats. The seaward edges of salt-marshes and mangroves will be eroded. Salt-marshes will be more frequently inundated by high tides. Plant communities will be displaced landwards, unless checked by a sea-wall, in which case coastal squeeze will lead to a narrowing of the wetland. The extent to which salt-marsh and mangroves can vertically accrete to keep pace with rising sea- levels will depend on factors such as availability of sediment, crustal stability, tides and currents, vegetation cover and the rate of sea-level rise. The Essex marshes are currently retreating and faced with this problem one solution has been to abandon old sea-walls and allow the sea to spread in. This in turn has encouraged new salt-marsh to form and created a natural form of sea defence.

(v) Deltas are likely to become increasingly eroded at their seaward edges unless maintained by coastal sedimentation. In Bangladesh, a low-lying, densely populated country, a 1 m rise in sea-level could result in the loss of 20% of the land area, which would affect 17 million people, many of whom are very poor. Salt-water intrusion already damages irrigation and drinking water supplies and flooding destroys rice crops. Erosion of coastal mangrove will lead to flooding of the Sundarbans, an ecologically important area, and home to the Bengal tiger. Tropical cyclones funnel up the Bay of Bengal creating storm surges and these, together with rising sea-levels, threaten coastal fishing and farming communities. Planting mangroves and strengthening coastal embankments can reduce the effects of flooding, and fishing communities may be able to relocate. Relocation is, however, not an option for poor agricultural communities, in a country where land is in short supply.

(vi) Low-lying islands which are less than 3 m above sea-level, such as the Maldives in the Indian Ocean, and Kiribati in the Pacific Ocean, face an increasing risk from rising sea-levels and more frequent, powerful tropical storms. Two uninhabited islands in Kiribati have already succumbed to the waves and on other islands farmland and homes are regularly flooded. Salt-water also intrudes into groundwater supplies, making water undrinkable. Corals can grow by up to 10 mm per year, although rates vary with water depth, sea-temperature and coral type. The extent to which coral atoll growth will be able to keep pace with future sea-level rise will depend not only on the rate of rise, but also whether corals are stressed by factors such as the increase in sea temperatures and pollution.

With 70% of the world's population now living in coastal areas and many large cities located by the sea, protecting the coast from sea-level rise will be expensive. The height of the Thames Barrier will have to be raised to protect London, while in Venice work has recently begun on the Moses Project. This involves constructing 78 gates across three inlets that link the lagoon to the Adriatic. Work started in 2008 and it is hoped it will be completed by 2014.

Bibliography

Bird, E. (2008) *Coastal Geomorphology*, Wiley, Chichester

Masselink, G. and Hughes, M. G. (2003) *Introduction to Coastal Processes and Geomorphology*, Hodder Arnold, London.

Focus Questions

1. Define **relative** and **absolute** changes in sea-level. Describe and explain the main causes of these changes.

2. Describe and explain the coastal landforms associated with sea-level change. Refer clearly to particular stretches of coastline which you have studied.

3. Outline the human causes of sea-level change and likely impacts on coastlines. Use examples from a variety of countries or regions.

Geofile Online

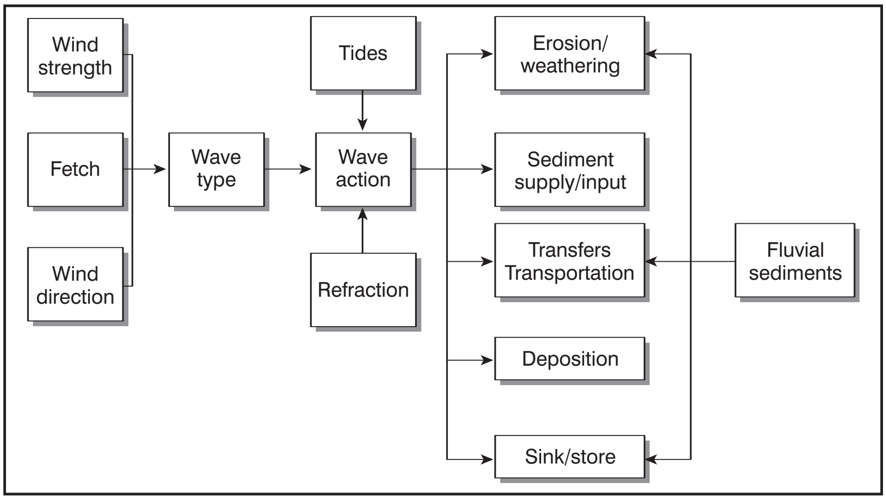
SEPTEMBER 2008
575

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

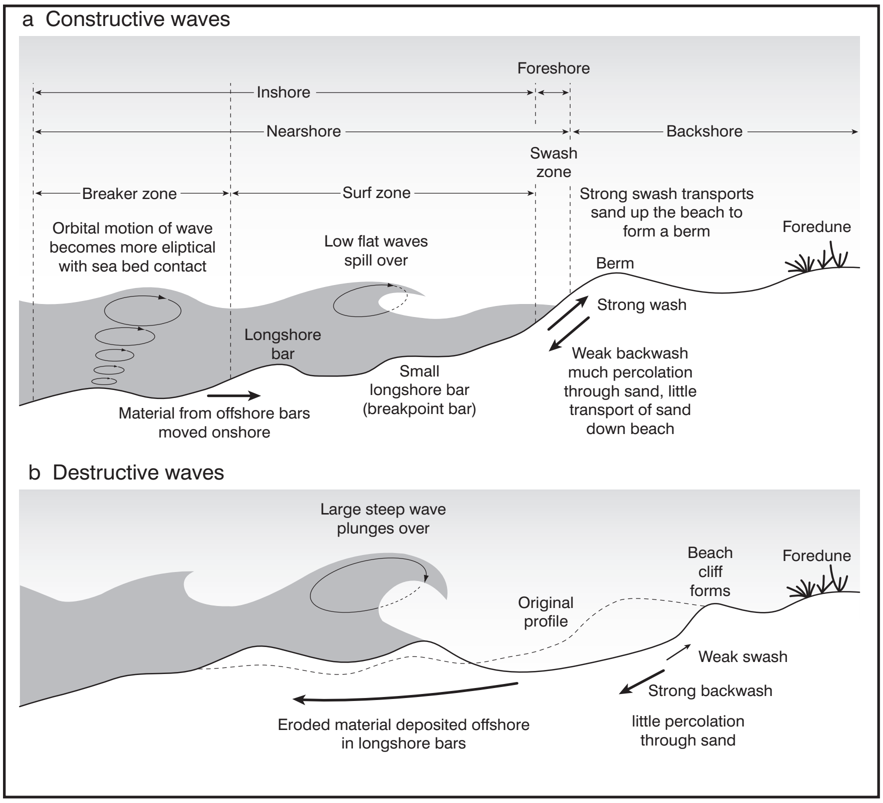
As a wave approaches the shore, and the water depth decreases, the wave length becomes shorter and the wave height increases to compensate. The circular motion of the wave becomes more elliptical as the wave base drags on the sea bed and the wave velocity decreases (Figure 2a). The wave steepens further, 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
- 6–10/minute

Figure 2: Constructive/destructive waves



Source: Guinness and Nagle, 2000, p. 116

- 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:

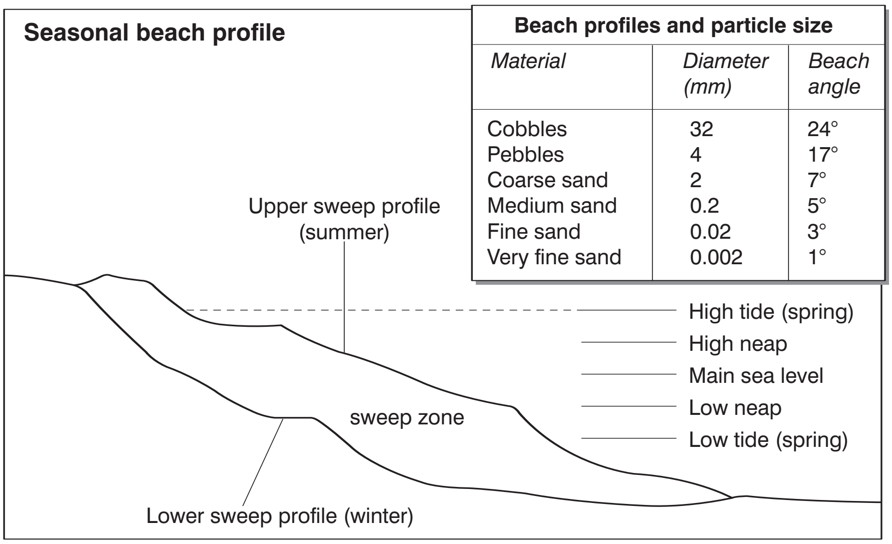
> 'A length of coastline and its associated nearshore area within which the movement of coarse sediment (sand and shingle) is largely self-contained. Interruptions to the movement of sand and shingle within one cell should not affect beaches in a neighbouring sediment cell.'

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.

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.

Figure 3: Beach morphology and sediment type

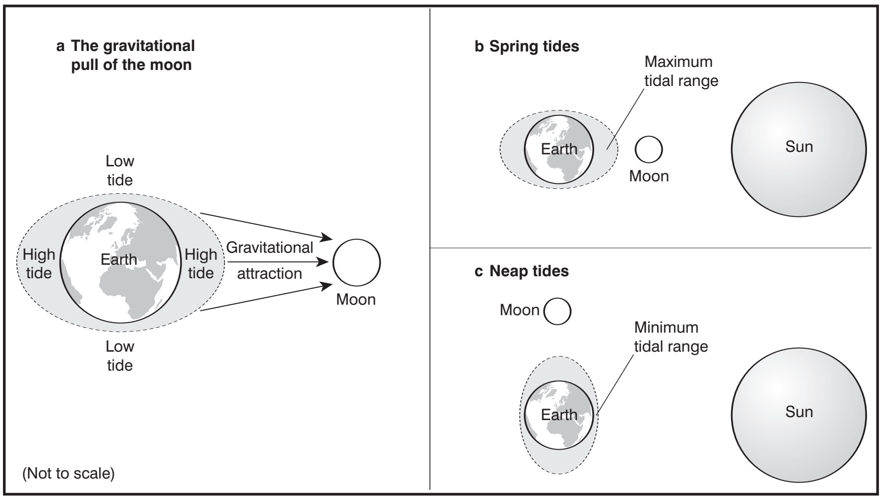


Beach profiles and particle size

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°

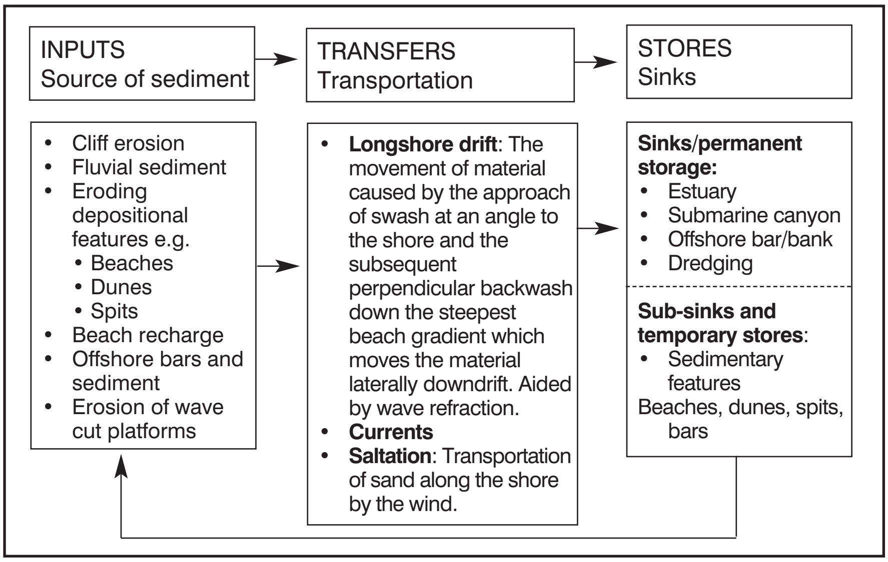
Source: Guinness and Nagle, 2000

Figure 4: Causes of tides



Source: Waugh 1995, p. 130

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



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.

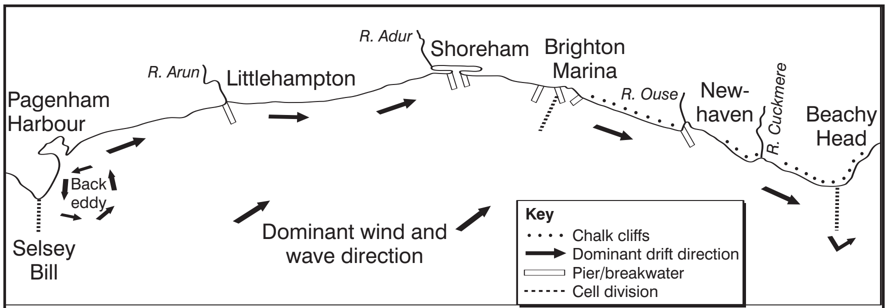
The South Downs sediment cell

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.

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.

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)

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.