Coastal landscapes

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Processes, systems and change

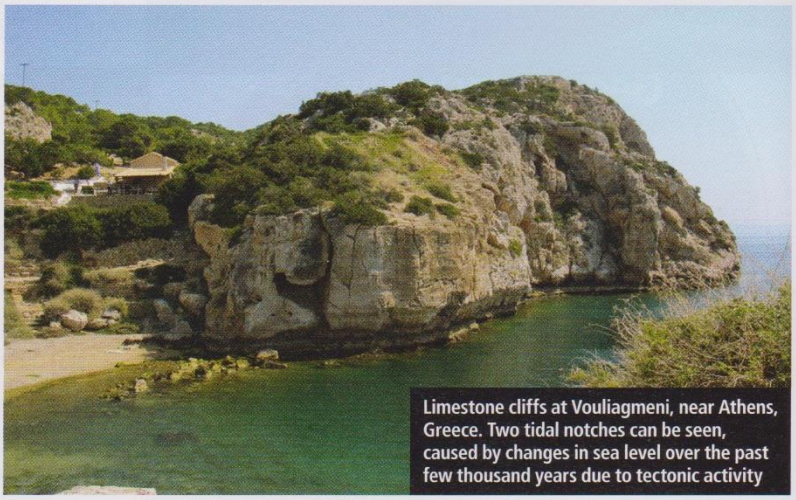
This article provides a clear summary of the processes that create coastal landscapes, and looks at the threats posed by sea-level change. It ends with a case study from the USA of a coastal landscape system under constant erosional change

GeographyReview*Extras*

For a quiz to test your knowledge of coasts go to: www.hoddereducation.co.uk/geographyreviewextras

Coasts are intensely settled areas. About 40% of the world's population lives within 100 km of the coast, and two thirds of the world's largest cities have coastal locations. Development in coastal areas is often faster than overall national development. It is predicted that, by 2100, around 600 million people will occupy coastal floodplain land below the elevation flooded by a 1,000-year return-interval flood.

Understanding **coastal landscapes**, the hazards that exist at the coast and how these will change through time is therefore important. Natural processes such as wave action, flooding, storm surges, coastal erosion and sedimentation can pose hazards to human occupation and use of the coast. However the single most important factor that will cause future coastal change is sea-level rise (see Box 1 and Figure 1). The way that sea-level rise impacts individual coasts depends on the type of coastal landscape and the different processes taking place in that location.



Limestone cliffs at Vouliagmeni, near Athens, Greece. Two tidal notches can be seen, caused by changes in sea level over the past few thousand years due to tectonic activity

Coastal processes

There are three main processes which affect all coasts and determine the **coastal morphology**. These are sea-level changes, waves and currents, and coastal sediment transport.

Sea-level changes

Sea-level changes can occur at intervals from hours to millennia. The shortest variation in sea level is caused by tides. Tides are produced by the gravitational force of the moon and the sun, which cause highs and lows on a daily cycle. Over days to years fluctuations are caused by storm surges, seasonal variations in pressure and changes in weather patterns caused by cycles such as the El Niño Southern Oscillation.

However the most important time scale of sea-level changes for determining coastal morphology is over thousands to millions of years. Ice-sheet growth and decay over many glacial cycles has caused dramatic changes in sea level and has shaped our present-day coastlines. At the last glacial maximum (the peak of the last ice age, 20,000 years ago), global sea level was about 130 m below present. Most of the world's coasts have experienced drowning due to sea-level rise since this time. For example as sea level rises, river valleys discharging into the sea become flooded by long fingers of sea extending upstream, known as rias.

Waves and currents

Over much shorter time scales wind-generated waves and currents are the most important energy input into the coastal zone and are responsible for coastal erosion and sediment transport. The height, length and period of waves increases with wind speed and with the length of time and distance over water that the wind blows. The stormiest parts of the

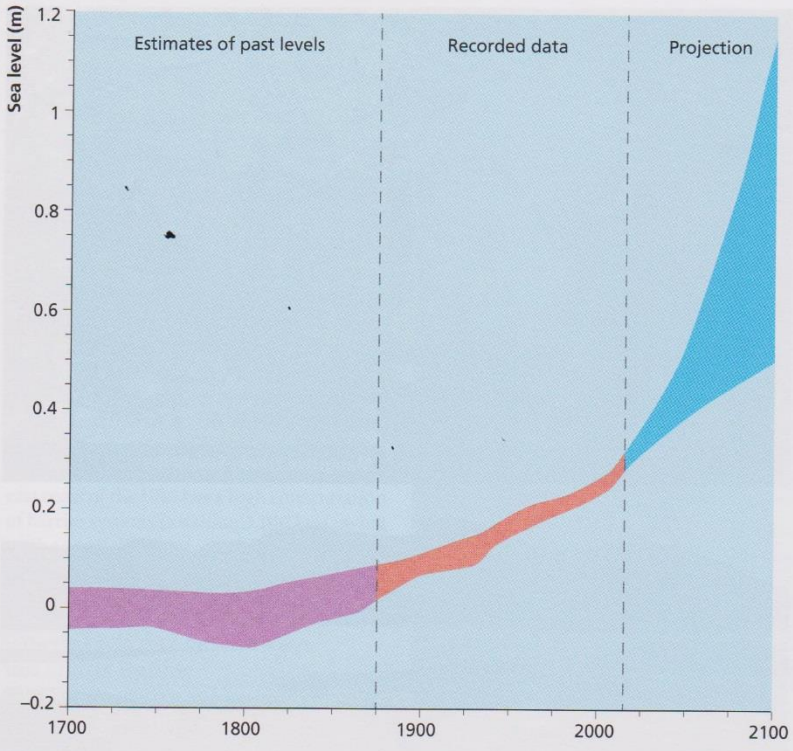
Glossary

Coastal landforms Individual features of the coast such as beaches, dunes, estuaries, cliffs and shore platforms

Coastal landscapes The broad-scale visible features of the coast.

Coastal morphology An intermediate between landforms and landscapes which describes an assemblage of landforms at the coast.

Coastal systems The morphology of the coast plus the processes that cause change.



Source: Fifth IPCC report

Figure 1 Rise in sea level relative to pre-industrial levels, projected for low and high greenhouse-gas emission scenarios

Box 1 Global sea-level rise

Current rates of global sea-level rise are measured by satellite altimeters which accurately record changes in the height of the sea surface over time. Globally, average sea level is rising by 3.4 mm y^{-1}. The Intergovernmental Panel on Climate Change (IPCC) uses models to predict what will happen to sea level in the future. These predict a globally averaged sea-level rise of between 28 and 98 cm between 2014 and 2100 depending on greenhouse-gas emissions between now and then (Figure 1). These figures are global averages, so sea-level rise will vary from one location to another. Note that Figure 1 shows sea-level rise since 1700. It is already around 30 cm above this baseline.

world (e.g. the roaring forties at 40° north and south) have the largest waves and therefore the most energetic coastal environments.

Nearshore currents get their energy from waves breaking. If waves break obliquely to the shore the current will run along the coast, carrying sediment with it. Longshore or littoral drift has a major effect on present-day coastal morphology and causes changes to beaches, bars and spits over hours to decades.

Sediment transport

Erosion, transport and deposition of sediment also determines the present-day morphology of the coast. Sediment is either eroded by waves and currents or brought to the coast by rivers. Coarse sediment is moved alongshore by high-energy waves and currents (longshore drift) and deposited as beaches and bars. Fine sediment moves under lower energy conditions and is deposited in quiet water in estuaries, bays and lagoons, forming mudflats, salt marshes and mangroves.

Coastal landforms

The processes described above produce **coastal landforms** and morphology. There are five main types of landforms found at the coast.

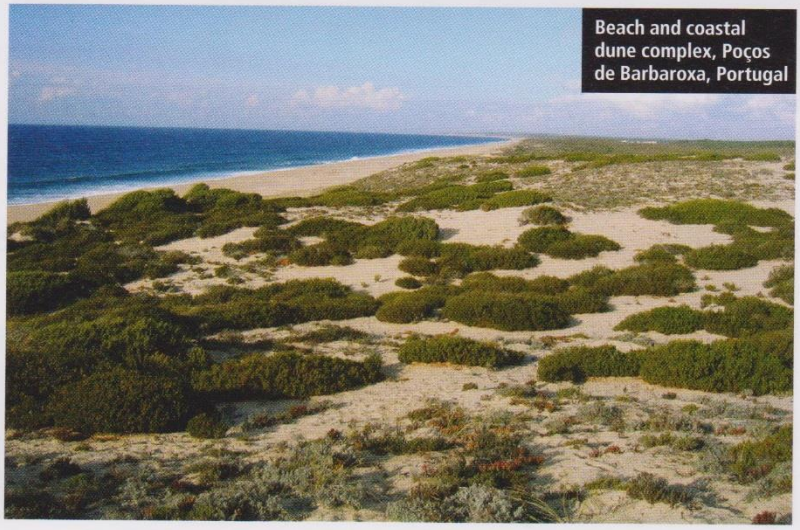
Rocky coasts

Coastal cliffs occur along approximately 80% of the world's coastline. Changes to their morphology occur relatively slowly and sporadically. Most change occurs due to mass movements, such as rockfalls and landslides. Mechanical wave action at the toe of cliffs is the main erosional process in stormy locations where waves are large. Eroded material is removed by waves and littoral drift, leaving a shore platform in the intertidal zone

Spectacular coastal features such as stacks, arches and sea caves are formed by mass movements, particularly where there are differences in the resistance of the rock strata. More resistant rock is left as stacks standing offshore, while the removal of less resistant rock forms sea caves and blow holes.

Beaches and sand dunes

Beaches and sand dunes are part of most coastal landscapes. Sand or gravel from offshore is deposited by waves. There can be a seasonal cycle of beach change, with a steep, well-nourished beach in summer and a flatter eroded beach in winter. Behind the



Beach and coastal dune complex, Poços de Barbaroxa, Portugal

Further reading

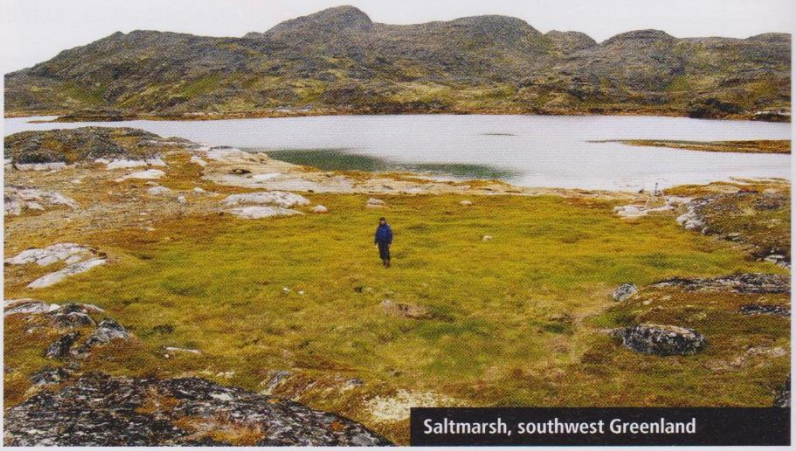
Google maps is a great tool for looking at coastal morphology anywhere in the world (don't forget to turn on the 'earth' function for high resolution satellite imagery).

US Geological Survey, *Coasts in Crisis*: **http://pubs.usgs.gov/circ/c1075/** Covers different types of coasts, coastal change and coastal management in detail.

University of Colorado Sea Level Research Group: **http://sealevel.colorado.edu** Up-to-date information on rates of sea-level rise and the different processes responsible.

North Carolina Coastal Hazards Decision Portal (NC COHAZ): **www.coastal.geology.ecu.edu/NCCOHAZ/** Coastal hazards information portal for the Outer Banks with information on the main hazards and links to reports on the state of the coast.

Mangrove creek, Seychelles



Saltmarsh, southwest Greenland

beach may be coastal dunes. They require consistent onshore wind and a large supply of sand to form. Well-developed dune systems act as a buffer to storms and prevent coastal flooding. Dunes eroded by storms are able to rejuvenate during calm conditions when sediment is brought back onshore by waves.

Salt marshes and mangroves

In low-energy environments such as estuaries and behind barriers salt marsh or mangroves can develop in the upper part of the intertidal zone. Salt marsh consists of salt-tolerant grasses and reeds and is confined to temperate latitudes. In the tropics salt-tolerant trees, collectively known as mangroves, are found instead. Sedimentation rates in salt marshes or mangroves can be so fast that sediment surface can grow upwards faster than current rates of sea-level rise.

Salt marshes and mangroves often occupy valuable coastal land that is reclaimed and redeveloped into farm land, locations for coastal industry or hotel complexes. However they provide a natural coastal buffer to sea-level rise and should be more widely protected.

Coral reefs and atolls

Coral reefs form where the sea is warm (continuously above 18°C) and shallow. Reefs grow from the build-up of large amounts of coral, which secretes calcium carbonate, bonding the coral and other organisms together into a wave-resistant body of limestone.

Coral reef islands (atolls) are formed in the deep ocean around old volcanoes which have subsided through time. The coral builds up on the shoulders of the volcano to form a concentric ring of islands. The volcanic crater in the centre may have long since subsided below the surface of the ocean, forming a lagoon.

Reefs also form in shallow tropical seas and have kept pace with sea-level rise which has progressively flooded the platform. The Great Barrier Reef in northeast Australia is a good

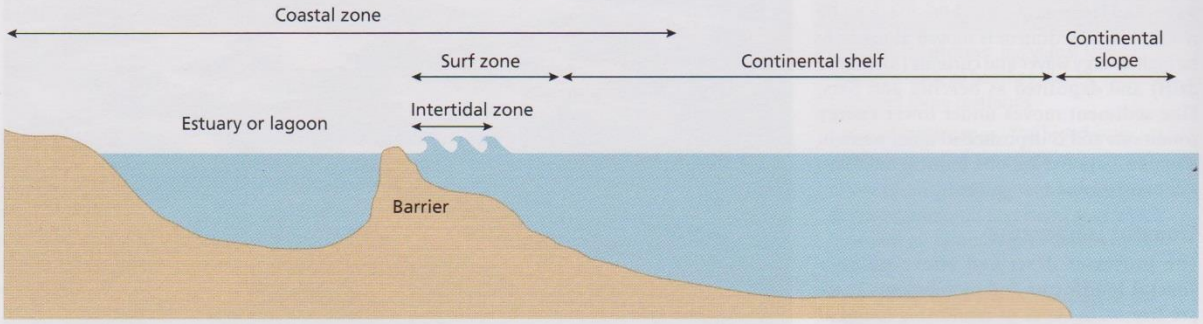


Figure 2 Cross section showing the coastal zone

example of a reef structure on the shallow continental shelf that has kept pace with sea-level rise since the last glacial maximum.

Coastal barriers

Coastal barriers constitute 15% of the world's coastlines. They are really coastal landscape systems rather than landforms, as they contain a series of different landforms including beaches and salt marshes. They consist of long, sandy islands that parallel the coastline, with beaches on their seaward side and salt marshes on their landward side. The protected area between the barrier island(s) and the mainland is called a lagoon (see Figure 2).

They are most common where there is a low gradient continental shelf, abundant sediment supplied from offshore or by littoral drift, and where tidal energy and tidal range are low. The east coast of the USA has a high concentration of barrier systems (totalling 3,100 km) owing to the availability of abundant sand-sized sediment from erosion of the Appalachian mountains.

Coastal barrier case study: the Outer Banks

The Outer Banks is a 300 km string of sandy barrier islands on the coast of North Carolina, USA (Figure 3). It has formed during sea-level rise since the last glaciation. The position of these islands jutting out into the Atlantic means they are often in the path of storms and hurricanes, which move sand onshore from sub-tidal shoals. This coastal system needs sediment to be able to move onshore and to be deposited in deltas just inside the lagoon which build up to become new islands over time (Figure 4).

The islands are a major tourist destination, receiving 2.3 million visitors per year because of opportunities for fishing, water sports and 'ocean-side' holiday rentals. Highway NC12 was built in the 1950s to encourage tourism by linking the islands north of Cape Hatteras together. This has had a detrimental effect on natural coastal processes. Because there are few inlets into the lagoon, sand can't be deposited and island-building has stopped. The islands have narrowed and erosion of the highway and ocean-front residential areas is a constant problem. The government spends millions of dollars each year nourishing beaches, building dune ridges and deploying sand bags to hold the coastline in place. Is

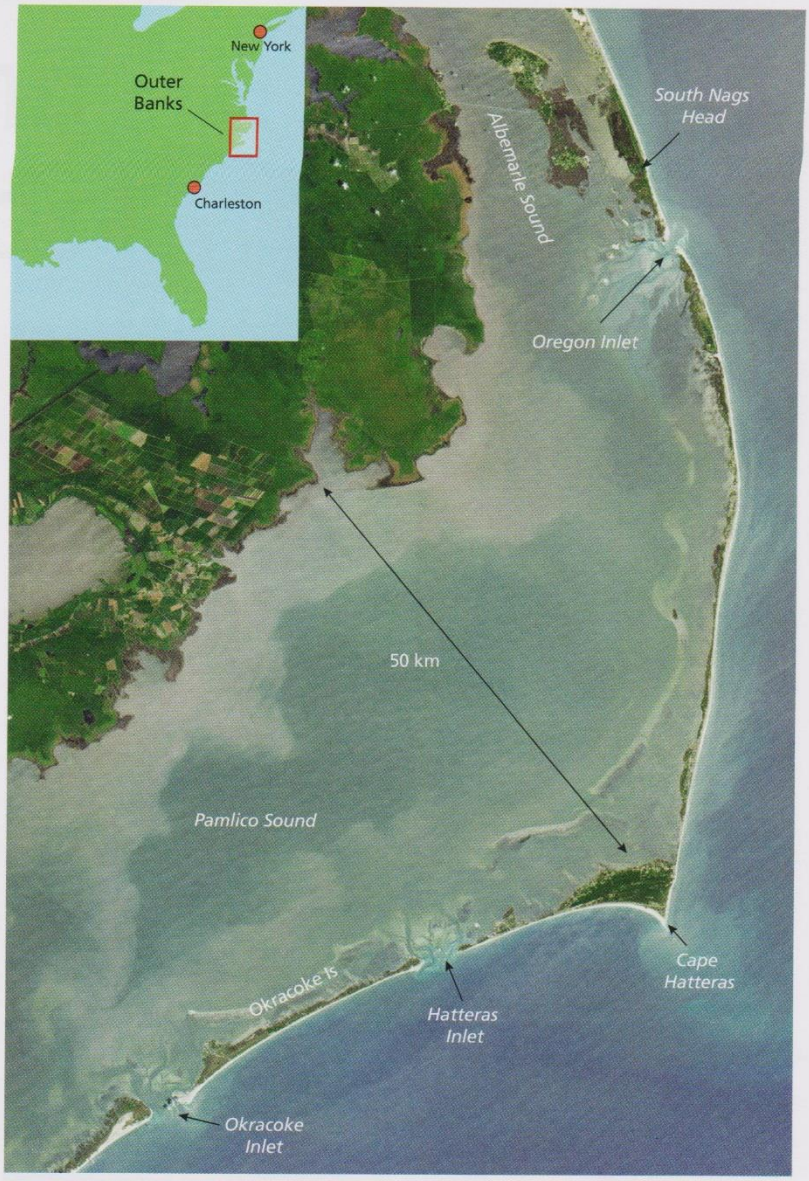


Figure 3 Aerial view of the Outer Banks showing the barrier islands and major inlets

A dune field built to protect highway NC12 on the Outer Banks. The beach on the left is the open coast and the water to the right is Pamlico Sound. At this point the barrier island from the top of the beach to the salt marsh in the lagoon is only about 100 m wide

'Ocean-side' properties at South Nags Head on the Outer Banks. Because of coastal erosion these properties were in the surf zone in 2008 when this photograph was taken but were still being offered as vacation rentals so long as their septic tanks were still connected. By 2016 they had been condemned and demolished

this approach sustainable in the long-term, especially under future sea-level rise?

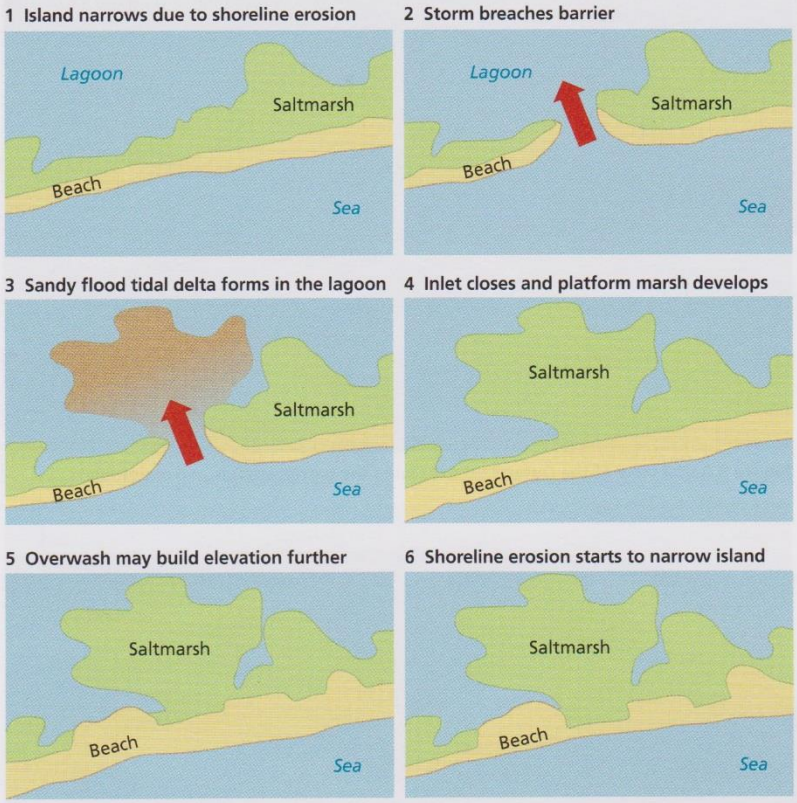
What is the solution?

If coastal management was stopped and the coastal highway was breached, the barrier islands would rejuvenate naturally as storms brought sand from offshore. The continuous barrier would probably break up into a series of larger barrier islands with inlets between them which could be marketed as destination villages linked by high-speed ferries. However local people argue that ferries couldn't keep pace with the number of visitors wanting access to the islands. They prefer to continue with expensive beach nourishment projects which are paid for by local taxes.

The future of the Outer Banks is uncertain, but the cost of artificially maintaining the area with a continuous highway will continue to increase, as erosion and island narrowing are intensified by sea-level rise.

Questions for discussion

1 What are the main factors controlling coastal cliff erosion?
2 Under what conditions do barrier-island coasts form? What are the typical features of this type of coastline?
3 Why will sea-level rise in the twenty-first century not be the same everywhere?
4 What are some of the problems with using hard engineering structures for coastal protection?



Source: North Carolina Coastal Geology Cooperative Research Program

Figure 4 Successional stages during barrier inlet and barrier island evolution

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Key points

- Coastal landscapes are made up of a series of landforms.
- The dominant processes acting on global coastal landscapes are sea-level changes, waves and currents, and sediment transport.
- Sea-level changes since the last glacial maximum have shaped the overall coastal landscape while waves, currents and sediment transport act at smaller and shorter scales.
- Coastal cliffs make up 80% of the world's coastline but change occurs here slowly and sporadically.
- Coastal barriers make up 15% of the world's coastline. Barriers are really coastal systems that contain beaches, sand dunes, salt marshes and lagoons.
- In the tropics coral atolls form in the deep ocean around subsiding volcanoes. They are relatively rare but have a spectacular morphology.