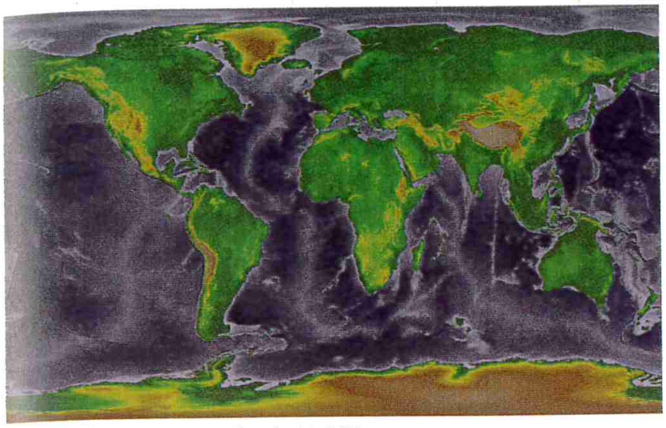

Figure 3.33 Global sea levels 18,000 years ago

A typical sequence of sea level rise to reflect the advance and retreat of the ice would have run as follows:

- **Stage 1:** As the climate begins to get colder, marking the onset of a new glacial period, an increasing amount of precipitation falls as snow. Eventually, this snow turns into glacier ice. Snow and ice act as a store for water, so the hydrological cycle slows down – water cycled from the sea to the land (evaporation, condensation, then precipitation) does not return to the sea. As a consequence, sea level falls and this affects the whole planet. Such a worldwide phenomenon is known as a **eustatic** fall.
- **Stage 2:** The weight of ice causes the land surface to sink. This affects only some coastlines and then to a varying degree. Such a movement is said to be **isostatic** and it moderates the eustatic sea level fall in some areas.
- **Stage 3:** The climate begins to get warmer. Eventually the ice masses on the land begin to melt. This starts to replenish the main store and sea level rises worldwide (eustatic). In many areas this floods the lower parts of the land to produce **submergent** features such as flooded river valleys (rias) and flooded glacial valleys (fjords).
- **Stage 4:** As the ice is removed from some land areas they begin to move back up to their previous levels (**isostatic** readjustment). If the isostatic movement is faster than the eustatic, then **emergent** features are produced such as raised beaches. Isostatic recovery is complicated as it affects different places in different ways. In some parts of the world it is still taking place as the land continues to adjust to having masses of ice removed. Today, the southeast of the British Isles is sinking while the northwest is rising. This reflects the fact that the ice sheets were thickest in northern Scotland and that this was the last area in which the ice melted.

Figure 3.34 shows how the sea level rise from 18,000 to 10,000 years BP was beginning to make the coastline of Western Europe recognisable. However, there were still significant land bridges, especially the extensive grassy plain that stretched between the southern Baltic and eastern Britain (known as Doggerland).

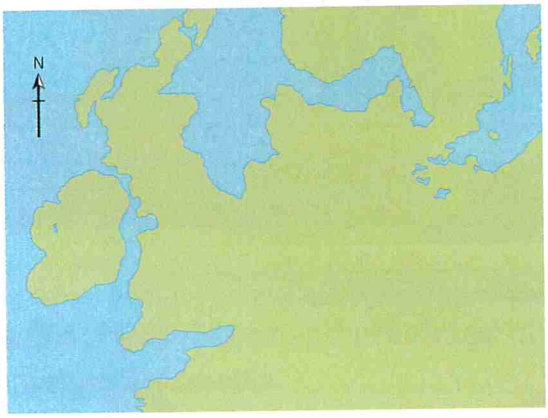

Figure 3.34 The coastline of Western Europe 10,000 years ago

Skills focus

There is an opportunity here to research the British coastline to identify examples of emergent and submergent sections of coast.

Coastlines of submergence and emergence

As mean global temperatures continue to rise, there is an inevitable consequence for sea levels. As more standing ice melts, particularly in Antarctica and Greenland, fresh water will be released into the oceanic store. This could have serious implications for many islands in the Indian and Pacific Oceans and for low-lying coastal areas.

Submergent features

Rias are created by rising sea levels drowning river valleys. The floodplain of a river will vanish beneath the rising waters, but on the edges of uplands only the middle- and upper-course valleys will be filled with sea water, leaving the higher land dry and producing this feature. In Devon and Cornwall, for example, sea level rose and drowned the valleys of the rivers flowing off Dartmoor and the uplands of Cornwall. Good examples are the Fowey estuary in Cornwall and the Kingsbridge estuary in south Devon. Rias have a long section and cross profile typical of a river valley, and usually a dendritic system of drainage (Figure 3.35, page 114).

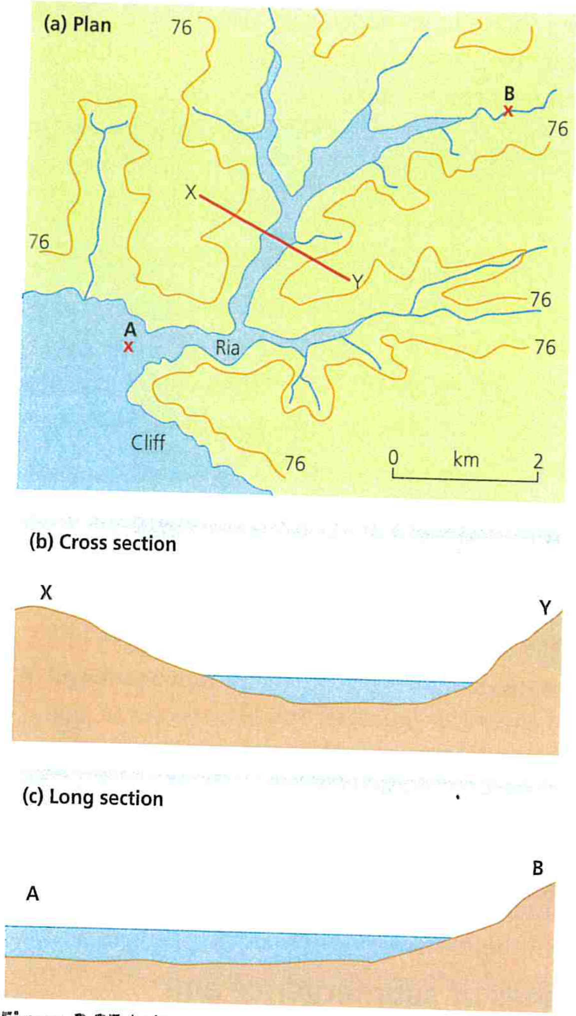

Figure 3.35 A ria

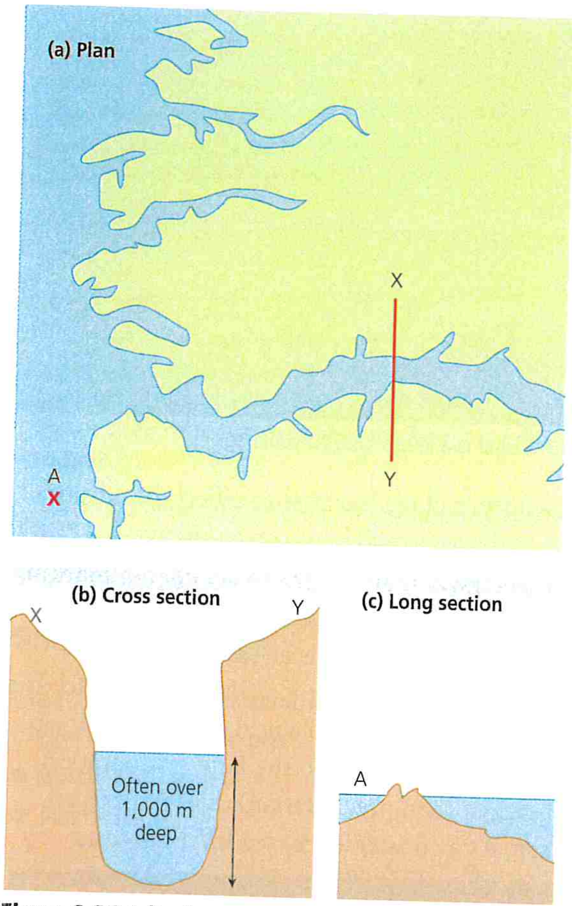

Figure 3.36 A fjord

Fjords are drowned glacial valleys typically found on the coasts of Norway, southwestern New Zealand, British Columbia in Canada, southern Chile and Greenland. The coast of western Scotland contains fjords which are not as well developed as those in the areas above because the ice was not as thick and did not last for the same length of time.

Fjords have steep valley sides (cliff-like in places) and are fairly straight and narrow (Figure 3.36). Like glacial valleys, they have a typical U-shaped cross section with hanging valleys on either side. Unlike rias, they are not deepest at the mouth, but generally consist of a glacial rock basin with a shallower section at the end, known as the threshold. They were formed when the sea drowned the lower part of glacial valleys that were cut to a much lower sea level. The threshold is thought to be due to reduced glacial erosion as the glacier came in contact with the sea and the ice became thinner. Good examples include Sogne Fjord in Norway, which is nearly 200 km long, and Milford Sound in New Zealand (Figure 3.37).

Figure 3.37 The entrance to Milford Sound fjord, New Zealand

Where the topography of the land runs parallel to the coastline and becomes flooded by sea level rise a **Dalmatian coast** is formed. Deriving their name from the Croatian coast in the Adriatic, the flooded valleys run parallel to the coast rather than at *right-angles* to it as in the case with fjords and rias. Here islands and peninsulas are aligned parallel to, but just offshore from, the mainland.

Skills focus

Use an atlas to find a map of the Adriatic Sea and draw and annotate a sketch map of the Dalmatian coastline of Croatia.

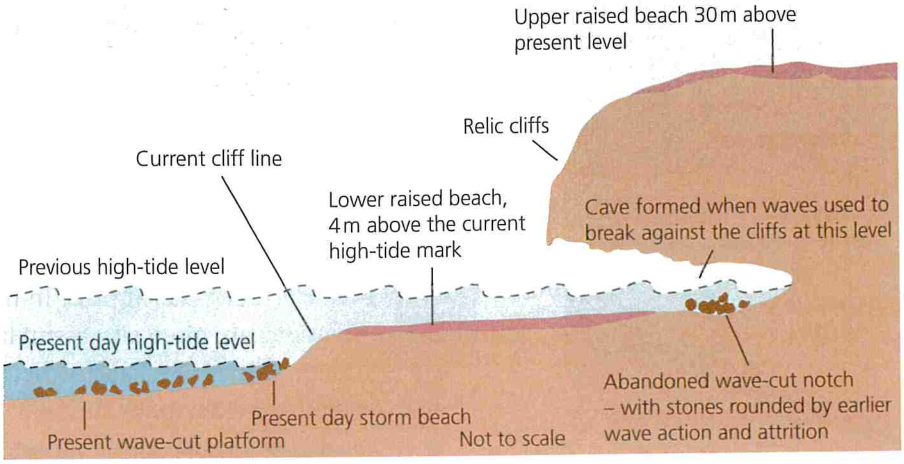

Figure 3.38 A simplified diagram of a raised beach

Emergent features

Raised beaches are areas of former wave-cut platforms and their beaches, which are at a level higher than the present sea level. Behind the beach it is not unusual to find old cliff lines with wave-cut notches, sea caves, arches and stacks. Raised beaches are common around the coasts of western Scotland where three levels have been recognised, at 8 m, 15 m and 30 m. Because of differential uplift these are only approximate heights.

On the west of the Isle of Arran there is a well-developed raised beach north of Drumadoon. This has a **relict cliff**, arches, stacks and caves, including the well-known King's Cave. This beach is around four or five metres above present sea level and is probably the equivalent of the lower raised beach in Figure 3.38. It was clearly produced when the sea was at that level, which initially suggests that the sea has fallen to its present level. However, we know that sea levels have *risen* considerably (eustatic) since the end of the last ice age, so the beach must have reached its raised position by isostatic rising of the land. The land locally must have risen faster than the eustatic rise in sea level to create this phenomenon.

Where a greater expanse of gently sloping formerly submerged land has been exposed by uplift or the lowering of sea levels, some geographers refer to this feature as a **marine platform**, or marine terrace. (Some see these terms, along with coastal terrace and perched coastline as interchangeable with 'raised beach'.) One distinction between a raised beach and a marine platform may be that in a marine platform what is now exposed is part of a gently sloping continental shelf, whose gentle gradient is now continued for some distance both offshore and inland.

Impacts of recent and predicted climate change on coasts

Sea level has been rising consistently over the last 10,000 years. In recent millennia it has risen quite slowly (about one or two millimetres per year), but the rate has increased recently to about four or five millimetres per year. The rate of rise in the future is uncertain with average predictions varying between 18 and 59 cm compared to 1990s levels by 2090.

Key question

Why do you think there is such uncertainty in the predicted sea level change by 2090?

Changes in sea level are the result of two processes:

- increases in the volume of the ocean
- subsidence of the coast.

There are two ways in which the volume of the ocean is increasing. First, and most obviously, as the Earth's climate warms, both naturally and due to current warming related to greenhouse gas emissions and a human-induced enhanced greenhouse effect, water currently stored on the surface as ice is released into the oceans as it melts. Second, as temperatures warm there will be thermal expansion of the oceans. Scientists have been improving their understanding of the impacts of both thermal expansion and the melting of ice caps and smaller valley glaciers, however, what is proving more difficult to predict is how the massive ice sheets will behave during future warming. This, alongside the complexity of the modelling involved,