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River Rejuvenation

River rejuvenation is associated with increased energy experienced by a river. This **Geofile** looks at:

- causes of rejuvenation
- landforms of rejuvenation.

Two short case studies are presented: one of past rejuvenation in the Nile basin, on a large scale, and a present-day small-scale study of the River Gwash in Rutland.

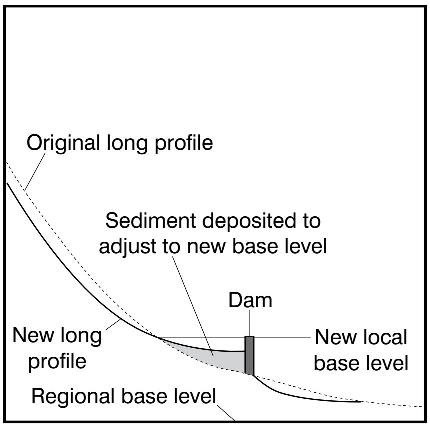
Causes of rejuvenation

There are three main causes of rejuvenation in rivers:

1. dynamic change
2. eustatic change
3. static change.

Both dynamic and eustatic changes affect the **base level** of a river. The **base level** is the lowest point to which a river can flow and erode. Usually it is sea level, the ultimate base level, as rivers cannot erode lower than this. The River Jordan is unusual in that its base level is the Dead Sea, 417m below sea level. **Local base levels** occur when a river meets a larger river, or discharges into a lake or a reservoir. In this case, the local base level would be the larger body of water into which the river flows. With the building of a reservoir, the river finds itself with a new local base level, and adjusts its profile, building it up by deposition upstream of the dam, and eroding downstream of the dam (Figure 1).

Figure 1: Adjustment of long profile following dam construction



Source: www.earthsci.org (Adapted from Prof. S.A. Nelson, Tulane University, Australia)

Rejuvenation involves a lowering of the base level. This can be either a *relative* change in base level, ie sea level stays the same but land levels rise (isostatic change), or an *absolute* change in base level where the sea level itself falls (eustatic change).

1. Dynamic changes

Dynamic changes involve a movement upwards of the land which raises the height of the river above sea level, its base level. This increases the gravitational potential of the river and so increases the energy available to the river to erode and transport material. Two mechanisms which cause land levels to change are

- orogenesis
- isostatic rebound.

Orogenesis
Plate movement is responsible for compressing and thickening the crust at convergent margins. This compression results in mountain-building – orogenesis – and is responsible for the linear belts of the Alps, Andes and Himalayas. The uplift accompanying this mountain-building effectively lowers base level, and rivers begin active downward erosion. Movement of the land upwards, usually along faults, involves a steepening of the river gradient and an increase of energy. In the foothills of the Himalayas, the Siwalik Hills, downwards erosion is about 10–15mm/yr.

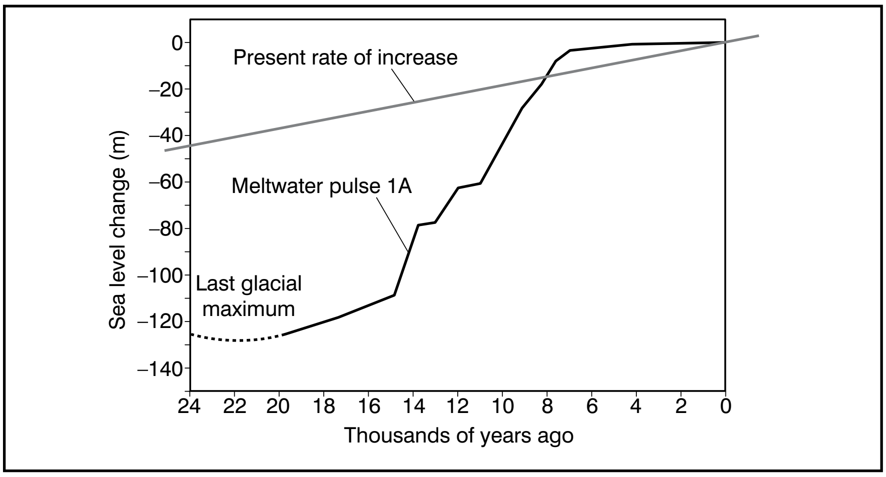
Isostatic rebound
During the last ice age, which reached its peak about 18,000 years BP (last glacial maximum), huge ice sheets covered the northern and southern land masses. Estimates of ice thickness for the North American (Laurentide) ice sheet and the Northern Europe (Fenno-Scandinavian) ice sheet) are uncertain, but estimates indicate that the North American ice sheet was about 3000m thick and the centre of the European ice sheet about 2700m thick. These large 'domes' of ice thinned towards their edges. In Western Scotland, in Arran, for example, ice thickness had thinned to about 600m above present-day sea level. Land higher than this was exposed to freeze-thaw conditions and is much more angular compared to the ice-smoothed surfaces at lower levels. The massive weight of the ice was enough to depress the crust underneath. Roughly speaking, for every 3 metres of ice, the crust was downwarped by a metre. In the centre of these sheets, the crust would have been forced down by almost a kilometre. This crustal depression was accommodated by the flow of the mantle asthenosphere away from the centre of the depression. When the ice sheets melted, about 10,000 years BP, this removed a huge weight from the crust, and the mantle started to flow back, pushing up the crust. Initial rates of rebound were quite quick, several centimetres a year but this has since slowed to about 9mm/yr at present for the area around the Gulf of Bothnia. So far, Scandinavia has risen by more than 800m ('The world isostatic rebound', *New Scientist*, 11 Jan 2003). This uplift of land increases the height of the land above sea level and rejuvenates rivers in the area.

2. Eustatic changes

Eustatic changes affect the volume of water in the oceans. In the case of rejuvenation, this means an actual fall in sea level or base level. Changes in sea level brought about by the growth or decay of the ice sheets are called **glacio-eustatic** changes, to distinguish them from other eustatic changes which may result from variations in the capacity of the ocean basins.

The growth of the ice sheets at the beginning of the last glaciation about 25,000 years BP interrupted the global water cycle by locking up precipitation as ice in glaciers and ice sheets. Although some water did return to the oceans as meltwater, the amounts removed through evaporation far exceeded this and sea levels fell. It is thought that sea levels at the last glacial maximum were about 125m lower than today's levels. This represents a substantial drop in base level and subsequent rejuvenation as rivers cut down to this level. Figure 2 shows the rise in sea level from the last glacial maximum.

Figure 2: Post-glacial sea level rise



Source: Wikipedia/www.theoildrum.com

Case study: the Nile – rejuvenation during the Messinian Salinity Crisis

Between 5.8 and 5.5 million years ago, the Mediterranean was isolated from the rest of the world's ocean water by a combination of lowered sea levels and tectonic movements. Although sea levels fell by about 60m, this would have been insufficient to close the links with the Atlantic. It is thought that tectonic uplift raised the land, forming a dam between the Atlantic and the Mediterranean. This isolation allowed the Mediterranean to gradually dry up, leaving behind salt layers up to 2 km thick in places: evaporite deposits formed as a precipitate from the evaporation of sea water. This period is called the Messinian Salinity Crisis. A deepwater sea (the Mediterranean is on average 1.5 km deep and over 5 km at its deepest) could only have evaporated if the basin was isolated, as, in ordinary circumstances, deep oceans never lose enough of their water to form evaporites.

The evaporation of the sea water meant that in the Mediterranean, sea level fell, and rivers running into this deep basin had to adjust to the new base level (the new 'lowstand') by cutting deep canyons. These canyons and gorges are found 'linked to the mouths of modern rivers around the Mediterranean' ('The Messinian Salinity Crisis', from the November 2005 issue of €U(RO)CK (OUGS Mainland Europe)). The Nile itself had cut down a gorge some 2500m deep at Cairo. At Aswan, when building the dam, it was found that the old river channel had cut a gorge in the granite several hundred metres below sea level. The Mediterranean refilled about 5.3 million years ago and the rivers readjusted by filling these gorges with sands and gravels.

3. Static changes

These do not involve changes in base level, but are the result of the river's ability to erode more, due to:

- changes in the load transported by the river
- increase in discharge due to increase rainfall
- increase discharge through river capture.

Changes in load

During glacial times, braided meltwater streams carried large volumes of material and redeposited them in wide, open valleys. The high discharges of the meltwater and unconsolidated nature of the glacial deposits made eroding this material easy and so large volumes of debris were carried and eventually deposited over river valleys, building up their height. Since deglaciation, the load of these rivers dropped and this meant that rivers could now employ their energy, which had previously been used in carrying material, to erode. Although their discharge, and also their ability to erode had dropped, it was the lack of load that enabled them to erode their valleys, albeit slowly. The drop in load was also brought about by the warming post-glacial climate which meant that vegetation was able to establish itself. This contributed to reducing the load by stablising the former bare surfaces and slowing down the delivery of debris from the sides of the valley where periglacial mass movement had previously contributed large volumes of debris to the river. The elevated levels of their floodplains also gave the rivers added energy to cut down through the fluvio-glacial sediments to try and establish a graded profile. In doing so they created a number of features typical of rejuvenated landscapes.

Increase in discharge

Discharge may vary due to climate change. Additional flow brings more energy with which the river can erode and transport material (increased precipitation) or by one river capturing another. This may mean a progressive lowering of the long profile as vertical erosion is dominant in the upper course of the river. The changes will become less obvious downstream as the difference in height between the old and the new, readjusted profile, become less evident.

Landforms of rejuvenation

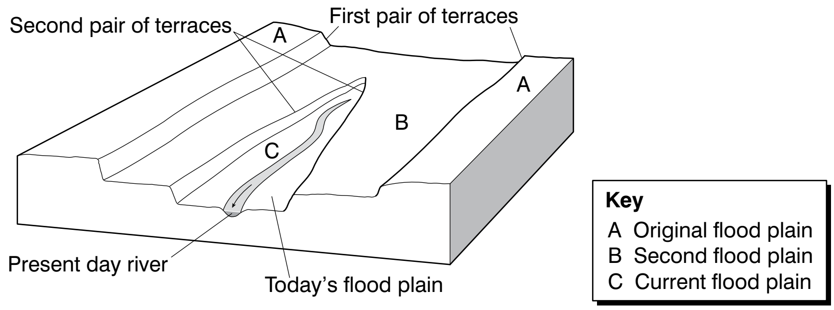
Rivers erode, transport and deposit material throughout their course. Over time, they lower the gradient and smoothe out irregularities. By lowering the profile over time, the river will reduce its energy, and the energy it has will only be enough to transport material. There won't be enough energy to erode, whilst at the same time there will be too much speed to allow the river to deposit debris. When the river reaches this state of balance, it is said to be graded and the gradient of the river remains stable. Although the gradient may be stable, material is still being transported downstream and replaced when it is removed. In long section, the river has a concave profile which has a gradual decrease in gradient.

Any rapid change in the gradient of a river, whether graded or otherwise, brings about changes which affect the whole of the river's course. In response to this change, the river will adjust its profile to try and bring it into line with the new base level, creating a new concave long profile. As a result of this, a number of features in river valleys are created by the reactivation or rejuvenation of the river as its processes become dominated by erosion once again.

There are three types of landform:

- terraces (paired, unpaired and types of terraces)
- knick points (waterfalls, rapids)
- incised meanders (entrenched, ingrown).

Figure 3: Paired river terraces



1. Terraces

Terraces are the level 'steps' that are seen on the sides of river valleys which mark the level of the old floodplain. Terraces can be continuous; they are seen as long benches stretching along the valley. The surface may 'dip' or slope downstream at the same angle as the present-day floodplain, but if uplift has been uneven, then it may differ. Younger terraces, nearer the present-day floodplain, are more likely to be continuous, whereas older terraces will have suffered more erosion and have sections missing.

Terraces can be formed through either dynamic or climatic causes. In either case, the river will cut down, eroding the old floodplain and leaving it above the new floodplain, and beyond the effects of flooding. In the case of tectonic causes, the extra energy enables the river to incise the old floodplain. In climatic cases, it is the reduction of load and the discharge: sediment ratio that increases which gives the river extra energy to cut down. Terraces are described as **paired** or **unpaired.**

Paired terraces

Paired terraces are levels on either side of the floodplain which are the same height. There may be several pairs of terraces on the floodplain, like a flight of steps with their corresponding terrace on the other side (Figure 3). With the decline in discharge common to many rivers after deglaciation, rivers changed their form from braiding to meandering. Meandering involves lateral reworking (erosion on the outside of the bend and deposition on the inside) of sediments on the floodplains. If downcutting of the river was quicker than lateral migration, it would have been quick enough to erode both sides of the floodplain equally, producing two terraces at the same level on either side of the river valley. There may have been discrete episodes of downcutting to produce the pairs of the terraces, which may have come about through episodic falls in base level. The Thames has two paired terraces, the Boyn Hill, being the higher and older, and the Taplow terrace lower down which are found on both sides of the river. The Boyn Hill terrace is found at Clapham Common on the south side and King's Cross on the north side of the Thames.

Unpaired terraces

Unpaired terraces form when lateral migration is dominant compared to incision. This is particularly clear in wide valleys where meander migration has taken place. Meandering rivers may cut down quite slowly, in which case, the meander migrates across the floodplain, eroding one side and then the other. By the time the meander has migrated back to the original side of the valley, sufficient uplift has occurred and will enable the river to cut down to a new, lower level and in so doing create another terrace, a step below the first one, but not on a level with the second terrace. This happens when downcutting is uninterrupted and there is a **slow fall** in base level.

2. Knick points

Eustatic changes usually affect the river's long profile from the mouth and rejuvenation focuses on the lower course. As the river cuts down and readjusts its profile to its new base level, it will come to a point upstream where the new 'readjusted' profile meets the older profile. This forms a sharp increase in gradient called a **knick point**, which can show itself as a waterfall or rapids. These will move back upstream by headward erosion as the river adjusts to a new energy balance. The Beezley Falls on the River Greta in Yorkshire are an example. The Horseshoe Falls on the Niagara in Canada have retreated by 11km in 10,000 years (over a metre a year), producing a long gorge as it does so. Gulfoss in Iceland has also cut a gorge during its retreat.

3. Incised meanders

If meanders are already established on the floodplain, then downcutting will result in **incised meanders,** which can cut down several metres below the old floodplain. There are two types of incised meander:

- entrenched meanders
- ingrown meanders.

Entrenched meanders

Entrenched meanders are those which cut down vigorously. Uplift is more rapid than downcutting, and as a result the river produces a symmetrical valley cross-section and the river is found at the bottom of a winding gorge. In this instance there is no meander migration, so the valley sides are symmetrical. The entrenched meanders of the San Juan River, a tributary of the Colorado, show this well. The valley sides are kept steep by a combination of downcutting, the hard rock and lack of weathering and mass movement in this dry region.

Ingrown meanders

Ingrown meanders have both components of downcutting and lateral erosion. They form when uplift or incision is gradual and this gives the meander time to shift sideways and so produce an asymmetric cross-section. This has a gentle slip-off slope and a steep river cliff, an enlarged form of the meander. Examples are on the River Wye at Tintern, South Wales.

Case study: River Gwash, Rutland

The River Gwash runs through the village of Braunston in Rutland and thence into Rutland Water. It is a small stream flowing in a valley which shows clear evidence of rejuvenation. During the last glacial maximum, ice covered most of Britain and Ireland, but extended further south in the west of the country, with most of Wales under ice, while most of the Midlands was ice-free. During this time there was probably considerable aggradation of many river valleys that carried

Figure 4: The River Gwash looking east; Braunston village and its church are visible in the distance

meltwater from the ice sheets, due to a combination of:

- variable but high discharge
- high debris loads
- lack of vegetation.

The area immediately south of the ice was probably tundra and may have resembled Siberia today, with a relatively restricted vegetation cover. The rivers that flowed over this tundra were probably **braided** and similar to those we see today in Alaska and would have carried large quantities of sediment, some of which is seen in a layer exposed in the river cliffs.

With the drop in discharge the river has changed to a meandering channel and it has cut down into the deposits, removing much of the sediment, leaving the old floodplains as terraces. In this instance, only the most recent paired terrace has survived whilst the older terraces have been eroded away. The river's downcutting has been quite slow, as marked by the ingrown meander.

Since then, there may have been episodes of erosion and deposition to produce today's landscape. The building of Rutland Water has produced a new, localised, base level which will limit the depth of incision by the streams which feed into it, in a manner similar to Figure 1.

Figure 4 shows a **paired terrace** on the River Gwash, marked by the tree on the left and the remains of a cross-country jump on the right, and **ingrown meanders**, one of which has cut into the paired terrace producing an enlarged river cliff. The students are standing on the remains of an **older terrace** which rises about 3–4m above the paired terrace. A part of this older terrace is seen sloping down gently from the right. River flow is away from the camera, to the east. The left paired terrace shows evidence of erosion by tributary channels which have cut down to the same depth as the present day channel.

Focus Questions

1. Using Figure 4, make a simple line sketch of the area. Label the following: river cliff, slip-off slope, ingrown meander, floodplain, river flow direction (indicate with arrow), paired terrace (left and right), earlier terrace.

2. Draw a simple diagram of the water cycle without the influence of ice. Draw a second diagram to explain how the development of ice sheets leads to eustatic falls in sea level by interrupting the flow of water in the water cycle.

3. Explain why a landscape, which appears to have few indications of rejuvenation, may, in fact, have a complex history of rejuvenation.

4. Make a table with two columns, one headed **fast downcutting,** the other **slow downcutting.** Put the following four landforms in the correct column of the table: paired terraces, unpaired terraces, entrenched meanders, ingrown meanders. Explain your choices.