

The Middle and Lower Course

Meanders

Once a river reaches relatively flat ground, it tends to form a relatively broad channel that slowly wanders back and forth like a snake. The **sinuosity** of a river is a measure of how 'bendy' it is. We call a bend in a river a meander. Meanders tend to occur at regular intervals along the river channel, depending on the flow rate. The higher the flow rate, the greater the distance between meanders tends to be. This average distance between meanders, for a given river, is known as the **meander wavelength** and is typically about ten times the channel width. Straight river channels are rare and straight channels eventually erode into meandering channels

Formation of meanders

The mechanism of meander formation is incompletely understood. However, an exam question might well ask you to explain how meanders form, in which case you have to be able to give the scientific theory of meander formation as we currently understand it. For meanders to form the river must have a low gradient (i.e. the channel must be relatively flat) and the banks have to be easily eroded.

The nature of the surface that the river flows over probably influence meander formation to a degree, for example, a slightly harder area in the river bed or one of its banks might put a slight kink in the river which grows into a meander. However, it is **inadequate to simply say that a river bends whenever it meets an obstacle or hard bit of rock**. Meandering is largely an inherent property of rivers themselves, regardless of the surface they flow over or cut through.

Look at fig(). Imagine beginning with a straight river. If this river is to meander then it must somehow preferentially erode the river bank on the outside of the mender and fill it in on the inside. Once a slight kink or bend in a river forms then the water velocity on the outside of the bend becomes higher than that on the inside.

Q. Why is the velocity highest on the outside of the bend?

A. Because the water here has further to travel if the river is to stay in one piece and so accelerates around the bend, whilst water inside the bend decelerates!

This increased velocity on the outside bend causes the meander to grow in **amplitude** by scouring away at the outer bank. **Helicoidal flow** contributes to this process. When a liquid flows around a curve, it naturally develops an internal helical motion (a helix is a corkscrew shape). (Such internal flows are called **secondary flows**, because they are secondary to the main flow of the water, which is turning around the bend, and so from the banks the helicoidal flow would not be visible, but if you were swimming in the water you would feel the helical currents). This helical flow tends to erode (scour) the outer bank of a meander and deposit transported materials on the inner bend. Furthermore, the flow velocity is lower in the inner bend, which also encourages the water to deposit transported material, as it loses the kinetic energy to carry this material.

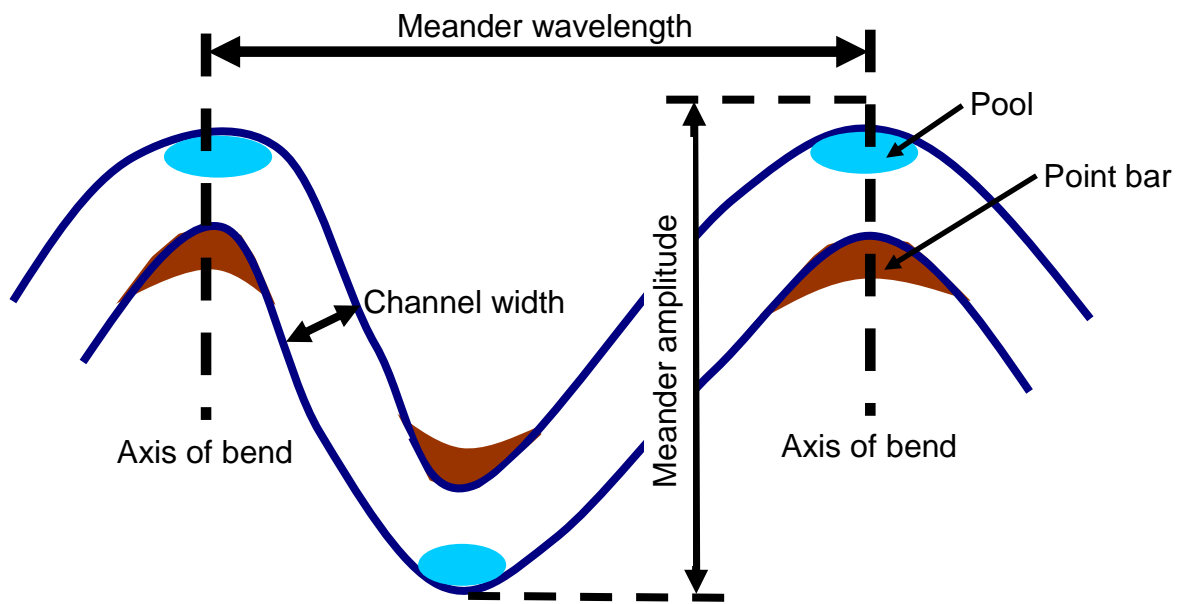
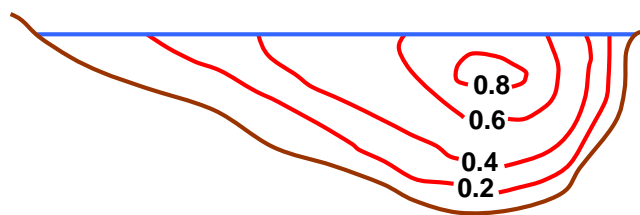
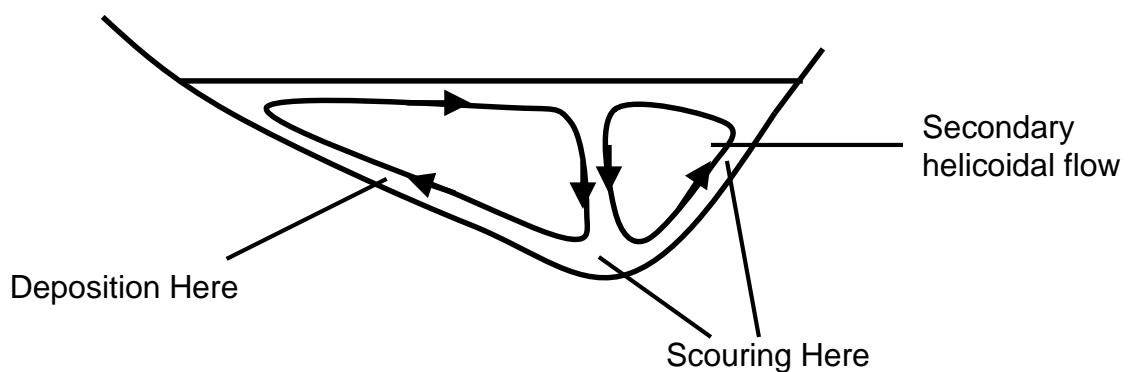


Fig. 1. Anatomy of a meander. The deposit of sand and gravel on the inside of the meander bend is called a **point bar**. The scouring or cutting back (erosion) of the outer bank also tends to scour out and deepen the river bed here to form a depression in the river bed, called a **pool**. The **meander wavelength** is the distance from one meander to another, and the **meander amplitude** is the overall width of the meandering channel.

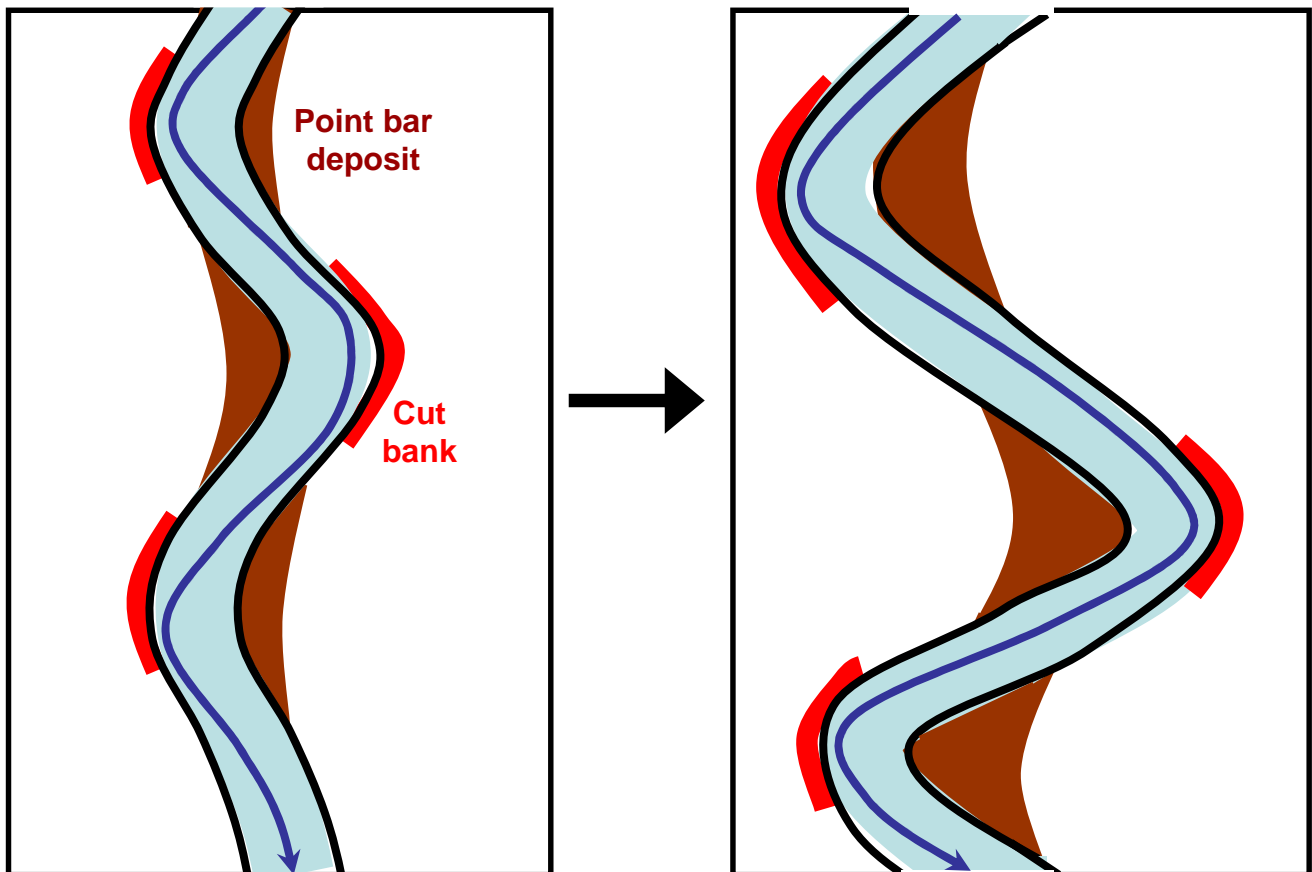


Isovels in m.s^{-1}



You should now have realised that it is easier to describe how meanders enlarge, once they have formed in the first place, than it is to say how they are initiated. The diagram below summarises how a meander will enlarge over time.

Fig. 2. Lateral meander growth and downstream migration



The regions in brown, in the above diagram (Fig. 2), represent sediment deposited along the inner bend of each meander as it migrates. These deposits are called **point bars**. As the channel continues to migrate, the old position of a point bar is preserved as a system of **ridges and swales** (depressions) referred to as **scroll bars**. The migrating meander also cuts into the bank on the outer bend, called the **cut bank**.

The secondary currents bring surface water to the river bed and carry bed water back to the surface. This allows the surface water to pick up river bed sediment from the outer bend, transport it to the inner bend and deposit it there. Look at figure 4 of p.25 of BP. You will notice that this diagram of a cross-section through a meander looks more like the one in Fig. 3A below, and not like the one shown above, which is shown again in Fig. 3B below. The meander in Fig. 3A has just a single 'cell' of secondary flow corkscrewing along and scouring out the meander, just like the one in BP; whilst the meander in Fig. 3B has two cells of secondary flow that scour the meander because they are fast and convergent. Notice that one of the cells is much smaller than the other and so Fig. 3B almost resembles Fig. 3A.

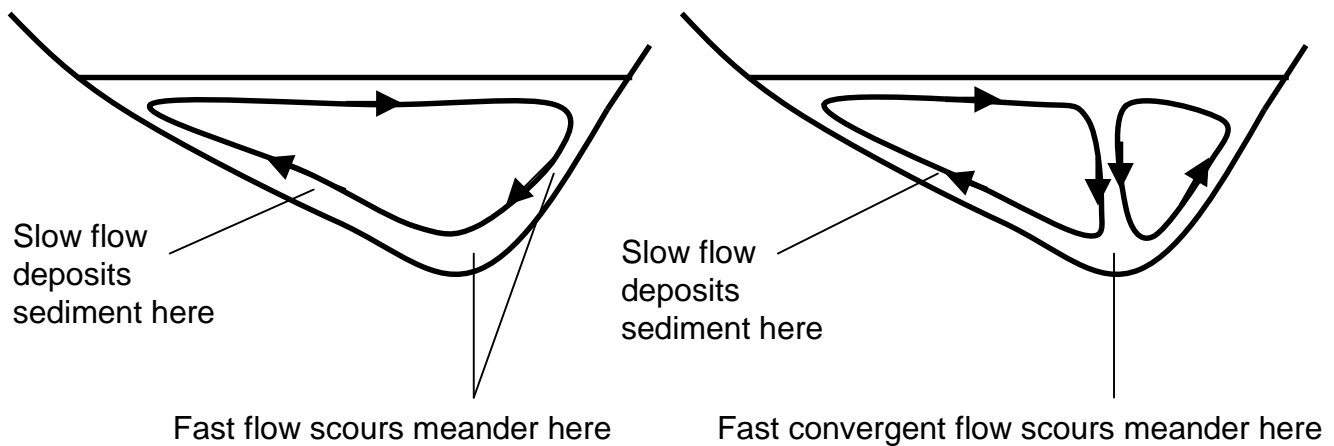


Fig. 3A. Single-cell helicoidal secondary flow in a meander cross-section.

Fig. 3B. Double-cell secondary flow in a meander cross-section.

Q. Which of these models of secondary flow in a meander, the one-cell model or the two-cell model, is correct?

A. They both are! Two thirds of meanders have two cells and one-third only have one cell. Both scour out a pool in the meander and both also increase the amplitude of the meander.

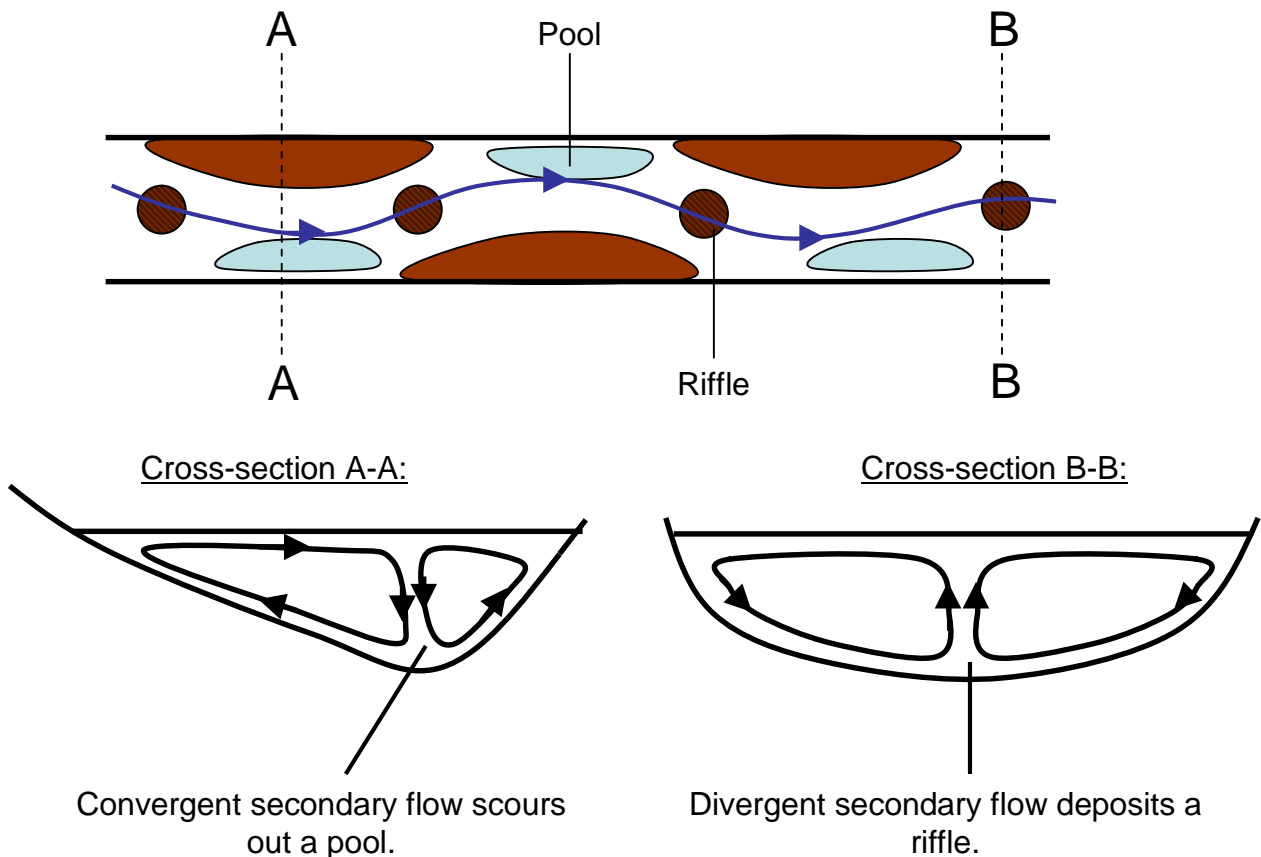
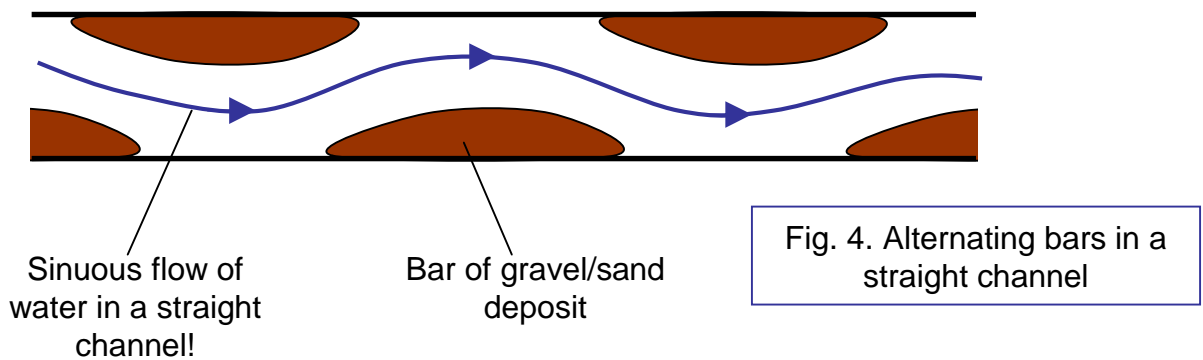
Q. What factors enhance meander formation?

A.

1. The presence of alternating sand bars in a straight river channel will make the flow become sinusoidal, causing it to start scouring the banks opposite to the bars and so initiate meanders.
2. As water flows around the bend in a meander, the water will speed up on the outside bend and so erode it more easily and slow down on the inside bend and so deposit sand and gravel on the inside bend. This increases the amplitude of meanders.
3. Secondary helicoidal flow, and possibly convergent flow increase scouring at the outer bend.

The Riffle-Pool Sequence

We have seen that flowing water has a natural tendency to undulate from side-to-side and to form meanders. Water also has a natural tendency to undulate up and down within a channel, even the surface may remain flat. Rivers tend to develop an alternating sequence of deep pools (depressions in the river bed) and shallows (riffles, bars of gravel) whether the main channel is straight or meandering, so long as the bed material contains a mixture of different sized particles in the right size range (2-256 mm) to be picked up and deposited. Pools are especially associated with meander bends. The gravel bars or riffles, form the intervening shallows (where the river has deposited gravel). In a straight channel, gravel bars may be deposited against alternate banks (Fig (4)) so that even here the water flows in a sinuous manner, from side-to-side, and then in addition riffles and pools may form, just like they do in a meandering channel.



The diagram below (Fig 5) shows the pattern of pools and riffle often found in a meandering river channel compared to that in a straight channel. The **thalweg** is an imaginary line that traces the deepest flowing water in a stream. Notice that the thalweg cuts through the deep poles and shallow riffles of the river. The fastest flowing water in a river also follows the thalweg.

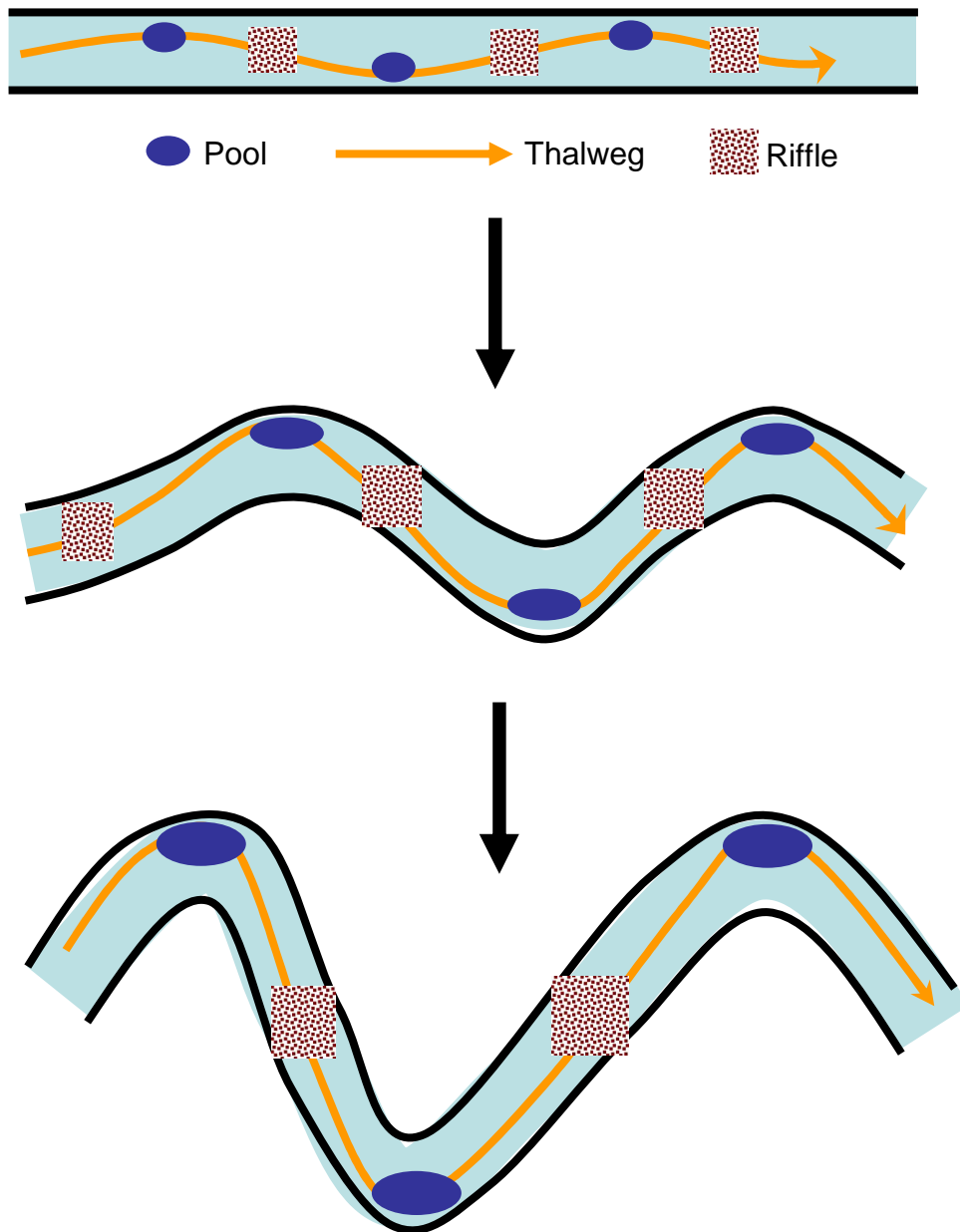


Fig. 5. The thalweg and riffle-pool sequence in straight and meandering rivers.

Meander Migration

Meanders shift their position over time. (A migration is a movement from one place to another).

- Meanders migrate sideways due to lateral erosion, broadening the floodplain and eroding the interlocking spurs.

- Meanders migrate downstream. The greatest erosion occurs at the downstream part of a meander bend, because the water comes rushing through the bend and is then forced to change direction again, causing it to accelerate as it races past the outer bank. The best way to understand this is to imagine that you are part of the stream and flowing quickly through a bend. Imagine a meander off to your right, so you get swung to the right, and then the meander swings back to the left, but you will tend to keep going straight towards the outer bank, and you will be forced to swerve suddenly, and you may well scoop out some of the bank as you do so! This downstream erosion of the outer bank is made worse, since the fastest flowing water is on the outside of the meander bend. Look how close the thalweg comes to the outer bank in the downstream part of the meander bend in figure () imagine all this fast-flowing water swerving past the outer bank and scouring it. Thus, over time the meander gets scoured away downstream, and as sediment deposits upstream, the meander moves downstream.

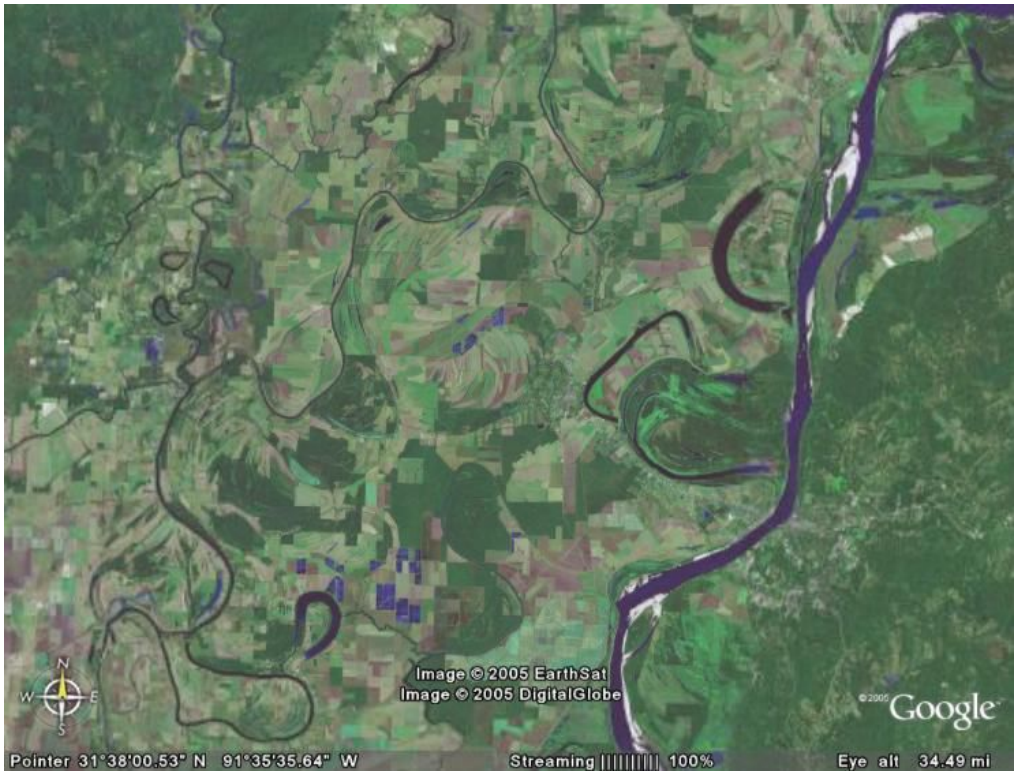
Oxbow Lakes

Figure 2 on page 26 of BP shows a meander changing over time in a different way. The thalweg (fastest and strongest river flow) is the strongest part of the river flow and causes most erosion when it comes near to a river bank. Look at the thalweg in this figure, and you can then see which parts of the meander are being eroded most. When the thalweg is near to one of the banks, then the opposite bank experiences slower flow and sediment tends to deposit here. As you can see in the diagram, this causes the meander neck to narrow over time and the meander amplitude to increase. Eventually, it becomes easier for the water to short-cut the meander and miss it out altogether and a new straight channel forms, leaving an oxbow lake stranded off to one side. As flow diminishes through the oxbow lake, sediment is deposited which seals off the lake from the new channel. Rivers tend to break through and short-cut meanders when they are at peak discharge or when they are flooded.

The lake becomes still water and deposits its sediment. Eventually the lake may dry up as a result of this filling-in by sediment, evaporation and as water infiltrates into the ground. A dried-up, filled-in oxbow lake becomes a meander scar.



Above: Meanders and oxbow lakes along the Mississippi River. Some specific examples are mentioned in the Mississippi case study. Can you see a meander that is almost an oxbow lake, with its neck closed, but still attached to the main river?



Above: part of the Mississippi River, right, can you see any meander scars?

Lower Course: Depositional Landforms

So far we have seen several landforms formed by erosional processes: V-shaped valleys, interlocking spurs, potholes, waterfalls, rapids, meanders and oxbow lakes. Although both erosion and deposition occur in meanders, streams of melt-water flowing across glaciers also meander, even though no material is deposited, they simply erode (melt) the ice, so meanders require only erosion to form. Now we look at landforms that result from deposition of river load. Depositional landforms become more important in the middle and lower courses.

Floodplains

A floodplain is the most common depositional landform associated with rivers. A floodplain is a flat area of land either side of the river, forming the valley floor. They are most developed in the lower course. They are covered in alluvium – a soil of materials deposited by the river during floods. Alluvium is a very fertile soil, making floodplains of vital importance to agriculture.

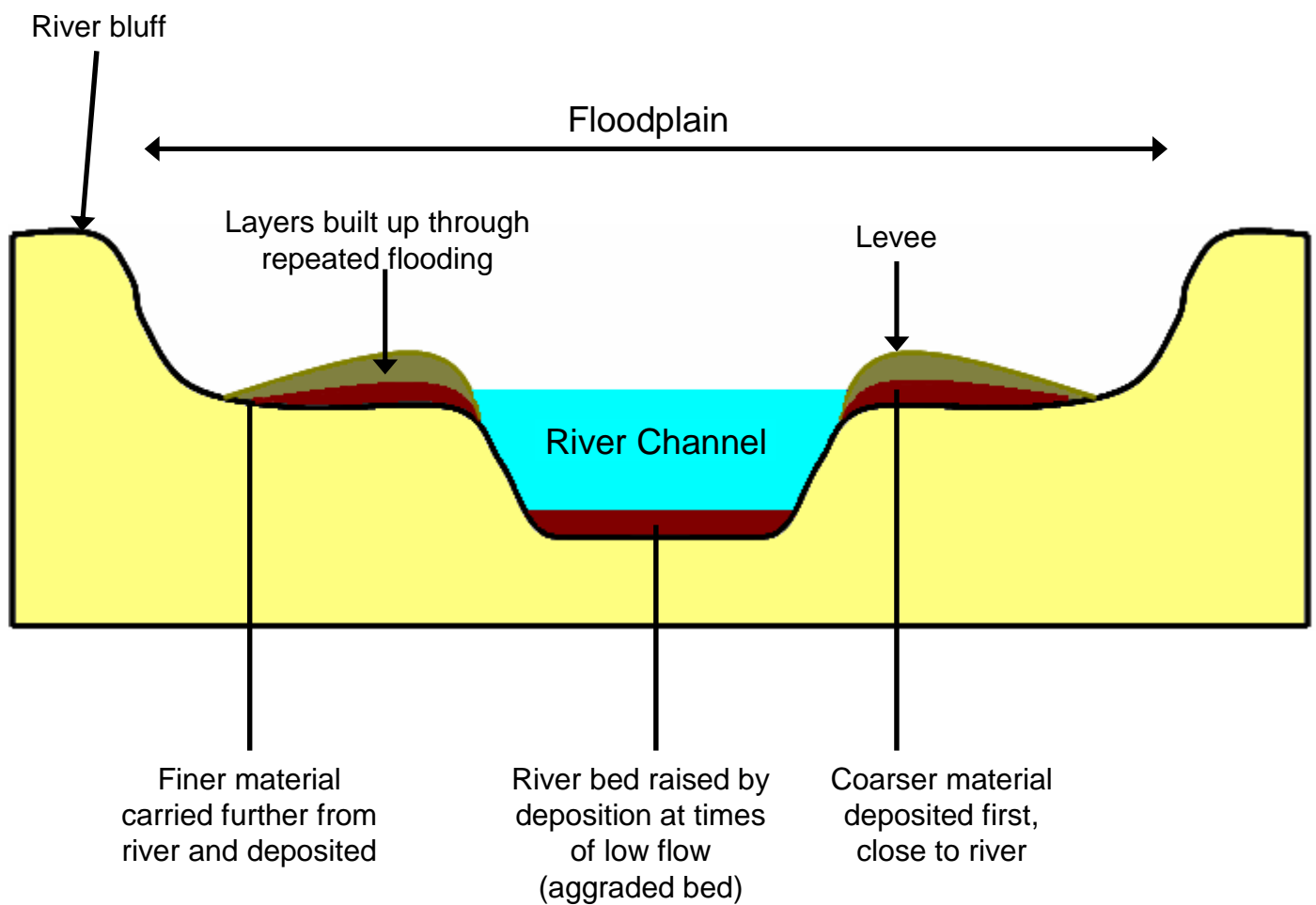
The width of the floodplain is determined by lateral erosion as meanders travel downstream (the width of the floodplain shows us the furthest extent of meanders at some point in the history of the river, as the river meanders and shifts its course along the floodplain – rather like a wriggling snake in slow motion!). The floodplain controls point bars and meander scars and eventually becomes covered with vegetation. Coarser materials like sand, gravel and pebbles are also incorporated into the floodplain whenever the river abandons a channel and forms a new channel.

Levéés (you can omit the acute accent and write this as levees).

Levees are **high banks of silt** close to the river channel, that top the banks. They form when the river floods. When the fast-flowing water leaves the river channel and spreads out onto the shallow or flat floodplain, it slows down and so loses the 'strength' to carry its load and deposits this material. The coarser sand and silt are deposited near to the channel, as levees, whilst finer sand and clay is deposited as **alluvium** across the floodplain. Each time the river floods it may add to the levees, causing them to grow in layers, though of course a flooded river may also break through its own levees.

Aggraded bed: when flow is low, the water loses some of its capacity to carry load and sand and silt may be deposited on the river bed, building it up or aggrading it.

SAQ.1 What affects do you think that levees and aggrading have on the likelihood of a river to flood, and the consequences when it does?



Above: **the formation of levees** (based on figure 5 page 27 of BP). When a river floods on to its floodplain, the waters may become practically stagnant, and only under these conditions will the water have insufficient energy to carry very fine **alluvium** (alluvium is sedimentary material deposited by a river) and these sediment out on to the floodplain, creating fertile soil. Coarser materials are deposited nearer the river as it first begins to spread across the floodplain and slow down, losing energy to carry heavier particles. These form raised banks of silt, called **levees**. When the river is low and flowing slowly, it also deposits material (but not the finest material) on to its river bed, raising the river bed. A river bed on which sediment has accumulated is called an **aggraded** bed. A **bluff** is high steep bank, usually formed by river erosion, in which case it is called a **river bluff**.

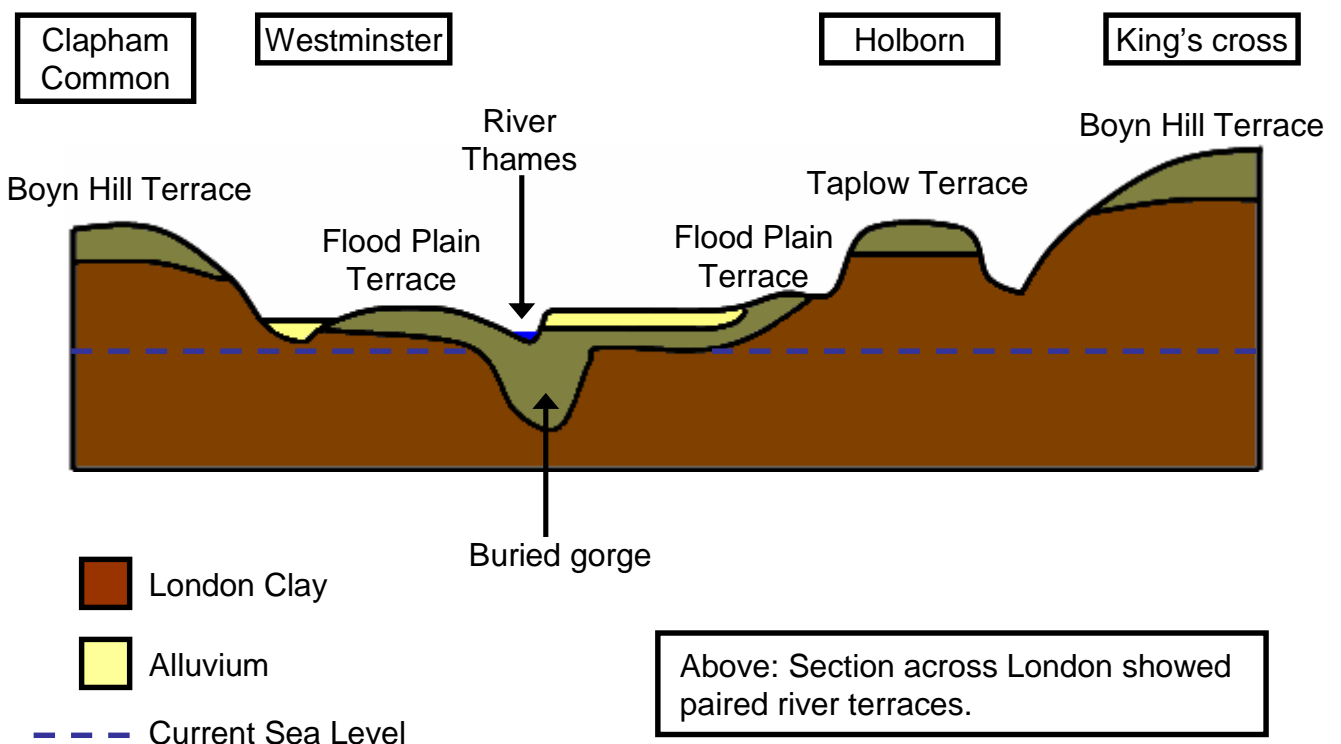
River Terraces

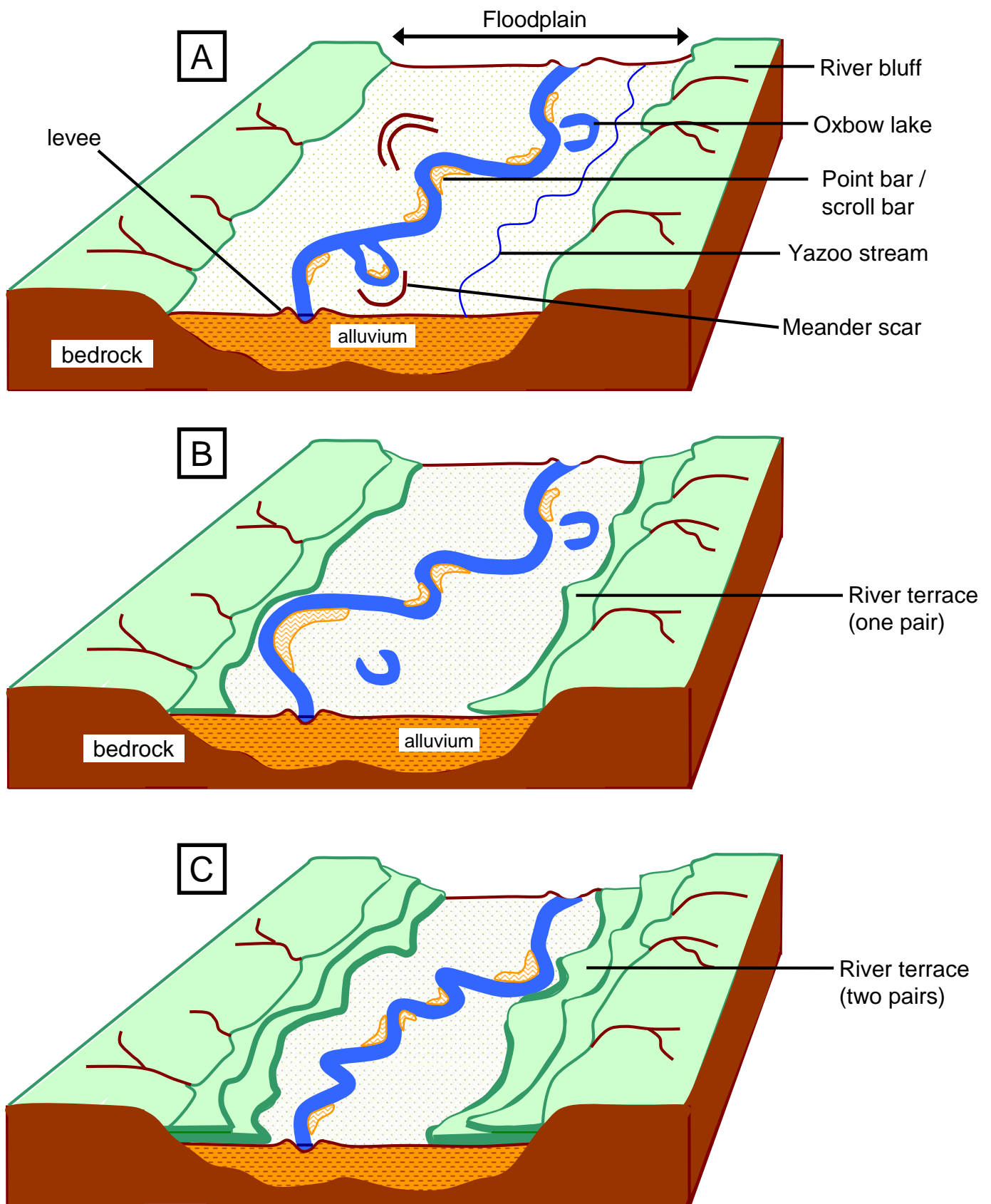
If the level of the land is raised relative to sea level (either because the land **uplifts** or the **sea level drops**) then the river has more work to do by down-cutting to return to its equilibrium profile. The river has renewed energy for this erosion (any system in nature when disturbed from its point of equilibrium or balance will push hard to try to return to equilibrium). Such a river is said to be **rejuvenated**.

A rejuvenated river will cut down into its original alluvial flood plain, which is then left as flat side terraces above the new level of the river. The new valley widens in time, forming a second flood plain within the first one, but at a lower level. (See the diagram on the next page below). If more uplift and rejuvenation occur then a second set of terraces may form. Many British and Western European valley's are terraced in this way. A typical terrace is a platform of bedrock covered with deposited gravel, sand and finer alluvium.

Example: River terraces in the Thames valley

Since the Pleistocene Period (from 1.8 million to 10 000 years ago), there have been about a dozen clear changes in sea level in the London Basin, that have left their marks as terraces (and buried river channels discovered by excavation). Three terraces can be easily seen in the Thames valley. The **Boyn Hill Terrace** is 30-60 m above sea level and consists of flint gravel covering a chalk platform. Fossils of extinct elephants, hippos and rhinos and old stone age tools have been found here. The **Taplow Terrace** and contains the remains of lions and bears and woolly mammoths as the climate cooled. The **Flood Plain Terrace** contains mammoth, reindeer and elk remains, and newer post-Ice Age forest remains as peat and Bronze Age deposits.





Above: sequence of events in the formation of two pairs of river terraces due to two successive uplifts of the land, each followed by down-cutting of the rejuvenated river. A) Before uplift; B) after one uplift episode followed by down-cutting; and C) after two uplifts and two episodes of down-cutting.

Braided Streams

A braided stream is one with a channel with **islands** or **eyots** of deposited material within the channel, splitting the channel into two or more intertwining sub-channels that flow around the eyots. Braided channels tend to be straight, but the eyots and sub-channels may constantly change shape (especially when the river floods).



Above: braiding in the Brahmaputra River channel, Bangladesh. The scale bar on the left-hand photo is 10 km long, whilst that on the right-hand diagram is 5 km. Notice the eyots, some of which are vegetated. What affects do you think vegetation will have on eyot stability?

Braided channels form in rivers that carry a heavy load of coarse sand and gravel. When a river periodically receives a high flow, such as from glacial melt-water in daytime or in the summer, or during flash-floods, much sediment may get washed down the river, but if the water-level suddenly drops (as at night or in the winter for glacial melt-water fed rivers, or if flood water infiltrates and evaporates) then the coarser material is deposited. The Brahmaputra, shown in the Google Earth photos above, is choked by sand and silt from the Himalayas, where the river has its source in the Chemayung-Dung glacier. Not only is the river fed by glacial melt-water, but the discharge of the Brahmaputra also drops during the dry season and then dramatically increases during the Monsoon season. An earthquake and catastrophic flood forced the river to change its course in 1787. It has many eyots (known locally as chars) in its braided channel.

Braiding is characteristic of rivers with very variable discharge, and which carry a large load of coarse sand and gravel during high discharge, to deposit it as islands within the channel, during times of low discharge.

Deltas

When a river reaches the sea much of its load may be quickly deposited at the mouth as sediment partly because the current drops if the river enters a calm sea, and partly because the salt water coagulates (sticks together) the fine particles into larger particles that sink out of suspension. These deposits may form a delta.

Deltas are areas of flat land at a river mouth, which are crossed by many streams called distributaries. The distributaries are often flanked by levees, which are joined together by **spits** and **bars** which enclose small shallow lakes, called **lagoons**. The lagoons eventually silt-up and become marshes and then become dry land – assuming that the delta continues to grow due to sediments being deposited.

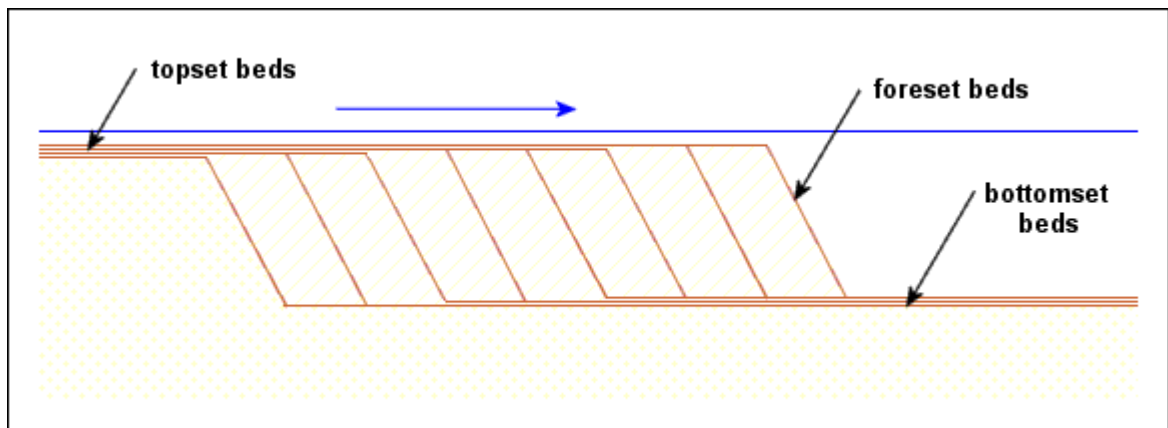
Spit: when offshore currents carry sediment into deeper water, the sediment may be deposited to form a shoal and eventually an embankment. This ridge increases in length as more sediment is added to its end, until waves or currents limit its growth. If the ridge terminates in open water, then it is called a spit. Spits tend to curve in towards the land.

Bar: a **barrier beach** that extends so far as to almost completely cut-off an area of the sea, which becomes a lagoon or marsh.

Coastal processes are covered in A2 geography, so don't worry too much about these terms at this stage, but search Google images (search for "spit" and "coast bar" or something similar) if you want to see some examples.

SAQ.2 Page 28 of BP lists six factors that help deltas to grow, what are they?

When you study the Nile case study, later on, you will see an example of how human actions have caused the Nile Delta to begin to erode and shrink. The Nile delta is shaped like a greek delta Δ and this is how "delta" got its name and the term is applied to deltas of various shapes, though they all resemble a triangle to some degree.



Above: a diagram showing how sediment is deposited in a growing delta. In a delta, the coarsest material are deposited first (would you expect this, if so why?) and forms the **topset beds**. Most of the sedimentary material gets carried out over these relatively flat topset beds and gets deposited over the edge as steeply-sloping **foreset beds**. The finest material gets carried further out and deposits as relatively flat **bottomset beds**. This process continues as the delta grows, accounting for the pattern of deposits seen in figure 2 of page 28.

Deltas are classified according to their shape, there are two main types:

1. An **arcuate delta**, usually triangular in shape, with a smooth coastline, e.g. the Nile delta in Egypt. (Arcuate: bent, curved or arched – think of a triangle with a rounded base, like a sector of a circle or a slice of pie).
2. A **bird's foot delta**, in which fingers of deposited material extend out into the sea, each finger containing a distributary, e.g. the Mississippi delta in the Gulf of Mexico. (These deltas are still often arcuate in overall shape).

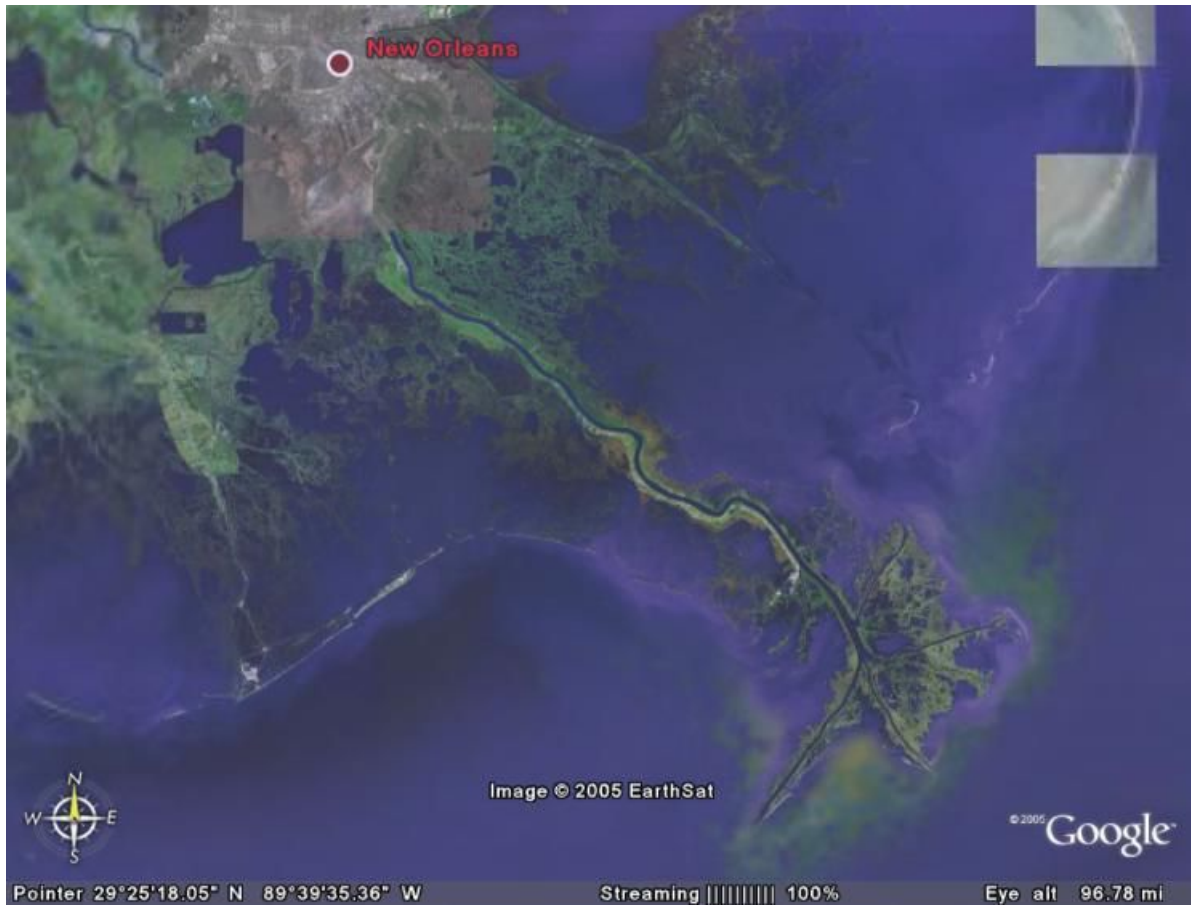
Study the pictures of these deltas shown overleaf, and if you like, have a look at them on Google Earth.

The Nile delta: a triangular arcuate delta



SAQ. Can you see a lagoon, a spit, a bar and distributaries on this map? P.28 of BP will help you.

Note, Cairo is called al-Qahirah by its local inhabitants and Alexandria is called al-Iskandariyah. Google Earth generally displays native names for places.



Above: the Mississippi delta: a bird's-foot delta. Notice the finger-like projections around each distributary.

Alluvial Fans (Alluvial Cones)

Alluvial fans are fan-shaped deposits formed on land when a river emerges from a steep mountain and suddenly enters a flatter and more gently sloping plain. The river flows swiftly through a canyon or ravine and then suddenly hits the flat lowlands, slowing down and broadening out as it does so. If the stream was heavily laden then this causes it to suddenly drop its sediment (why?). The deposited sediment spreads out as an alluvial fan, obstructing the stream and often causing its channel to divide into an interlaced network of distributaries, with shoals and islands of shingle in-between. (An example of braiding). The coarser gravel is deposited first, at the apex of the cone-shaped fan, and finer gravel and sands are deposited further out towards the edges of the fan. The fans become shallower, broader and less steep away from the apex.

Alluvial cones may also occur when a river experiences varying discharge (as in glacial environments, temperate or semi-arid environments) this causes a river to deposit its load when its discharge suddenly drops, which, as we have seen may lead to channel braiding, but it can also lead to the development of an alluvial fan. An alluvial cone may be fan-shaped (and up to 160 km across) or narrow cone-shaped.

Semi-arid environments typically have very variable rainfalls and may experience flash floods. Temperate climates, are by their very nature, subject to variable weather and hence very variable rainfall. Glacial environments experience increased glacial melting in summer and during the day; a stream that receives this melt-water will, therefore, experience very variable flow. Also, in arid or semi-arid regions, most of the water sinks into the porous sand (in the lowlands) and much of it evaporates, causing the river to suddenly lose a lot of water and so deposit its sediment. Also, arid and semi-arid climates may have sporadic very heavy rainfall, which loosens debris from the mountains and carries them to the rivers, which become choked by sediment

Death Valley – Badwater alluvial fan

