Chapter 5 Landforms Made by Running Water

The Development of a River System

When rain falls, part of it sinks into the ground, some is evaporated back into the atmosphere and the rest runs off as rivulets, brooks, streams and tributaries of rivers that flow down to the sea. This running water forms a potent agent for denuding the earth's surface. Denudation is the *general lowering* of the earth's surface. This takes place because such agents of erosion as rivers, ice, wind and waves wear away the rocks and transport the eroded debris to lower land or right down to the sea. But erosion cannot take place unless the rocks are first weakened or shattered by exposure to the elements. Rain, frost and wind weather the rocks so that they can be eroded more easily. Unlike glaciers and snow, which are confined to the cold and temperate latitudes; waves which act only on coastlines; winds, which are only 'efficient' in deserts; the effect of running water is felt all over the globe *wherever water is present*. Running water is thus the most important single agent of denudation.

The source of a river may be a spring, a lake or a marsh, but it is generally in an *upland* region, where precipitation is heaviest and where there is a slope down which the run-off can flow. The uplands therefore form the catchment areas of rivers. The crest of the mountains is the divide or watershed from which streams flow down the slopes on both sides to begin their journey to the oceans. The initial stream that exists as a consequence of the slope is called the consequent stream. As the consequent stream wears down the surface by deepening its channel downwards, it is joined by several tributaries either *obliquely* or at *right angles* depending on the alignment and the degree of resistance of the rocks.

If the rocks are composed of homogeneous beds of uniform resistance to erosion, the tributaries will join the main valley obliquely as insequent streams. The drainage pattern so evolved will be *tree-like* in appearance, and is therefore described as dendritic drainage, after a Greek word *dendron* meaning 'tree' (Fig. 34). On the other hand, if the rocks are made up of alternate layers of hard and soft rocks, the tributaries tend to follow the pattern of the *rock structure*. If the outcrops of the rocks occur at right angles to the main valley, the tributaries will join it at right angles as subsequent streams.

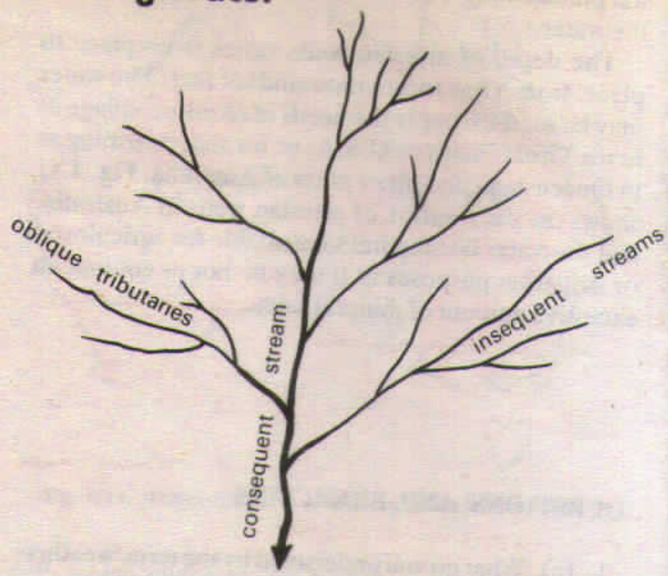


Fig. 34 Dendritic or tree-like drainage pattern developed on homogeneous rock or beds of equal resistance

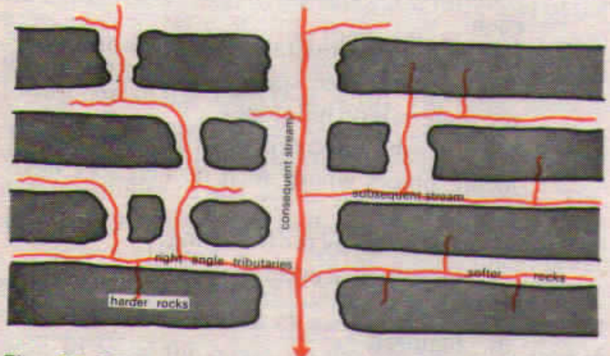


Fig. 35 Trellised or rectangular drainage pattern developed on alternating outcrops of harder and softer rocks

The drainage pattern so developed will be *rectangular* in shape and is called trellised drainage (Fig. 35).

The Mechanism of Humid Erosion

Humid erosion covers the entire scope of sculpturing effects of running water from the action of rainwater to that of the rivers. Mass movements of earth and weathered materials on hill-slopes down to valleys are mainly due to the lubricating action of water which allows a mass of materials to move under gravity. This is particularly acute where the slopes are steep. The *slow* movement of soil down a hill-slope is call soil-creep. A more *sudden* movement due to the lubricating effect or rain-water may cause widespread landslides. In mountainous districts where the roads and railway tracks are cut through steep-sided valleys landslides may obstruct railway lines, cut off road communications and even bury villages and people.

The Processes of River Action

When a river flows it carries with it eroded materials. These comprise the river's load, and may be divided into *three* distinct types.

1. Materials in solution. These are minerals which are dissolved in the water.

2. Materials in suspension. Sand, silt and mud are carried along suspended in the water as the stream flows.

3. The traction load. This includes coarser materials such as pebbles, stones, rocks and boulders, which are rolled along the river bed.

It has been estimated that for every square mile of the earth's surface, more than 200 tons of solid materials in suspension and more than 50 tons of materials in solution are being carried off by running water every year. The Mississippi River which drains an area almost half the size of the United States itself, removes more than two million tons of eroded material into the Gulf of Mexico daily. Consequently the river basins are being lowered, and in the case of swift-flowing rivers like the Irrawaddy, its drainage basin is being lowered by about a foot in every 400 years! During floods the amount of rock debris swept off by rivers is very much greater. We can see this from the mud that colours the river-water during a heavy rain. The ability of a river to move the various grades of materials depends greatly upon the volume of the water, the velocity of the flow and lastly the size, shape and weight of the load. It is said that by doubling the velocity of a river, its transporting power is increased by more than 10 times! It is therefore not surprising to find huge boulders that are 'stranded' in normal times, but may be moved during seasonal floods. The movement of rivers is thus intermittent, acting vigorously in certain parts of the year and remaining less active at other times.

River Erosion and Transportation

In rivers, erosion and transportation go on simultaneously, comprising the following inter-acting processes.

1. Corrasion or abrasion. This is the mechanical grinding of the river's traction load against the *banks and bed* of the river. The rock fragments are hurled against the sides of the river and also roll along the bottom of the river. Corrasion takes place, in two distinct ways.

(a) Lateral corrasion. This is the sideways erosion which widens the V-shaped valley.

(b) Vertical corrasion. This is the downward action which deepens the river channel.

2. Corrosion or solution. This is the chemical or solvent action of water on soluble or partly-soluble rocks with which the river comes into contact. For example calcium carbonate in limestones is easily dissolved and removed in solution.

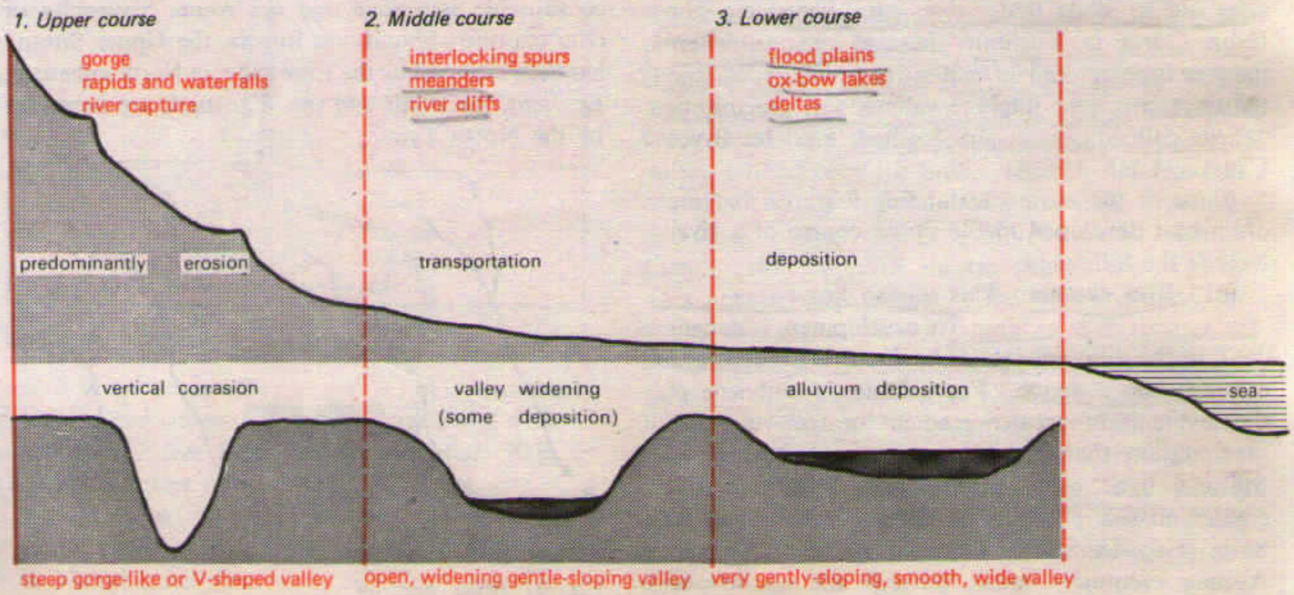


Fig. 36 The graded long profile and typical cross section of a river from source to mouth

3. Hydraulic action. This is the mechanical loosening and sweeping away of materials by the river water itself. Some of the water splashes against the river banks and surges into cracks and crevices. This helps to disintegrate the rocks. The water also undermines the softer rocks with which it comes into contact. It picks up the loose fragments from its banks and bed and transports them away.

4. Attrition. This is the wear and tear of the transported materials themselves when they roll and collide into one another. The coarser boulders are broken down into smaller stones; the angular edges are smoothed and rounded to form pebbles. The finer materials are carried further down-stream to be deposited.

The Course of a River

The course of a river may be divided into *three* distinct parts (Fig. 36). 1. The upper or mountain course (in the stage of youth), 2. The middle or valley course (in the stage of maturity), 3. The lower or plain course (in the stage of old age).

1. The Upper or Mountain Course

This begins at the source of the river near the watershed, which is probably the crest of a mountain range. The river is very swift as it descends the steep slopes, and the predominant action of the river is vertical corrasion. The valley developed is thus deep, narrow and distinctively V-shaped. Down-cutting takes place so rapidly that *lateral corrasion* cannot keep pace. In some cases where the rocks are very resistant, the valley is so narrow and the sides are so steep that gorges are formed e.g. the Indus Gorge in Kashmir. In arid regions, where there is little rainfall to widen the valley sides, and the river cuts deep into the valley-floor, precipitous valleys called canyons are formed, e.g. the Bryce Canyon, Utah, U.S.A.

Some of the more outstanding features that are often best developed in the upper course of a river include the following.

(a) River capture. This is also known as river piracy or river beheading. Its development is dependant on the different rate of back-cutting (headward erosion) into a divide. For instance, if one side of the divide is of greater gradient or receives more precipitation than the other, stream A in Fig. 37 will cut back more rapidly than stream B. Its greater erosive power will succeed in enlarging its basin at the expense of the weaker stream. Stream A may eventually break through the divide and capture or pirate stream B. The bend at which the piracy occured is termed as the elbow of capture. The beheaded stream (Z) is called the misfit. The valley below the elbow is the wind gap, and may be valuable as a road and rail route. Examples of river capture abound. In Burma, the Upper Sittang has been captured by the Irrawaddy; in Northumberland, England, the Blyth and the Wansbeck are beheaded by the North Tyne.

A deep gorge in the Cuzco Department of Peru *Paul Popper*

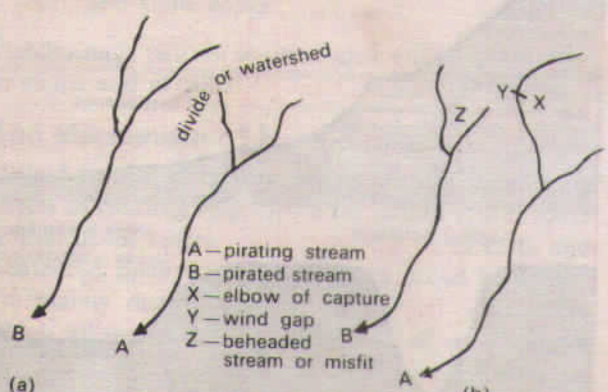


Fig. 37 River capture
(a) before capture (b) after capture

(b) Rapids, cataracts and waterfalls. These are liable to occur at any part of the river course, but they are most numerous in the mountain course where changes of gradient are more abrupt and also more frequent. Due to the *unequal resistance* of hard and soft rocks traversed by a river, the outcrop of a band of hard rock may cause a river to 'jump' or 'fall' downstream. Rapids are formed (Fig. 38). Similar falls of

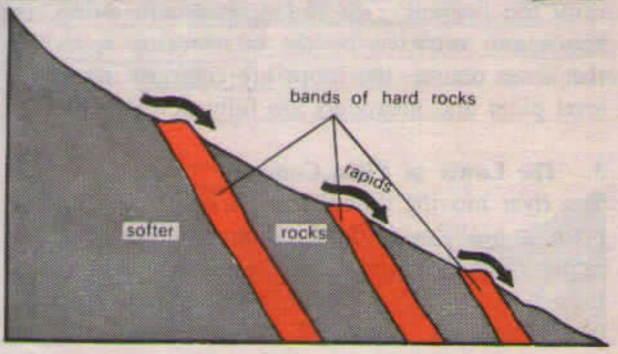


Fig. 38 Rapids, cataracts

greater dimensions are also referred to as *cataracts*, of which there are five along the Nile that interrupt smooth navigation. When rivers plunge down in a sudden fall of some height, they are called waterfalls (Fig. 39). Their great force usually wears out a plunge-pool beneath. Waterfalls are formed in several ways.

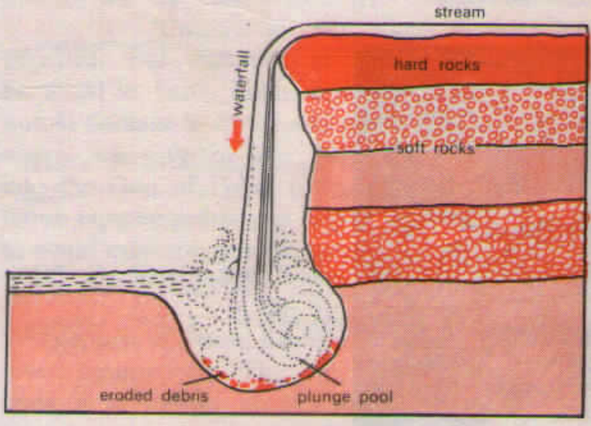


Fig. 39 A waterfall with plunge pool

i. When a bar of resistant rock lies transversely across a river valley, e.g. the Niagara Falls, U.S.A., which is 167 feet high and the Kaieteur Falls in Guyana, 825 feet high.

ii. When a fault-line scarp caused by faulting lies across river, e.g. Victoria Falls on the River Zambezi, plunging 360 feet.

iii. When water plunges down the edge of a plateau like the River Congo which leaps for 900 feet through a series of more than 30 rapids as Livingstone Falls.

iv. Glaciation produces hanging valleys where tributary streams reach the main U-shaped valley below as waterfalls, e.g. the Yosemite Falls of California with a total descent of 2,560 feet.

2. The Middle or Valley Course

In the middle course, lateral corrasion tends to replace vertical corrasion. Active erosion of the banks widens the V-shaped valley. The volume of water increases with the confluence of many tributaries

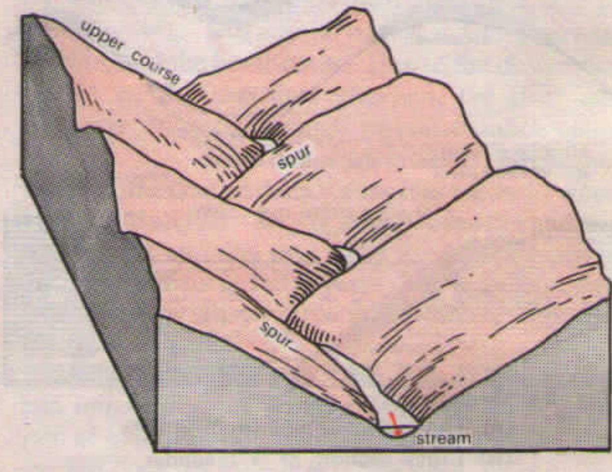


Fig. 40 Interlocking spurs

and this increases the river's load. The work of the river is predominantly transportation with some deposition. Downstream, the interlocking spurs (Fig. 40) that project from both sides of the valley are cut back into a line of bluffs. Rain-wash, soil creep, landslides and gullying gradually widen the valley, cutting back the sides. The river's treble task of valley-cutting, bed-smoothing and debris-removal are being carried out in a more tranquil manner than in the mountain course though the velocity does not decrease. Some of the load is dropped or deposited. Again this depends on the *volume of flow*, for in the event of flood, the river's erosive power and its capability for load-carrying is greatly increased. The more outstanding features associated with the valley course are these.

(a) Meanders. As water flowing under gravity seldom flows straight for any long distance, a *winding* course soon develops. The irregularities of the ground force the river to swing in loops, forming meanders, a term derived from the winding River

Meanderez in Asia Minor. The mechanism of meander formation is illustrated in Fig. 41.

(b) River cliffs and slip-off slopes. When the flow of water PQ (in Fig. 41) enters the bend of the river, it dashes straight into Q, eroding the outer bank into a steep river-cliff at Q. The water piles up on the outside of the bend because of the centrifugal force. A bottom current RS is set up in a cork-screw motion and is hurled back into mid-stream and the inner bank. Shingle is thus deposited here at S, where the slip-off slope is very gentle. The outer bank is therefore the bank of continuous erosion and the inner bank is the bank of continual deposition.

(c) Interlocking spurs. As the stream flows on, the meanders migrate progressively outwards with the interlocking spurs alternating with the undercut slopes as shown in Fig. 40. It must be pointed out at this stage that meanders in the middle course are only the beginning of the downstream swing, for bends are restricted by the interlocking spurs. In the lower course, the loops are enlarged across the level plain and meanders are fully developed.

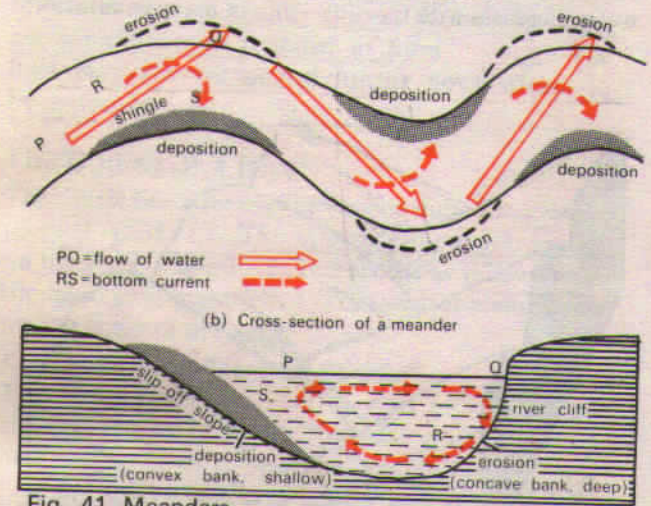


Fig. 41 Meanders
(a) The development of meanders
(b) Cross-section of a meander

3. The Lower or Plain Course

The river moving downstream across a broad, level plain is heavy with debris brought down from the upper course. Vertical corrasion has almost ceased though lateral corrasion still goes on to erode its banks further. The work of the river is mainly deposition, building up its bed and forming extensive *flood plains*. The volume of water is greatly swelled by the additional tributaries that join the main stream. Coarse materials are dropped and the finer silt is carried down towards the mouth of the river. Large sheets of materials are deposited on the level plain and may split the river into several complicated channels, so that it can be described as a braided stream. Some of the major plain course features are the following.

The Sg. Muara in Negri Sembilan. The river swings from side to side in tight meanders. Note the sand deposited on the slip-off slope
G.C. Morgan

(a) Flood plain. Rivers in their lower course carry large quantities of sediments. During annual or sporadic *floods,* these materials are spread over the low-lying adjacent areas. A layer of sediment is thus deposited during each flood, gradually building up a fertile flood plain (Fig. 42). When the river flows normally its bed is raised through the accumulation of deposits and material is also dropped on the sides forming raised banks called levees. It will not be long before the water level flows dangerously close to the top of the levees. In an attempt to

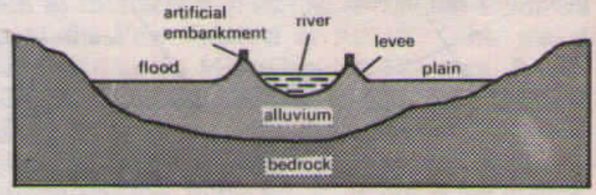


Fig. 42 Section of a flood plain (with levee and artificial embankment)

minimise the risk of floods, artificial embankments are erected on the natural levees, but this allows the river to rise further. When they can no longer withstand the pressure of the flood water, the banks burst, damaging property and drowning thousands. Disastrous floods of this nature frequently occur in the Yang-tze Kiang, Mississippi, Po and Ganges plains. But the best known river for floods is the Hwang-Ho, 'China's Sorrow', where millions have perished. For example, in 1852 the Hwang-Ho breached its bank, killing a million people and did untold damage to farms and properties. The river's course was diverted over 300 miles away, draining into the Gulf of Pohai instead of the Yellow Sea. Nowadays, huge dredgers help to deepen the channels to avoid excessive sedimentation.

(b) Ox-bow lakes. These are also known as cut-offs or bayous in the Mississippi basin. In the lower course of a river, a meander becomes very much more pronounced. The outside bend or concave bank is so rapidly eroded that the river becomes almost a complete circle. There will come a time when the river cuts through the narrow neck of the loop, abandoning an ox-bow lake or *'mortlake'* (meaning dead lake). The river then flows straight. The ox-bow lake will later degenerate into a swamp through subsequent floods that may silt up the lake. It becomes marshy, and eventually dries up (Fig. 43).

(c) Delta. When a river reaches the sea, the fine materials it has not yet dropped are deposited at its mouth, forming a fan-shaped alluvial area called a

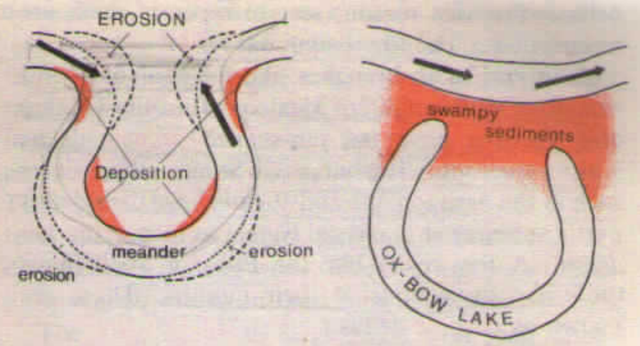


Fig. 43 The formation of an ox-bow lake

delta, a word which originated from the Greek letter Δ which closely resembled the triangular delta of the Nile (Fig. 44). This alluvial tract is, in fact, a seaward extension of the flood-plain. Due to the obstruction caused by the deposited alluvium, the river may discharge its water through several channels called distributaries. Some deltas are extremely large. For instance, the Ganges delta is almost as big as the whole of West Malaysia. Deltas extend sideways and seawards at an amazing rate. The River Po extends its delta by over forty feet a year. The town of Adria, located nearly fifteen miles inland was a seaport in the time of Christ!

Deltas differ much in their size, shape, growth and importance. A number of factors such as the rate of sedimentation, the depth of the river and the sea-bed, and the character of the tides, currents and waves greatly influence the eventual formation of

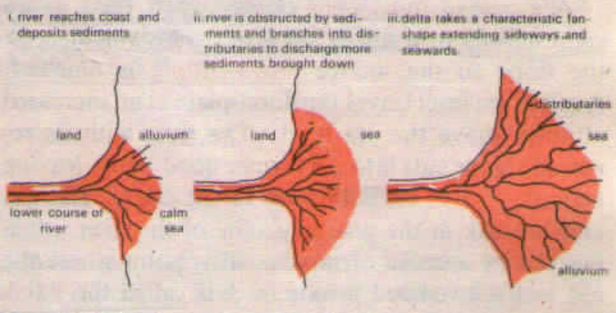
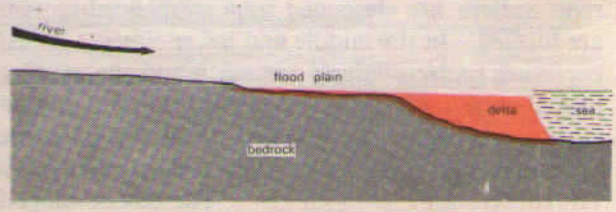


Fig. 44 The formation of deltas
(a) Stages in the formation of a delta



(b) Section through the lower course of a river, showing flood plain and delta deltas. For this reason, several types of delta are recognisible. The Mississippi has a bird's-foot *delta*, with several main branches like the foot of a bird extending into the Gulf of Mexico. The Nile, Ganges and Mekong have the fan-shaped arcuate deltas with numerous distributaries. Some other rivers such as the Amazon, Ob and Vistula have their deltas partly submerged in coastal waters to form estuarine *deltas*. A few rivers like the Ebro of Spain have tooth-like projections at their mouths. These are known as cuspate deltas.

The following summarises the conditions favourable for the formation of deltas.

(i) Active vertical and lateral erosion in the upper course of the river to provide extensive sediments to be eventually deposited as deltas.

(ii) The coast should be sheltered preferably *tideless*.

(iii) The sea adjoining the delta should be shallow or else the load will disappear in the deep waters.

(iv) There should be no large lakes in the river course to 'filter off' the sediments.

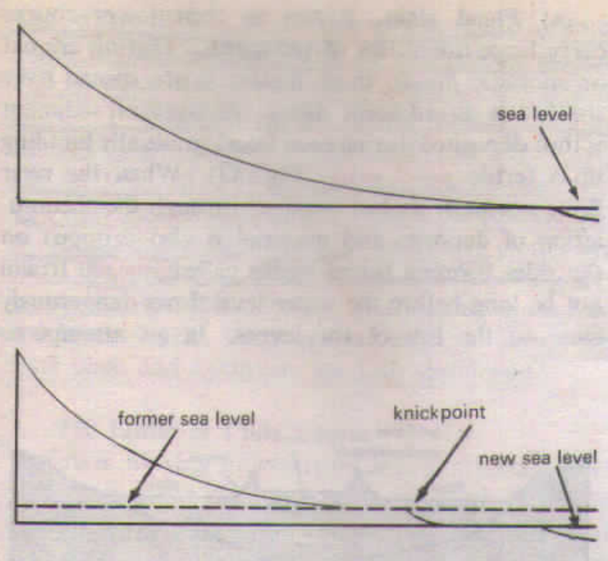
(v) There should be no strong current running at right angles to the river mouth, washing away the sediments.

River Rejuvenation

The earth's crust is far from stable and it is not surprising that, in the course of a river's development, parts may be uplifted or depressed, giving rise to certain characteristic features associated with rejuvenation, i.e. being young again.

A negative movement occurs when there is an *uplift of land* or a *fall in sea level*. This will steepen the slope so that active down-cutting is renewed. A fall in sea level leaves the flood-plain at an increased altitude above the sea level. The river with its renewed vigour cuts into the former flood-plain, leaving behind terraces on both sides of the river. There is also a break in the graded profile of the river, often marked by a series of rapids. This point where the old and rejuvenated profile meet is called the knick point or *rejuvenated head* (Fig. 45).

If rejuvenation occurs in the upper-course, the river valleys are deepened and steep-sided gorges are formed. In the middle and lower course vertical corrasion replaces lateral corrasion and the existing meanders are vertically eroded by the rejuvenated stream. A distinct new inner trench is cut in the old valley, and the river develops a deep valley with entrenched or incised meanders. The best developed incised meanders are those of the River Colorado, U.S.A., where the uplift of 7,000 feet in the Tertiary



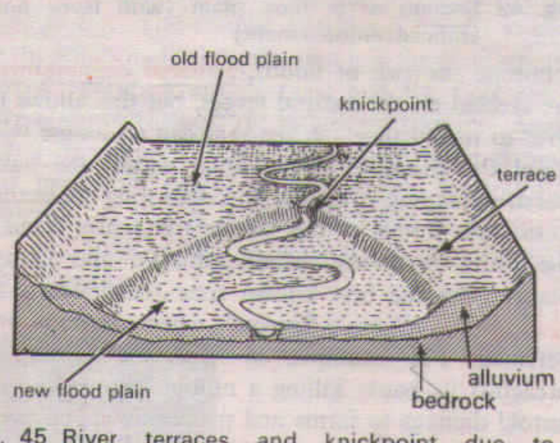


Fig. 45 River terraces and knickpoint due to rejuvenation

The rejuvenated river cuts down into previously deposited sediments to form a new valley leaving terraces at either side. At the head of rejuvenation the river falls to its new valley at a knickpoint

period renewed down-cutting to a fantastic depth. In some parts of the Grand Canyon, the depth is almost a mile. It is 10 miles wide at the top and 300 miles long. Other examples are the River Moselle in Germany, the River Wear at Durham, England, and the Wye Valley, Monmouthshire.

A positive movement occurs when there is a *depression* of land or a *rise in sea level*. This will submerge the lands along the coast, 'drown' the valleys and weaken the erosive power of the river. The flow is checked and large quantities of sediment will be dropped. The lower course of the river may be partly in the sea and features of deposition are shifted upwards to the middle course. The upper course is little affected when there is a rise in sea level. In many areas where the sea has risen this was probably caused by the release of water locked up in the ice masses during the Quaternary Ice Ages.

The Human Aspects of Rivers

In many countries, rivers form the chief highway of commerce and transport. The Yang-tze Kiang is navigable up to a thousand miles from its mouth. The Amazon, the world's greatest river is navigable 2,300 miles up-stream to the foot of the Andes, though it is less extensively used. Even the Nile with its cataracts is navigable for its first 960 miles up to the First Cataract at Aswan. Other major rivers such as the Mississippi, St. Lawrence, Rhine, Danube, Congo, Murray, Darling, Mekong and Irrawaddy all serve as important waterways for their respective countries. Some of them are useful for transporting logs to the saw mills, others are used to export bulky goods and import foodstuffs and raw materials.

But all rivers undertake three closely interrelated activities *erosion, transportation and deposition*. Their work has therefore both advantages and disadvantages from a human point of view. Rapids and waterfalls, interrupt the navigability of a river. By depositing large quantities of sediments in the lower course, the river silts up ports preventing large steamers from anchoring close to the shores. Deltas are thus less satisfactory sites than estuaries for the siting of large ports. Though this can be overcome by the construction of *artificial harbours* or by dredging this is expensive and, in some instances, impracticable. Some rivers change their courses from time to time, others are made difficult for navigation by their seasonal variations in the amount of water discharged, and others may suffer from ill-drained marshes and stagnant waters, leading to ill health and water-borne disease. Many rivers flood, bursting levees and causing untold damage to crops. The floods may add a layer of fertile silt to the flood plain, but excessive flooding as in the Orinoco may discourage people from cultivating crops at all.

On the other hand, the advantages of rivers often outweigh the destruction that they cause. In the upper course, rivers with steep gorges and waterfalls, provide natural sites for the generation of hydro-electric power, leading to the establishment of metallurgical industries, engineering and aluminum smelting, which can be profitably run on cheap, abundant power. *Dams* constructed across rivers hold back flood-water which if allowed to flow downstream unchecked may cause widespread disastrous floods in the lower course, e.g. in the Indus and Ganges plains. In regions of insufficient rainfall such as Egypt and the Chao Phraya basin in Thailand irrigation canals fed by the main stream enable many crops to be successfully cultivated. The upper streams develop river captures and the resultant wind gaps may facilitate construction of upland roads and railways. The river valleys provide a convenient means of land *communication*.

The flood plains of large rivers with their thick mantles of fine silt are some of the richest agricultural areas of the world. They may support very dense populations and a chain of large cities may be strung along their banks. Many deltas are equally fertile, e.g. the Ganges delta accounts for almost all the jute grown for world consumption; the Nile delta produces superior quality cotton and several crops of rice a year. The productive hinterlands are able to support ports such as New Orleans for the Mississippi basin, Rotterdam for the Rhineland and Calcutta for the Indo-Gangetic Plain.

Fresh-water fishing is important along many rivers and lakes. The organic matter brought down by the river waters provides valuable food for fish and for spawning purposes. Rivers supply water for domestic consumption, sewerage and other industrial purposes. In Lancashire, the soft-water from the Millstone Grit is used for washing, dyeing and bleaching textiles. Rivers form the political boundaries between many countries. The Mekong separates Laos from Thailand; and the Yalu forms a well defined border between North Korea and the eastern U.S.S.R.

QUESTIONS AND EXERCISES

1. What are the characteristic features you would expect to find in a river valley at the stage of youth, maturity and old age? Illustrate some of the more outstanding features with diagrams and examples.

2. By reference to specific examples, describe the major constructive and destructive processes at work along the course of a river from its source to its mouth.

3. With the aid of annotated diagrams, explain the constrasting features of any *three* of the

following pairs of features of a river:

(a) dendritic and trellised drainage pattern
(b) rapids and waterfalls
(c) estuary and delta
(d) tributaries and distributaries
(e) river capture and river cliff

4. Explain any *three* of the following statements briefly:

(a) Mass movement of earth is mainly due to the lubricating action of rain-water and gravitional forces.
(b) Vertical corrasion is dominant in the upper course of a river.
(c) The work of the river in the lower course is mainly depositional.
(d) Ports are better sited on estuaries than on deltas.
(e) Incised meanders are features of river rejuvenation.

5. *Either:* Describe and explain with relevant sketches the various types of river deltas

Or: Explain the ways in which river erosion occurs.