

Geological work of Running Water

Drainage System

Runoff, in its attempt to progress efficiently to lower levels and eventually to reach the sea, it organises itself into drainage system, each consisting of a more or less leaf shaped or pear shaped area of the land bounded by a drainage divide, defining a drainage basin. It posses a narrow mouth, through which water and mineral material are discharged by a single channel.

The drainage system has the ultimate goal to reduce the land to a surface of faint relief close to sea level. It is a converging mechanism to funnel all the water of the drainage basin.

Running Water as a geologic agent (The work of river)

Surface water flow, both over the slopes of the land and in stream channels, collectively designated as runoff. Runoff may be derived both from:

1. Direct surface accumulation of precipitation that does not infiltrate, and
2. From ground water outflowing along lines where the water table intersects the surface in streams, lakes and marshes.

Two fields of earth sciences are joined in th study of drainage system:

1. Hydrology
2. Geology

1. Here interest lies particularly in the watert itself, with emphasis upon the quantity of water moved in a given time and the relation between precipitation and runoff. It is treated as a branch of civil engineering.

2. Here, interest is centered on the processes of erosion and transportation going on within the drainage system and upon the geometrical forms of the channels and landslopes. These studies are carried by geologists.

Hydraulic Geometry

To describe a stream channel and the flow of its water the collective term is hydraulic geometry.

d: Stream depth: It is measured at any desired point
w: Width, is the distance across the stream from bank to bank

A: Crossectional area, is given for a vertical crossection at right angles to the direction of flow.

P: Wetted perimeter. The length of the line of contact of water with channel, measured along the crossection. units- feet or meters.

r: Hydraulic radius = A/P

Overland Flow (Stream channels and stream flow)

The term overland flow is given to the movement of runoff downslope on the ground in a more or less broadly distributed sheet or film, or in a very shallow interconnected rills(sheet flow).

Channel flow (stream flow)

It occurs in a long, narrow, trough like depression bounded by banks or valley walls that slope towards the channel.

Stream channel

A stream channel is simply a long narrow, sloping trough shaped by the concentrated flow of water in a manner most effective for moving the mixture of water and sediment supplied by runoff.

Channels range in size from insignificant brooks one can step across in a single stride, to the trenches of great rivers hundreds of feet wide. Channels do not necessarily need to contain flowing water to be so defined. Many channels of desert streams are dry most of the time.

Numerous attempts have been made to find a generally acceptable expression for C.

$$\text{or } v = C \cdot R^{1/2} \cdot s^{1/2}$$

This equation states that the mean velocity varies as the square root of hydraulic radius and as the square root of slope.

Hydraulic radius is essentially equivalent to the average stream depth. An increase of velocity with increase in depth is to be expected when slopes held constant.

For a broad shallow stream the hydraulic radius (cross-sectional area (A)/ Perimeter (P) will be very nearly same as the average depth.

Form ratio: To express deepness and shallowness of a stream channel form ratio is determined.

$$\text{Form ratio} = d/w$$

where, d = average depth
w = width

For example, Form ratio 1:160 means that the stream is 160 times as wide as it is deep on the average.

The Chezy equation has been revised a number of times on the basis of additional measurements. In wide use today is the Manning equation:

$$v = 1/n R^{2/3} \cdot s^{1/2} \text{ (on the basis of experiments)}$$

n: is a numerical constant. It is a numerical estimate of the roughness of the stream bed. In C.G.S. unit the value of n varies from 0.015-0.060 in natural streams.

The river flow or stream flow

The velocity of a river depends upon:

- a. Channel gradient
- b. Volume and
- c. Configuration

One of the most commonly used equations applicable to open channel hydraulics is the Chezy formula.(1775).

$$v = C \sqrt{rs}$$

where, v: mean velocity

C: a coefficient which varies with the characteristics of the channel (a numerical constant)

r hydraulic radius

s slope as percent grade

The experimental values of n vary from approximately 0.01 for smooth metal surfaces to 0.06 for natural, irregular channels containing large stones.

1. clean straight channel with no pools
0.025-0.033
2. channel containing weed/sand stones
0.030-0.040
3. channel containing large stones
0.045-0.060

Discharge of a stream

The volume of water flowing through a cross-section of a stream channel during a given time is its discharge. Sediments and ions carried and deposited by stream may also be referred to as stream discharge.

$$Q = w \cdot d \cdot c \quad (w \cdot d = A, \text{ area})$$

where, q = the volume of water discharge

w = width

d = depth

c = speed of the current

or $Q = AV$

A = cross-sectional area

V = mean velocity

Units: cfs (cubic feet/sec), cms (cubic meters/sec)

Analysis of Drainage Networks

In analyzing a drainage network, the stream channels are traced out in full upon a map or air photo to include all clearly defined flow lines, even those which carry water only in times when overland flow occurs. Surface slopes converge towards the head of each of the smallest or fingertip channels where runoff collects in sufficient quantity to scour a permanent channel.

As channels join each other, at angles that are usually acute, the discharge of water and sediment load is funneled into exit channels of progressively larger dimension. For each unit of channel length, the channel is provided with a proportionate surface area of runoff.

Causes of discharge variations at a single station

It results from changes in the supply of water within the drainage area. Such changes can be caused by:

- a. The seasonal distribution of rainfall
- b. Seasonal melting of snow and ice
- c. Rain storm erratically formed
- d. Release of water from upstream dams etc.

Playfair's law (origin of valleys)

Before nineteenth century, the origin of valleys was a subject of vigorous debate. Three groups of ideas were prevailing:

1. Valleys were great cracks where the earth's crust had been split open and that rivers merely found the ready-made valleys and simply flowed through them.
2. Valleys had been scoured by swift currents on the sea floor at times when the ocean had covered all the lands.

Speed of the flow or distribution of speeds of flow

The speed of flow varies in different parts of the channel. The location of maximum speed of flow depends upon:

1. The channel shape
2. Roughness
3. Sinuosity

The point where the current flows fastest lies near the centre of the channel and below the surface about $1/4^{\text{th}}$ of the way to the bottom.

3. Rivers carve the valleys in which they flow. This third idea became known as Playfair's law.

Streams do not simply occupy valleys, but create them. According to him, the channel dimensions, discharge, and gradients of streams bear some definite mathematical relation to areas of the contributing watershed.

Drainage Density

Total length of the stream channels
per mile

basin area (sq miles)

Erosion by overland flow

The flow of a sheet or film of water over the soil surface exerts a shearing stress, or drag upon the mineral grains. If this stress is sufficient to overcome the cohesive forces binding a grain to the parent mass, the grain is entrained into the flowing layer and is rolled, dragged or carried down slope. This progressive removal of grain in this manner is described as soil erosion.

Geological work of stream (Geologic work of running water)

Streams are major agents of land sculpture, creating a vast array of erosional and depositional landforms besides transporting sediment and depositing in basin. The fluvial denudation is the predominant agent of landscape evolution.

Fluvial denudation: The total process of landscape sculpturing involving weathering, mass wasting, and overland flow is called the fluvial denudation.

Splash erosion: on barren soil surface, the impact of falling rain drops dislodges and moves the soil particles and called splash erosion.

Sheet erosion: on barren land due to deforestation, soil is removed by sheet erosion. by sheet flow. Gradually the upper fertile horizon is lost and subsoil and bed rock remains.

Work of stream

Streams perform three closely interrelated forms of geologic work:

1. Erosion
2. Transportation
3. Deposition

These phases of geologic work can not be separated one from the other, because where erosion occurs, there must be at least some transportation and eventually the transported particles must come to rest.

Erosion

Erosion occurs when the force provided by the river flow exceeds the resistance of the material over which it runs.

Stream erosion is defined as the progressive removal of mineral matter from the surfaces of a stream channel, whether the exposed material consists of bedrock, residual or transported overburden (regolith) or soil.

The nature of stream erosion depends upon the materials of which the channel is composed and the means of erosion available to the stream.

In other words, four types of fluvial erosion have been distinguished:

1. Hydraulic action
2. Attrition
3. Corrasion or abrasion
4. Corrosion

The concept of erosion cycle

Stages in the erosion cycle

The erosion cycle is thought to begin with the uplift of a land mass, ranging from an island to a mountain range to an entire continent.

The cycle is presumed to end when this uplifted area has been eroded away and all that is left is an almost flat plain known as peneplain lying near base level.

1. Hydraulic action is the force of the water itself. It is the effect of pressure and shearing force of flowing water exerted upon grains projecting from the bed and banks.

Weakly consolidated bed rock and various forms of uncemented transported and residual overburden are readily worn away by hydraulic action alone, but the process has little effect on strongly bonded bed rock.

2. Attrition is the disintegration which occurs when two or more particles which are suspended in water collide.

William Morris Davis(1850-1934) gave the Davis erosion cycle. It includes three stages as:

1. Youth
2. Maturity
3. Old

1. In the youthful stage of the cycle, streams erode head-ward actively. valley walls are steep even vertical, waterfalls and rapids are numerous and large areas between streams have not yet been dissected. Erosion tends to be greatest in the lower part of the drainage basin.

3. Corrasion or abrasion: Mechanical wear, termed abrasion occurs through the impact of rock particles carried in the current striking against the exposed bed rock of the channel surfaces. Most of the erosion done by a river is attributed to corrasive action. Due to this erosion variety of erosional forms are produced like chutes, plunge pools, potholes (cylindrical pit).

4. Corrosion: It is the solvent action of river water. Chemical reactions between ions, carried in solution in stream water, and the exposed mineral surfaces result in a form of erosion designated as corrosion. It is similar to chemical rock weathering.

2. The stage of maturity is achieved when the young valley have been cut into the uplifted block, new network of tributaries have formed and all valleys show typical V-shaped profiles. Flood plains appear on valley floors. As the basin develops, the zones of maximum erosion moves upstream and accordingly it is concentrated along the divide in the later stage.

3. The old stage: It is little doubtful. It is supposed to have low relief across which streams meander.

Rate of erosion

Erosion by a river in a given time depends upon:

- a. Its volume and velocity of flow (influences the quantity of energy)
- b. Character and size of its load
- c. Rock type and geologic structures
- d. Infiltration capacity of the area it drains
- e. Vegetation which affects stability and permeability of the soil

Traction: The rolling of the coarsest fragments along the river bed.

Saltation: Without being in suspended load, a particle may rise a few cm to as much as 30 cm above the bottom, travel down some distance, and then be pulled back by gravity. Such movement is known as saltation (Jumping motion).

Suspension: Fine sand, silt and mud are transported in suspension.

Solution: Soluble material is carried in solution.

TRANSPORTATION

The load which a river carries is transported in different ways. Water moves sediments in two contrasting ways:

1. Within the current, and
2. Along the base of the current

Streams as environments for depositing Sediments

A geologic agent that erodes and transports material can also function as a mechanism for depositing sediment. All stream deposited sediments are known as alluvium.

Finer particles are moved within the current. They become entrained within the flow and are wafled about by the irregular flow paths within the turbulent flow. Particles that do not become caught up within the turbulent eddies can be transported along the bottom of the current. They constitute the bed load.

The load which a river carries is transported in four different ways:

1. Traction
2. Saltation
3. Suspension
4. Solution

1. **Fans:** Where a stream leaves a bed rock valleys in a high land block and enters an open low land in which its channel is free to change directions, it deposits fans. They are low, fan shaped cones of alluvial sands and gravels ranging from a few meters to many km in extent.

Cones: Width 26-260 km nearly flat (slope less than 1°) moderate width (4-6°). Small steep sided cones (up to 15°) by short formed by torrential rains.

Piedmont alluvial plains: For example Gangetic plain

2. Braided channels

In streams with highly variable discharge and easily erodable banks, the channels may become interspersed with bars and islands, forming a pattern named braided stream. The process of building up the channel in this way is aggradation. (opposite of degradation, deepening of stream).

Braided streams typically are broad and shallow. Also formed by melting ice. Amazon and Ganges rivers are good examples.

4. Deltas

When a stream flows into a lake or the ocean, its speed is checked and it deposits its sediment.

The body of stream laid sediment deposited at the mouth of a river is a delta (after the Greek letter delta became of triangular shape).

For example Nile river delta (but may have any shape)

Four environmental settings from upstream areas to the mouth of streams in which streams may deposit sediments are:

1. Fans (alluvial fan)/alluvial cone
2. Areas having braided channels
3. Low land where channels form sweeping curves (flood-plain rivers)
4. Deltas

DELTAIC ENVIRONMENT

General Information

At the confluence of rivers with large water bodies large sediment cones, known as deltas, are developed. Moore and Asquith (1971) define a delta:

“The subaerial and submerged contiguous (adjoining) sediment mass deposited in a body of water (ocean or lake) primarily by the action of a river”.

3. Flood Plain rivers

Three major features of flood plain rivers are:

1. The channel and its bordering low ridges composed of sediments
2. The great curves named meanders, and associated features/point bars
3. The wide low lying flood plains (oxbow lakes)

Levees width varies from 20m to several km. Height 10 cm to several tens of meters.

The present day deltas are relatively young, as they have been formed only after the increased sea level during post-Pleistocene times. However, their size is rather impressive, because of increased rate of deposition.

The most important factors for the development of a delta are a large supply of sediments by streams and subsidence in the area of deposition. The ideal form of a delta is considered to be a cone; this idea shape is seldom achieved

STRUCTURE OF A DELTA

According to classical concept, a delta is made up of

- Topset,
- Foreset and
- Bottomset deposits

These three subdivisions of a delta are themselves composed of a smaller units which are deposited in rather varied environmental conditions.

Bottomset Deposits

Bottomset deposits are made up of offshore clays under the influence of active deltas. In the Mississippi delta such offshore clays are up to 10 m thick.

Topset Deposits

Topset deposits of a delta are mainly made up of marsh deposits and delta front silts and sands. Also present are river channel deposits and natural levee deposits, together with crevasse splay deposits.

Muddy sediments with shell layers are deposited in the bays between the distributaries and the tidal channels. These various sediments are associated with each other in a very complicated way. Their lateral and vertical boundaries both gradational and sharp.

Marginal Deposits

These are transitional deposits between bottomset deposits and the deposits of the subsurface, which were deposited before the building up of the delta.

In many present-day examples the underlying deposits of a delta are Pleistocene in age. The marginal deposits of a Mississippi delta are strongly bioturbated, and made up of sandy and muddy sediments.

Foreset Deposits

Foreset deposits are made up of pro-delta silty clays and rather coarse sand, silt, and clay deposits formed off the major deltaic distributaries.

In the delta foresets (also known as delta front slopes) are also incorporated delta front gullies.

Prodelta slope or delta front slope

Beyond the platform is a slope known as the prodelta slope, or delta front slope. Part of this shelf which have been influenced by Recent sediment deposition are referred to as open shelf with recent delta influence. Actually, they can be termed bottomset deposits.

Prodelta Environment

The region seaward of the delta front environment is the prodelta environment, which is closely associated with the prograding delta system. It is also known as the delta front slope.

Prodelta deposits are characteristically fine-grained muddy sediments, i.e., clay and silty clay. The prodelta deposits are transitional into the shelf-mud deposits.

Subenvironments of Topset deposits

Topset deposits can be differentiated into two parts:

- Subaerial, and
- Subaqueous

Subaerial topset deposits are marsh and river channel deposits. Subaqueous topset deposits are delta front deposits, accumulating almost entirely under the influence of fluvial processes. They include: Channel deposits, Natural levee deposits and Flood basin deposits including lake and swamp deposits.