Center for Environmental Research at Hornsby Bend

Fluvial Process: Waterways and Hydrology

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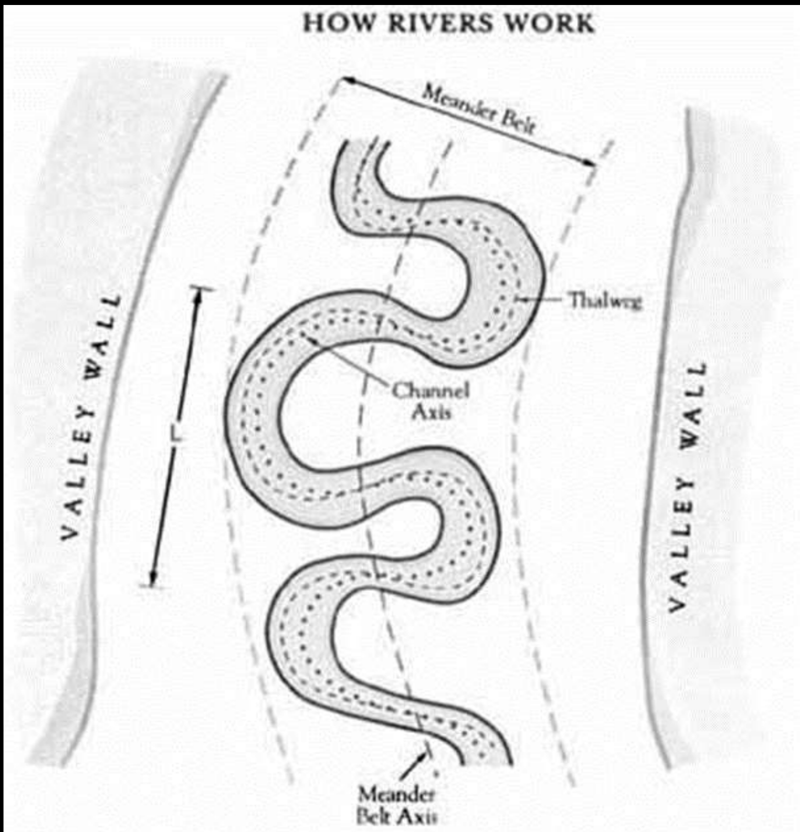
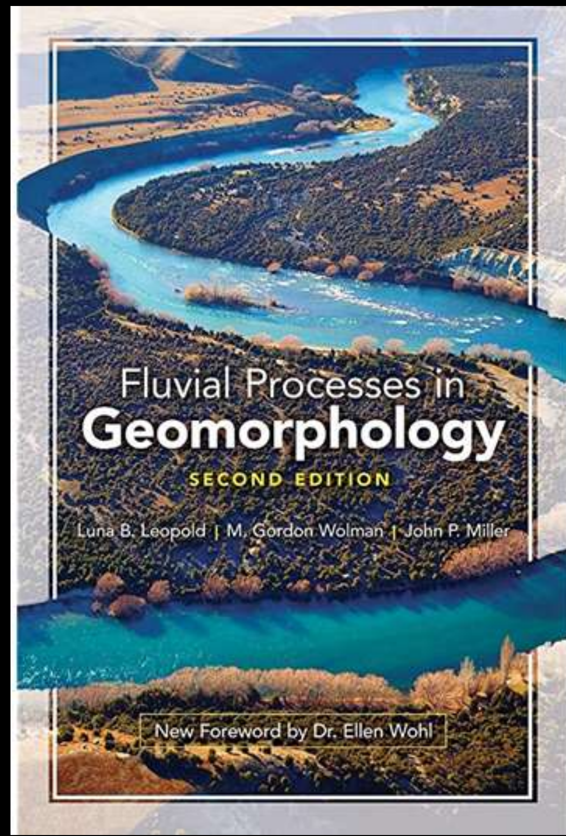
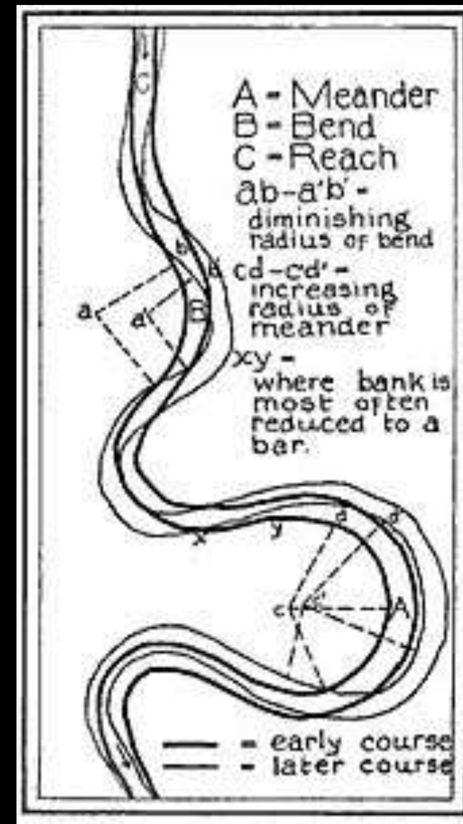






A Fluvial Journey

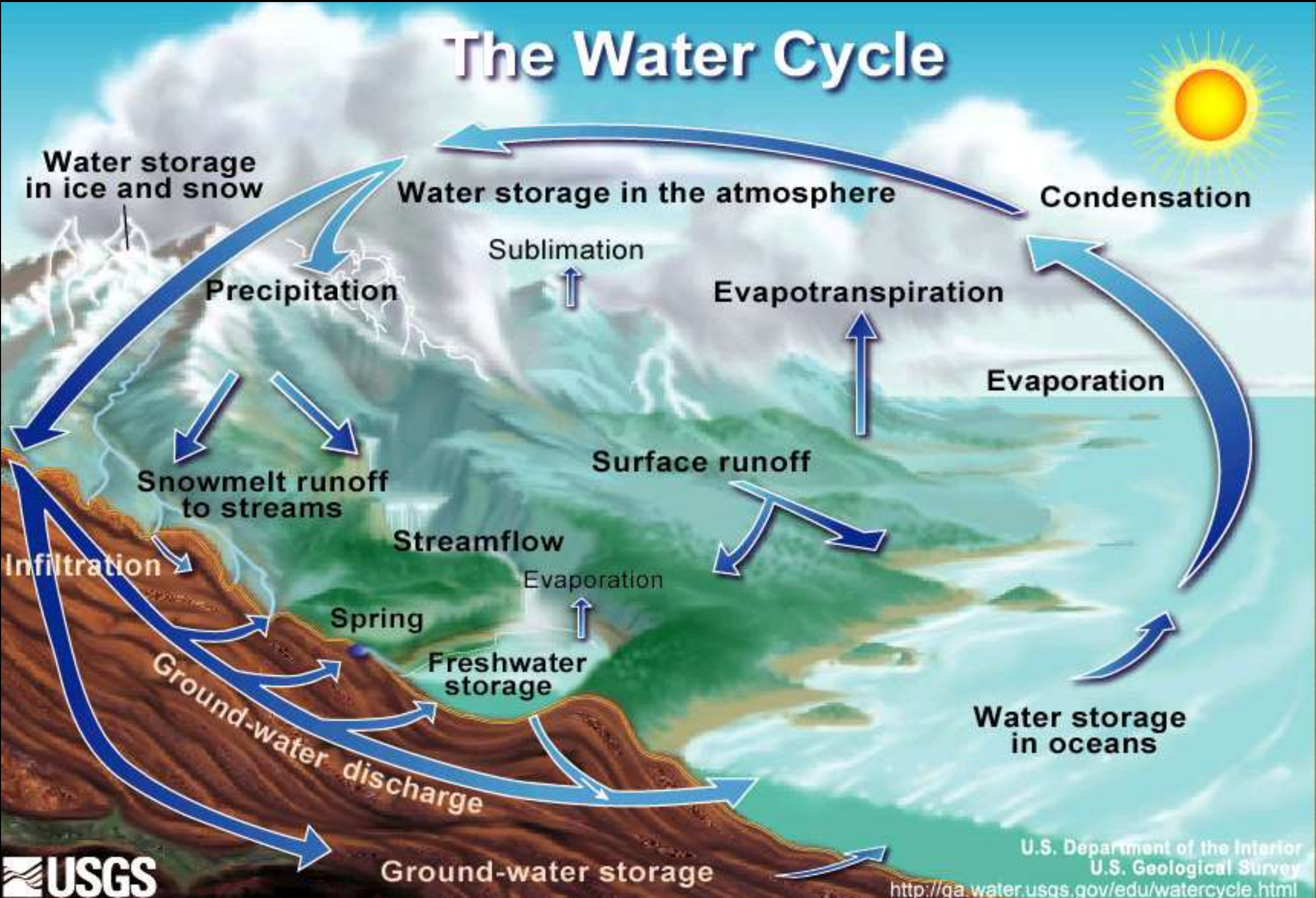
Fluvial - of, relating to, or living in a stream or river

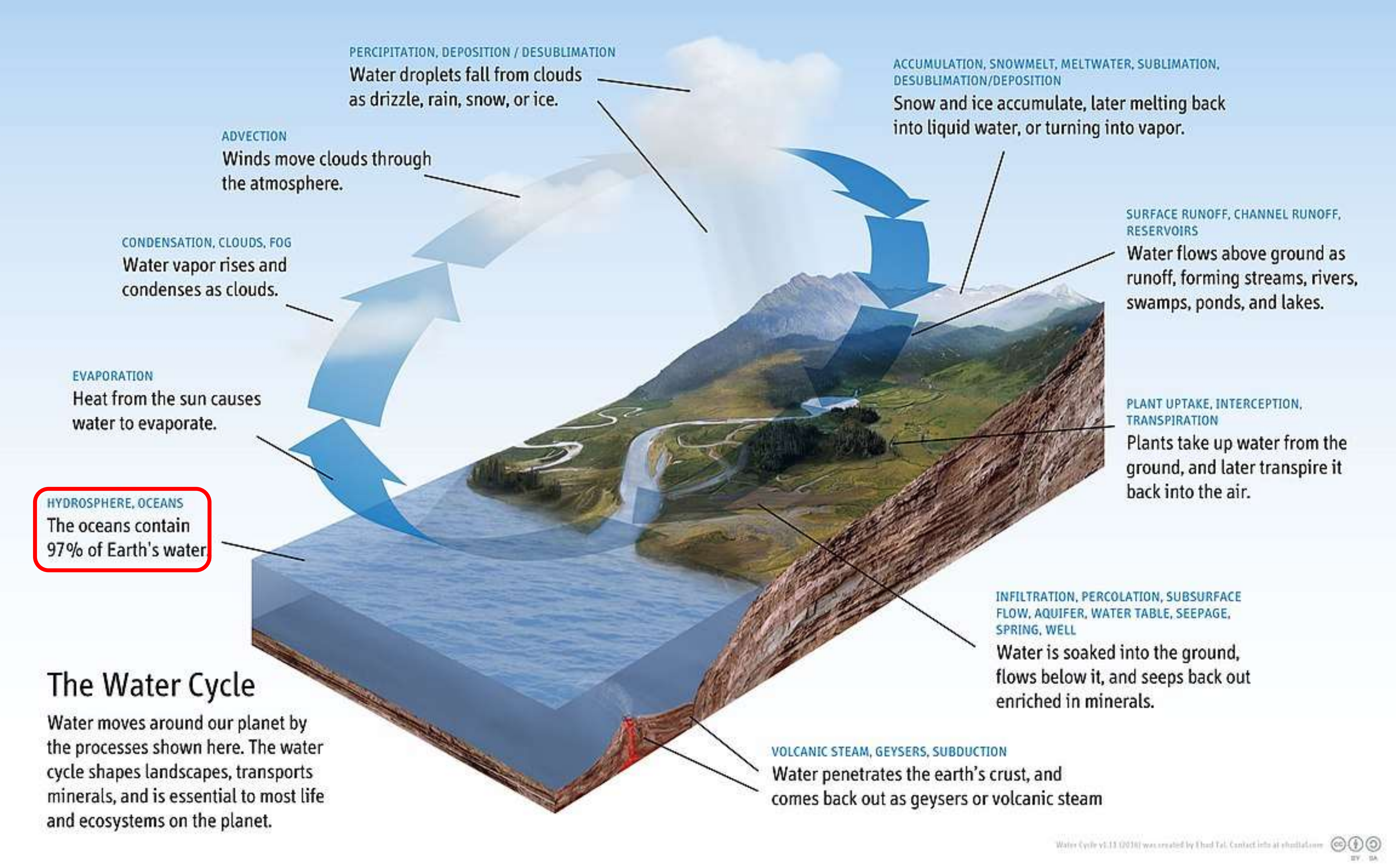
Fluvial Geomorphology - the study of how moving water shapes a landscape over time

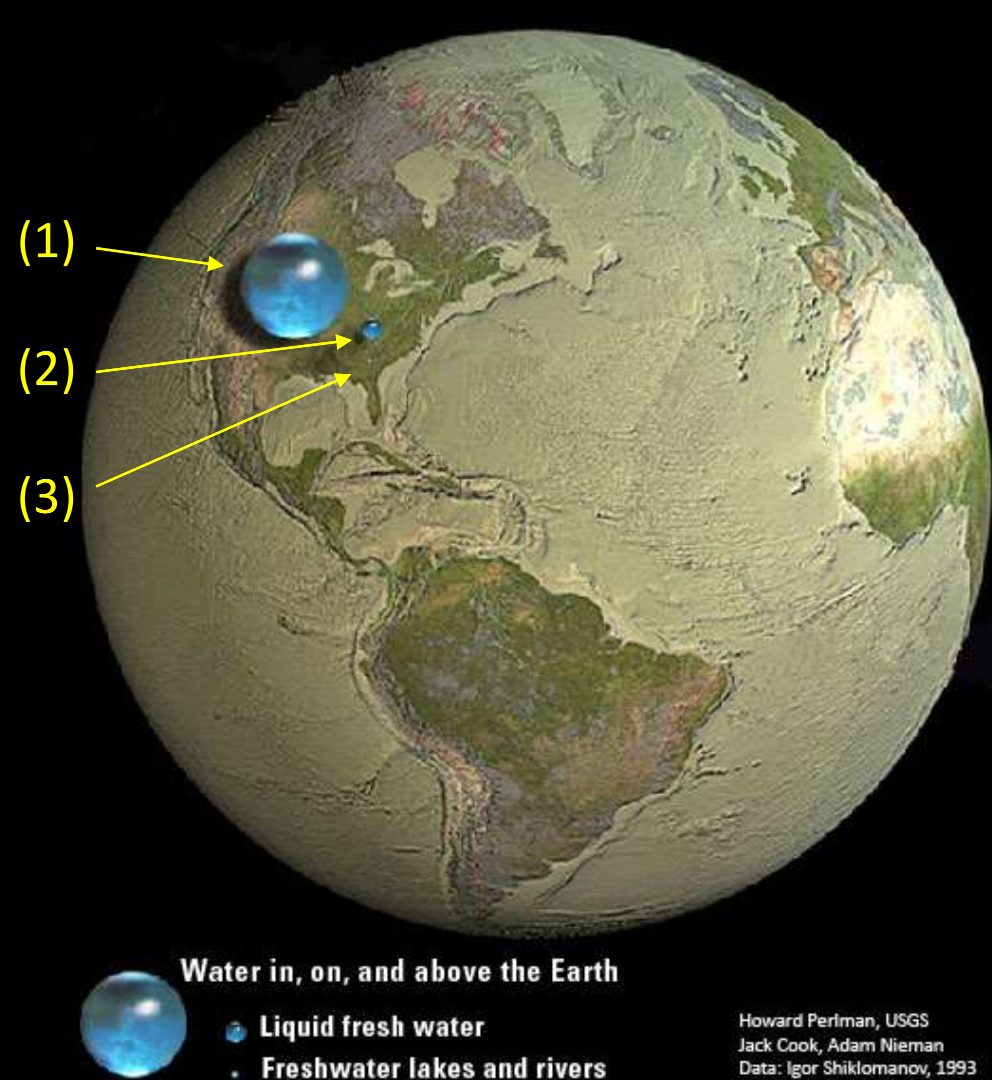
Flowing water always wants to carry a sediment load

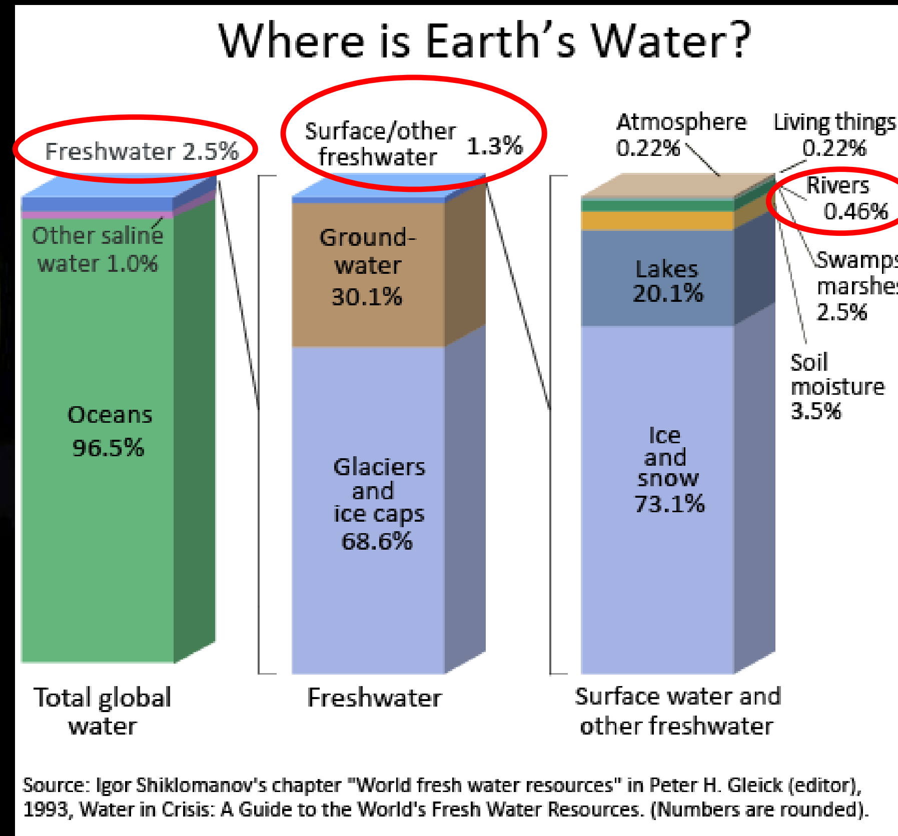
Sinuosity is inversely proportional to slope

Hydrology - the study of the distribution and movement of water on and below the Earth's surface and the impact of human activity on water availability and conditions.




PERCIPITATION, DEPOSITION / DESUBLIMATION
Water droplets fall from clouds as drizzle, rain, snow, or ice.
ACCUMULATION, SNOWMELT, MELTWATER, SUBLIMATION, DESUBLIMATION/DEPOSITION
Snow and ice accumulate, later melting back into liquid water, or turning into vapor.
ADVECTION
Winds move clouds through the atmosphere.
SURFACE RUNOFF, CHANNEL RUNOFF, RESERVOIRS
Water flows above ground as runoff, forming streams, rivers, swamps, ponds, and lakes.
CONDENSATION, CLOUDS, FOG
Water vapor rises and condenses as clouds.
EVAPORATION
Heat from the sun causes water to evaporate.
PLANT UPTAKE, INTERCEPTION, TRANSPIRATION
Plants take up water from the ground, and later transpire it back into the air.
HYDROSPHERE, OCEANS
The oceans contain 97% of Earth's water
INFILTRATION, PERCOLATION, SUBSURFACE FLOW, AQUIFER, WATER TABLE, SEEPAGE, SPRING, WELL
Water is soaked into the ground, flows below it, and seeps back out enriched in minerals.
The Water Cycle
Water moves around our planet by the processes shown here. The water cycle shapes landscapes, transports minerals, and is essential to most life and ecosystems on the planet.
VOLCANIC STEAM, GEYSERS, SUBDUCTION
Water penetrates the earth's crust, and comes back out as geysers or volcanic steam





(1) Total Global Water (sphere over western U.S., 860 miles in diameter)

(2) Fresh liquid water in the ground, lakes, swamps, and rivers
(sphere over Kentucky, 169.5 miles in diameter)

(3) Fresh-water lakes and rivers
(sphere over Georgia, 34.9 miles in diameter).

General Differences Between Streams and Lakes

Streams (Lotic) vs	Lakes (Lentic)
One direction of flow, upstream to downstream	Various flows, no particular direction
Normally oxygen rich	Oxygen depletion exists at times in deeper water
Shallower	Deeper
Narrower and longer	Wider and shorter
Various effects from different terrestrial environments along the stream's course. The shoreline has more potential to affect water quality because a larger portion of the water body is near shore.	Terrestrial environment similar all around the lake shore. A smaller portion of the water is in close proximity to the shore.
Stream continually cuts into the channel, making it longer, wider, and deeper	Lakes become shallower over time from depositing sediments
Age progression of a stream goes from young stream, narrow and shallow, to mature stream, wider and deeper	Age progression of a lake or pond goes from lake to marsh or swamp to land
Shorter retention time for water	Longer retention time for water
Top and bottom waters generally have the same temperature	May have different temperatures from the top to bottom

Flowing Water vs. Nonflowing Water
Lotic vs. Lentic

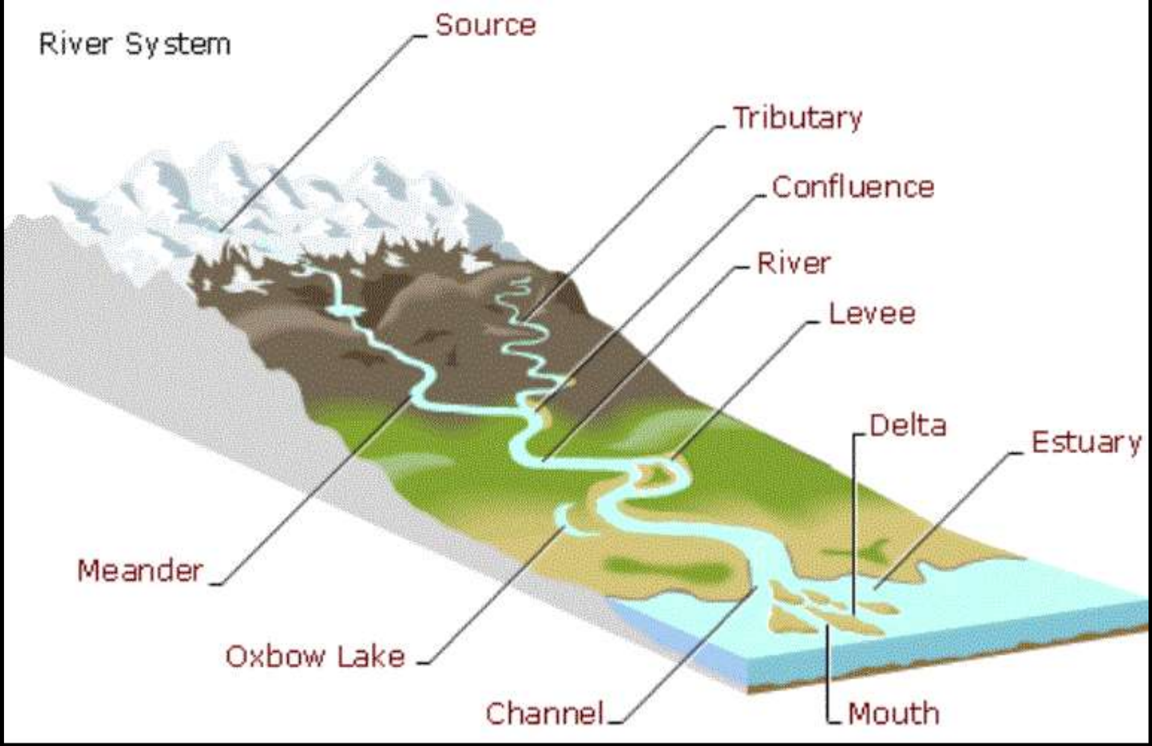
The Geography of Flowing Water

Waterway
River/Stream/Creek
- a body of water flowing along a channel

Fluvial Geomorphology

Fluvial Anatomy

A river or stream starts at the <u>source</u> or <u>headwaters</u> and flows along its course/channel ending in a <u>confluence</u> with another stream or river (<u>tributaries</u>) or drains into a lake, sea, gulf, or ocean at its <u>mouth</u> forming a delta/estuary



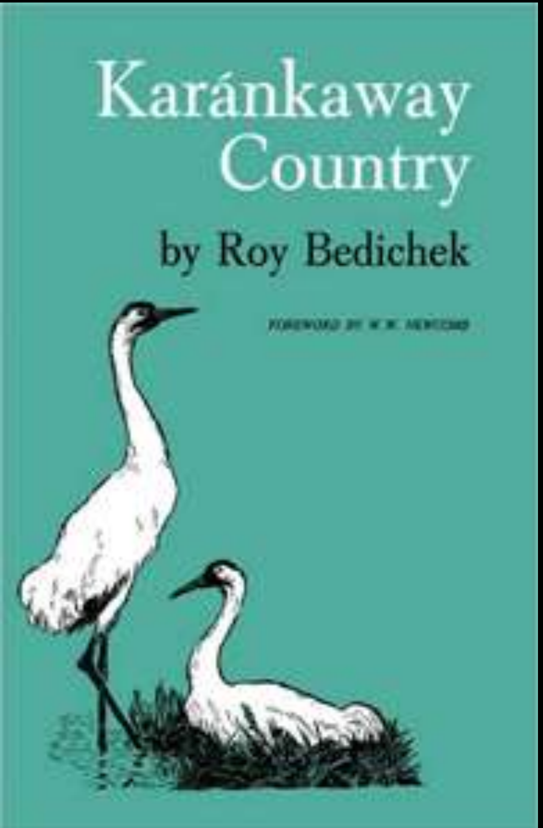
Problem of Anatomy and Fluvial Language – mouth, head, source

"I think that <u>ancient misnomer 'mouth</u>,' which we use to designate the place where a river empties, has done the cause of conservation incalculable harm.

Our river imagery is muddied at its source.

<u>We speak of the head of a river, but there is no mouth in the head</u>.

<u>That orifice in our curious anatomy is at the other end</u>. We speak of *the* source of a river, but a river has a thousand sources."

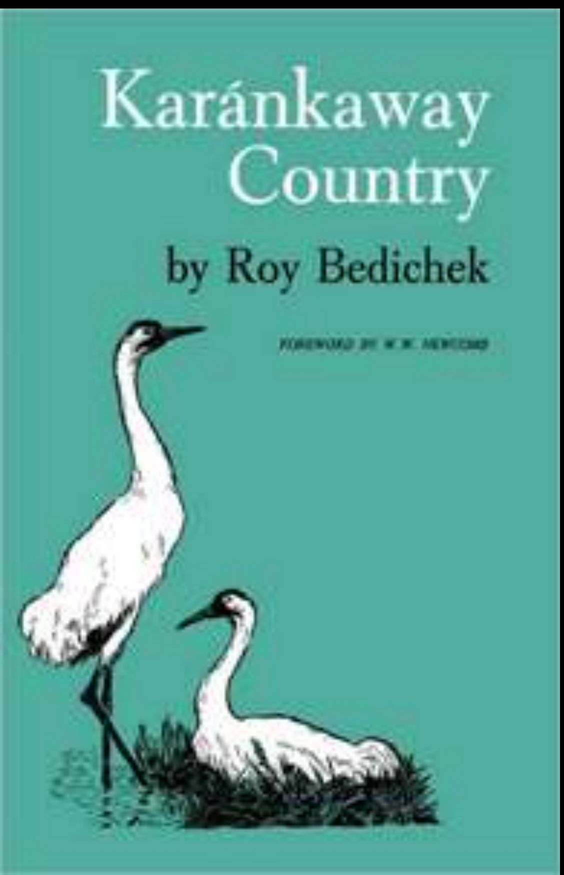


Bedichek (left) with Frank Dobie at Barton Springs

Problem of Anatomy and Fluvial Language – mouth, head, source

"There is no better place than at the so-called 'mouth' of a diseased river to diagnose its ailment, for there we find out what it is being fed, whether it is digesting what it is taking in, the condition of its circulatory system, and whether or not its eliminations are normal.

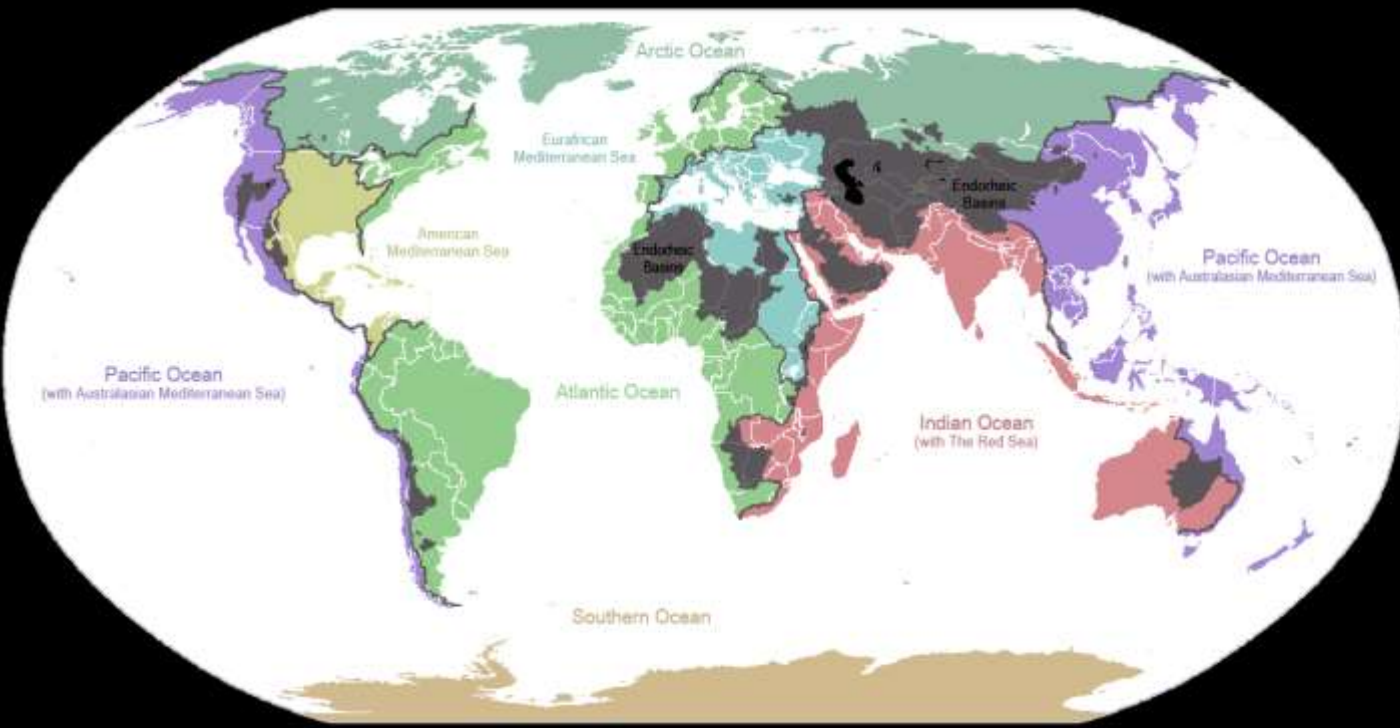
By the same token, there is generally no worse place to begin the treatment of the disease after its nature is discovered."



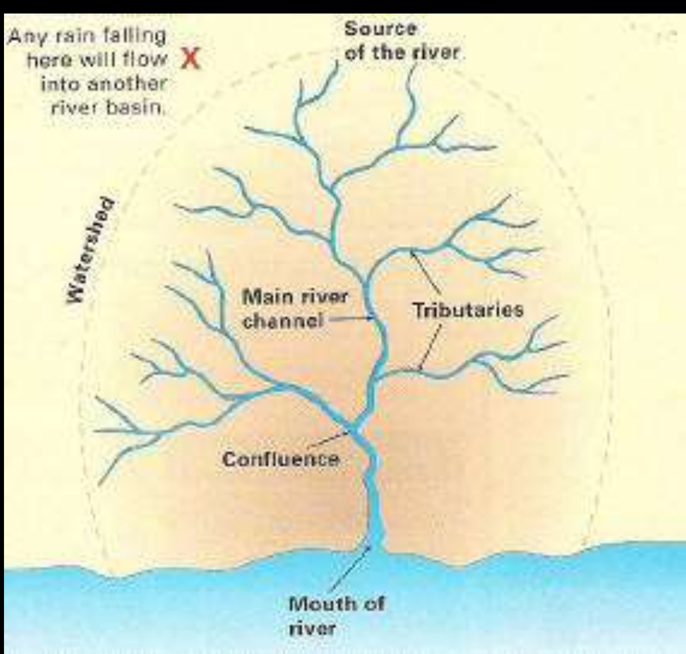
Bedichek (left) with Walter Prescott Webb and Dobie

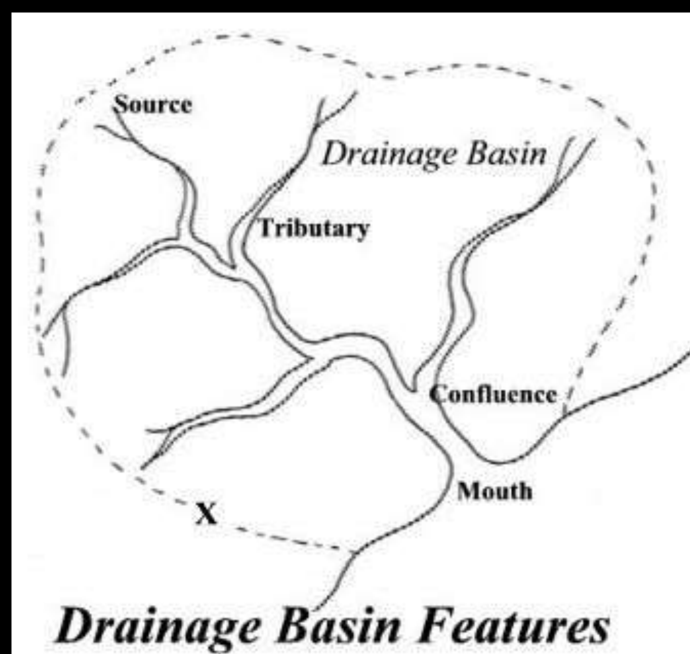
Fluvial Language

Watersheds vs. Drainage Basin/ Catchment Area



A <u>watershed</u> (US usage) or <u>drainage basin/catchment area</u> (British usage) is an area of land which is drained by a river and its tributaries.



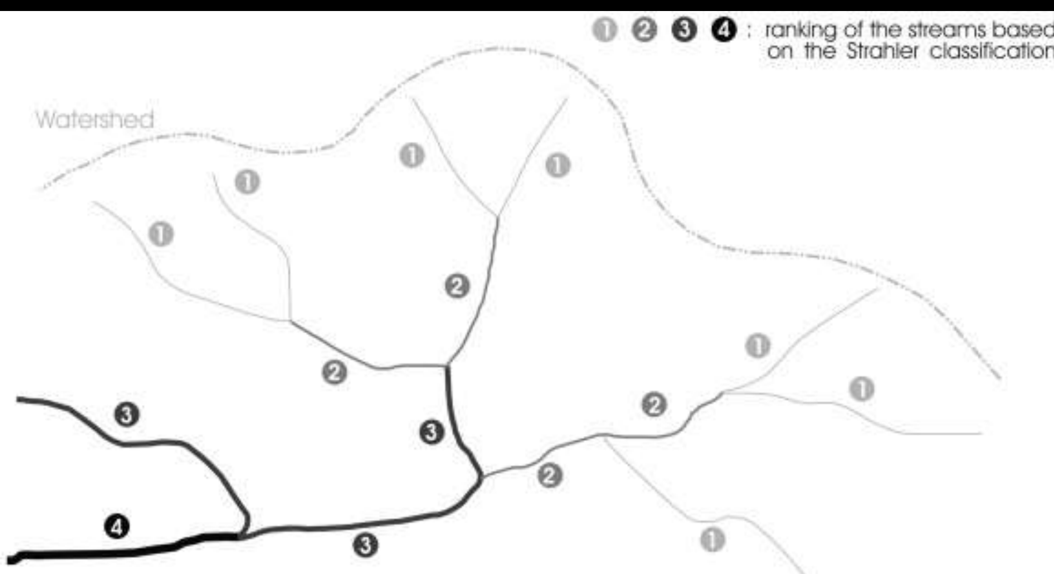


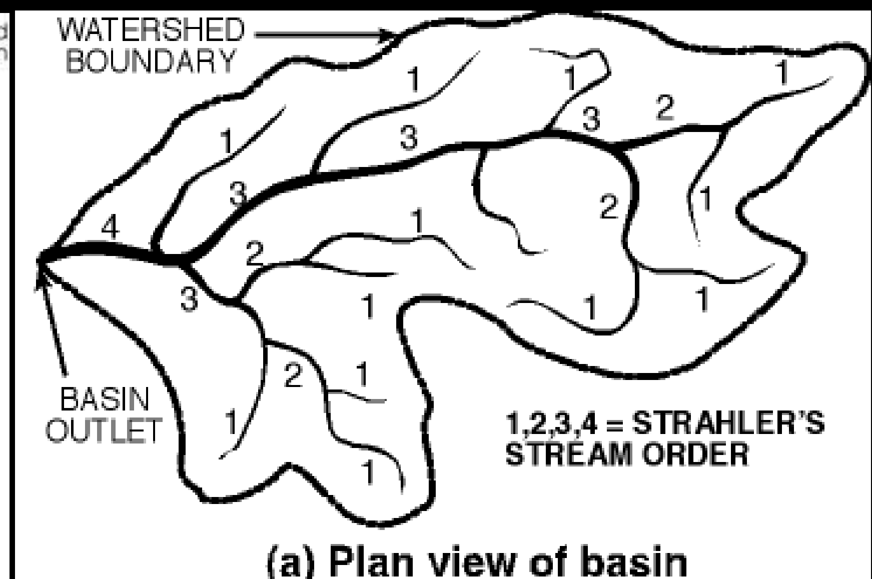
In British usage, a watershed is the <u>boundary</u> separating one drainage basin from another. It usually follows the ridge or crest of a hill or mountain.

River Network – The Strahler Stream Order

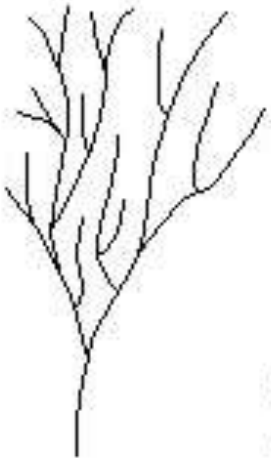
Strahler number or Horton–Strahler number

- a mathematical tree with a numerical measure of its branching complexity
- These numbers were first developed in hydrology by Robert E. Horton (1945) and Arthur Newell Strahler (1952, 1957)
- They are referred to as the Strahler stream order and are used to define stream size based on a <u>hierarchy of tributaries</u>.



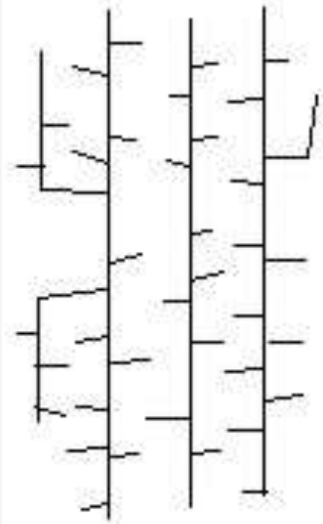


Fluvial Landscapes - Drainage Patterns



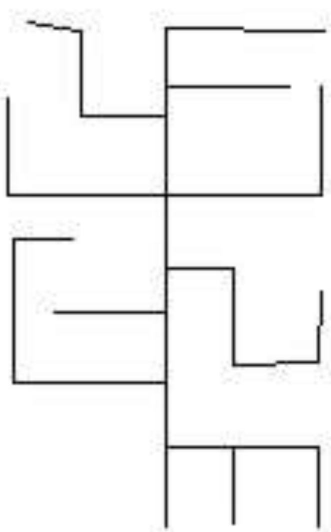
DENDRITIC – tributaries meet at low angles and branch in random, tree-like pattern. Form on roughly planar surfaces of conmsistently erodable rocks or sediment.

FLINT/CHATTAHOOCHEE/ APALACHICOLA SYSTEM



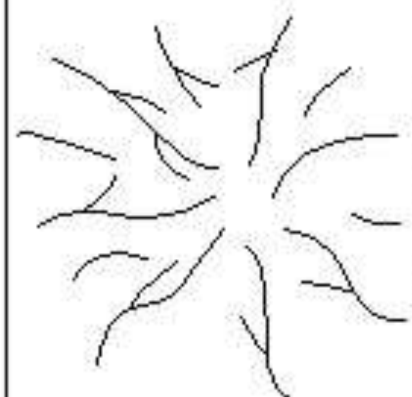
TRELLIS – Short tributaries meet long trunk streams at near right angles. Few connections between trunks. Form on folded or tilted sedimentary rocks of different resistances to erosion.

POTOMAC SYSTEM



RECTANGULAR – Straight tributaries meet straight trunk streams. Bends approximate right angles. Form on faulted or otherwise fractured bedrock. (**ANGULAR** drainage is similar but bends/junctions are at some angle other than 90°).

COTTONWOOD CREEK, UTAH (ANGULAR DRAINAGE)



RADIAL – Flow outward from a well-defined central point. Form on volcanoes and other round uplifts of the land.

DRY VALLEYS ON NORTH MENAN BUTTE, IDAHO

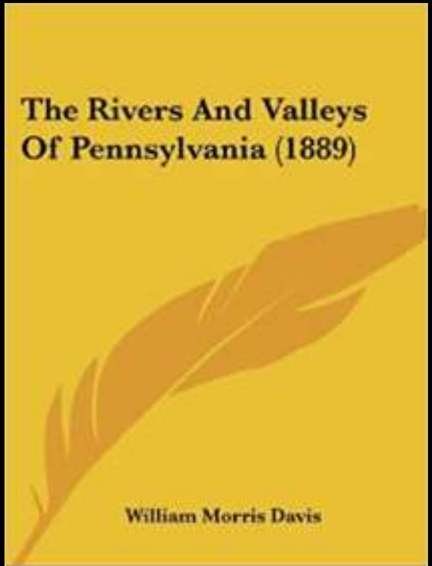
Flowing Water and Erosion – Earth Writing

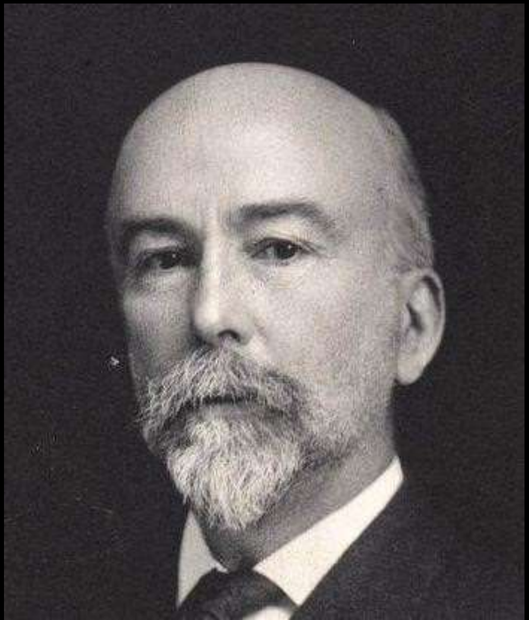
William Morris Davis (1850 - 1934) - American geographer, geologist, geomorphologist, and meteorologist, often called the "father of American geography".

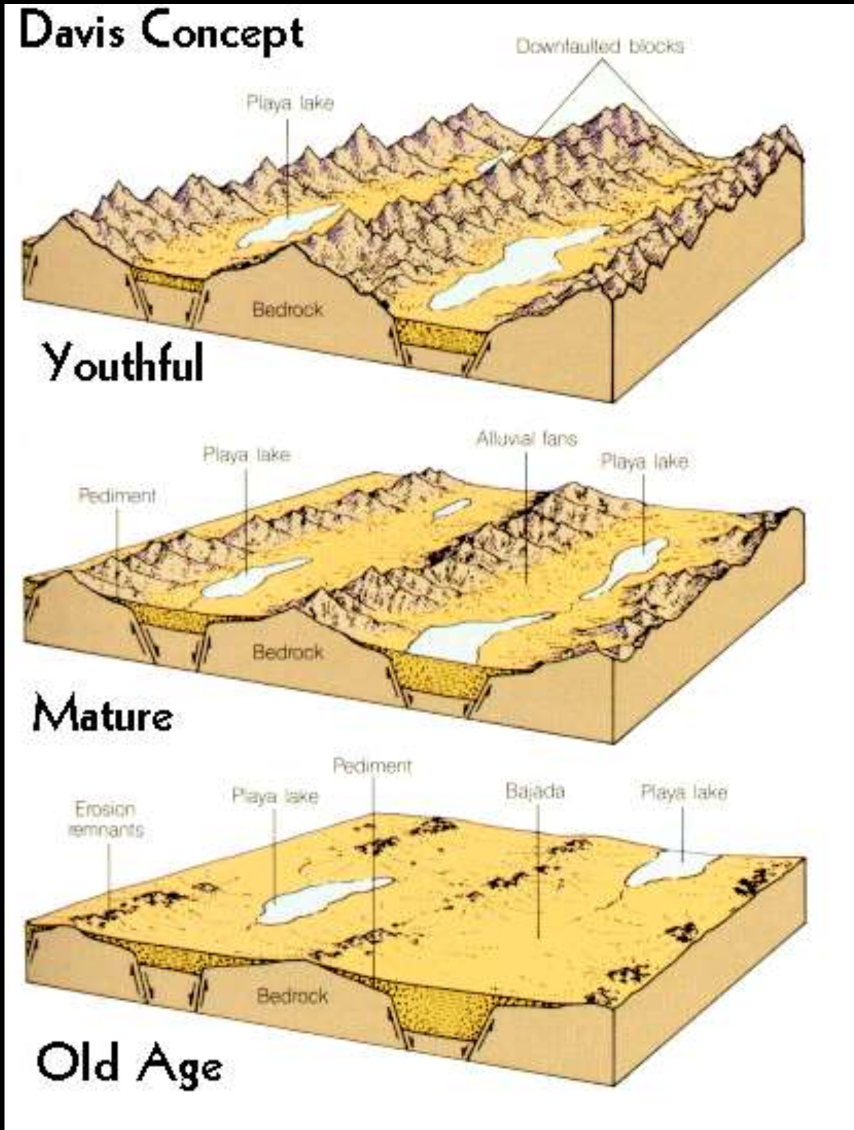
The Geographical Cycle – Erosion Cycle

His most influential scientific contribution was the "geographical cycle" or the cycle of erosion, first defined around 1884, which was a model of how rivers create landforms.

Flowing water always wants to carry a sediment load





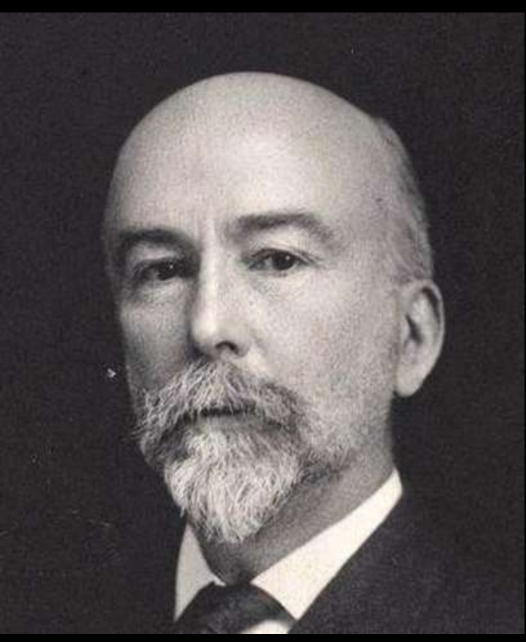


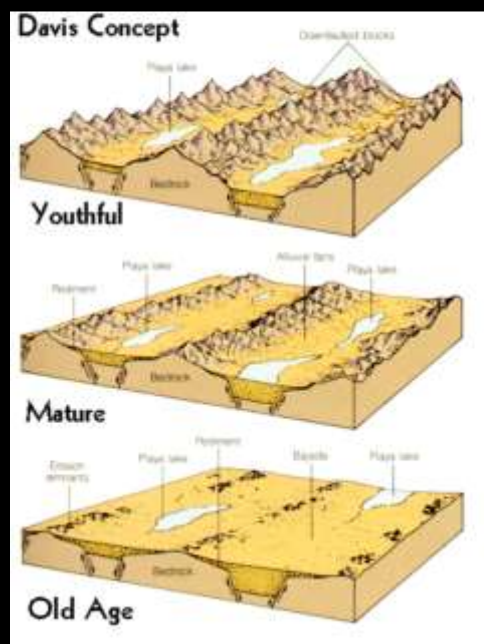
Waterways: The Life of a River – Davis and the Metaphorical Landscape

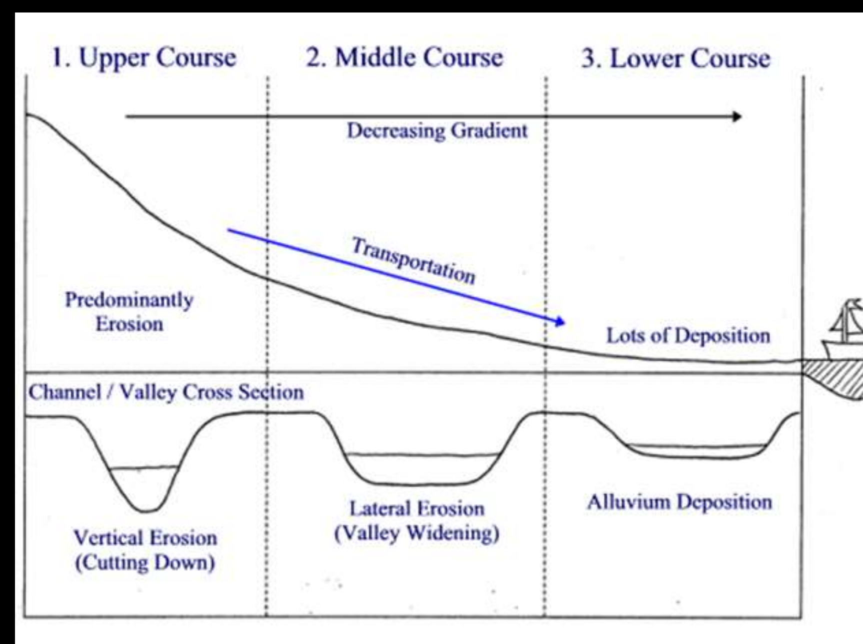
Luna Leopold, "A Reverence for Rivers"

Davis "viewed the river system as having a life of its own -

- Its youthful headwaters are steep and rugged. It rushes toward the sea, eroding bed and bank on its way.
- In its central part, it is mature, winding sedately through wide valleys adjusted to its duty of transporting water and sediment.
- Near its mouth it has reached, in its old age, a nearly level plain through which it wanders in a somewhat aimless course toward final extinction as it joins the ocean that had provided the sustaining waters through its whole life span."





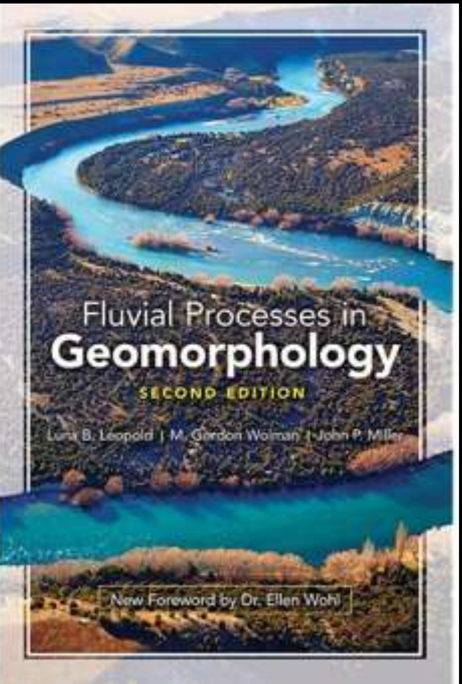


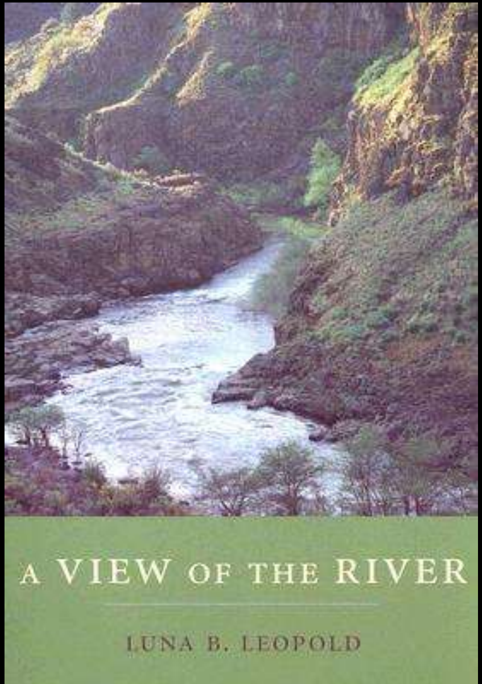
The Dean of American Fluvial Geomorphology - Luna Leopold
(October 8, 1915 – 2006)

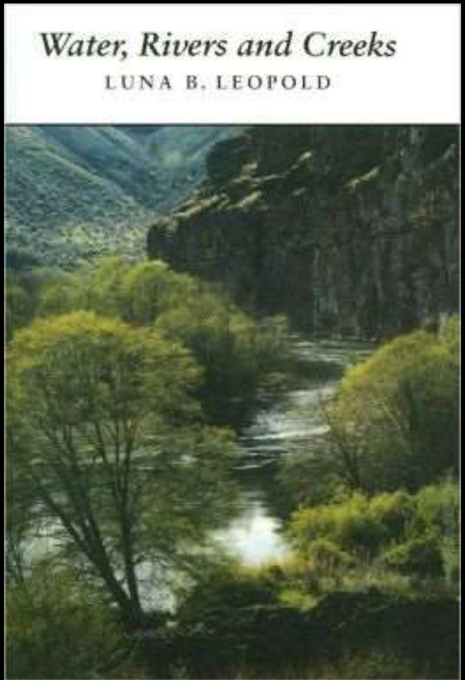
- He was a leading U.S. geomorphologist and hydrologist
- Son of Aldo Leopold
- USGS 1950-72, UC Berkeley 1972-86

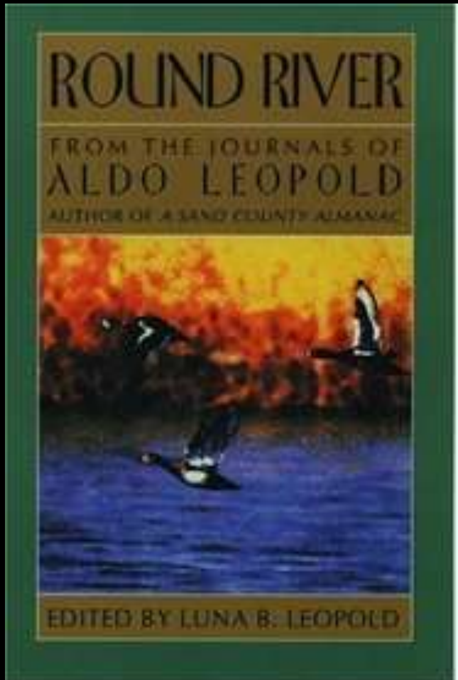
A View of the River (1994, reprinted 2006).
Water, Rivers and Creeks (1997).
Fluvial Processes in Geomorphology (1964).
Round River: From the Journals of Aldo Leopold (1972) Editor.

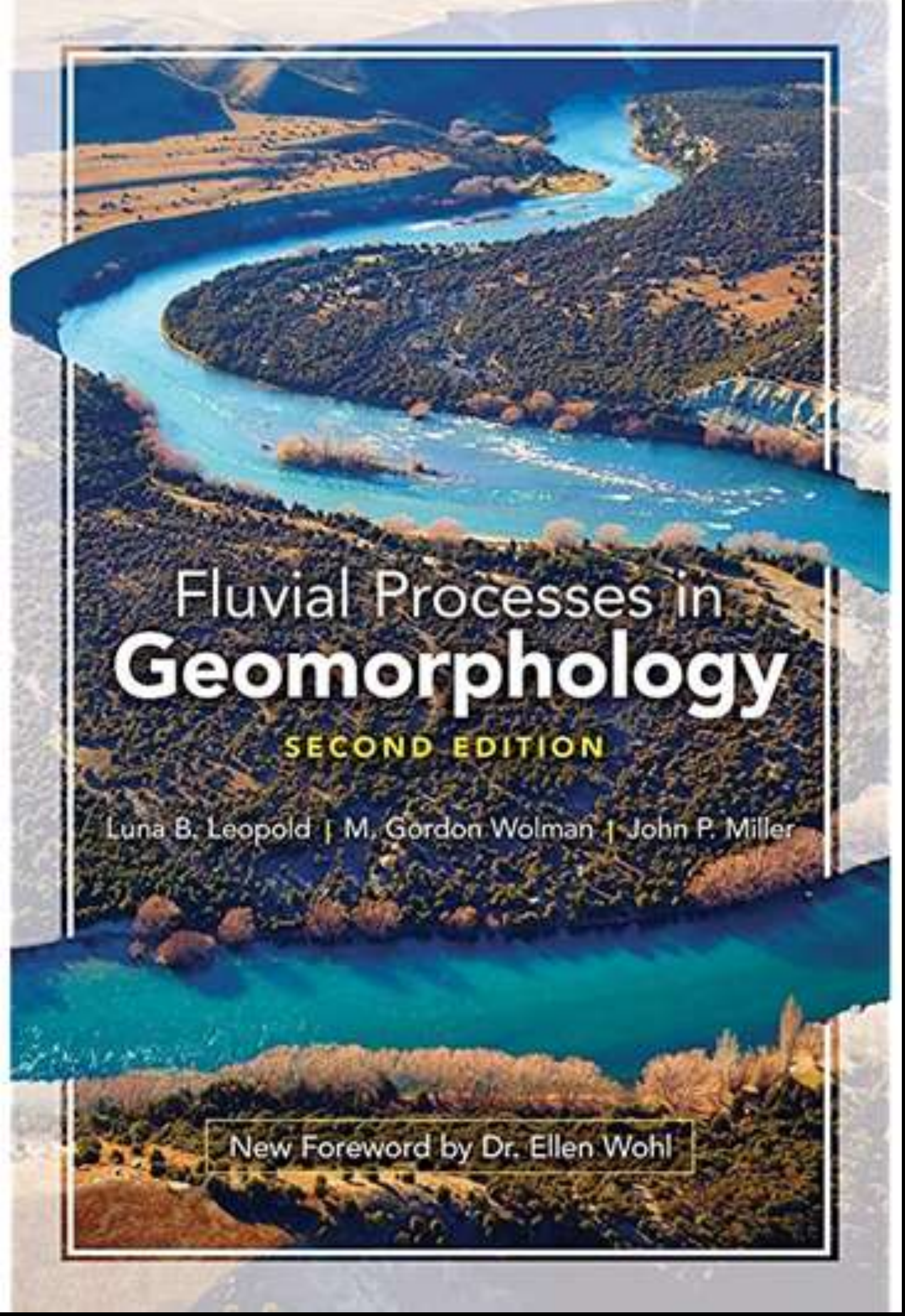
The Virtual Luna Leopold Project http://eps.berkeley.edu/people/lunaleopold/











Fluvial Geomorphology

the study of how moving water shapes a landscape over time

Flowing water always wants to carry a sediment load

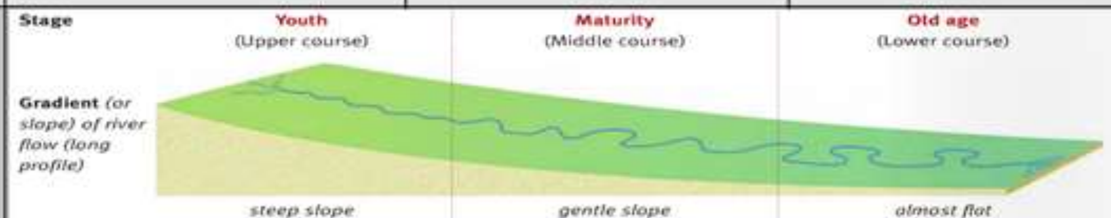
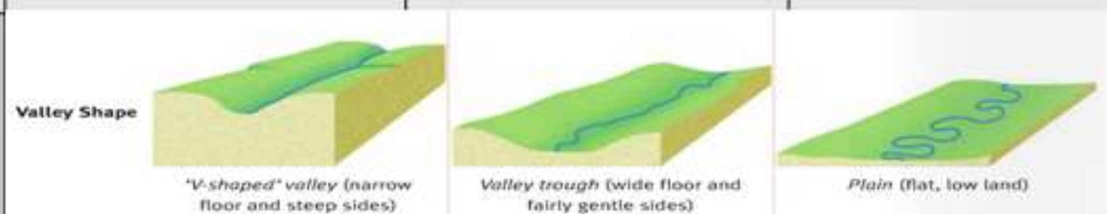
Sinuosity is inversely proportional to slope

Waterways - A Fluvial Life (Davis and Leopold)

The Upper Course: steep and rugged

The Middle Course: winding sedately through wide valleys

The Lower Course: a somewhat aimless course toward final extinction

Course Stage	**Upper Course Youth Stage**	**Middle Course Mature Stage**	**Lower Course Old Age Stage**
Slope			
Main processes	Hydraulic Action Abrasion **Erosion**	**Erosion** and **Deposition**	**Deposition**
Valley shape			
Main features	V-shaped Valleys Interlocking Spurs Waterfalls	Meanders and Ox-Bow lakes	Deltas Levees Flood Plains (and m+ob lakes)

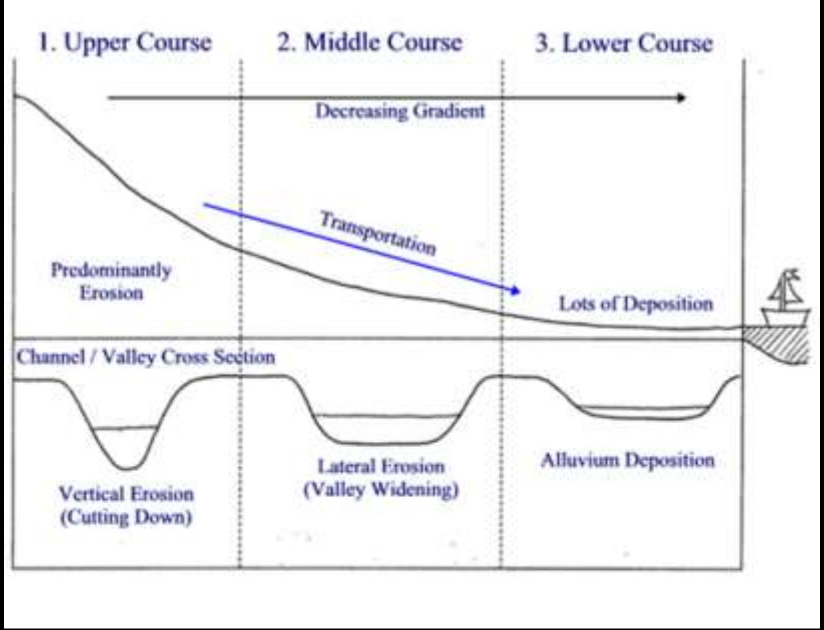
The Upper Course - Youthful Headwaters

Speed of Flowing Water (velocity)

<u>The velocity of a river</u> is the speed at which water flows along its course.

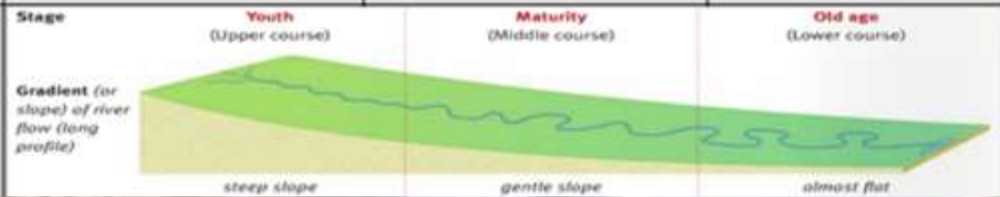
The velocity will change along the course of any river, and is determined by factors such as;

- the <u>gradient</u> (how steeply the river is losing height)
- the <u>volume of water</u>
- the <u>shape of the river channel</u>
- the amount of <u>friction</u> created by the bed, rocks and plants.



Upper Course - Gradient of river

- The steeper the slope, the faster the flow.
- Steep V-Shaped Valley
- Narrow/Shallow Channel

Course Stage	Upper Course Youth Stage	Middle Course Mature Stage	Lower Course Old Age Stage
Slope			

River Competence and Bed Load

- Davis - Flowing water always wants to carry a sediment load
- Rivers and streams carry sediment that ranges in size from clay (smallest) to boulders (biggest).
- The biggest sized particle that a river could carry at a specific point is called the river's competence.
- Bed Load – sediment that is transported along the bed of a river or stream

Wetted perimeter

- The wetted length of bed and bank.
- Larger wetted perimeter (banks and bed in contact with water), the river has to overcome more friction and is slowed down.

The Upper Course
Rapids and Roughness

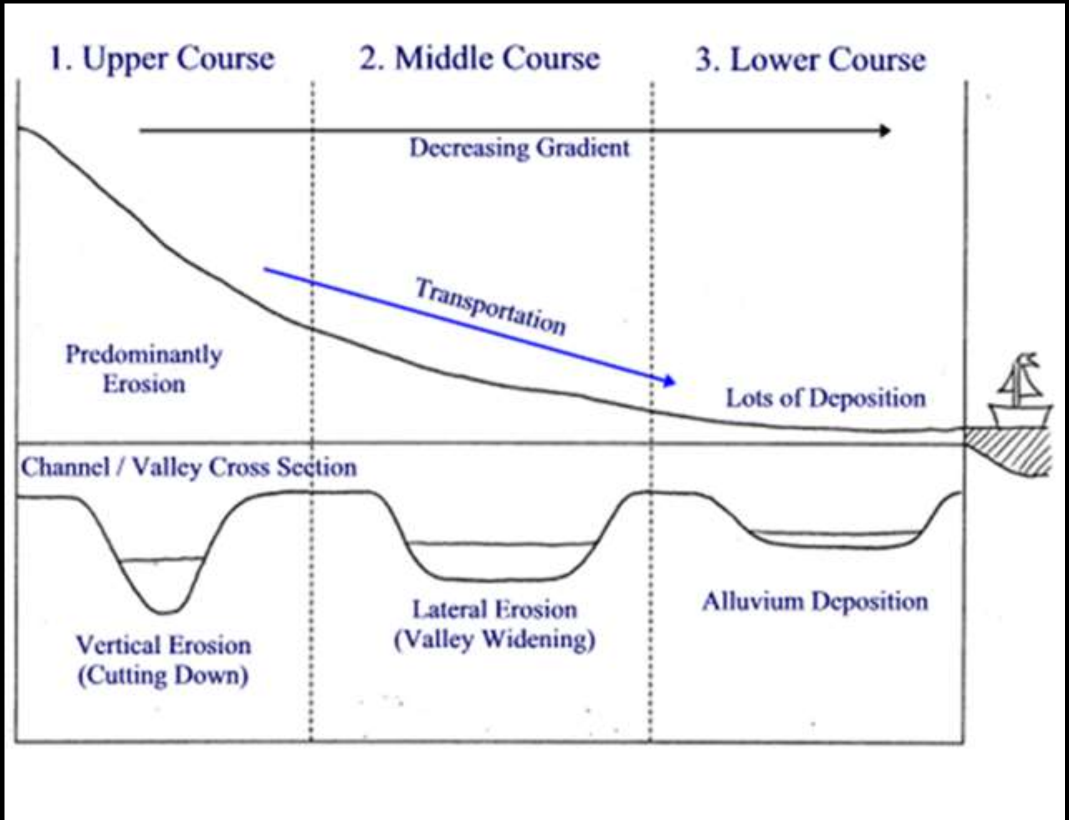
- Rapids are most commonly found in the upper course of the river and form as a result of the river cutting down rapidly in a localized section of the river.
- The main characteristics of rapids are distinctly steeper gradients marked by steps in the channel and high turbulence, which is the result of large bedload in the channel.
- Due to the roughness of the channel, flow is turbulent and known as whitewater.
- The velocity of the river is noticeably faster at rapids but not efficient in its flow.

youthful headwaters are steep and rugged

The Upper Course vs. Lower Course
Apparent Velocity, Channel Roughness vs Efficiency

The channel in the upper course is “rough” - shallow and punctuated with large angular bedload. The rougher the channel, the slower is the flow, because the water has to overcome the friction of the river bed and banks.

As a consequence it has low channel efficiency and therefore the quantity of transported bedload is lower.

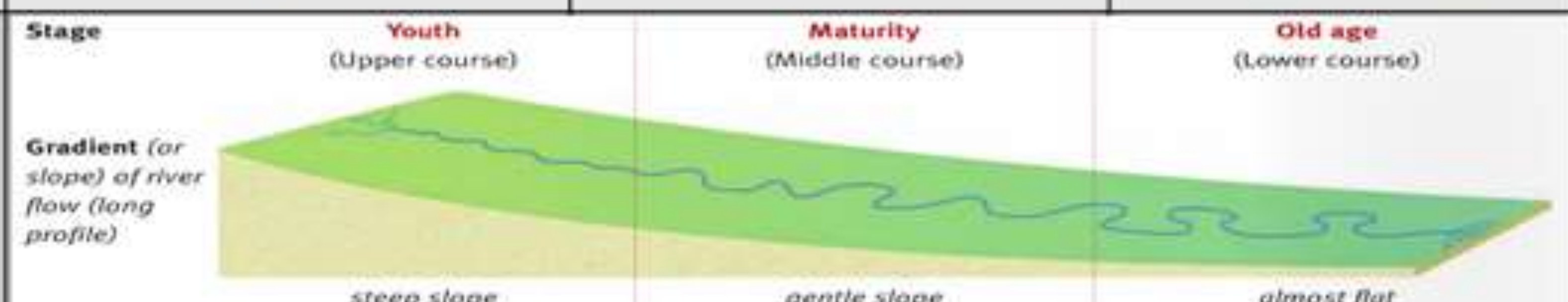


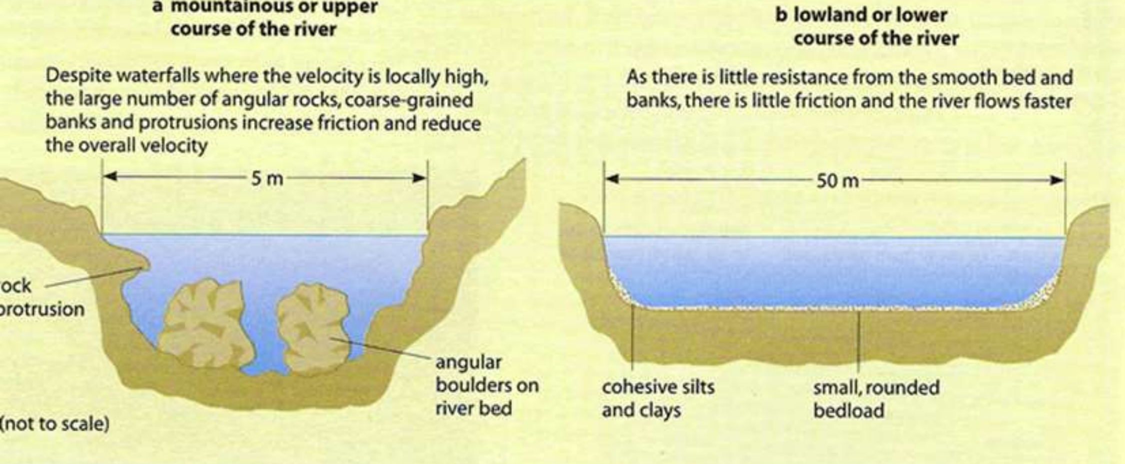
The Upper Course vs. Lower Course
Channel Efficiency and Capacity

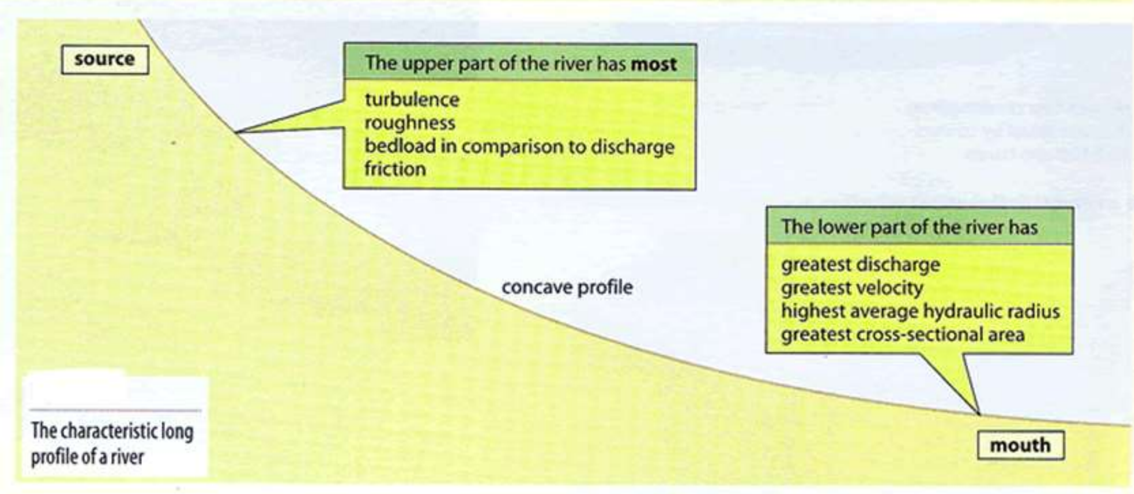
Channel efficiency is the river's ability to transport bedload and discharge. Smooth semi-circular channels are the most efficient channels and are located typically on the lower course. Rough angular channels of the upper course are inefficient.

Capacity - Rivers can only carry so much load depending on their energy. The maximum volume of load that a river can carry at a specific point in its course is called the river’s capacity.

Since channel efficiency of a river increases downstream, channel capacity does too! (Old age over youth!)

Course Stage	Upper Course Youth Stage	Middle Course Mature Stage	Lower Course Old Age Stage
Slope			





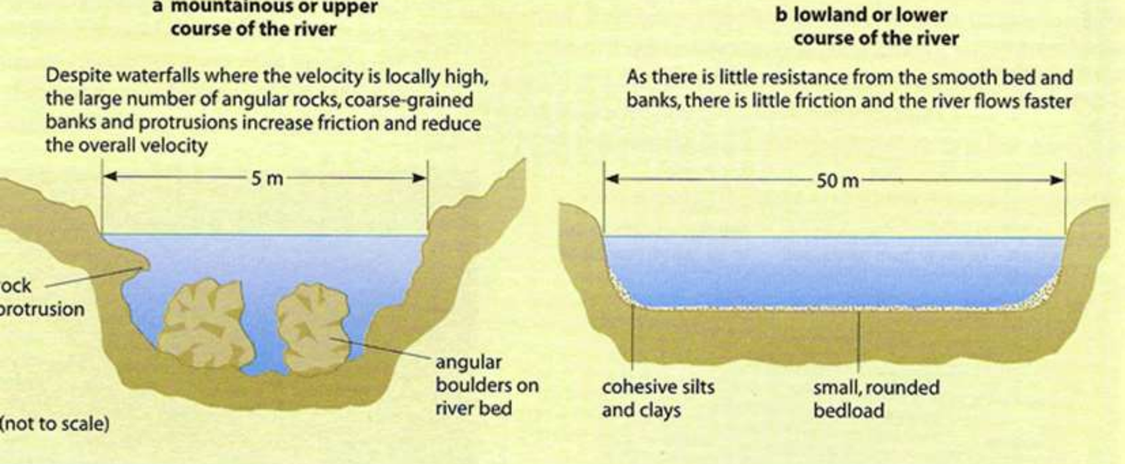
Luna Leopold
Apparent vs. Mean Velocity

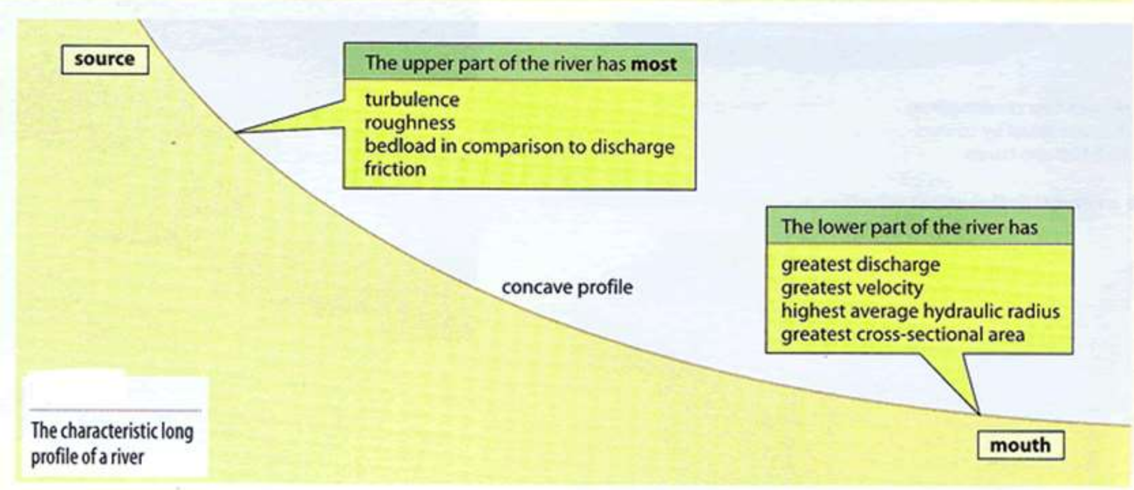
"Downstream Change of Velocity in Rivers"

Luna Leopold *American Journal of Science*, VOL. 251, August 1953

Because river slope generally decreases in a downstream direction, it is generally supposed that velocity of flow also decreases downstream.

Analysis of some of the large number of velocity measurements made at stream-gaging stations demonstrates that mean velocity generally tends to increase downstream.





Competence vs. Capacity

"Downstream Change of Velocity in Rivers"

Luna Leopold *American Journal of Science*, VOL. 251, August 1953

Near the streambed, shear in the vertical profile of velocity (rate of decrease of velocity with depth) tends to decrease downstream because of the smoothness of the channel (lower friction).

This downvalley decrease of shear implies decreasing competence downstream (the stream/river can transport smaller and smaller particles – silt not boulders).

The Upper Course → Middle Course

In its central part, it is mature, winding sedately through wide valleys adjusted to its duty of transporting water and sediment

The Duty of a River

Erosion → Transportation → Deposition

Four Types of Erosion

1. Hydraulic action - the force of the water flow against the banks and bed.

2. Abrasion - the suspended load, transported by the flow, collides with the bed and bank.

3. Solution - the chemical reaction between carbonic acid in the water and mineral elements in the rock.

Abrasion, hydraulic action and solution all erode the bed and banks of the river, deepening and widening the river.

4. Attrition - takes place through small collisions between bedload material as they are transported downstream.

Santa Elena Canyon

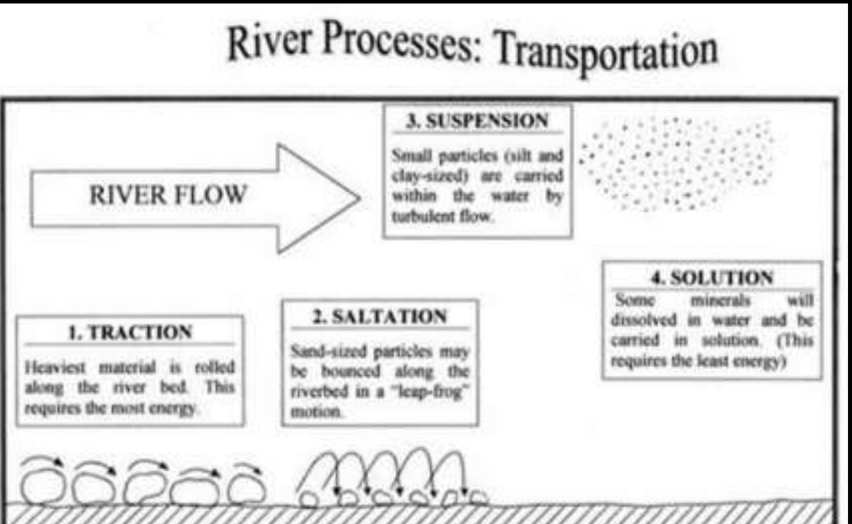
Four Modes of Transportation

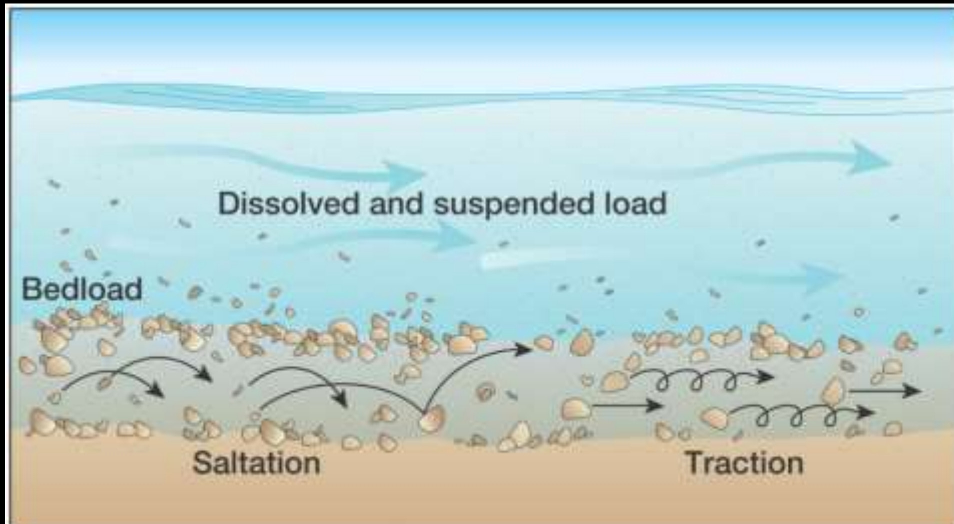
1. Traction - The largest of particles such as boulders are transported by traction. These particles are rolled along the bed of the river, eroding the bed and the particles in the process, because the river doesn't have enough energy to move these large particles in any other way.

2. Saltation - Smaller particles, such as pebbles and gravel, are transported by bouncing along the bed of the river because the river has enough energy to lift the particles off the bed but the particles are too heavy to travel by suspension.

3. Suspension - Fine particles like clay and silt are suspended in the water. Most of a river's load is transported by suspension.

4. Solution - This is where particles are dissolved into the water so only rocks that are soluble, such as limestone or chalk, can be transported in solution.

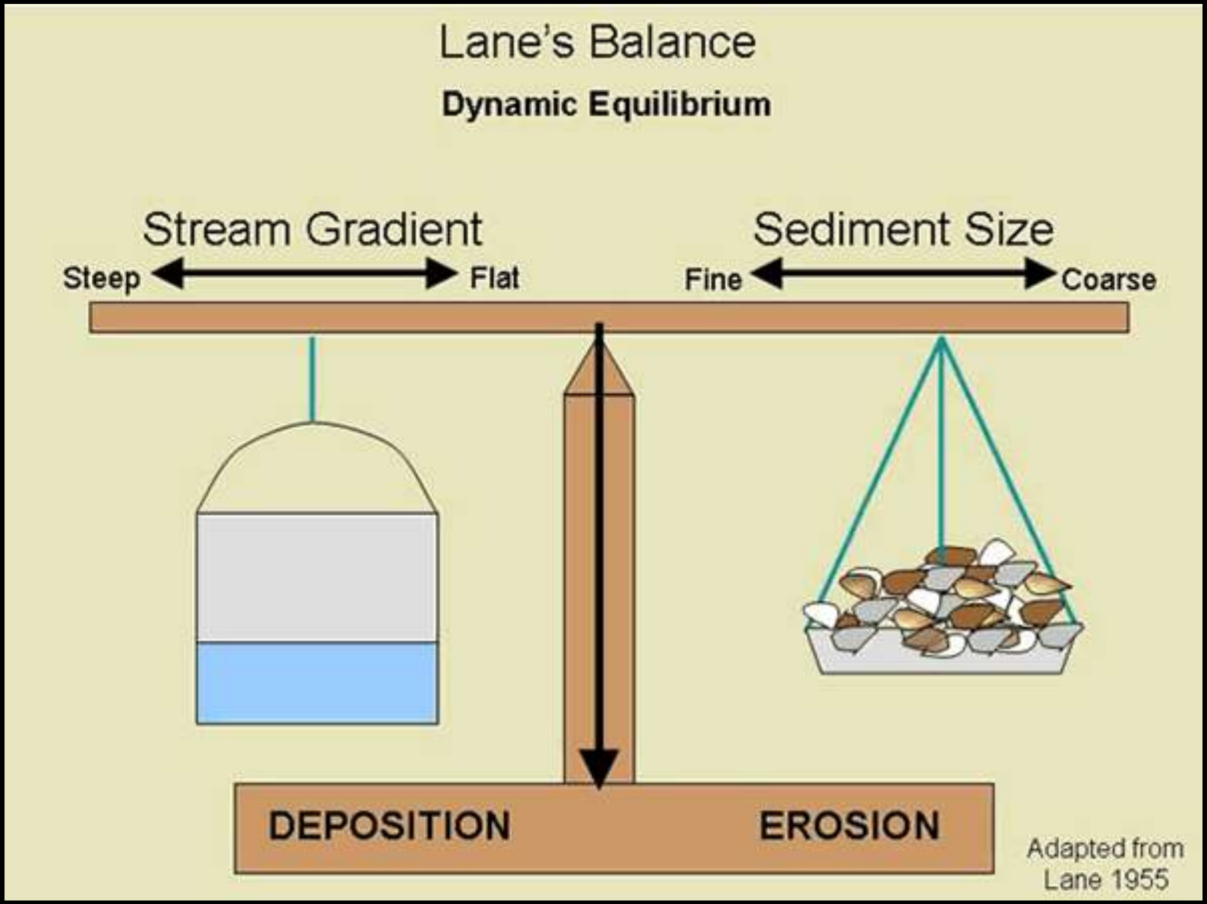




Erosion → Transportation → Deposition

All Flowing Water Wants To Carry Sediment

As long as it can…Deposition

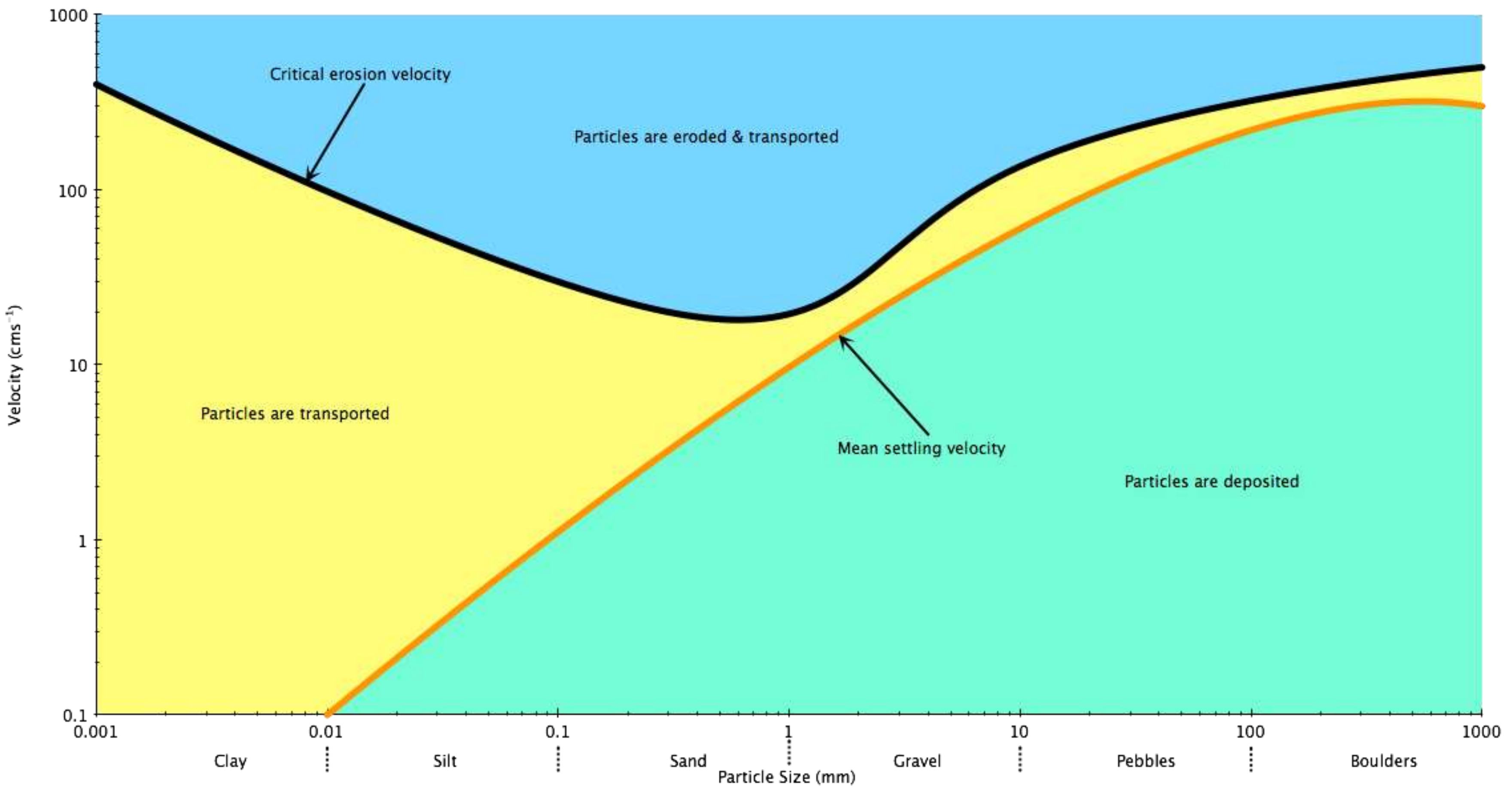


Hjulstrom Curve

For each grain size there is a specific velocity at which the grains start to move, called entrainment velocity.

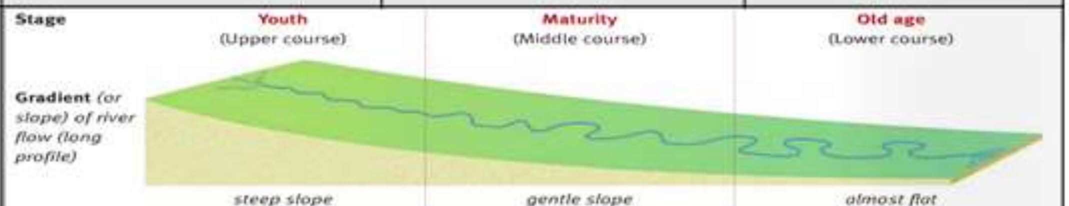
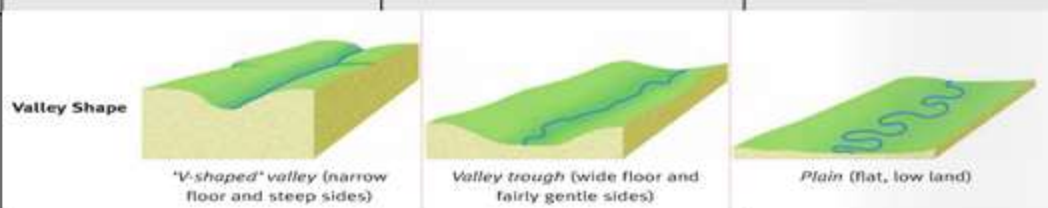
However the grains will continue to be transported even if the velocity falls below the entrainment velocity due to the reduced (or removed) friction between the grains and the river bed. Eventually the velocity will fall low enough for the grains to be deposited.

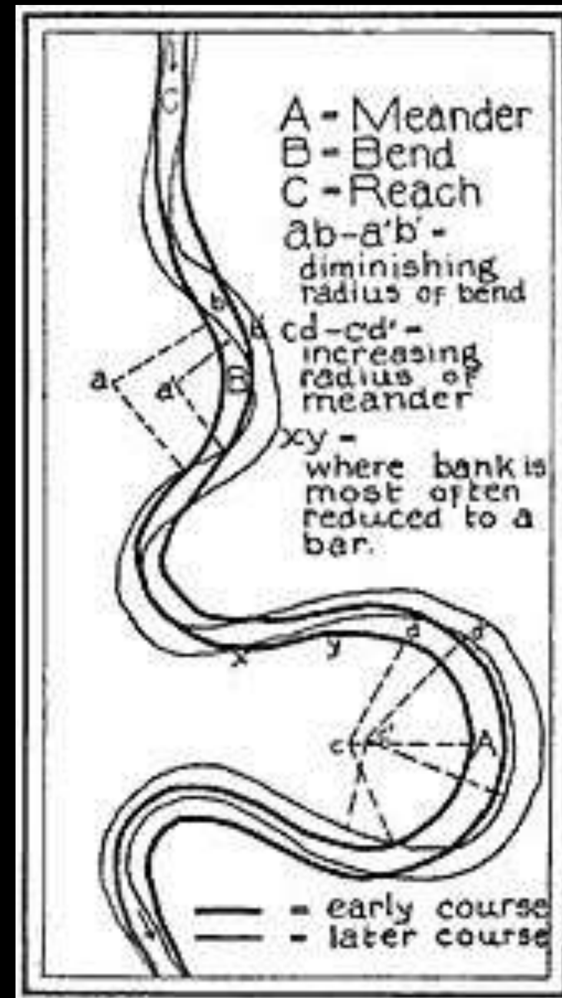
This is shown by the Hjulstrom curve.



Middle Course - Winding sedately through wide valleys

Sinuosity is inversely proportional to slope

Course Stage	**Upper Course Youth Stage**	**Middle Course Mature Stage**	**Lower Course Old Age Stage**
Slope			
Main processes	Hydraulic Action Abrasion **Erosion**	**Erosion** and **Deposition**	**Deposition**
Valley shape			
Main features	V-shaped Valleys Interlocking Spurs Waterfalls	Meanders and Ox-Bow lakes	Deltas Levees Flood Plains (and m+ob lakes)

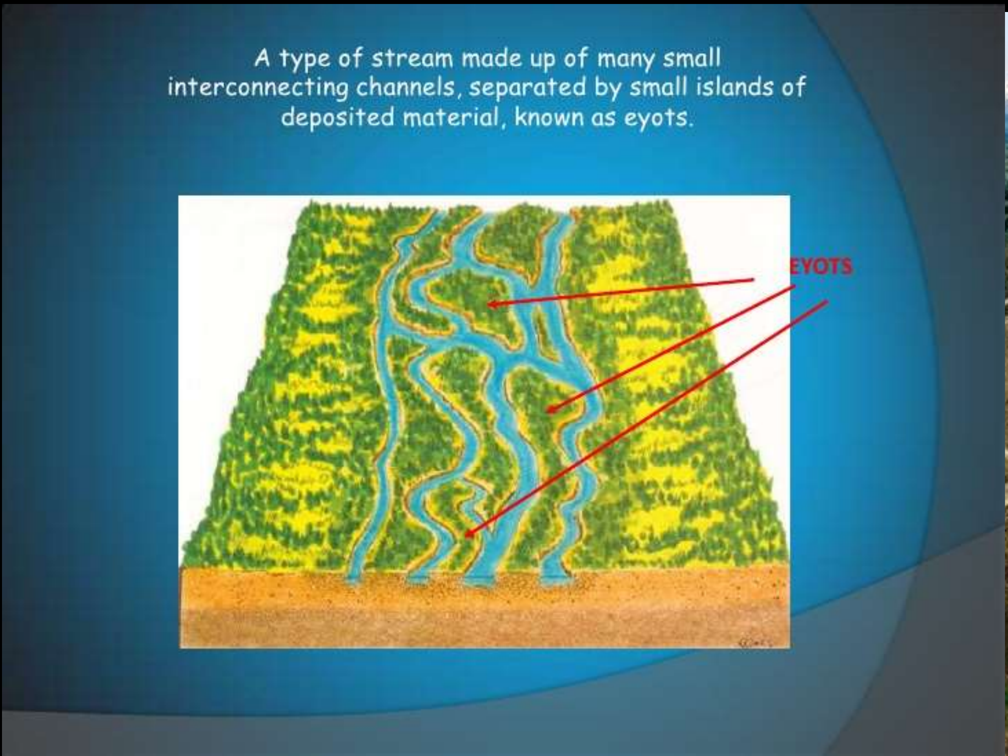


Upper Course to Middle Course - Deposition and Channel Patterns

Braided channels - dominated by multiple channels (braids) and sediment bars (eyots).

This unique channel characteristic develops due to changes in velocity and discharge, and often form as the slope decreases and river competence lowers, so the river deposits course sediment.

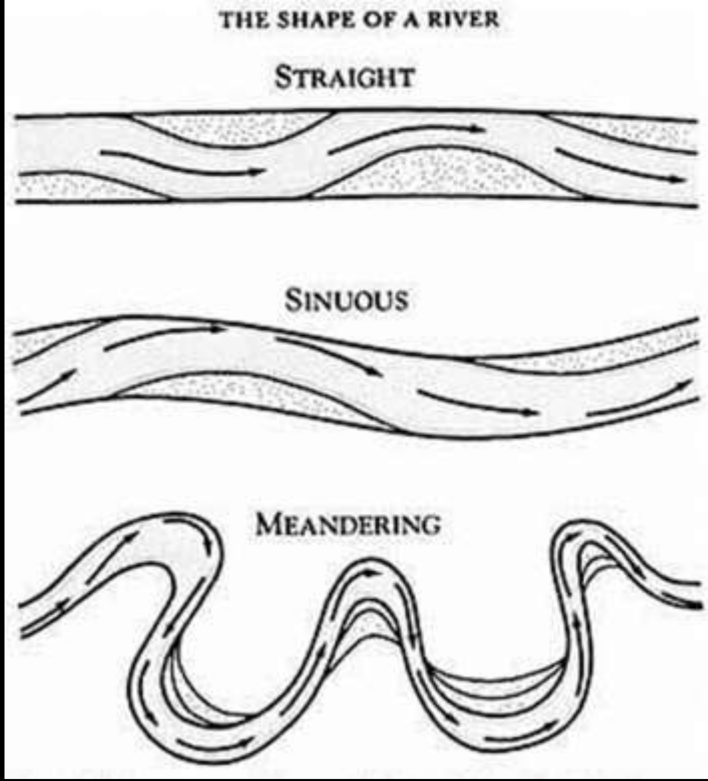
During periods of increased discharge, the capacity of the river to transport sediment increases and eyots become eroded. The competence of the river to transport larger bedload also increases. The braids widen and merge.



Meanders - Winding sedately

Meanders are loop-like bends in a river.

- The water flows round the meander in a <u>spiral manner</u>.
- This causes <u>erosion</u> to take place on the <u>outer bank</u> and <u>deposition</u> on the <u>inner bank</u>.

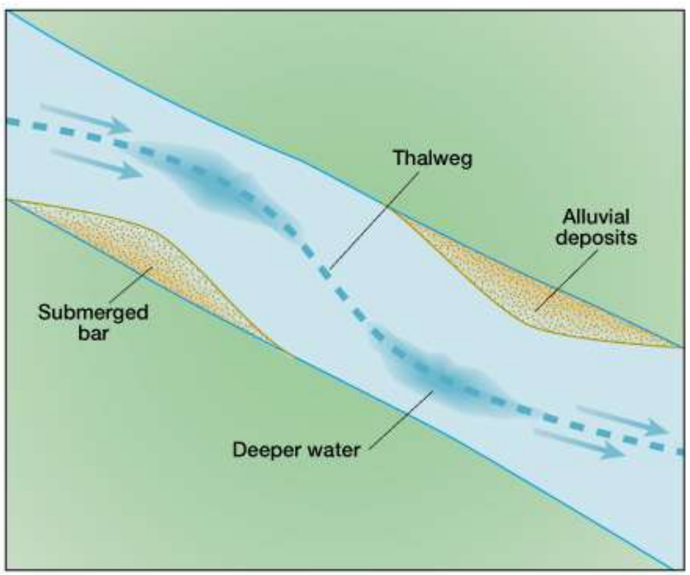


The Thalweg - Line of Fastest Flow

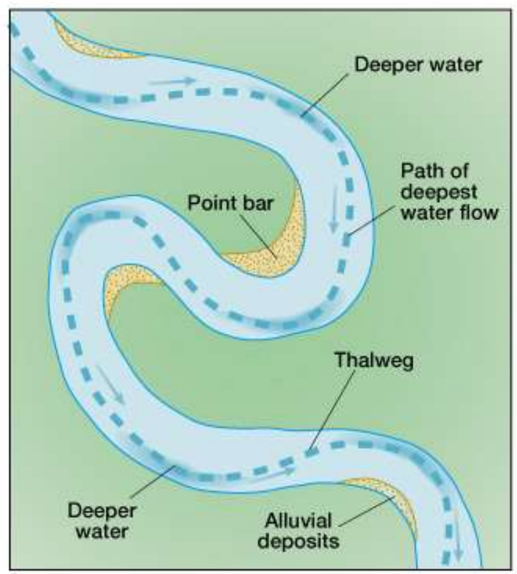
The word derives from German "Talweg" meaning "valley way".

The thalweg is <u>a line drawn to join the lowest points</u> along the entire length of a stream bed or valley in its downward slope, defining its deepest channel.

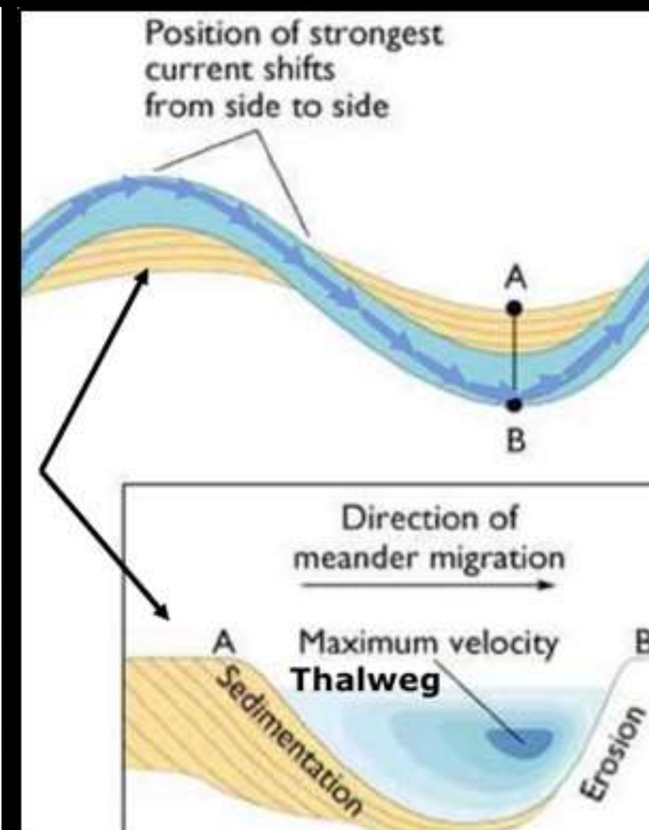
The thalweg is almost always the <u>line of fastest flow</u> in any river.



(a)



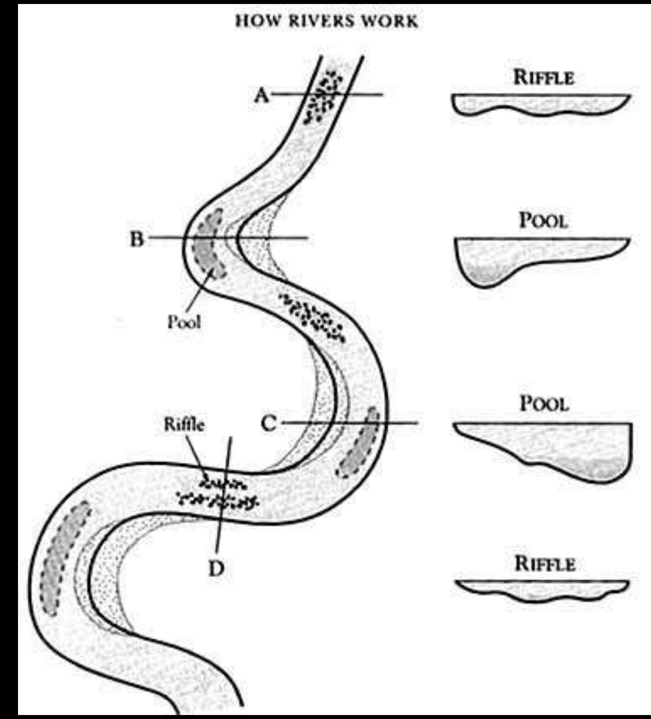
(b)

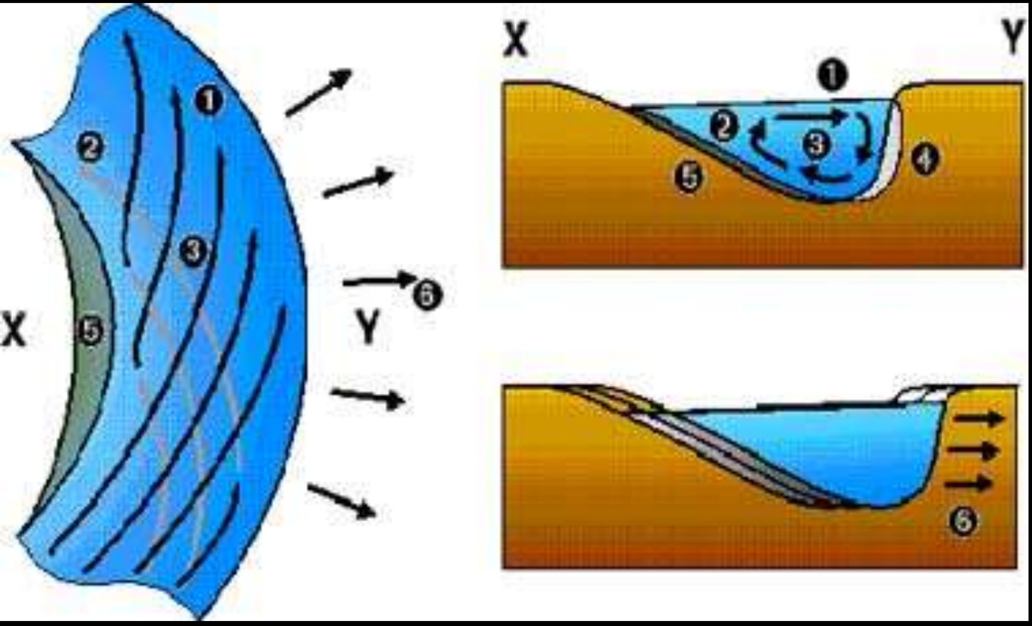


Helical Flow, Erosion, Deposition

Higher velocity chutes within a stream tend to be driven to the outside of a meander seen at point 1. On the outside of the meander, the surface of the water has a tendency to be slightly higher because it has gained momentum and acceleration, in the same way as centrifugal force works.

Here, the flow is forced down the outer bank which results in the scouring of the bank and bed. It returns to the surface toward the inside of the meander where flow is less turbulent, seen at point 2.

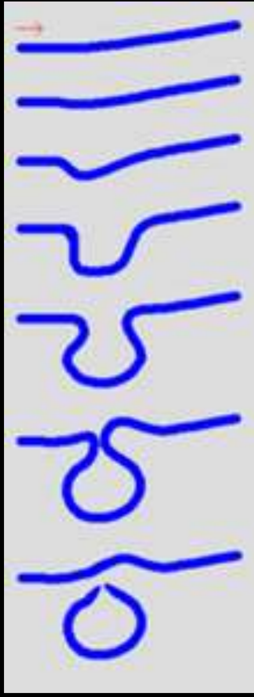


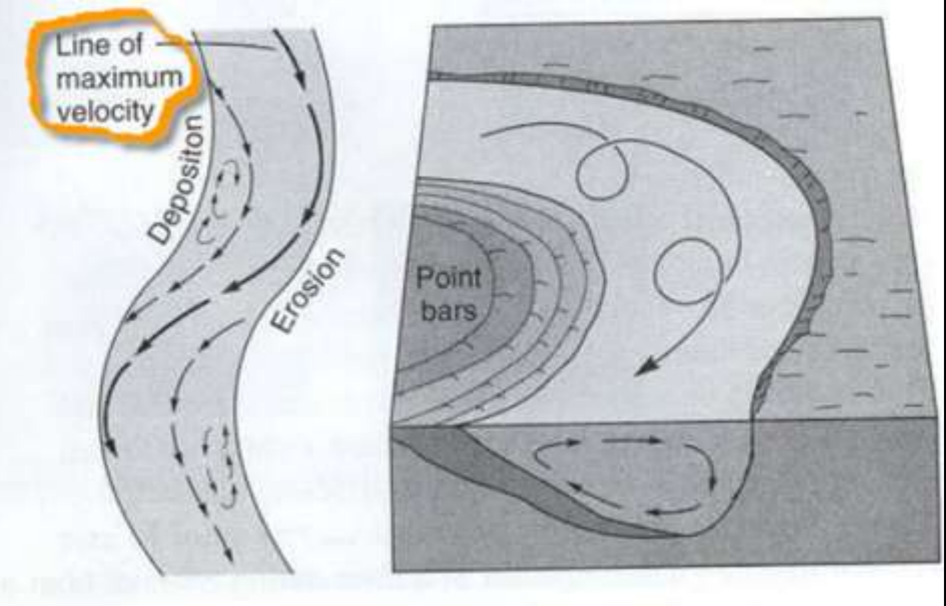


The helical flow of water plays an important role in the formation of meanders, especially in the developing river cliffs and slip-off slopes.

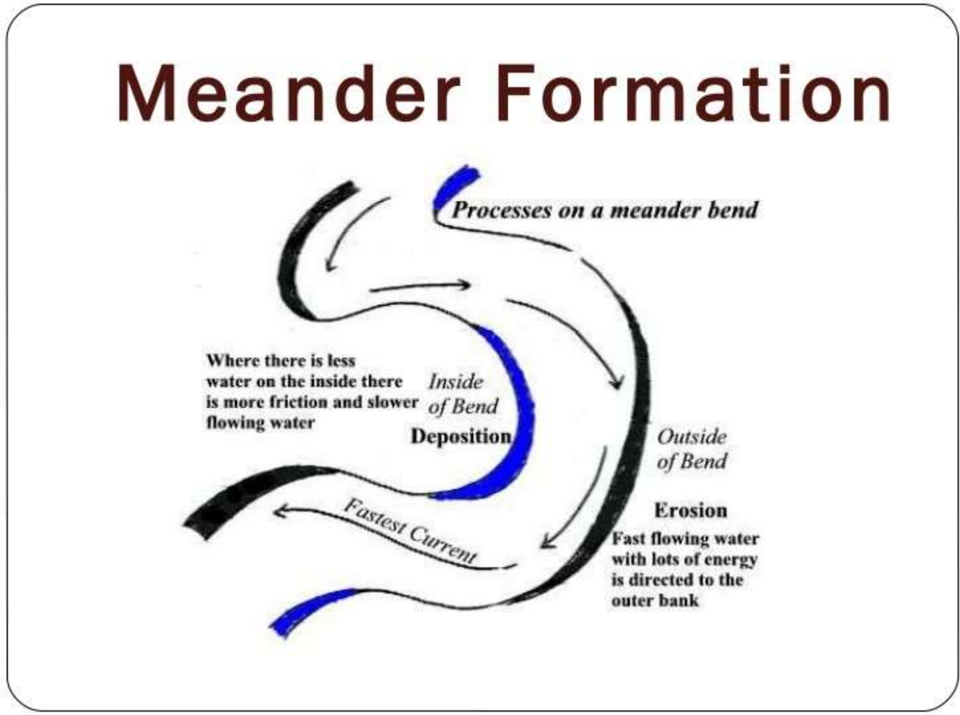
The Life of a Meander – River to Lake to Wetland to Scar

- The helical flow erodes the outside of the bend and deepens the pool.
- At the same time it redistributes scoured material and deposits it on the slip-off slope and riffle section.
- This continuous process cause meanders to migrate and contract at their neck.
- When a river meanders in very big loops, the outer bank is so rapidly eroded that the river cuts through the narrow neck of the meander.



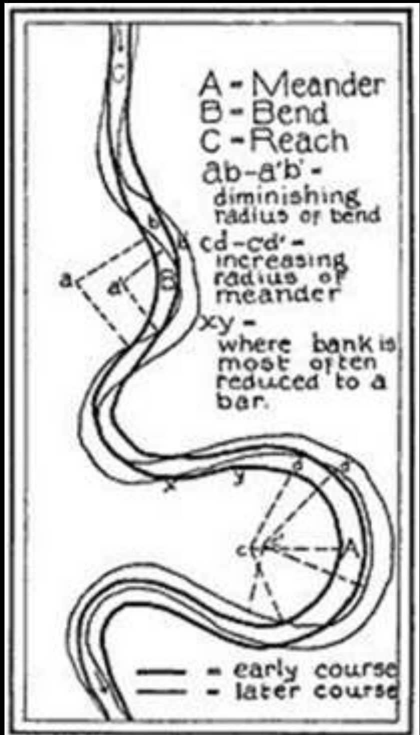


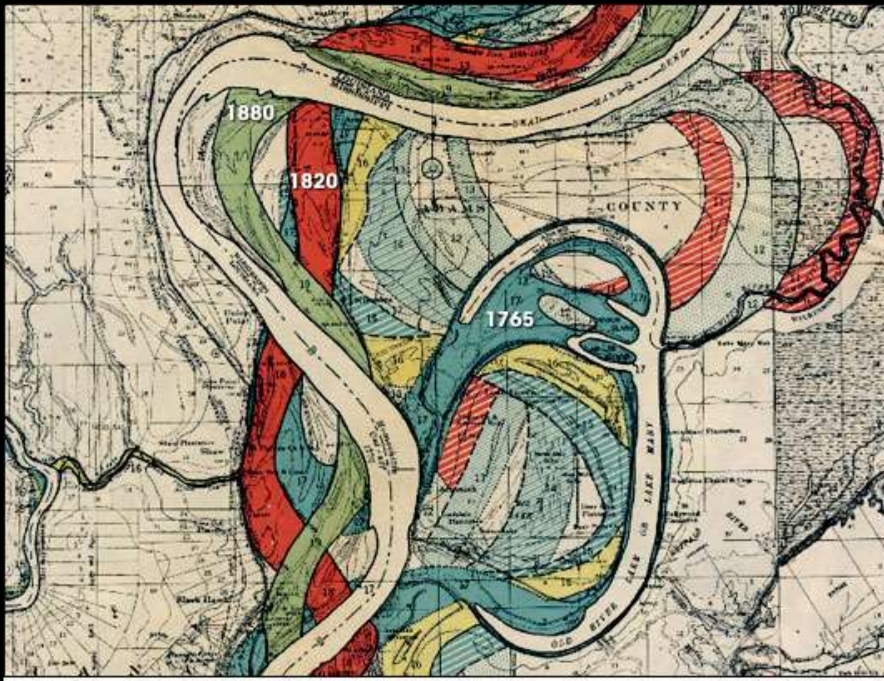
Helical flow in a meander.



The Life of a Meander

- The river then flows straight through the cut channel.
- When deposition seals off the cut-off meander from the river channel, an <u>oxbow lake</u> is formed. It may silt up and eventually dry up.
- This leaves <u>meander scars</u> on the floodplain that simply mark the old channel.

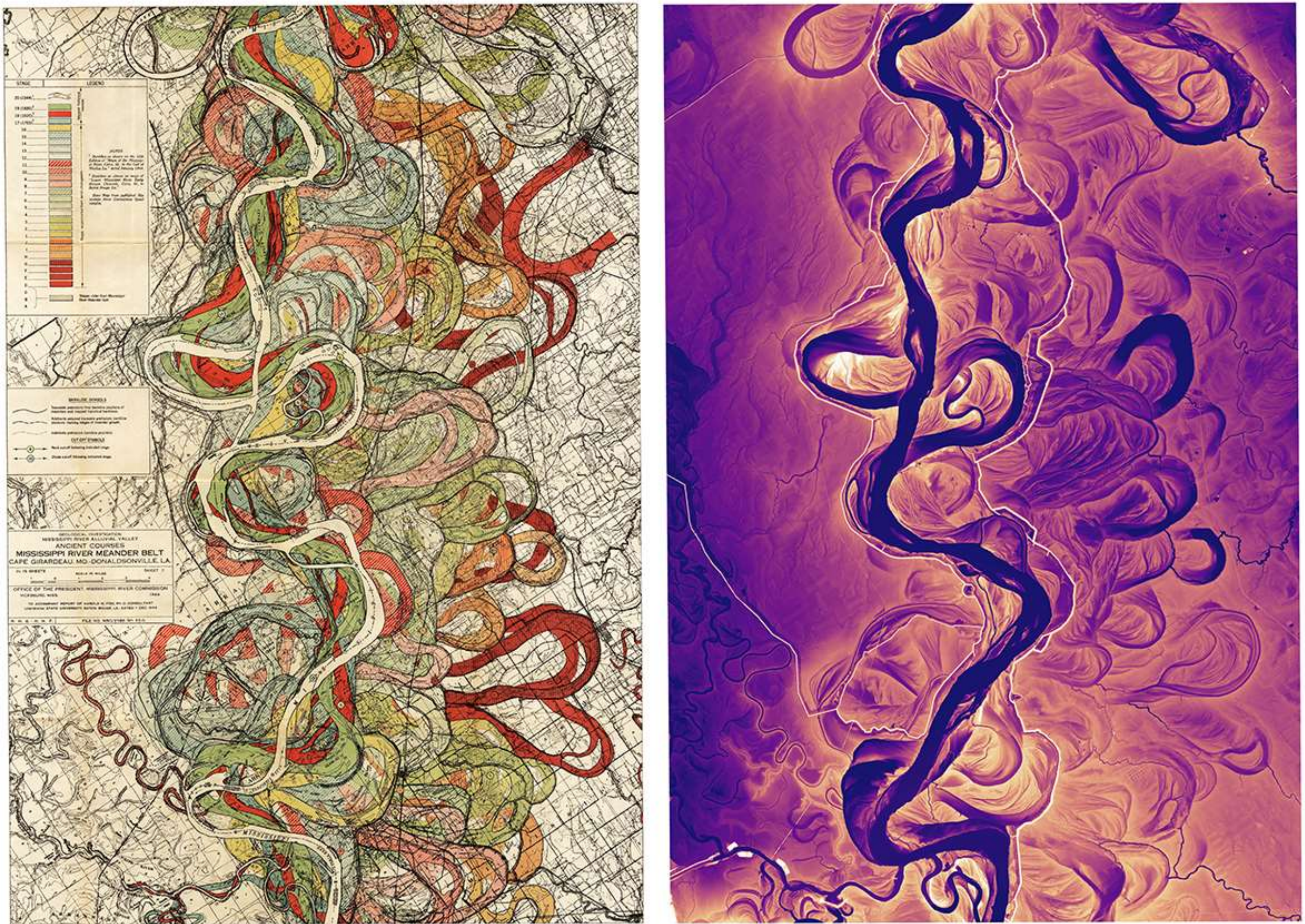




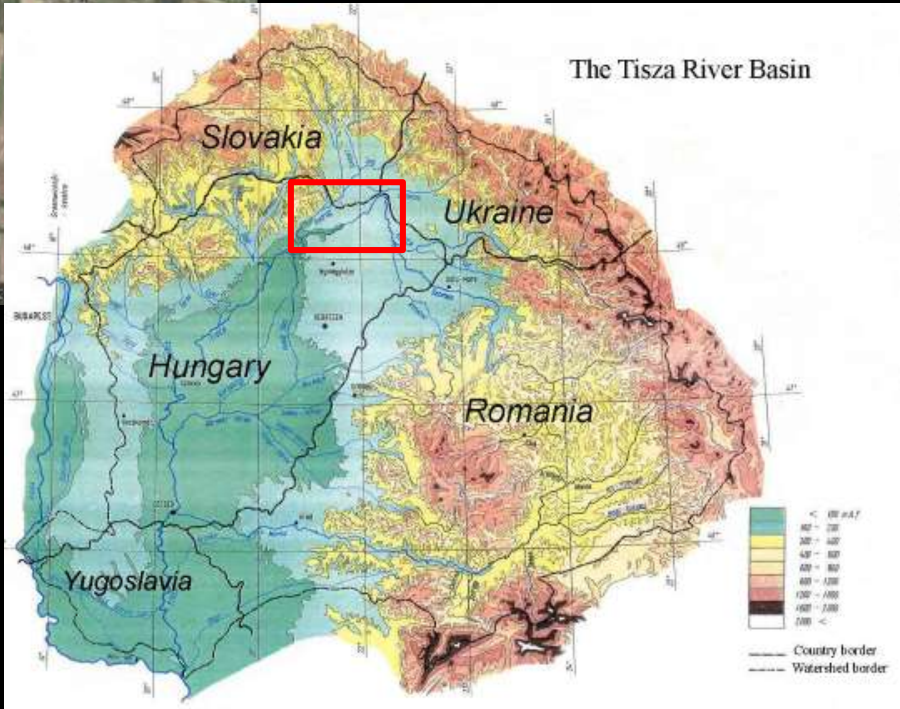
Map, 1944

Satellite Image, September 22, 1999

Comparison of Plate 7 from Harold Fisk's 1944 report "The Alluvial Valley of the Lower Mississippi River" with a modern-day lidar derived image of the same area.



Oxbow Lakes and Meander Scars – The Bodrogköz
The Tisza and Bodrog Rivers – Northeastern Hungary



- The Bodrogköz lowland region between the Bodrog and Tisza rivers in Hungary.
- The southern part belongs to Hungary and the upper Bodrogköz is in Slovakia.
- Now a cross-border UN Ramsar Wetland of International Importance

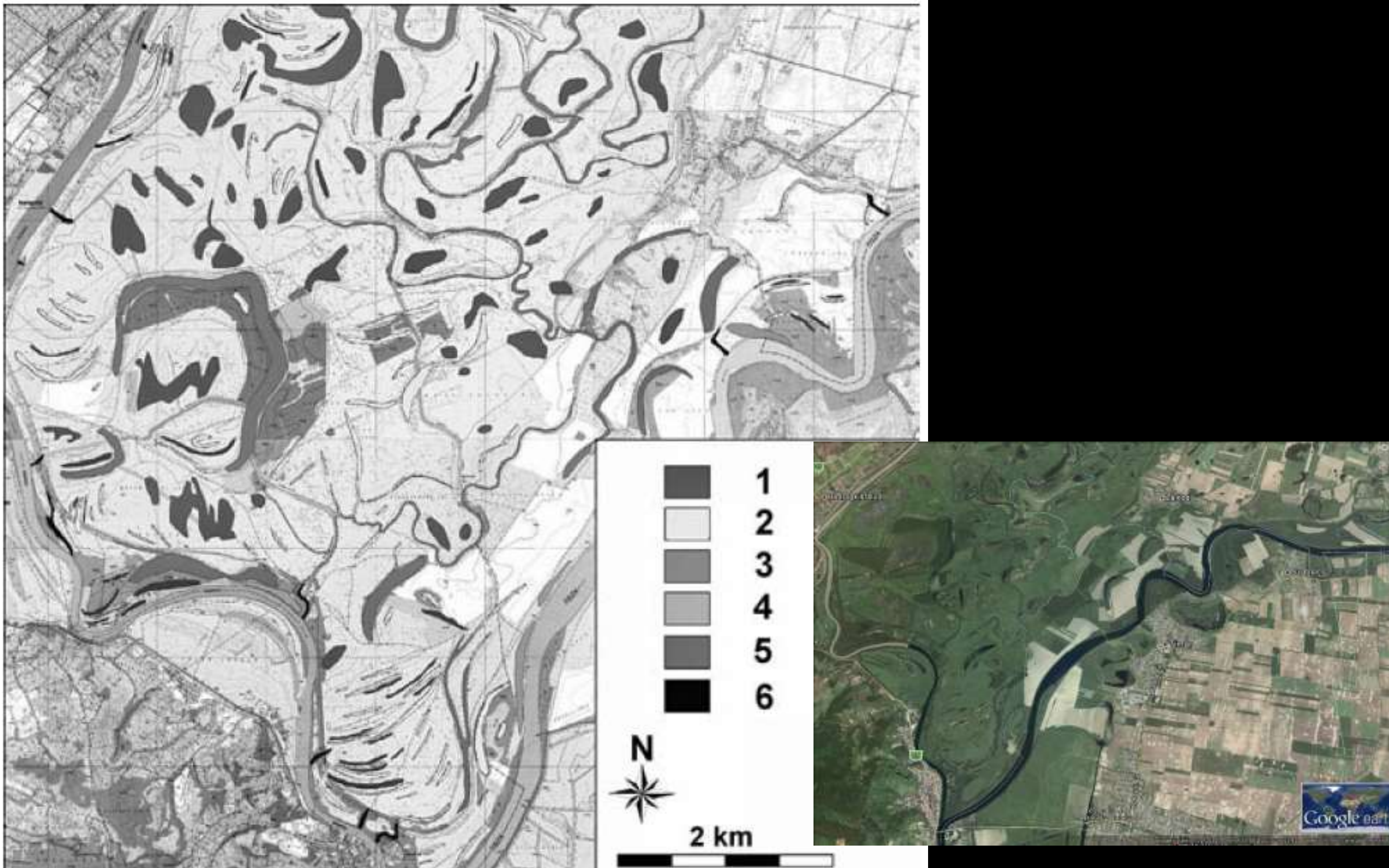
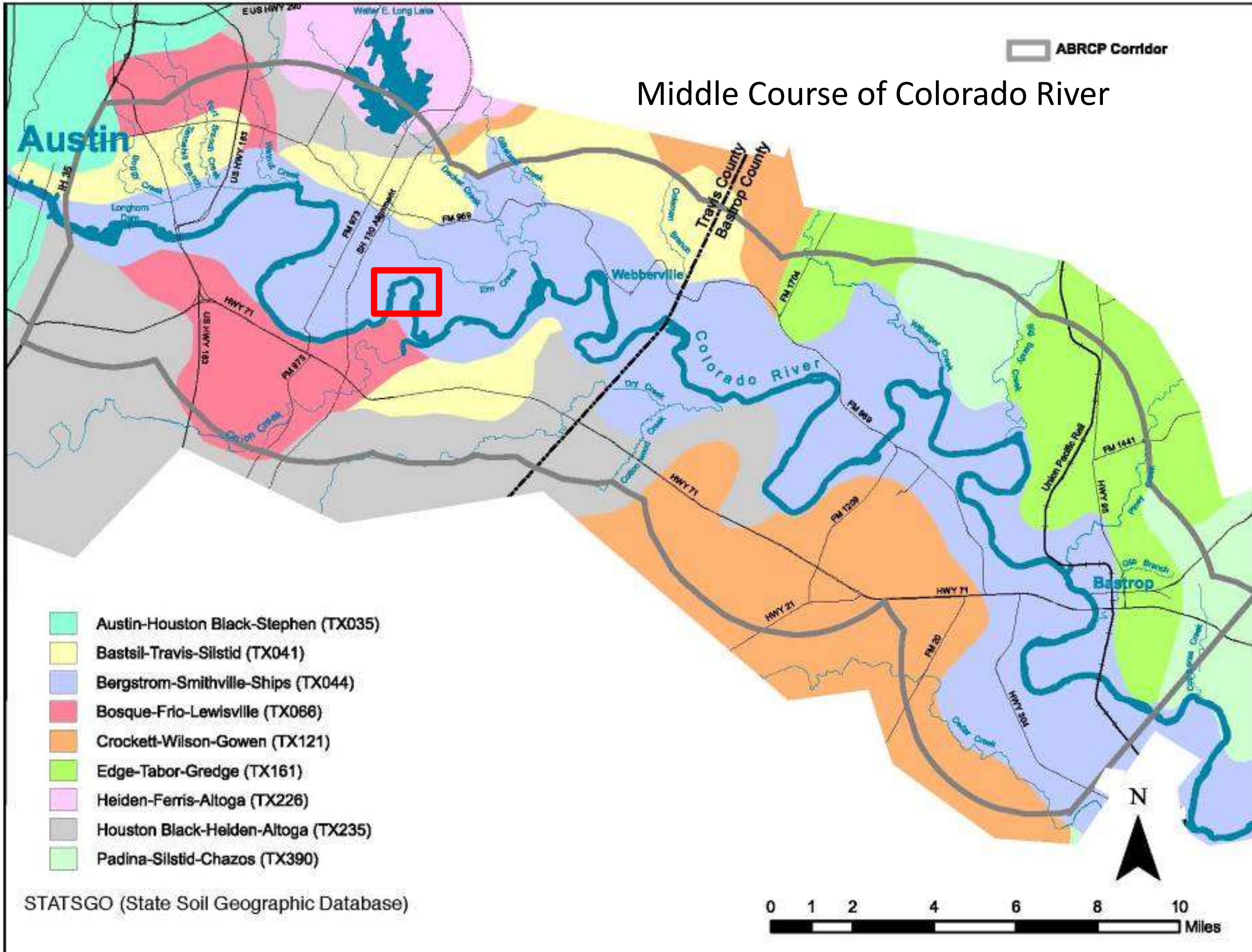


FIG. 2 - Landforms of the SW Bodrogköz (In: Szabó & *alii*, 2004). 1: fluvial ridge, 2: swale, 3: abandoned cut-offs, 4: present natural levee, 5: backswamps, 6: (remnants of) one-time flood-plain ditches.

Middle Course of Colorado River




Old Mining Pit
2003

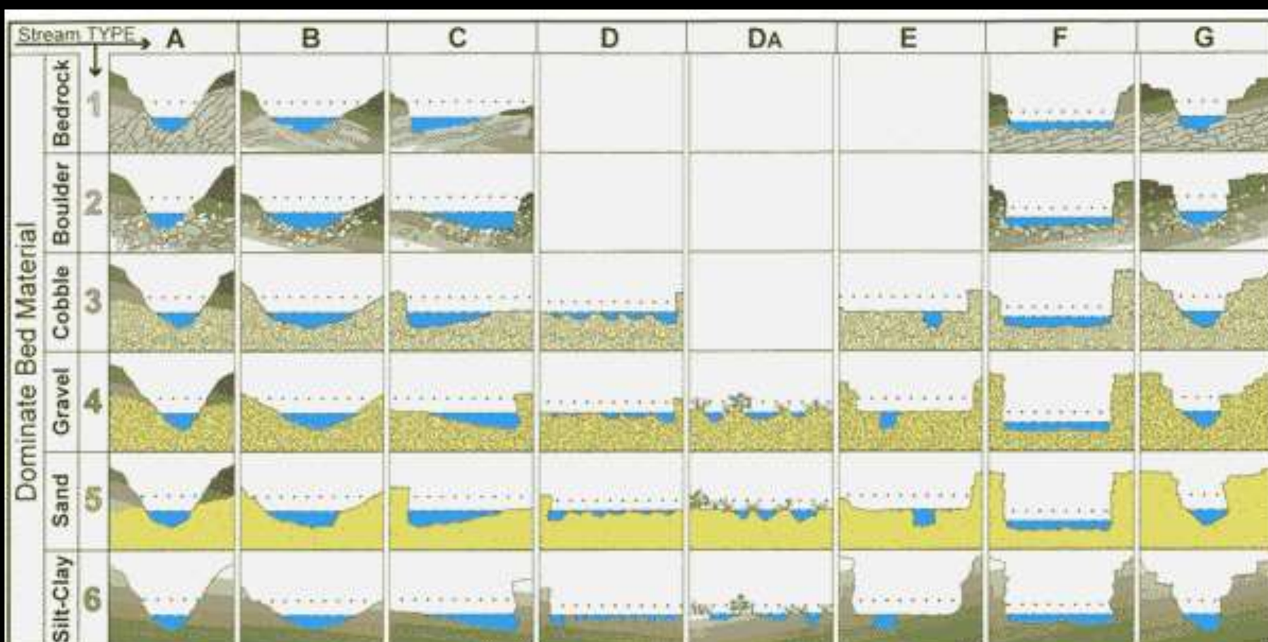

2006

80 feet
130 feet
Breach
Mining Pit
2006

How a River Works – The Rosgen Cookbook
River Morphology – Complexity and Patterns

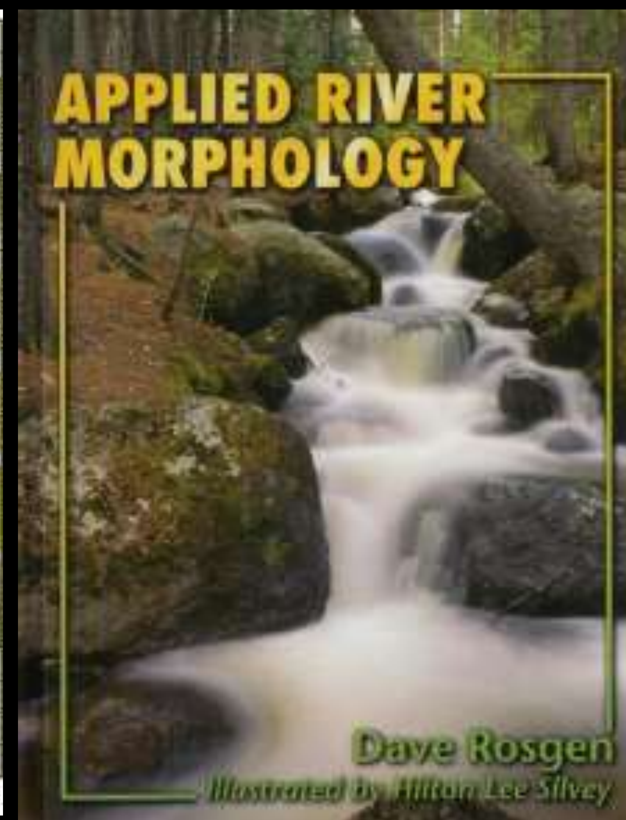
Dave Rosgen - Principal Hydrologist of Wildland Hydrology Consultants.

- Classifying streams on the basis of channel morphology
- Categories of discrete stream types so that consistent, reproducible descriptions and assessments of condition and potential can be developed.

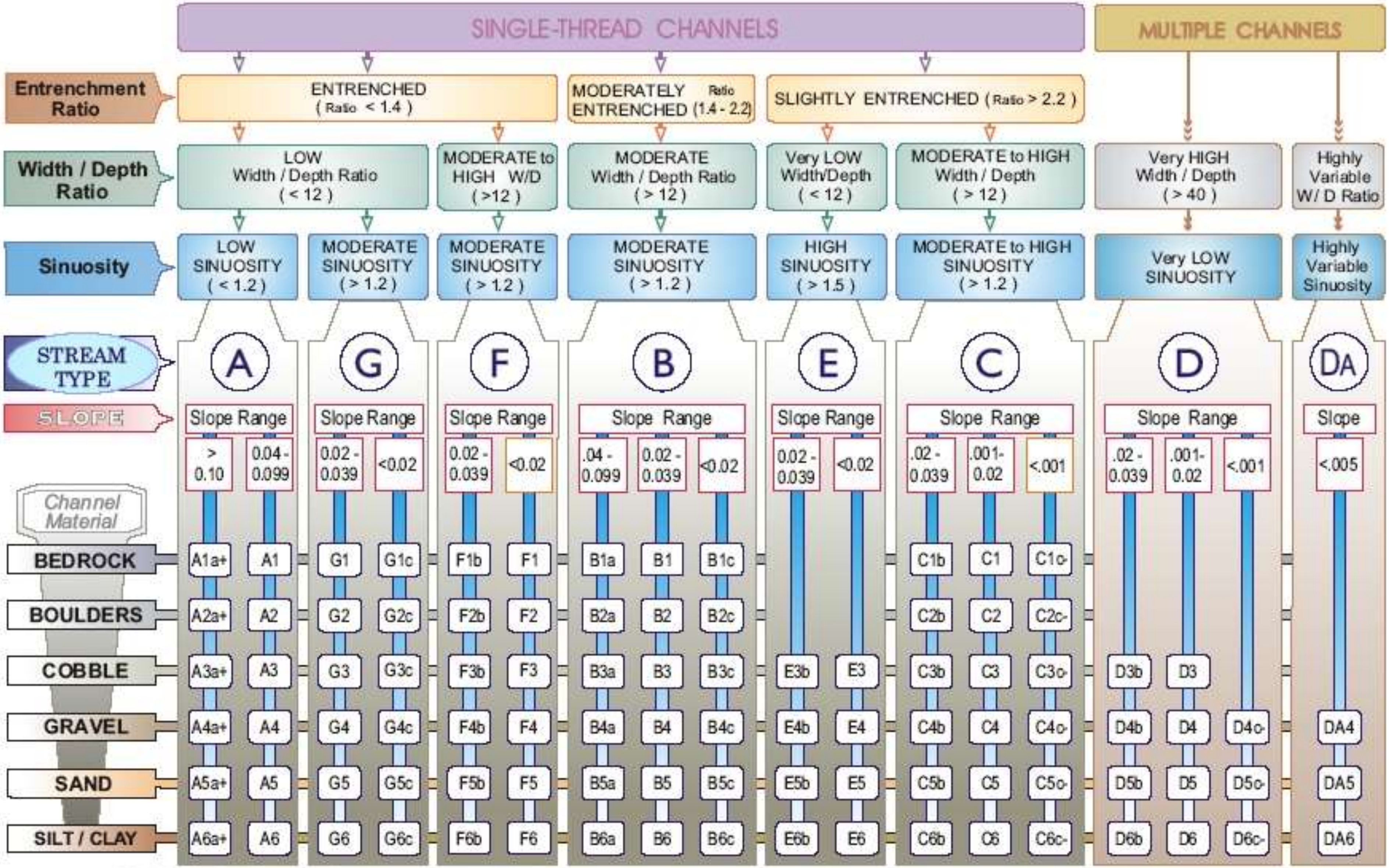


Stream TYPE	A	B	C	D	DA	E	F	G
Entrchmnt	< 1.4	1.4 - 2.2	> 2.2	n/a	> 4.0	> 2.2	< 1.4	< 1.4
W/D Ratio	< 12	> 12	> 12	> 40	< 40	< 12	> 12	< 12
Sinuosity	1 - 1.2	> 1.2	> 1.2	n/a	variable	> 1.5	> 1.2	> 1.2
Slope	.04-.099	.02-.039	< .02	< .04	< .005	< .02	< .02	.02-.039

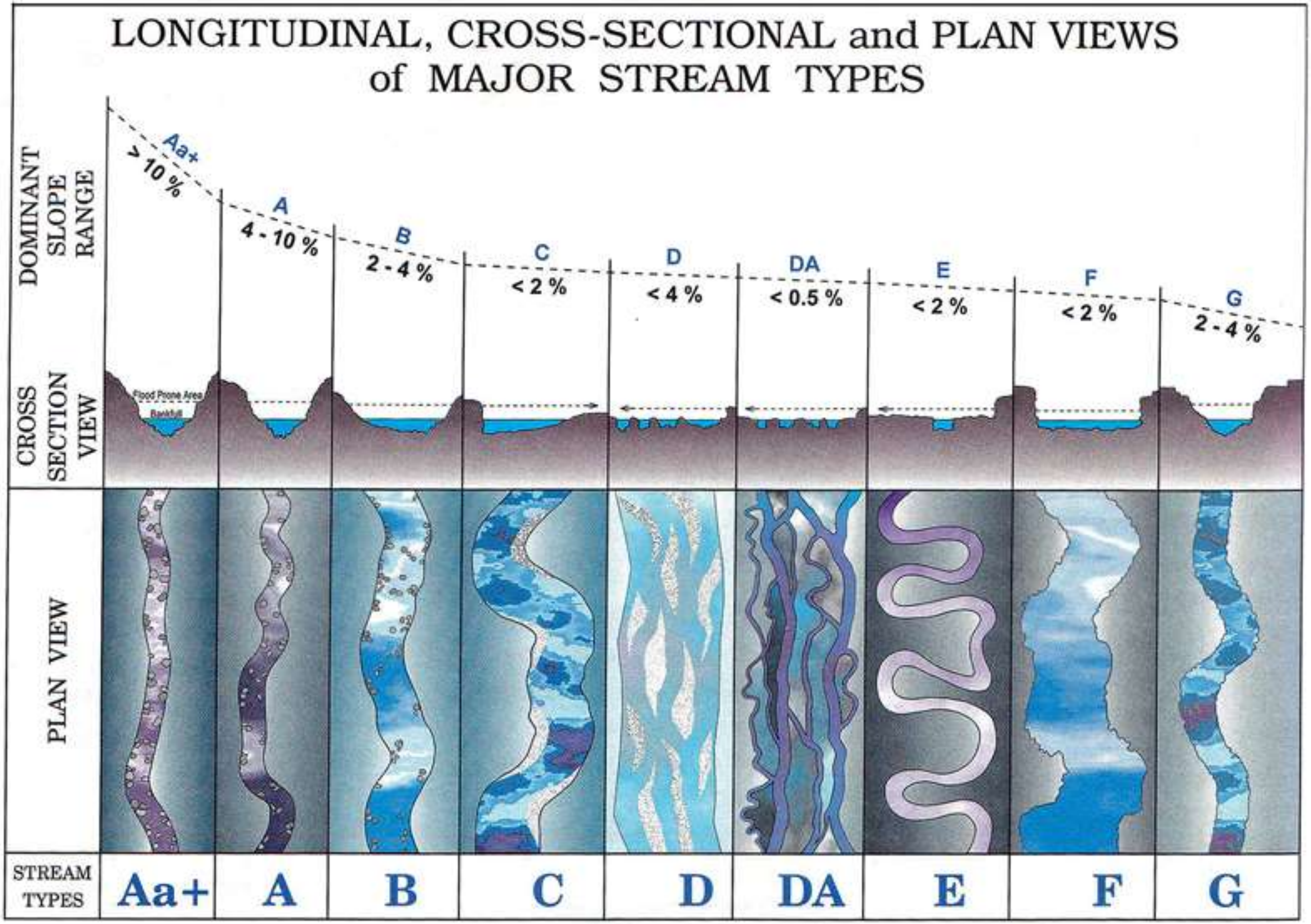
Applied River Morphology. Pagosa Springs: Wildland Hydrology Books, 1996. www.wildlandhydrology.com



The Key to the Rosgen Classification of Natural Rivers



KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the *"continuum of physical variables"* within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

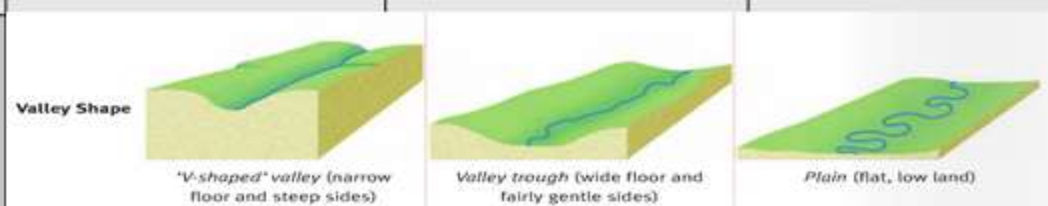


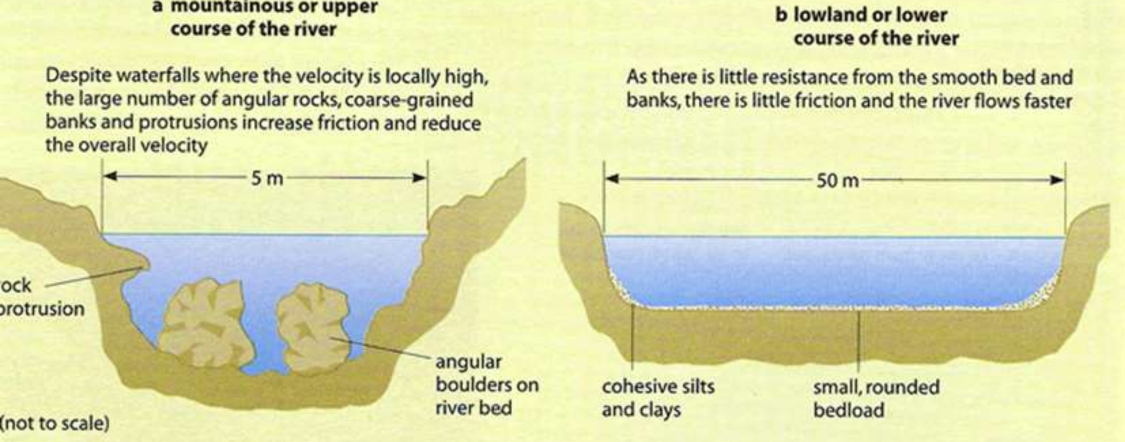
Sinuosity is inversely proportional to slope

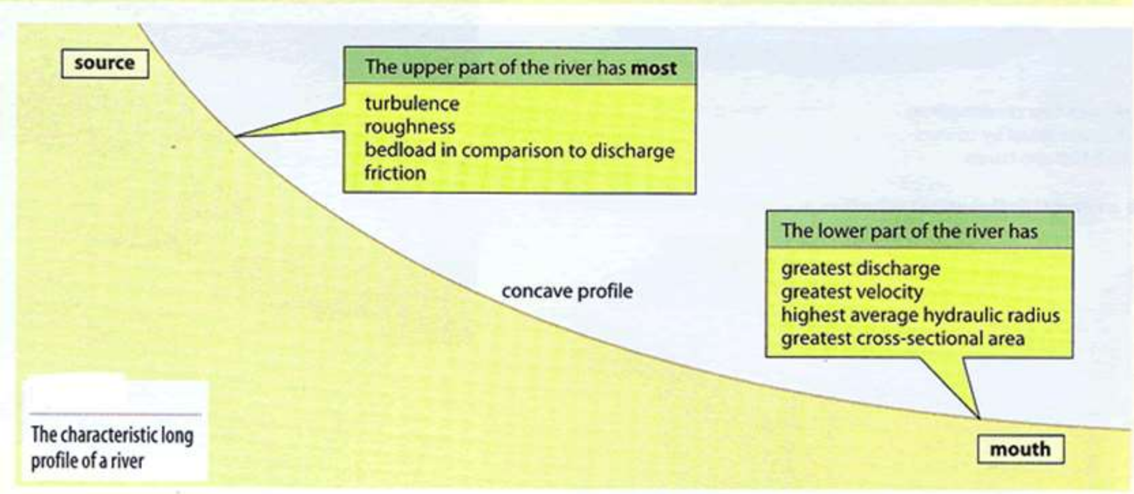
The Lower Course – Old Age

a somewhat aimless course toward final extinction

Wandering and Deposition

Course Stage	Upper Course Youth Stage	Middle Course Mature Stage	Lower Course Old Age Stage
Slope			
Main processes	Hydraulic Action Abrasion **Erosion**	**Erosion and Deposition**	**Deposition**
Valley shape			
Main features	V-shaped Valleys Interlocking Spurs Waterfalls	Meanders and Ox-Bow lakes	Deltas Levees Flood Plains (and m+ob lakes)





Competence vs. Capacity

"Downstream Change of Velocity in Rivers"

Luna Leopold *American Journal of Science*, VOL. 251, August 1953

Near the streambed, shear in the vertical profile of velocity (rate of decrease of velocity with depth) tends to decrease downstream because of the smoothness of the channel (lower friction).

This downvalley decrease of shear implies decreasing competence downstream (the stream/river can transport smaller and smaller particles – silt not boulders).

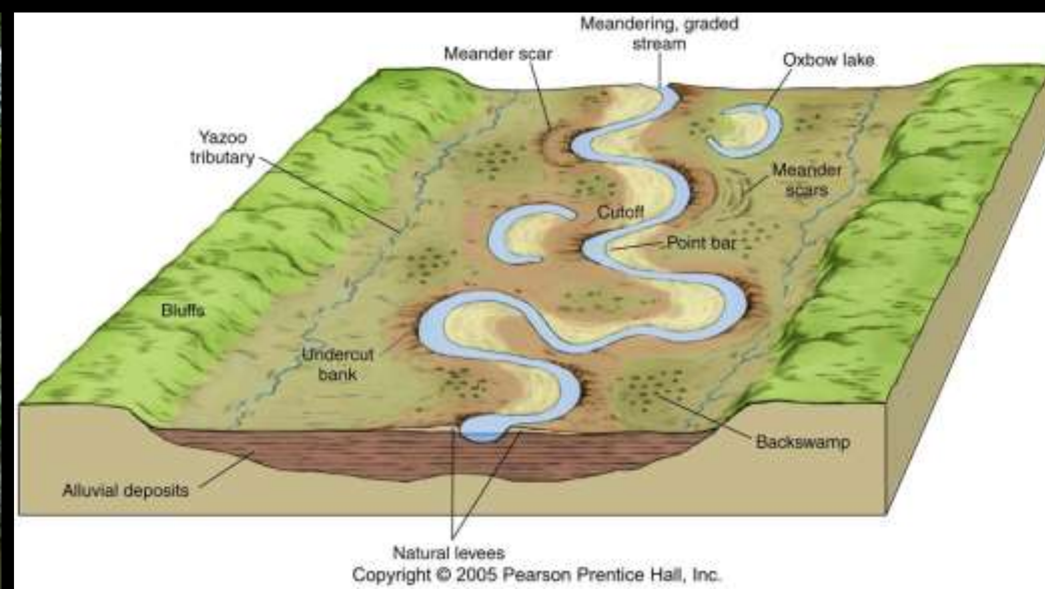
Floodplains and Levees

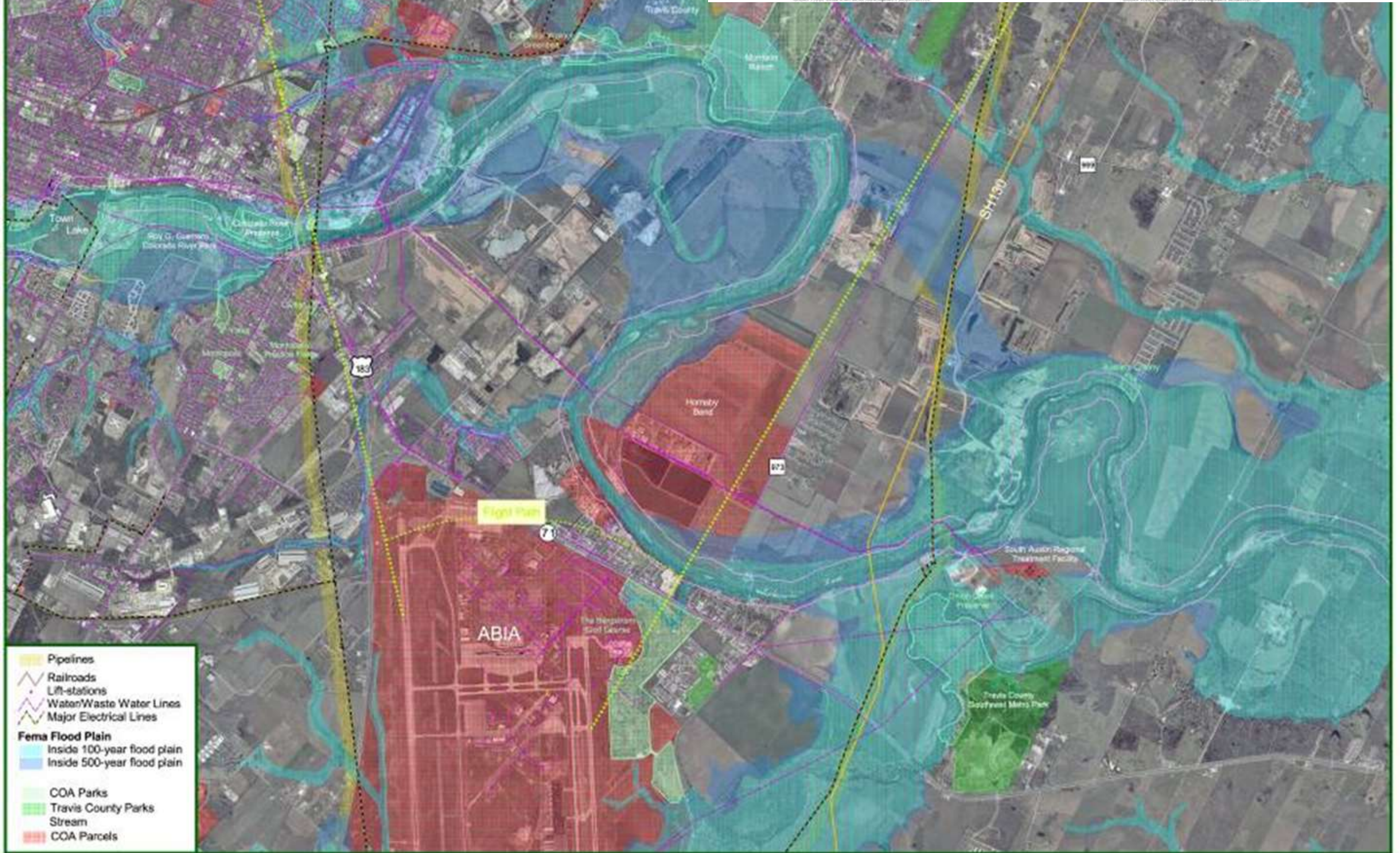
A floodplain is a low-lying plain on both sides of a river that has repeatedly overflowed its banks and flooded the surrounding areas.

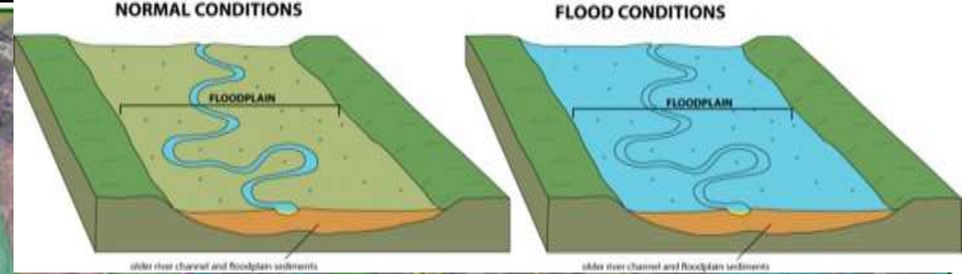
When the floods subside, alluvium is deposited on the floodplain.

The larger materials, being heavier, are deposited at the river banks while the finer materials are carried and deposited further away from the river.

The larger materials at the river banks build up into embankment called levees.




Study Area: Colorado River Corridor:
Longhorn Dam to Onion Creek
Utilities and Floodplain
Town Lake
ABIA
SH130
183
71
973
Hornsby Bend
South Austin Regional Treatment Facility
Pipelines
Railroads
Lift-stations
Water/Waste Water Lines
Major Electrical Lines
Fema Flood Plain
Inside 100-year flood plain
Inside 500-year flood plain
COA Parks
Travis County Parks
Stream
COA Parcels


NORMAL CONDITIONS
FLOOD CONDITIONS
FLOODPLAIN
FLOODPLAIN
older river channel and floodplain sediments
older river channel and floodplain sediments

Delta - final extinction as it joins the ocean

- River deltas form at the mouth of the river
- There is great variation in the shapes of deltas due to the complex interaction between fluvial and marine systems.
- Their shape is influenced by the amount and type of sediment being transported by the river, the velocity, discharge and capacity of the river and the strength of marine tides and waves.

<u>Arcuate deltas</u> - the most common type of delta - a gently curving shoreline, smoothed by longshore currents - a distinct pattern of branching distributaries and tend to be dominated by courser material.

<u>Bird-foot deltas</u> - have long finger-like projections that reach out to the sea - broad, shallow shelves - long thin shape

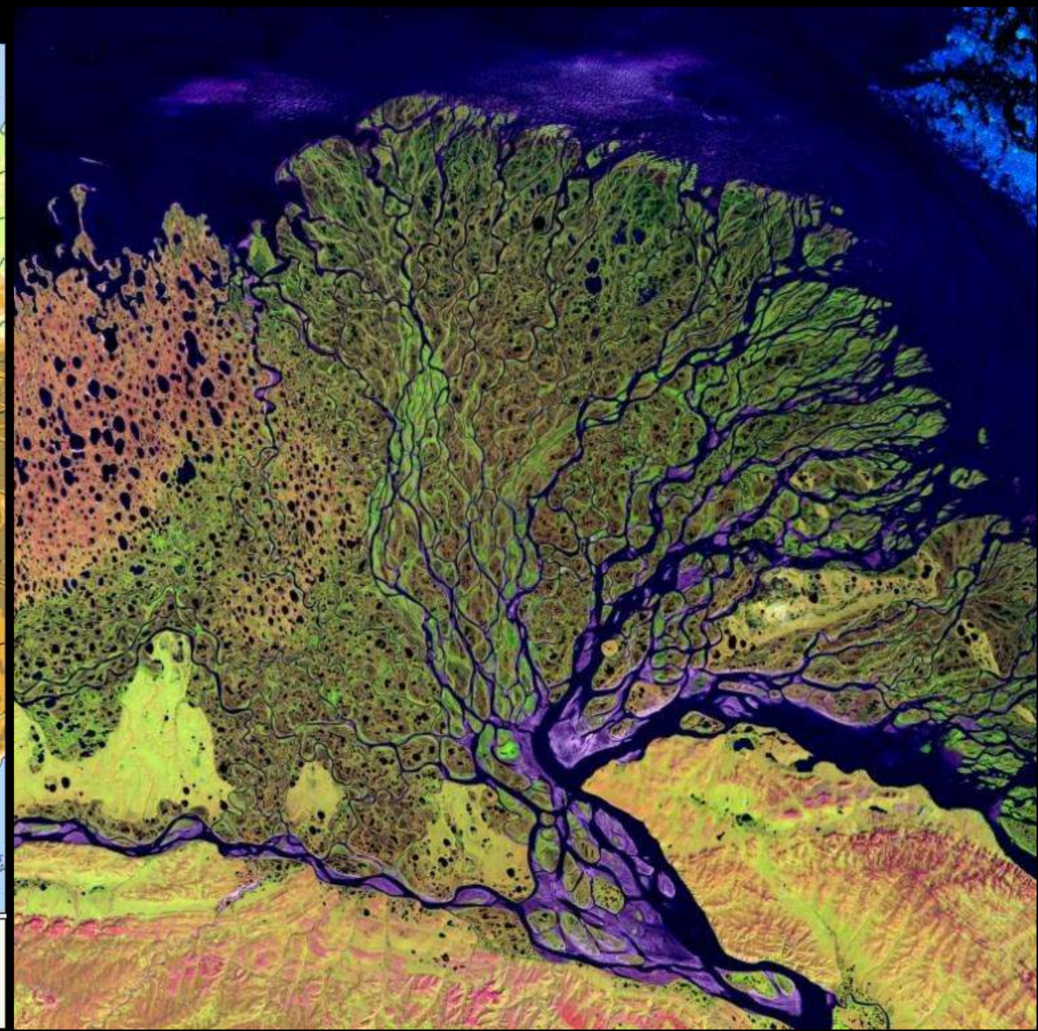

Arcuate delta
The Nile

The Danube Delta is the second largest river delta in Europe, after the Volga Delta.

- The greater part of the Danube Delta lies in Romania, while its northern part, on the left bank of the Chilia arm, is situated in Ukraine .
- The approximate surface is 4,152 km², of which 3,446 km² are in Romania.

The Lena River

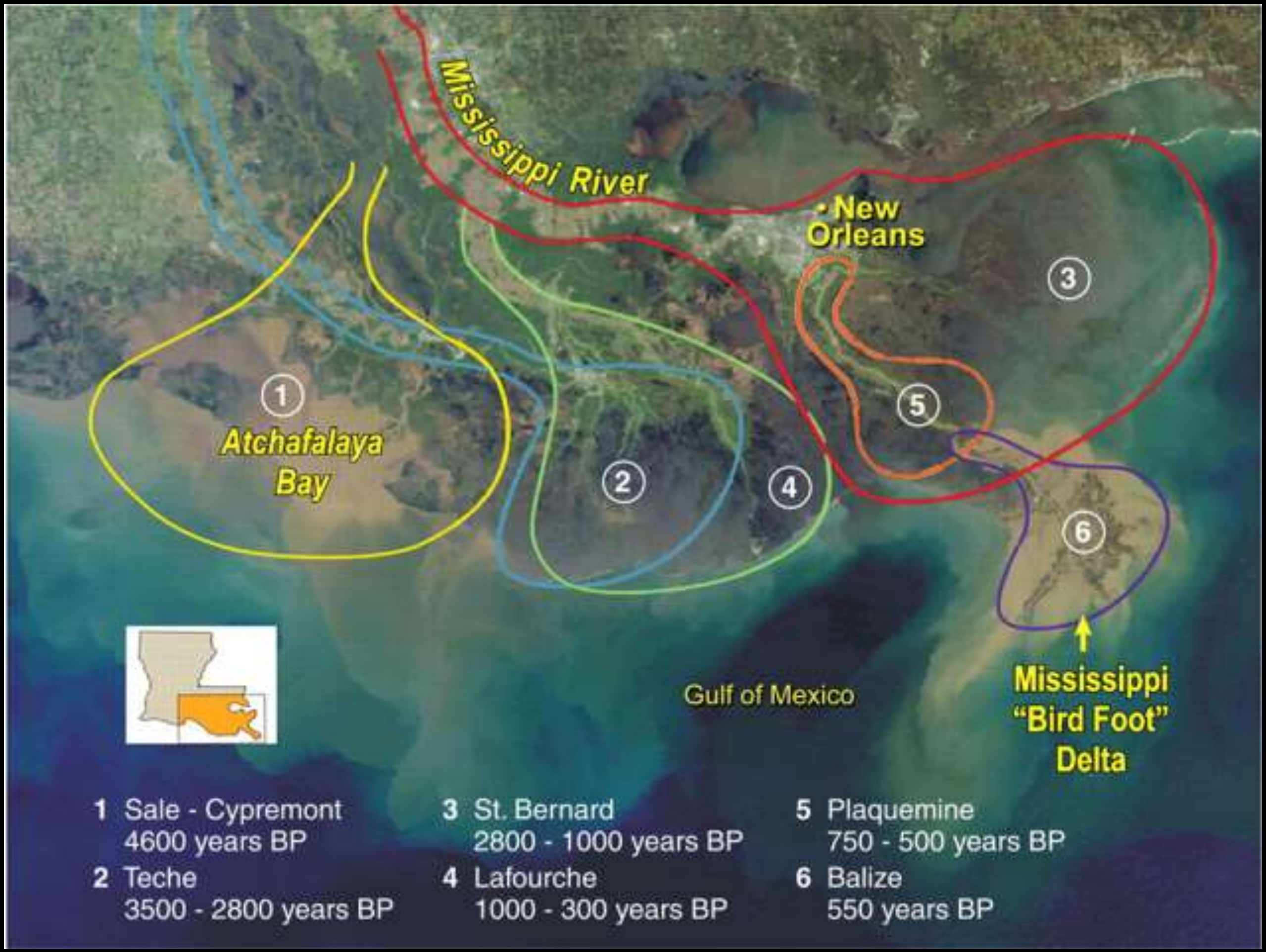
- 2,800 miles (4,400 km) long and flows north into the Arctic
- The delta is frozen tundra for about 7 months of the year, but in May transforms the region into a lush wetland for the next few months.
- The Lena Delta Reserve is an important refuge and breeding ground for many species of Siberian wildlife.



Avulsion

Rapid abandonment of a river channel and the formation of a new channel

This process of avulsion in deltaic settings is also known as delta switching. When this avulsion occurs, the new channel carries sediment out to the ocean, building a new deltaic lobe. The abandoned delta eventually subsides



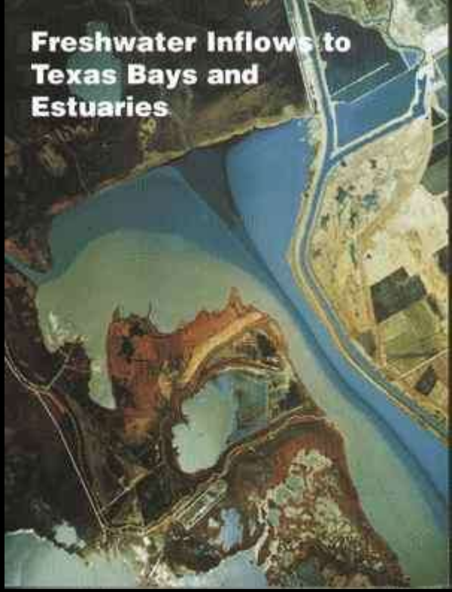
Location of Mississippi River channels discharging water into the Gulf of Mexico over the past 5000 years. Notice the location changes from time to time, keeping all areas of the delta supplied with sediments that balance the natural sinking of the delta. Today, two-thirds of the flow are through the Bird Foot Delta (6) and one third through the Atchafalaya

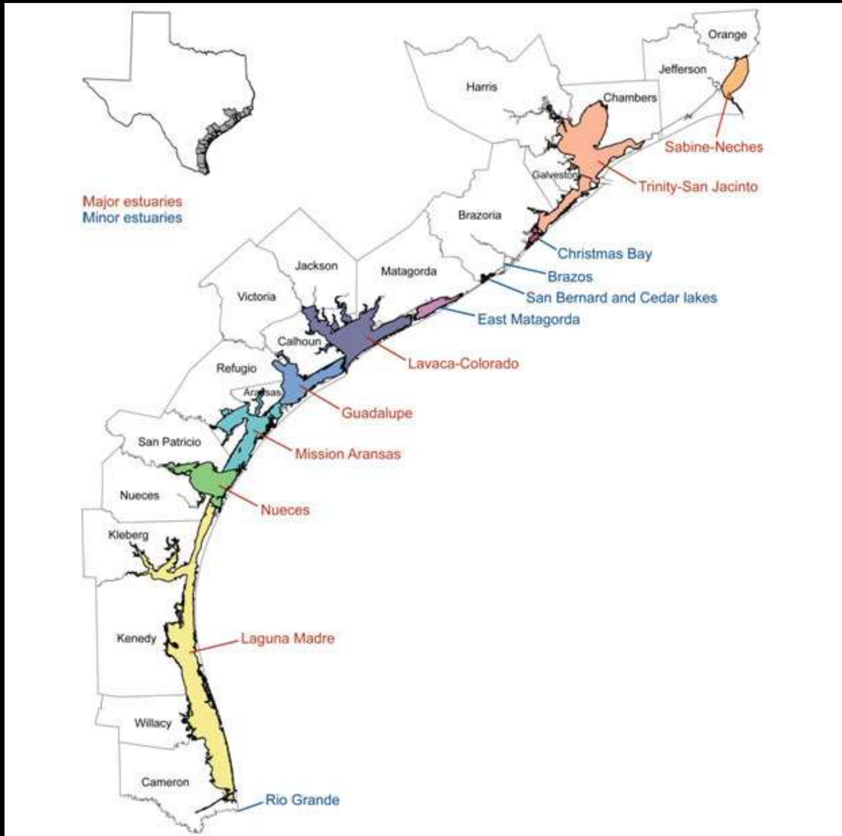
Estuary

- An estuary is a semi-enclosed coastal body of water, which has a free connection with the open sea, and within which seawater is measurably diluted with freshwater derived from land drainage.
- Most existing estuaries formed during the Holocene epoch with the flooding of river-eroded or glacially scoured valleys when the sea level began to rise about 10,000–12,000 years ago.
- Estuaries form a transition zone between river environments and maritime environments
- The inflows of both sea water and fresh water provide high levels of nutrients in both the water column and sediment, making estuaries among the most productive natural habitats in the world

Bar-built estuaries – Texas

- Found in a place where the deposition of sediment has kept pace with rising sea levels so that the estuaries are shallow and separated from the sea by sand spits or barrier islands.
- Building up of offshore bars by wave action, in which sand from the seafloor is deposited in elongated bars parallel to the shoreline growing into barrier islands.



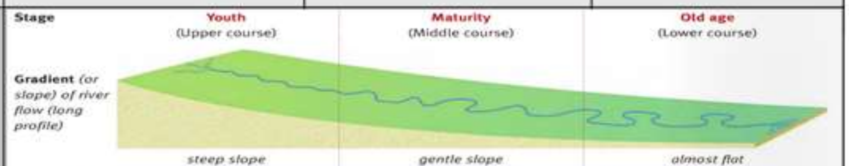
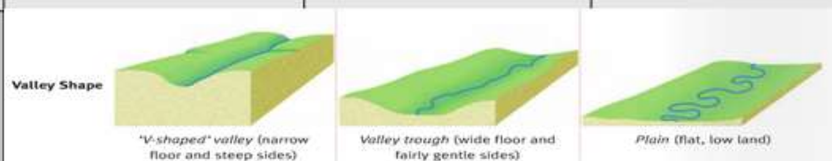


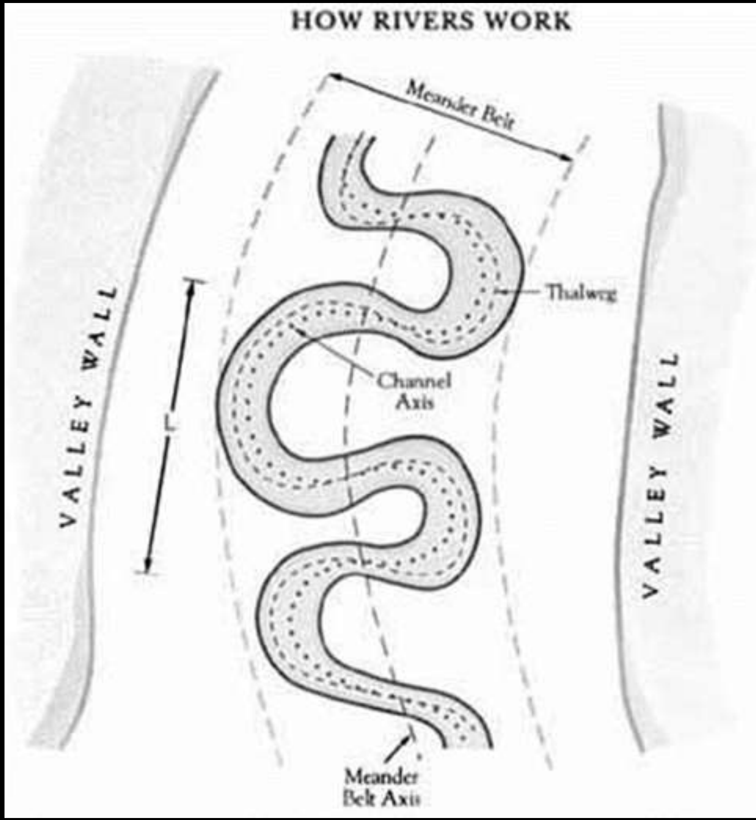
Fluvial Process - A Fluvial Life

The Upper Course: steep and rugged

The Middle Course: winding sedately through wide valleys

The Lower Course: a somewhat aimless course toward final extinction

Course Stage	Upper Course Youth Stage	Middle Course Mature Stage	Lower Course Old Age Stage
Slope	 Stage; Youth (Upper course); Gradient (or slope) of river flow (long profile); steep slope	Maturity (Middle course); gentle slope	Old age (Lower course); almost flat
Main processes	Hydraulic Action Abrasion **Erosion**	**Erosion** and **Deposition**	**Deposition**
Valley shape	 Valley Shape; 'V-shaped' valley (narrow floor and steep sides)	Valley trough (wide floor and fairly gentle sides)	Plain (flat, low land)
Main features	V-shaped Valleys Interlocking Spurs Waterfalls	Meanders and Ox-Bow lakes	Deltas Levees Flood Plains (and m+ob lakes)



Flowing water always wants to carry a sediment load

Sinuosity is inversely proportional to slope