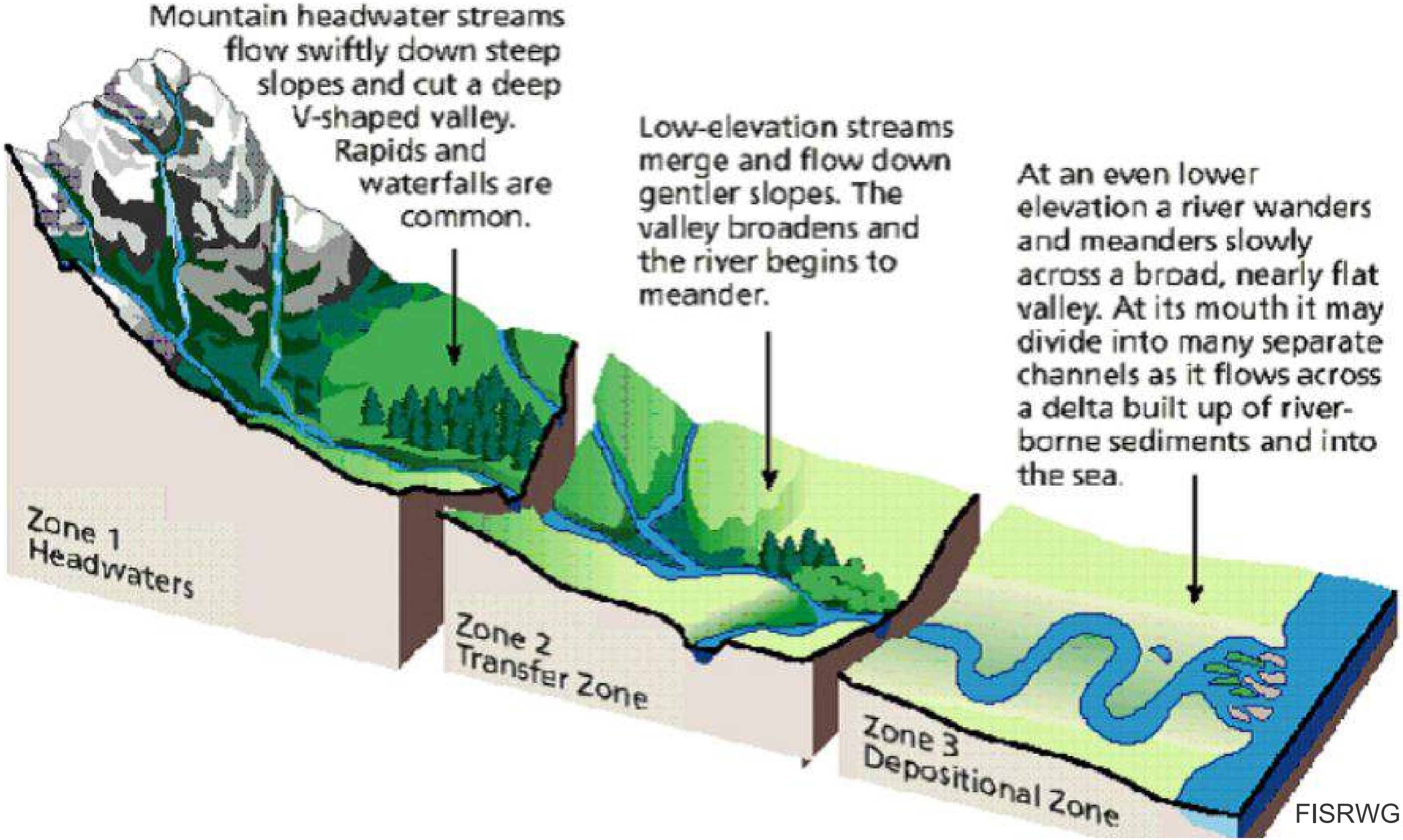
Topic 6: Erosion and Sediment Transport

Work example by students

Main Points

- Definition of Alluvial, Semi-Alluvial and Non-Alluvial Streams
- Slope, Discharge and Sediment Transport
- Bernoulli 2 - More in Depth

Definition of Alluvial, Semi-Alluvial, and Non-Alluvial Streams

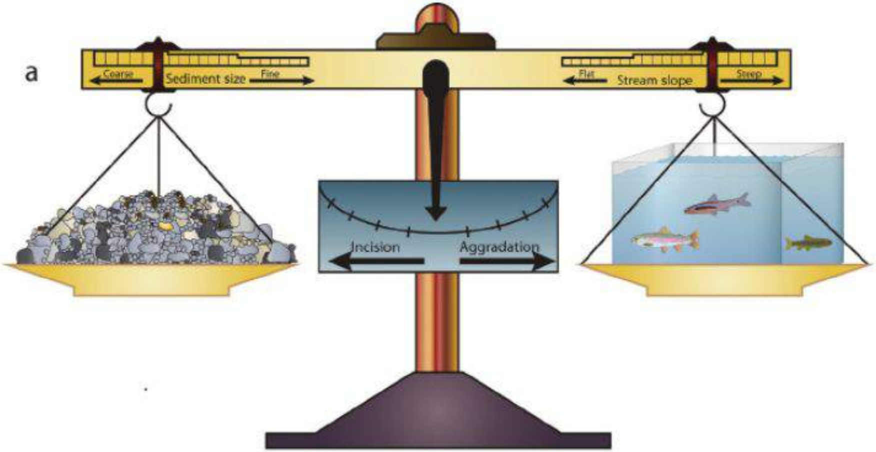


FISRWG, 1998

Non-alluvial ⟷ Alluvial

Classifying Streams

- Riverbanks
- Stream bed
  - Sediment supply
  - Grain size, mass, shape (texture and form), density
- Lane's Balance
  - "Measures the product of a river's sediment load/size in relation to rivers slope/discharge" - Miller, 2017



Pollock *et al.* (2014)

Why do Rivers Curve? - MinuteEarth

https://www.youtube.com/watch?v=8a3r-cG8Wic&list=PLEIB7nLNHZvhfuBhJ73p1hnol3e3NBV5n&index=9

- Only the first 30 seconds of this video since we have already seen it in a previous presentation and it is not as relevant to topic 6

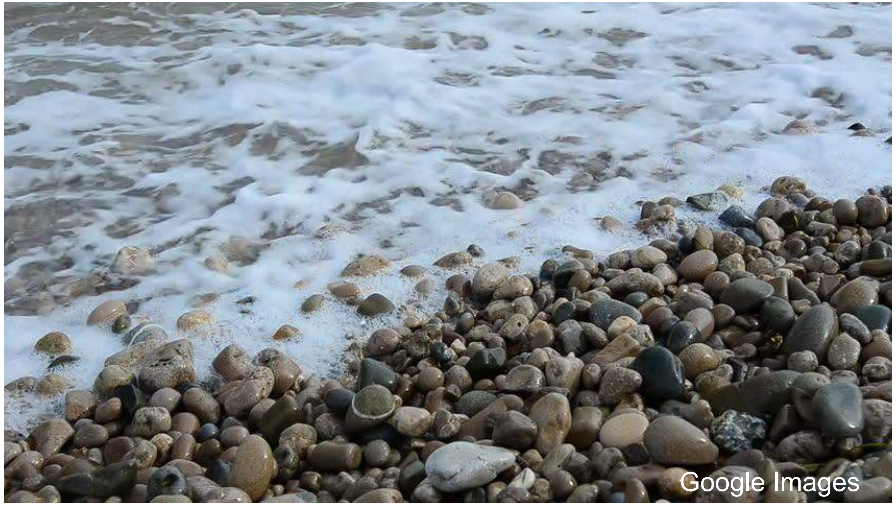
Non-Alluvial

- Travel through mountainous environments
- Their course is determined by the bedrock that was carved by glaciers and years of erosion
    - As the video said, it is “set in stone”
- Streams are often straight down steep cliffs
- Wide range of sediment that the stream can carry
- Forms white-water streams
    - Rapids, waterfalls, etc.

Semi-Alluvial

- Mountain slopes flatten and reach lower elevations
- River slows
- Increased interaction between the stream and sediment supply
- No longer flowing over solid bedrock.

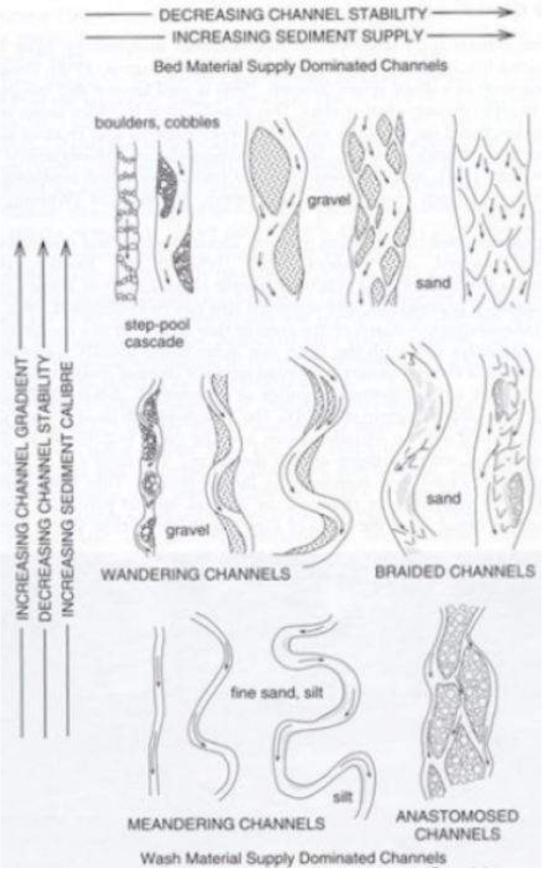
- Straight or slight bending streams



Alluvial

- “channels that flow through sediments which they have previously deposited, and therefore, rivers that are competent to modify morphology of their channel” - Robert (2003)
- Open plains where there is soft soil
- Streams “wander”
    - Braided, meandering, anastomosed
- This is where the streams often meet the sea/ocean to form river deltas

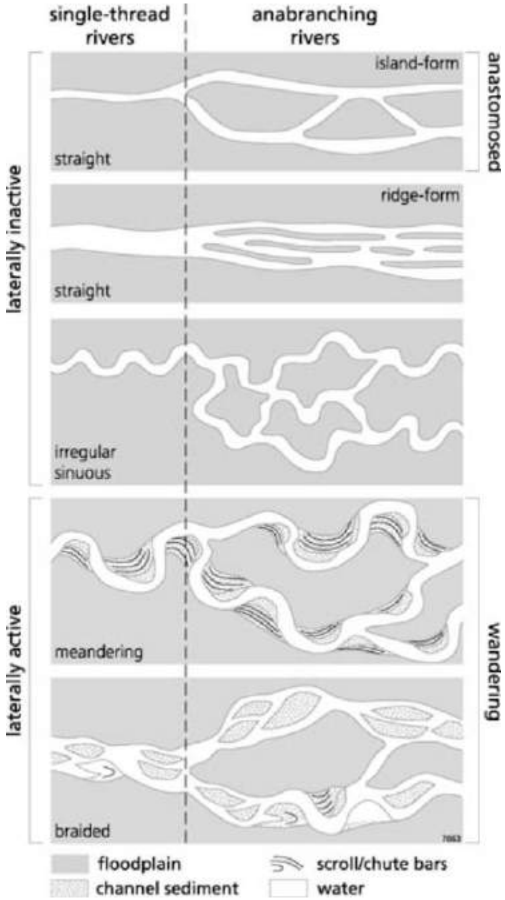

Google Images



Robert (2003)

Non-alluvial

Alluvial

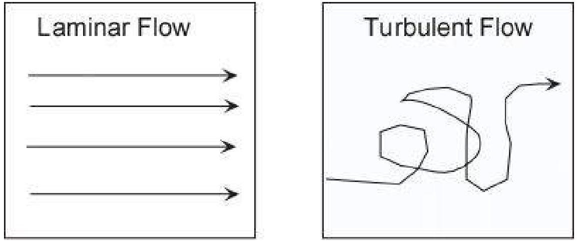


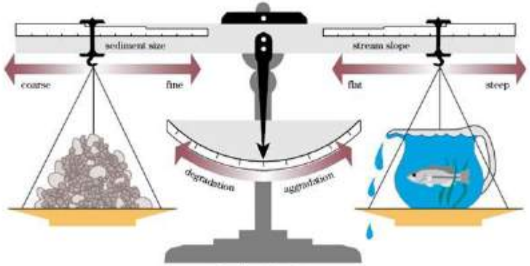
Miller, 2017

Slope, Discharge, and Sediment Transport

Slope

- As slope increases flow becomes more turbulent.
- A higher gradient will increase the stream’s kinetic energy and therefore ability to erode.
- Slope of banks are steeper in headwaters, therefore more erodible compared to the depositional zone.
- Slope will decrease towards the bottom of a watershed leading to deposition.





$Q_s \cdot D_{50} \propto Q_w \cdot S$

From Rosgen (1996), from Lane, Proceedings, 1955.
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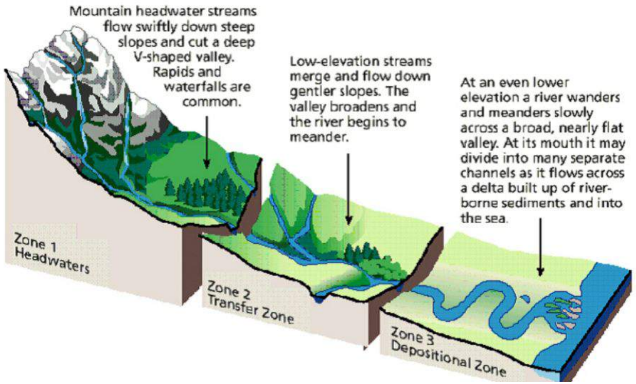
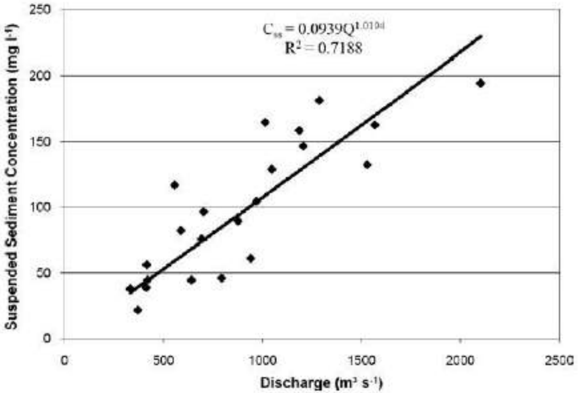


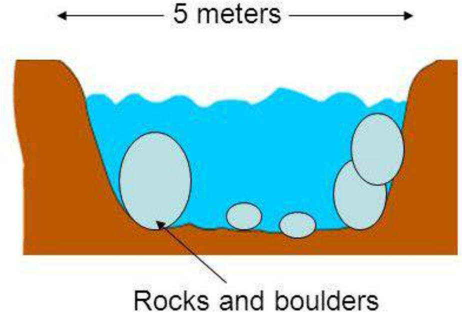
Discharge

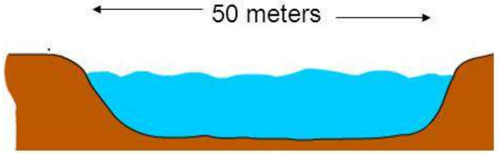
Q=V*A

Discharge=Velocity*Cross sectional Area

Stream capacity and **stream Competence** increase with discharge.







Sediment Transport

<u>Overview</u>

1. Sediment and Bulk Properties
2. Packing and Entrainment of Sediment
3. Classification Based on Mechanics
4. Types of Sediment Transport

Sediment and Bulk Properties

Size

- Greatest parameter influence
- Sediment movement and mechanisms are dependent
- Controls mass, thereby controlling mode of sediment movement and rate of transport
    - Force exerted by a moving fluid
    - Mass increases with diameter (external)
    - Represents measure of inertia of a body
- Measurement of external diameter
    - External 'caliper' diameter
    - Sieve diameter
    - Equivalent spherical diameter

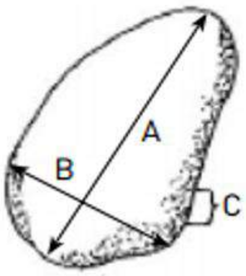


Figure 4. Particle axes (from Potyondy and Bunte, 2002).
A = Longest axis (length)
B = Intermediate axis (width)
C = Shortest axis (thickness)

Wentworth Grain Size Scale

$$\Phi = -\log_2 D$$

Where,

Φ=logarithmic particle size, D=Particle size in mm

- Statistical Analysis of grain size distribution and quantifies unit measurement of particle sizes

Millimeters (mm)		Micrometers (µm)	Phi (φ)	Wentworth size class	
	4096		-12.0	Boulder	Gravel
	256		-8.0	Cobble	
	64		-6.0	Pebble	
	4		-2.0	Granule	
	2.00		-1.0	Very coarse sand	Sand
	1.00		0.0	Coarse sand	
1/2	0.50	500	1.0	Medium sand	
1/4	0.25	250	2.0	Fine sand	
1/8	0.125	125	3.0	Very fine sand	
1/16	0.0625	63	4.0	Coarse silt	Silt
1/32	0.031	31	5.0	Medium silt	
1/64	0.0156	15.6	6.0	Fine silt	
1/128	0.0078	7.8	7.0	Very fine silt	
1/256	0.0039	3.9	8.0	Clay	Mud
	0.00006	0.06	14.0		

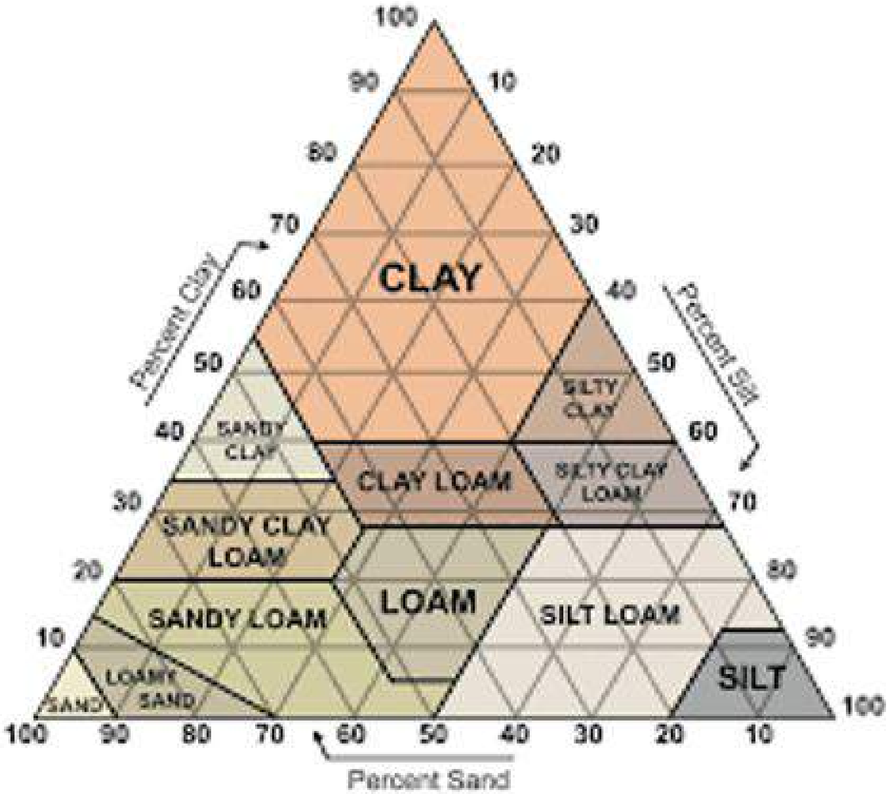
Sediment Types

- Soil usually composed of a mixture of sand, silt and clay
- Texture Triangle

<u>Example:</u>

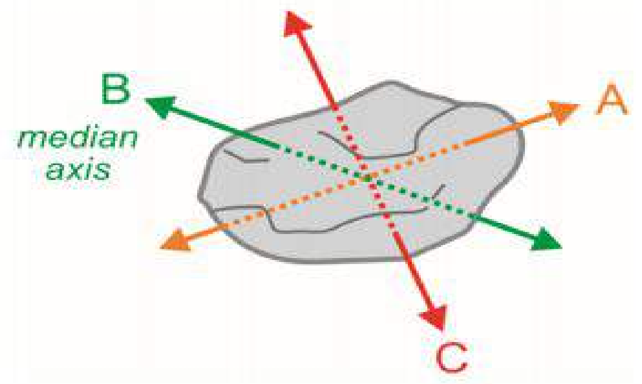
30% sand, 30% clay,40% silt

What is the soil type?

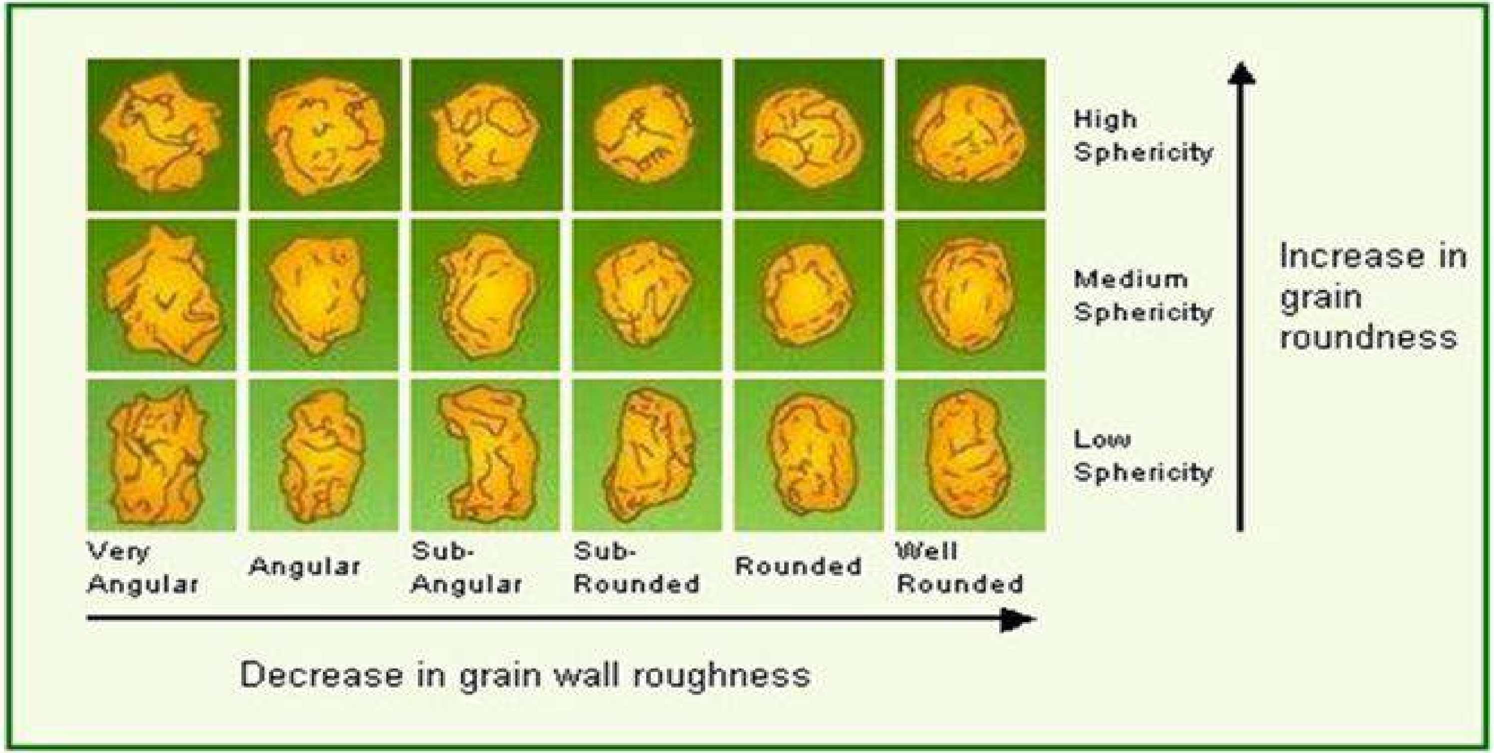


Shape

- Actual form of grain and the surface texture
- Influence on fall velocity
  - Ie. flatter particle settle slower than spherical ones
- Significant factor of initial movement
- Affects amount of surface area exposed to the flow and rollability
- Factors
  - Elongation (A/B)
  - Flatness (C/B)
    - A -longest axis
    - B-intermediate axis (width)
    - C-shortest axis (thickness)



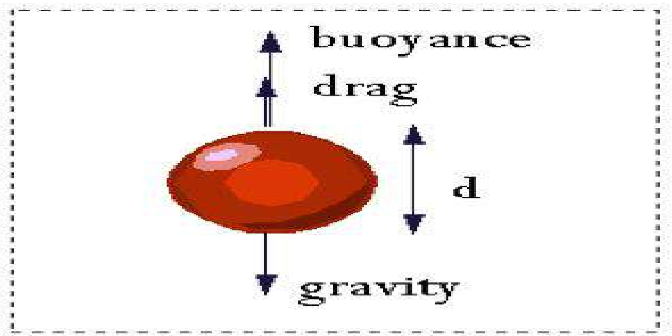
Shape

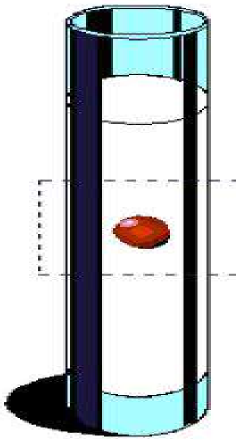


High Sphericity
Medium Sphericity
Low Sphericity
Increase in grain roundness
Very Angular
Angular
Sub-Angular
Sub-Rounded
Rounded
Well Rounded
Decrease in grain wall roughness

Settling Velocity

- The downward vertical motion of particles in suspension
- Magnitude is determined by the balance of forces
  - Downward force(submerged weight of the material) vs. Opposing viscous and inertial resistance forces





Settling Velocity

Particle Reynolds Number

$$\mathbf{Re_p = V_O D / v}$$

- D is the particle diameter
- V is the kinematic viscosity

Fall Velocity

$$V_0 = (1/18)\ D^2\ (p_s - p)g/\mu$$

- p_s is the sediment density
- **p** is the water density
- **D** is the grain diameter
- **g** is gravitational constant
- **μ** is the dynamic viscosity

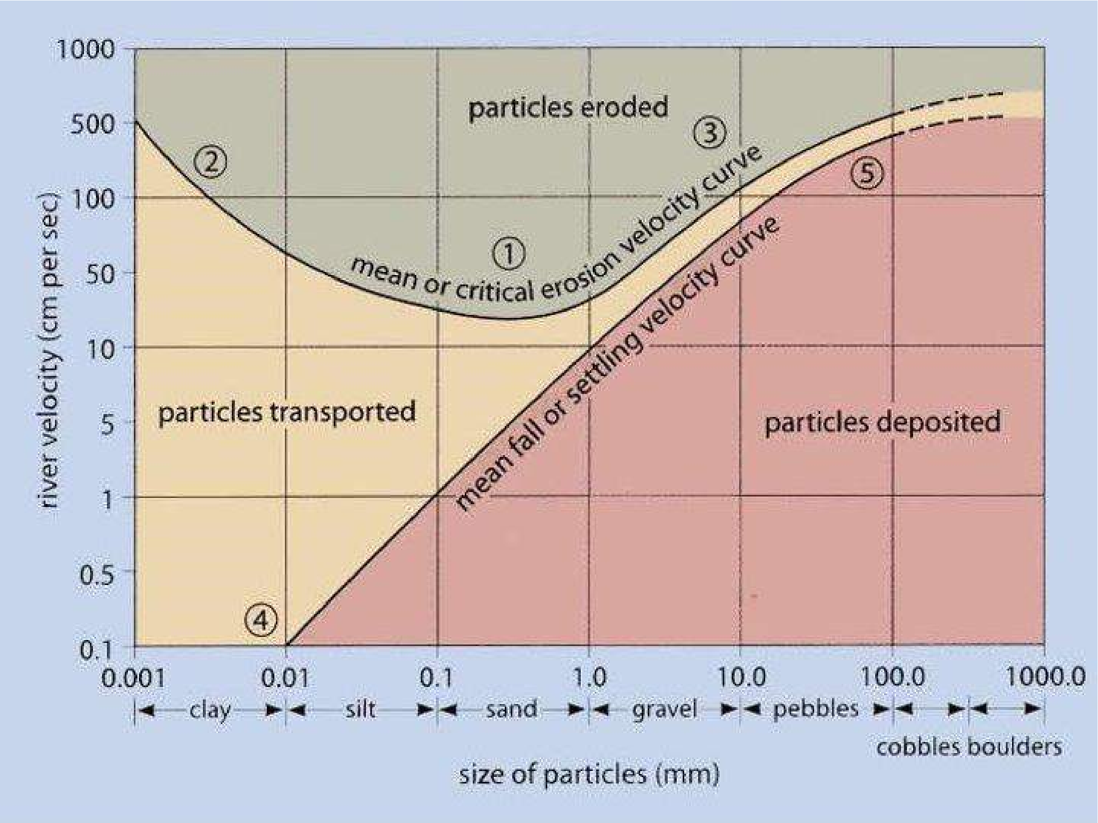
➔ Silt and clays

➔ The fall velocity varies significantly with water temperature(fluid vicosity changes with temperature)

Fall Velocity

$$V_0 = \sqrt{[2/3Dg(p_s - p)/p]}$$

- For coarse material > 2mm
- Experience resistance from the inertia of the water
- Viscosity is unimportant



Hjulström Curve

Packing and Entrainment

Sediment Deposit

Solid Particles + Void Particles = Packing

Packing

- The organization of the particles on the stream bed
- Can be expressed in term of a volume concentration,

C=(Volume of grains)/(volume of grains + void space volume)

- Influenced by
  - Sorting
  - Sediment Shape
  - Packing Shape
- Significant bulk sediment property
- Helps describe poorly sorted sediments, irregular particles and coarse gravels

Porosity and Void Ratio

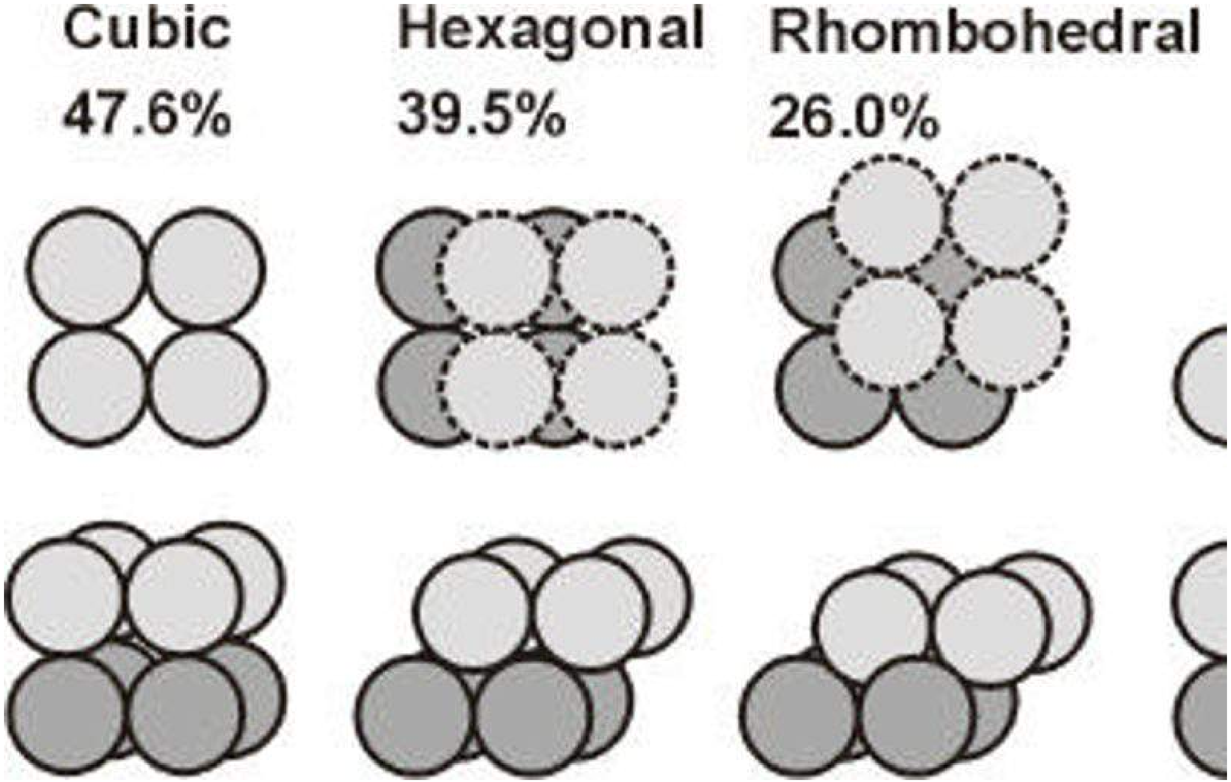
- The void ratio is the volume of voids to the volume of solids (**e**)
- Porosity is defined as the ratio of volume of voids to the total volume (**p**)
- The two are related: **$e=V_v/V_s$, $p=V_v/V$**

By Algebra, **$e=p/(1-p)$** and **$p=e/(1+e)$**

Table 3.3 Range of porosities and void ratios (from Dingman, 1984)

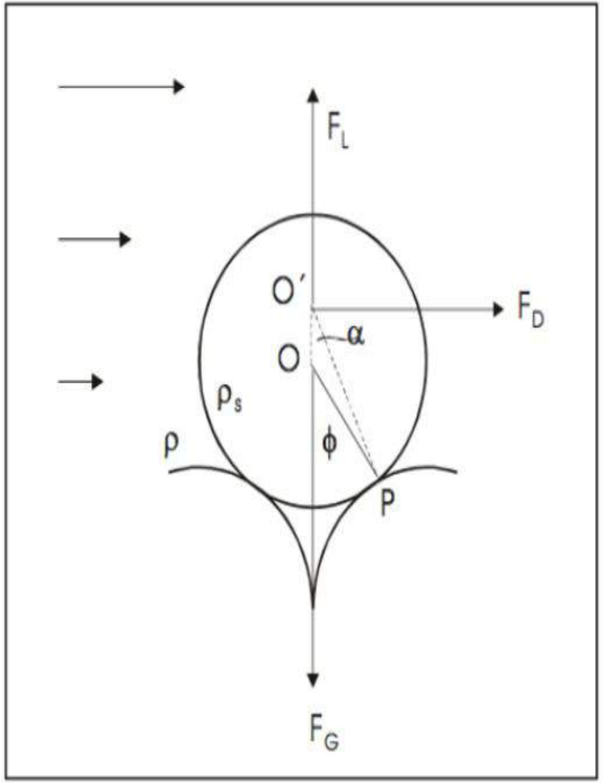
Materials	*p*	e
Gravel	0.25–0.40	0.33–0.67
Sand	0.25–0.50	0.33–1
Silt	0.35–0.50	0.54–1
Clay	0.40–0.70	0.67–2.3

Packing Arrangements



Entrainment

- Lift and drag forces action on a stagnant particle
- Correlated to velocity
- Small changes in velocity = big changes in forces



Friction Angle (Φ)

- This parameter is taken from two particles that lay over each other
- Varies with the ratio of the size of the grain to the size of the grain upon which it rests
- Influences the **rollability** of a particle (how easily a grain can be moved from its resting position).
- **Frictional Forces** acting on sediment, is the ability for a grain to resist movement from the acting fluid

Frictional Angle

$$\Phi = \alpha(D/K)^{\beta}$$

Φ= Pivoting Angle or Angle of repose

α= influenced by particle size

D= Diameter of the grain

K= Diameter of the base grain

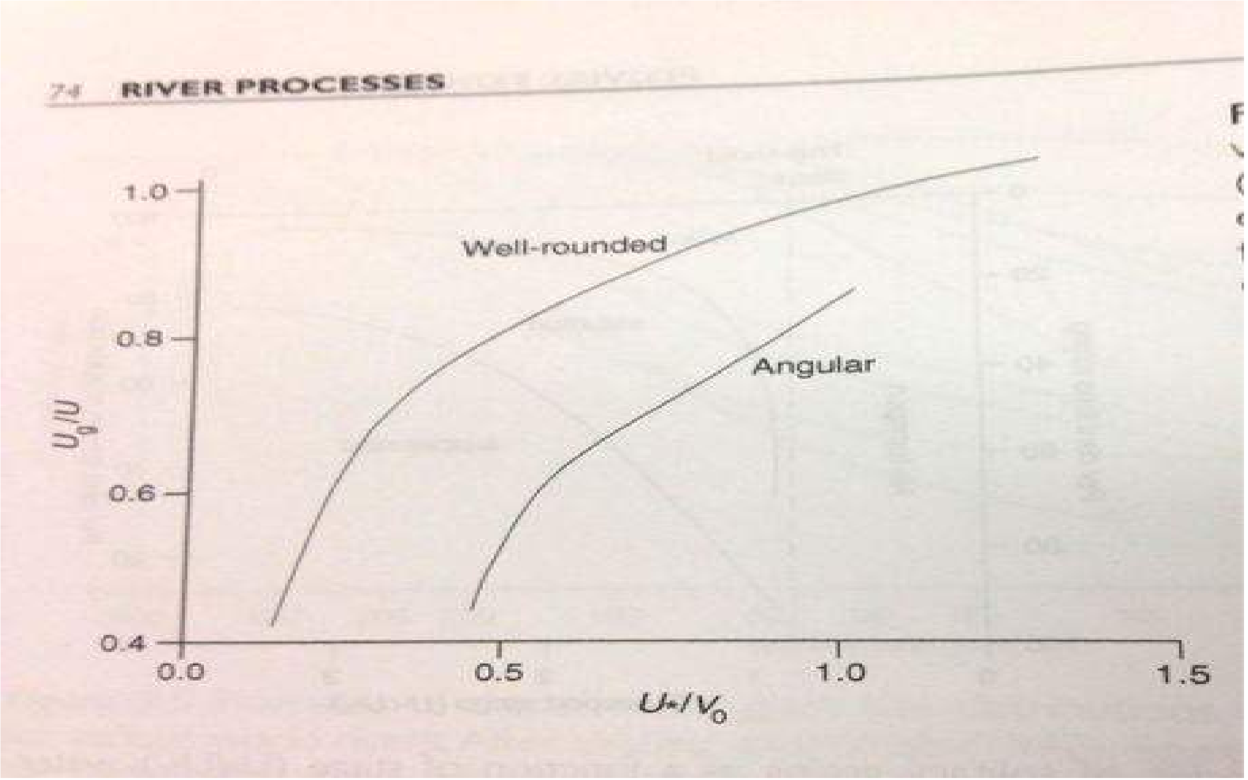
β= Influenced by particle shape

Classification Based on Mechanics

Transport Stages

- Particles are displaced downstream when the threshold of initial movement has been met
- Mode of transport varies with
  - Sediment size intensity
  - Flow
- Criteria
  - Shear velocity (**U_***)
  - Settling Velocity (**V_o**)
- Criteria Ratios
  - $U_*/V_o > 1$, suspension occurs
  - $U_*/V_o = 1$, grains are travelling at equal speeds to the moving fluid

Forward Velocity Ratio



Transport Mechanism

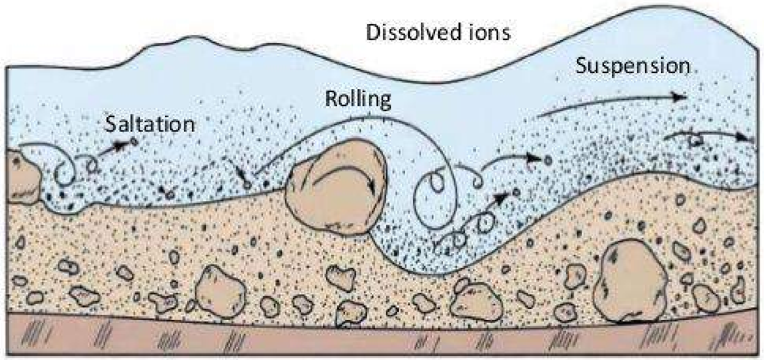
3 general types of grain movement:

1. Rolling/Traction

2. Saltation

3. Suspension

MOVEMENT OF THE SEDIMENT LOAD



in a stream is accomplished in a variety of ways. Mud is carried in suspension. Particles that are too large to remain in suspension are moved by sliding, rolling, and saltation. Some ions are dissolved and carried in solution. Increases in discharge, due to heavy rainfall or spring snowmelt, can flush out all of the loose sand and gravel, so the bedrock is eroded by abrasion.

1. Rolling/Traction

- This movement occurs with sediment in contact with the bed surface
- Usually coarse materials involved. (gravel)
- Resting ‘pockets’

2. Saltation

- This movement occurs with intermittent contact between particle and bed surface
- Drag and lift forces causes particles to jump sporadically
- The transfer of momentum from bouncing movement can cause other particles resting on bed surface to begin transport

3. Suspension

- Occurs with fine particles being transported in water column.
- As flow intensity increase so does the duration and distance a grain travels during suspension.

Visualization of Movement

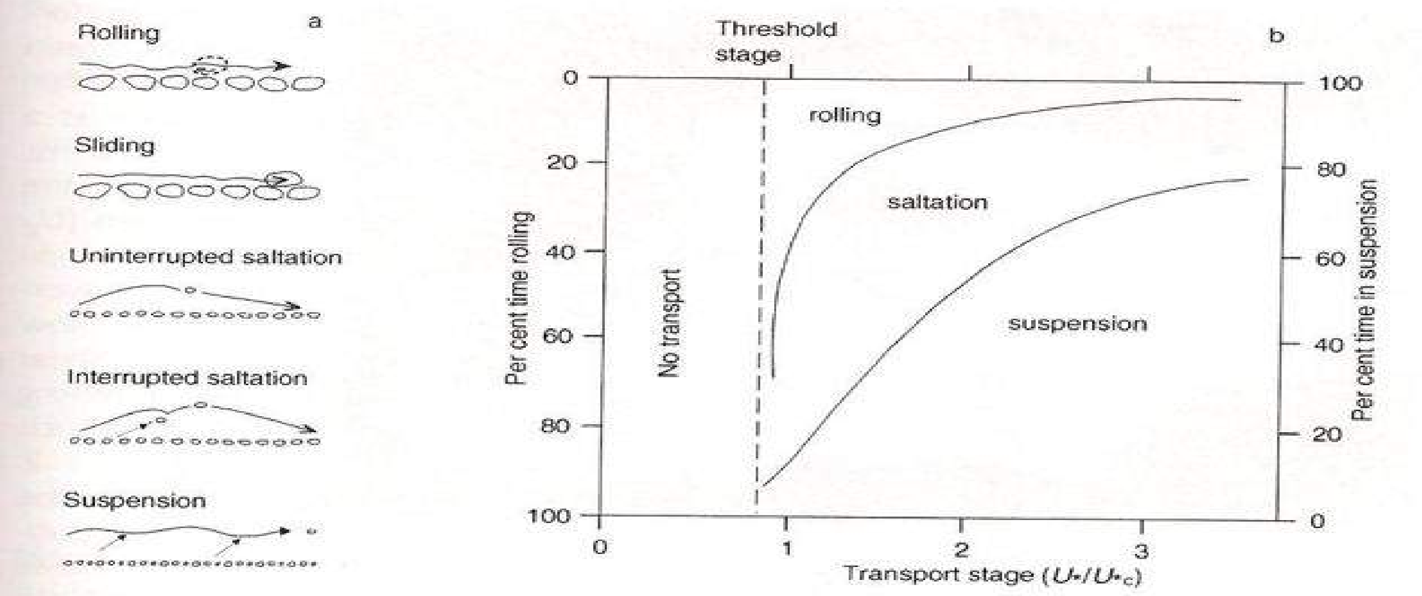


Figure 3.6 Transport modes of solitary grains as a function of stage (U_*/U_{*c}): water depth 48 mm, and grain size 8.3 mm. After Abbott and Francis (1977) and Knighton (1998). Diagram of transport stages reproduced with the permission of the publishers, The Royal Society, London, UK.

Types of Sediment Transport

Transport Components

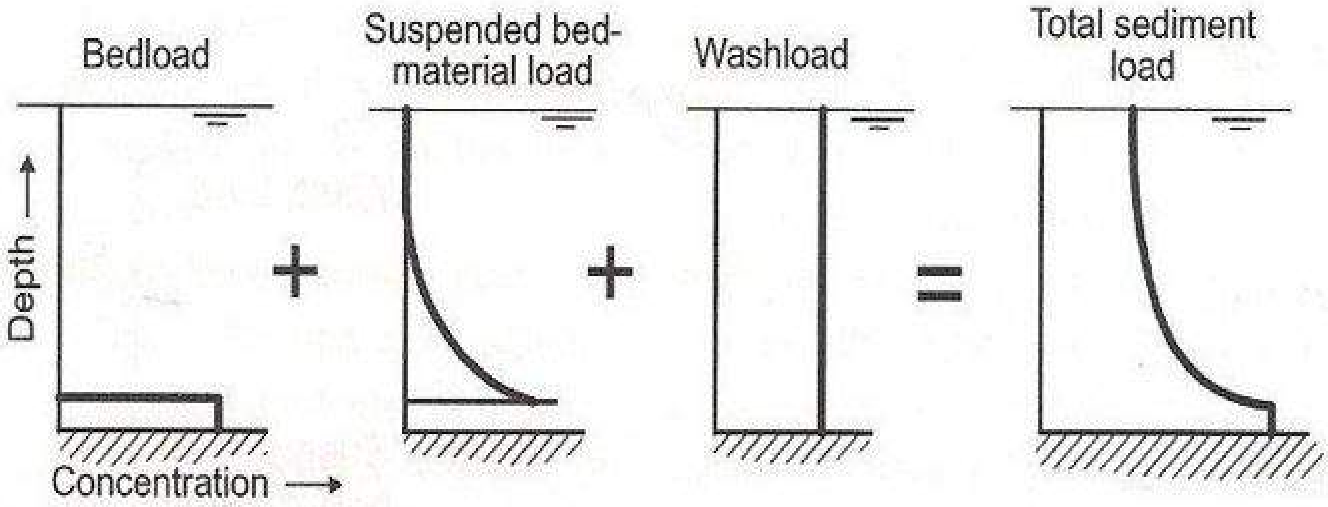


Figure 7.2. *Schematic diagram of the vertical distribution of sediment load concentrations*

1. Bedload

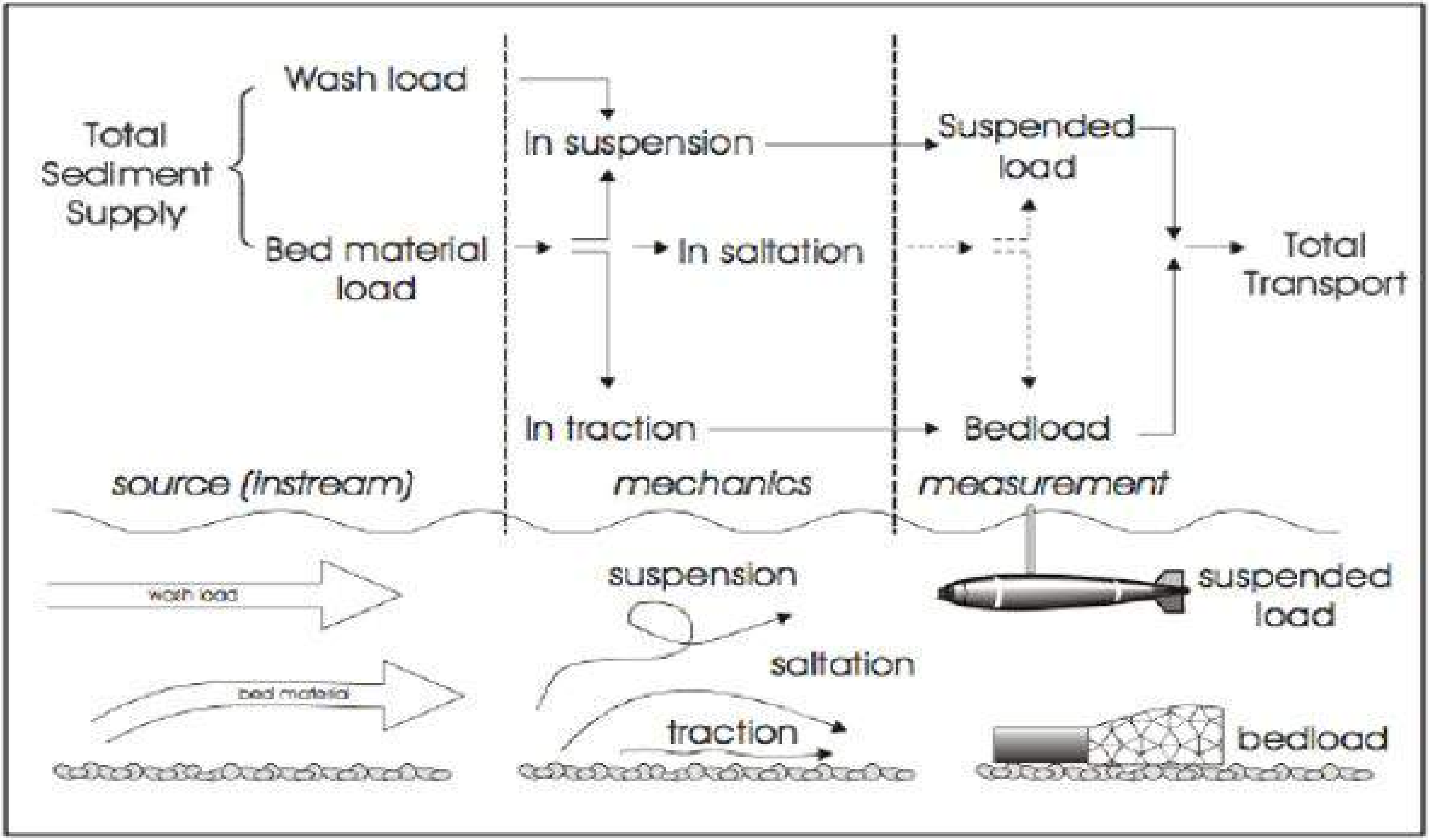
- This type of movement occurs with particles moving along the bed surface.
  - Occurs with sand and coarse grained material
  - Mechanisms involved include traction and saltation
  - Particles can become suspended if vertical velocity exceeds settling velocity

2. Suspended Bed Loads

- This is the sediment that is suspended within the flow of the water.
    - Weight of particle is supported by upward turbulence
    - Depends on particle size and flow conditions

3. Wash Load

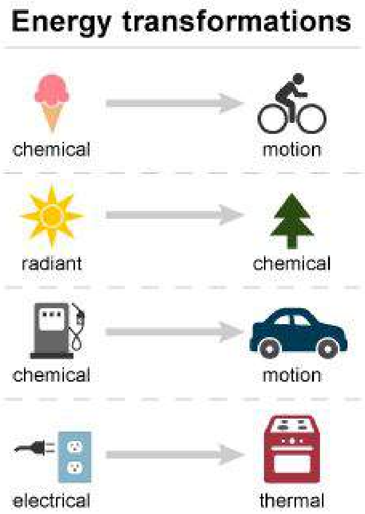
- These are the sediments carried by the fluid near the water surface
    - Fine sediments
    - Continuous suspension



Total Sediment Supply
Wash load
Bed material load
In suspension
In saltation
In traction
Suspended load
Bedload
Total Transport
source (instream)
mechanics
measurement
wash load
bed material
suspension
saltation
traction
suspended load
bedload

Bernoulli 2 - More in Depth

$$P_1 + \frac{1}{2}\rho V_1{}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2{}^2 + \rho g h_2$$



Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.

$$P_1 + \frac{1}{2}\rho V_1{}^2 + \rho g h_1$$

Potential Pressure Energy

P: Pressure

$$P_1 + \frac{1}{2}\rho V_1^{\ 2} + \rho g h_1$$

ρ :Density of fluid
=m/v
=1g/cm3 for water

V: Velocity of fluid
= ΔL/ΔT

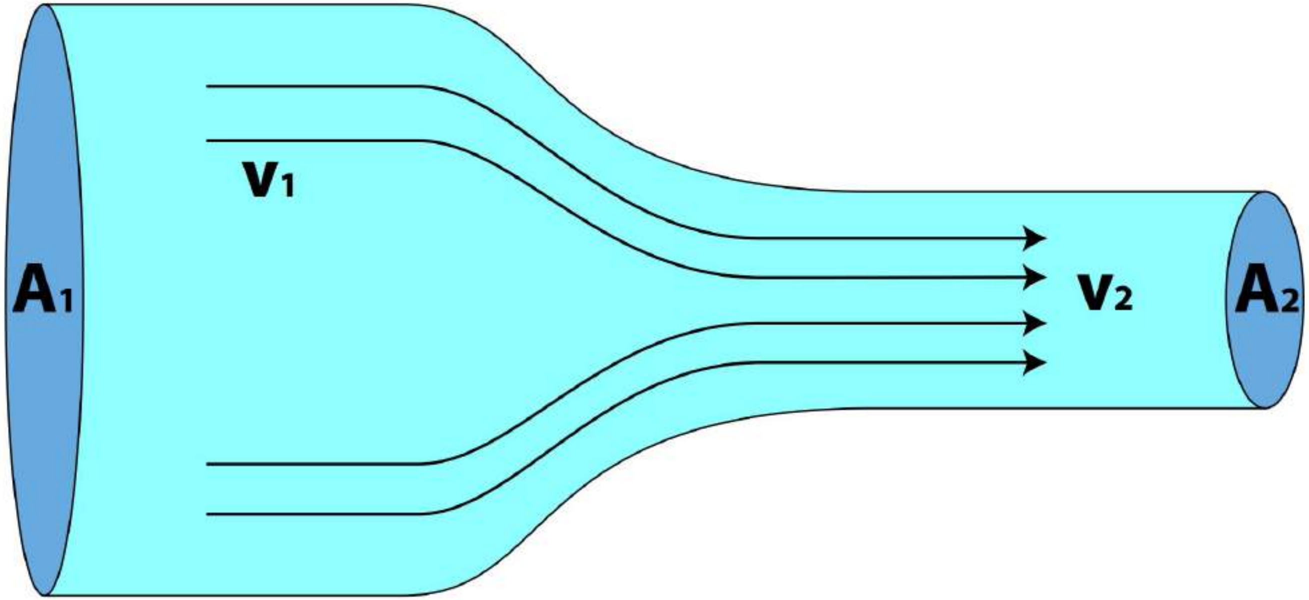
Kinetic Energy of Flow

$$\boxed{P_1} + \boxed{\frac{1}{2}\rho V_1{}^2} + \boxed{\rho g h_1}$$

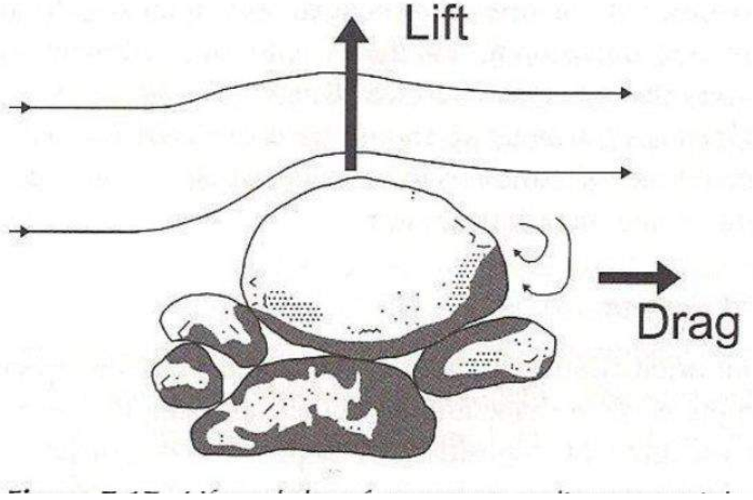
g: Acceleration due to gravity
= 9.8m/s2
h: Elevation head

Gravitational Potential Energy

$$P_1 + \frac{1}{2}\rho V_1{}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2{}^2 + \rho g h_2$$



$$P_1 + \frac{1}{2}\rho V_1{}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2{}^2 + \rho g h_2$$



Kahoot Quiz

- Use your phone, tablet, or laptop internet browser and go to kahoot.it
- https://kahoot.com/welcomeback/
- Winner Gets a Prize!

Thanks for Listening

References

FISRWG (10/1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US gov't). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.

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