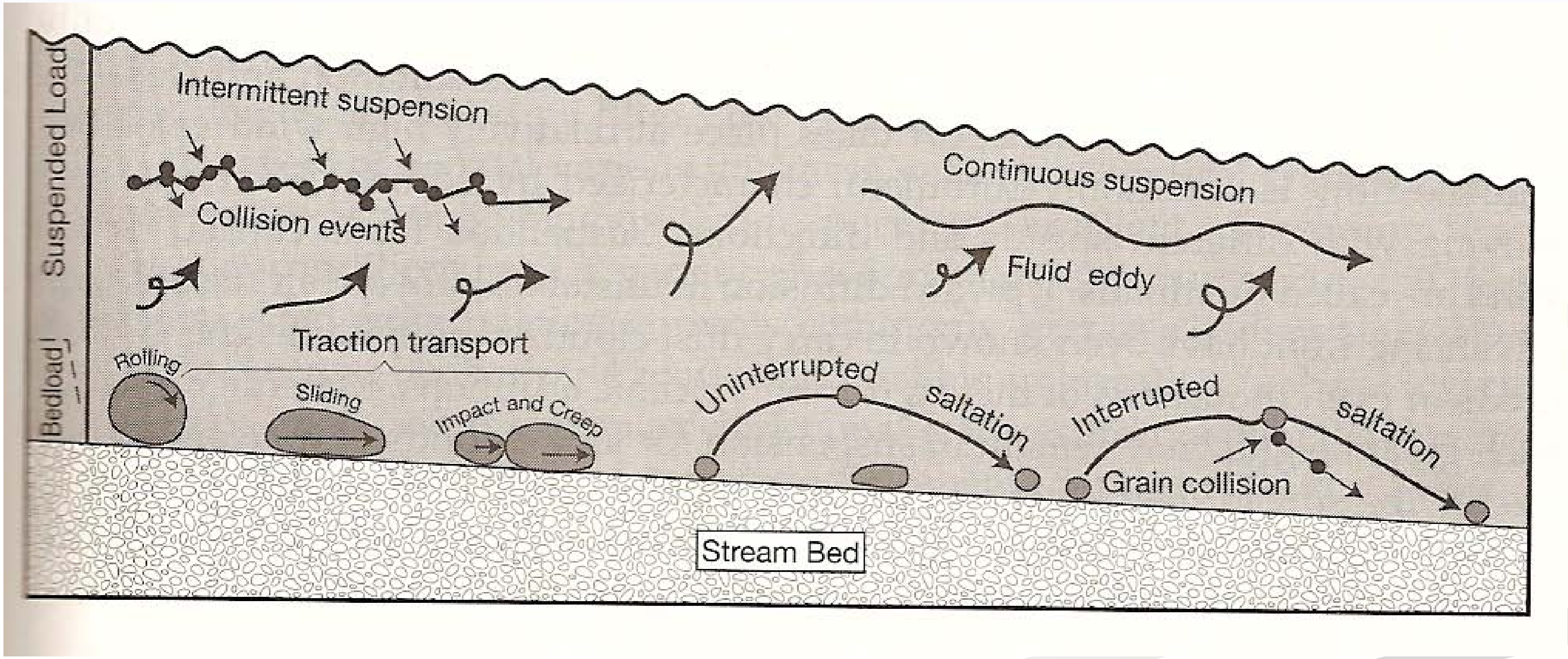
Transport processes

Part I – fluid flow and particle transport

Fluvial transport: Sediment load and transport path



Boggs S. Jr. (2012) Principles of Sedimentology and stratigraphy

Check out these videos:

http://serc.carleton.edu/NAGTWorkshops/sedimentary/visualizations/unidirflow.html

Sedimentload and transport path

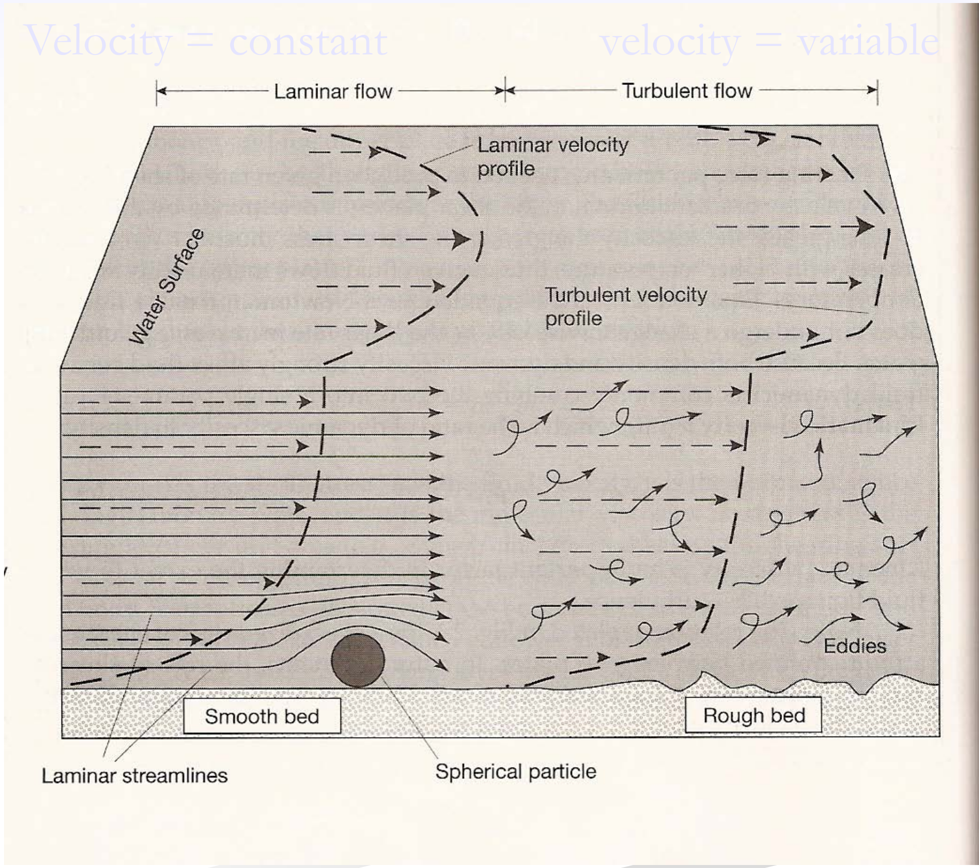
- Bed load transport
  - Traction (coarse sand and gravel)
    - Rolling, sliding, and creep
  - Saltation (mainly sand)
    - Intermittent contact with the bed
    - Steep angle rise (~ 45°), low angle descent path (~ 10°)
      - Interrupted by turbulence or by collision with other grains
- Suspended load (fine-grained sediments)
  - May be intermittent due to erratic lift forces
  - Continuous suspension (very fine particles)
    - Move with the fluid (wash load)

Fluid flow

- Fluid density ρ (g/mL)
  - Affects
    - Magnitude of forces involved
    - Settling velocity
    - Influences gravity flow
  - Density ↑ with ↓ Temp. (ρ_{water}=0.998g/mL at 20°C)
    - >700 times greater than that of air
      - Water transport >> larger particles than wind
- Fluid viscosity
  - Measure of the ability of fluids to flow
    - ice >> water >> air
    - Viscosity of water at 20°C ≈ 55 times that of air
      - ↑ viscosity = ↓ temperature
    - Influences water turbulence
      - ↑ viscosity = ↓ turbulence
        - ↓ settling velocity
        - ↓ erosion and transport capacity of running water

Laminar vs turbulent flow

- **Laminar flow**
  - Streamlines (movement occurs on a molecular scale)
  - Occur at very low fluid velocities over smooth beds
  - If velocity ↑ or viscosity ↓ the stream becomes highly distorted
- **Turbulent flow**
  - Irregular or random component of fluid motion
  - Eddies: highly turbulent water masses
  - Eddy viscosity: apparent > viscosity due to turbulence



Most flow of water and air under natural conditions is turbulent

Boundary layers and velocity profiles

- Boundary layer = zone of resistance (e.g. streambed)
  - Frictional resistance
  - Greater τ is required in turbulent flow to maintain *du*/*dy* (velocity gradient; u is velocity and y is height)
    - Velocity profiles have different shapes than do laminar flow v-profiles
    - Nature of the bed influences the shape of the profile

>> obstacles = >> turbulence

An important factor in <u>initiating grain movement</u>

Boundary (bed) shear stress

The balance between the driving and resisting forces leads to:

$$\tau_0 = \rho g h S$$

ρ = fluid density

g = acceleration due to gravity

h = flow depth

S = the slope of the bed

τ_0 increases linearly with fluid density, depth and slope

Greater ability to erode and transport sediment in water than air flows, in larger channels and high gradient streams

Particle transport

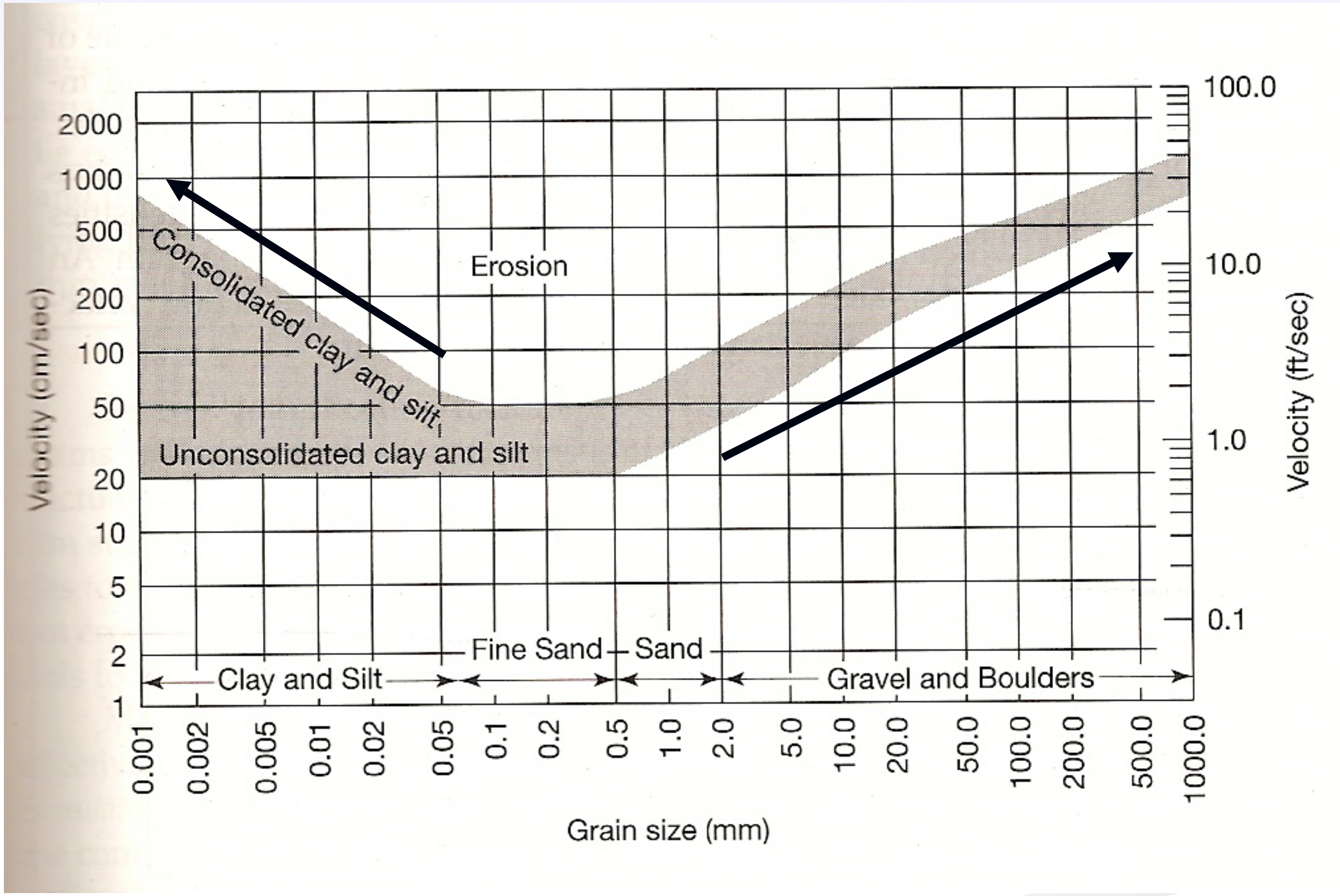
- Erosion and entrainment of sediment from the bed
- Sustained downcurrent or downwind movement of sediment along or above the bed
  - More energy is required to initiate particle movement than to keep them in motion

What are the conditions necessary for particle entrainment?

Particle entrainment by currents

- Gravity forces act downward to resist motion
- Frictional resistance between particles
- Drag force acts // to the bed (related to τ_0)
- Lift force (Bernoulli effect)
- Complicating factors
  - Shape, size, and sorting of grains
  - Bed roughness, and cohesion of small particles

Hjulström diagram

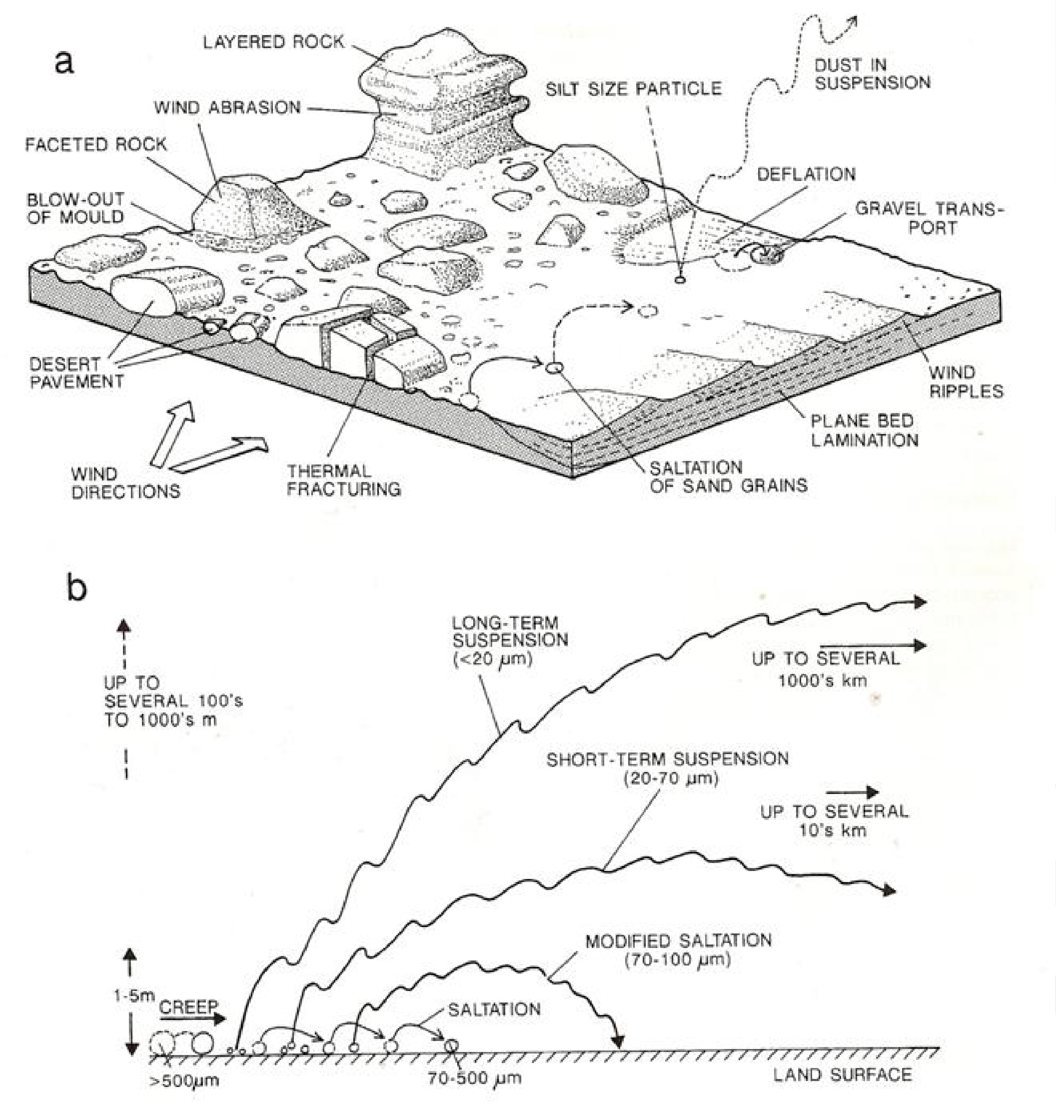


Hjulström diagram: experimentally derived threshold graph for initiation of grain movement

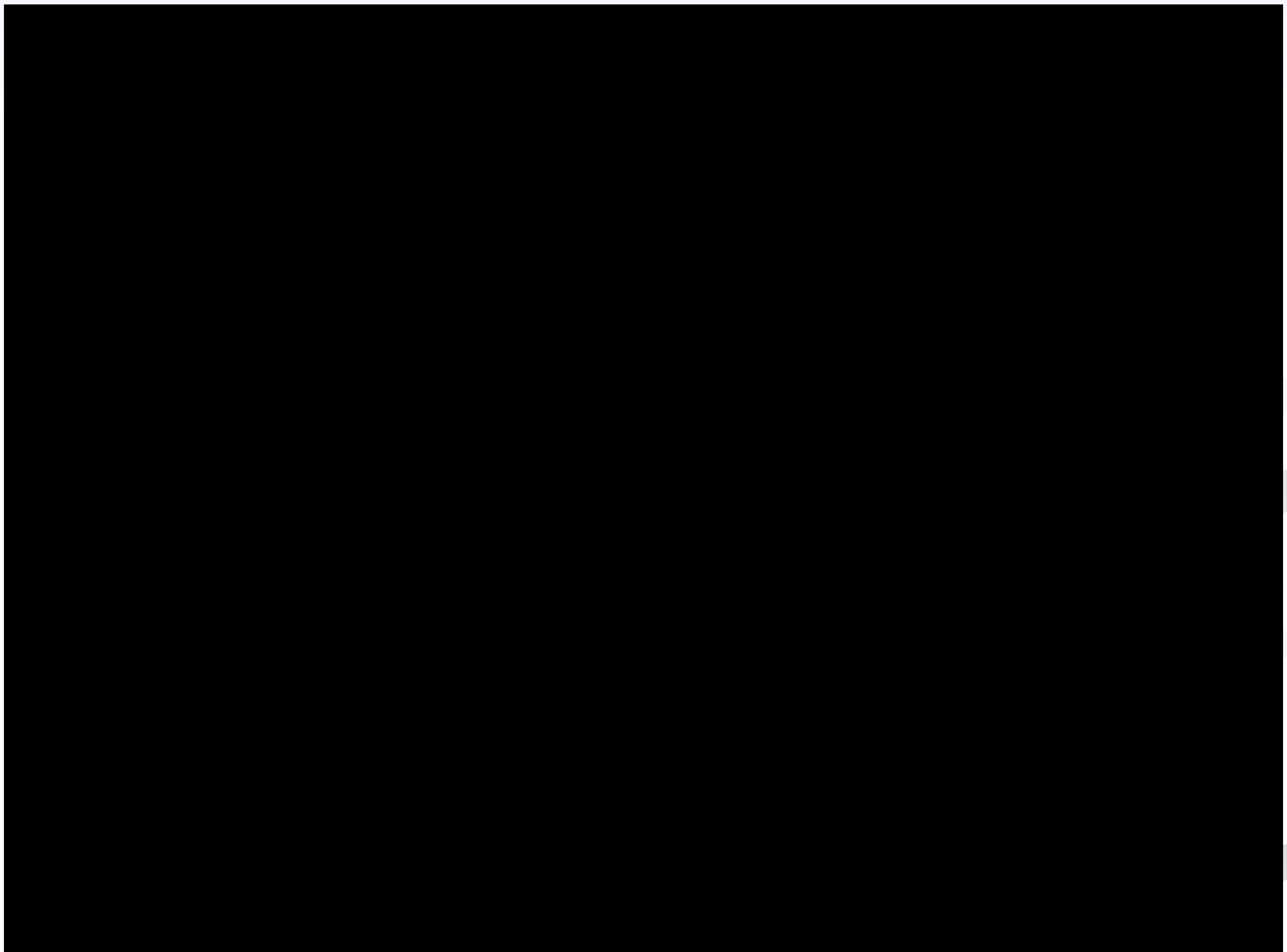
Critical velocity for movement of quartz grains on a plane bed (water depth = 1m)

ρ_f , ρ_s, and μ are constant (e.g. freshwater stream in a given season during average flow)

Transport by wind



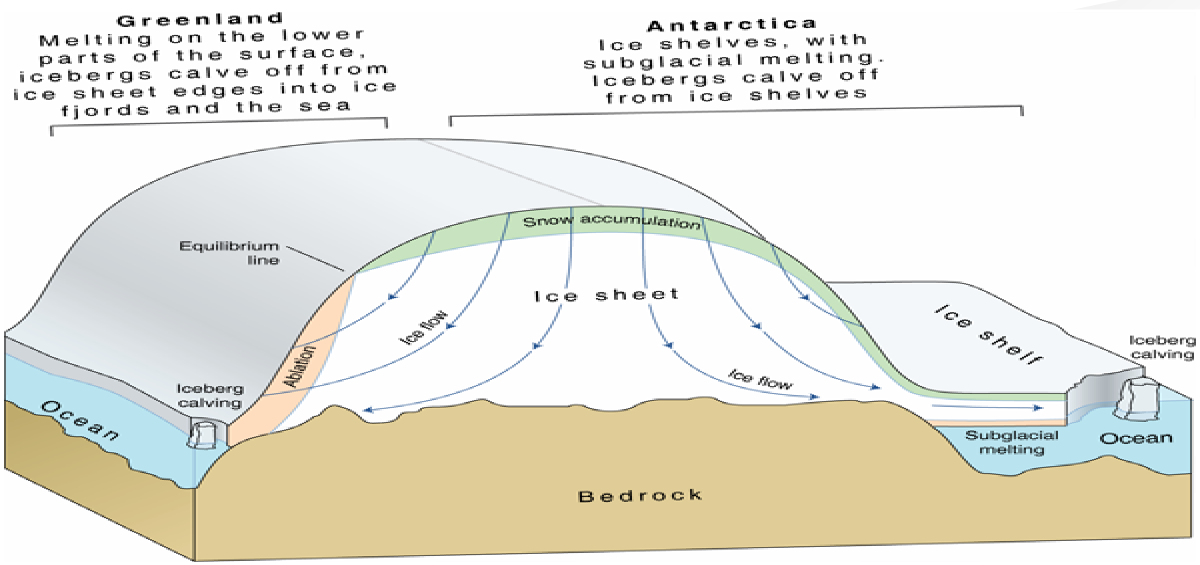
Wind across outwash plain, Iceland



Some basic notions of glacier motion

- Deformation and sliding of glaciers
  - Force of gravity
  - Slowly transfers snow and ice from
    - High-accumulation areas (continental interiors)

    To…
    - Areas of ablation
  - Allows glacial erosion and debris transport to take place

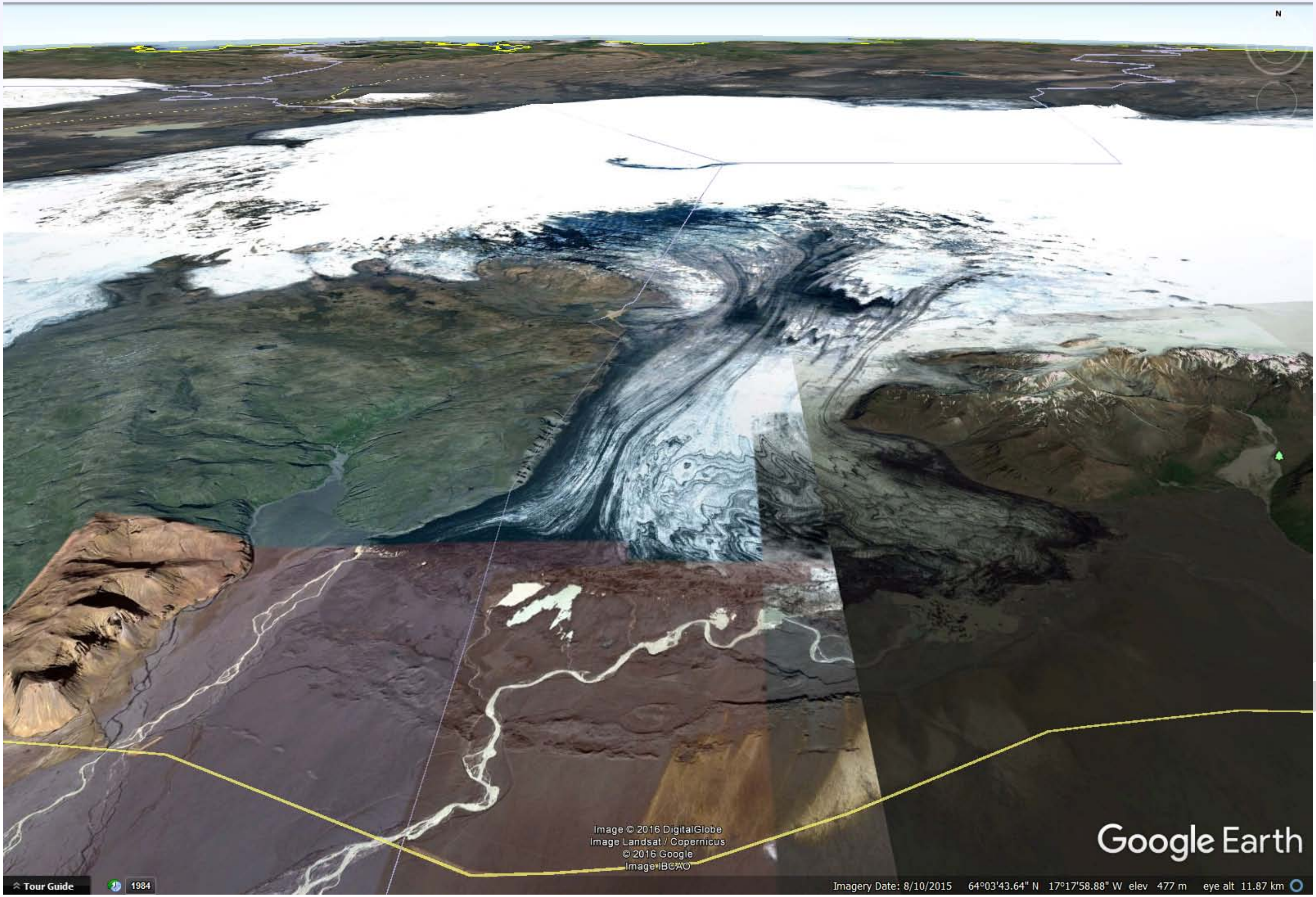


https://nsidc.org/cryosphere/sotc/ice_sheets.html

Driving and resisting forces

- Driving stresses
  - Surface slope and weight of the ice (ice thickness)
    - Influenced by gain and loss of mass
- Resistive stresses
  - Strength of the glacier ice (ice viscosity)
  - Ice/bed interface (basal drag) and sides (lateral drag)
  - Longitudinal stress gradients (pushing or pulling forces)
- Over long periods of time, glaciers tend to equilibrium state
  - In most glaciological situations, the two stresses are close to being in balance, and acceleration can be ignored
- Variations in water input and storage at the bed
  - Glaciers may speed up or slow down over varying timescales

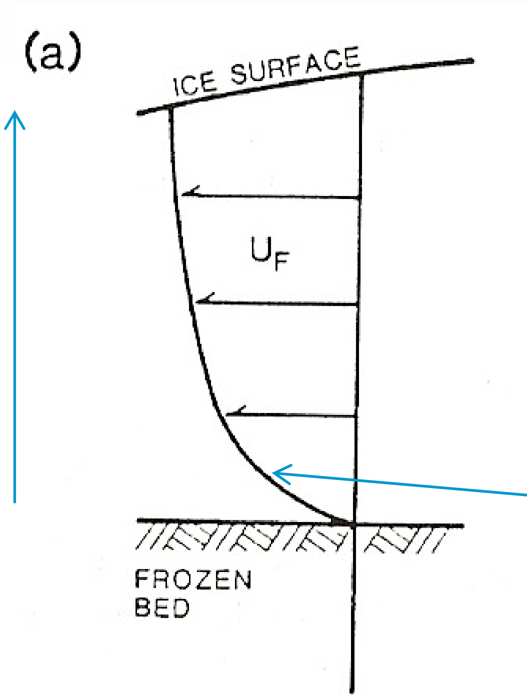
Vatnajökull National Park, Iceland



Deformation of ice

Ice deforms in response to stress…

Cumulative effect of strain rates



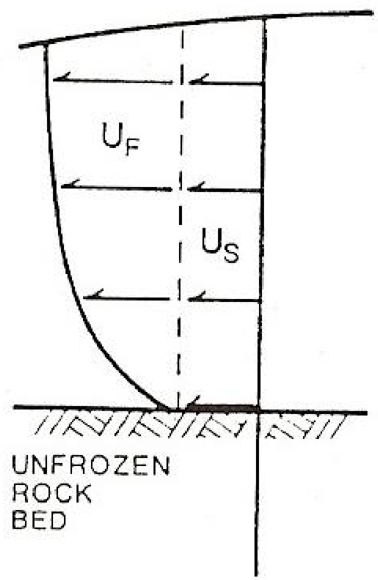
Ice creep velocity increases towards the surface

In the case of a frozen-based glacier, velocity at the bed is zero

Increase in velocity with height is most rapid near the base

Subglacial sliding

- Involves glacier bed decoupling due to increased basal water pressures



Warm-based glacier…
Ice-bed interface above the pressure-melting point

Allows subglacial erosion and debris transport to take place…

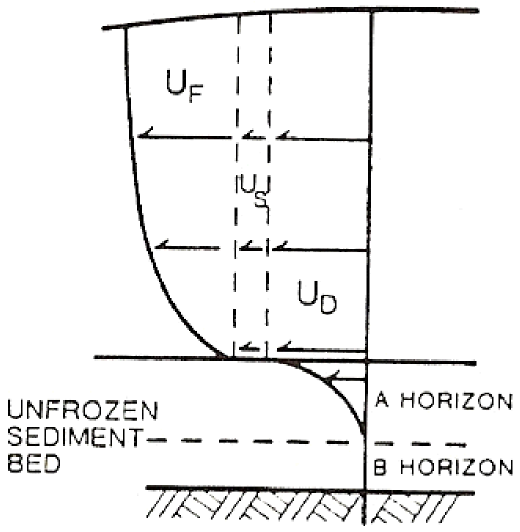
Check out this online material:

http://www.antarcticglaciers.org/modern-glaciers/glacier-flow/

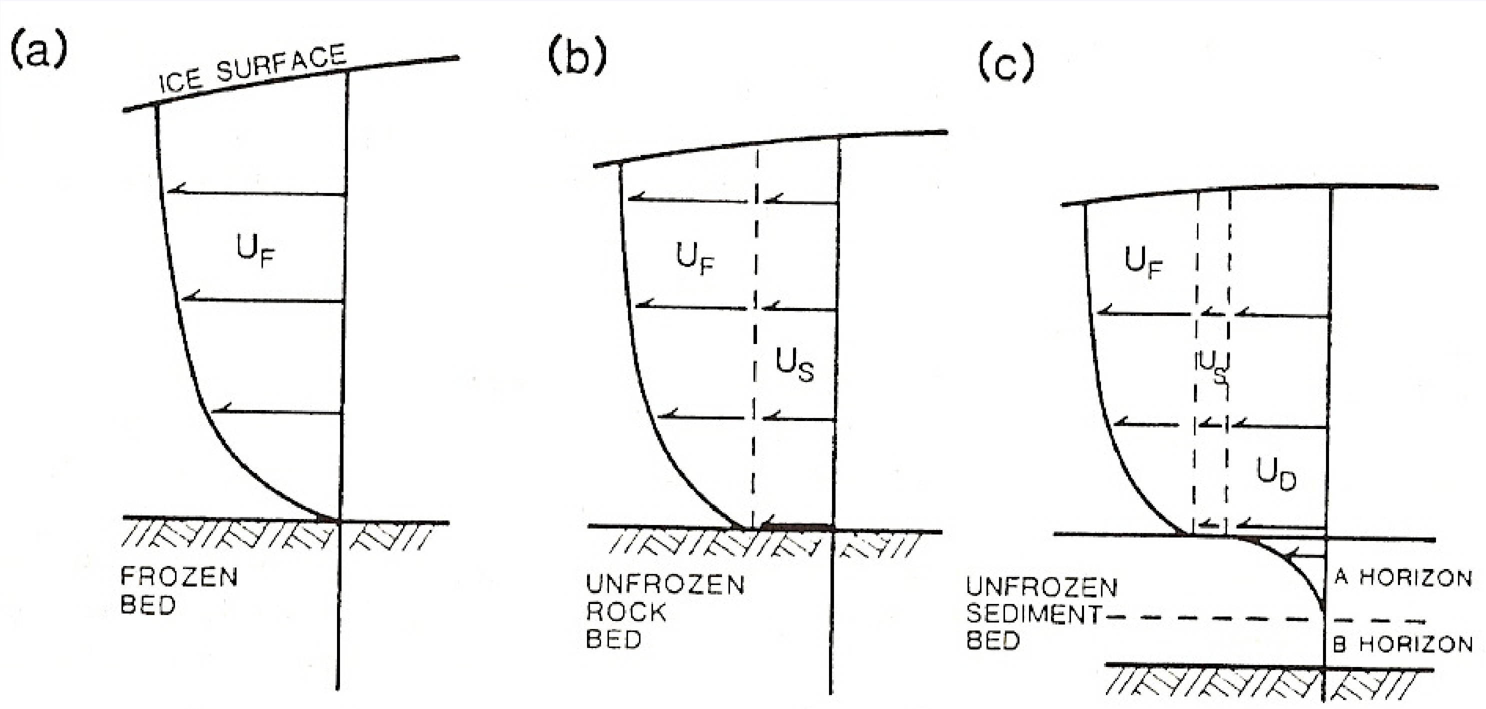
Subglacial deformation

- The subglacial deformation of sediments and soft rocks accounts for some of the forward motion of many glaciers
- Subglacial sediments behave plastically, but undergo spatially distributed deformation
  - pattern of displacement resembles a viscous material

Allows subglacial erosion and debris transport to take place…



Summary – Glacier motion and subglacial sediment transport



Ice deformation only

Ice deformation and basal sliding

Ice deformation, basal sliding and deformation of sediments

Boulton (1996) *J Glaciology*