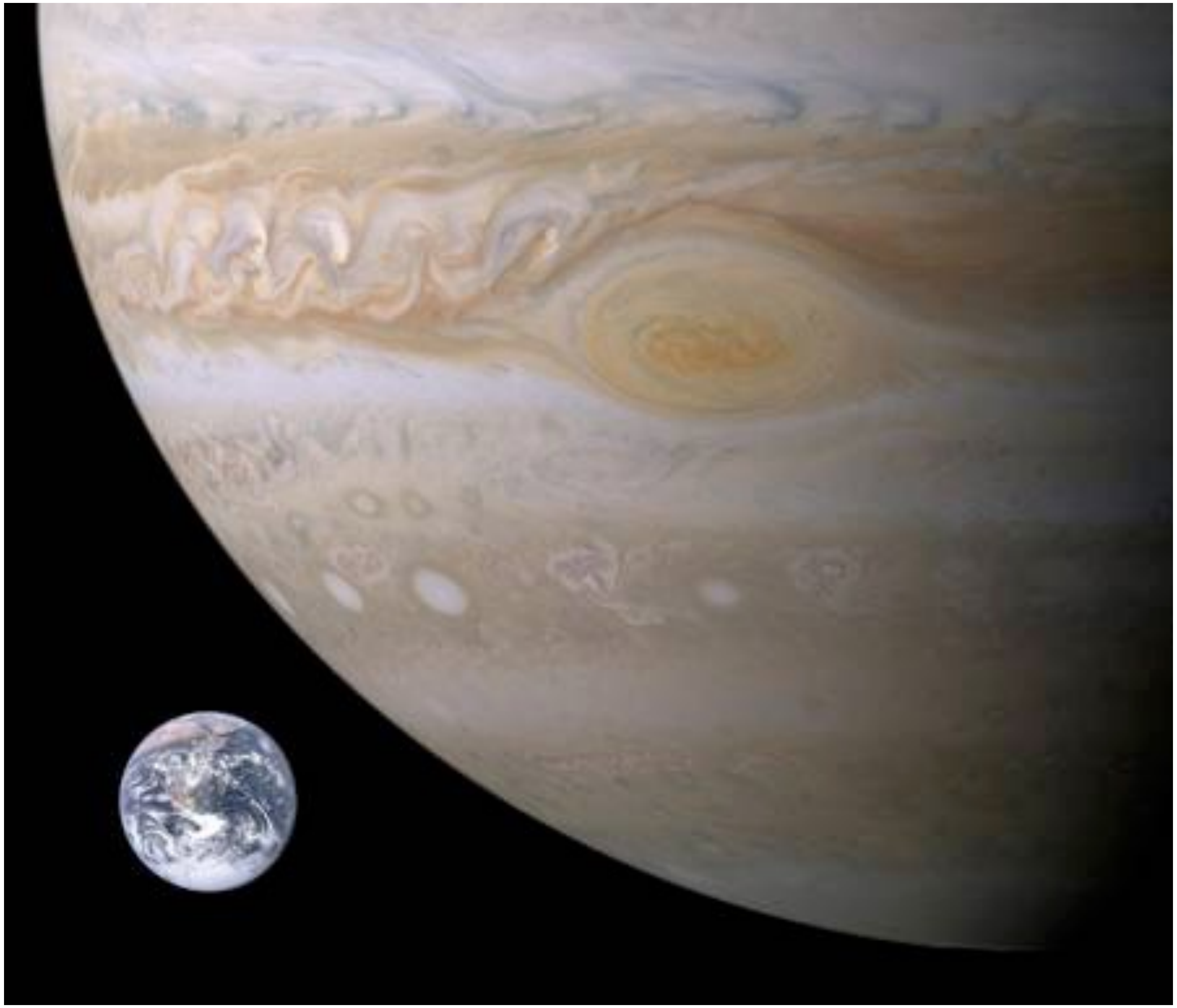
Geophysical Fluid Dynamics

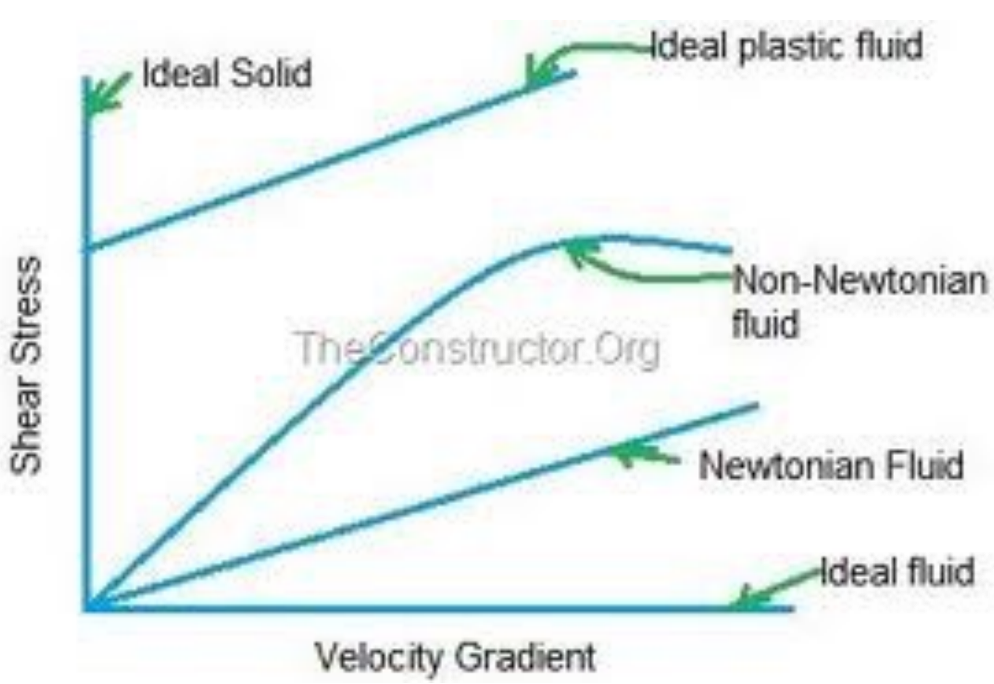
Lecture 1:
Introduction & Properties of fluids 1

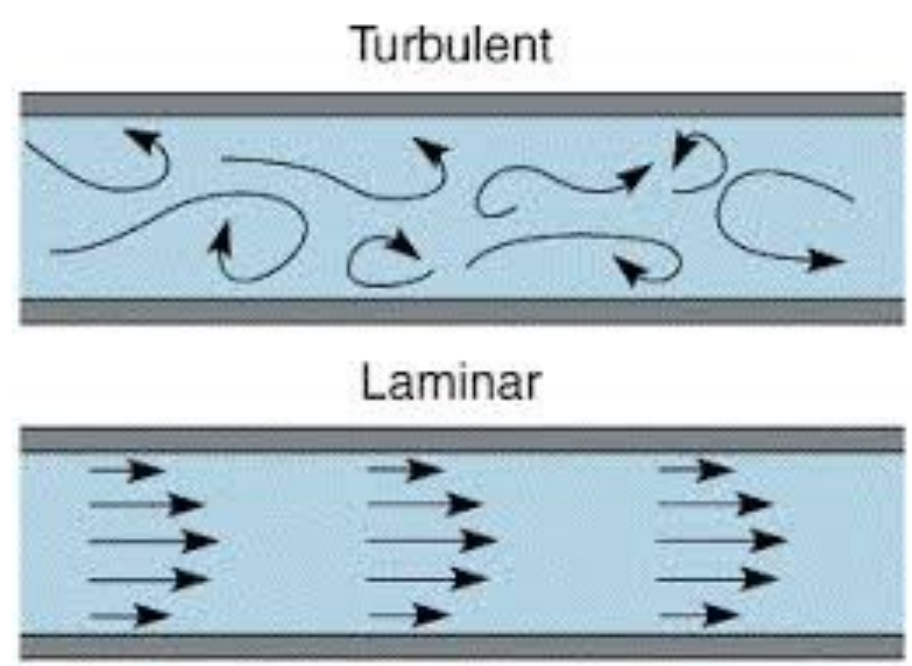
Fluids are Everywhere



a single storm eddy (the Great Red Spot) on Jupiter is larger in size than planet Earth

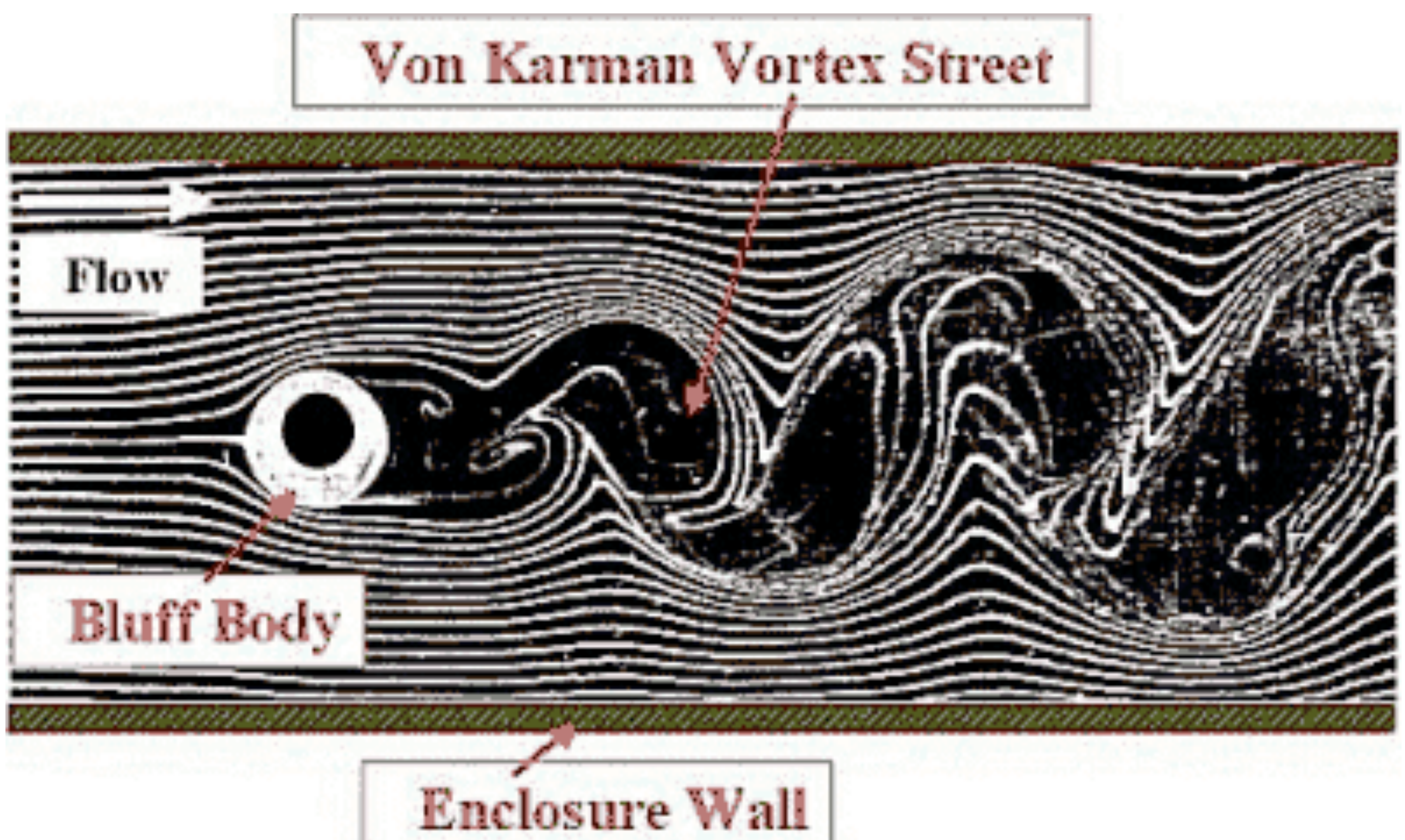
they have many useful properties ...

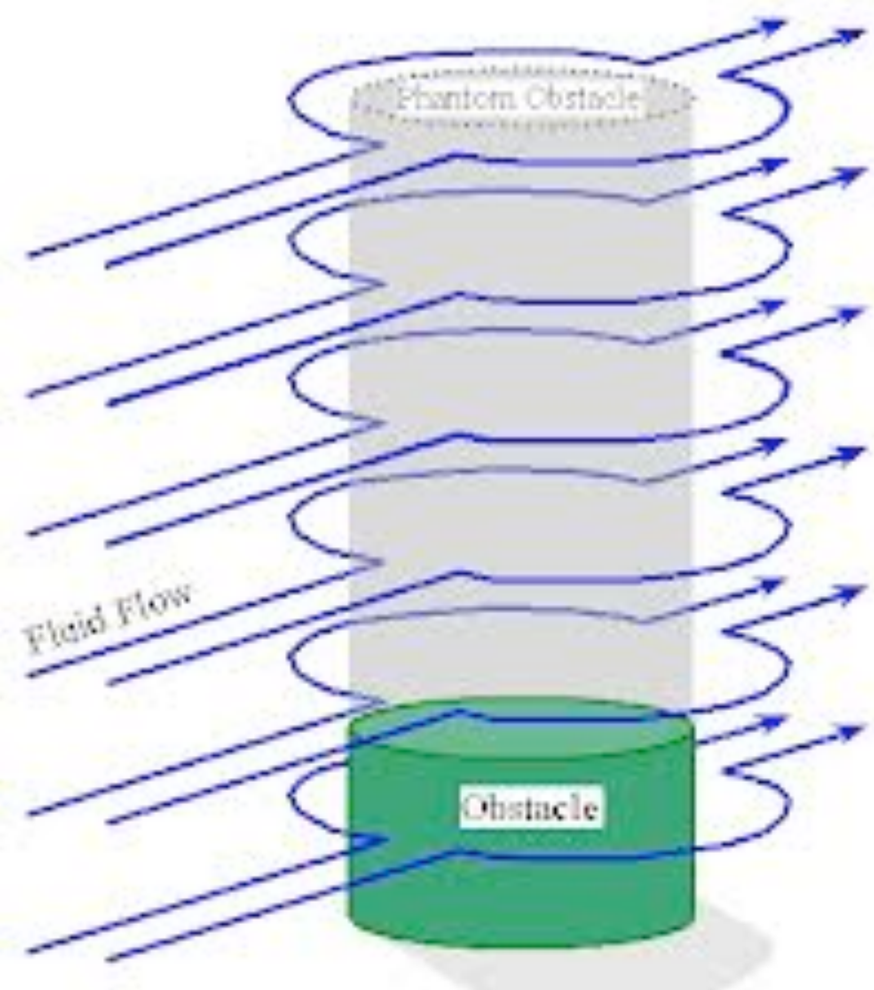




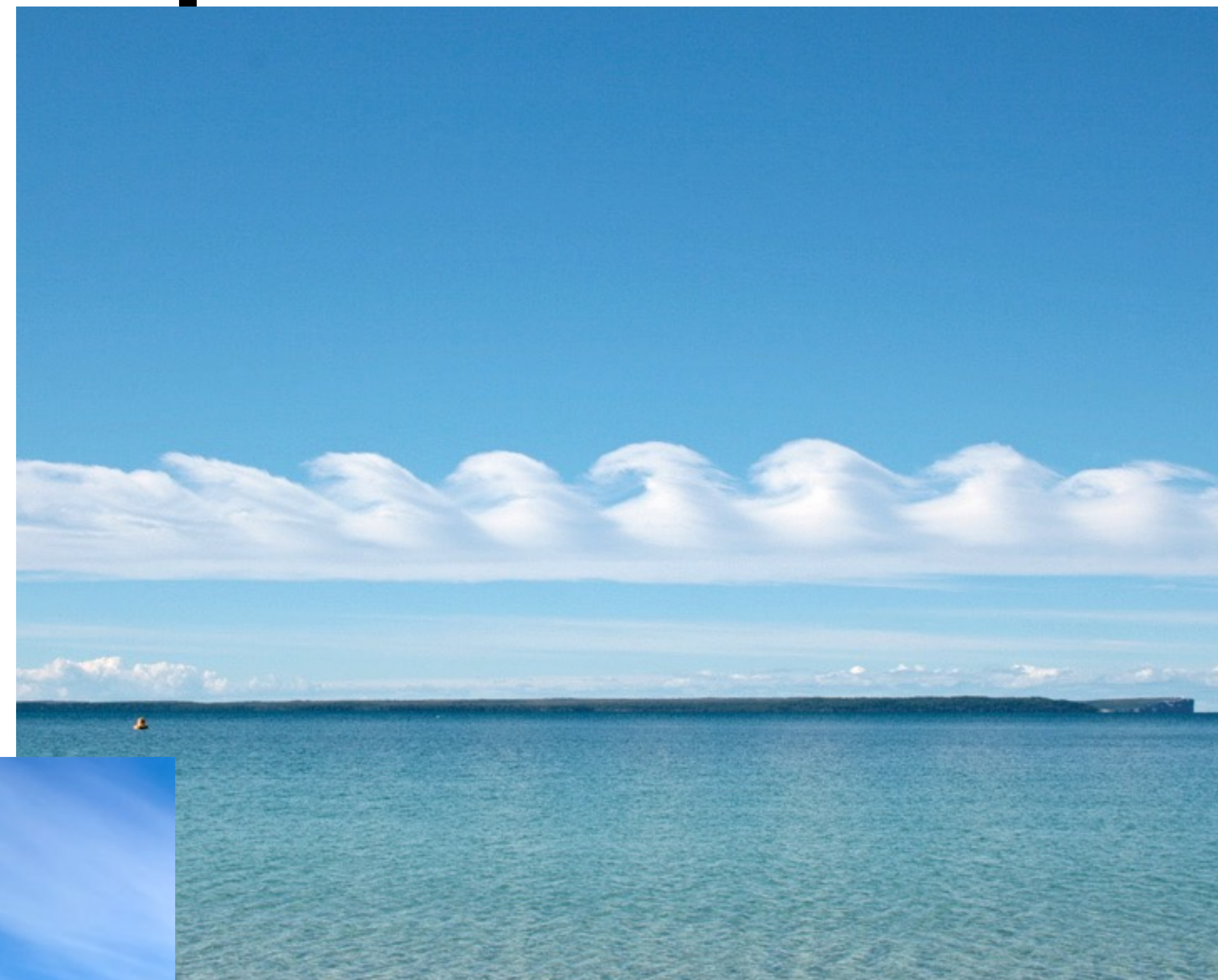
properties change with the environment

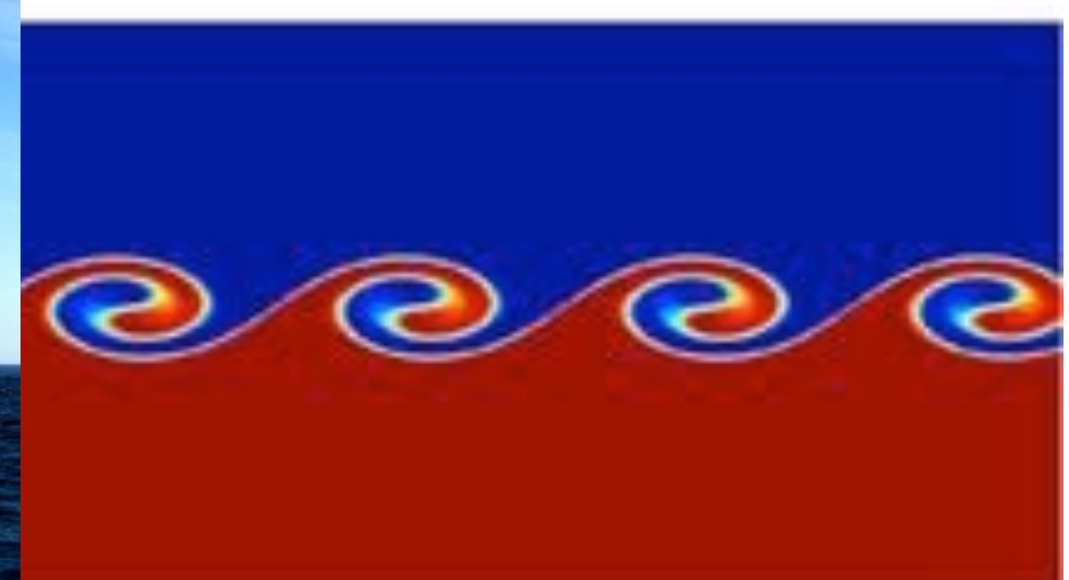
laminar & turbulent flow
boundary layers
instabilities



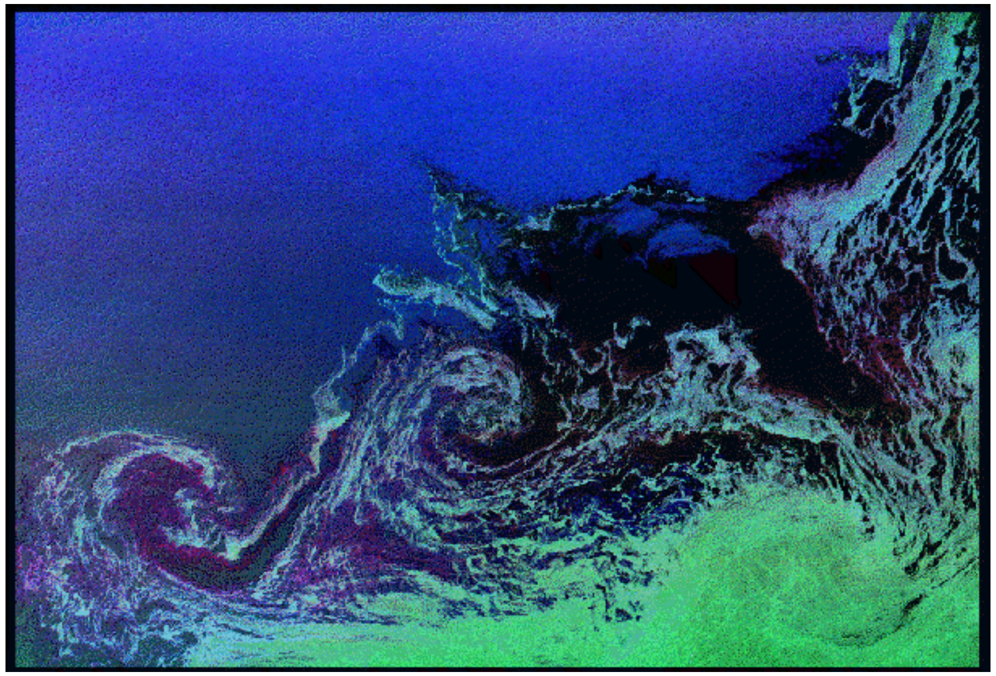


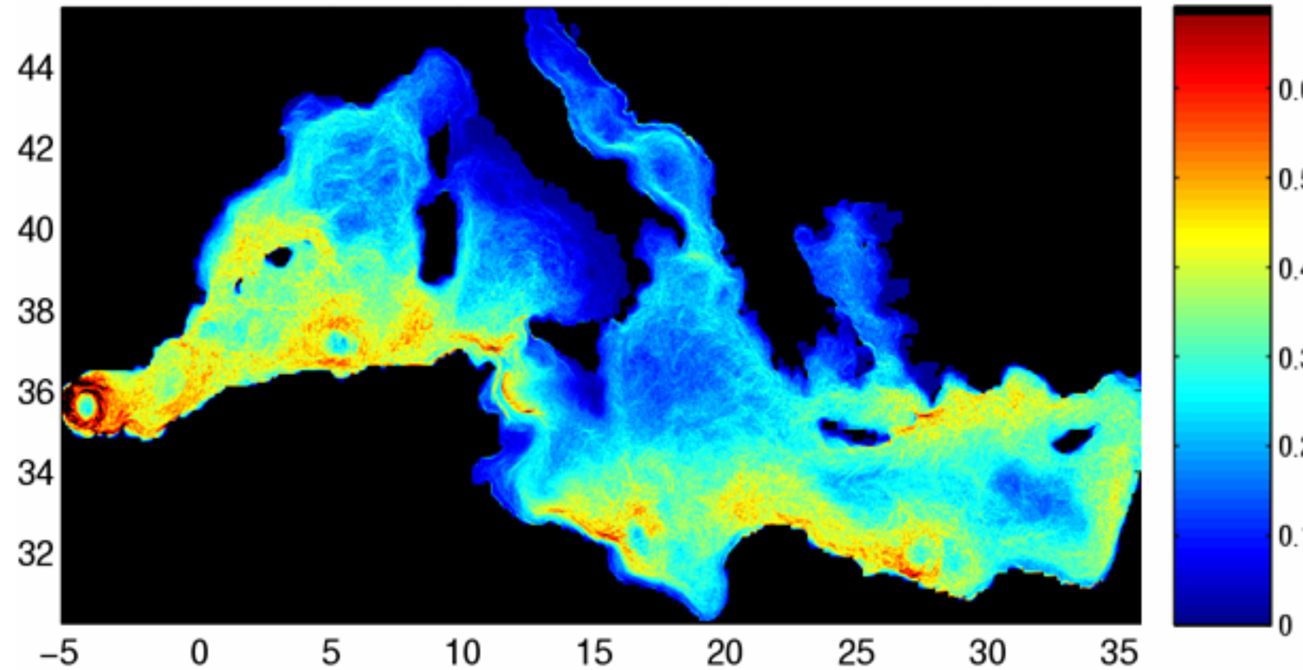
atmospheric phenomena

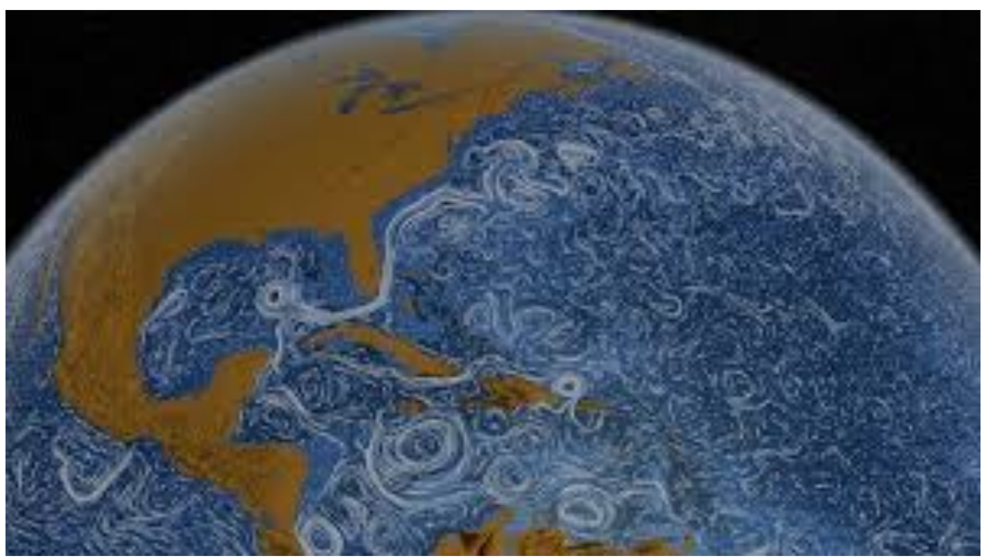


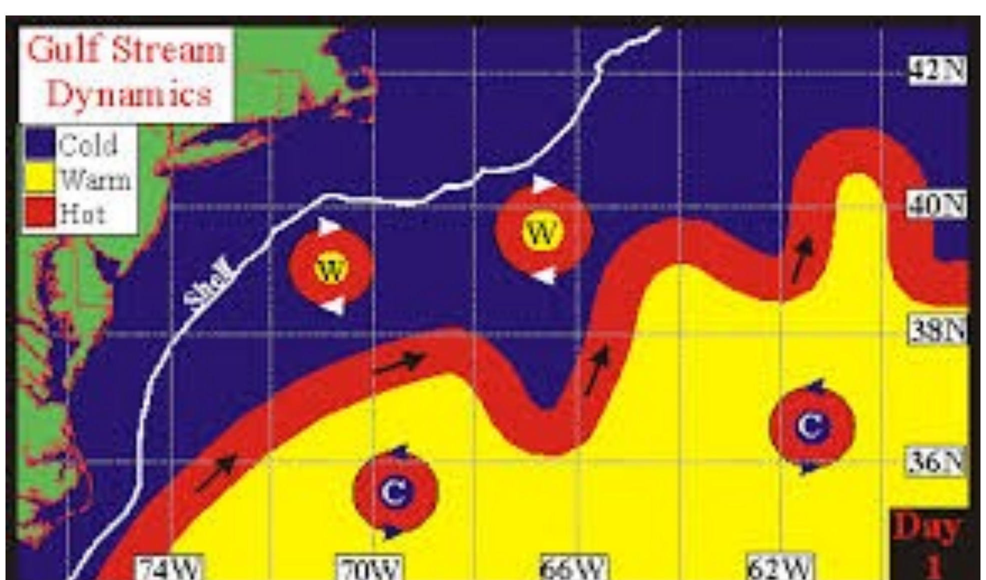


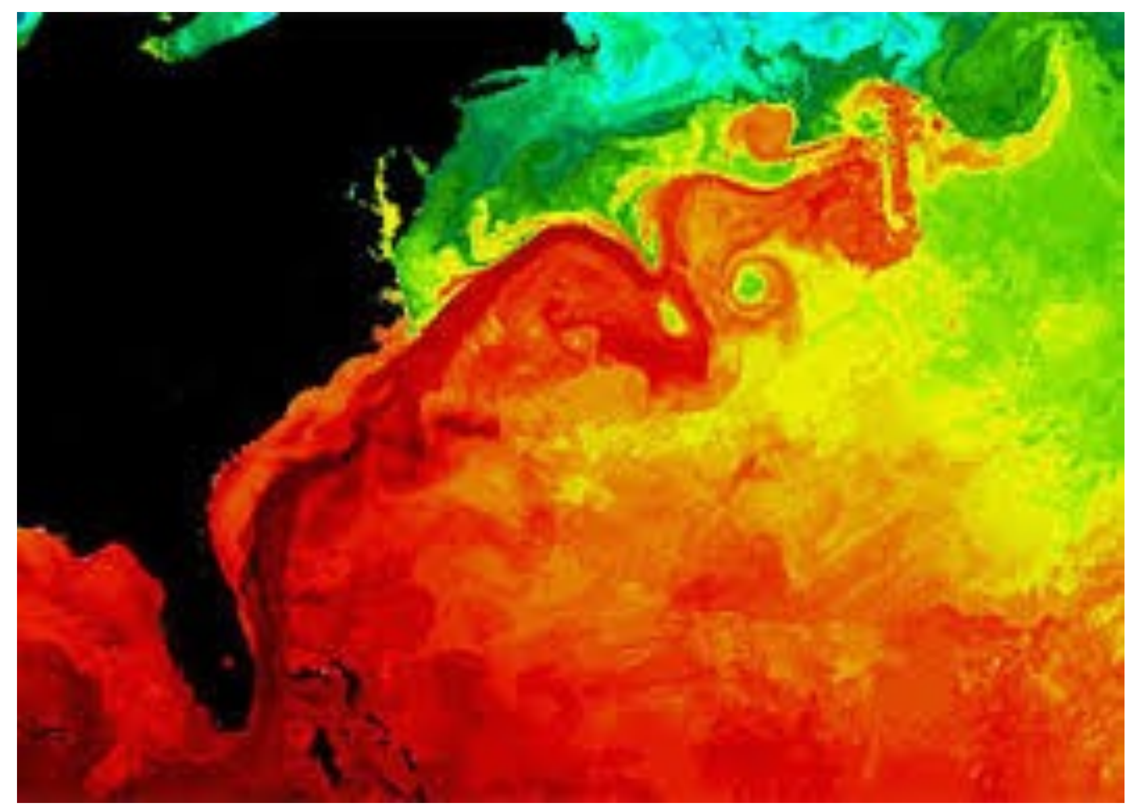
Oceanic phenomena



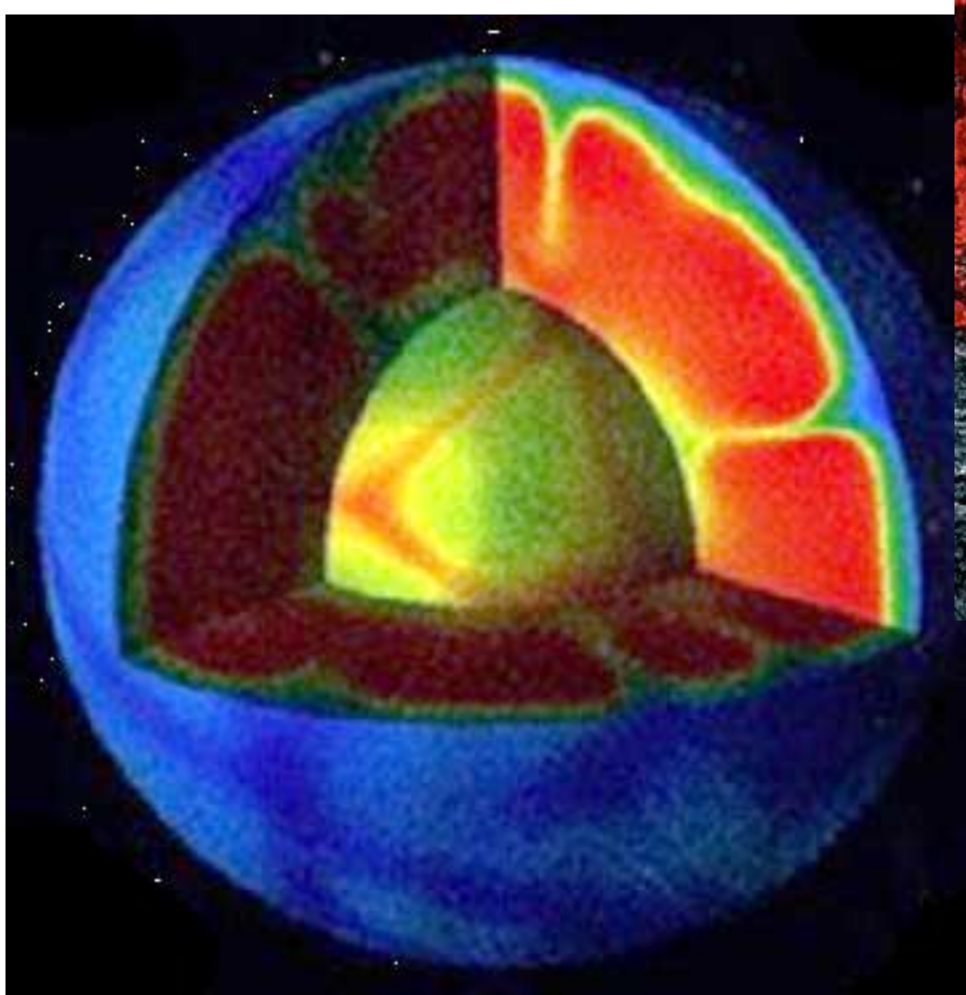








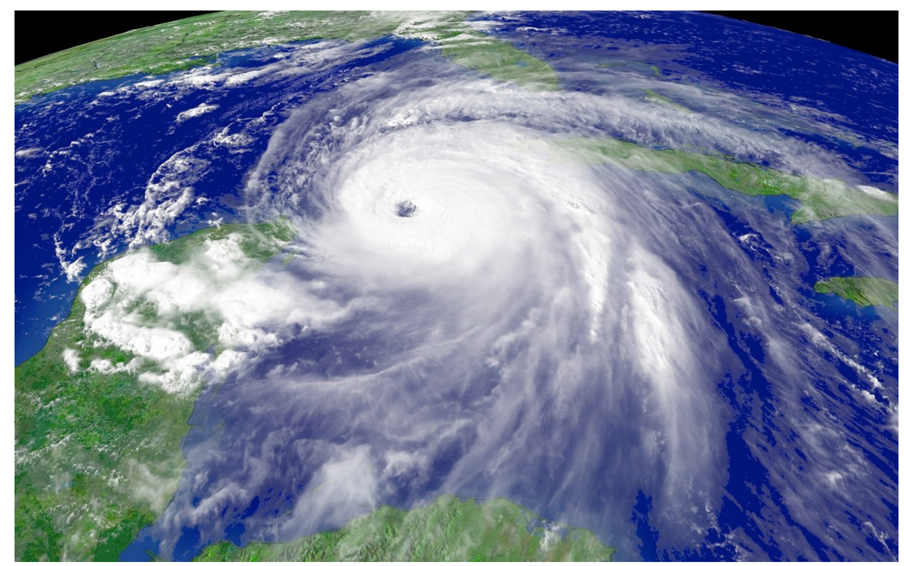
Earth Interior



What is a fluid

- water

- air

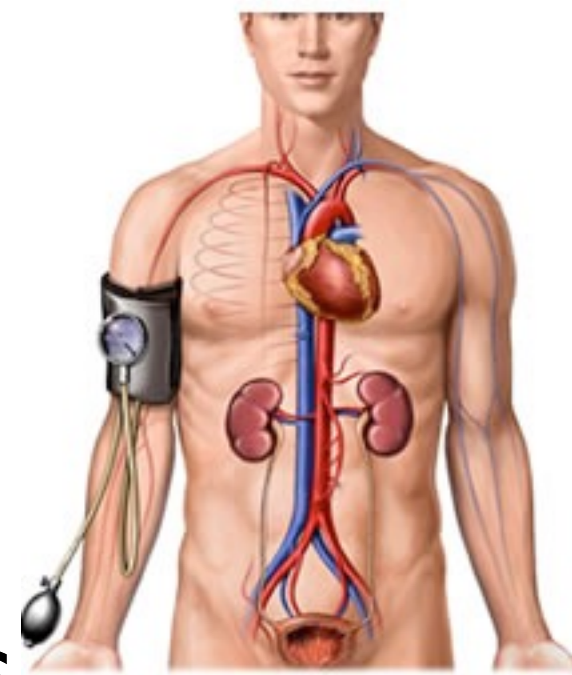


- oil

Fluid vs non-fluid

- it flows ...

- it deforms



- takes the form of its container (glass,balloon)

Scope of Fluid Mechanics:

it tries to explain fluids and their motions

- Fluids are: liquids and gases
- Engineering: flow in pipes, jets, aerodynamics, projectile motion, lubrication, irrigation, combustion
- Environmental: meteorology, oceanography, geophysics, sedimentation, irrigation
- Medicine: blood vessels

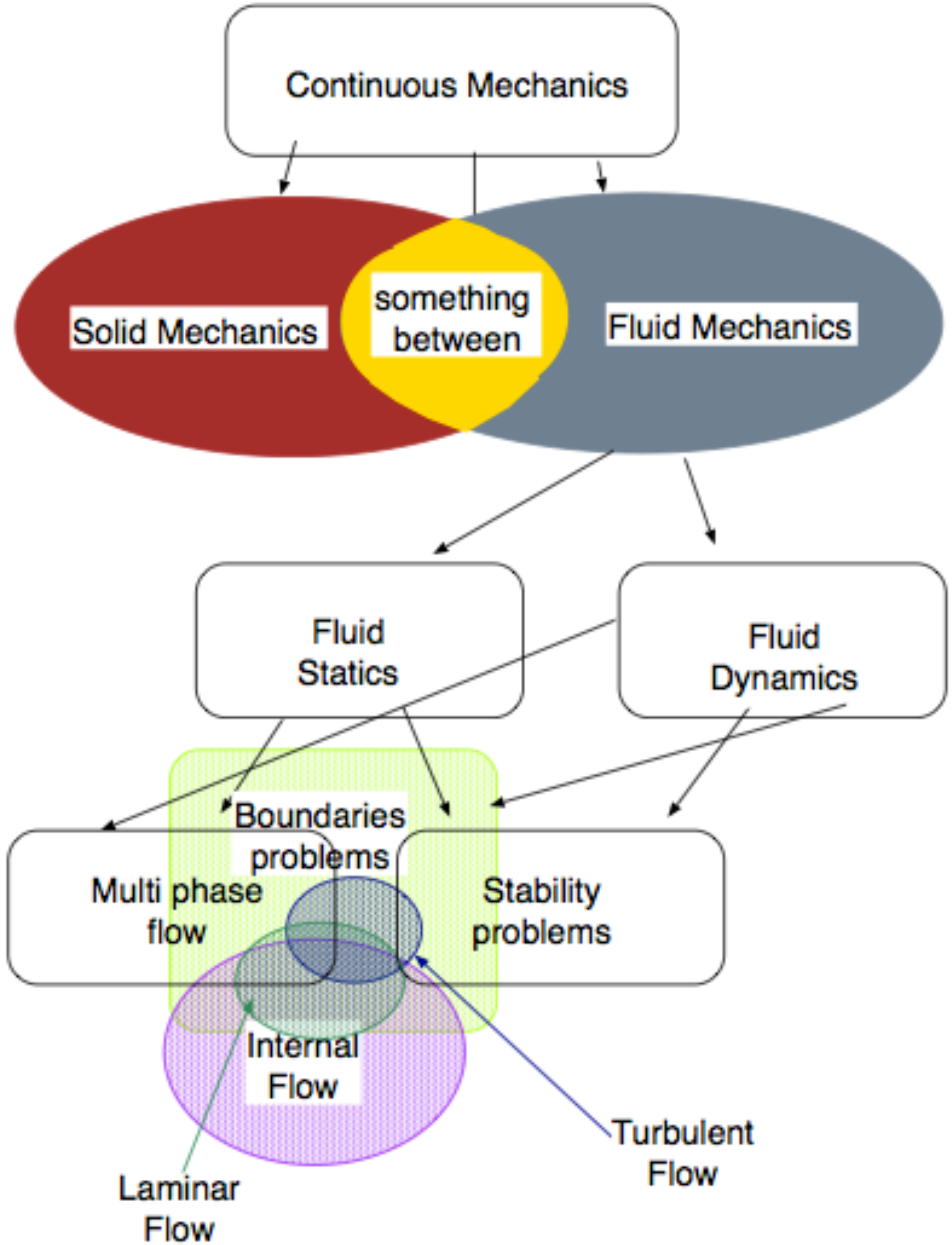


Fig. -1.1. Diagram to explain part of relationships of fluid mechanics branches.

Branches

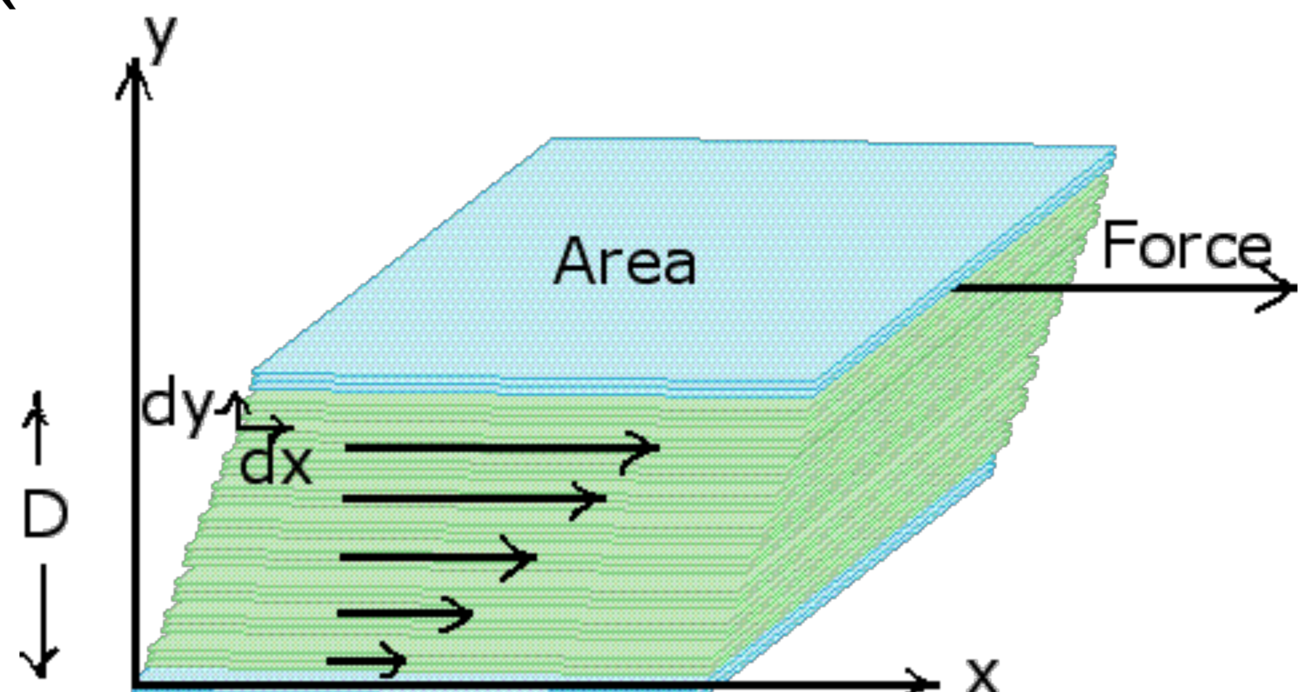
- **Statics**: fluids at rest
- **Kinematics**: velocities and streamlines
- **Dynamics**: velocity & accelerations, forces
- ... we'll get into Geophysical Fluid Dynamics

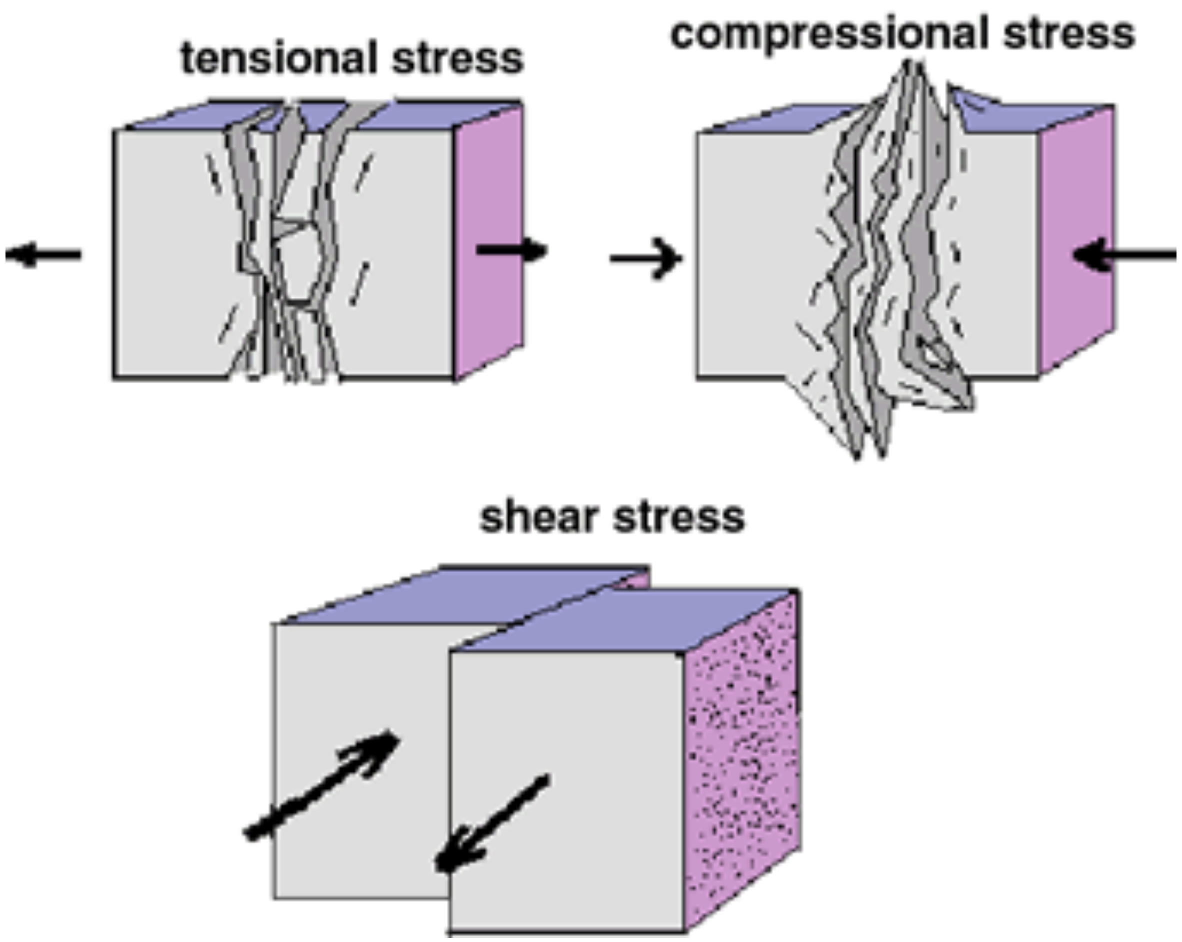
Properties of Fluids

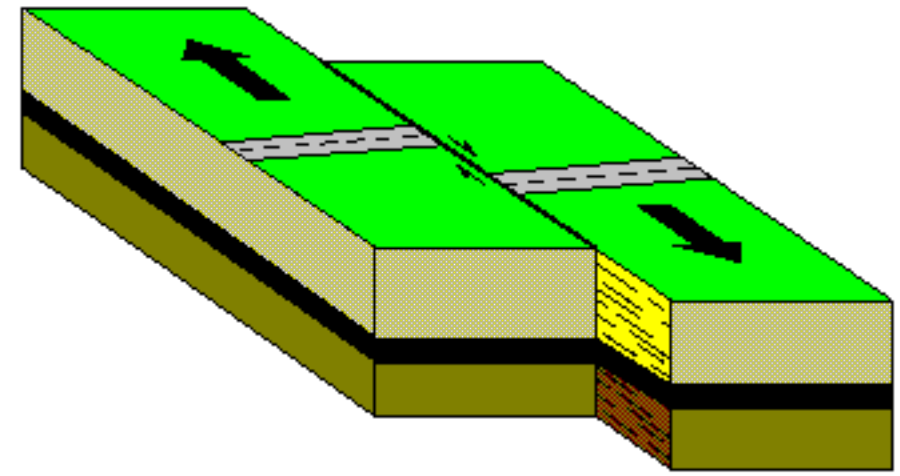
- definition of a Fluid
- dimensions and units
- mass and weight
- density and specific weight

Definition of Fluid

- A substance that deforms continuously when acted on by a shearing stress (water, air, syrup)
- SHEAR STRESS tangential force per unit area (different from a normal stress)

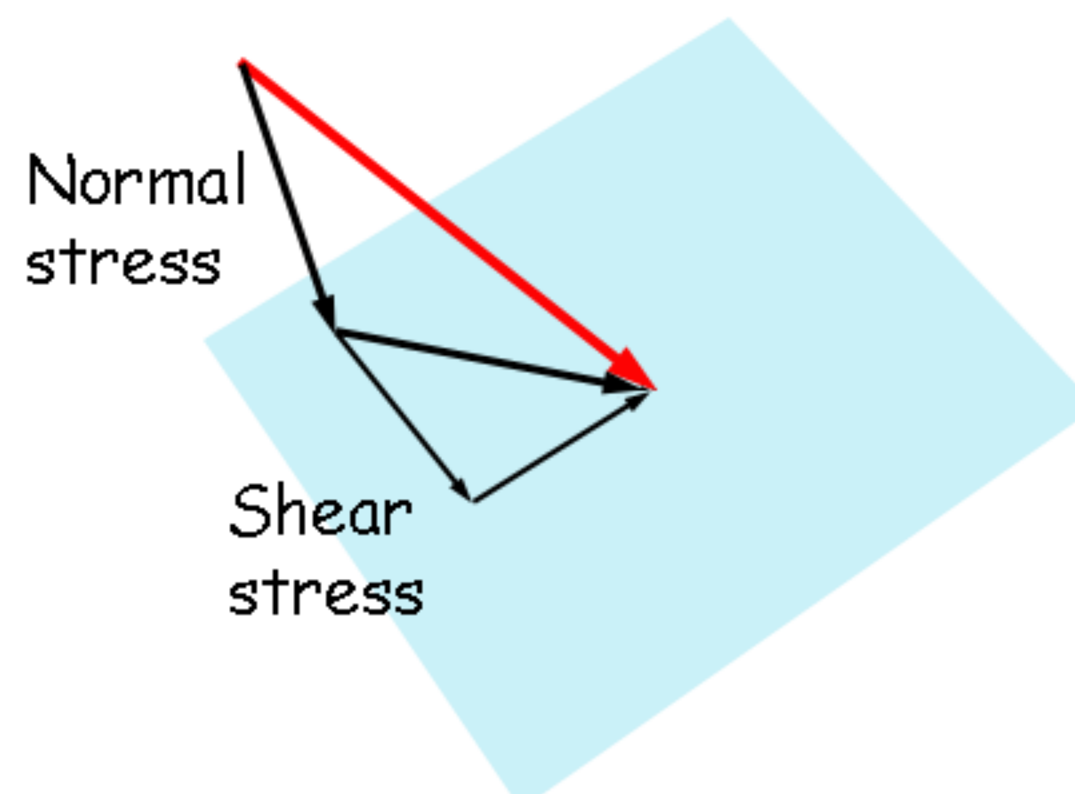






This fault is an example of shearing stress within the Earth

Stress or traction on a plane



Non-fluids

- rubber
- ice
- steal
- These are SOLID: they can deform to a new equilibrium state when shearing stress is applied. They don't flow like a liquid because of **structural rigidity**

Another definitions is

- a substance that takes the shape of the container in which it is placed

Fluids vs Non-Fluids

- FLUID: Liquid water deforms assuming shape of glass. Gravity provides the force. Balance is achieved when force by walls is balanced by force of gravity = STATICS

Fluids vs Non-Fluids

- NON-FLUID: solid ice cubes maintain shape with air gaps between the cubes. A solid will not deform.

Distinction between a Solid and a Fluid

- Molecules of solid closer together than those of fluid
- Solid: intermolecular forces larger than in fluid
- Elastic solid: 1. deforms under load 2. recovers state when unloaded
- Plastic solid: 1. deforms under load 2. does not return to original state

Distinction between a Gas and a Liquid

- Fluids: gases or liquids
- GAS: molecules farther apart; very compressible; tends to expand indefinitely
- LIQUID: relatively incompressible; does not expand if no pressure.

Distinction between a Gas and a Liquid

- VAPOR: 1. gas whose T and P very near the liquid phase 2. steam is vapour, state near that of water
- GAS: super-heated vapour, far away from liquid phase.

Dimensions and Units

- qualitative and quantitative description of fluid characteristics
- Qualitative: DIMENSIONS (length, time, velocity)
- Quantitative: a number plus a UNIT (9.8 m/s)

DIMENSIONS

- PRIMARY (basic): mass M, length L, time T or force F, length L, time T
- SECONDARY (derived): velocity [V] = L/T, acceleration [a] = L/T^2, Newton's Second Law F = [m][a] = M L/T^2

Units (S.I. Units)

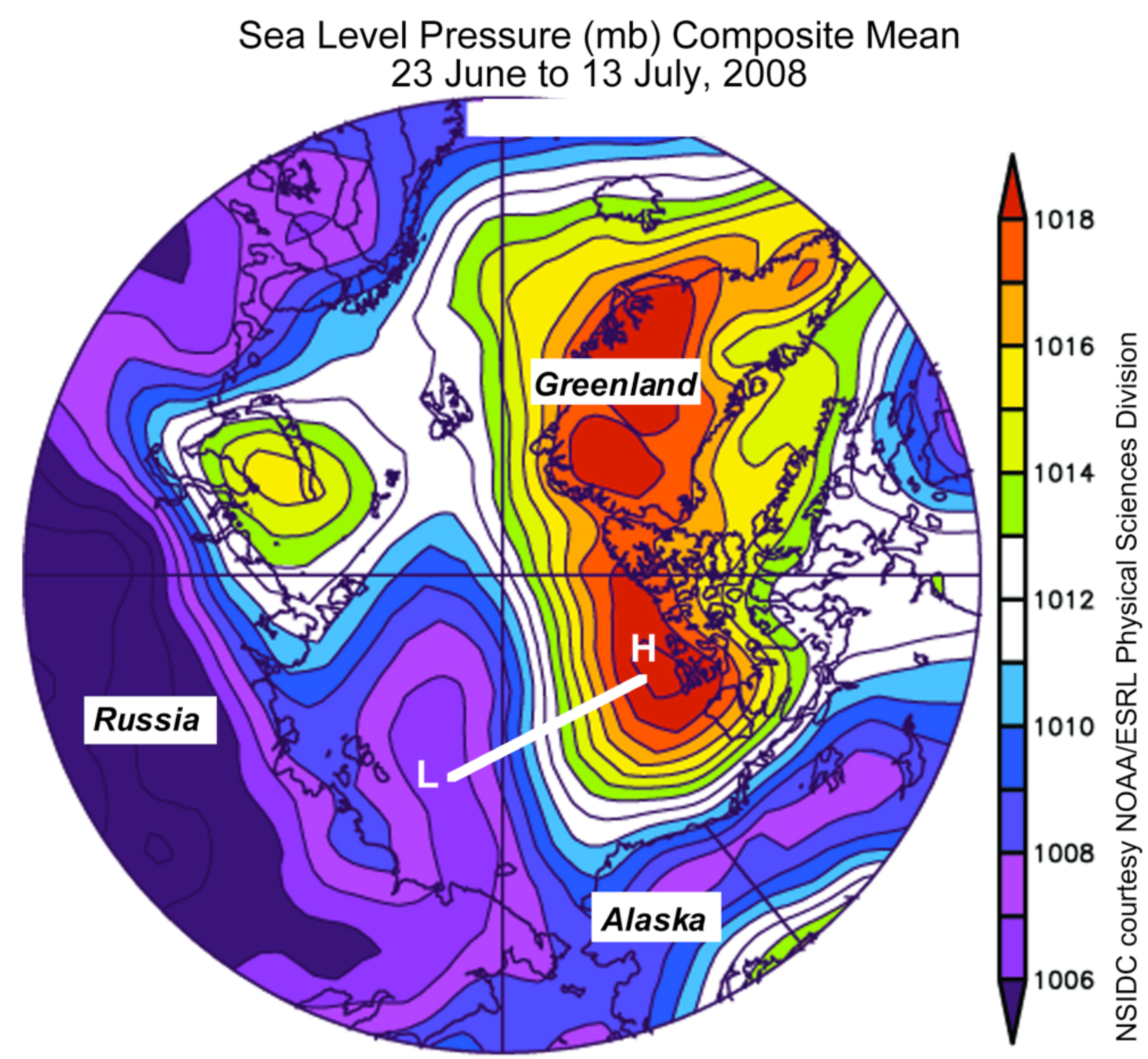
- Length (m) meter
- Mass (kg) kilogram
- Force (N) Newton (kg m/s^2)
- Time (s) second
- Temperature (K) Kelvin for absolute (-273.15 C)
- Temperature (C) Celsius for ordinary

Mass and Weight

- Weight, W = m g (g gravitational acceleration = 9.81 m/s^2)
- W = mg = (1 kg) (9.81 m/s^2) = 9.81 N
- same mass different weight for 2.5 kg of water
- On Earth: W = (2.5kg)(9.81 m/s^2) = 24.53 N
- On Moon: W = (2.5kg)(9.81 m/s^2)/6 = 4.087 N

Properties of Fluids: Density

- Density rho = M / V (mass per unit volume)
- Density can vary :
- from one fluid to another
- with temperature and pressure rho=f(T,P)
- in space



Densities of common Fluids

- water 1000 kg/m^3
- seawater 1030 kg/m^3
- crude oil 800 kg/m^3
- air 1.2 kg/m^3
- helium 0.166 kg/m^3

Perfect gases

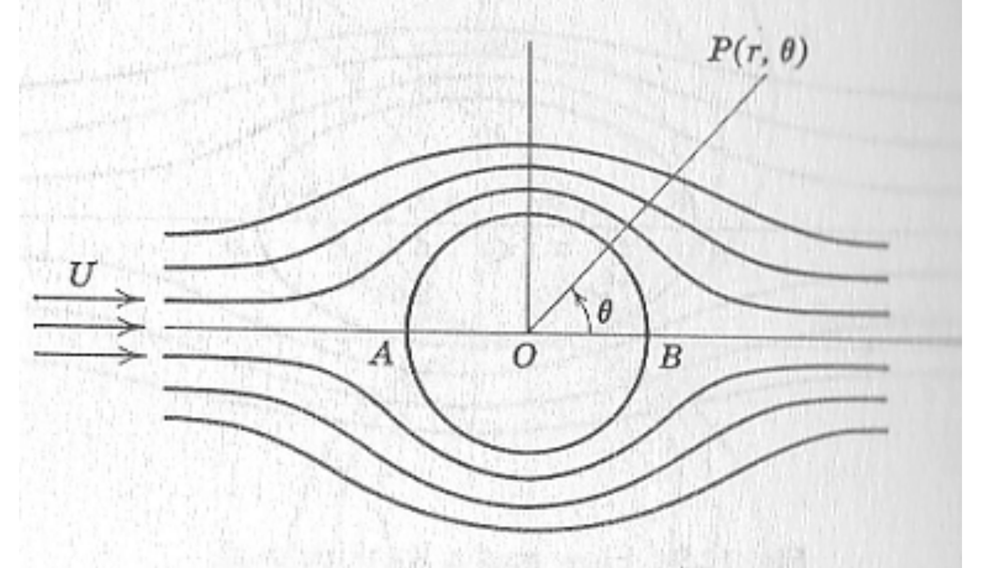
Gases with constant Specific Heats that obey the perfect-gas law

p/rho = R T

<u>Remember that:</u> The Specific Heat is the amount of HEAT per unit mass required to raise the temperature by one degree Celsius: Q = c m Delta T

heat = (specific heat)(mass)(change in T)

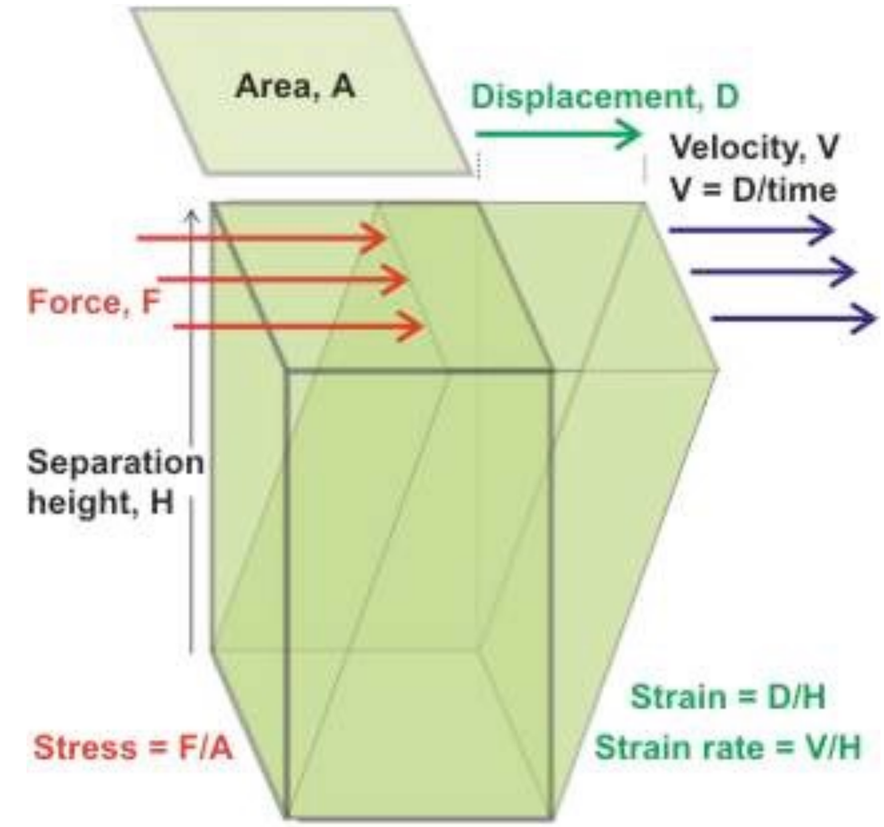
Ideal Fluids



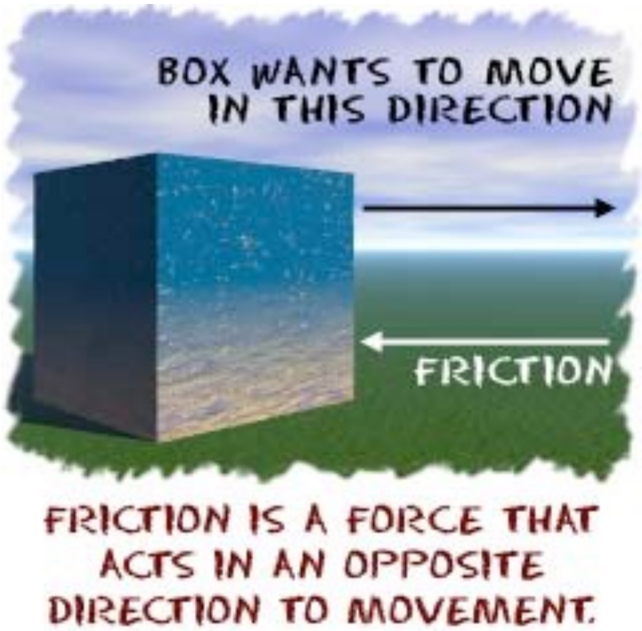
- a fluid with no friction
- said to be an 'inviscid fluid' (zero viscosity)
- internal forces at any section are normal (pressure forces)
- Many flows are almost frictionless flow away from solid boundaries (some GFD approx.)
- Do not confuse ideal fluid with a perfect gas
- Steady - incompressible - nonviscous - irrotational

Ideal fluid is only an imaginary fluid as all the fluids which exists have some viscosity

Real Fluids



- Tangential or shearing forces always develop where there is motion relative to solid body
- fluid friction is created
- Shear forces oppose motion of one particle past another
- Friction forces give rise to a fluid property called VISCOSITY



Remember: Shear is a sideways force. Friction is drag - from any direction.

Viscosity

- Definition of viscosity
- how shear stress and velocity are related
- Newton's law of viscosity
- how to determine shear stress in viscous fluid flow
- values of viscosity for different fluids

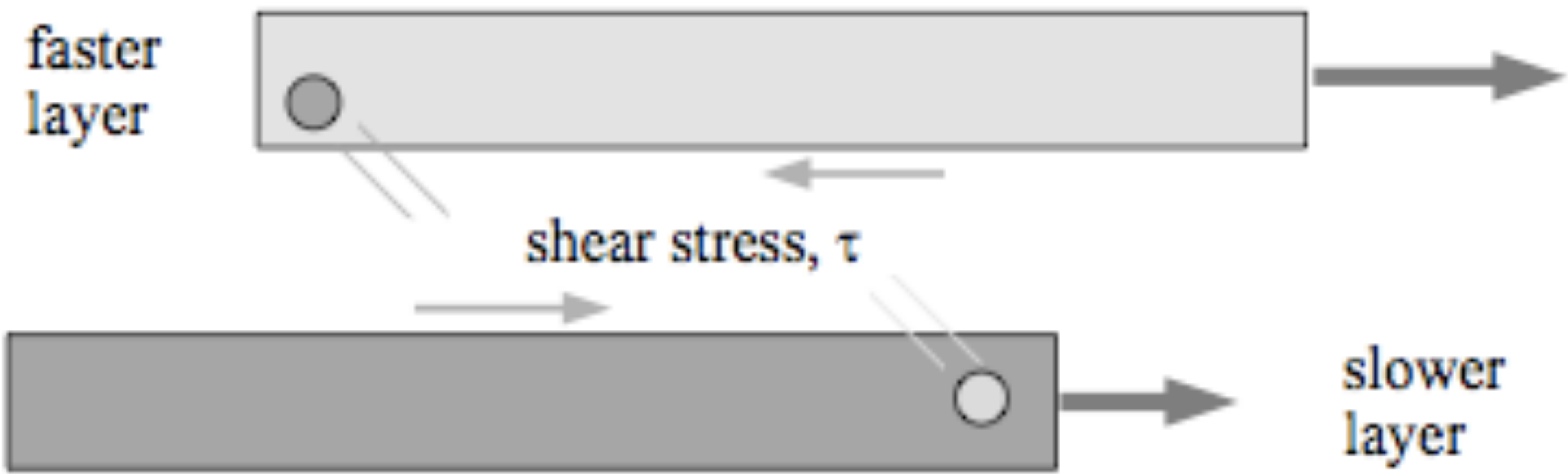
Viscosity

Viscosity is a measure of the resistance of a fluid to being deformed by a shear stress.

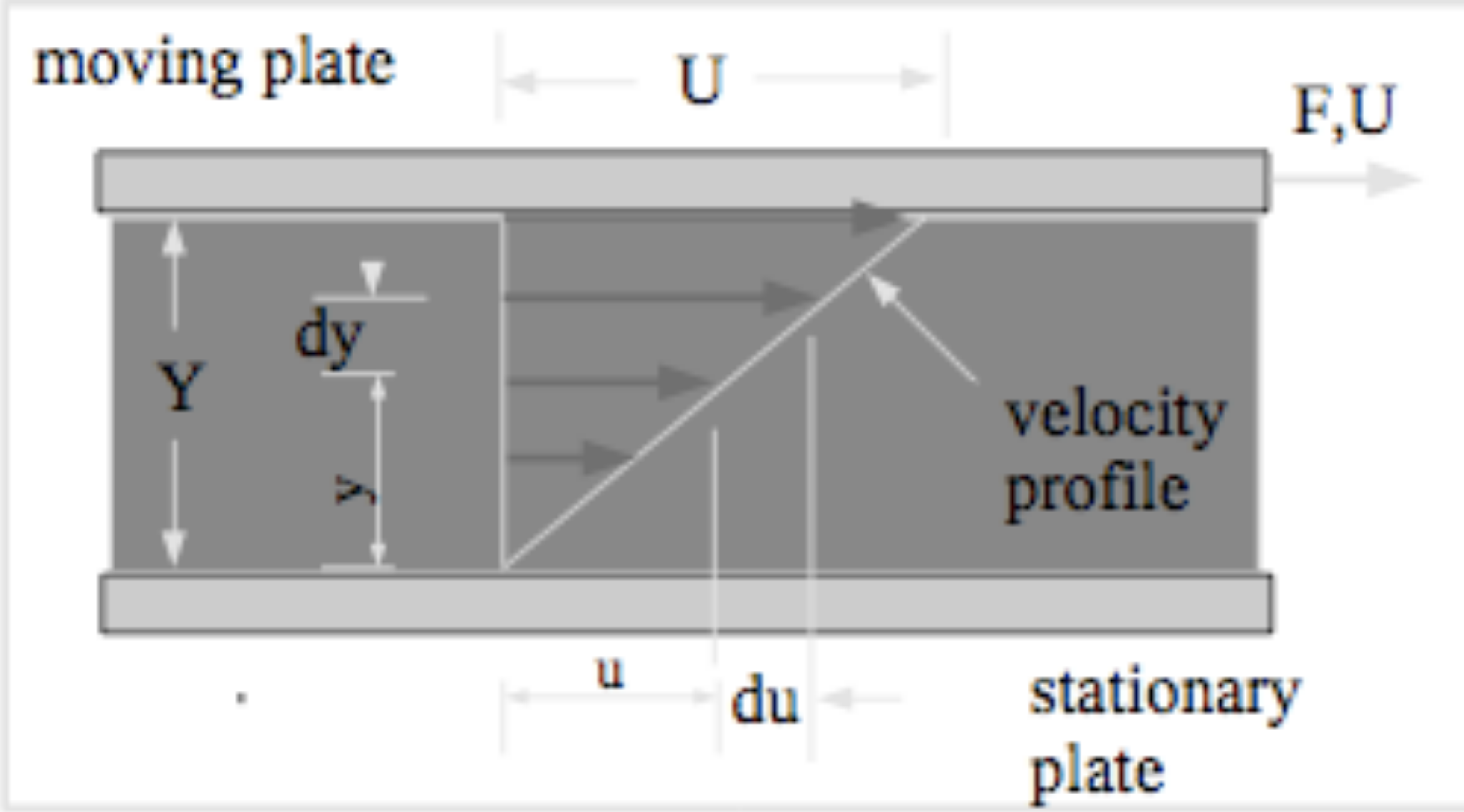
Fluids with low viscosity are ‘thin’ and are easily deformed by a small shear stress.

Fluids with high viscosity are ‘thick’ and need higher shear stress to deform.

Velocity and shear stress (to define viscosity)



- fast-moving molecule into slow-moving layer: speeds up the layer
- slow-moving molecule into fast-moving layer: slows down the layer



Shear stress is:

$$\tau = F/A$$

Experiments show that:

$$F \sim AU/Y$$

- Fluid particles adhere to walls: *no-slip condition*
- U(bottom) = 0; U(top) = U
- For small U and Y, velocity profile is linear (and no net flow)

$$\tau \propto U/Y$$

$$\tau = \mu du/dy$$

Newton's law of viscosity

shear stress is proportional to the velocity gradient

For an incompressible and isotropic Newtonian Fluid:
shear stress = shear viscosity x velocity gradient

$$\tau = F/A = \mu du/dy$$

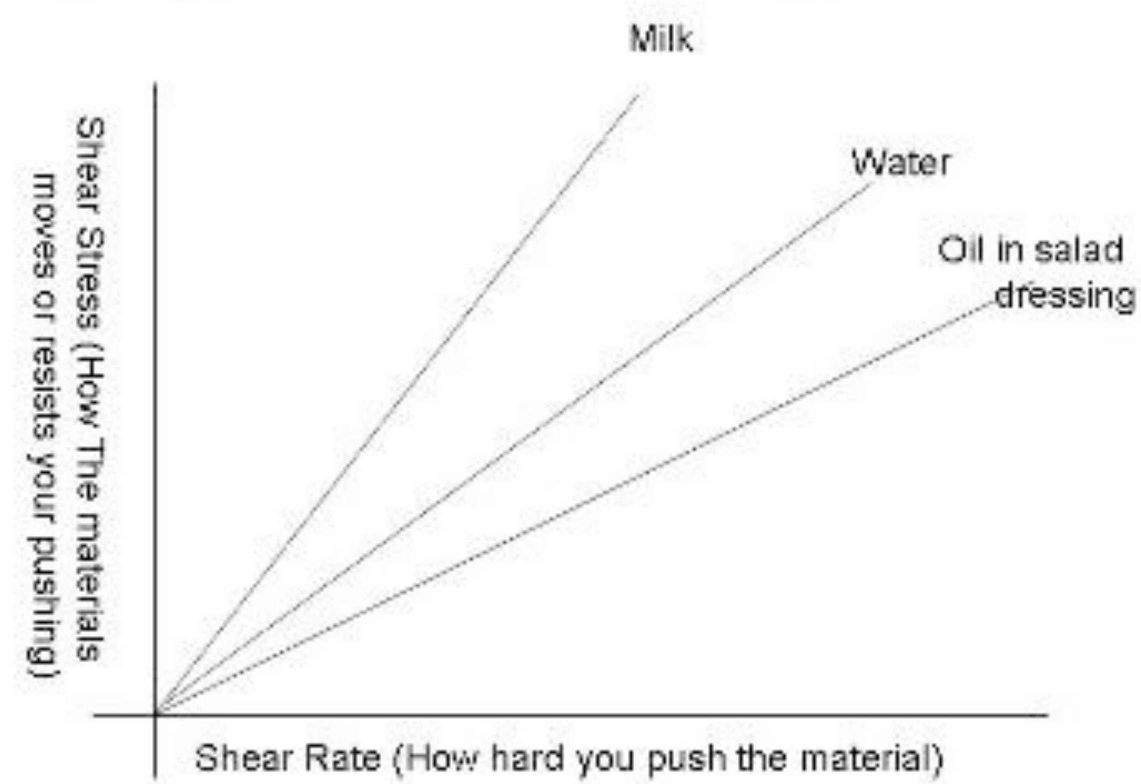
proportionality constant = viscosity coefficient

Newtonian Fluid

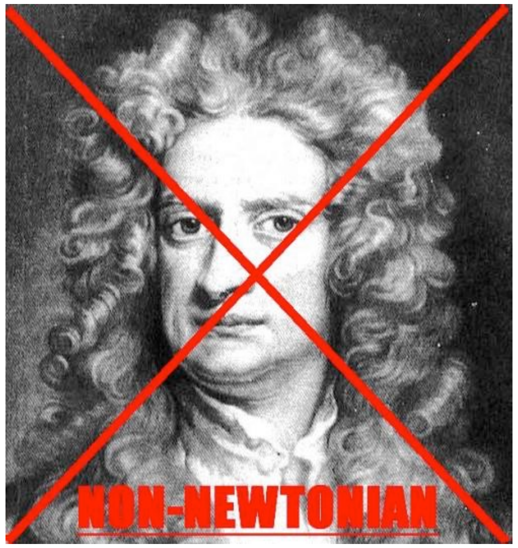
- Obeys Newton's Law of Viscosity
- velocity gradient = shear rate $$\tau = \mu du/dy$$
- slope = viscosity (constant)

Units: (N/m^2) / (m/s / m) = N s / m^2

Examples of Newtonian Fluids



Non-Newtonian Fluids



Examples: paint, blood, lava, water-corn starch.

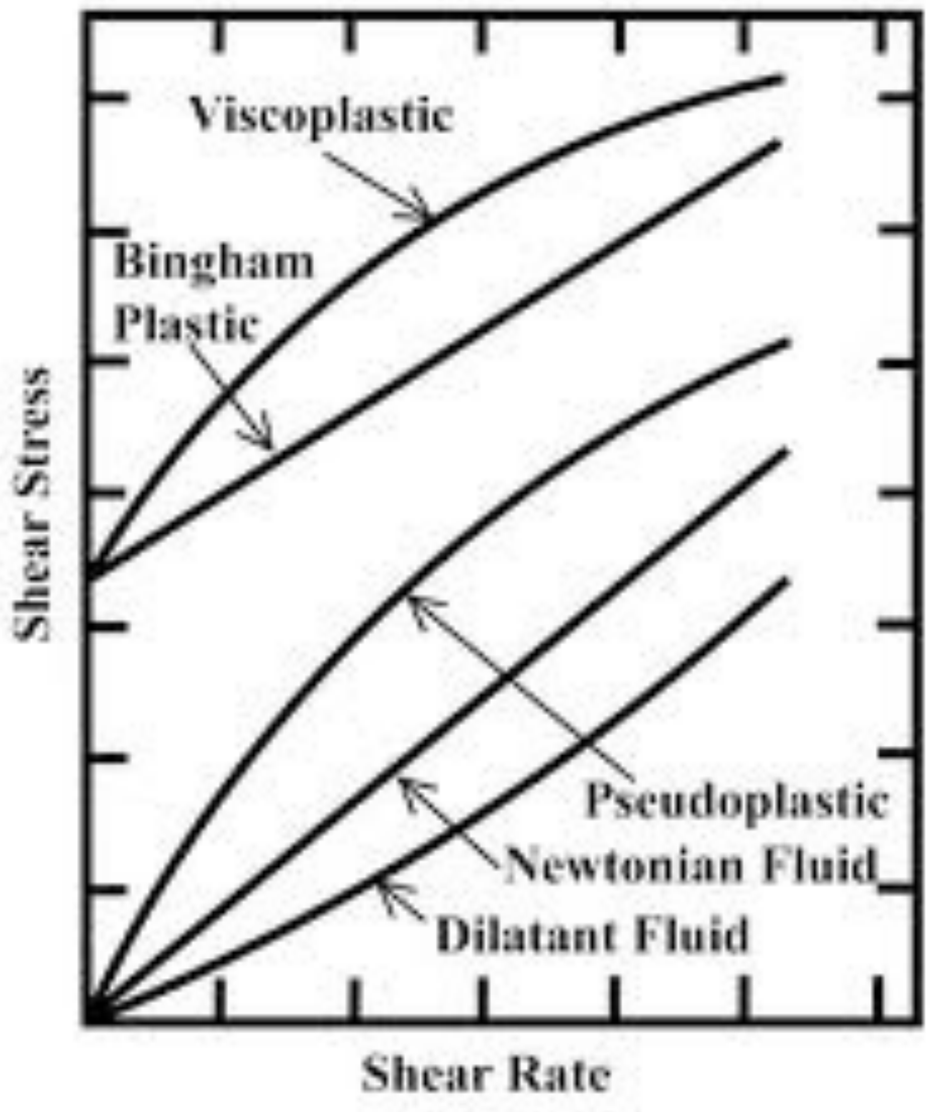
- viscosity depends on shear rate

$$\mu = f(du/dy)$$

- shear thinning (pseudoplastic: paints, ketchup)
- shear thickening (dilatant: corn starch)
- Bingham Plastic: not a solid, not a fluid (toothpaste, mayonnaise)

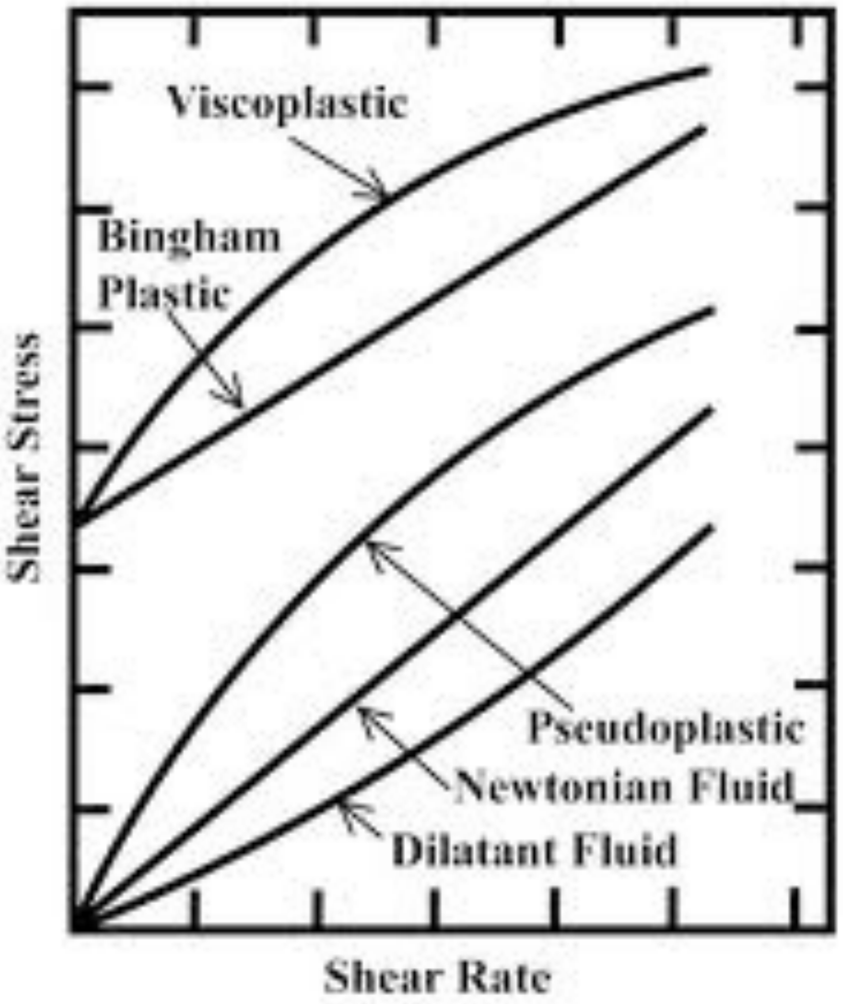
When stress is applied to the liquid it exhibits properties of a solid.

VIDEO



- **Shear thinning** is an effect where a fluid's <u>viscosity</u>—the measure of a fluid's resistance to flow—decreases with an increasing rate of <u>shear stress</u>. Another name for a shear thinning fluid is a **pseudoplastic**. This property is found in certain complex solutions, such as <u>**lava**</u>, <u>ketchup</u>, <u>whipped cream</u>, <u>blood</u>, <u>paint</u>, and <u>nail polish</u>

LAVA

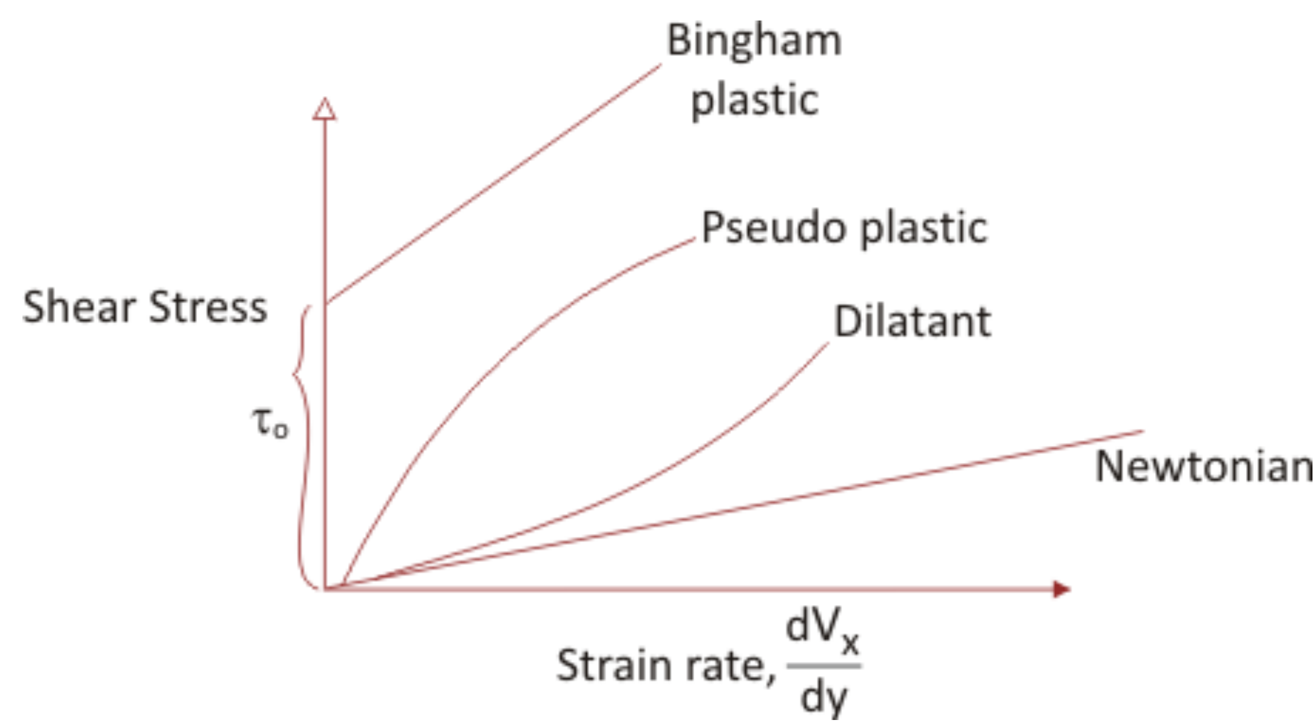


Dynamic / Kinematic Viscosity

- Dynamic viscosity [N s/(m^2)]
- Kinematic viscosity [m^2/s]
- dynamic useful for most fluids because independent of pressure
- kinematic for gases since it changes with pressure (changes in density)
- what is \mu for an ideal fluid?

$$\tau = \mu du/dy$$

$$\nu = \mu/\rho$$



Summary

- Viscosity is an important fluid property
- It causes fluid to stick to a surface, creates boundary layers
- Newton's law of viscosity: TAU is proportional to fluid mu and the velocity gradient
- Newtonian vs No-Newtonian
- liquid have high viscosity
- gases have low viscosity