
بسم الله الرحمن الرحيم

GPH 301

Geophysical Exploration

Dr. Sattam Abdulkareem Almadani

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- Ph.D. (2011) Geophysics, Missouri University of Science & Technology (MST), Rolla, Missouri, USA.
- M.S. (2003) Marine Physics, King Abdulaziz University (KAAU), Jeddah.
- B.S. (1999) Marine Physics, King Abdulaziz University (KAAU), Jeddah.

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Meeting Time:

Sun Tue 1:00 – 1:50 pm

Credits:

3 hours (2+1)

Reference Books:

- An introduction to geophysical exploration (3rd edition) - P. Keary, M. Brooks, and I. Hill, Blackwell Publishing, 2002. ISBN: 0-632-04929-4
- Introduction to applied geophysics: Exploring the shallow subsurface - H.R. Burger, A.F. Sheehan, and C.H. Jones, W.W. Norton and Company, 2006. ISBN: 0-393-92637-0

Course Description:

Magnetic and gravity exploration, Geoelectric methods, Electrical resistivity, Self-potential and induced polarization, Electromagnetic methods, Seismic methods, Seismic reflection and refraction methods, Seismology, Ground penetrating radar, Radioactive and thermal methods.

Grades:

■ Attendance	5%
■ Participation	5%
■ Homework	10%
■ Lab	20%
■ 1st Midterm Exam	10%
■ 2nd Midterm Exam	10%
■ Final Exam	40%

Course Topics:

- ❑ Fundamental Considerations
- ❑ Seismic Refraction Method
- ❑ Seismic Reflection Method
- ❑ 1st Midterm Exam
- ❑ Earthquake Seismology
- ❑ 2nd Midterm Exam
- ❑ Electrical Method
- ❑ Gravity Prospecting
- ❑ Magnetic Method
- ❑ Final Exam

What I need from you:

- Your attendance:
  - Never to be late more than 10 minutes before lecture
  - Never play with your cell phone while giving lecture.
  - Never talk to your friend while giving lecture.
  - Never miss more 25% of the total lectures.
- Your participation:
  - Involve in all group discussions and activities.
  - Write down all important information in your notebook.
- Homework assignments:
  - Answer all your homework assignments on-time.
  - Never cheat from others.

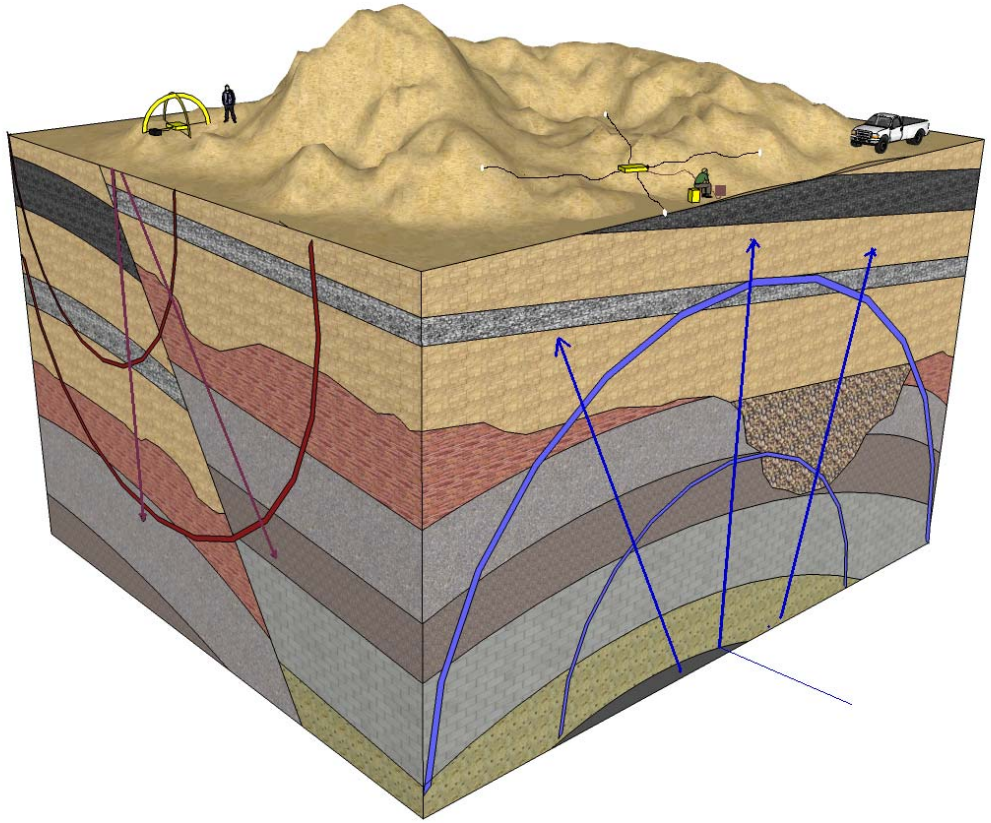
My advice to you:

- Group study.
- Ask questions.
- Don't copy.
- Arrange your time.
- Always prepare a plan to achieve your targets.

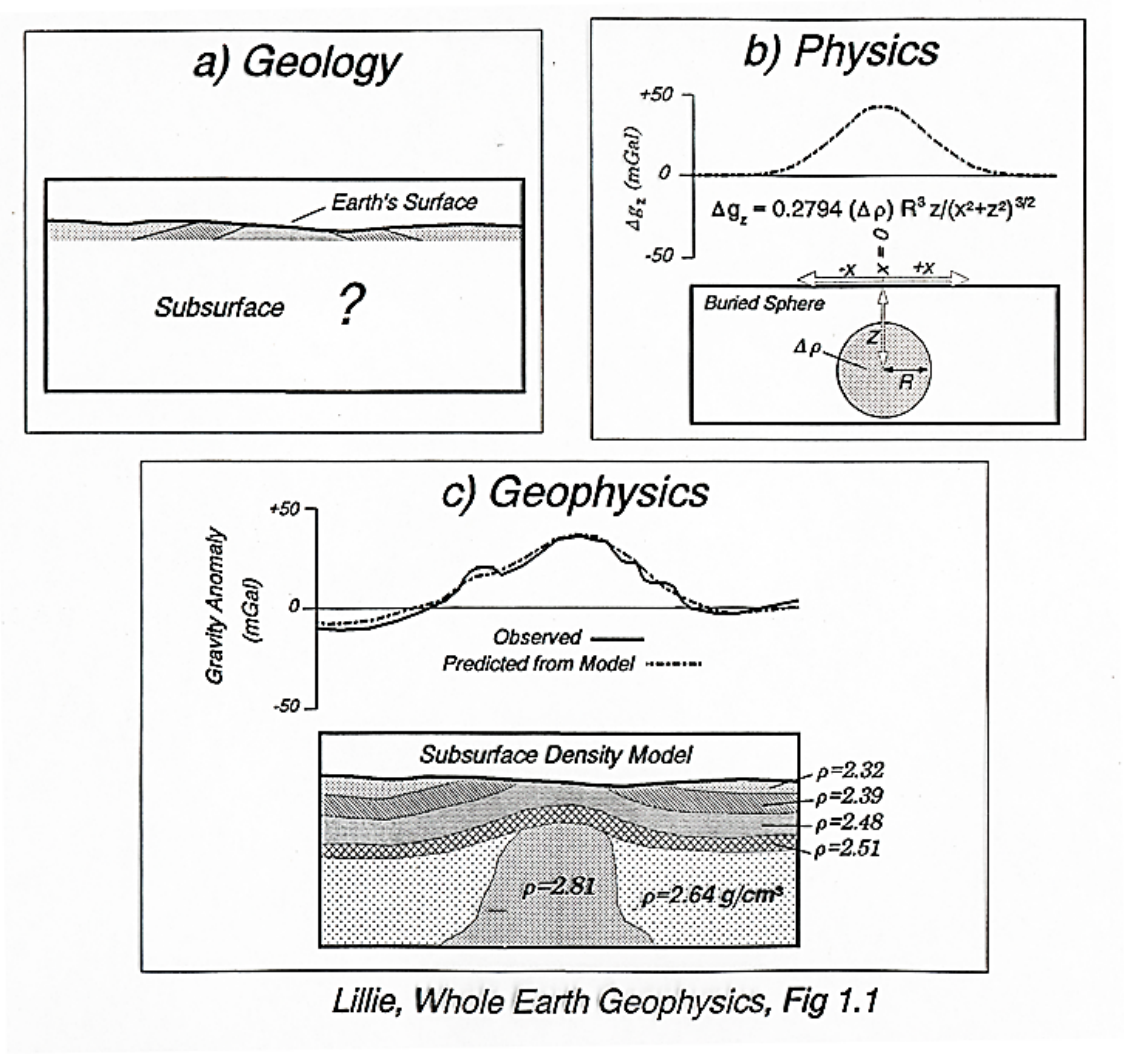
Any questions?

What is Geophysics?

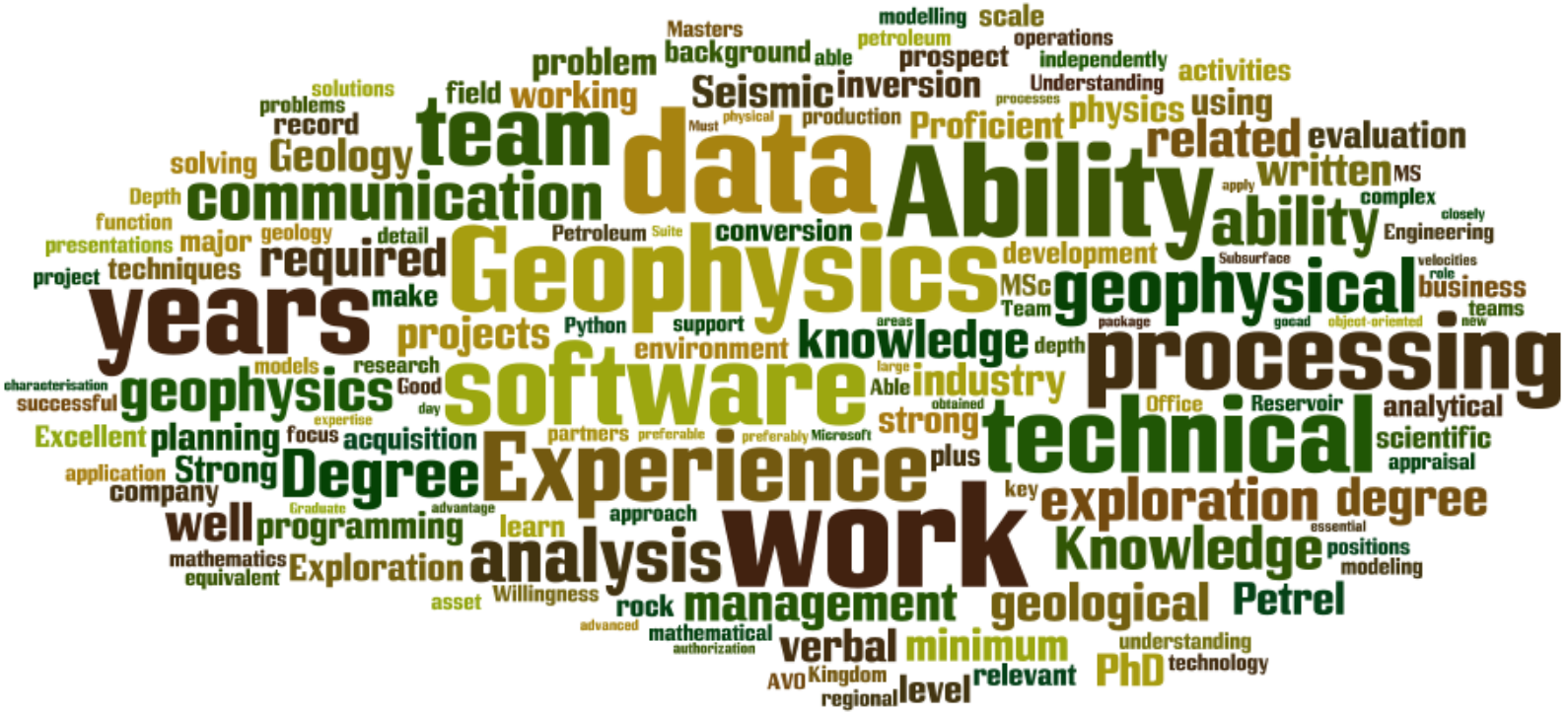
Geophysics: is the science which deals with investigating the Earth, using the methods and techniques of Physics.



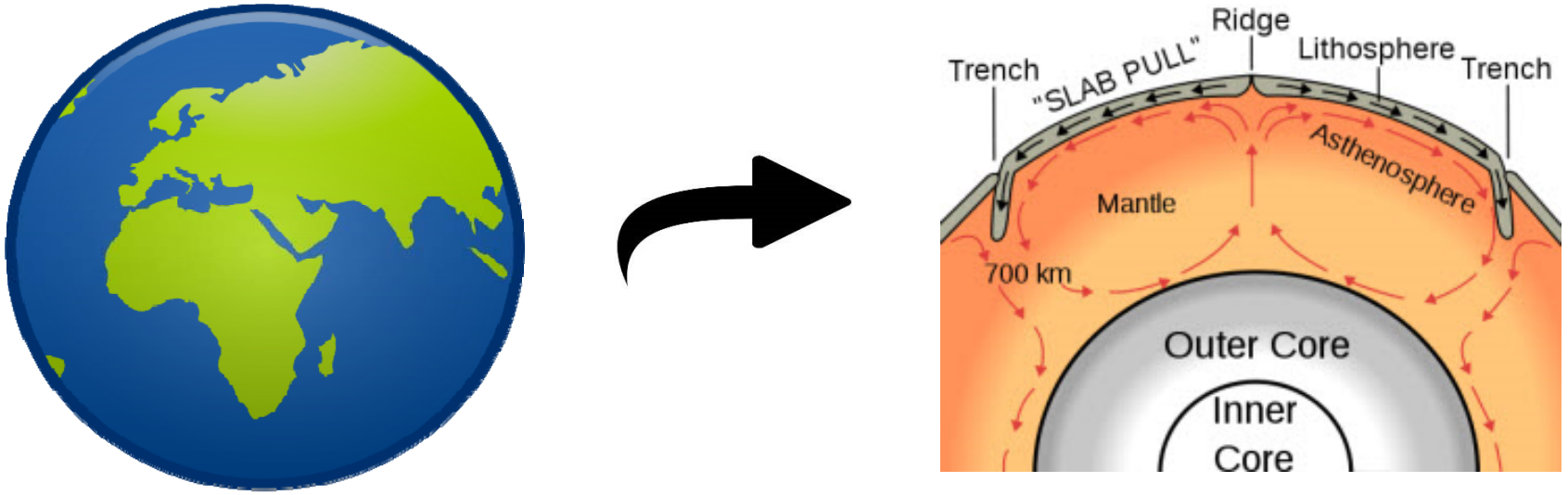
Geophysics = Geological observations + Physical laws

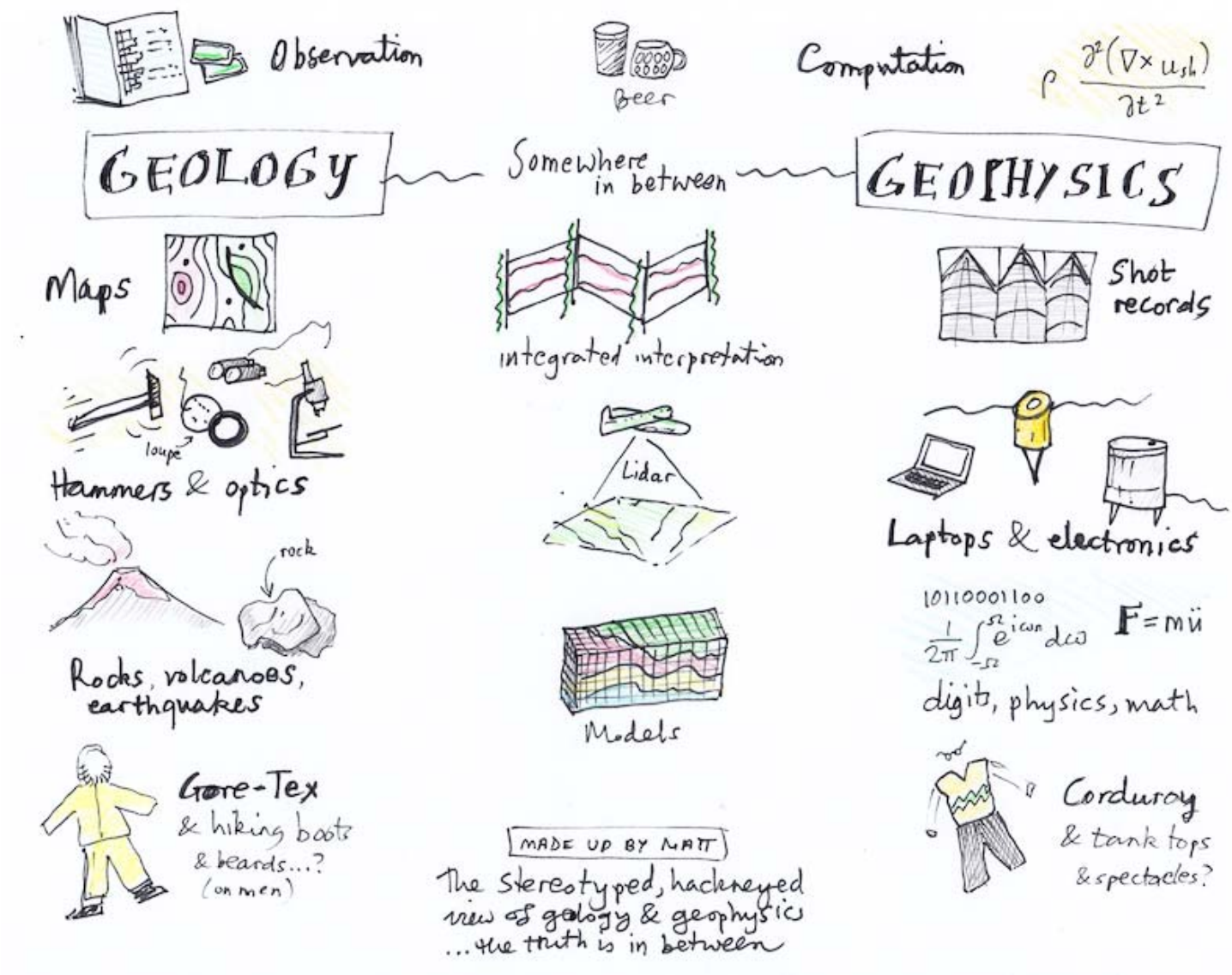


Lillie, Whole Earth Geophysics, Fig 1.1



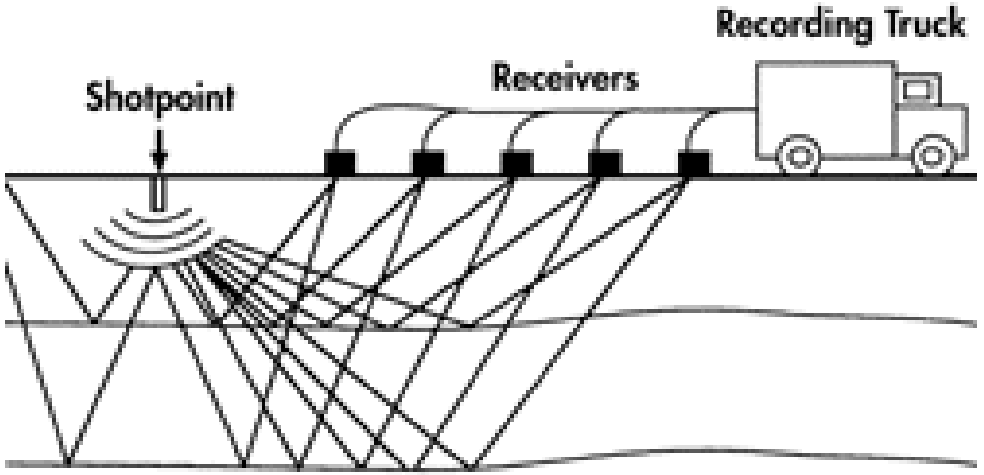
GPH 301 - Fundamental Considerations


Ridge
Trench
"SLAB PULL"
Lithosphere
Trench
Asthenosphere
Mantle
700 km
Outer Core
Inner
Core


Observation
beer
Computation
$\rho \frac{\partial^2(\nabla \times u_{sh})}{\partial t^2}$
GEOLOGY
Somewhere in between
GEOPHYSICS
Maps
integrated interpretation
Shot records
loupe
Hammers & optics
Lidar
Laptops & electronics
rock
Rocks, volcanoes, earthquakes
$\frac{1}{2\pi}\int_{-\Omega}^{\Omega} e^{i\omega n} d\omega$
$F = m\ddot{u}$
digits, physics, math
Models
Gore-Tex
& hiking boots
& beards...?
(on men)
Corduroy
& tank tops
& spectacles?
MADE UP BY MATT
The stereotyped, hackneyed view of geology & geophysics ...the truth is in between

Divisions of Geophysics:

- Global Geophysics: study earthquakes, magnetic field, physical oceanography, and meteorology.
- Exploration Geophysics: Search for oil, gas, water, and minerals.



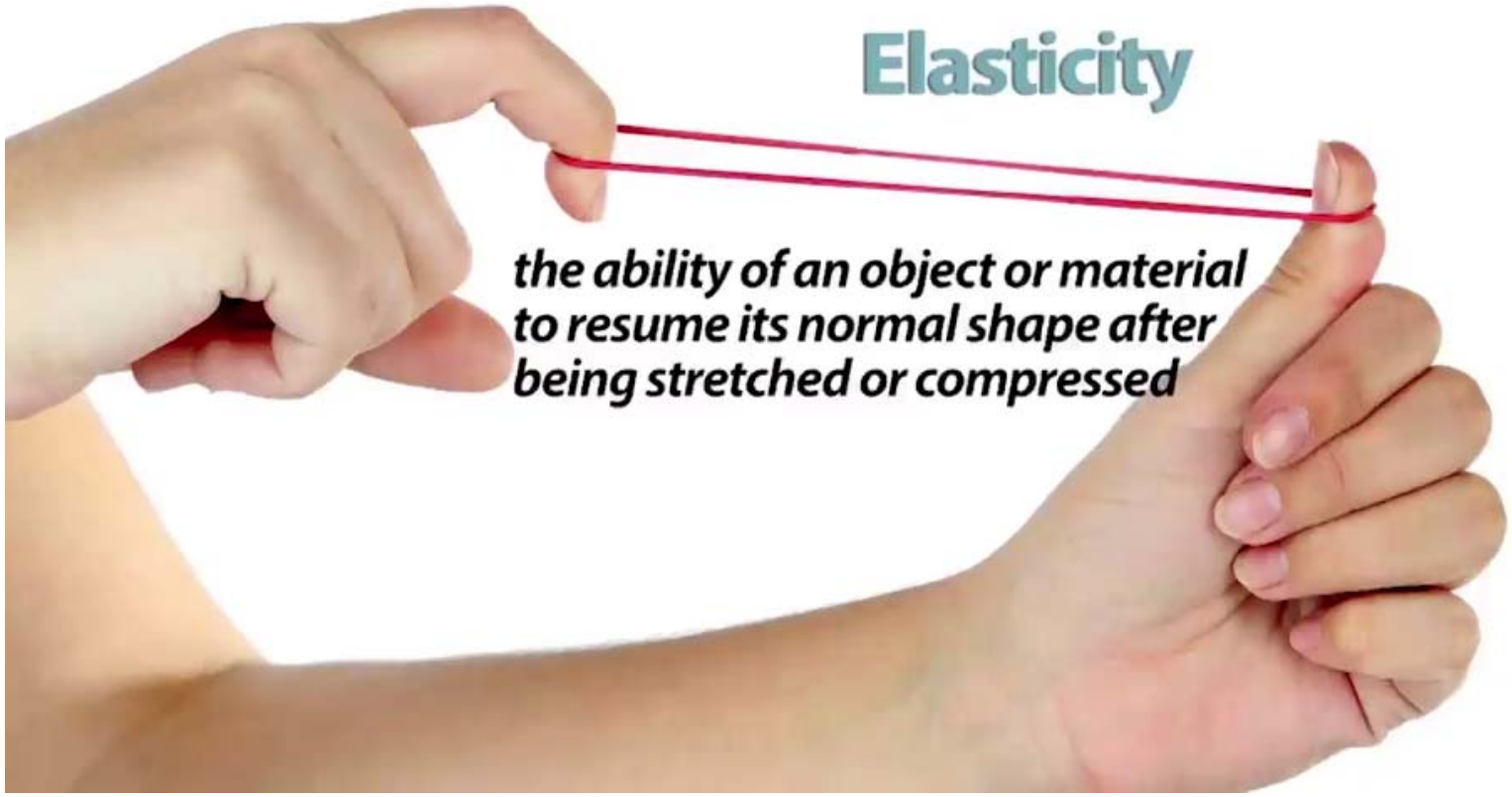
Geophysical Exploration Methods:

- Passive Methods (Natural Sources): incorporates of natural occurring fields or properties of the Earth [i.e. Magnetotelluric, Telluric, Gravity, Magnetic].
- Active (Induced Sources): a signal injected into the earth and then measure how the earth respond to the signal [i.e. Resistivity, Seismic Refraction, GPR].

Fundamental Considerations:

- Theory of Elasticity
- Stress-Strain relationship
- Elastic coefficients
- Seismic waves
- Huygens and Fermat principles
- Snell's law in refraction

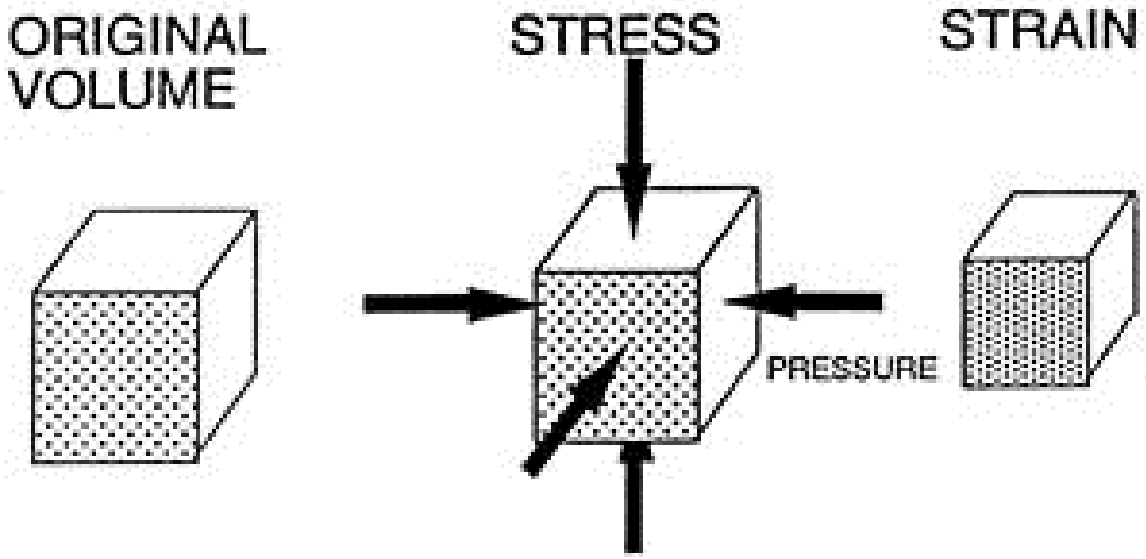
Q. Is the ball the same in the two photos? Why?

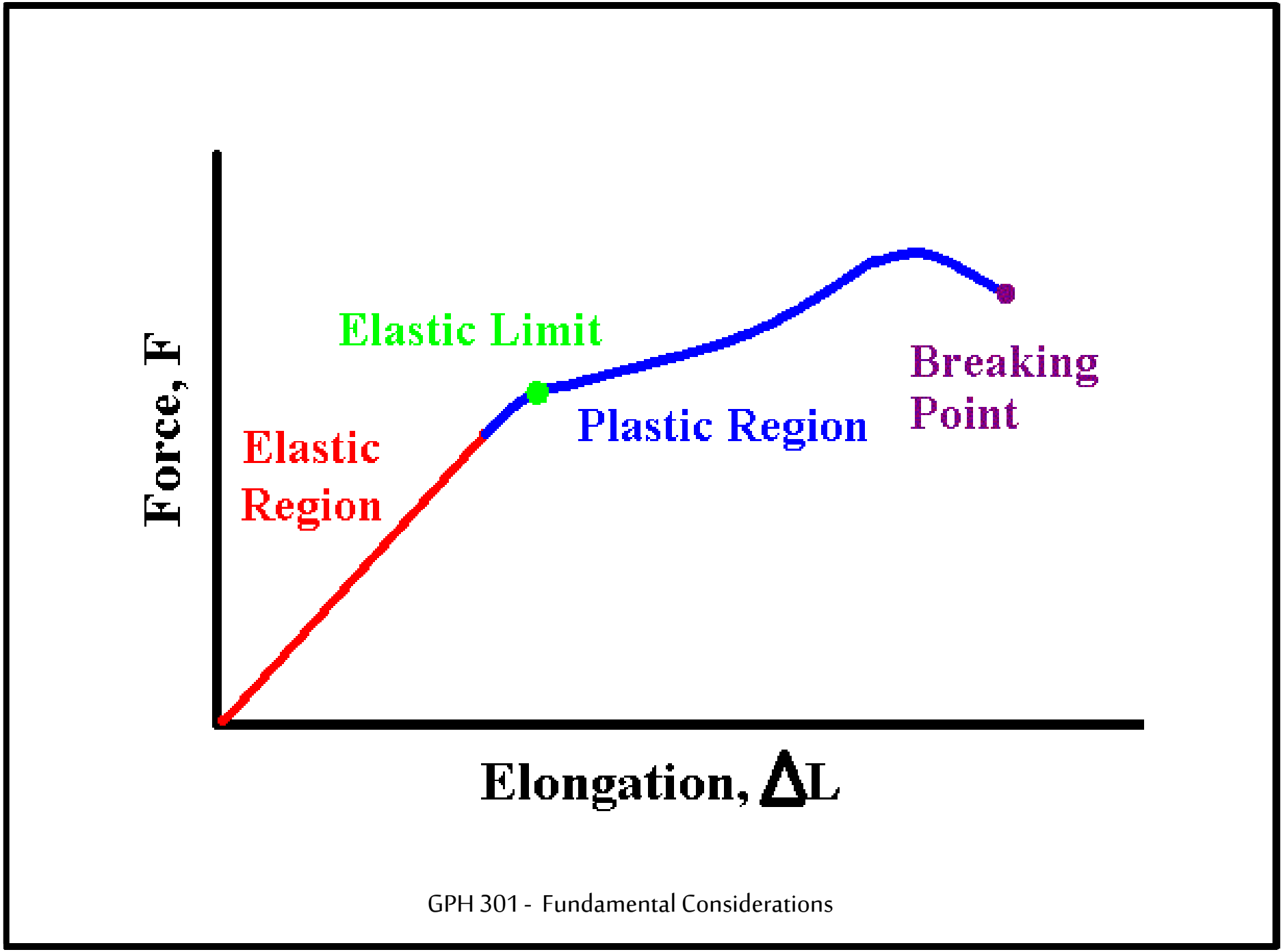

Elasticity
the ability of an object or material
to resume its normal shape after
being stretched or compressed

Theory of Elasticity:

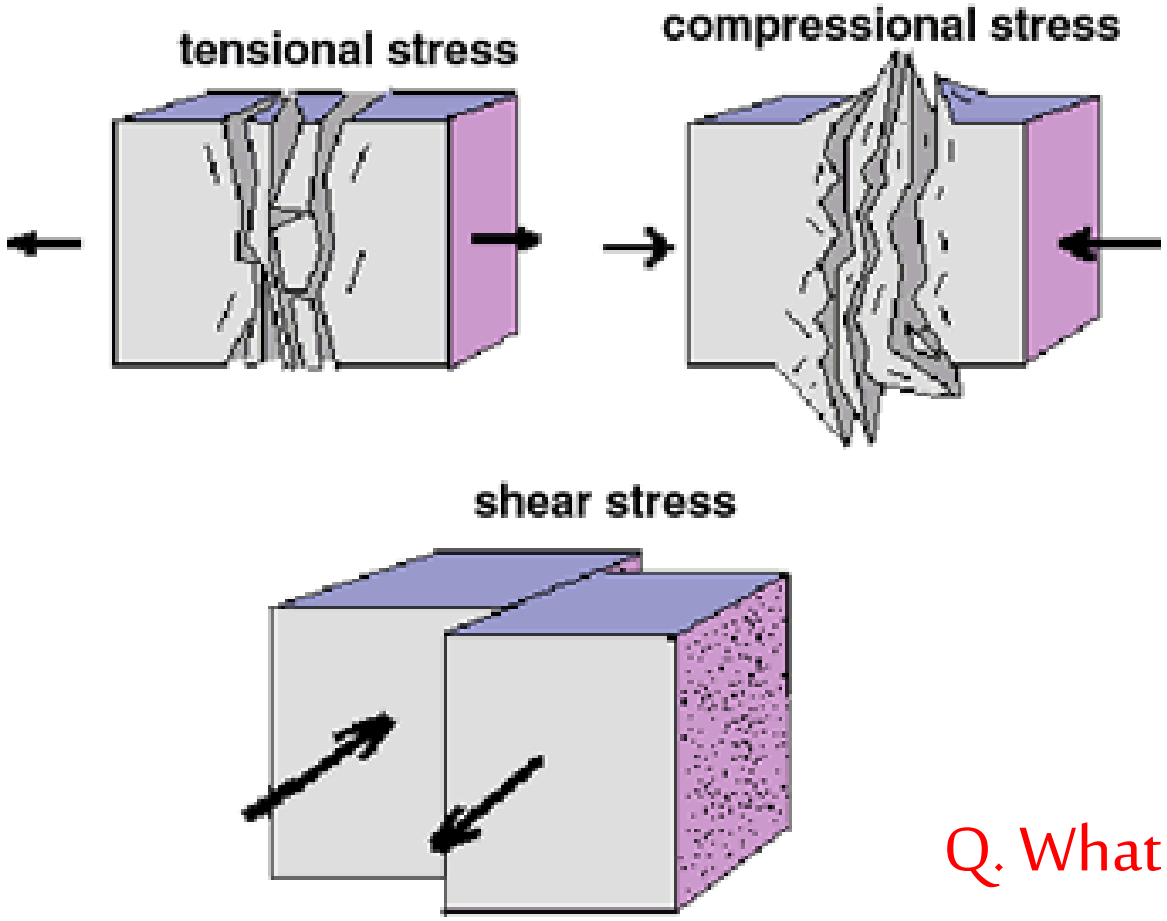
Stress: is the ratio of applied force F to the area across which it is acts.

Strain: is the deformation caused in the body, and is expressed as the ratio of change in length (or volume) to the original length (or volume).




Force, F
Elastic Limit
Breaking Point
Plastic Region
Elastic Region
Elongation, ΔL

https://www.youtube.com/watch?v=zqp1TUGIYhM



Q. What is going on Earth?

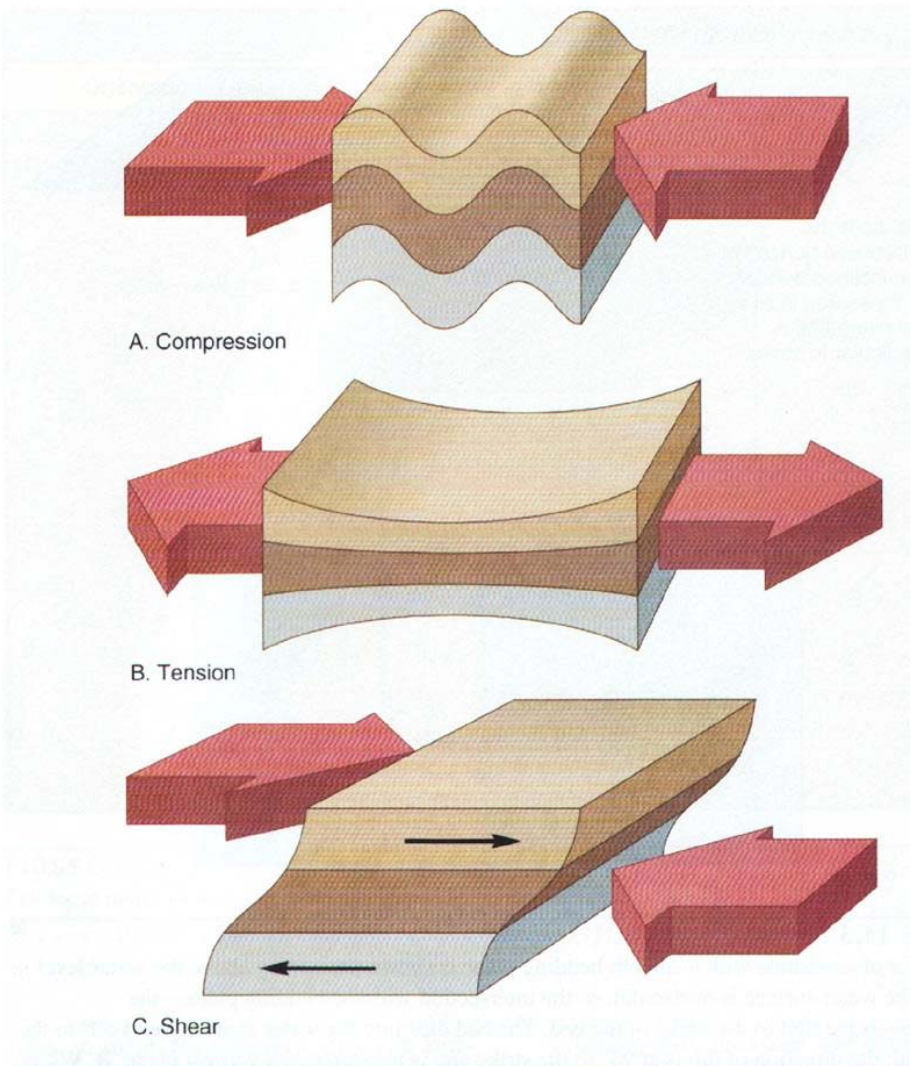
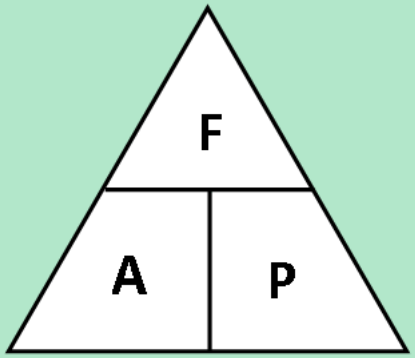


FIGURE 14.1
The three principal types of stress; A. compression; B. tension; C. shear.
(Adapted from Jones, 2001: Laboratory Manual for Physical Geology, 3rd Edition)

Q. What is pressure?

$$\text{PRESSURE} = \frac{\text{FORCE}}{\text{AREA}}$$

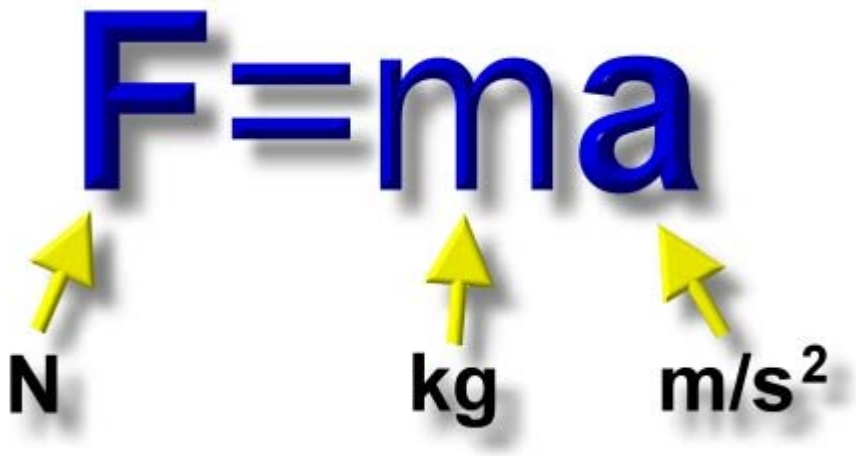
Force Area Pressure



$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

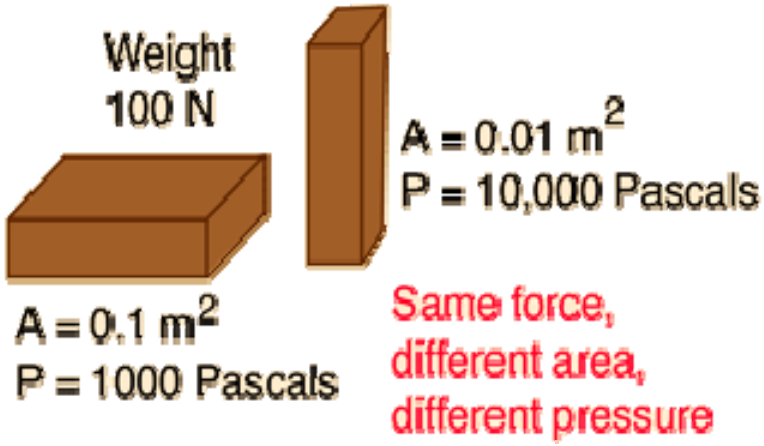
$$\text{Area} = \frac{\text{Force}}{\text{Pressure}}$$

$$\text{Force} = \text{Area} \times \text{Pressure}$$

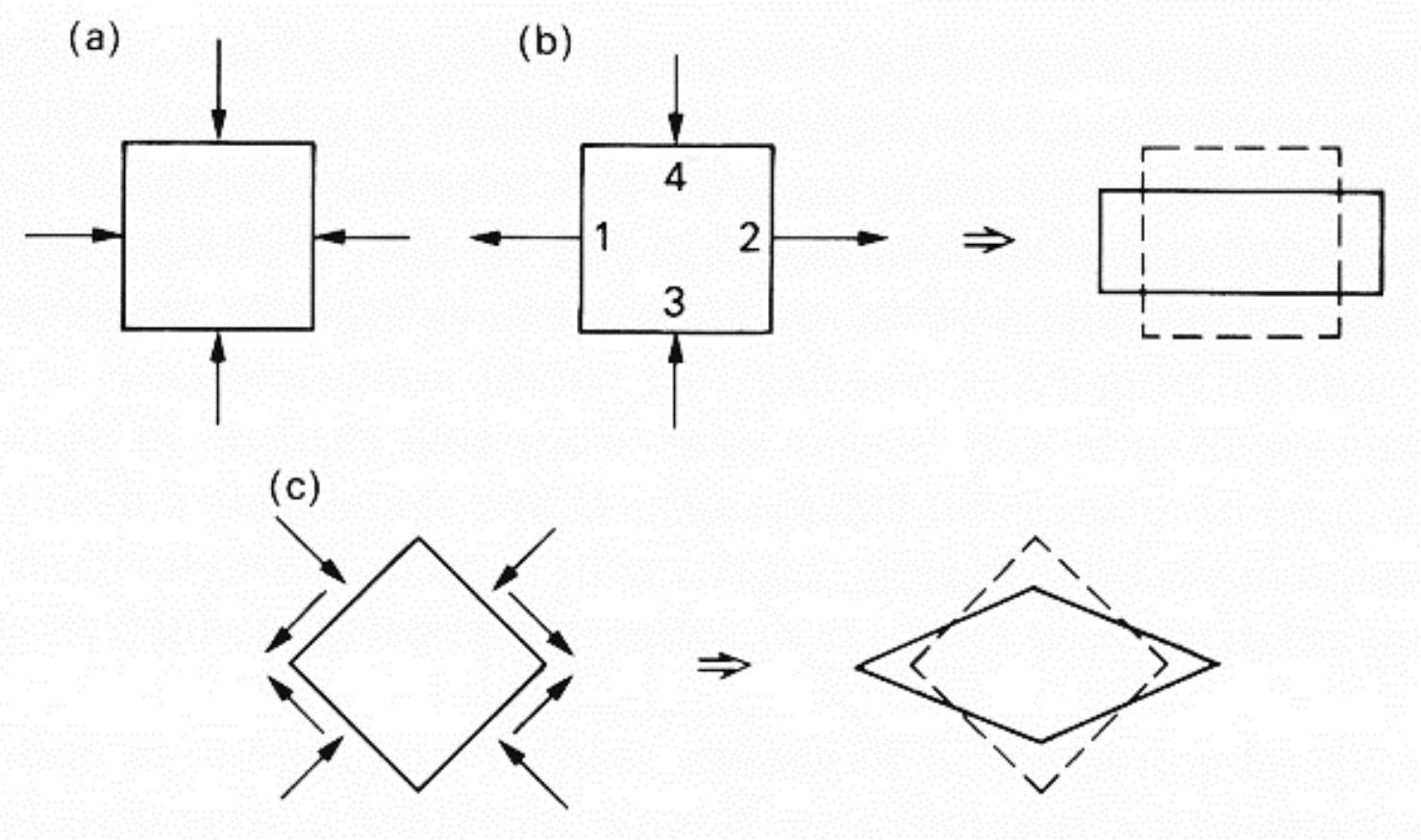


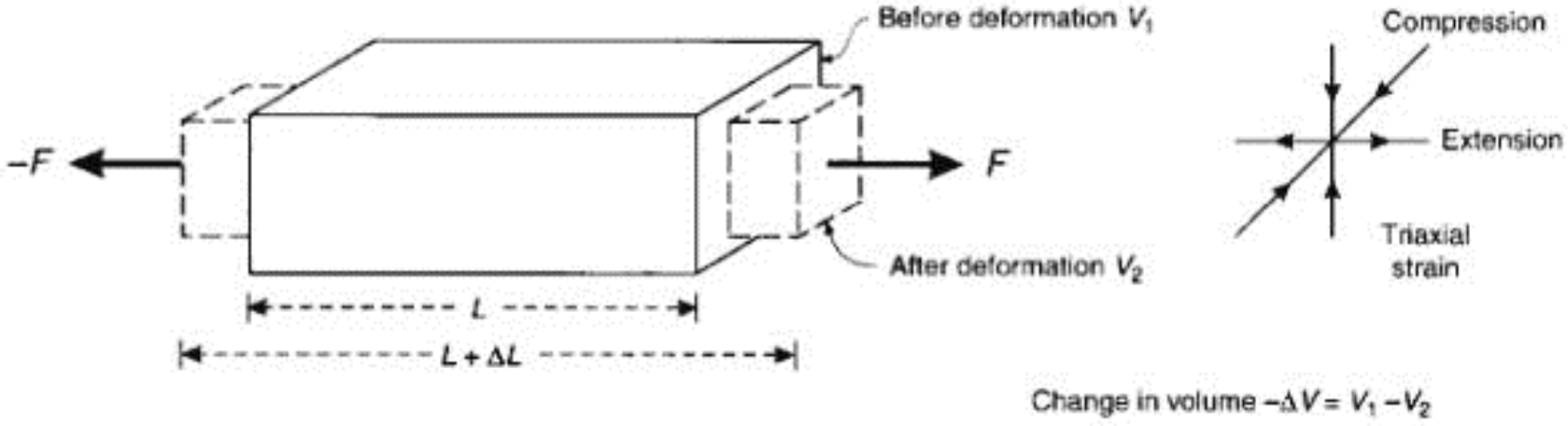
F = Net force
m = mass
a = acceleration

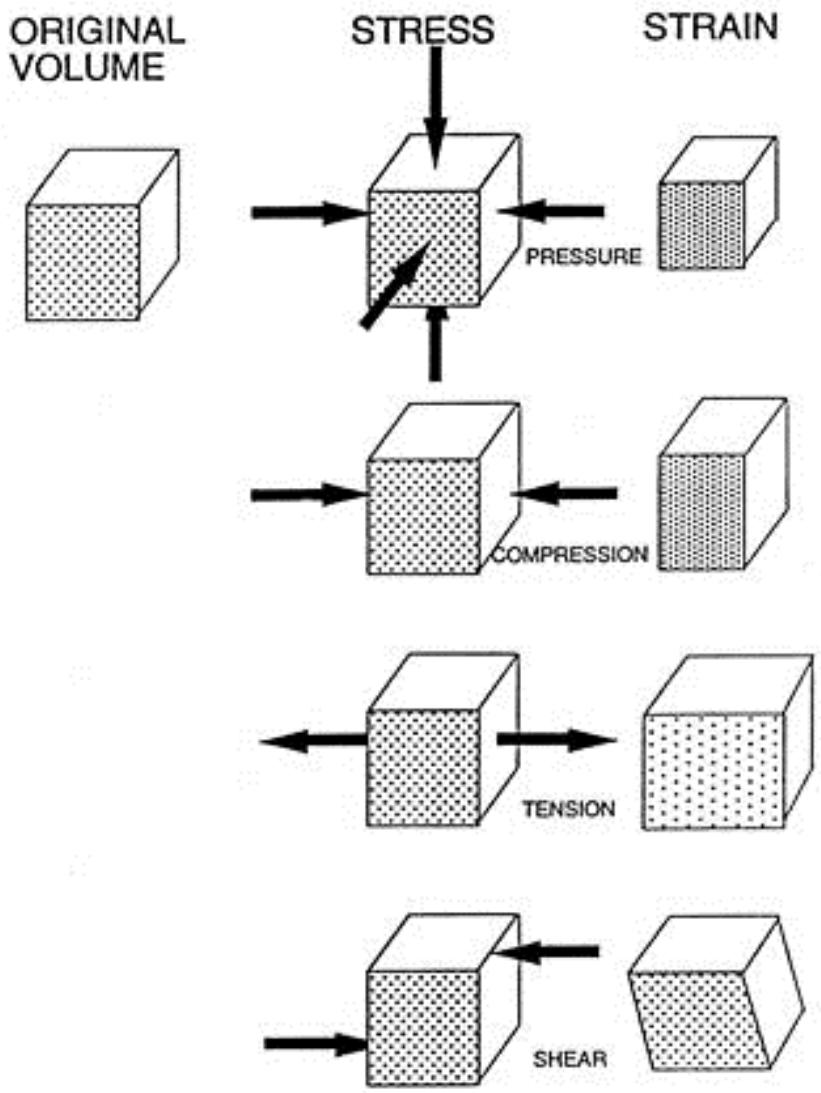
$$Pressure = \frac{Force}{Area} = \frac{F}{A}$$

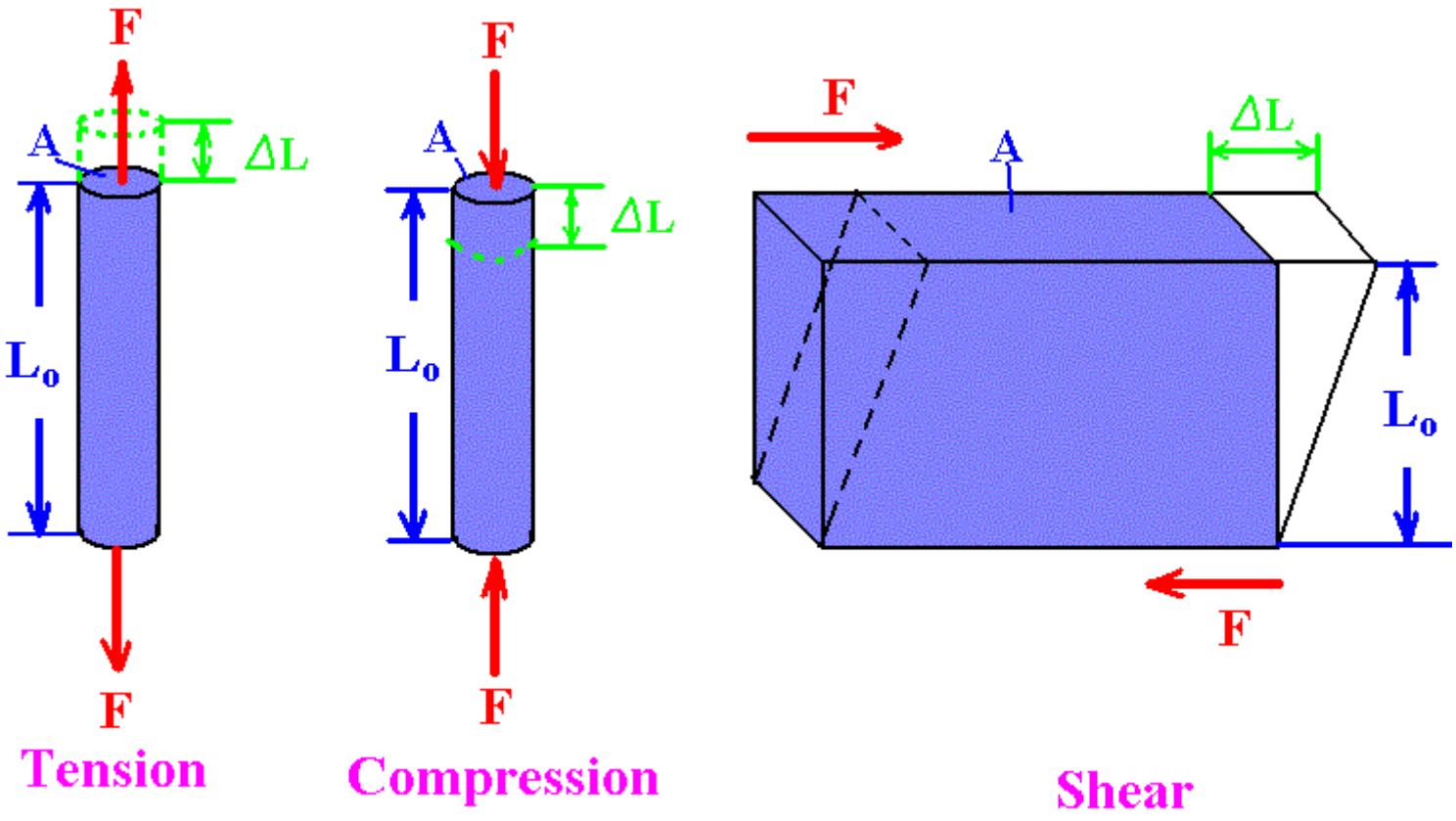


Pressure: Forces act equally in all directions perpendicular to faces of body.

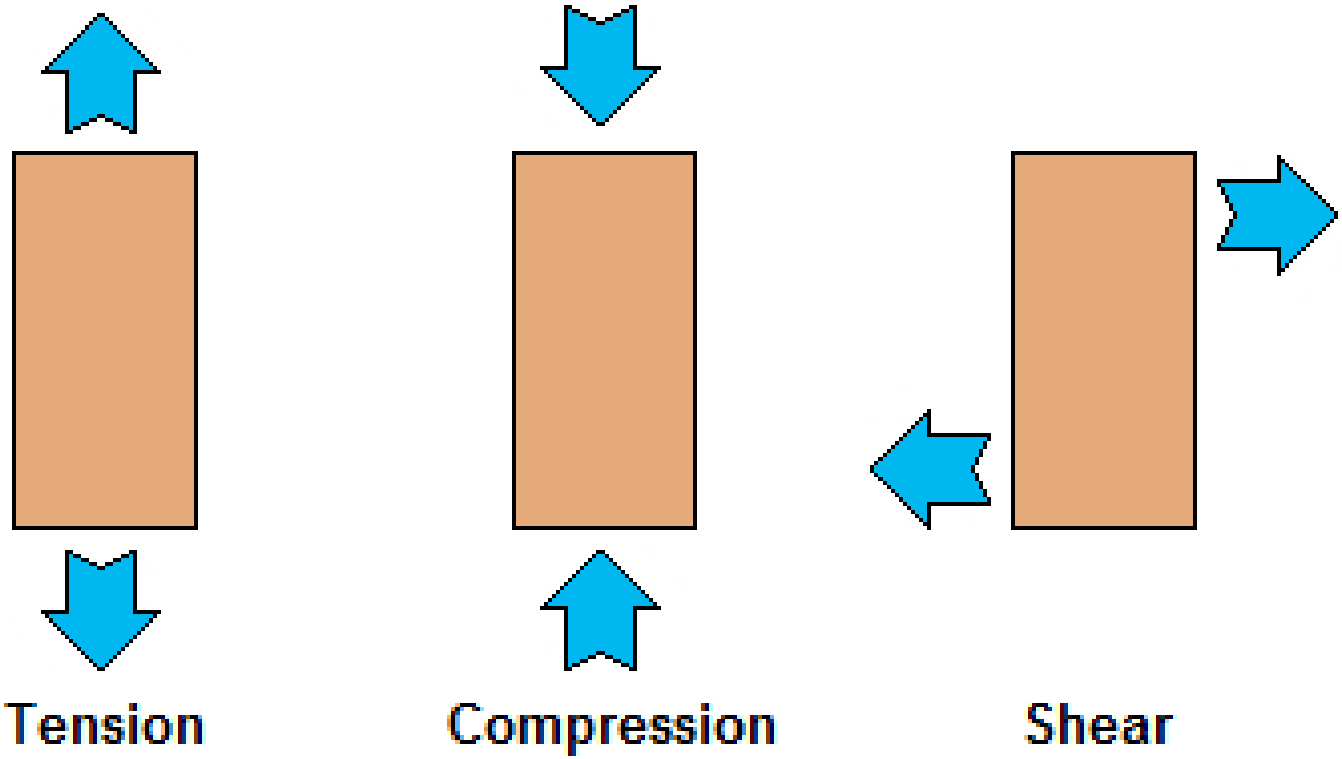



Before deformation V_1
$-F$
F
After deformation V_2
L
$L + \Delta L$
Compression
Extension
Triaxial strain
Change in volume $-\Delta V = V_1 - V_2$


ORIGINAL VOLUME
STRESS
STRAIN
PRESSURE
COMPRESSION
TENSION
SHEAR

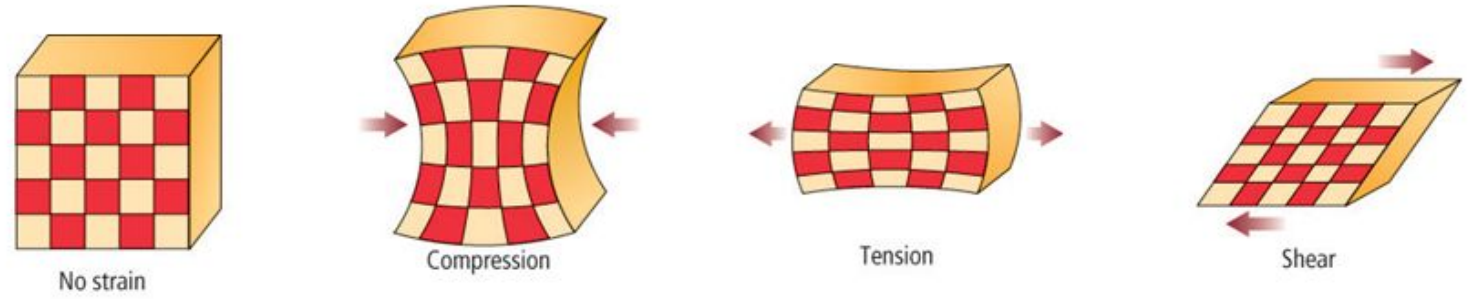

F
A
ΔL
L_o
F
Tension
F
A
ΔL
L_o
F
Compression
F
A
ΔL
L_o
F
Shear

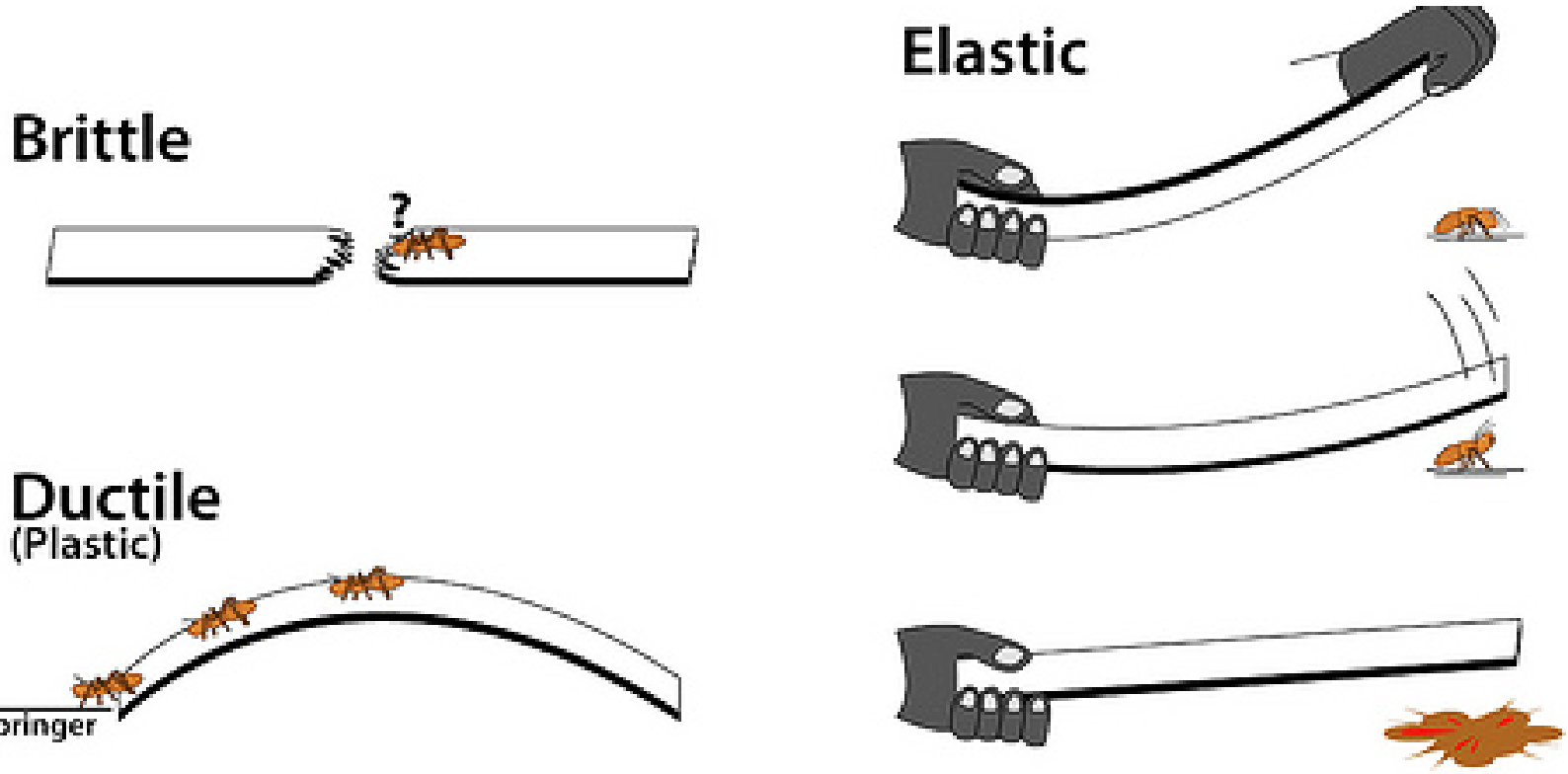
Types of stress:



Types of stress:

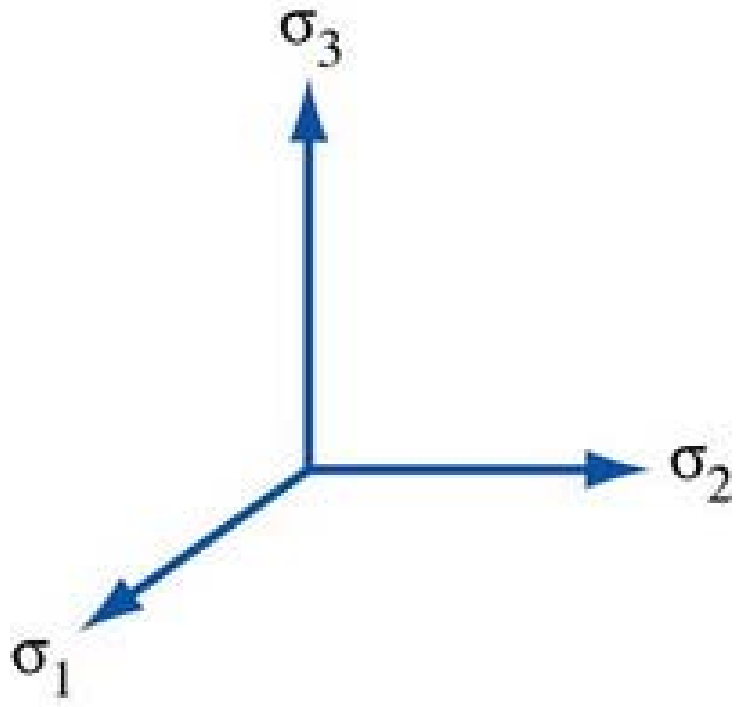
- **Compression** causes a material to shorten.
- **Tension** causes a material to lengthen.
- **Shear** causes distortion of a material.





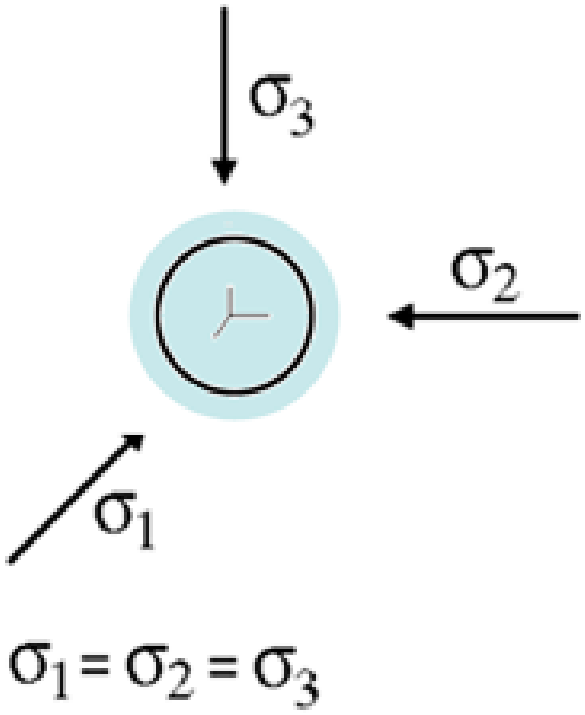
Q. What are the differences between them?

Principal-stress axes: Three mutually perpendicular axes (designated, σ_1, σ_2, and σ_3) which are parallel to the directions of maximum, intermediate, and least principal stress. Their separate lengths and directions describe the state of stress at a particular point.



If all 3 principal stresses are equal ($\sigma 1 = \sigma 2 = \sigma 3$), the body is subjected to a pressure.

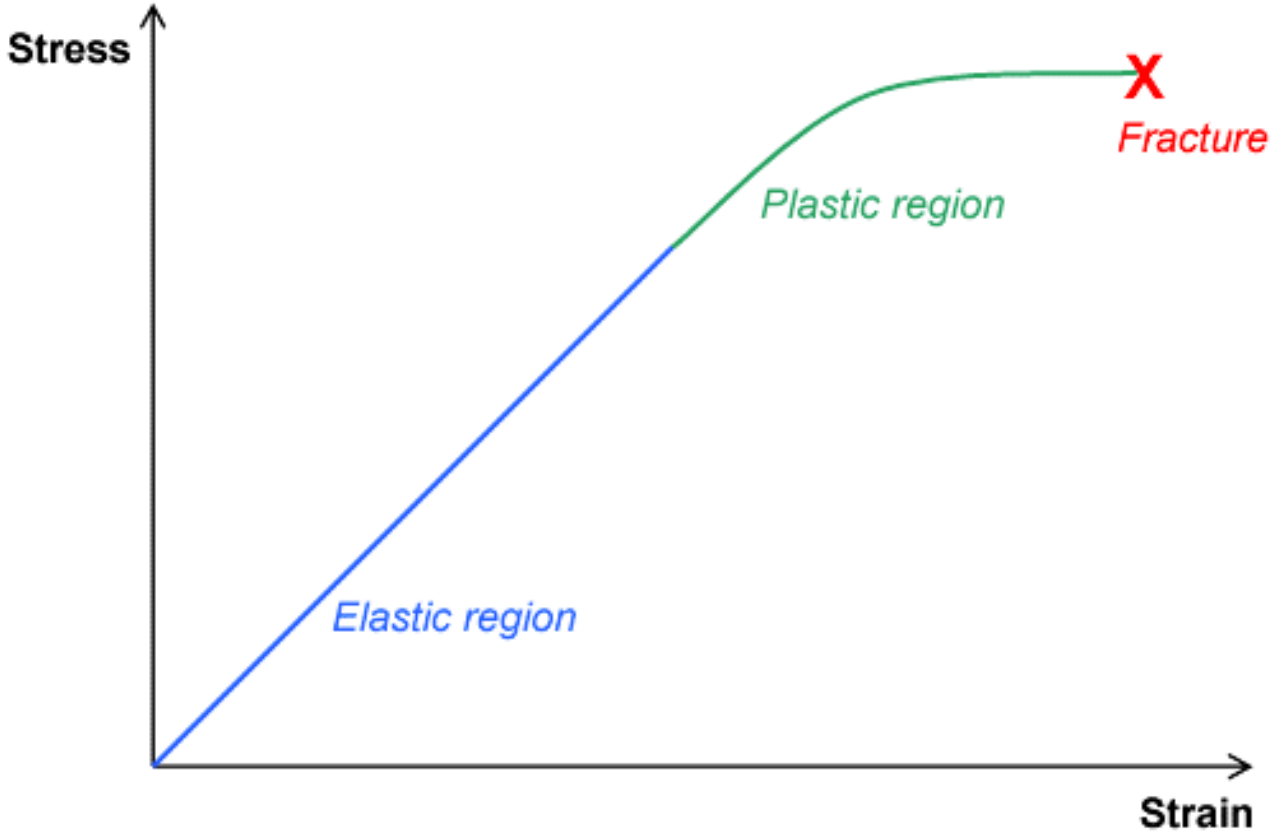
Pressure = sum of principal stresses/3



- Stresses towards the interior: compression.
- Stresses towards the exterior: tension (extension, dilatation).

Hooke's Law

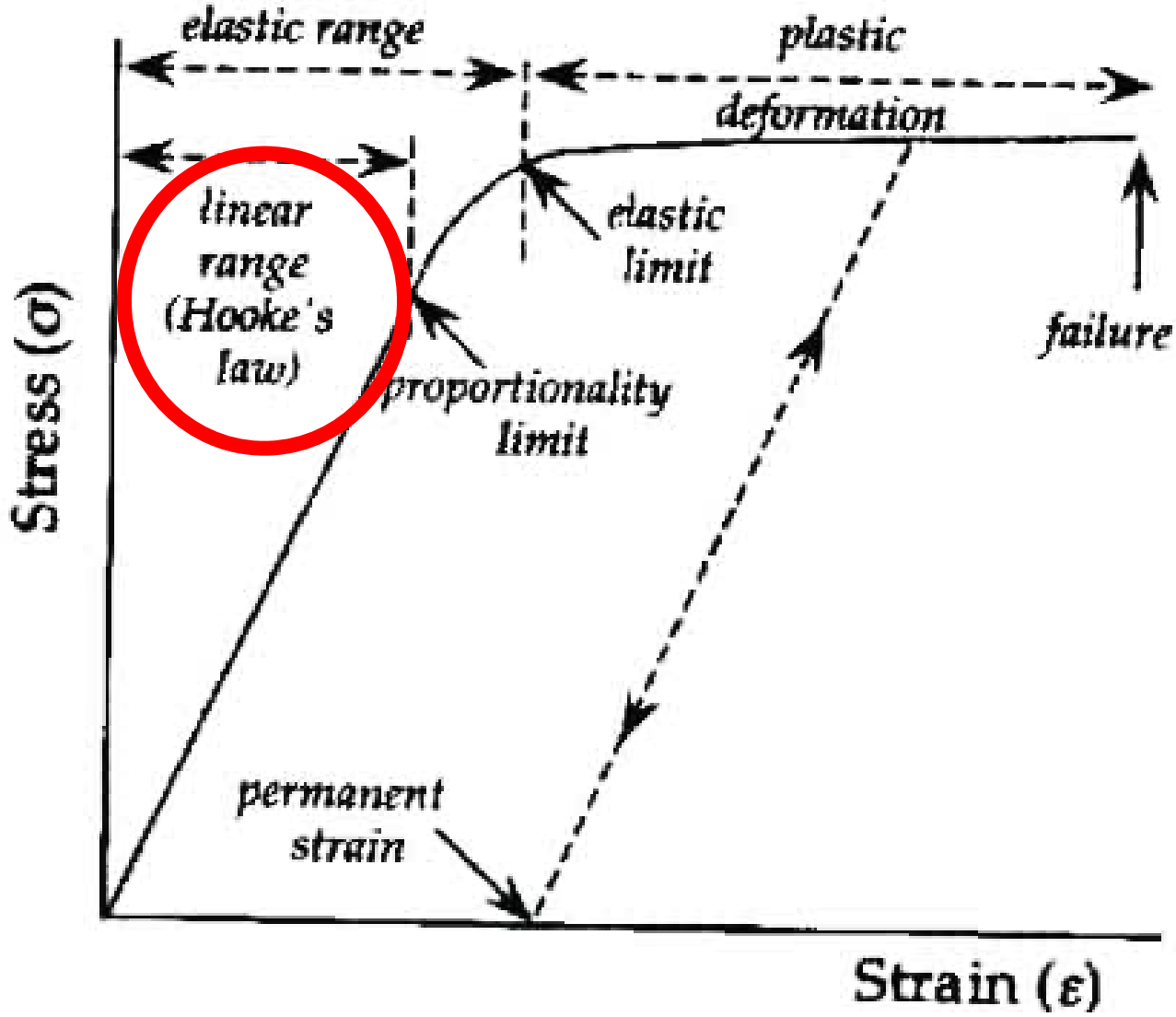
Hooke's Law essentially states that stress is proportional to strain.

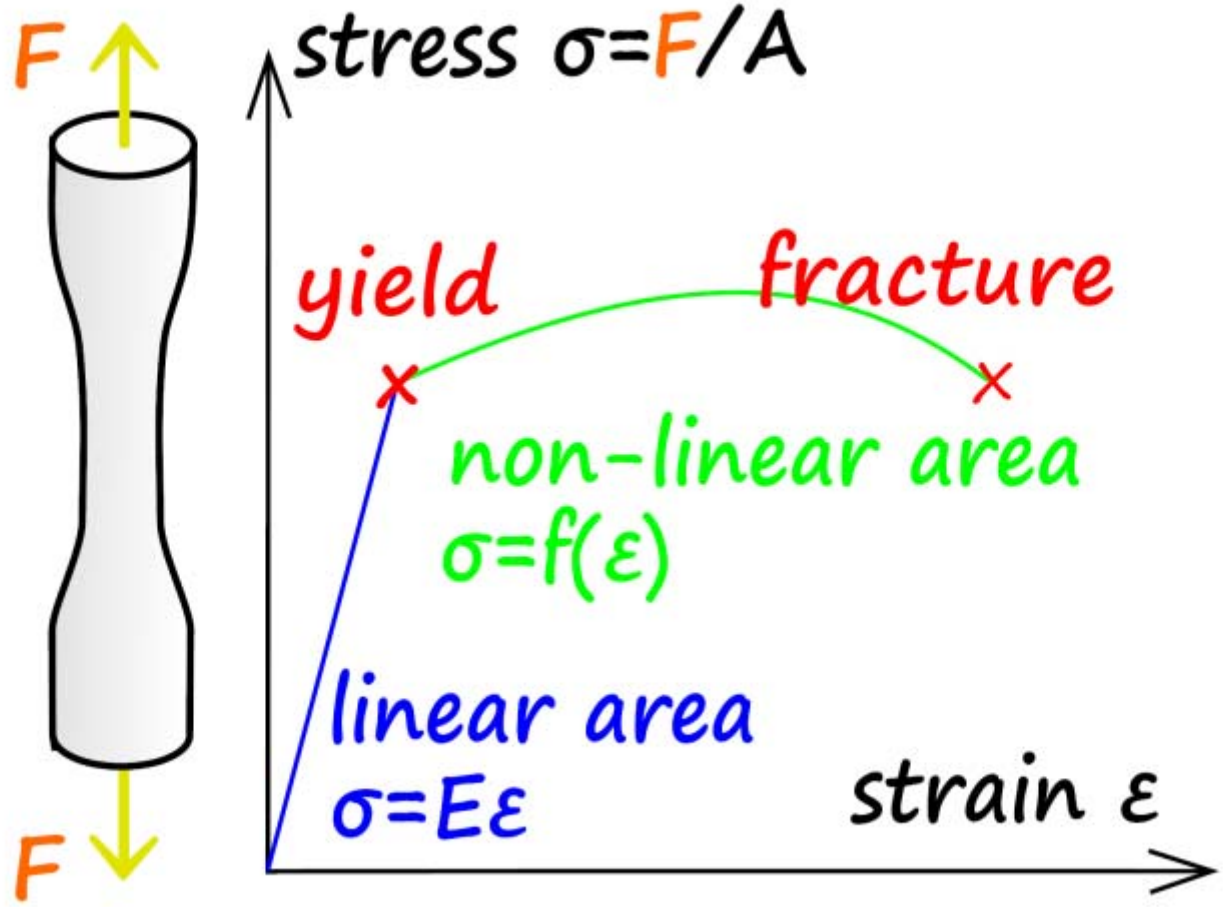


Hooke's Law

- Hooke's law states that:

$$F \propto e$$


elastic range
plastic deformation
linear range (Hooke's law)
elastic limit
failure
proportionality limit
permanent strain
Stress (σ)
Strain (ε)


F
stress σ=F/A
yield
fracture
non-linear area
σ=f(ε)
linear area
σ=Eε
strain ε
F

Elastic Constants

Elastic constants describes the strain of a material due to applied stress.

Modulus = stress/strain

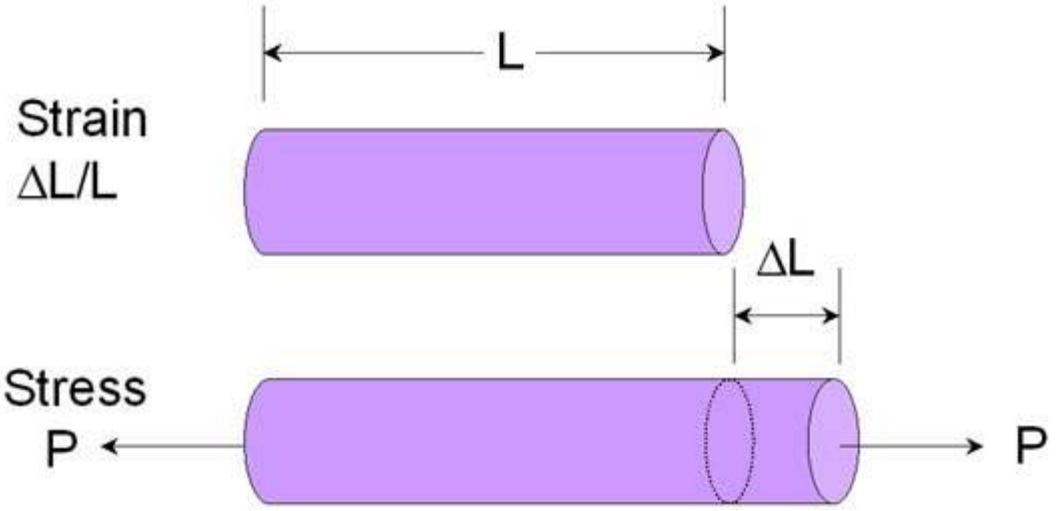
The higher the value of the modulus, the stronger the material, the smaller the strain produced by a given stress.

Elastic constants include:

- Young's Modulus E
- Bulk Modulus K
- Shear Modulus μ
- Axial Modulus ψ
- Poisson's Ratio σ

Young's Modulus (E)

$$E = \frac{stress}{strain} = \frac{F/A}{\Delta l/l_o}$$

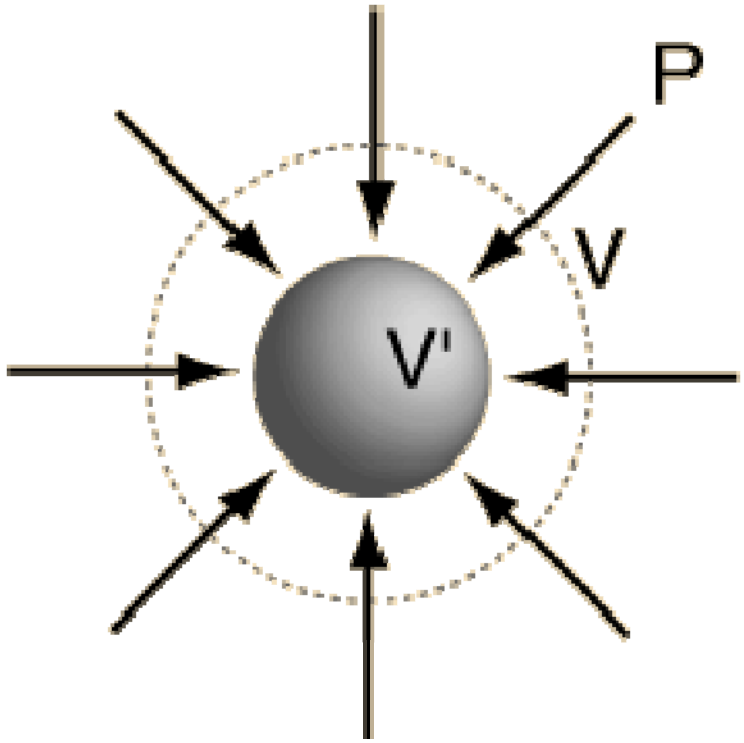


Bulk Modulus (K)

Bulk modulus:

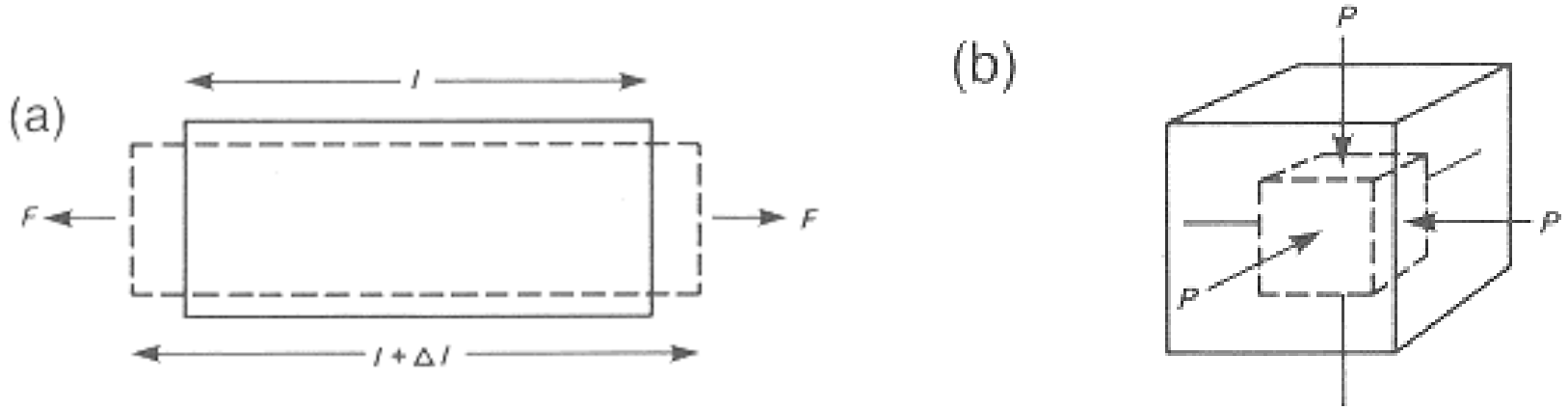
$$B = \frac{\Delta P}{\Delta V / V}$$

P = pressure
V = volume

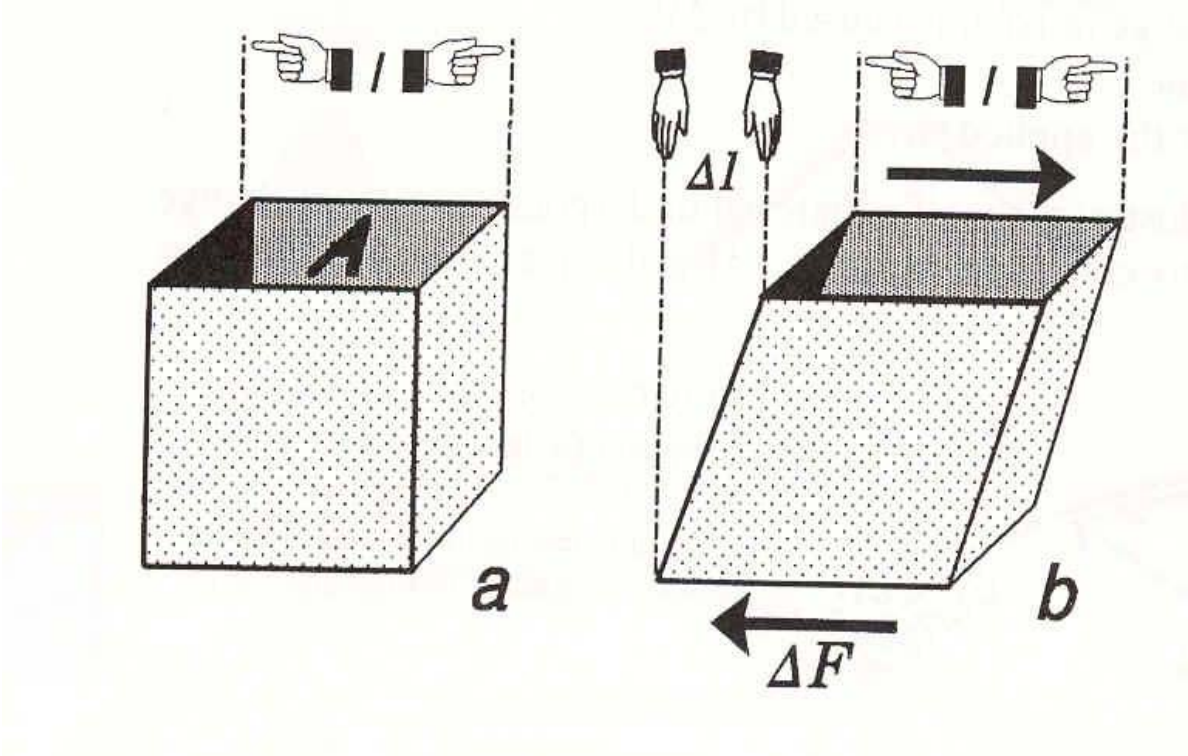


Measure of the capacity of the material to be compressed. It can be carried out for solid, liquid, and gas.

Q. What is the difference between (a) and (b)?



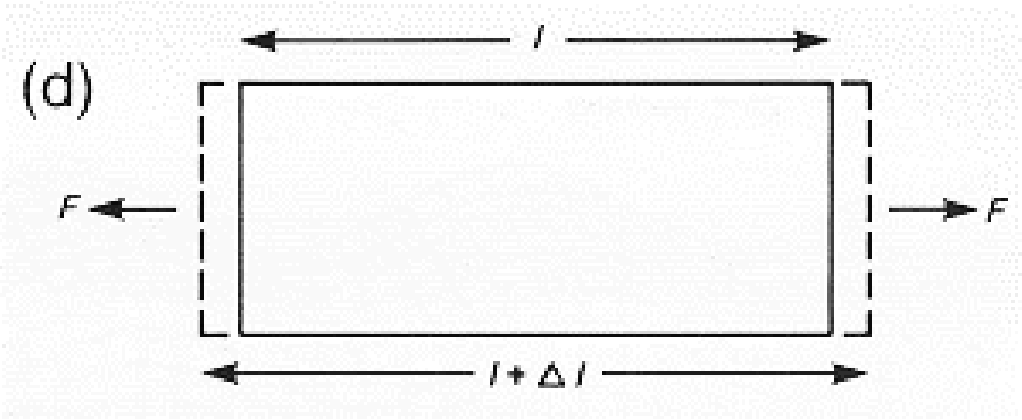
Shear Modulus (μ)



Measure of the effort needed to change the shape of a material without change of volume (μ =0 for liquid or gas).

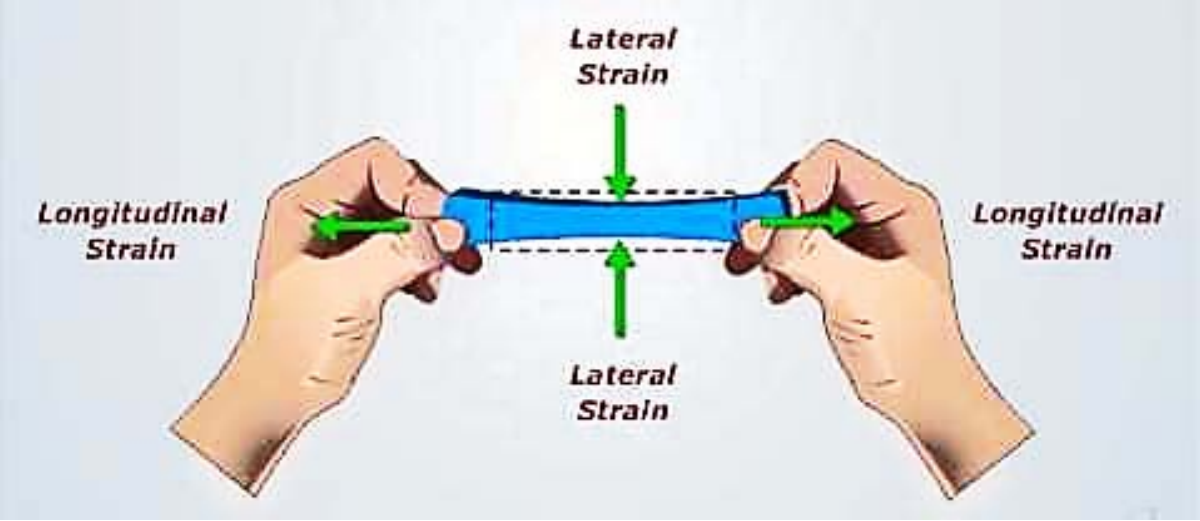
Axial Modulus (**ψ**)

Response to longitudinal stress, similar to Young's Modulus except that strain is uniaxial – no transverse strain associated with the application of the longitudinal stress.



Poisson's Ratio (σ)

When a material is compressed in one direction, it usually tends to expand in the other two directions perpendicular to the direction of compression.



μ = shear modulus (as before)

λ = first Lamé coefficient (no direct physical interpretation)

Young's Modulus: $E = \mu(3\lambda + 2\mu) \div (\lambda + \mu)$

Bulk modulus: $K = \lambda + 2/3\ \mu$

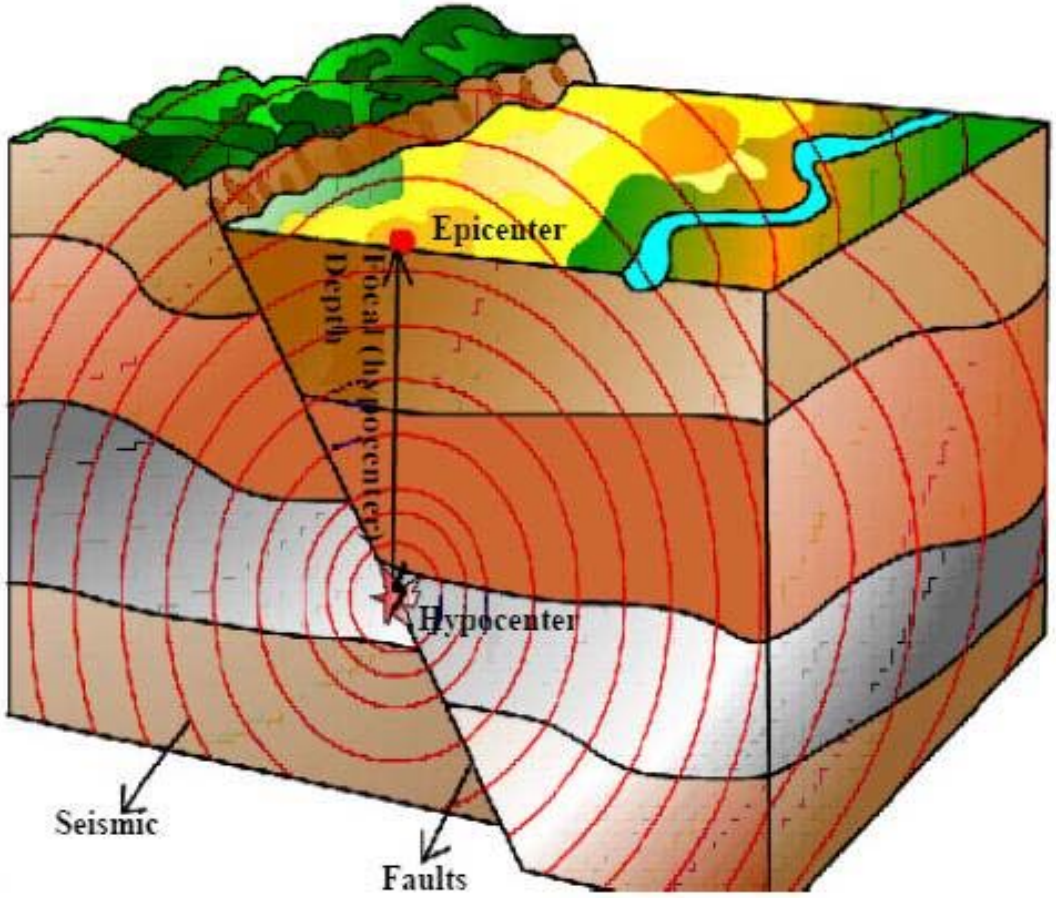
Poisson's Ratio: $\sigma = \lambda / 2(\lambda + \mu)$

Lamé 1 in terms of Poisson & Young

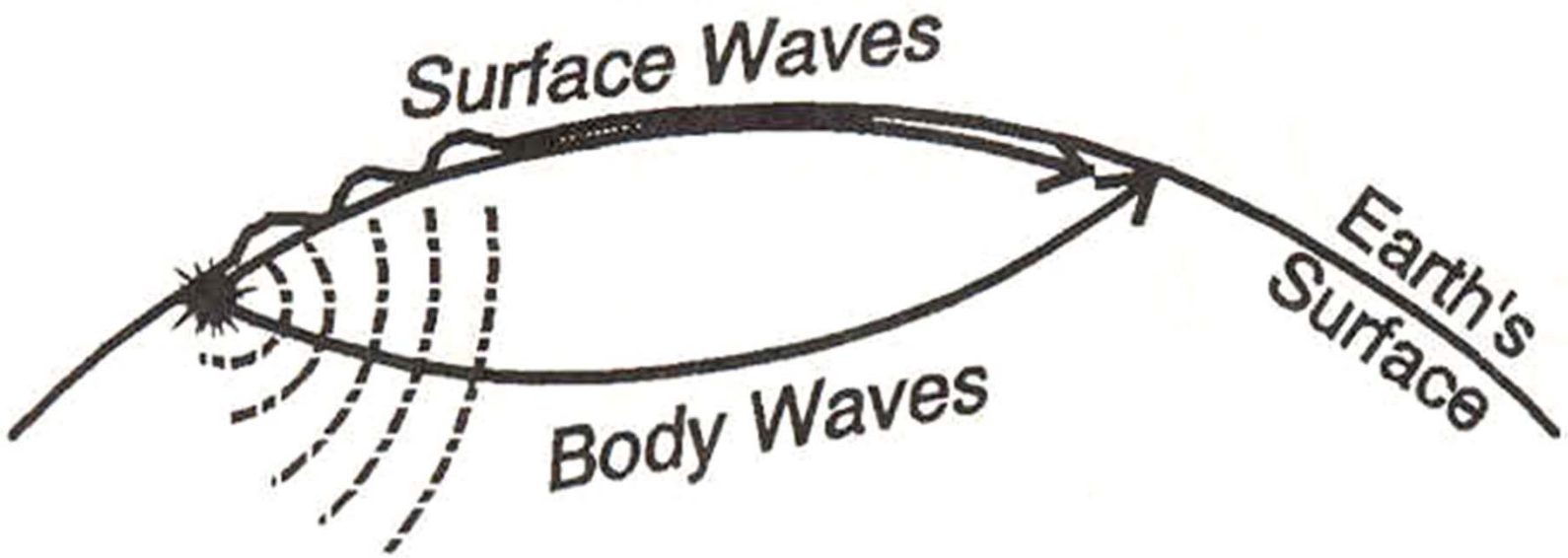
$\lambda = E\sigma / (1 + \sigma)(1 - 2\sigma)$

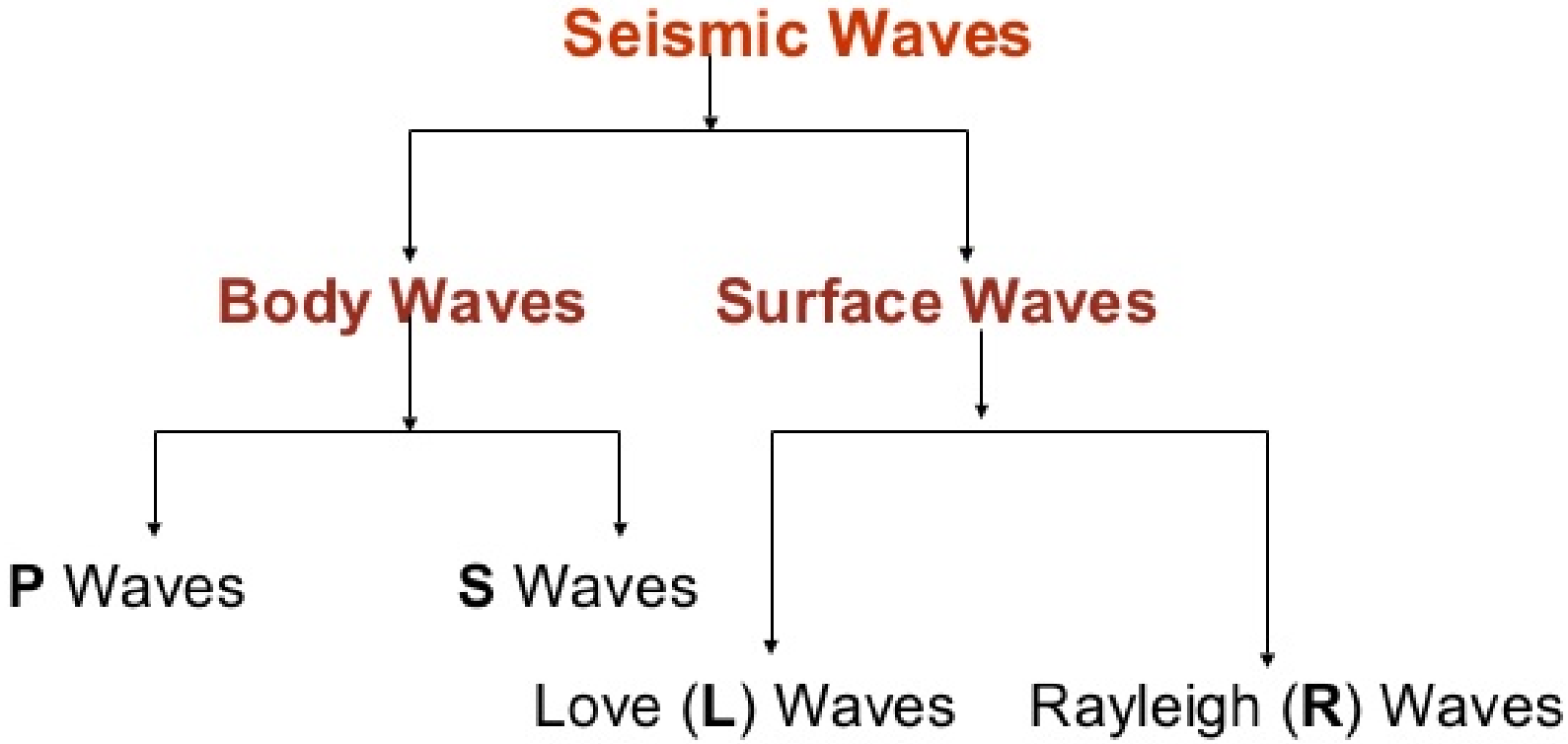
Q. What are seismic waves?

Seismic waves are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs.



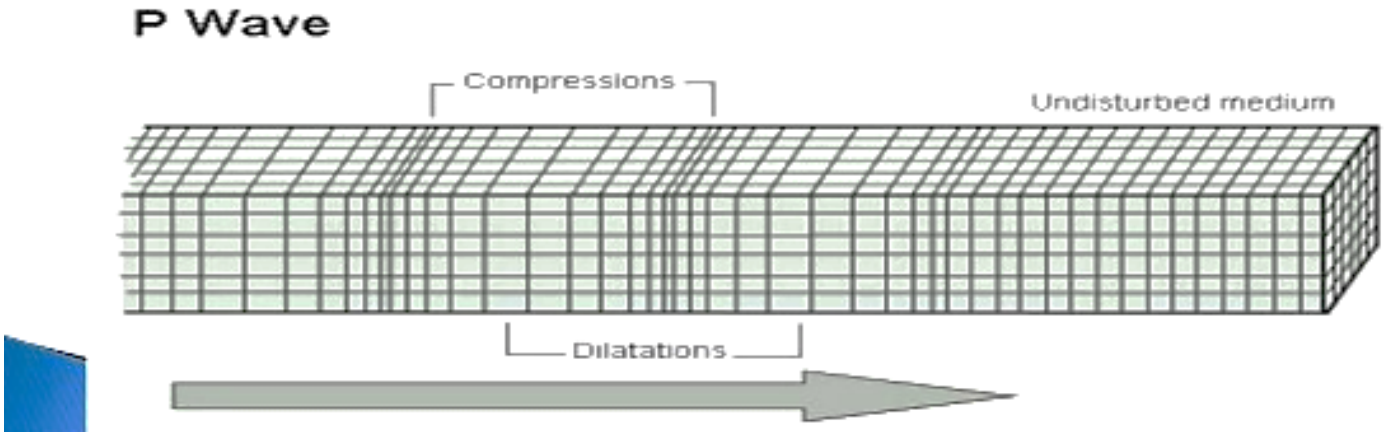
Waves of energy that travel through the Earth's layers, and are a result of an earthquake, explosion, or a volcano.


Surface Waves
Earth's Surface
Body Waves


Seismic Waves
Body Waves
Surface Waves
P Waves
S Waves
Love (L) Waves
Rayleigh (R) Waves

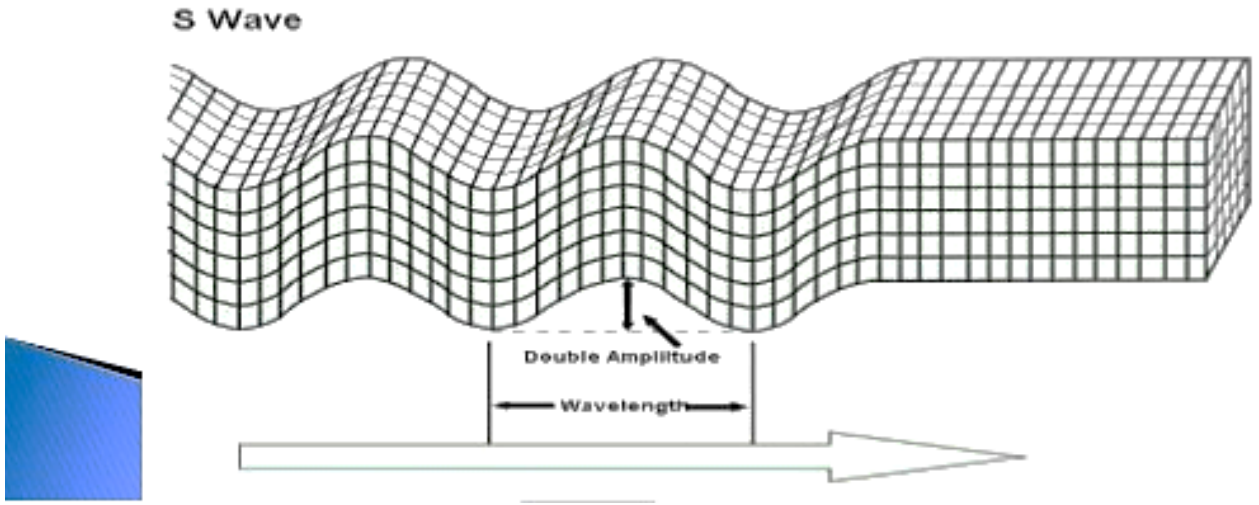
Body Waves

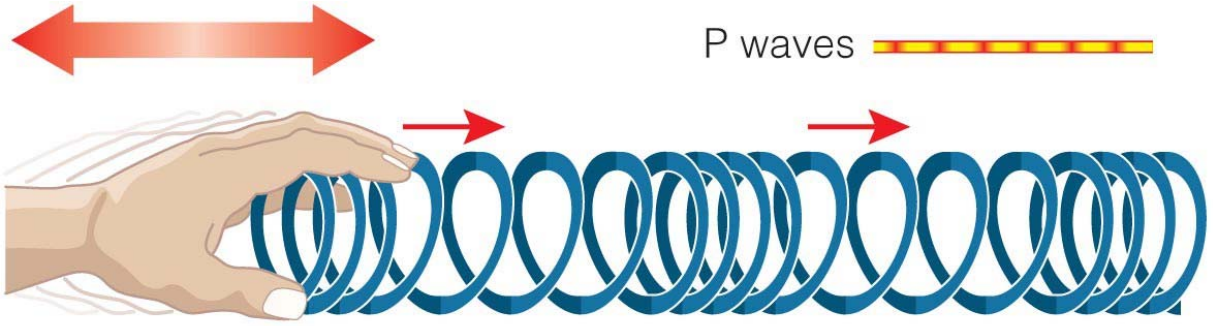
- **P Waves (compression wave)**
- The first kind of body wave is the **P wave** or **primary wave**. This is the fastest kind of seismic wave. The P wave can move through solid rock and fluids, like water or the liquid layers of the earth. It pushes and pulls the rock it moves through just like sound waves push and pull the air.



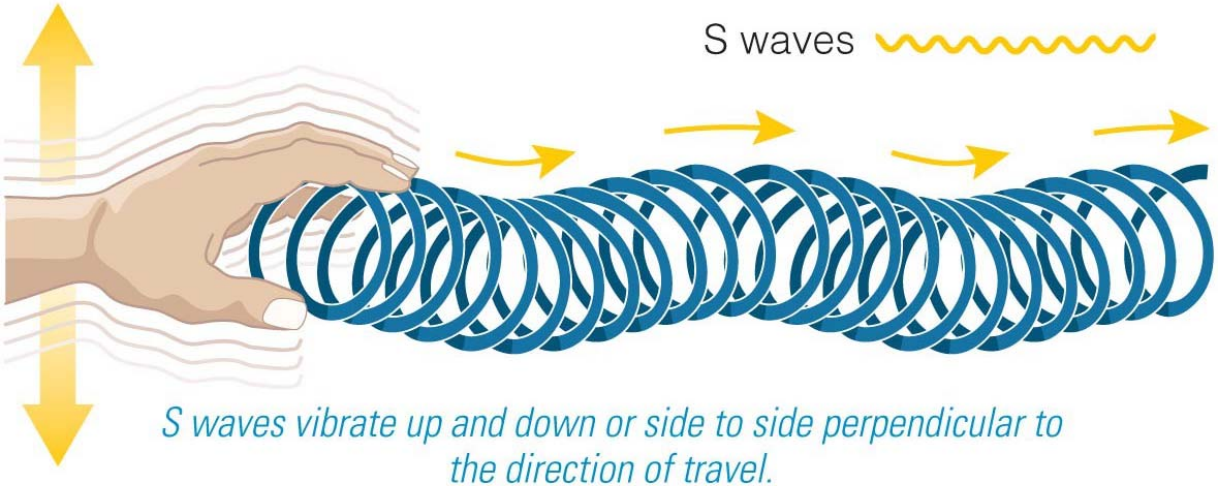
Body Waves

- **S wave (transverse wave)**
- The second type of body wave is the **S wave** or **secondary wave**, which is the second wave you feel in an earthquake. An S wave is slower than a P wave and can only move through solid rock. This wave moves rock up and down, or side-to-side.

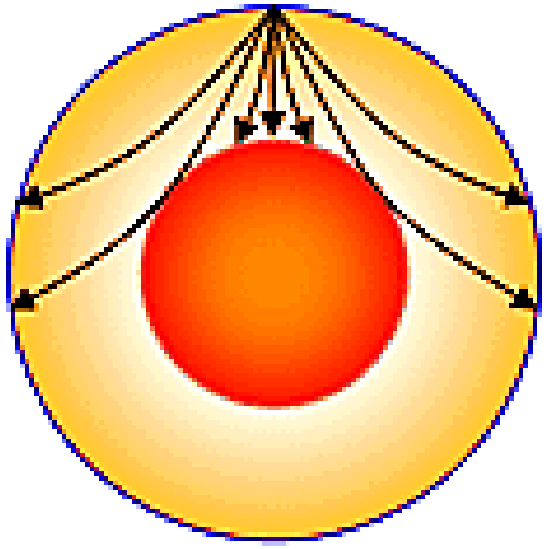


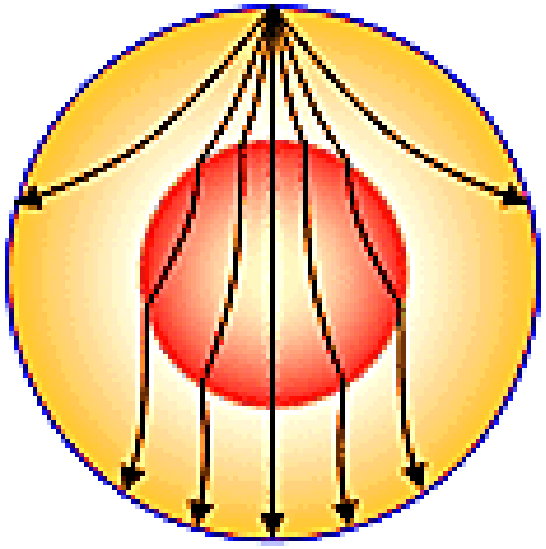


P waves result from compression and stretching in the direction of travel.



S waves vibrate up and down or side to side perpendicular to the direction of travel.





S waves
- transverse
- slow moving
- travel through solids only

P waves
- longitudinal
- fast moving
- travel through liquids and solids

Relationship between Vp and Vs

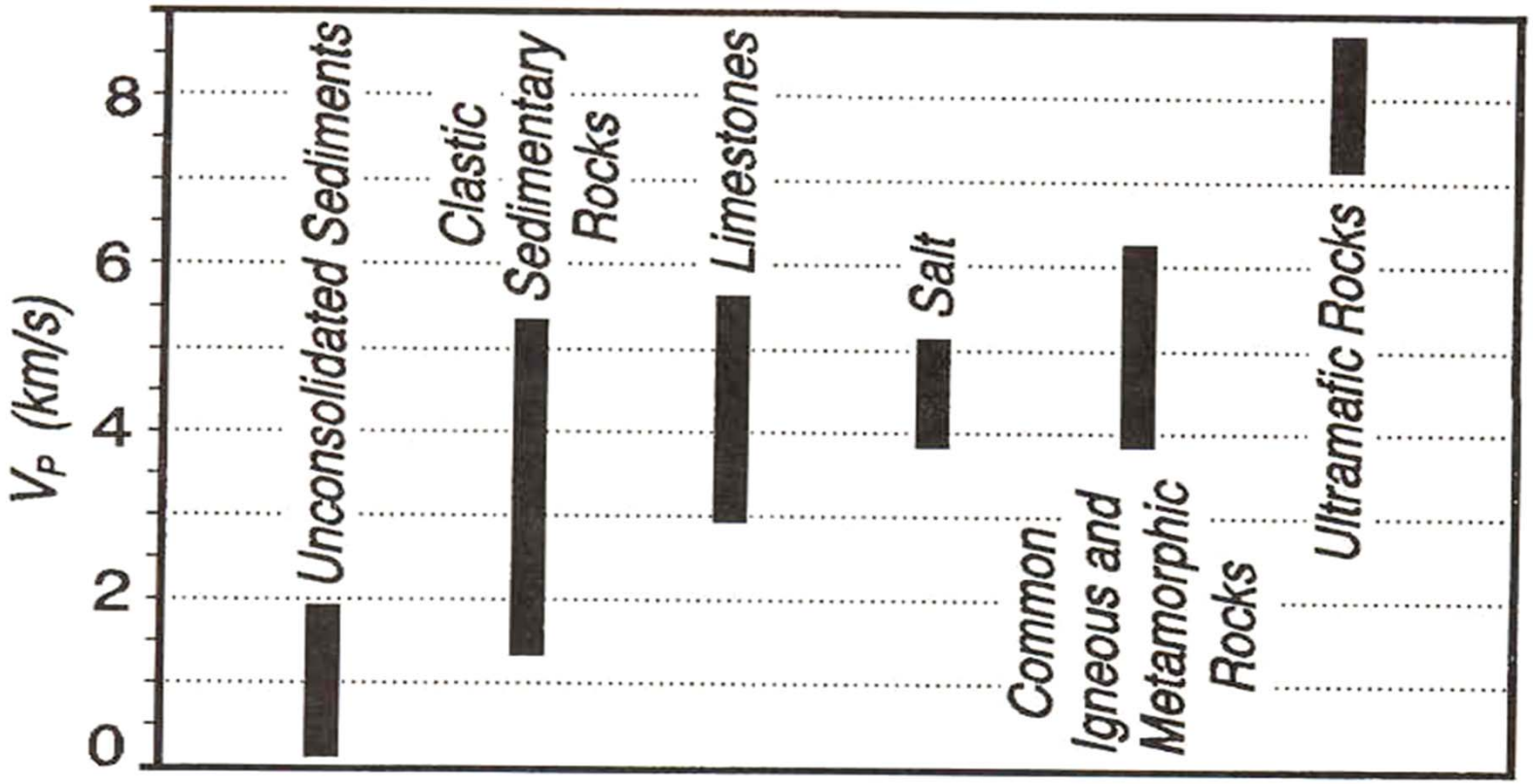
Compressional Waves

$$V_p = \sqrt{\frac{\left(\frac{4}{3}\mu + k\right)}{\rho}}$$

Shear Waves

$$V_s = \sqrt{\frac{\mu}{\rho}}$$

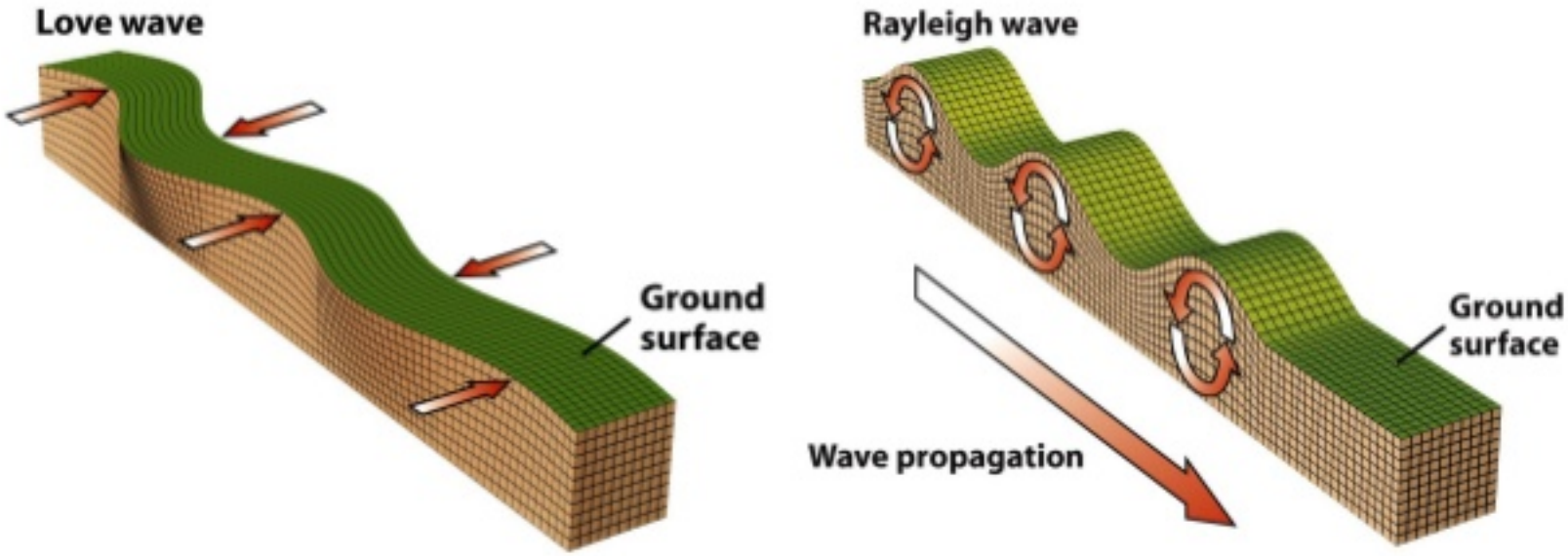
- Averaged Vp/Vs = 1.732 for the crust
- For mafic rocks, Vp/Vs = 1.81
- For felsic rocks, Vp/Vs = 1.70

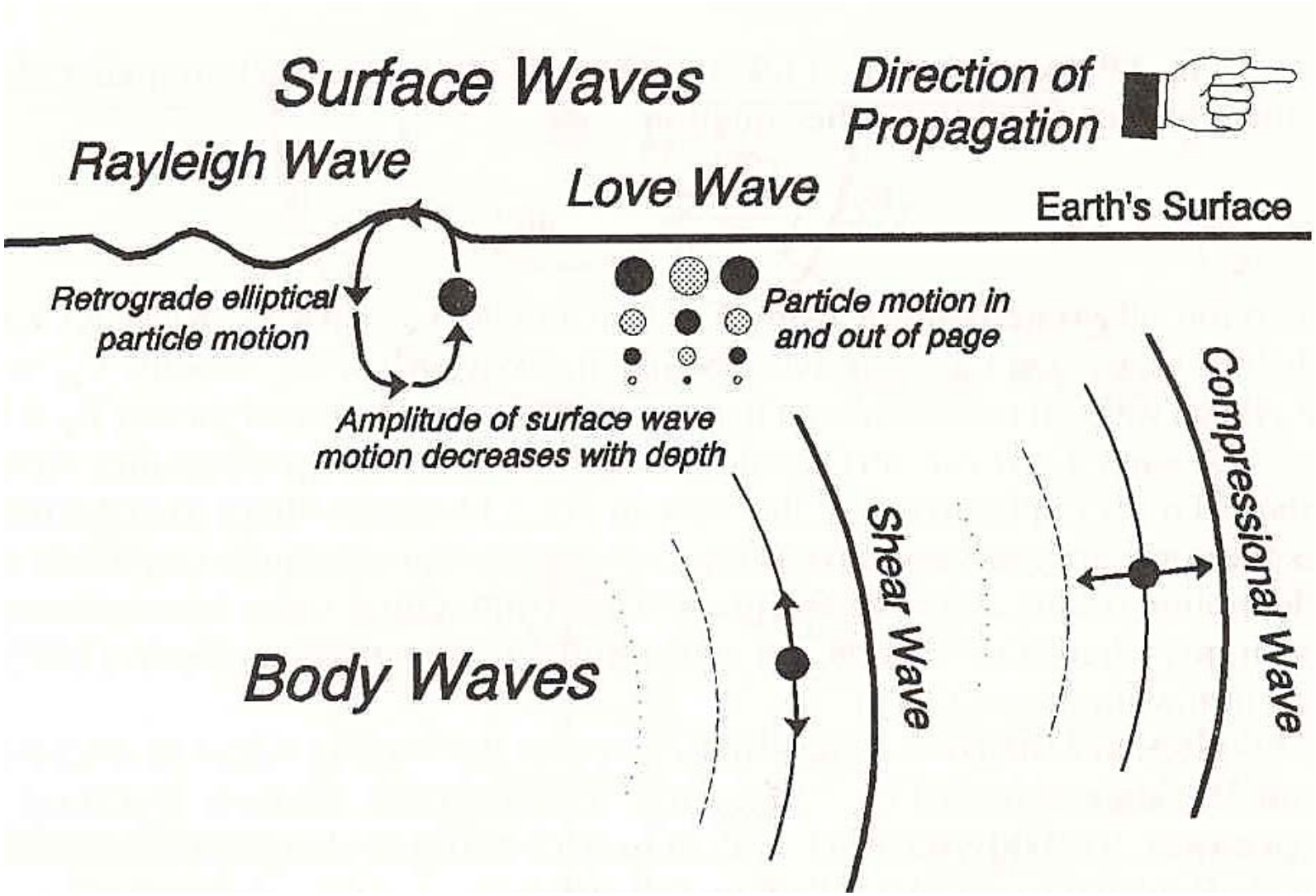

V_P (km/s)
0
2
4
6
8
Unconsolidated Sediments
Clastic Sedimentary Rocks
Limestones
Salt
Common Igneous and Metamorphic Rocks
Ultramafic Rocks

Surface waves- travel along Earth's surface

1. Love waves – S-waves that intersect the surface
   Back and forth motion
2. Rayleigh waves – P-waves at the surface
   move like ripples on a pond

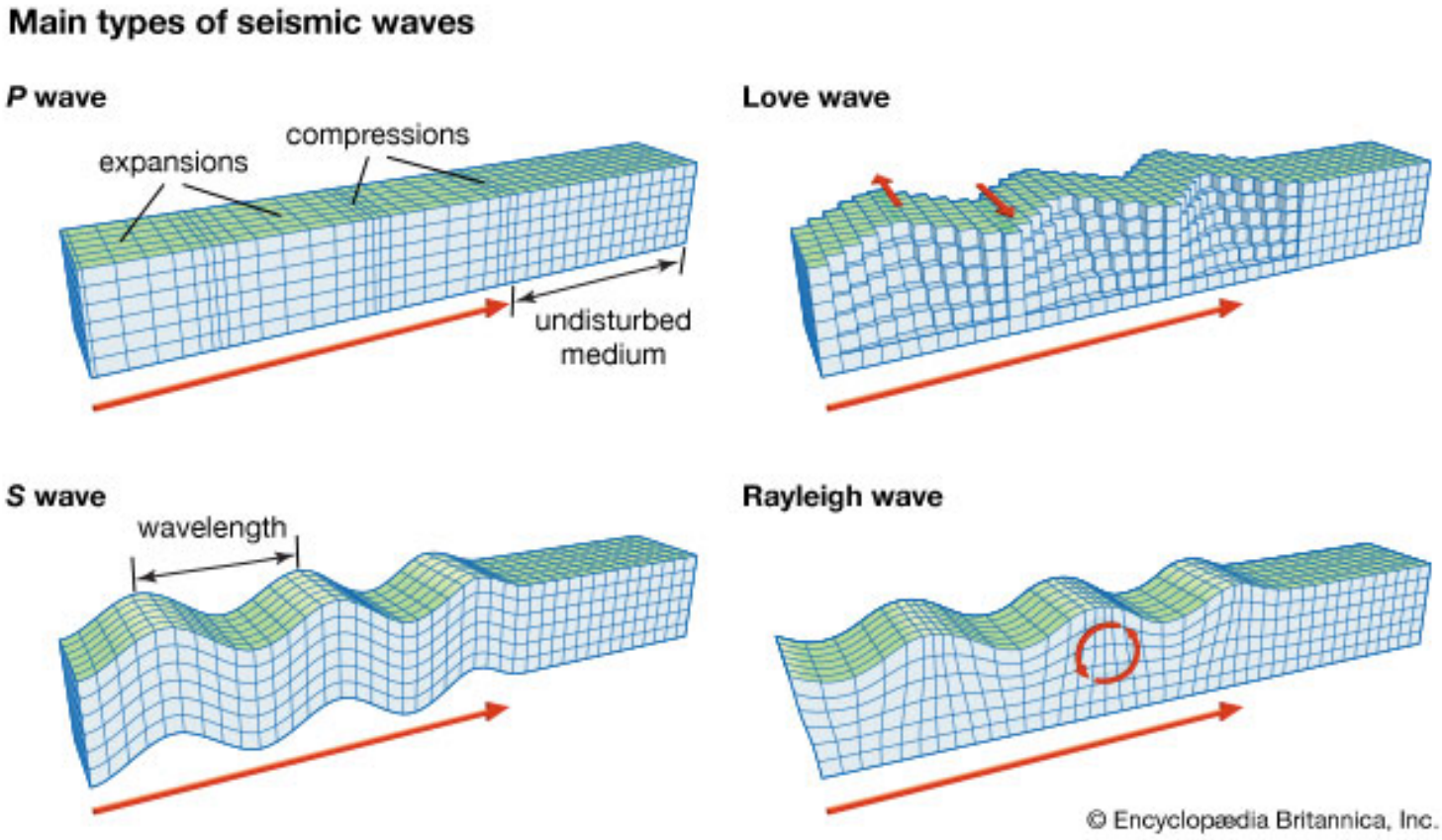
These waves- slowest and more destructive




Surface Waves
Direction of Propagation
Rayleigh Wave
Love Wave
Earth's Surface
Retrograde elliptical particle motion
Particle motion in and out of page
Amplitude of surface wave motion decreases with depth
Body Waves
Shear Wave
Compressional Wave

Types of Seismic Waves

Primary Wave (P-wave)	Secondary Wave (S-wave)	Surface Wave
• Travels through ground	• Travels through ground	• Travels ***only*** on Earth's surface
• Fastest waves	• Medium speed waves	• Slowest waves
• Can travel through solid and liquid	• Only travel through solids	


Main types of seismic waves
P wave
expansions
compressions
undisturbed
medium
Love wave
S wave
wavelength
Rayleigh wave
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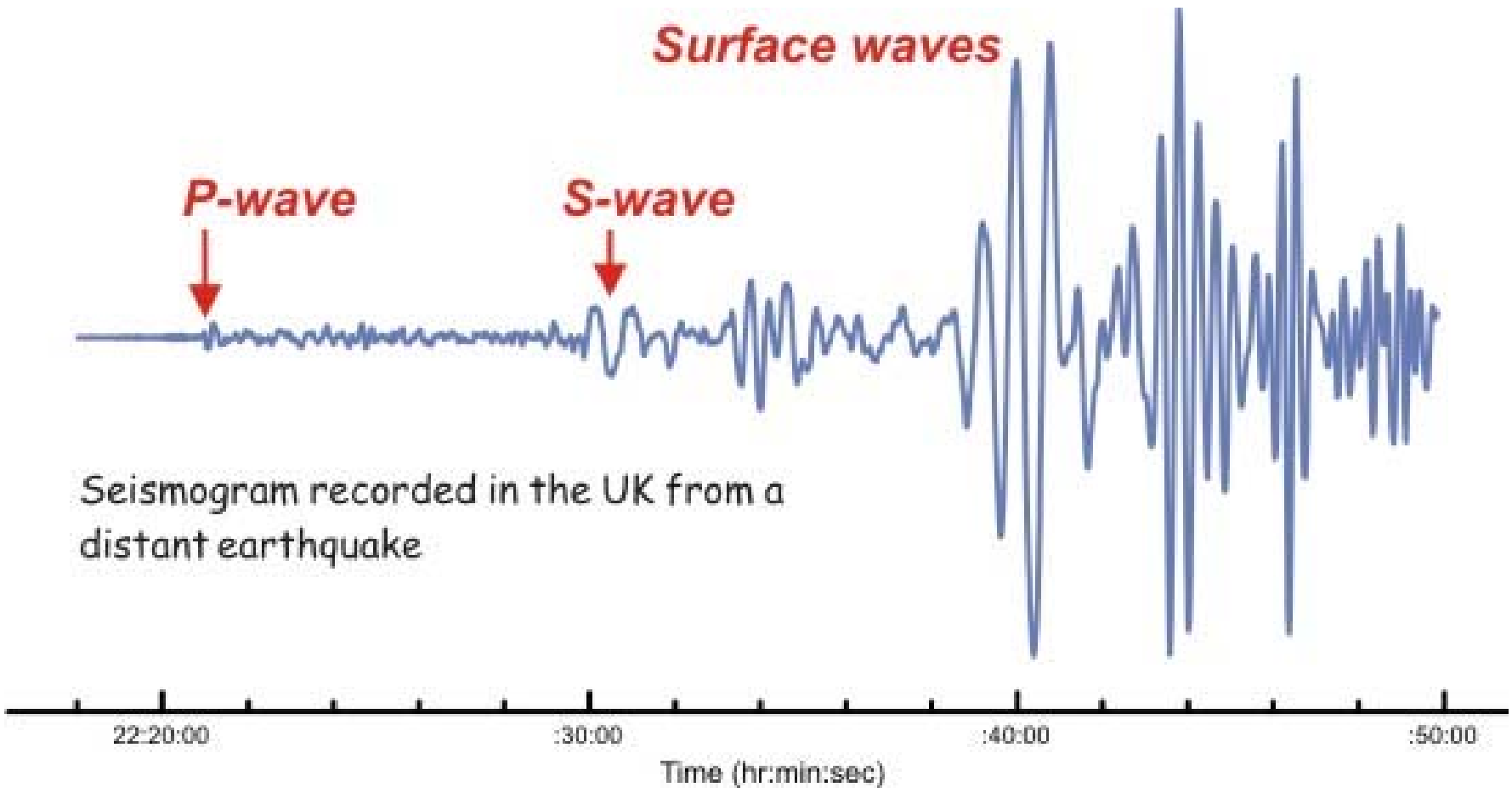
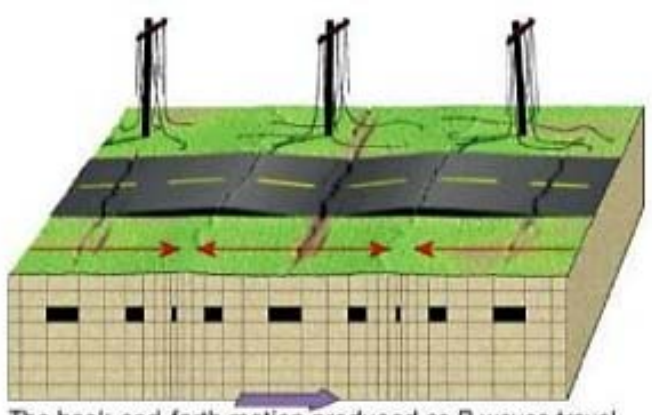
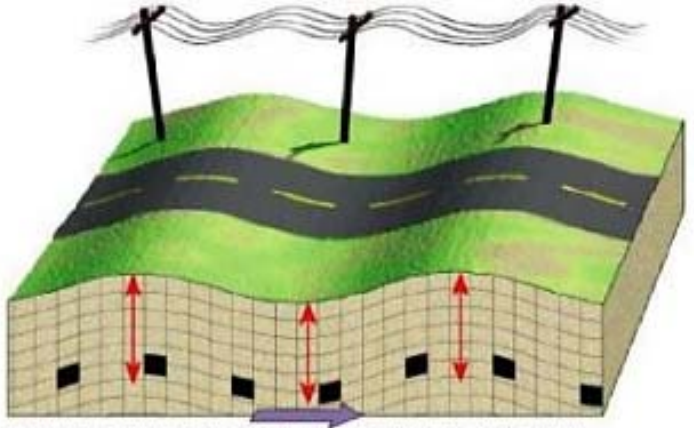
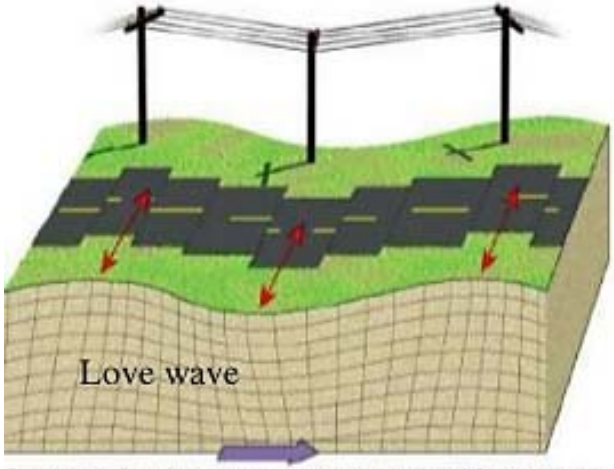

Surface waves
P-wave
S-wave
Seismogram recorded in the UK from a distant earthquake
22:20:00
:30:00
:40:00
:50:00
Time (hr:min:sec)



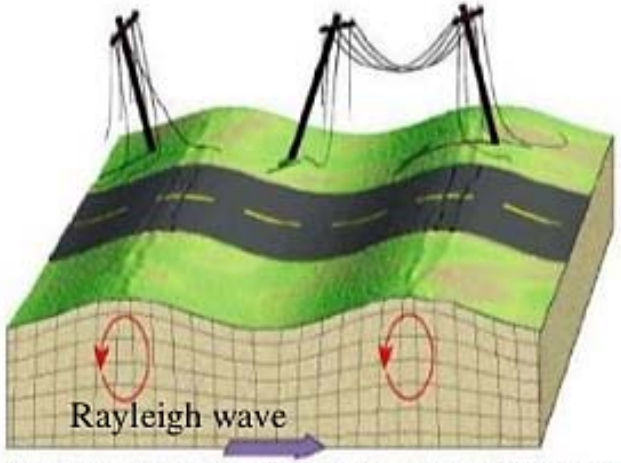
The back-and-forth motion produced as P waves travel along the surface can cause the ground to buckle and fracture.



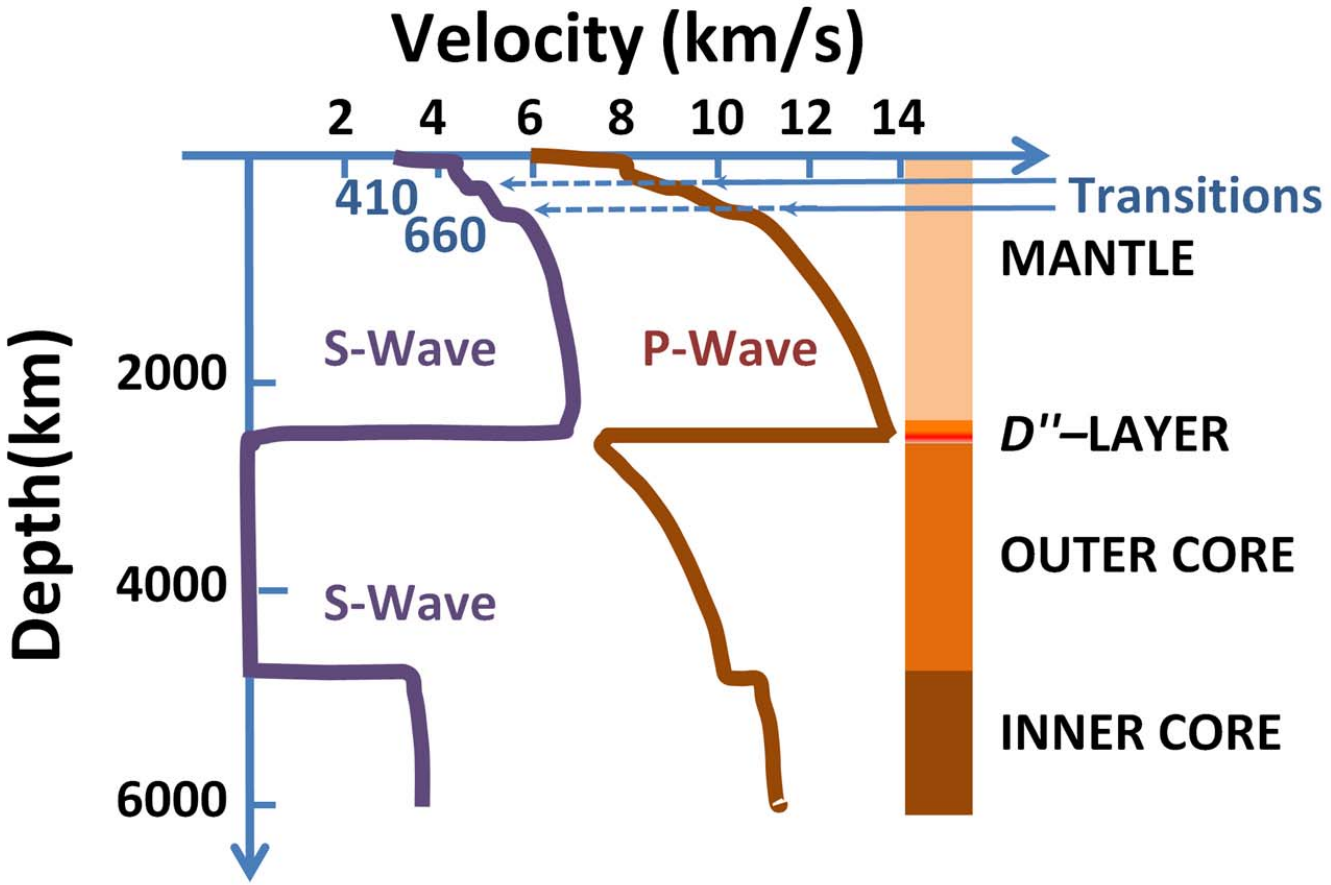
S waves cause the ground to shake up-and-down and sideways.



One type of surface wave moves the ground from side to side and can damage the foundations of buildings.



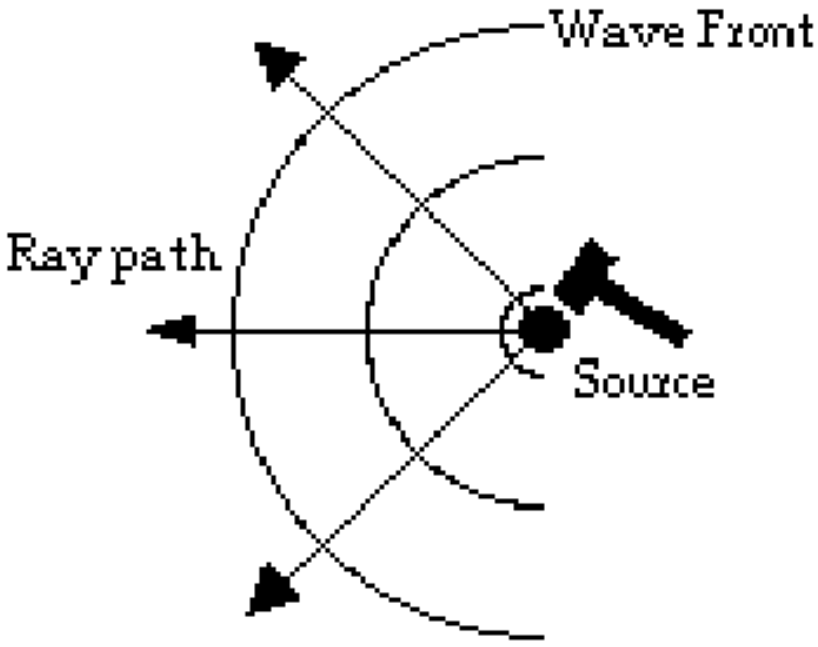
Another type of surface wave travels along Earth's surface much like rolling ocean waves. The arrows show the movement of rock as the wave passes. The motion follows the shape of an ellipse.

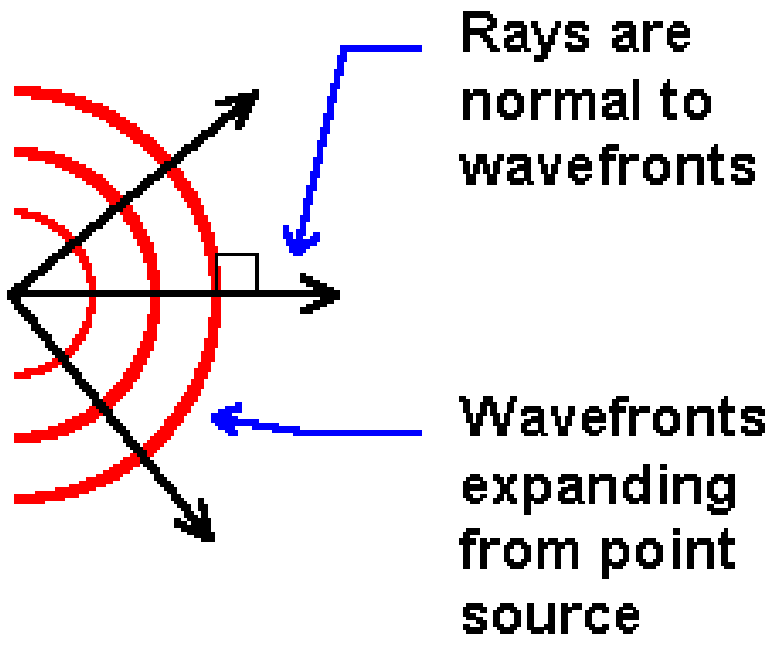


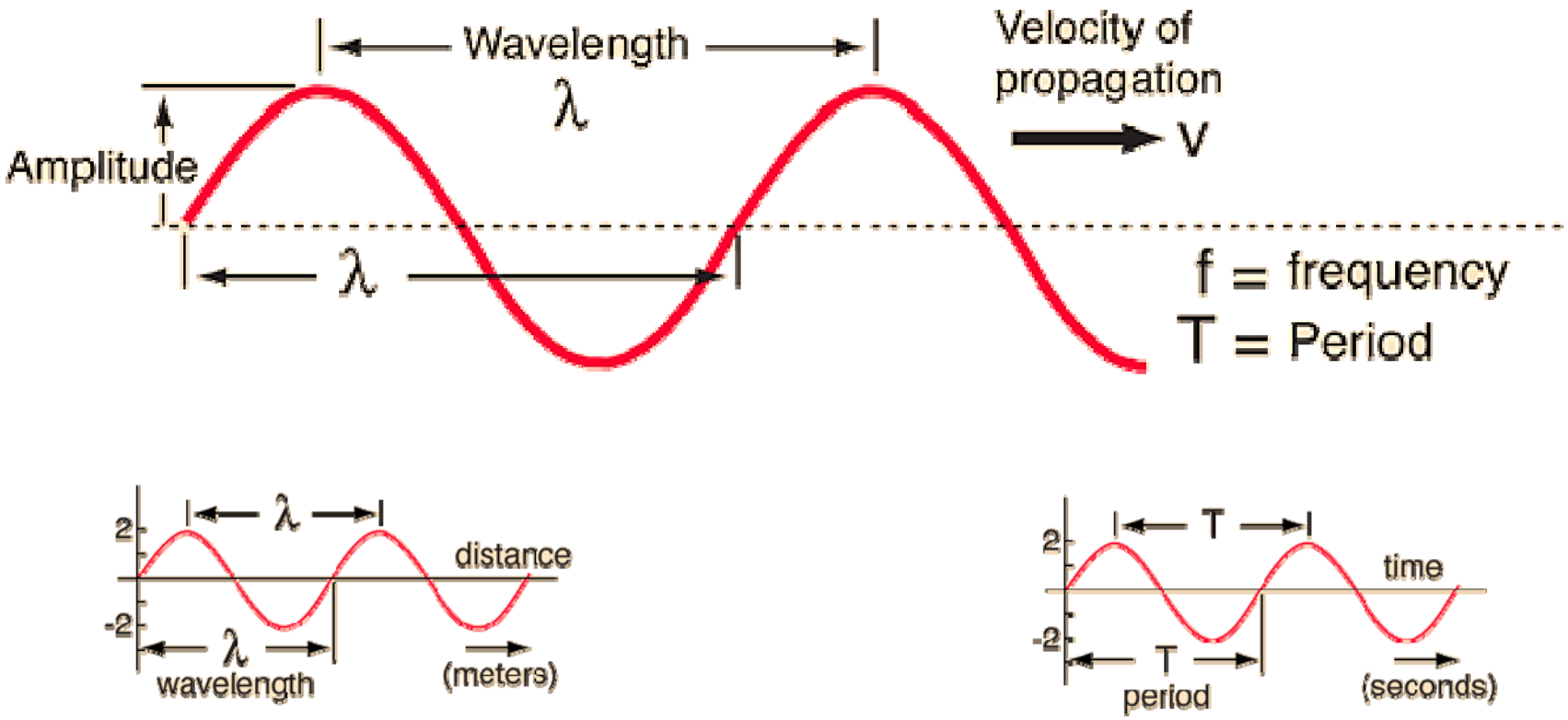
In general, velocity rises with increasing pressure.

Q. What is a wave front? And ray path?

- The wave front is the direct boundary between the seismic waves in the earth material, and the material that the seismic energy has not yet reached
- ray is the vector perpendicular to a wave front.





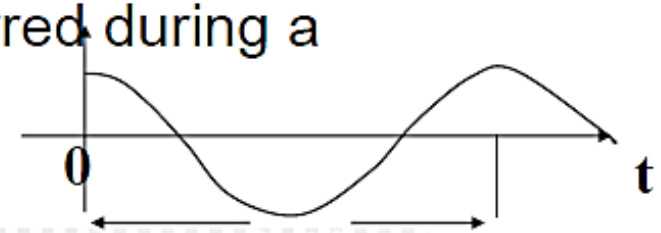

Wavelength
λ
Velocity of
propagation
V
Amplitude
λ
f = frequency
T = Period
2
λ
distance
-2
λ
wavelength
(meters)
2
T
time
-2
T
period
(seconds)

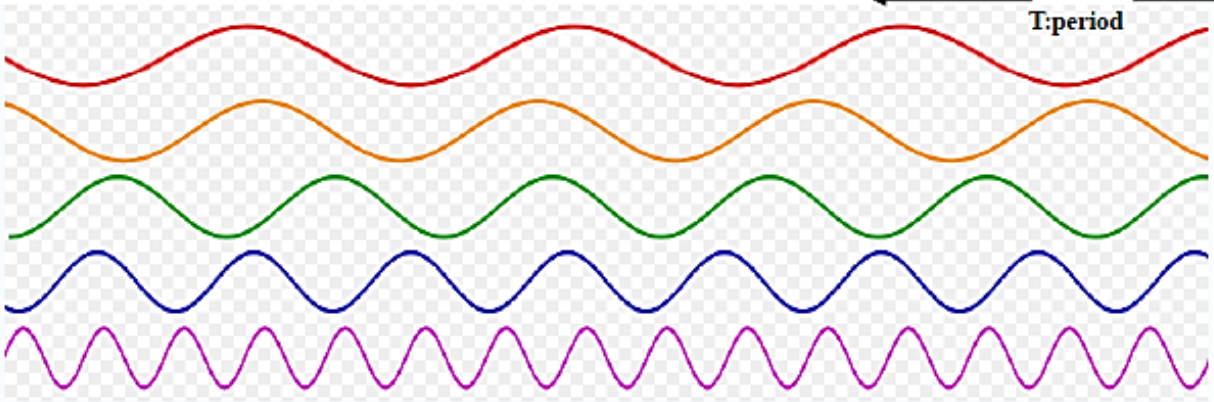
Wave Parameters

- Wave speed (v): unit: m/s; $V = x / t = \lambda / T$
- Wave period (T): unit: s

  Time needed from one peak to another successive peak.
- Frequency (f): unit: Hertz; f=1/T

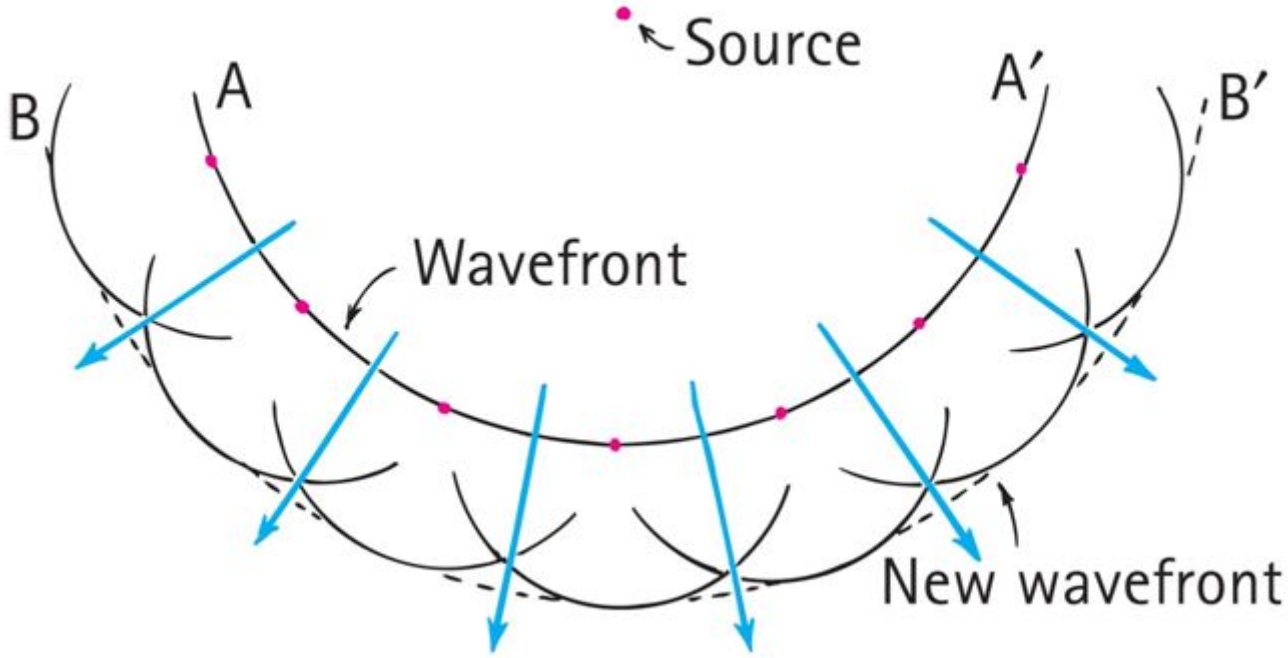
  Number of oscillations occurred during a standard interval of time
- Wave number: $K = 2\pi / \lambda$





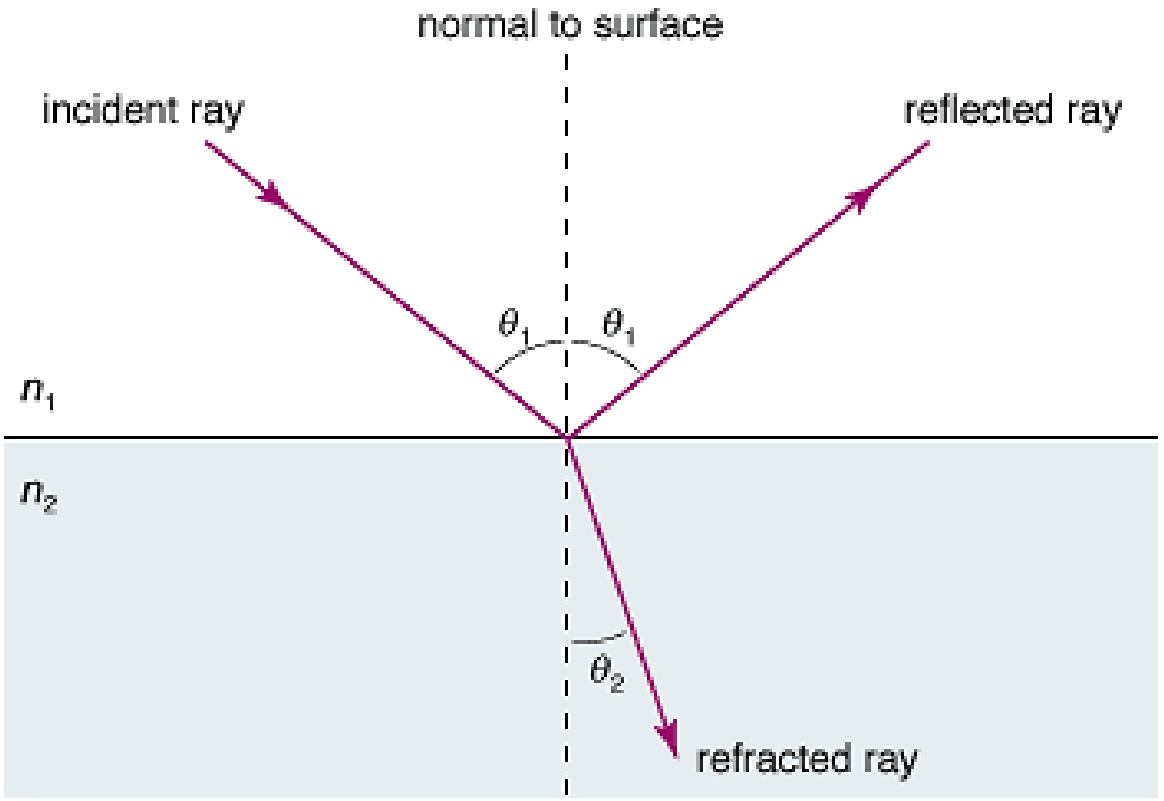
Q. What is Huygens's Principle?

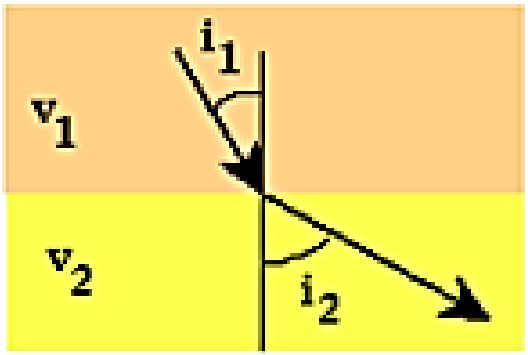
- Huygens's Principle is a method of analysis applied to problems of wave propagation.
- He proposed that every point on a wave-front may be considered a source of secondary spherical wavelets which spread out in the forward direction at the speed of light.



Q. What is Snell's Law?

Snell's Law: describes how elastic waves are reflected and refracted across a boundary separating layers of differing velocity.



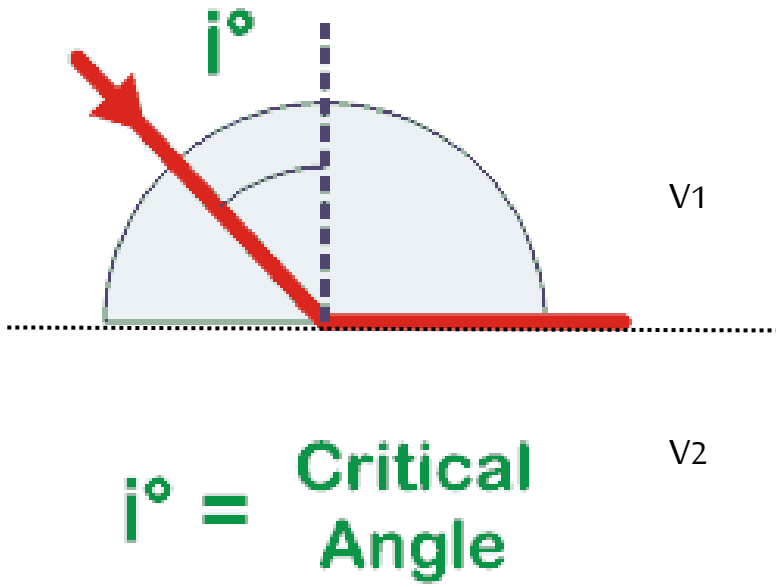


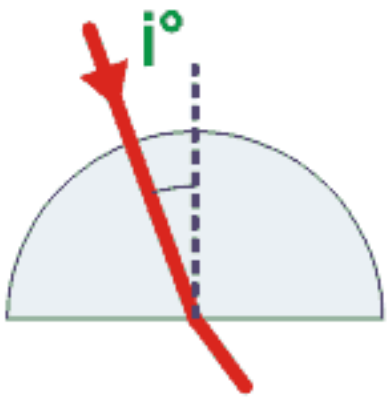
$$\frac{\sin i_1}{v_1} = \frac{\sin i_2}{v_2}$$

i_1 (angle of incidence) and i_2 (angle of refraction)

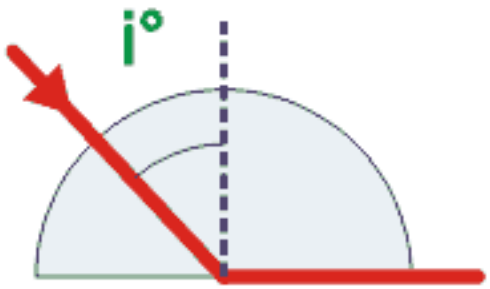
Q. What is the critical angle?

When V2 is greater than V1, the angle of refraction is greater than the angle of incidence, then the angle of incidence for which this occur us called the critical angle.

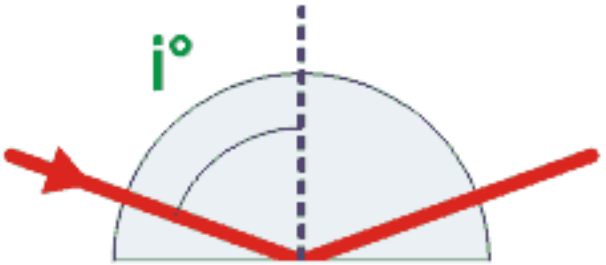




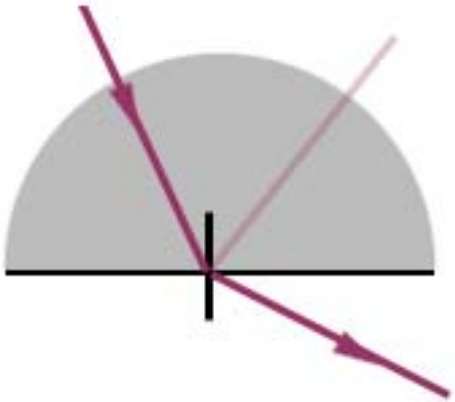
i° < Critical Angle



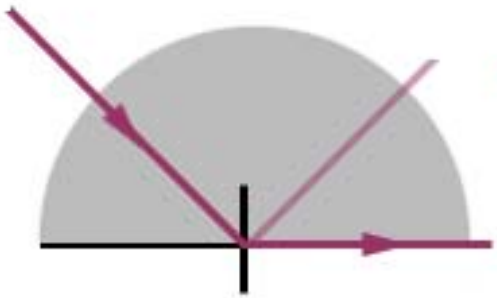
i° = Critical Angle



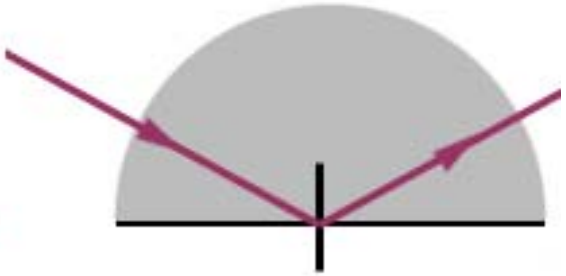
i° > Critical Angle



The angle of incidence is less than the critical angle.
Ray is refracted with a very small reflection.



The angle of incidence is equal to the critical angle.
Ray emerges along the edge of the block.



The angle of incidence is greater than the critical angle.
The ray is totally internally reflected.