

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

GPH 201

Principles of Geophysics

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:

Physical and mathematical laws and its relation to the Earth properties, Elasticity theory and properties of wave propagation in seismic reflections, refractions, wave equations, Seismic wave characteristics, Potential field theories, Principles of different exploration techniques, Interpretation of earth's structures from geophysical data.

Grades:

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

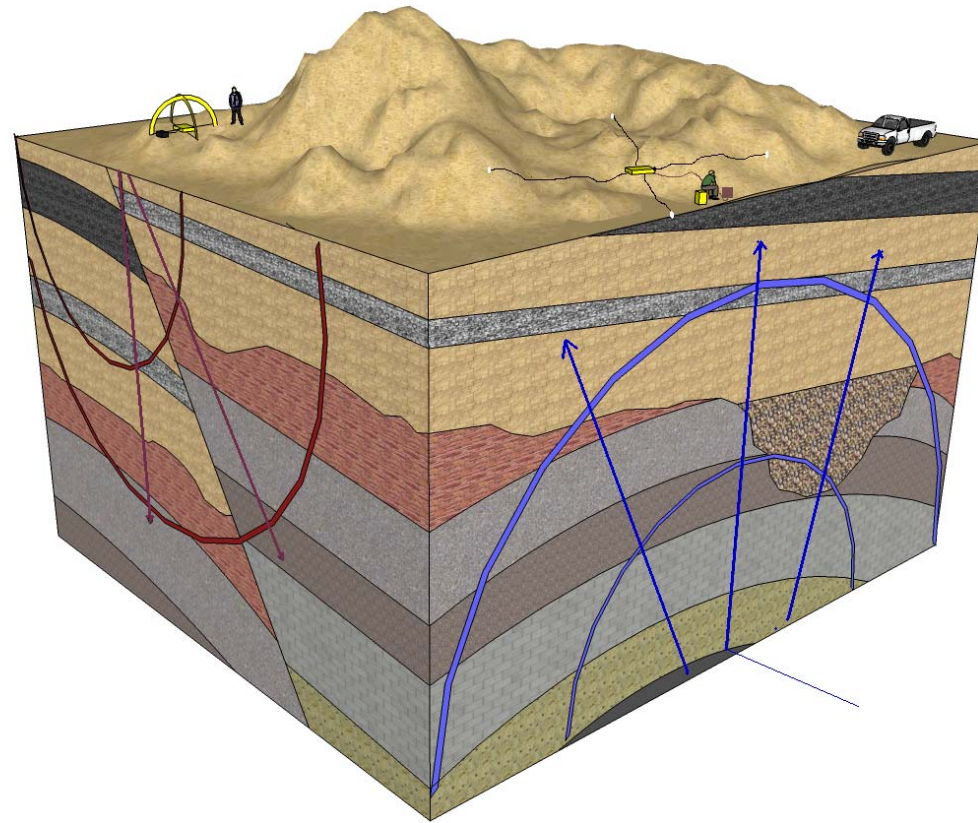
- Group study.
- Ask questions.
- Don't copy.
- Arrange your time.
- Always prepare a plan to achieve your targets.

Any questions?

What is Geophysics?

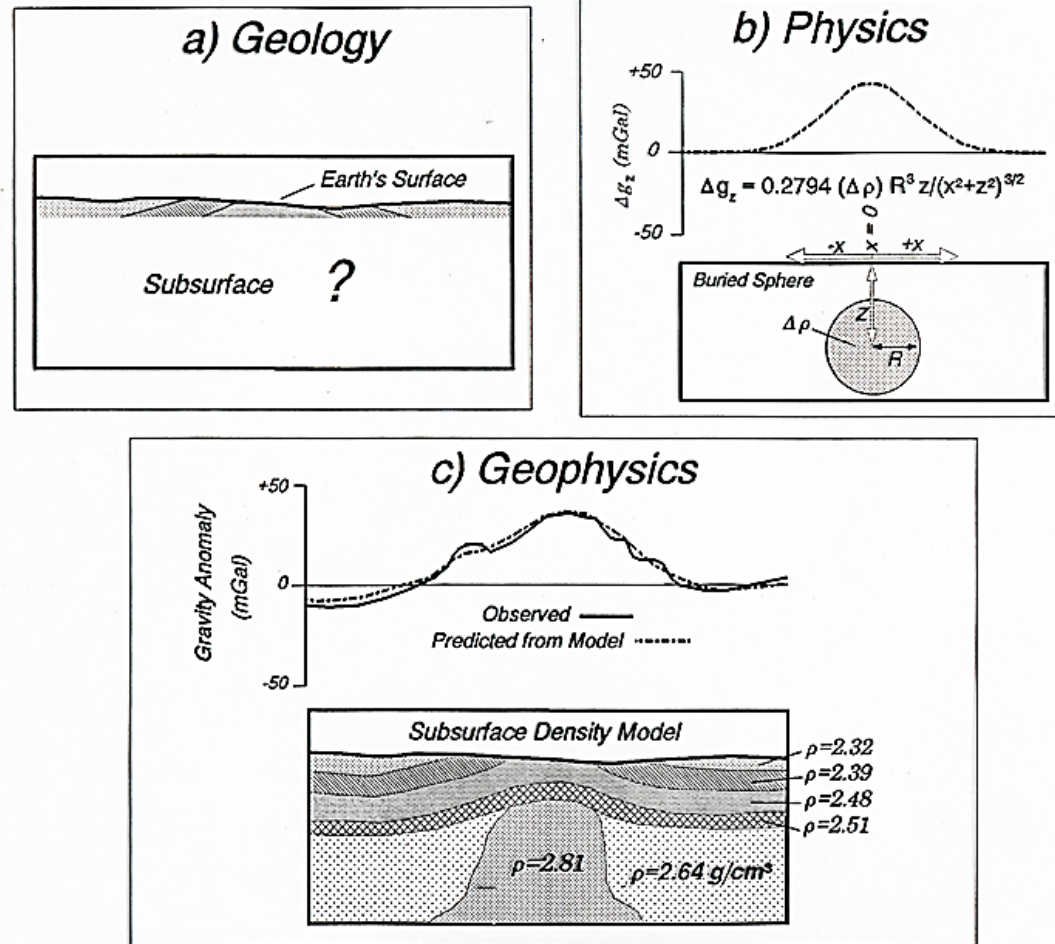
GPH 201 - Fundamental Considerations

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



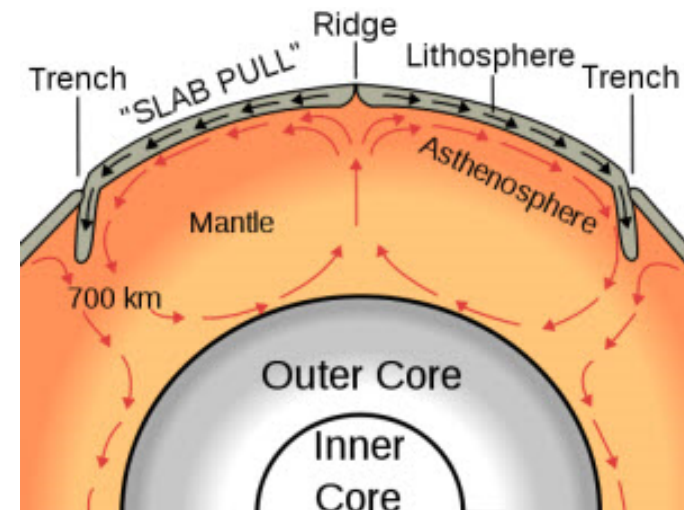
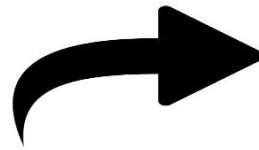
GPH 201 - Fundamental Considerations

Geophysics = Geological observations + Physical laws



Lillie, *Whole Earth Geophysics*, Fig 1.1







Observation



Beer

Computation

$$\rho \frac{\partial^2 (\nabla \times u_{sh})}{\partial t^2}$$

GEOLOGY

Somewhere
in between

GEOPHYSICS

Maps



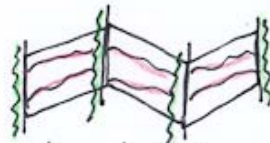
Hammers & optics



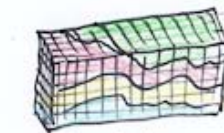
Rocks, volcanoes,
earthquakes



Gore-Tex
& hiking boots
& beards...?
(on men)



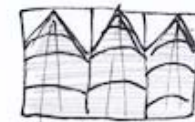
integrated interpretation



Models

MADE UP BY MATT

The stereotyped, hackneyed
view of geology & geophysics
... the truth is in between



Shot
records



Laptops & electronics

10110001100

$$\frac{1}{2\pi} \int_{-\infty}^{\infty} e^{i\omega t} d\omega$$

$$\mathbf{F} = m\ddot{\mathbf{u}}$$

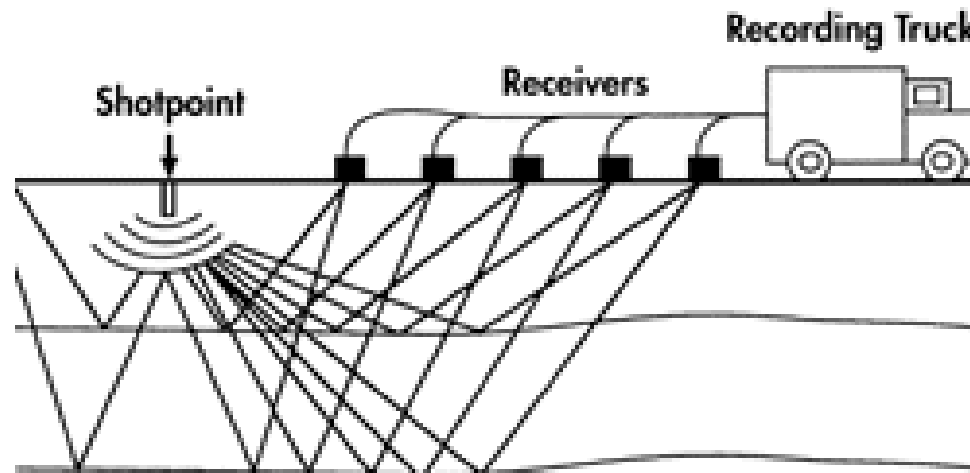
digit, physics, math



Corduroy
& tank tops
& spectacles?

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

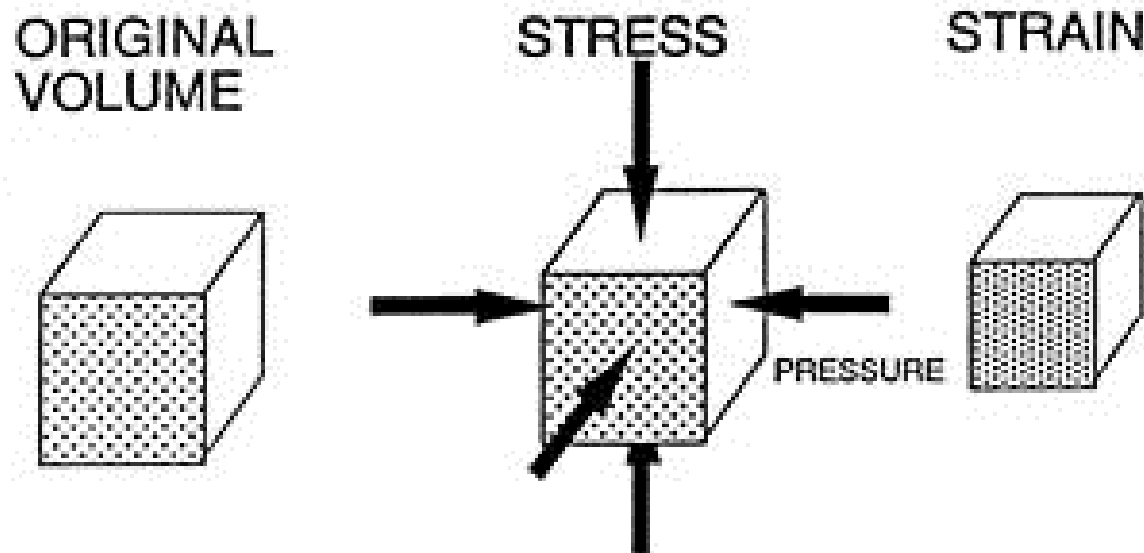
*the ability of an object or material
to resume its normal shape after
being stretched or compressed*

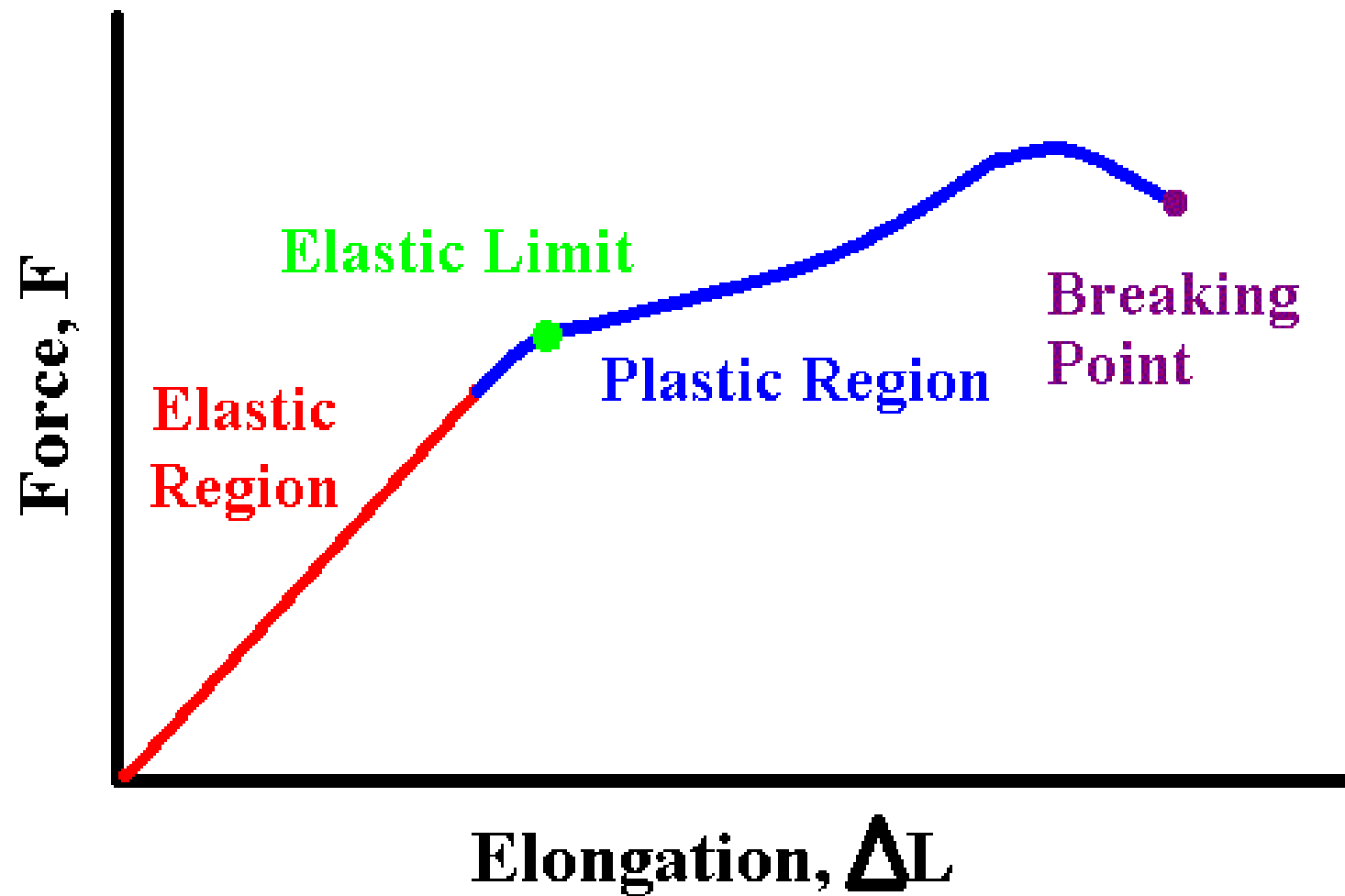


Theory of Elasticity:

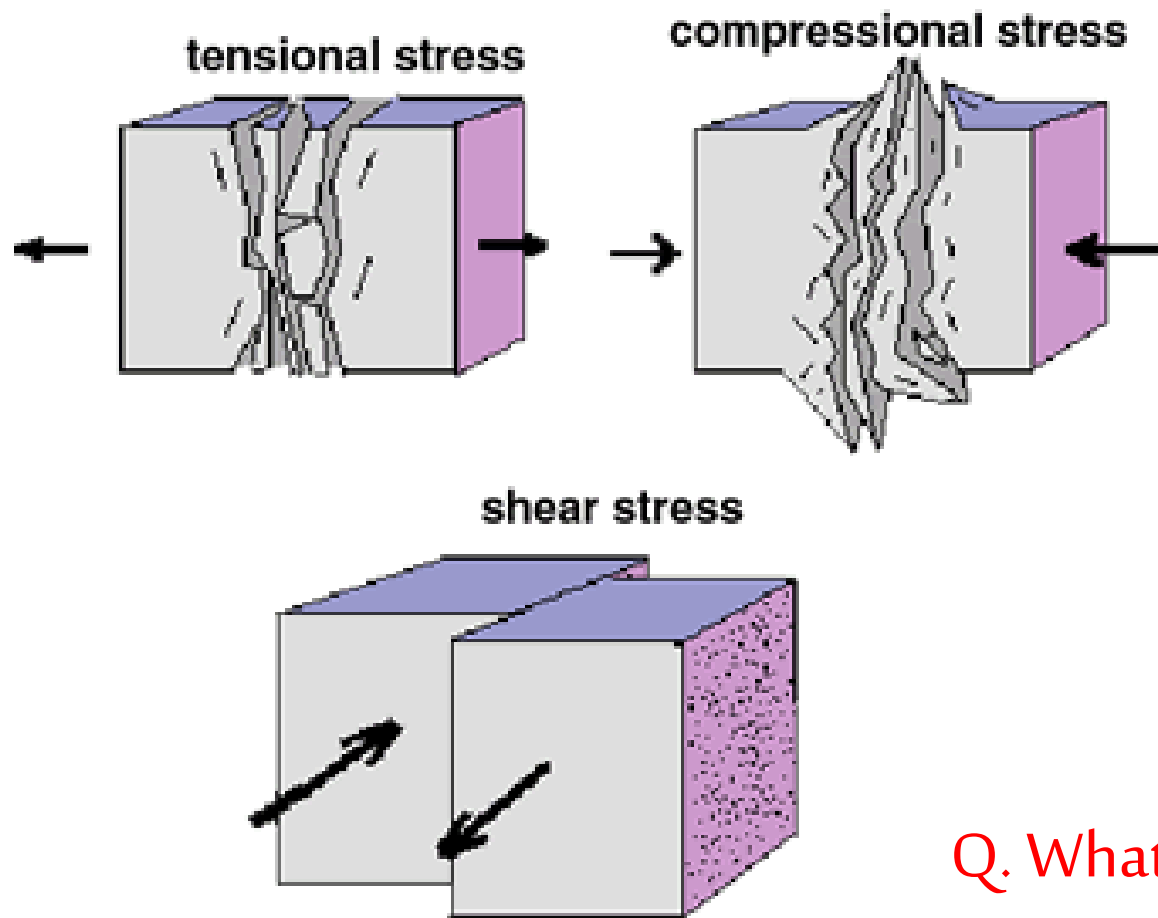
Stress: is the ratio of applied force F to the area across which it acts.

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).





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



Q. What is going on Earth?

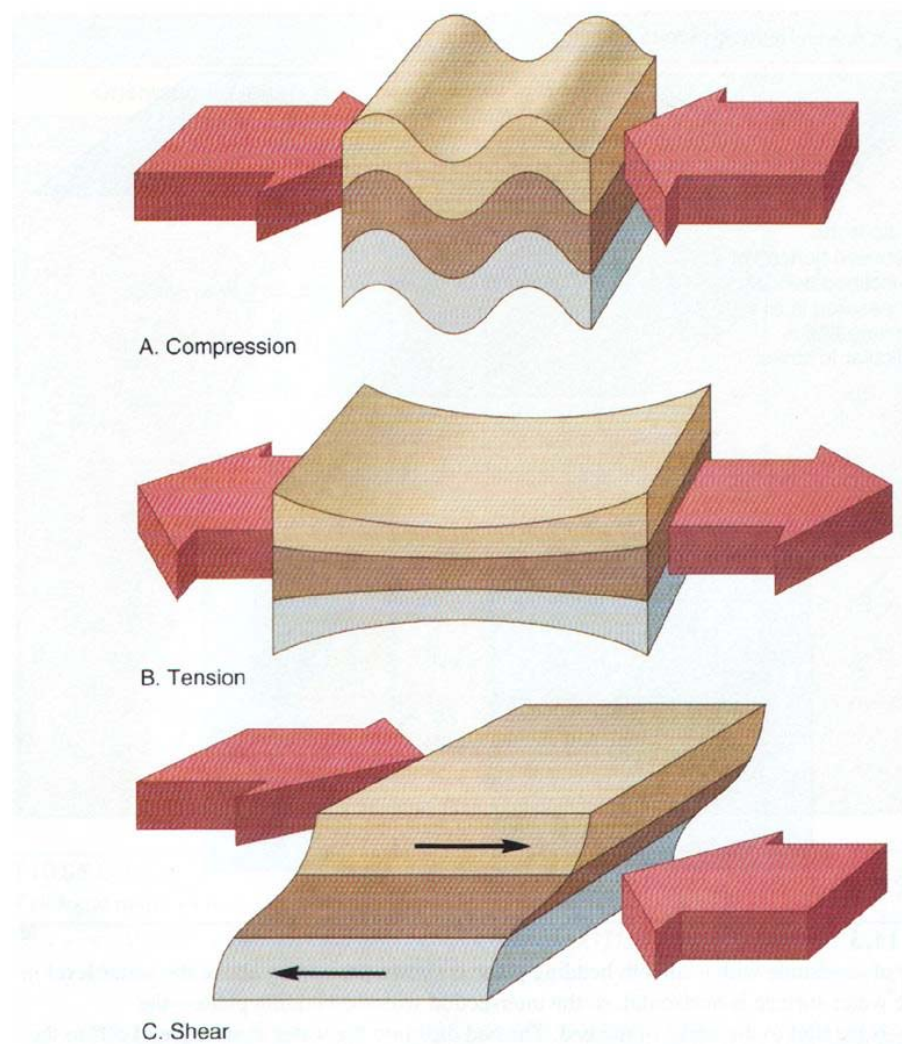


FIGURE 14.1

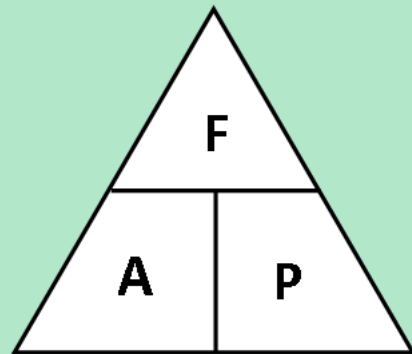
The three principal types of stress; A. compression; B. tension; C. shear.
(Adapted from Jones, 2001: Laboratory Manual for Physical Geology, 3rd Edition)

Q. What is pressure?



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


Force Area Pressure



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

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

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

$$F = ma$$


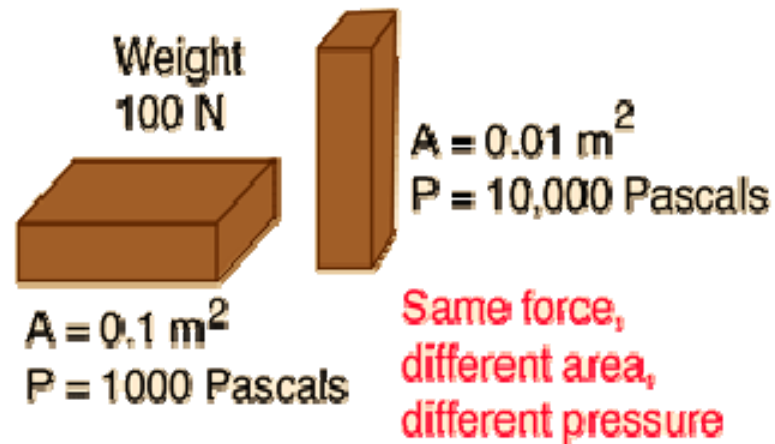
N **kg** **m/s²**

F = Net force

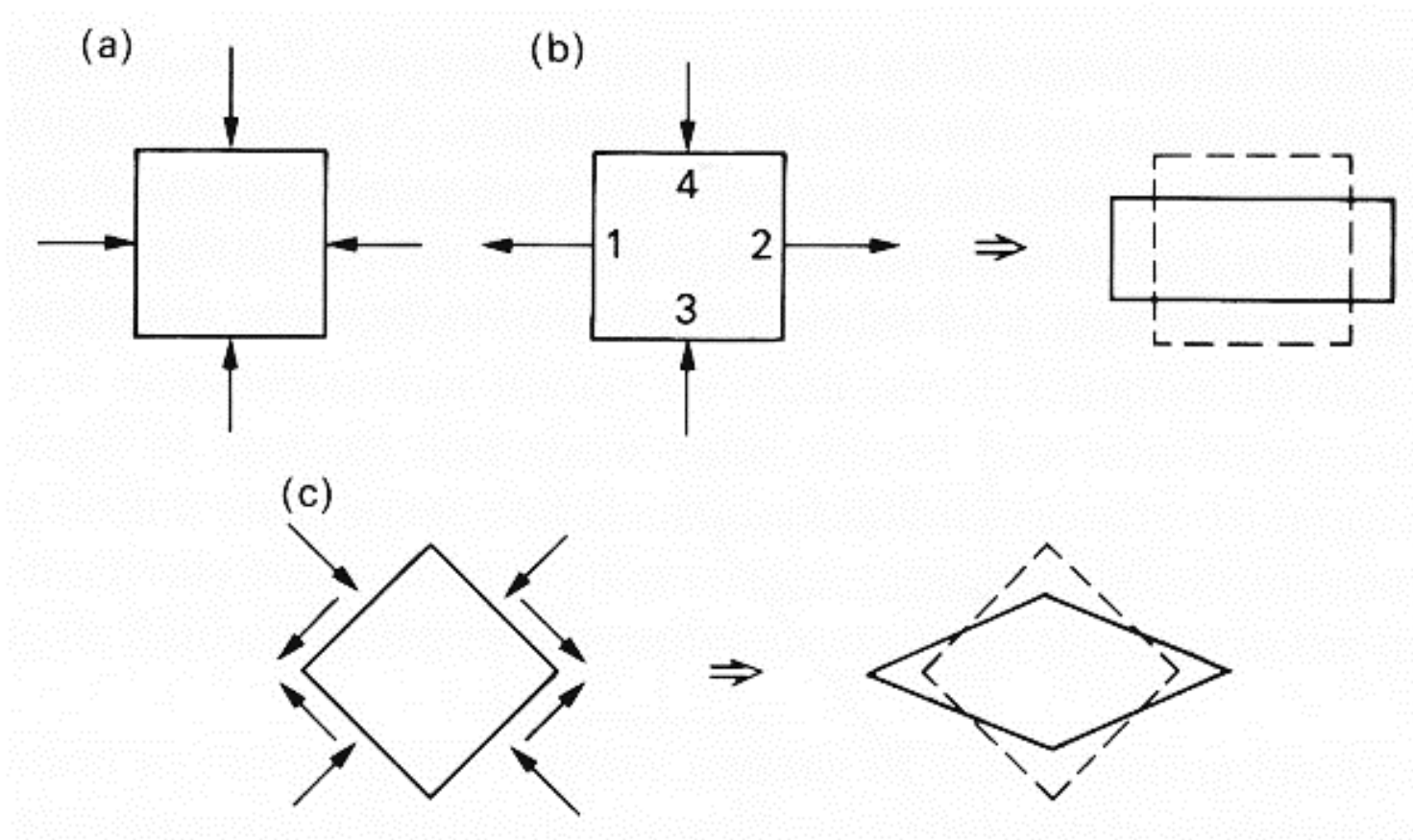
m = mass

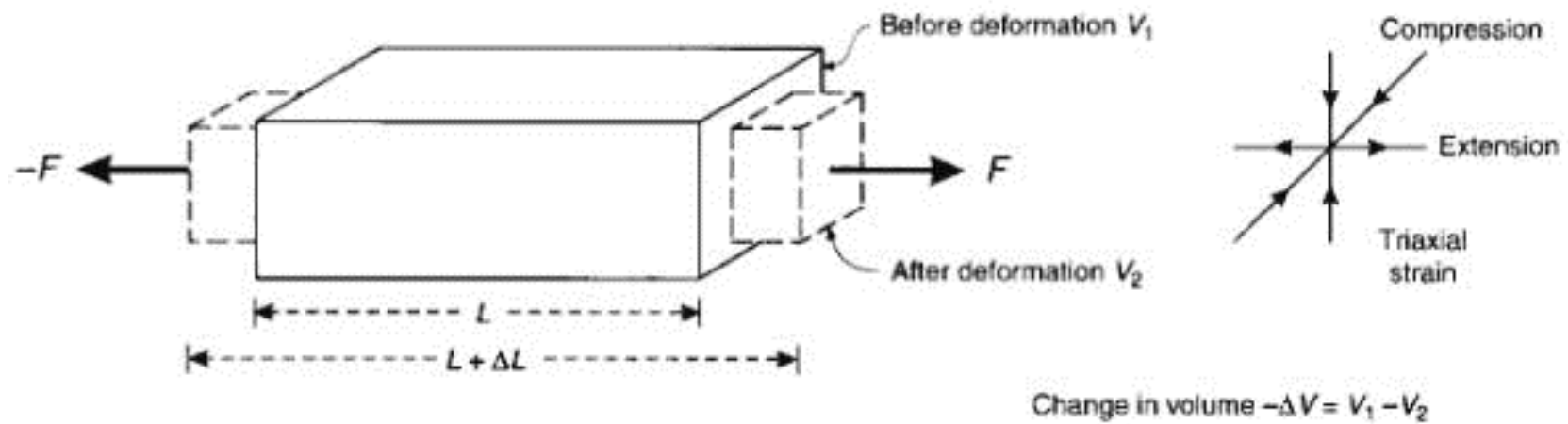
a = acceleration

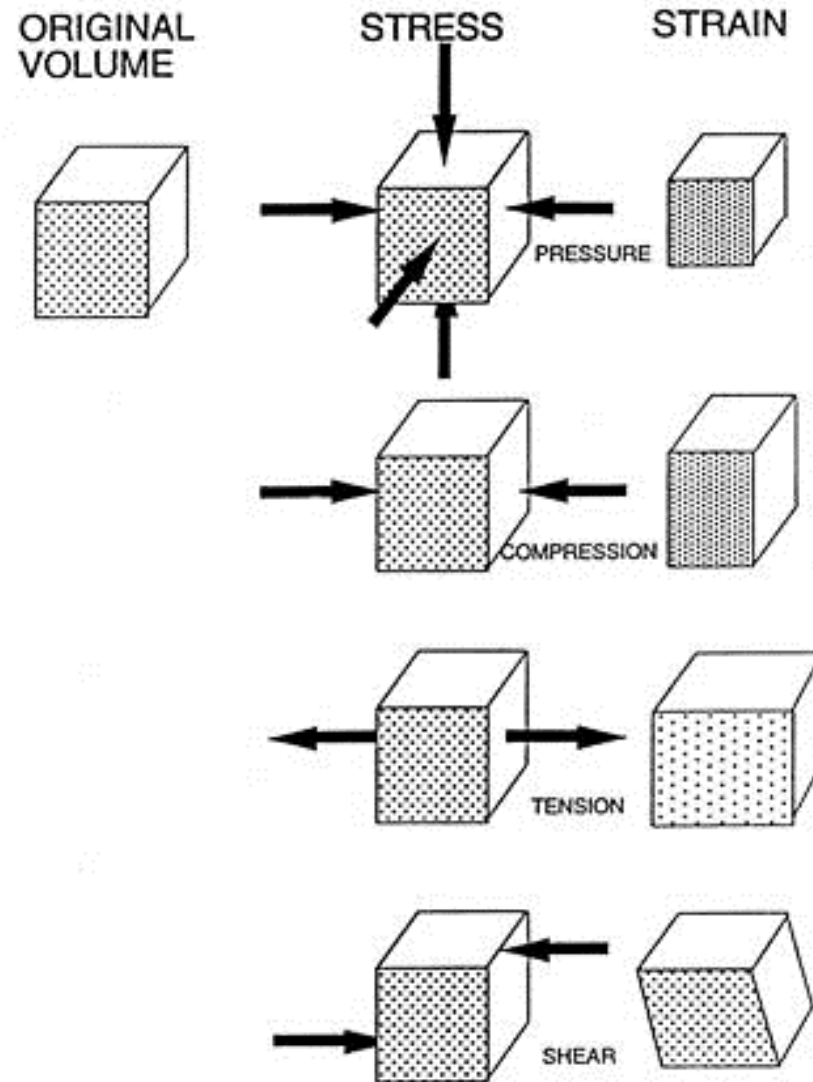
$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

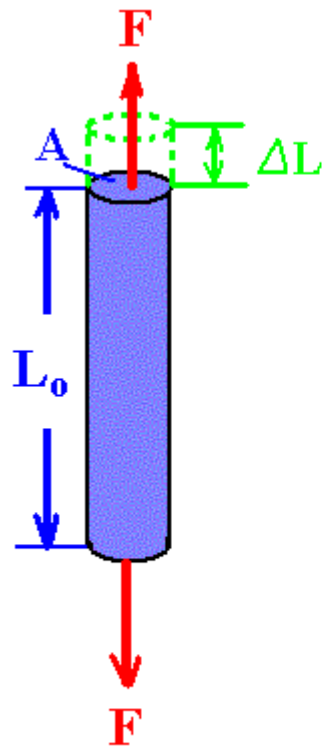


Pressure: Forces act equally in all directions perpendicular to faces of body.

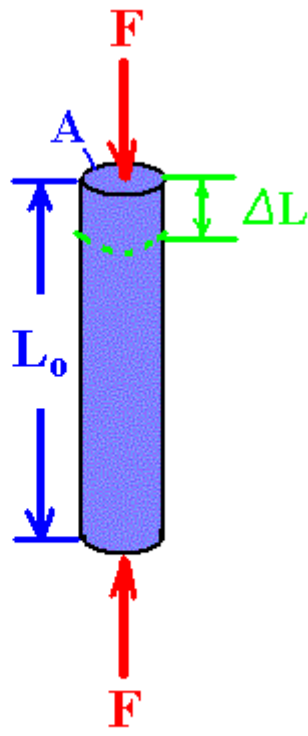




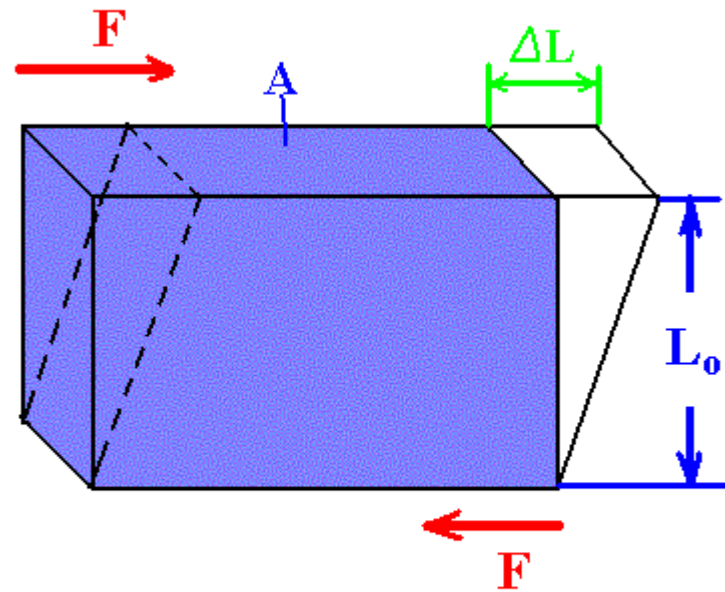




Tension

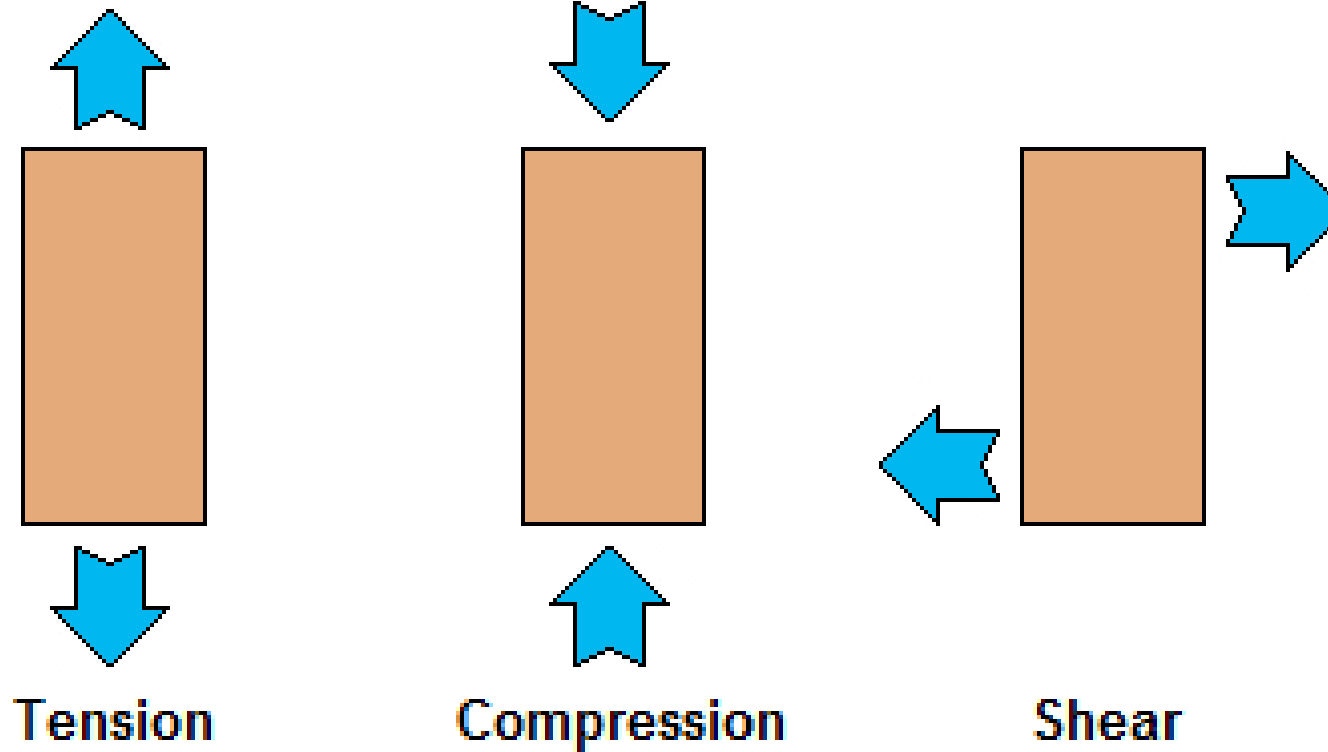


Compression



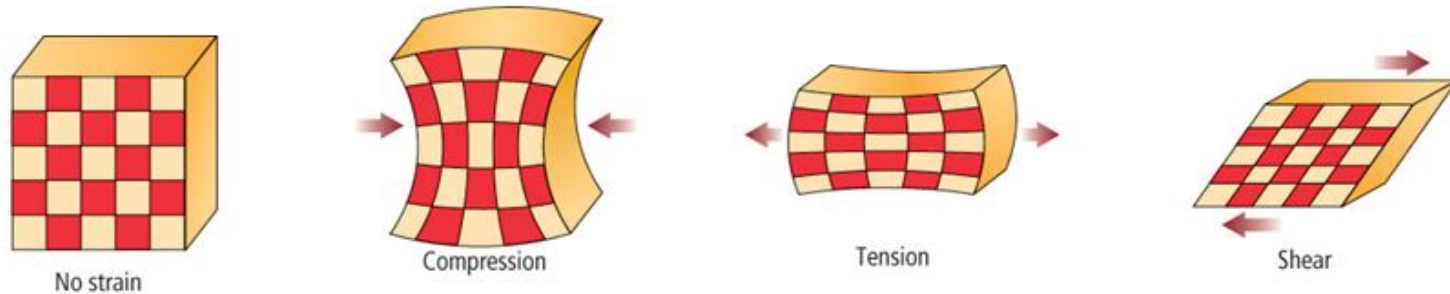
Shear

Types of stress:



Types of stress:

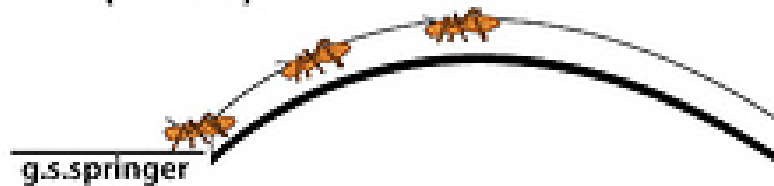
- **Compression** causes a material to shorten.
- **Tension** causes a material to lengthen.
- **Shear** causes distortion of a material.



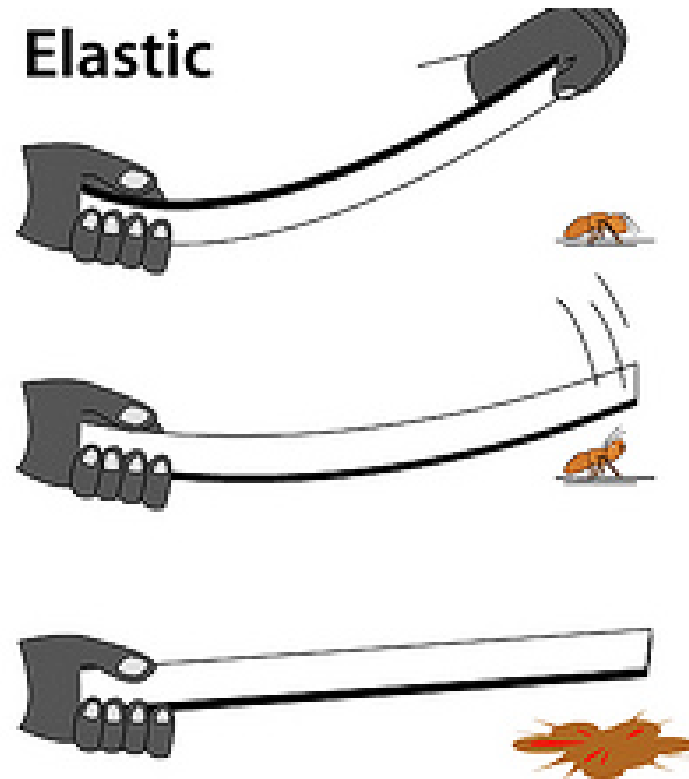
Brittle



**Ductile
(Plastic)**

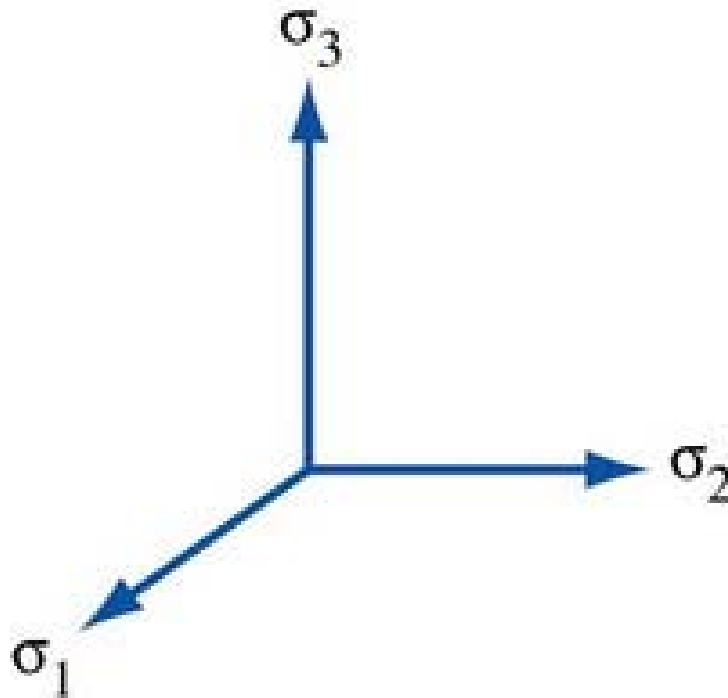


Elastic



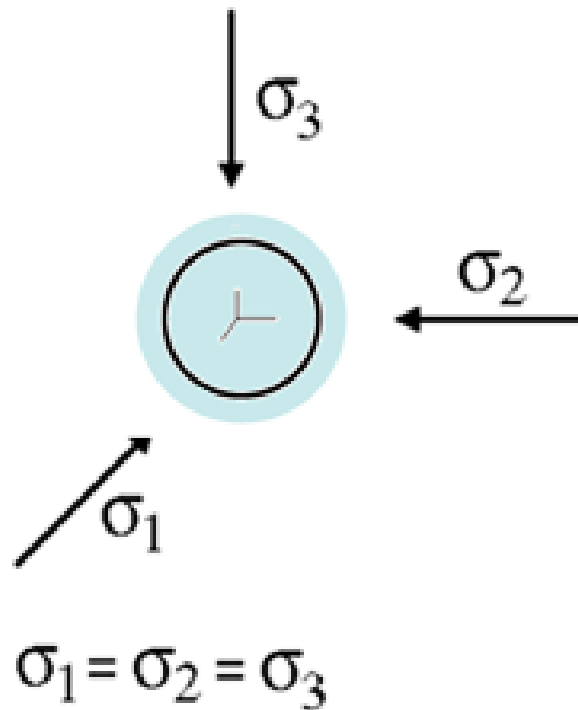
Q. What are the differences between them?

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.

$$\text{Pressure} = \text{sum of principal stresses}/3$$

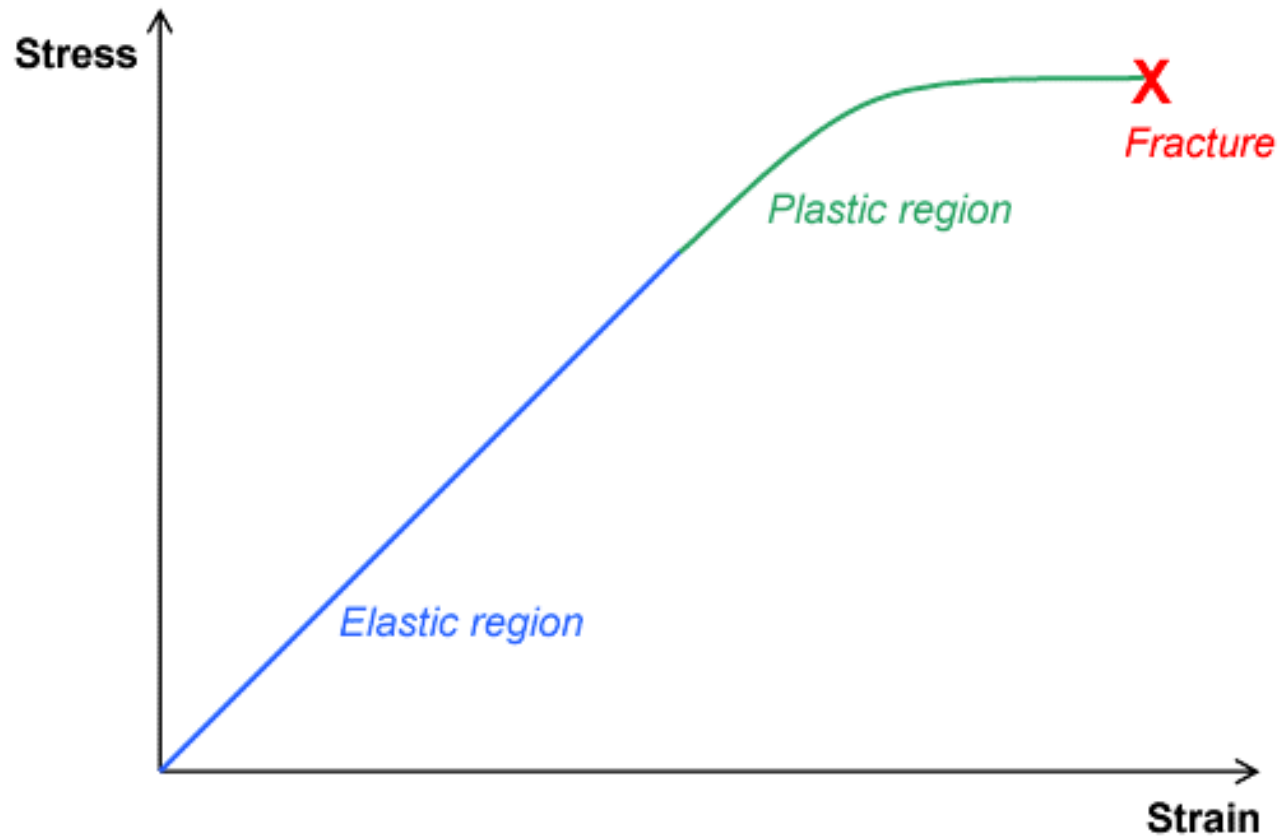


- Stresses towards the interior: compression.
- Stresses towards the exterior: tension (extension, dilatation).



Hooke's Law

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




Hooke's Law


- Hooke's law states that:

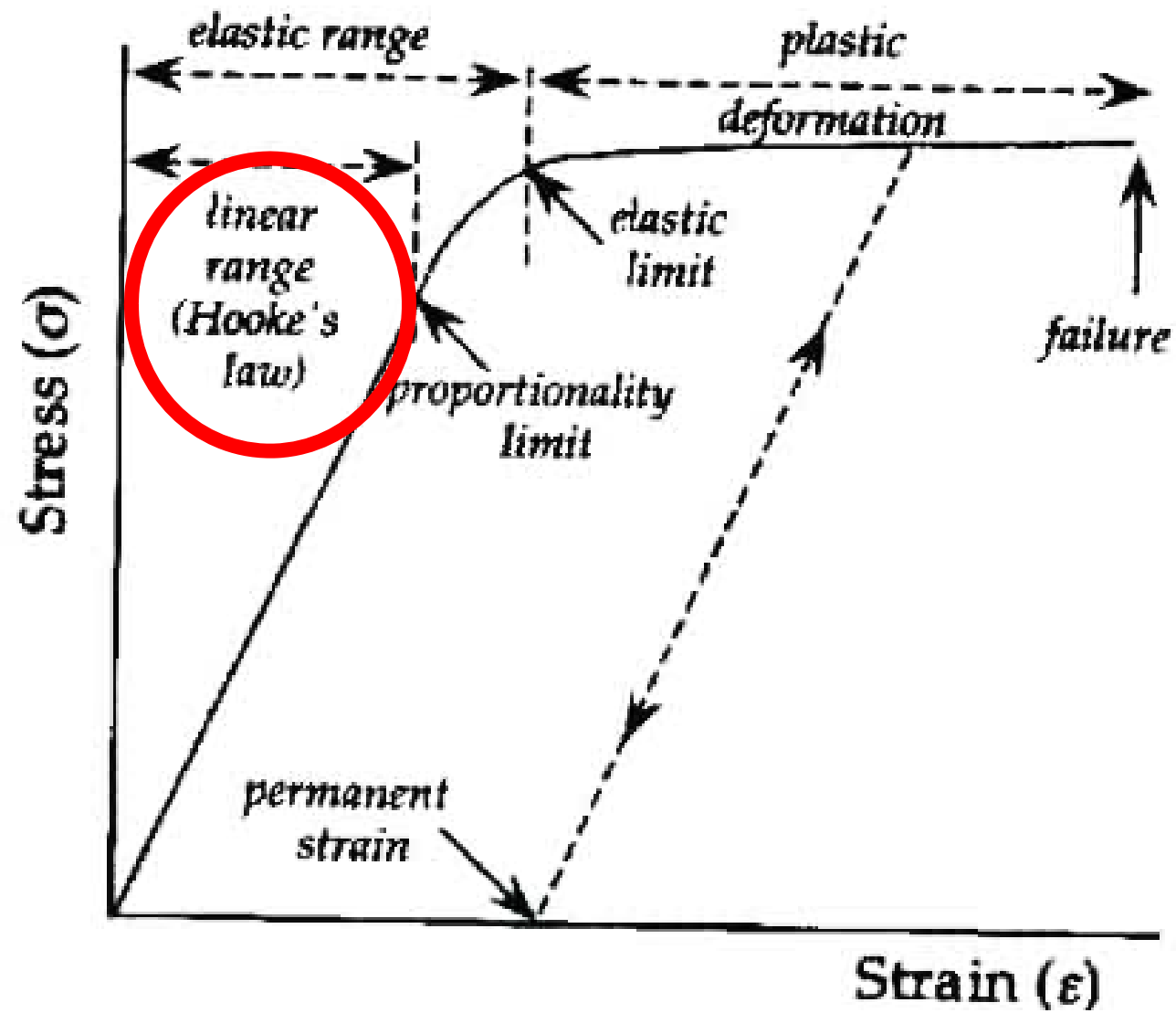
$$F \propto e$$

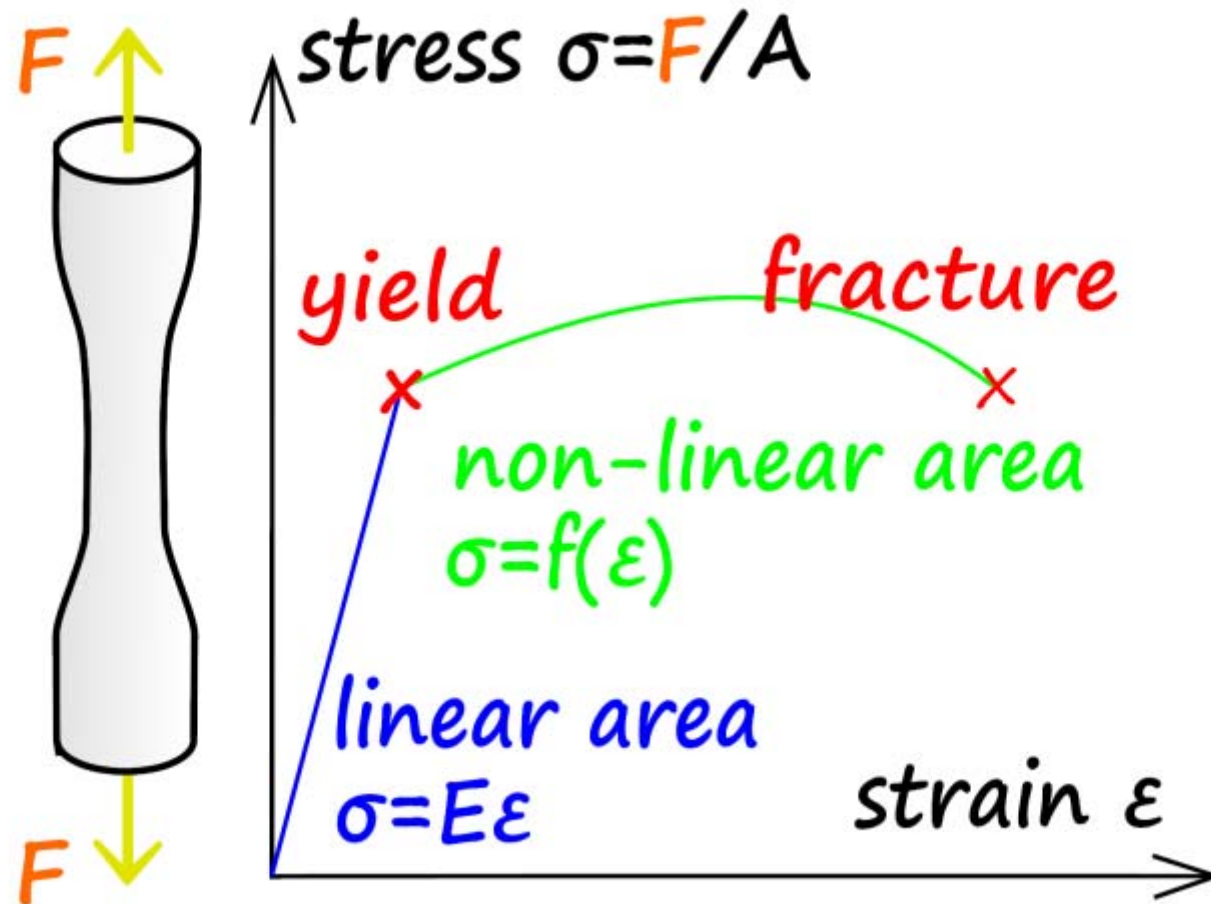
This is the
force applied
(N)



This is the
extension (m)







Elastic Constants

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

$$\text{Modulus} = \text{stress/strain}$$

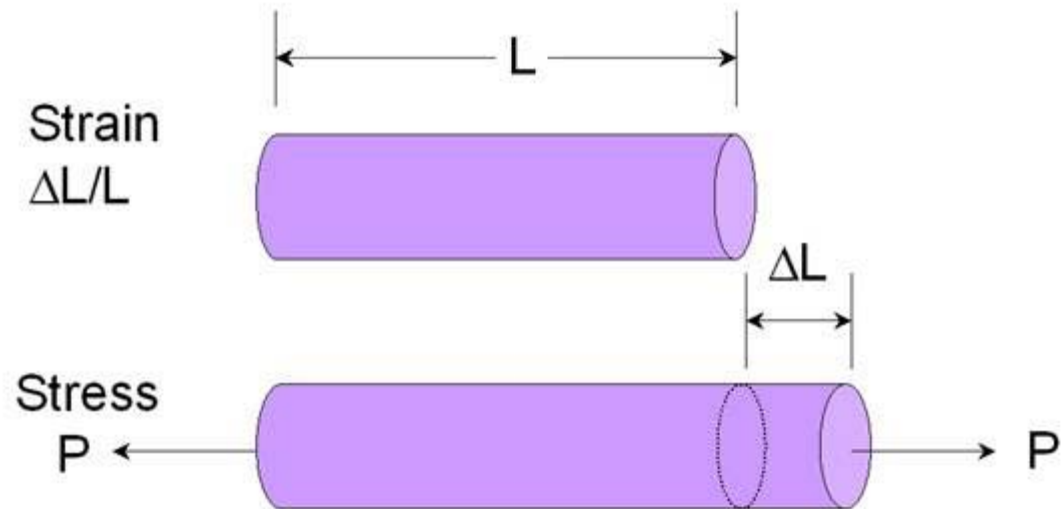
The higher the value of the modulus, the stronger the material, the smaller the strain produced by a given stress.

Elastic constants include:

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

Young's Modulus (E)

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



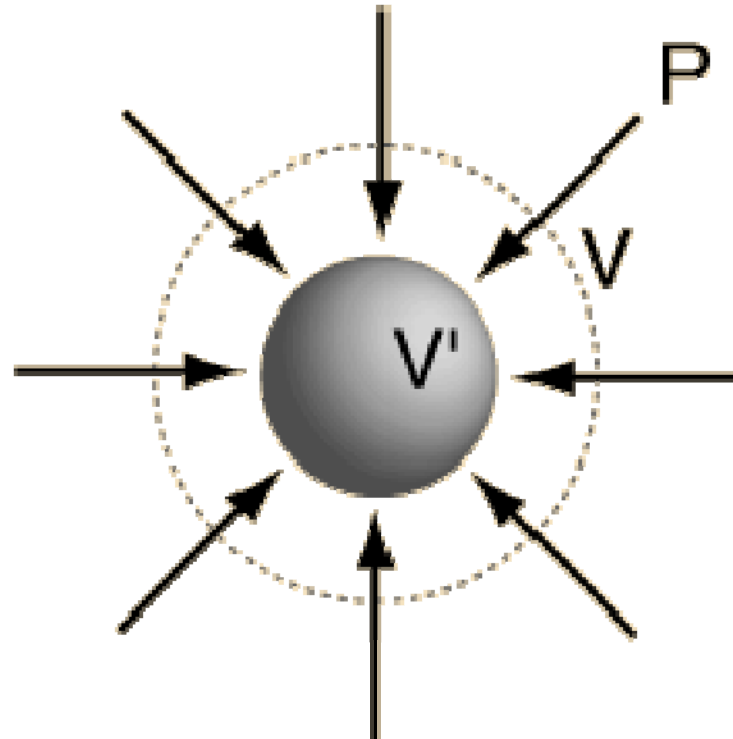
Bulk Modulus (K)

Bulk modulus:

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

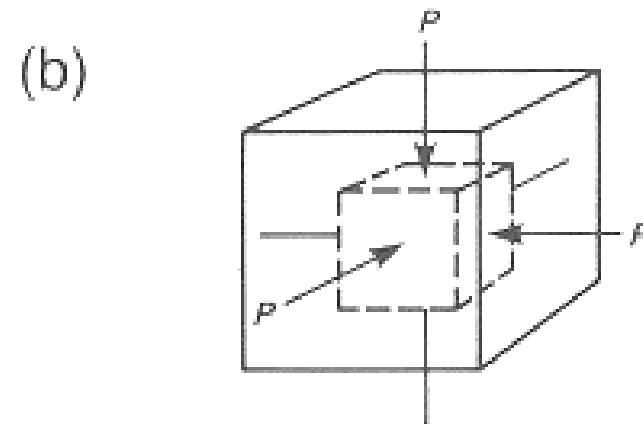
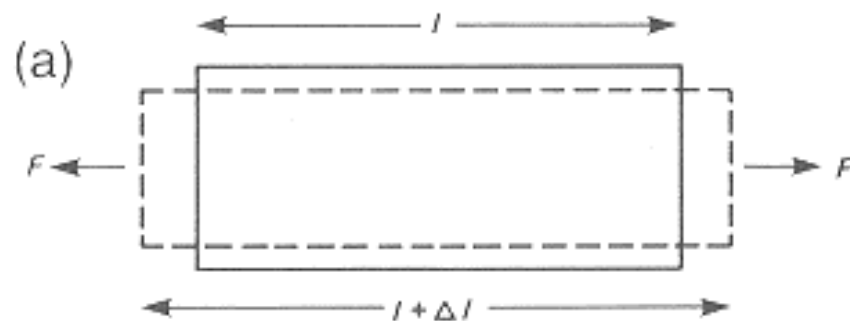
P = pressure

V = volume

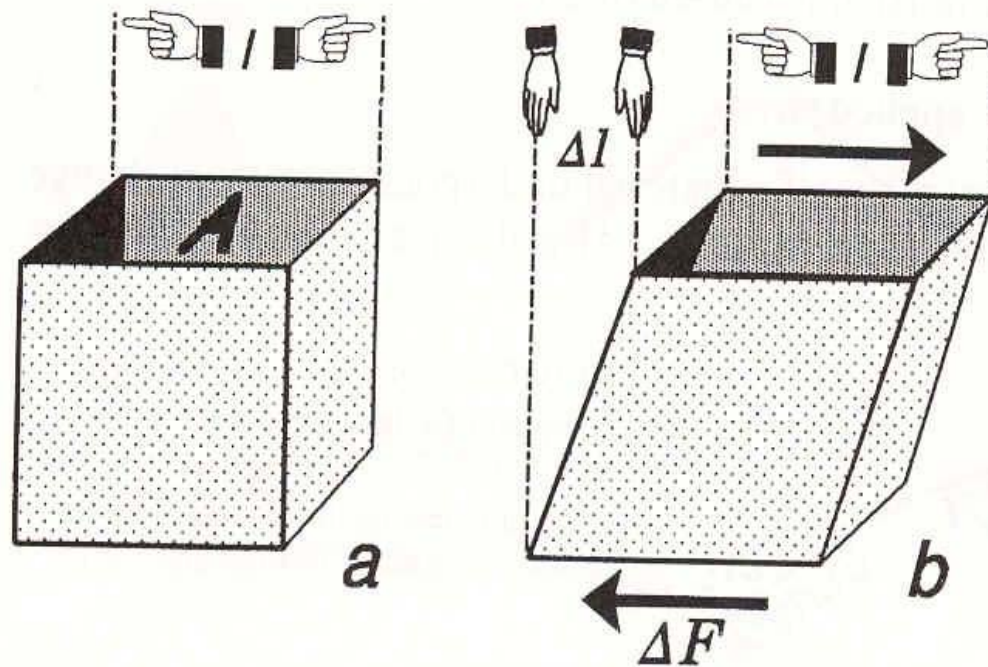


Measure of the capacity of the material to be compressed. It can be carried out for solid, liquid, and gas.

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



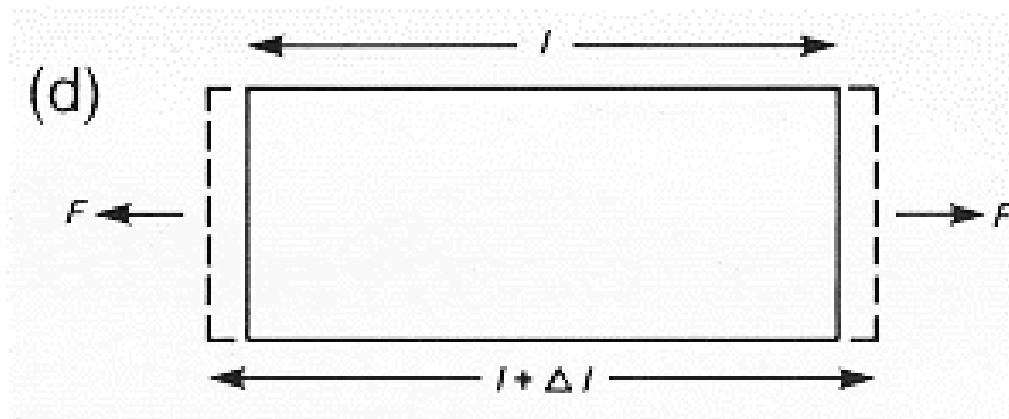
Shear Modulus (μ)



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

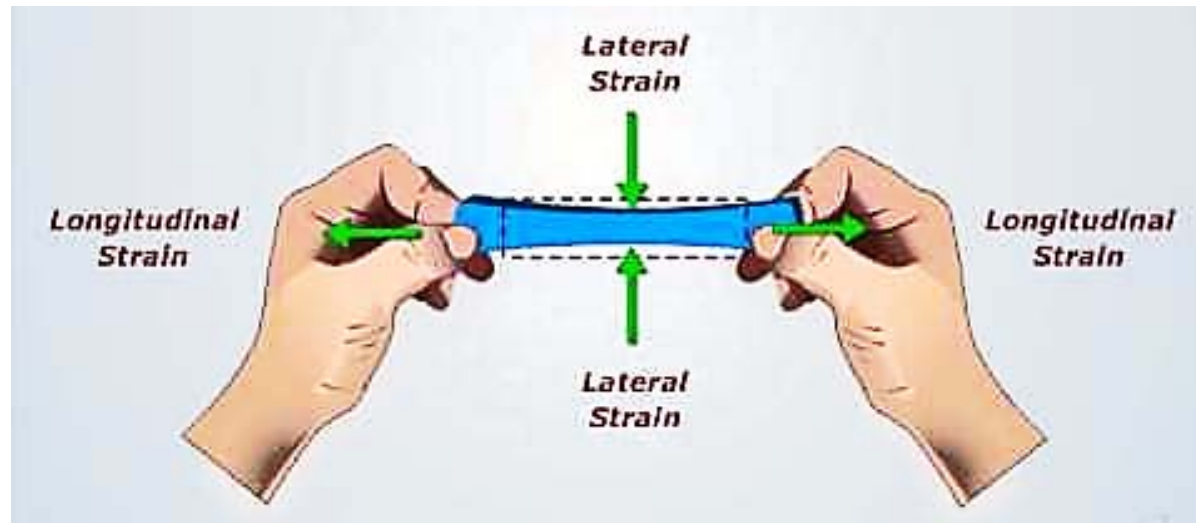
Axial Modulus (Ψ)

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

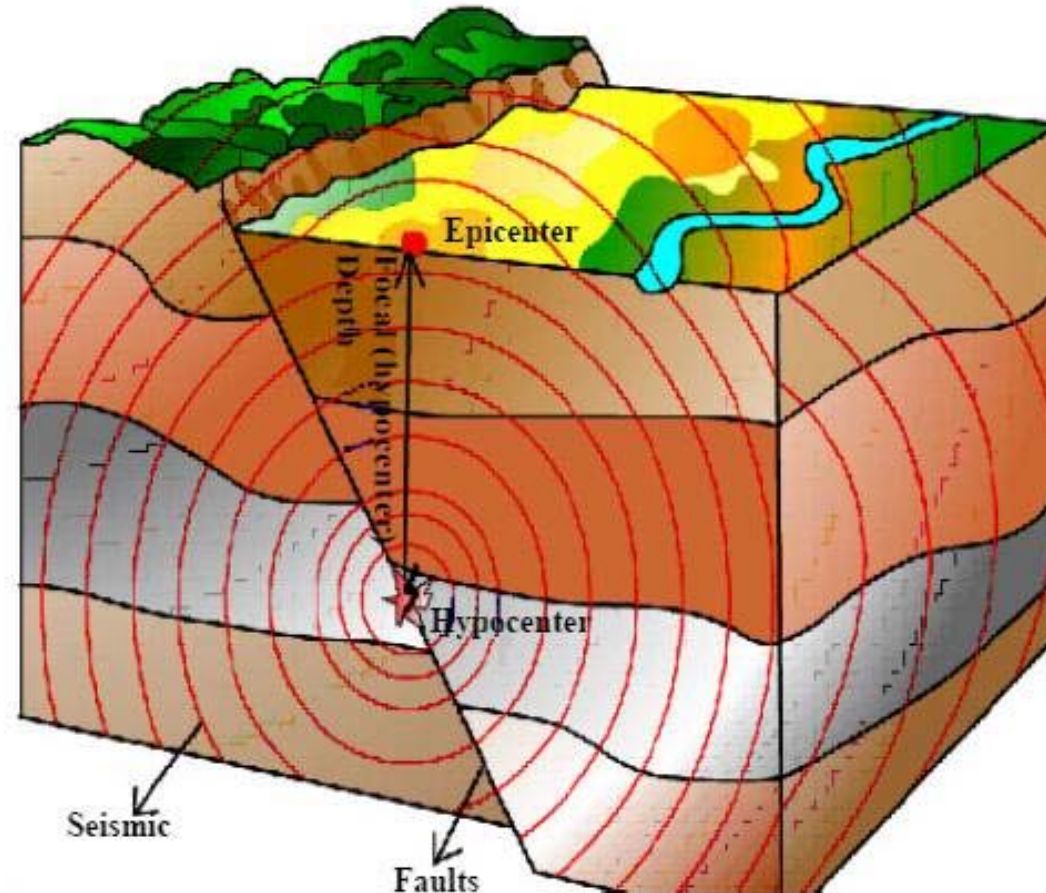
Poisson's Ratio: $\sigma = \lambda / 2 (\lambda + \mu)$

Lamé 1 in terms of Poisson & Young

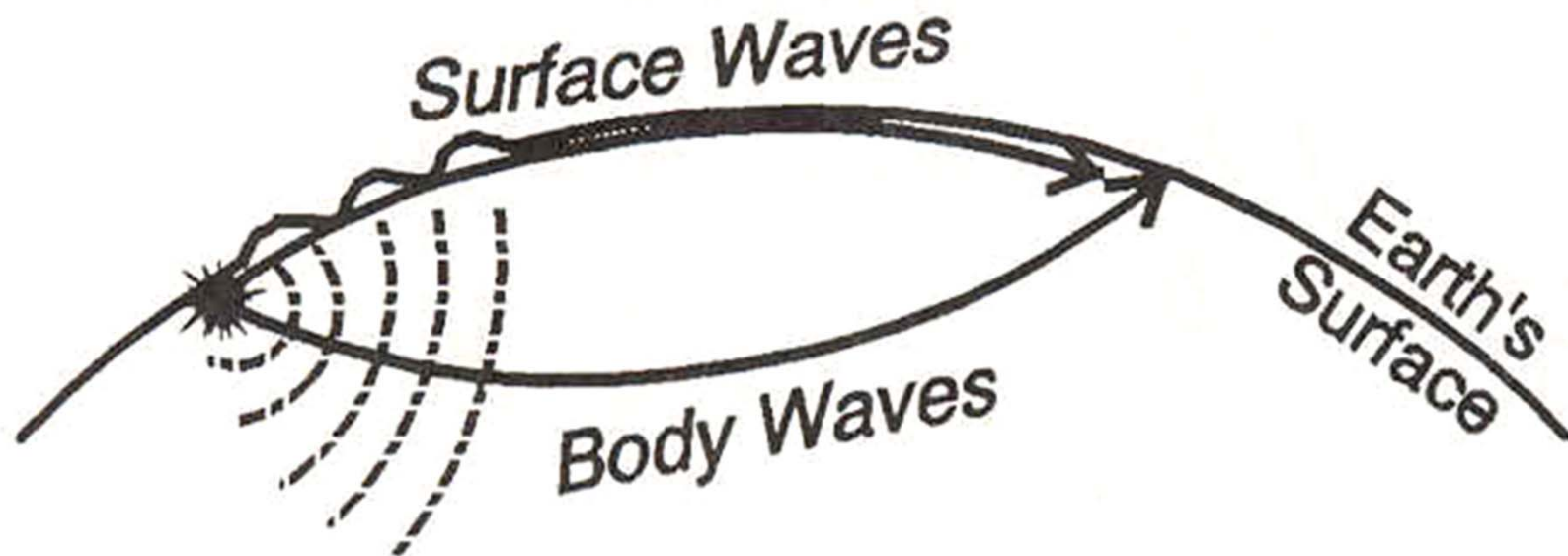
$$\lambda = E \sigma / (1 + \sigma)(1 - 2\sigma)$$

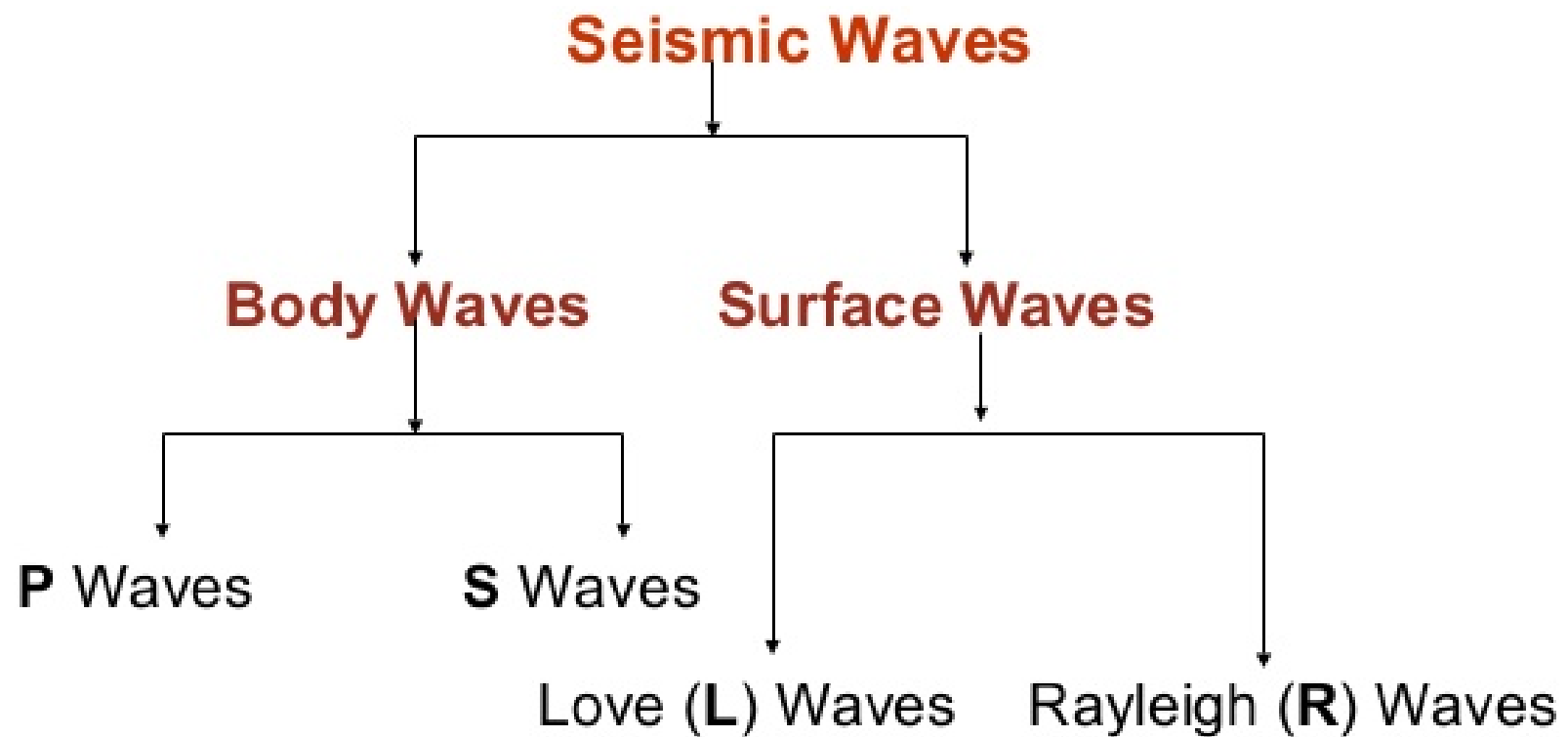
Q. What are seismic waves?

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.



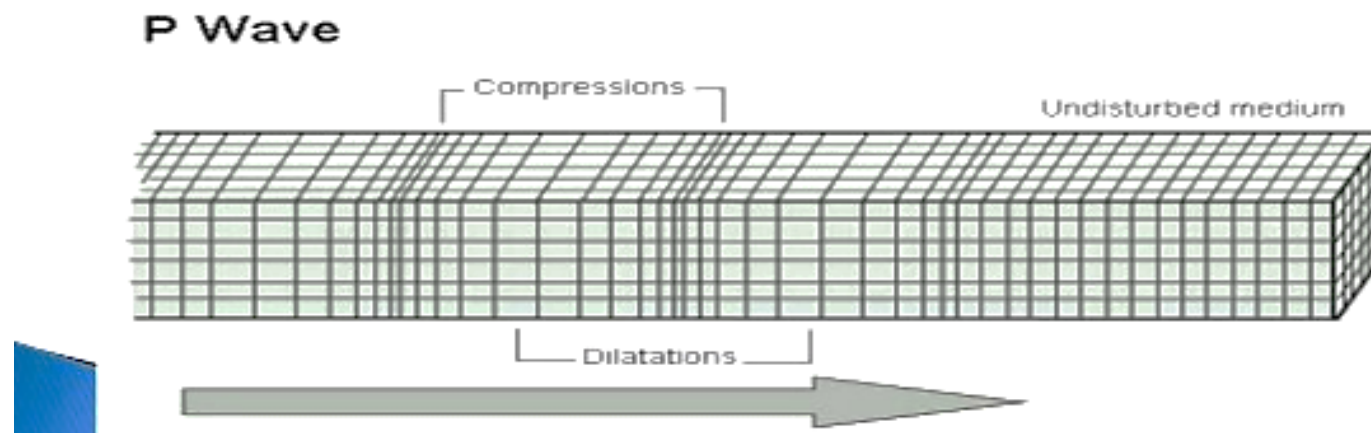
Waves of energy that travel through the Earth's layers, and are a result of an earthquake, explosion, or a volcano.





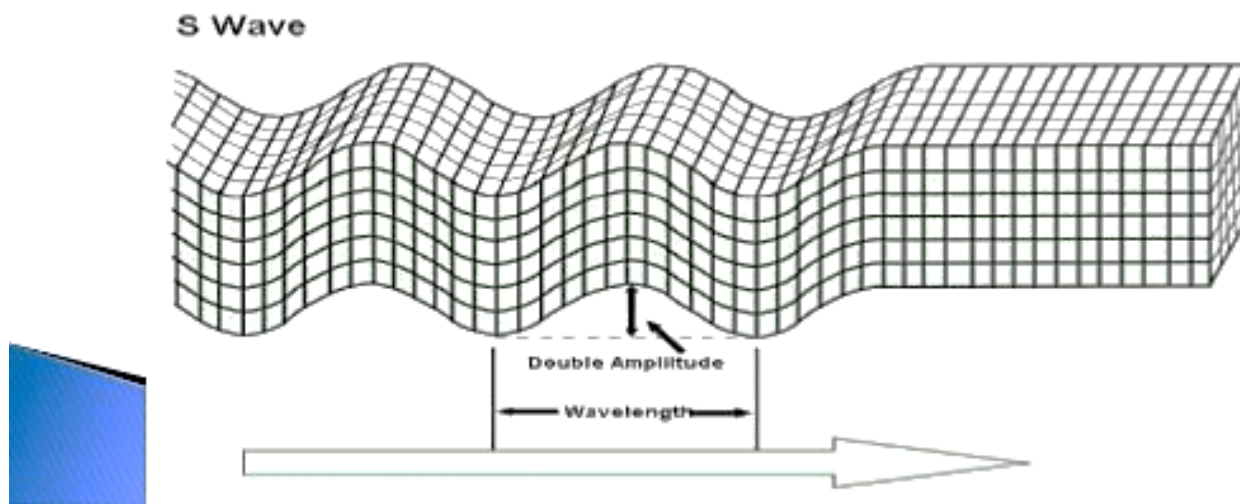
Body Waves

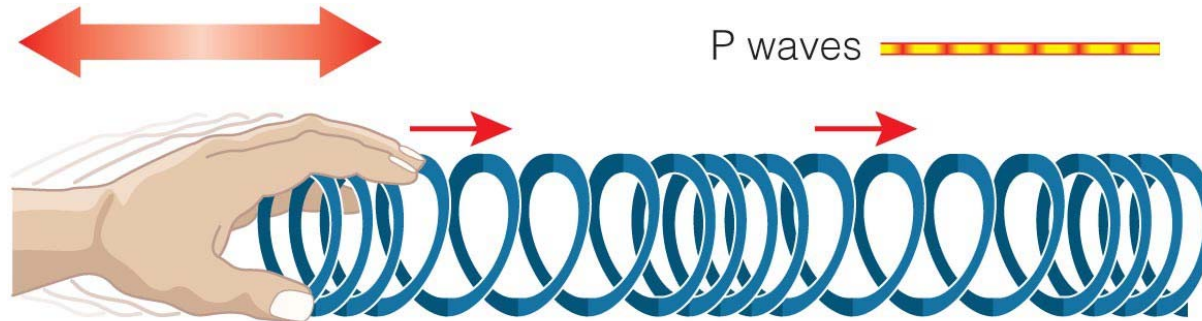
- ▶ **P Waves (compression wave)**
- ▶ The first kind of body wave is the **P wave** or **primary wave**. This is the fastest kind of seismic wave. The P wave can move through solid rock and fluids, like water or the liquid layers of the earth. It pushes and pulls the rock it moves through just like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



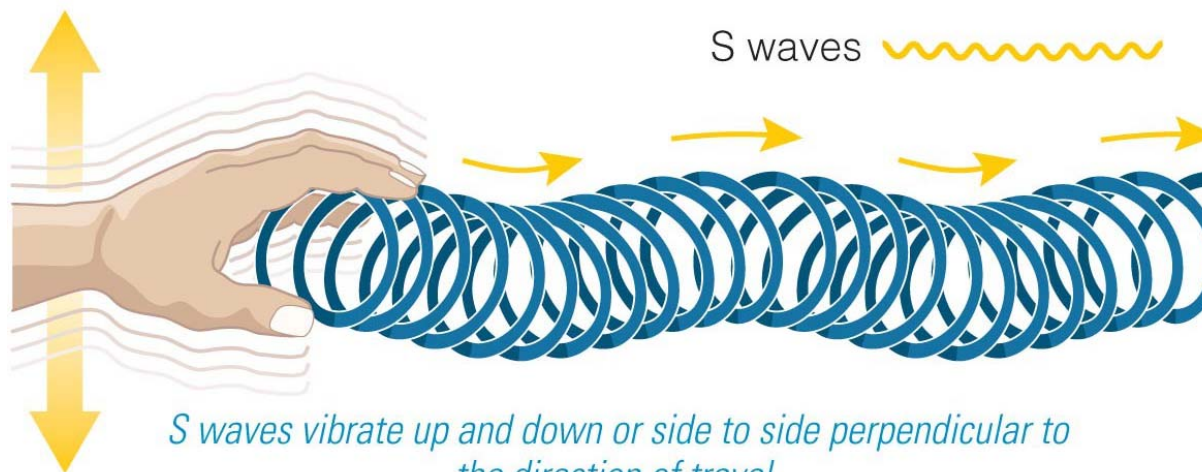
Body Waves

- ▶ **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.



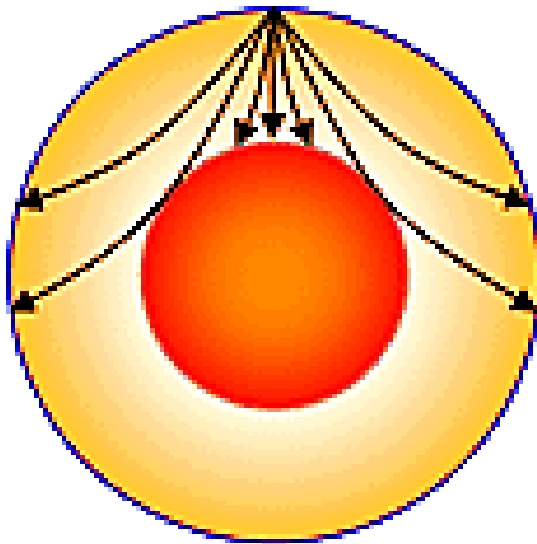


P waves result from compression and stretching in the direction of travel.



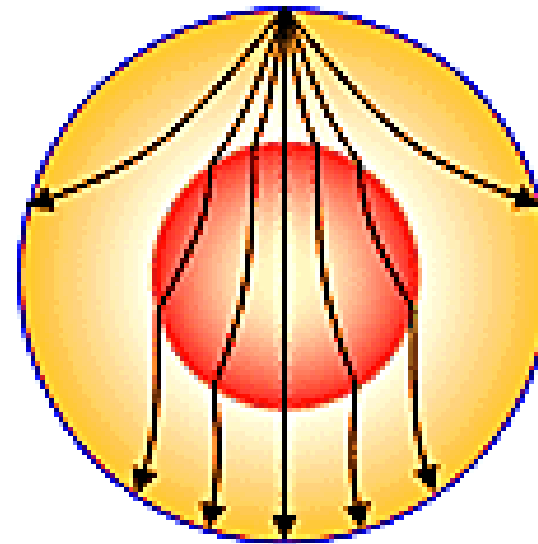
S waves vibrate up and down or side to side perpendicular to the direction of travel.

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S waves

- transverse
- slow moving
- travel through solids only



P waves

- longitudinal
- fast moving
- travel through liquids and solids

Relationship between V_p and V_s

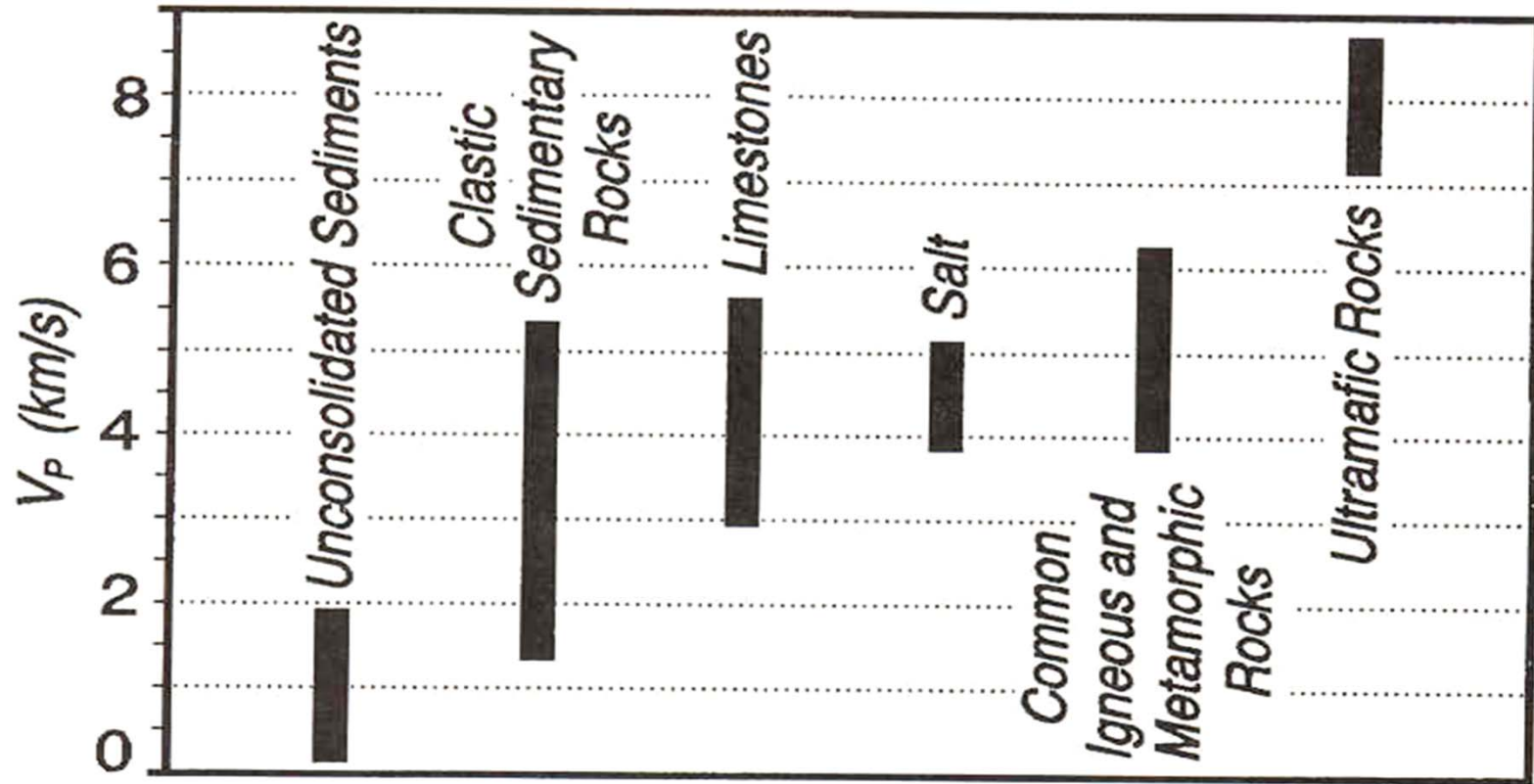
Compressional Waves

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

Shear Waves

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

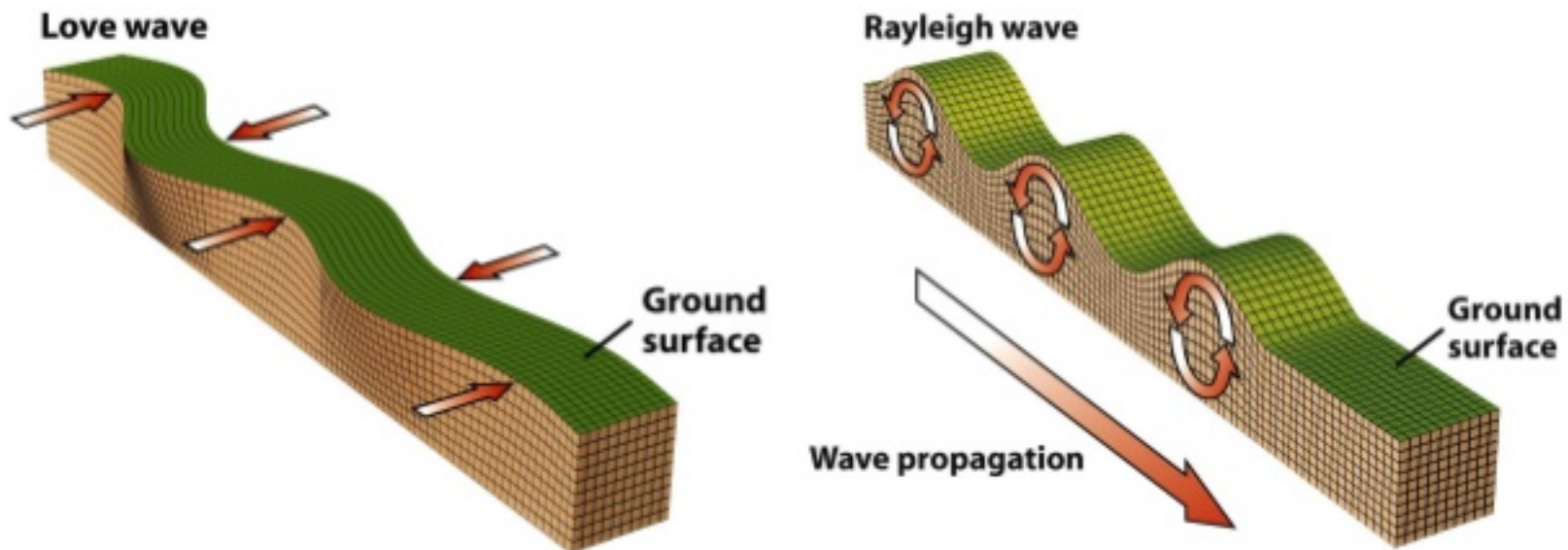
- Averaged $V_p/V_s = 1.732$ for the crust
- For mafic rocks, $V_p/V_s = 1.81$
- For felsic rocks, $V_p/V_s = 1.70$

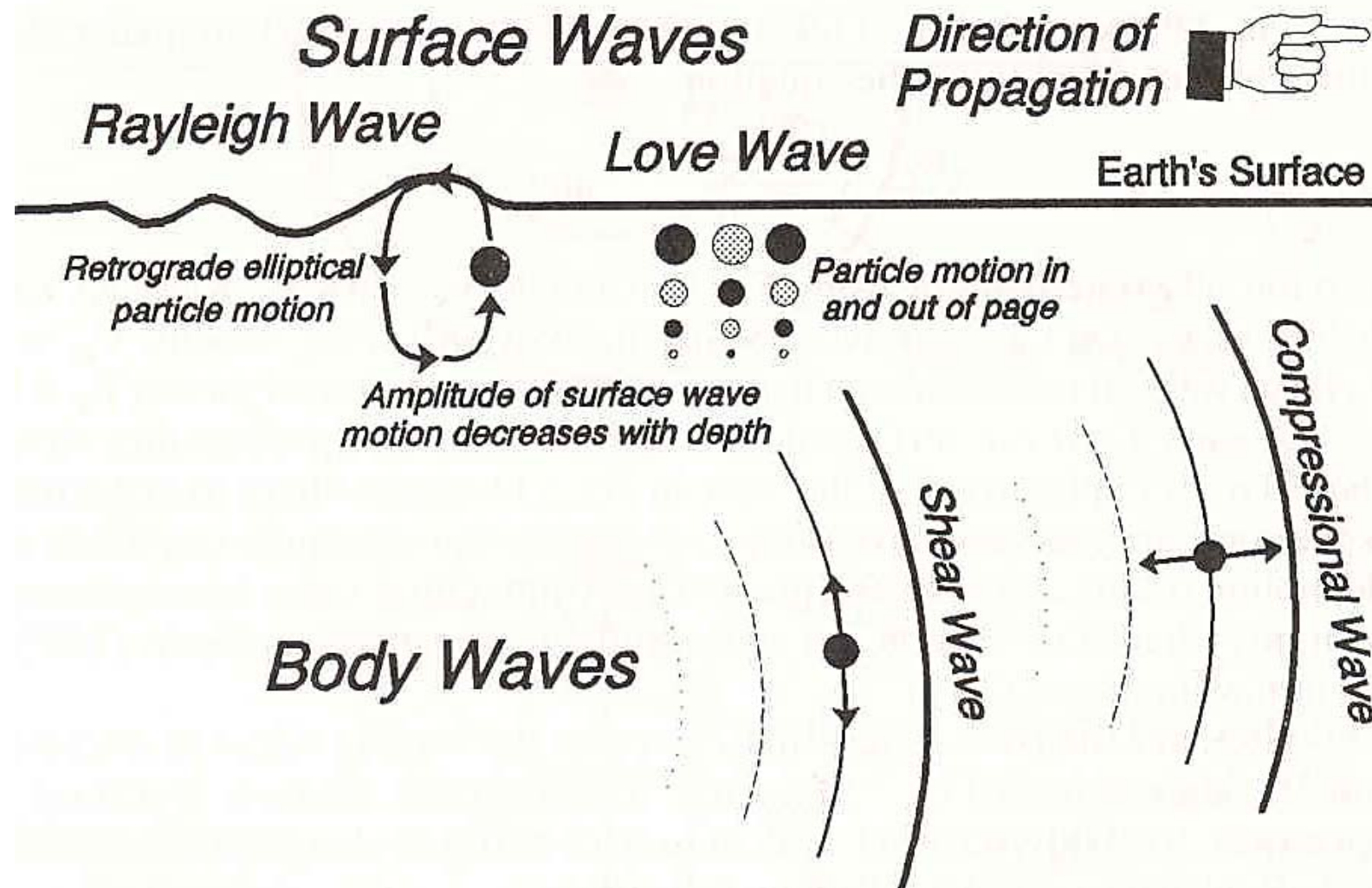


Surface waves- travel along Earth's surface

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



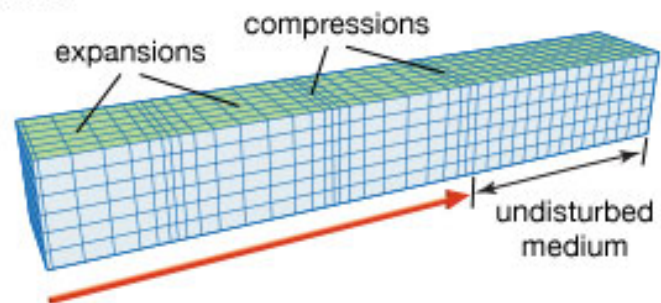


Types of Seismic Waves

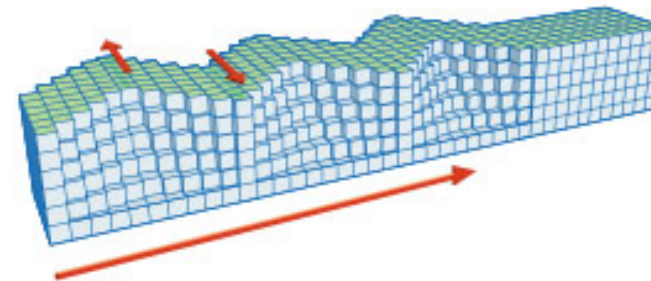
Primary Wave (P-wave)	Secondary Wave (S-wave)	Surface Wave
<ul style="list-style-type: none">• Travels through ground	<ul style="list-style-type: none">• Travels through ground	<ul style="list-style-type: none">• Travels <i>only</i> on Earth's surface
<ul style="list-style-type: none">• Fastest waves	<ul style="list-style-type: none">• Medium speed waves	<ul style="list-style-type: none">• Slowest waves
<ul style="list-style-type: none">• Can travel through solid and liquid	<ul style="list-style-type: none">• Only travel through solids	

Main types of seismic waves

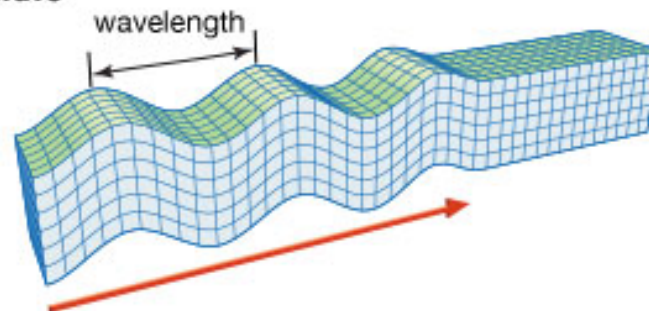
P wave



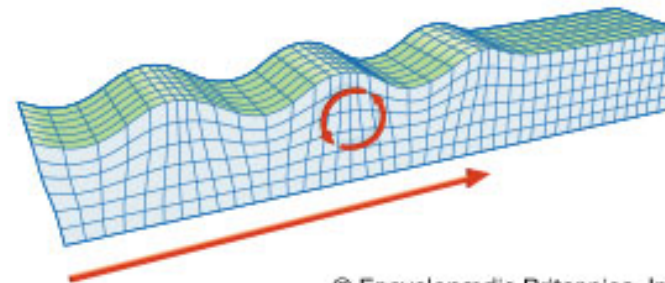
Love wave



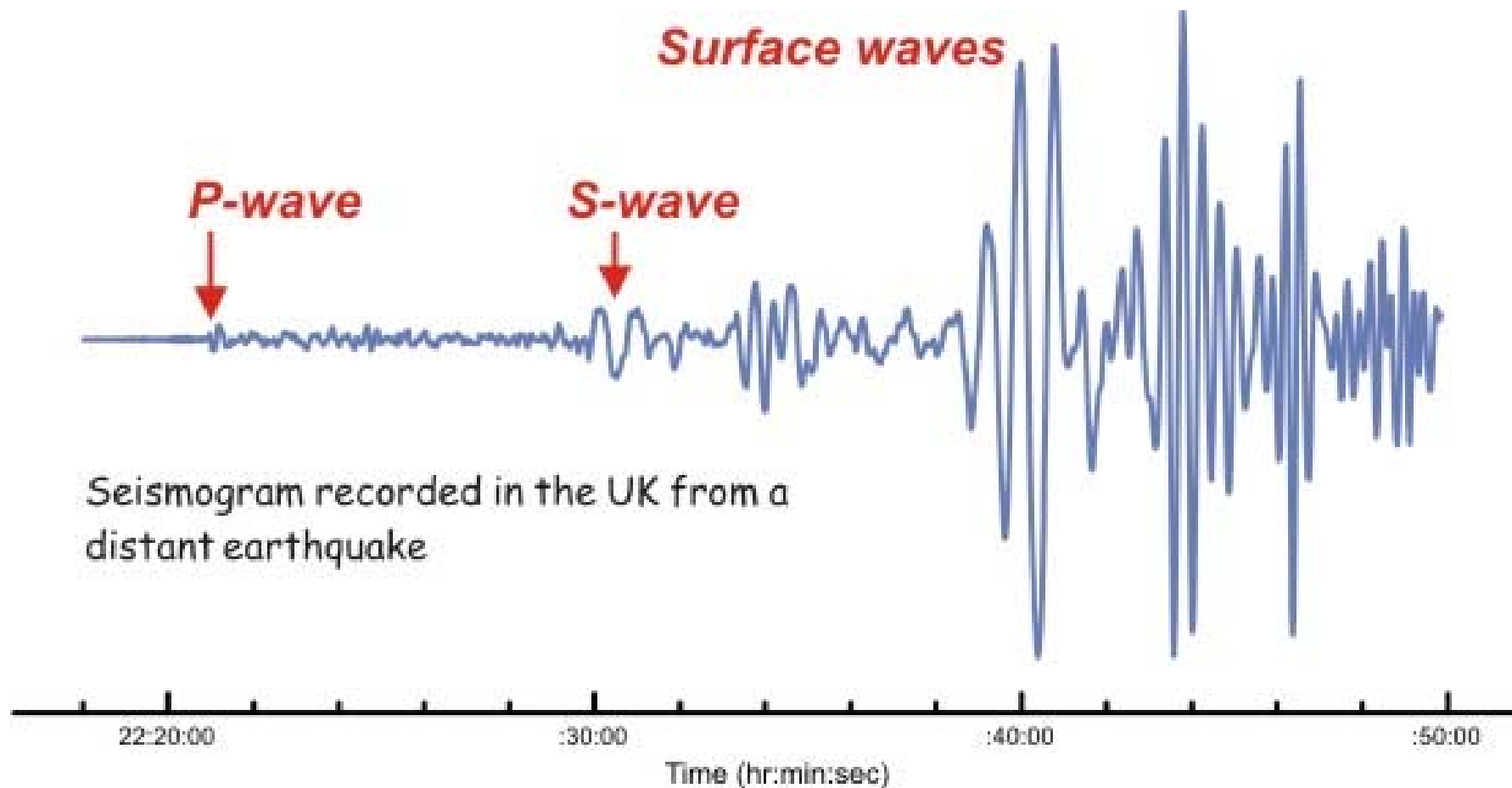
S wave

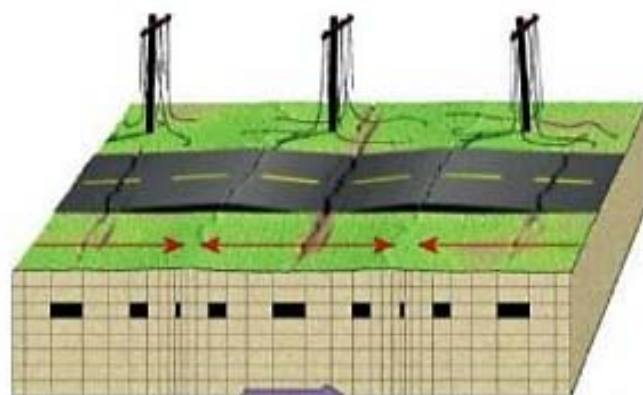


Rayleigh wave

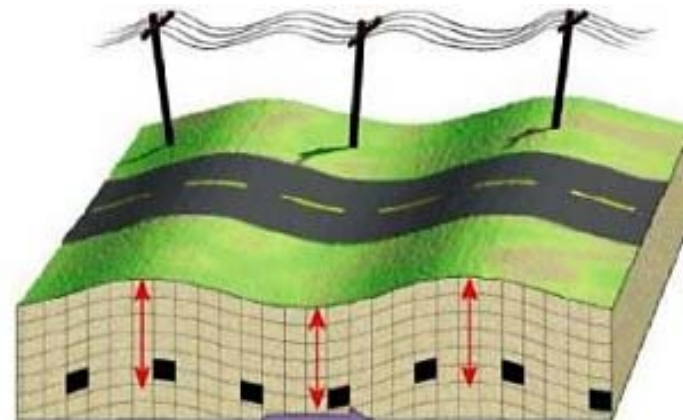


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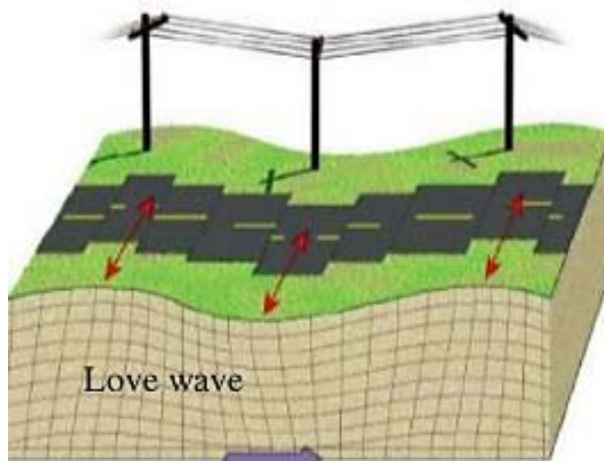




The back-and-forth motion produced as P waves travel along the surface can cause the ground to buckle and fracture.

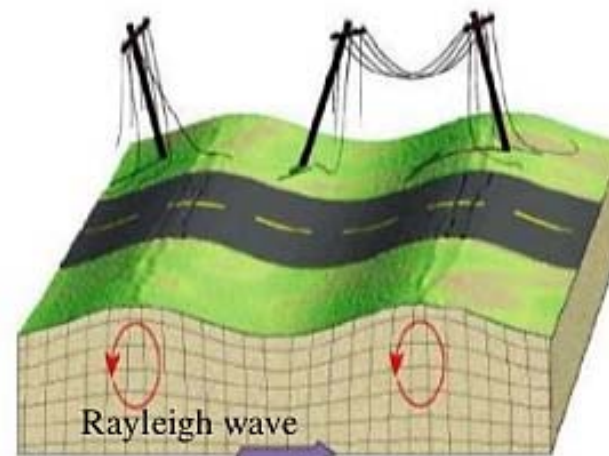


S waves cause the ground to shake up-and-down and sideways.



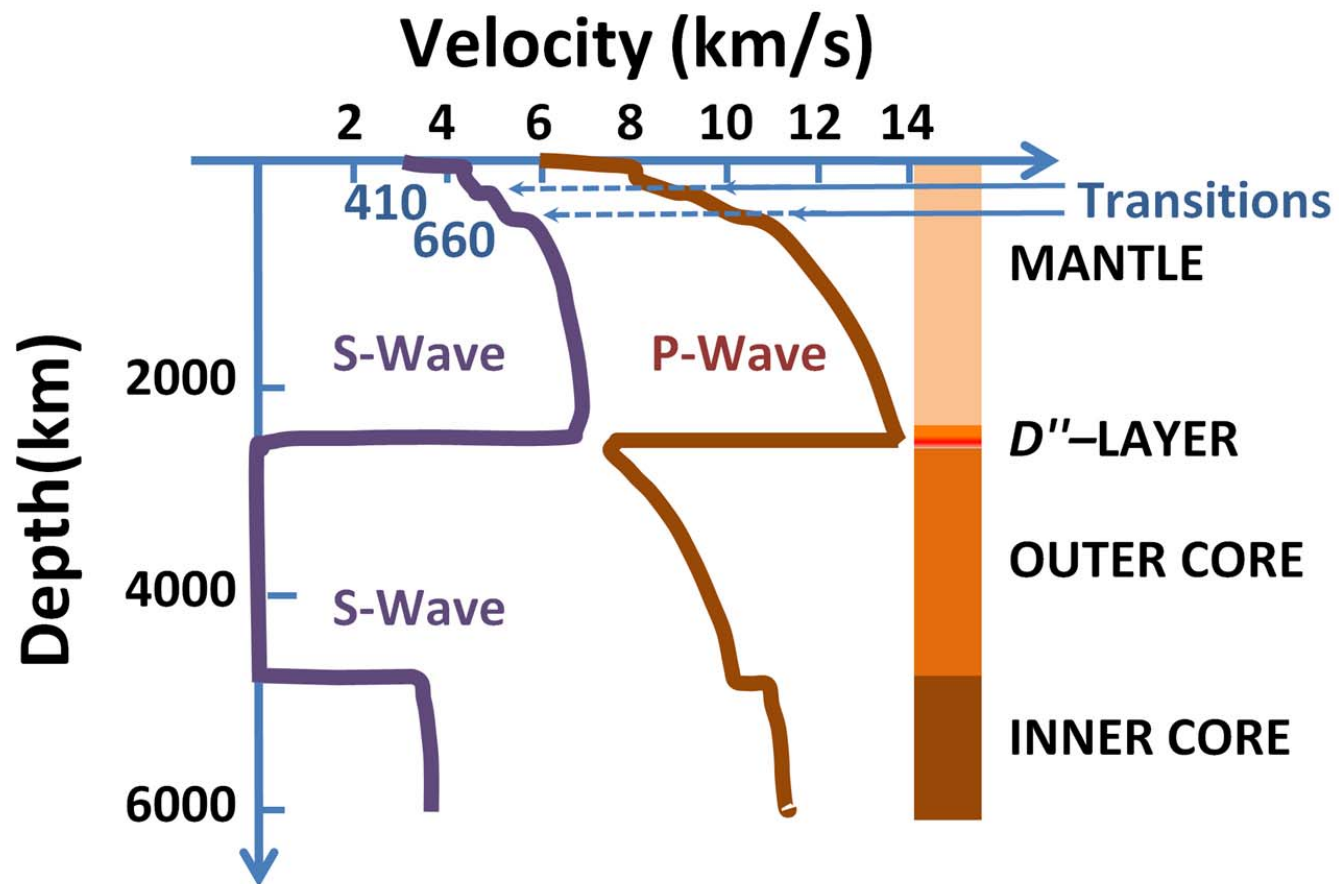
Love wave

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



Rayleigh wave

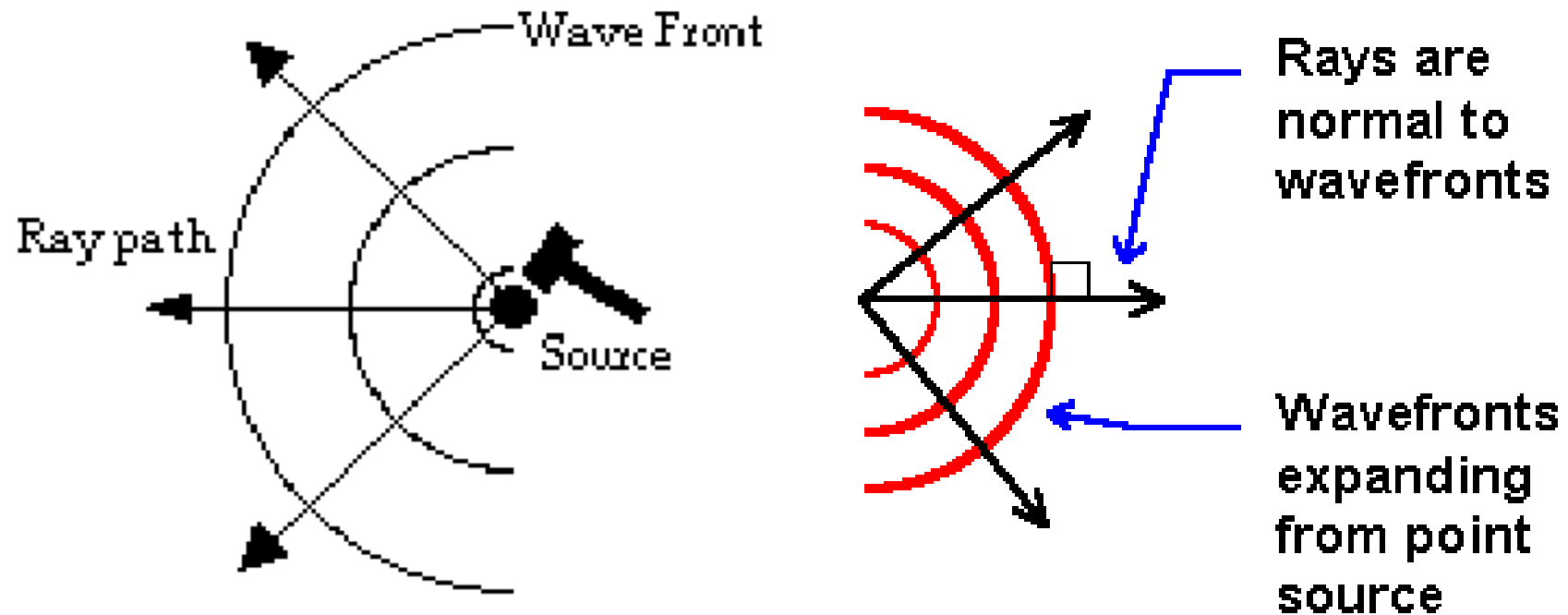
Another type of surface wave travels along Earth's surface much like rolling ocean waves. The arrows show the movement of rock as the wave passes. The motion follows the shape of an ellipse.

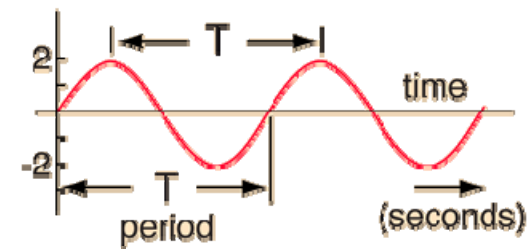
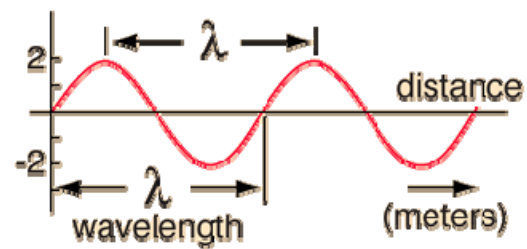
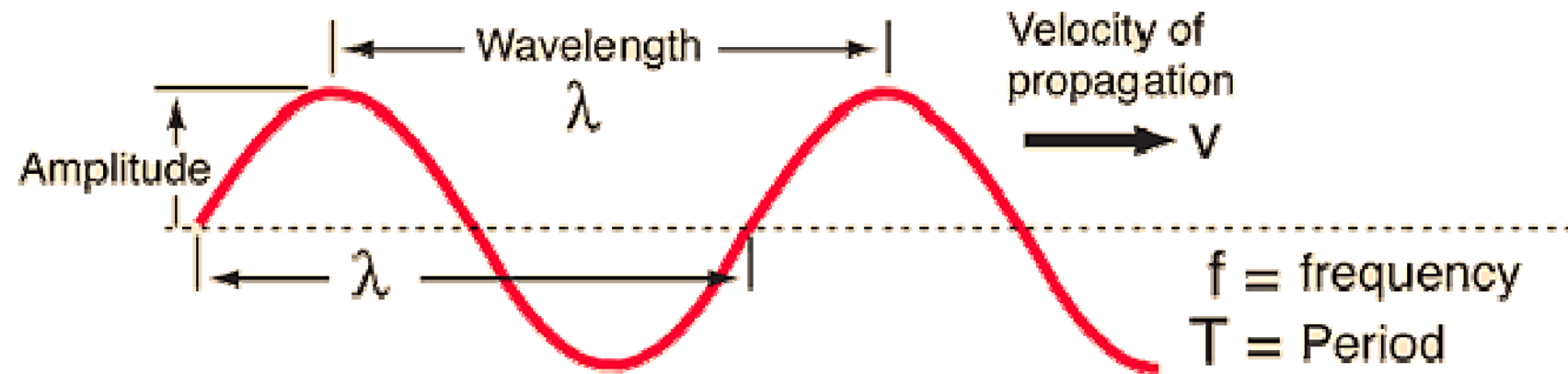


In general, velocity rises with increasing pressure.

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

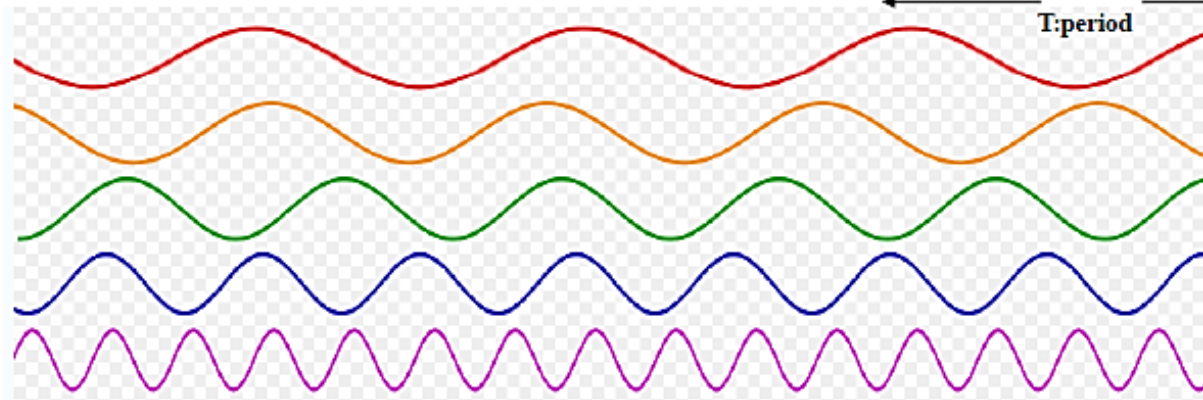
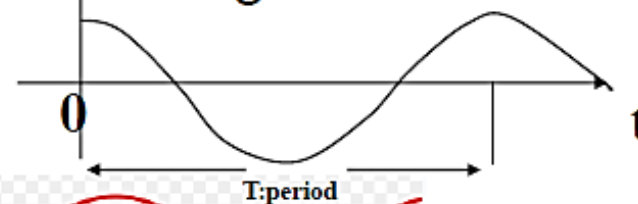
- The wave front is the direct boundary between the seismic waves in the earth material, and the material that the seismic energy has not yet reached
- ray is the vector perpendicular to a wave front.





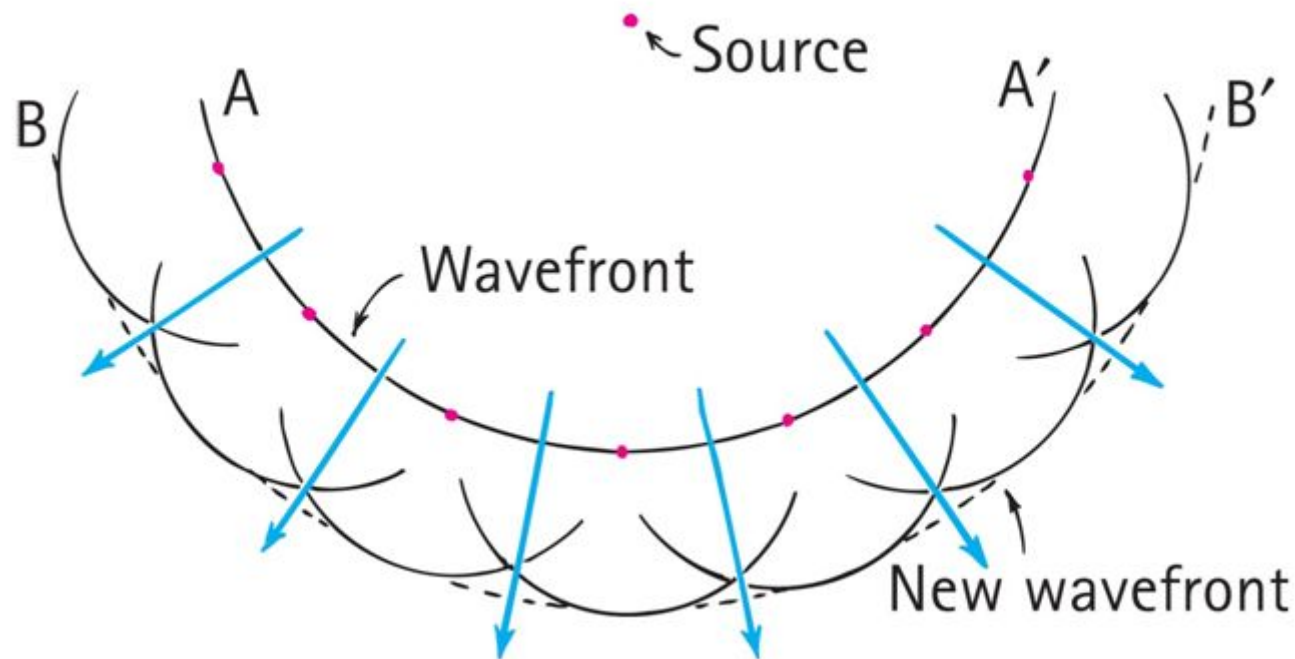
Wave Parameters

- 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: $K = 2\pi / \lambda$



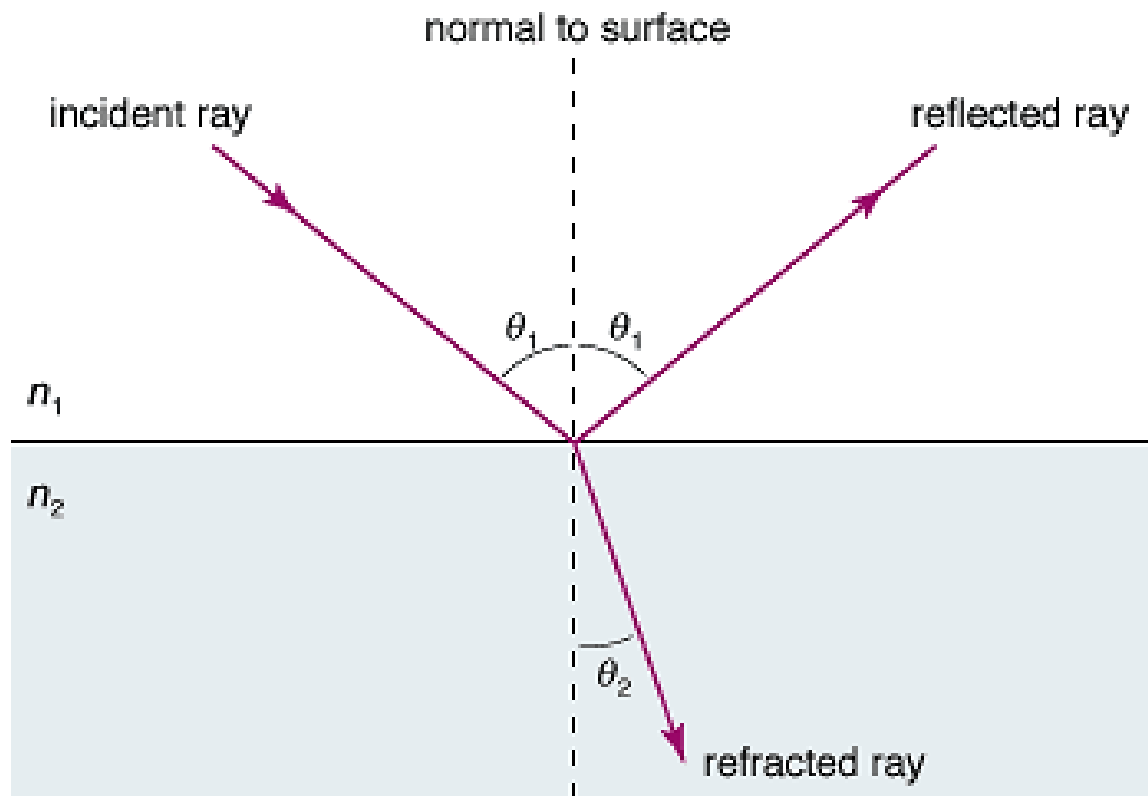
Q. What is Huygens's Principle?

- 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.

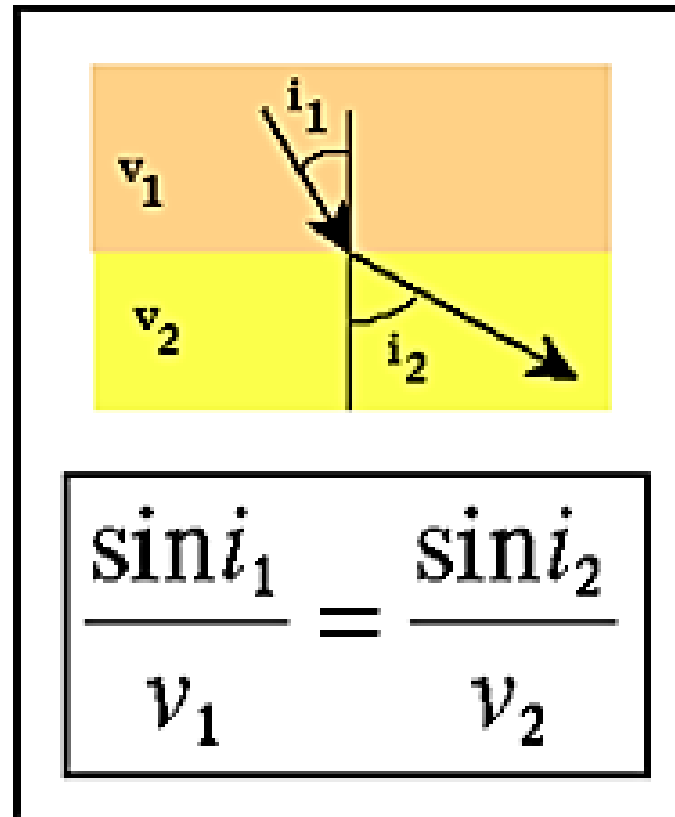


Q. What is Snell's Law?

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



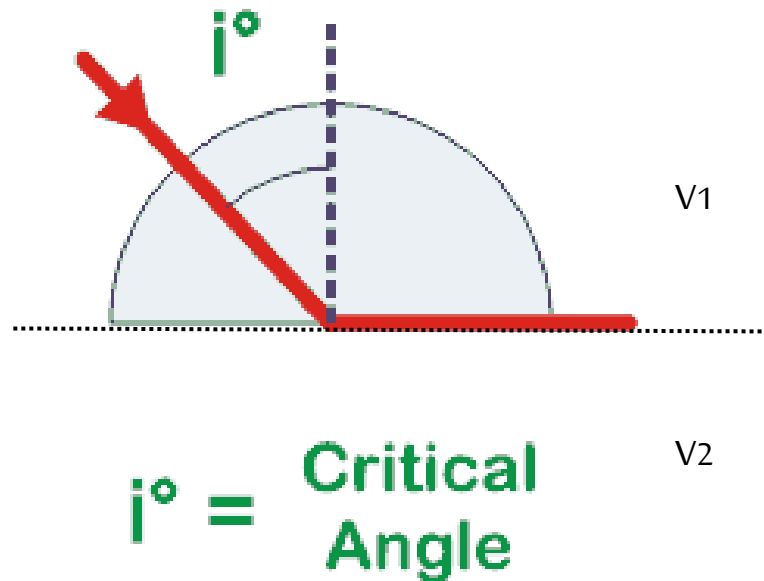
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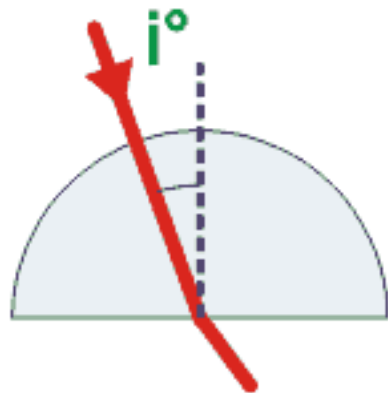


**i_1 (angle of incidence) and i_2
(angle of refraction)**

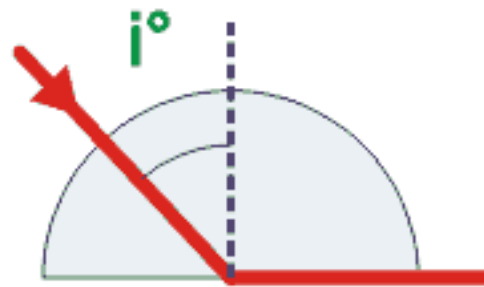
Q. What is the critical angle?

When V_2 is greater than V_1 , the angle of refraction is greater than the angle of incidence, then the angle of incidence for which this occurs is called the critical angle.

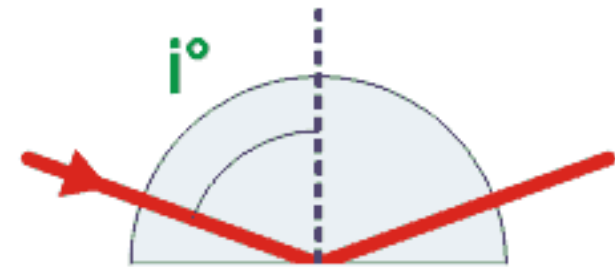




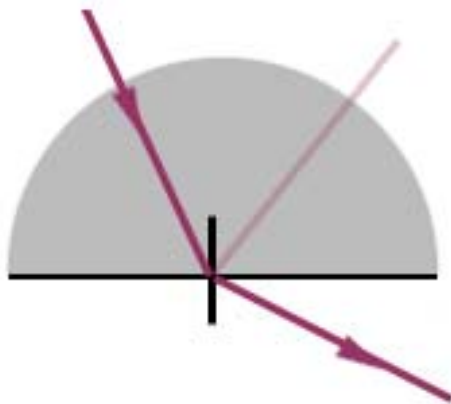
$i^\circ < \text{Critical Angle}$



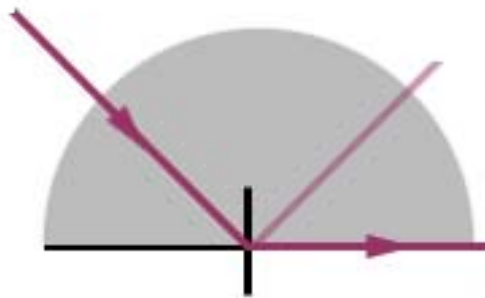
$i^\circ = \text{Critical Angle}$



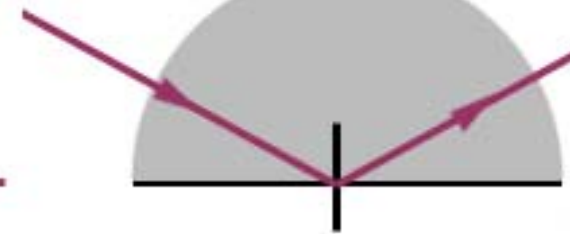
$i^\circ > \text{Critical Angle}$



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**.