Rock behavior

I- Definitions :

Force :

is a **vector quantity** that tends to produce a change in the motion or the state of a body, or is the **push or pull** on an object with mass that causes it to change velocity (to accelerate). A force is defined by its magnitude and direction.

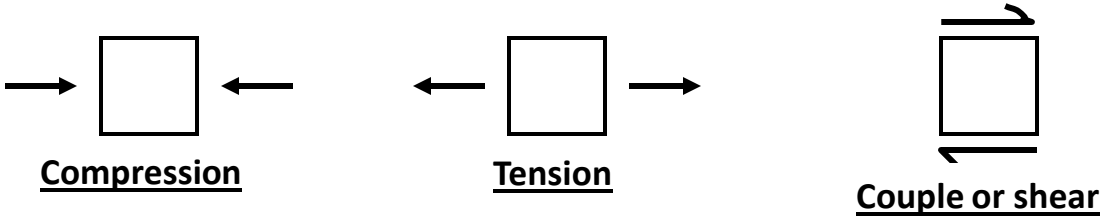
$F = m * a$

Where, "m" is the mass of the body, "a" is the acceleration of motion of the body.

Its units is Newton. **Newton** is equal to 1 $kg*m*s^{-2}$.

Stress (pressure):

Stress is the **force per unit area.** Stresses may form a compression, tension or couple. Its units is pascal (Pa, that is, newtons per square meter = 1 N/m^2) in the International System, or pounds per square inch (psi) in the Imperial system. Stresses could be compression, tension or couple (shear).



Confining pressure (hydrostatic pressure, lithostatic pressure) :

Confining pressure is the stress acting on a body from all sides by the same value.

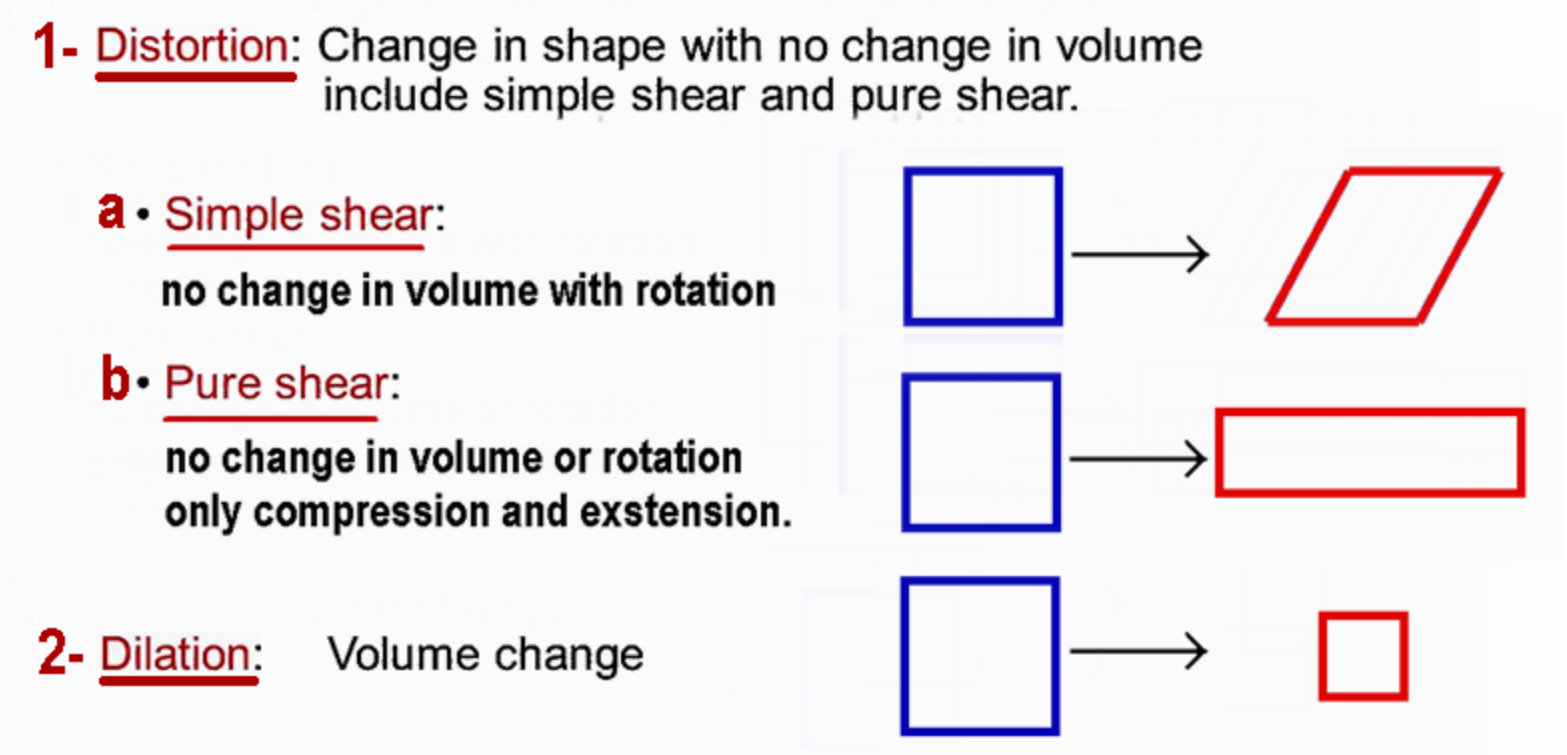
Isotropic material :

A material that has the same properties in **all directions**. These properties are such as density, electrical and thermal conductivity, magnetic properties,…etc. This also means that the rock will have the same chemical and mineralogical composition; the same grain size, porosity and permeability in all directions. **Glass and metals** are examples of **isotropic materials**. There is any natural rock that can be considered isotropic. All natural rocks are anisotropic.

Homogeneous material : A material that has the same properties in at every point. The term is some what equivalent to “isotropic”. There is any natural rock that can be considered homogeneous . All natural rocks are inhomogeneous .

Strain :

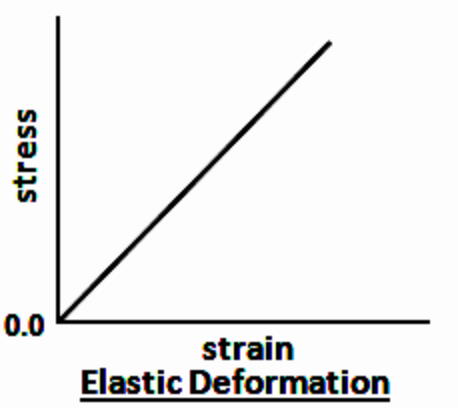
Strain is the deformation caused by the effect of stresses. Strain may be Dilation (change in volume) or Distortion (change in shape) or both.



II- Stages of deformation:

Any material affected by stresses, it will pass through **three stages** of deformation. These stages are:

1- Elastic deformation.
2- Plastic deformation.
3- Rupture.

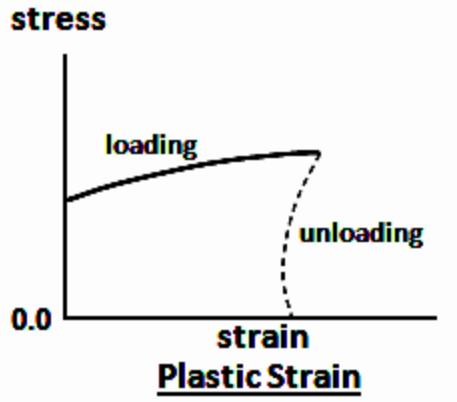


1) The elastic deformation :

The first stage of deformation is termed the "elastic deformation". This type of deformation is characterized by :

a- The strain is **reversible**, i.e. when the stress is removed, the material will return to its original shape before the application of stress.

b- **Strain is directly proportional to stress**, i.e. stain increases by the increase in stress . The relation between strain and stress is along a **straight line** passing by the origin (point 0.0).



2) Plastic deformation :

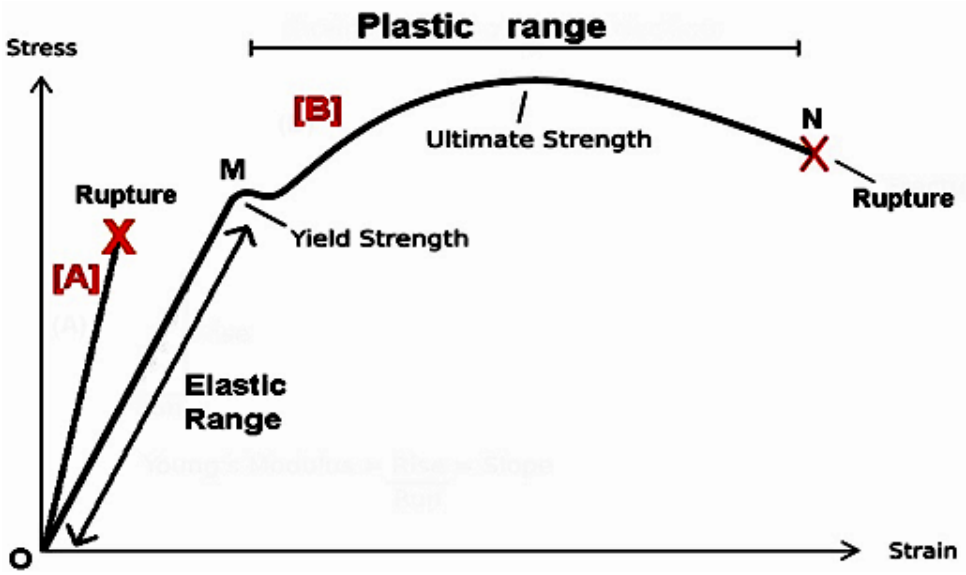
The second stage of deformation is termed the "Plastic deformation". It is characterized by :

a- The strain is **irreversible** and **permanent**, i.e. when the stress is removed, the material does not return to its original shape before the application of stress.

b- **Strain increases by the increase in stress**. The relation between strain and stress is along a **curve** that does not pass by the origin (point 0,0). When stress returns to zero value, strain does not return to zero, but still has a value which is the permanent plastic strain.

III- Stress-strain diagram :

Curve (A) represents a brittle material.
Curve (B) represents a ductile material.
OM is the elastic range of the deformation.
MN is the plastic range of the deformation



The relation between stress and strain can be represented in graphs known as "stress-strain diagrams". The stress is plotted on the vertical axis, and strain is on the horizontal axis. On the diagram, curve (A) represents the stress-strain diagram of a brittle material, while curve (B) represents a ductile material.

1- **In a brittle material,** the stress-strain diagram (curve A) shows two stages of deformation. Deformation starts as an **elastic** strain, then at a certain value of stress the material **ruptures** without showing plastic deformation or may show a narrow range of plastic deformation before rupture.

2- **In a ductile material, the stress-strain diagram (curve B) shows three stages of deformation**:

a) Deformation starts as an **elastic** strain and the material behave as an elastic material through the range (OM). Point (M) is the elastic limit (yielding strength) of the material above which the deformation is **plastic**. **The elastic limit (yielding strength)** is the maximum stress that can be applied to a material without producing a permanent plastic deformation. It is the **stress** at which a material begins to deform **plastically.**

b) When stress reaches the elastic limit of the material (point M) the plastic deformation starts and the material behave as a plastic material through the range (MN).

c) At point (N) is ruptured. Point (U) on the curve is termed the ultimate strength of the material. **The ultimate strength** is the maximum stress that a material can bear without being ruptured.

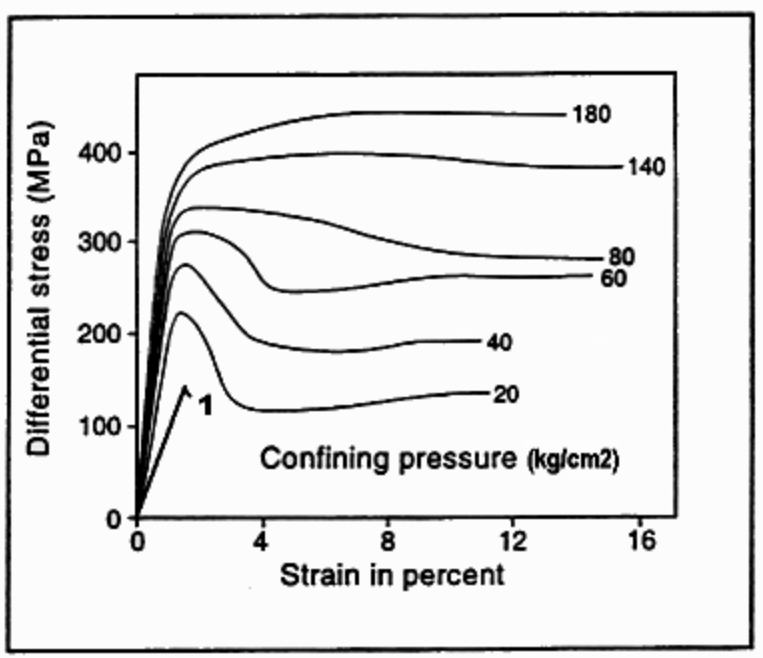
IV- Factors controlling the rock behavior

There are several environmental factors affect and control the behavior of rocks. These factors are : the confining pressure, temperature, time, solutions, and the presence of anisotropy.

1- Confining pressure:

The confining pressure is the stress acting on the material from all sides by equal value. To study the effect of confining pressure on the behavior of the material, a stress-strain experiment is done on the material several times. Each time is at a different confining pressure. The following stress-strain diagram represents the results of the experiment. The diagram indicates that at low confining pressure (= 1 kg/cm^2), the material is brittle. It deforms without any plastic range in its curve.

At higher confining pressure, the material deform with a good range of plastic deformation. This indicates that:

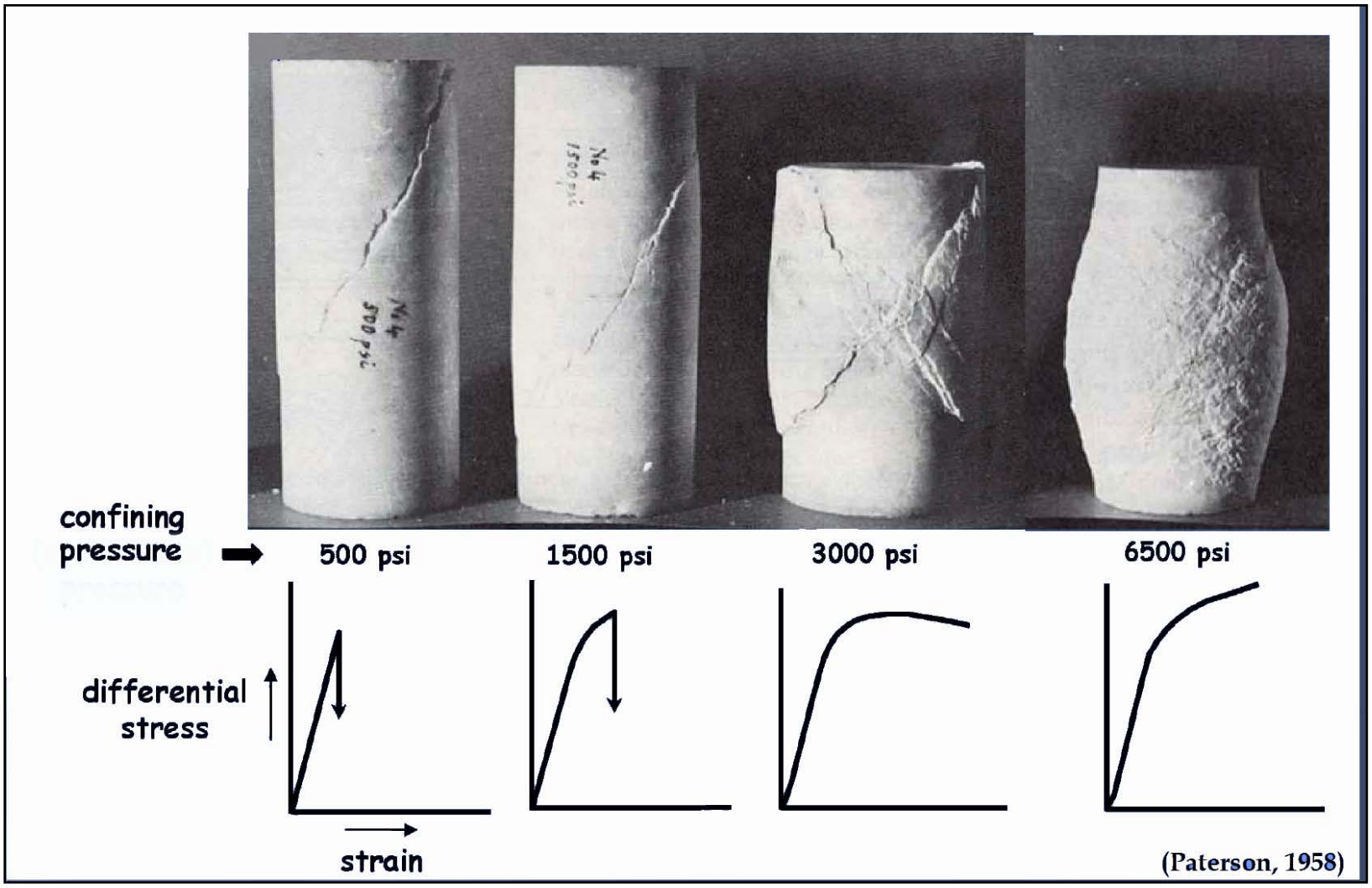


a) The effect of confining pressure is to **collect** the parts of the material together and **increase** its **strength**. The increase in confining pressure **increases the ductility** of the material.

b) Brittle materials will behave as ductile material at higher confining pressure.

c) Rocks will be more brittle **near the earth's** surface and deform by rupture (e.g., faulting).

d) Rocks will be more ductile at **depth** within the earth and deform by plastic deformation (e.g. folding).

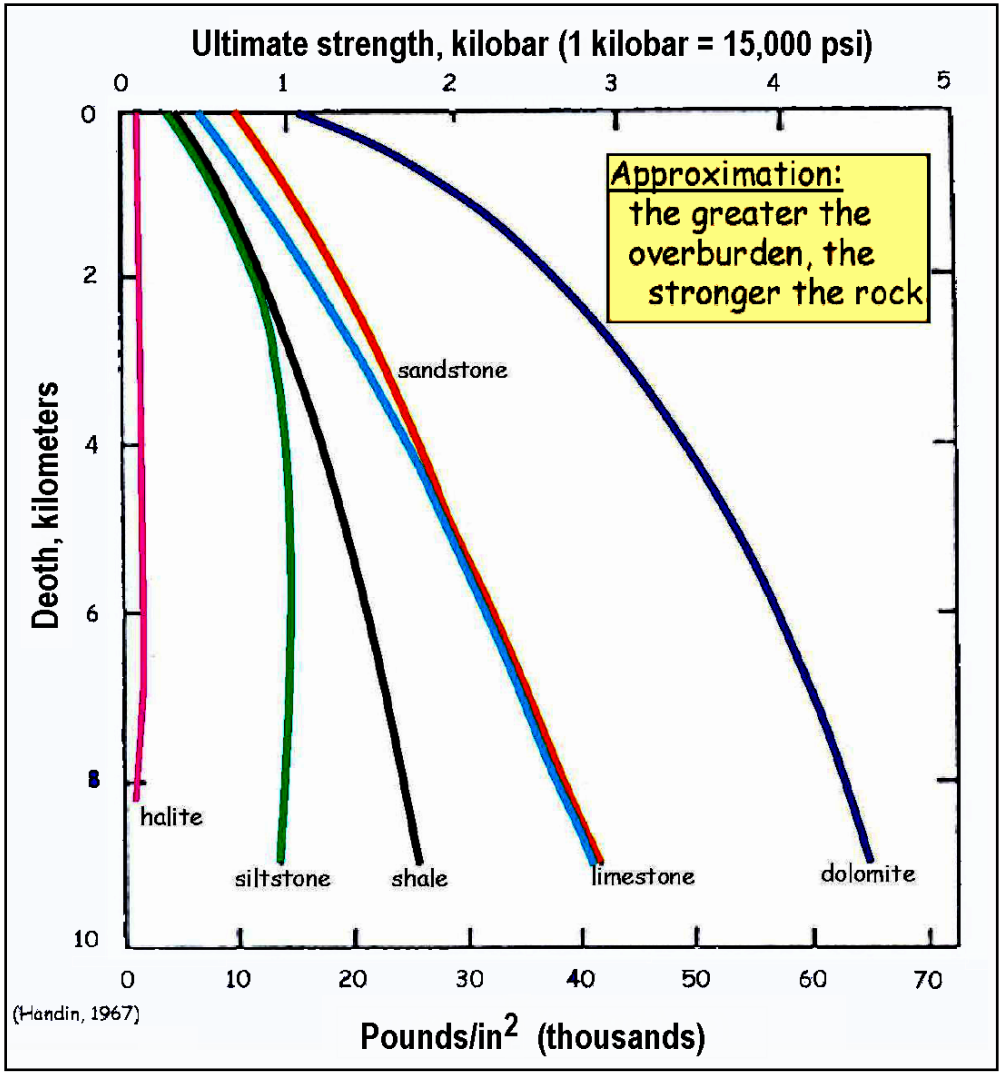


Experimentally deformed cylinders of marble, and their associated schematic stress-strain curves. The deformation mode changes from brittle to ductile with increasing confining pressure.

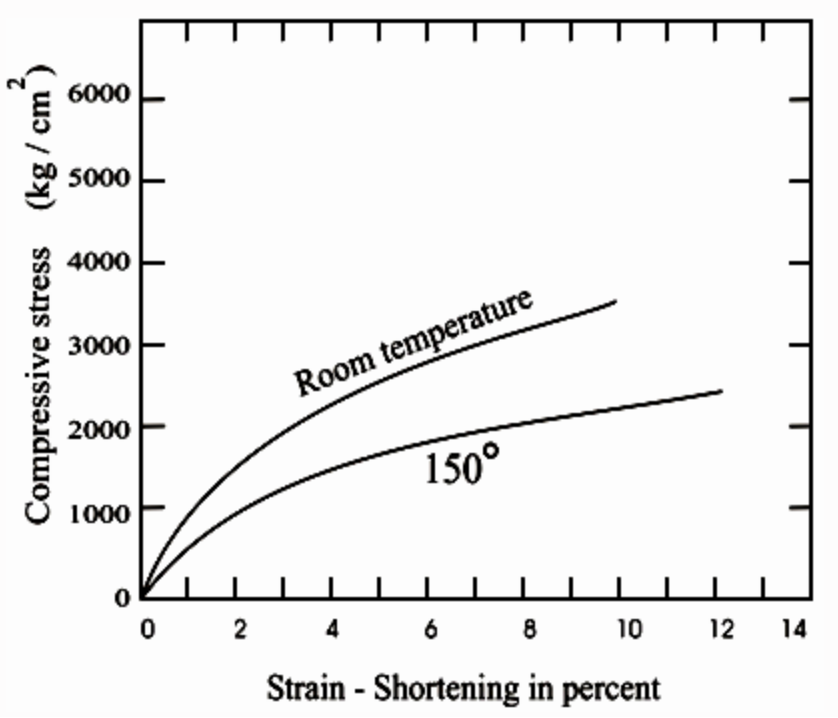
The relative strengths and ductility of various rocks as a function of depth of burial.

The ultimate strength of material increases with depth due to the increase in confining pressure**.**

<u>It is well known that, rocks behave as a viscous material below the depth of 700 km within the earth due to the very high confining pressure. No earthquakes occur below that depth.</u>



2- Temperature:

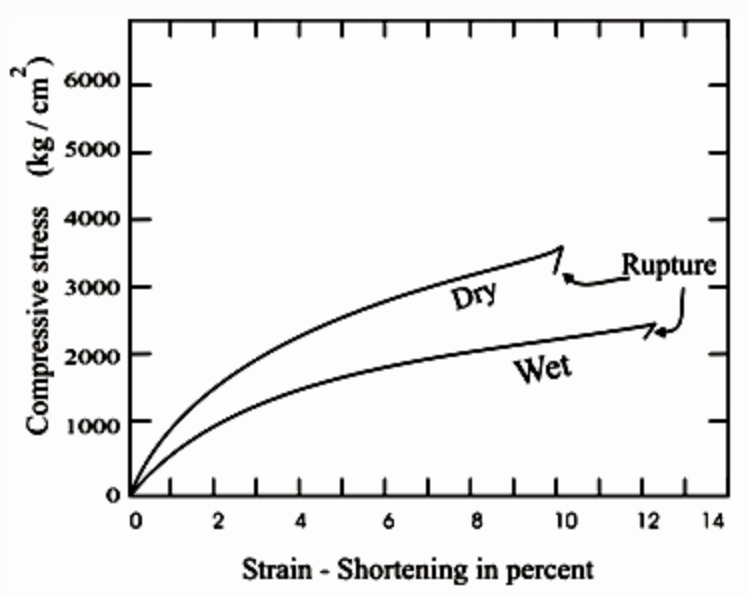


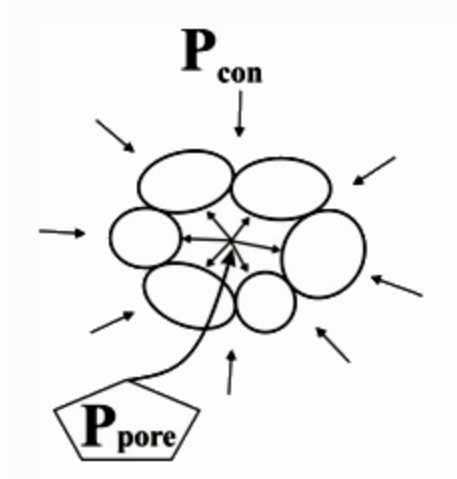
- Temperature affects the behavior of the material. Hot steel undergoes plastic deformation more easily than cold steel.
- Experimental data indicates that, the same amount of plastic deformation is produced at higher stresses in cold sample and at lower stresses in hot sample.
- Temperature increases the ductility of material.
- Plastic deformation (e.g. folding) is more common at depth below the earth's surface due to the high confining pressure and temperature.

3- <u>Solutions</u> :

- Wet material deform more easily than dry one**.**
- Experimental data indicates that, to get rupture you need lower stresses in wet sample than for dry one.
- Solutions have a pore pressure (P_{pore}) on the walls of the pores within the material.
- It lowers the strength of the material.
- The direction and effect of the pore pressure is opposite to the confining pressure (P_{con}).
- In wet material :

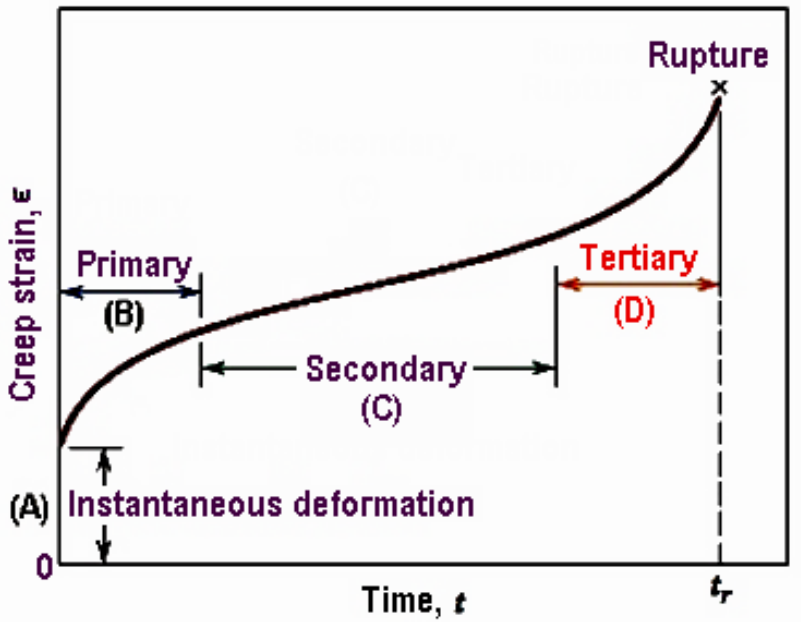
The effective pressure (P_{eff}) = P_{con} - P_{pore}





4- Time :

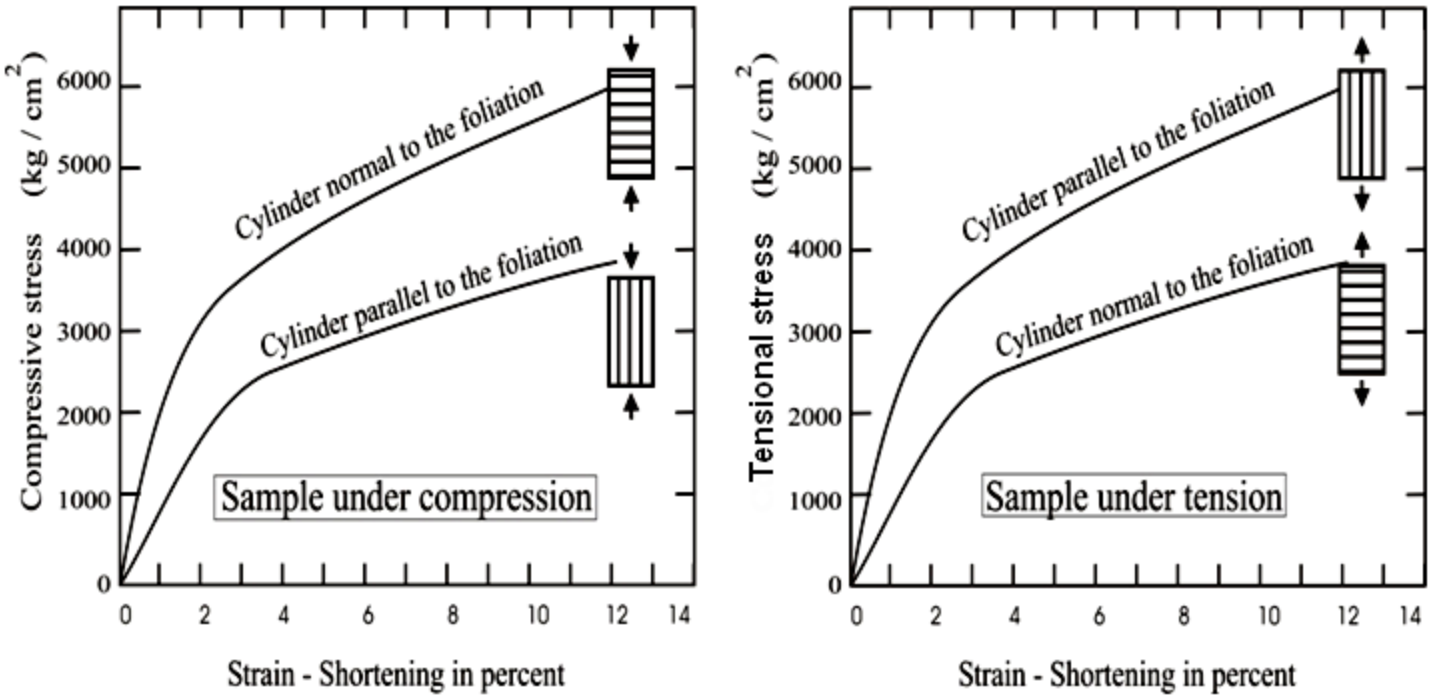
- All geologic processes take a long period of time. So, the time factor is very important in deformation processes that affect rocks.
- The application of stresses on rocks for a long period of time results in what is known as the **"Creep".**
- **Creep:** is the slow continuous deformation of the rocks with the passage of time under the effect of small stresses that are **smaller than the elastic limit** of the material. The ideal curve of the process of creep is given below.
- When a stress smaller than the elastic limit is applied on the material, an instantaneous elastic strain will occur at the same moment the stress is applied. This strain is represented by the region (A) in the creep diagram.



(A) Instantaneous elastic deformation.
(B) Primary creep.
(C) Secondary creep.
(D) Tertiary creep.

- With the passage of time, the material deforms plastically through three stages known as : the primary creep (B), the secondary creep (C), The tertiary creep (D).
- The tertiary creep (D) is characterized by a high rate of deformation, and is followed by the rupture of the material.
- From the previous explanation, it is clear that small stresses lower than the elastic limit of the material can produce plastic deformation and rupture when the stress is applied for a long period of time.

5- The anisotropy :



- The anisotropy is any structural feature affecting the material, such as fractures, faults, and foliation. The presence of anisotropy affects the behavior of the material under stresses.
- **Under compression**, the cylinder of the material normal to the foliation is stronger than the cylinder parallel to the foliation.
- **Under tension**, the cylinder parallel to the foliation is stronger than the cylinder normal to the foliation.

N.B.:
Some of the figures used in this lecture are used after previous literatures for the purpose of teaching for students.