MODES OF DEFORMATION OF ROCKS

- Within the Earth, rocks are continually being subjected to forces that tend to bend them, twist them, or fracture them.
- When rocks bend, twist or fracture we say that they deform (change shape or size).
- The forces that cause deformation of rock are referred to as stresses (Force/unit area). So, to understand rock deformation we must first explore these forces or stresses.

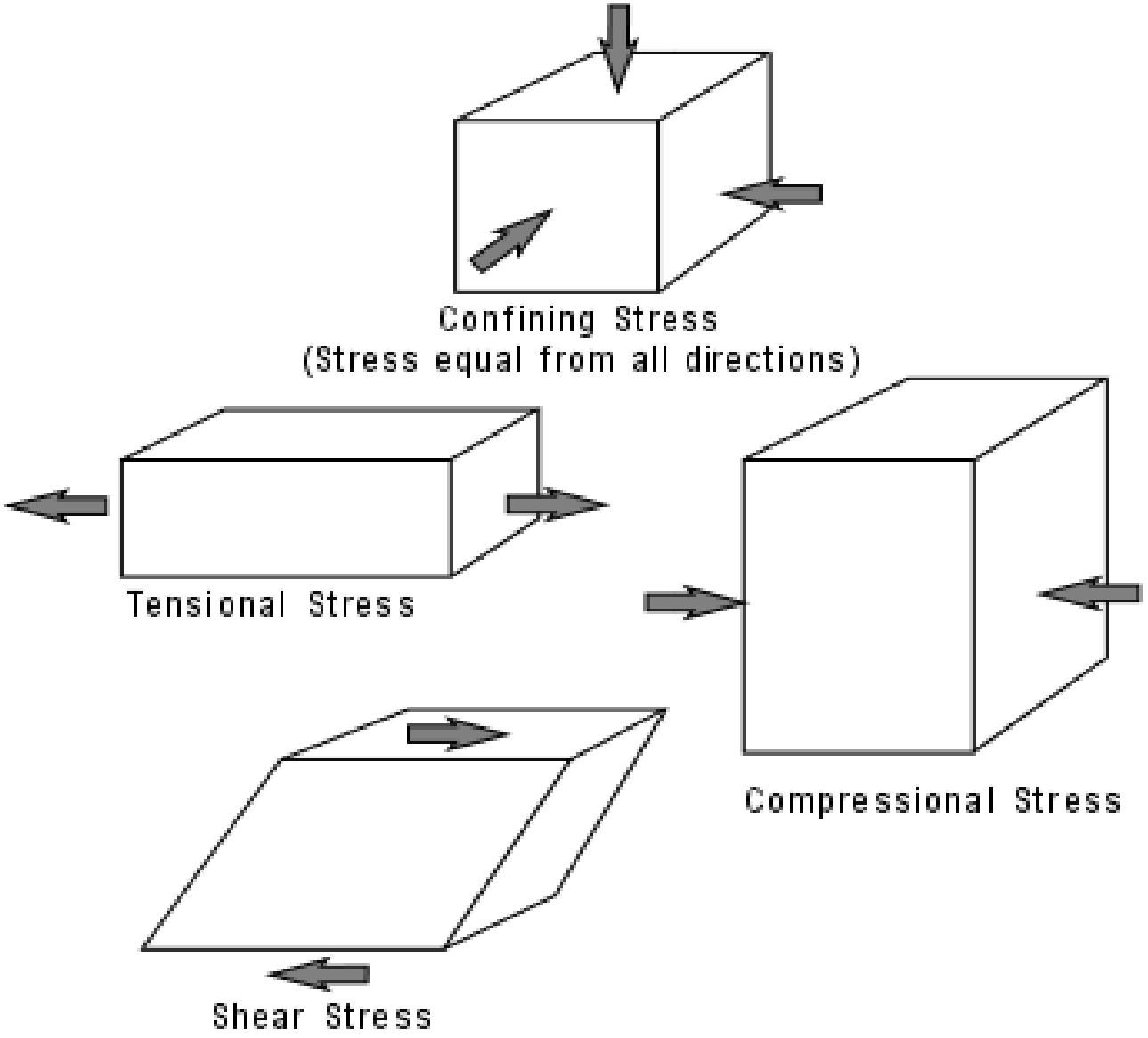
Stress and Strain

- Stress is a force applied over an area. One type of stress that we are all used to is a uniform stress, called pressure.
- A uniform stress is a stress wherein the forces act equally from all directions. In the Earth the pressure due to the weight of overlying rocks is a uniform stress, and is sometimes referred to as confining stress.

- When rocks deform they are said to ***strain***.
- A strain is a change in size, shape, or volume of a material.

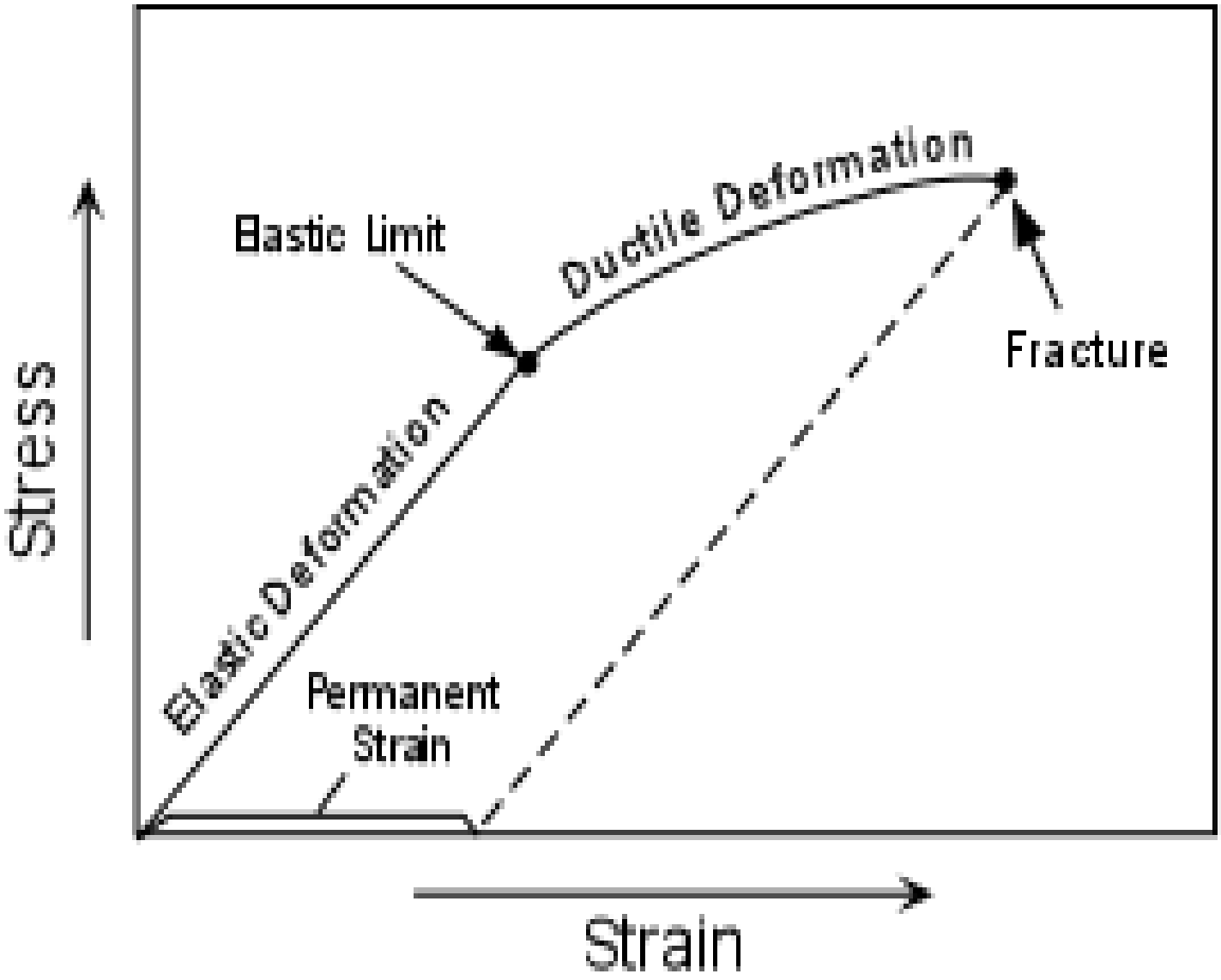
Differential Stress

- If stress is not equal from all directions then we say that the stress is a differential stress. Three kinds of differential stress occur.
- **Tensional stress (or extensional stress),** which stretches rock;
- **Compressional stress**, which squeezes rock;
- **Shear stress**, which result in slippage and translation.


Confining Stress
(Stress equal from all directions)
Tensional Stress
Compressional Stress
Shear Stress

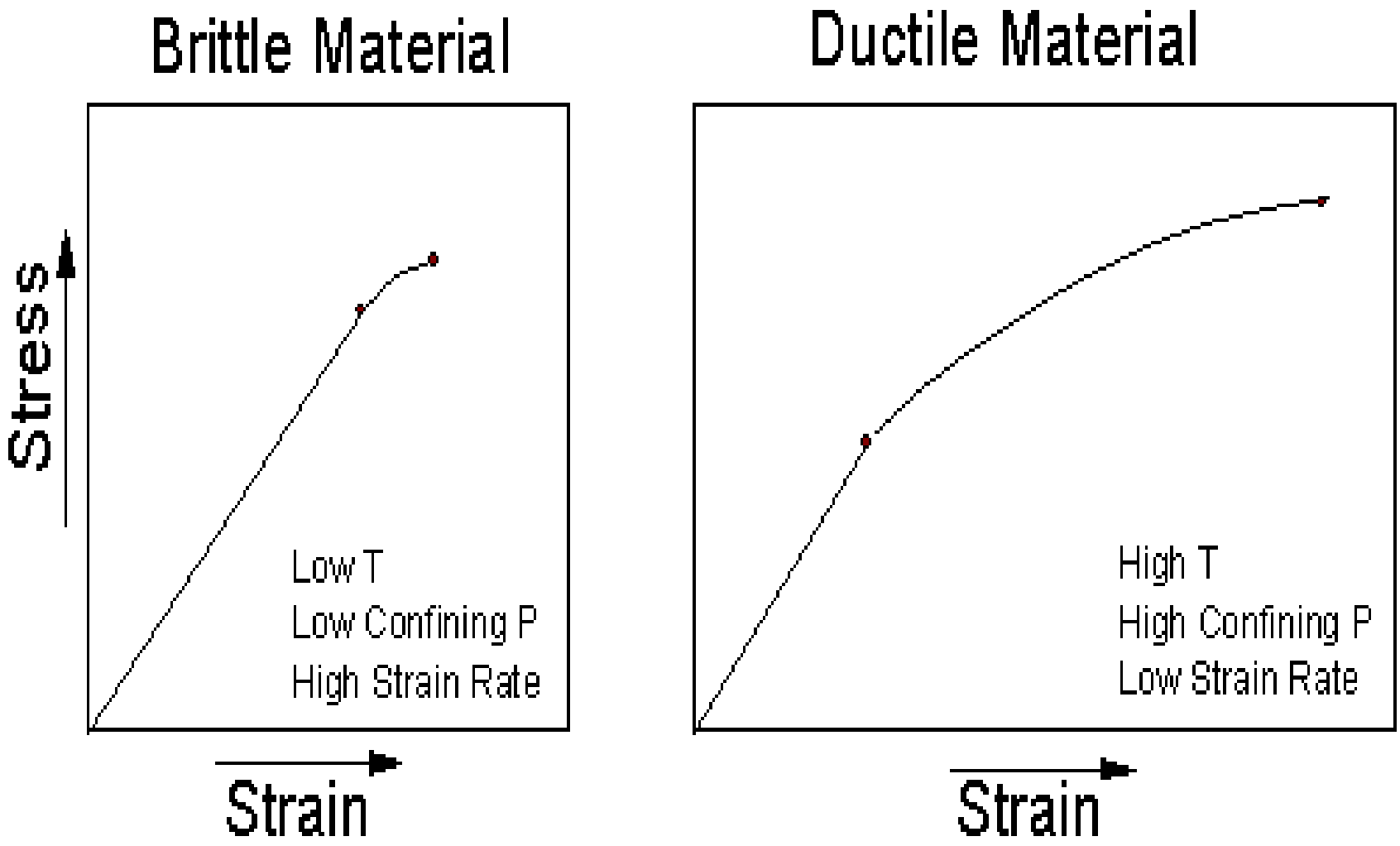
Stages of Deformation

- When a rock is subjected to increasing stress it passes through 3 successive stages of deformation.
- **Elastic Deformation** -- wherein the strain is reversible.
- **Ductile Deformation** -- wherein the strain is irreversible.
- **Fracture - irreversible strain--** wherein the material breaks.


Stress
Elastic Limit
Ductile Deformation
Fracture
Elastic Deformation
Permanent
Strain
Strain

- We can divide materials into two classes that depend on their relative behavior under stress.
- **Brittle materials** have a small or large region of elastic behavior but only a small region of ductile behavior before they fracture.

- **Ductile materials** have a small region of elastic behavior and a large region of ductile behavior before they fracture.


Brittle Material
Stress
Low T
Low Confining P
High Strain Rate
Strain
Ductile Material
High T
High Confining P
Low Strain Rate
Strain

Factors effecting the behavior of materials

- How a material behaves will depend on several factors. Among them are
- **Temperature**
- **Confining Pressure**
- **Strain rate**
- **Composition**

- **Temperature**
- At high temperature molecules and their bonds can stretch and move, thus materials will behave in more ductile manner.
- At low Temperature, materials are brittle.

- **Confining Pressure**
- At high confining pressure materials are less likely to fracture because the pressure of the surroundings tends to hinder the formation of fractures.
- At low confining stress, material will be brittle and tend to fracture sooner.

- **Strain rate**
- At high strain rates material tends to fracture. At low strain rates more time is available for individual atoms to move and therefore ductile behavior is favored.

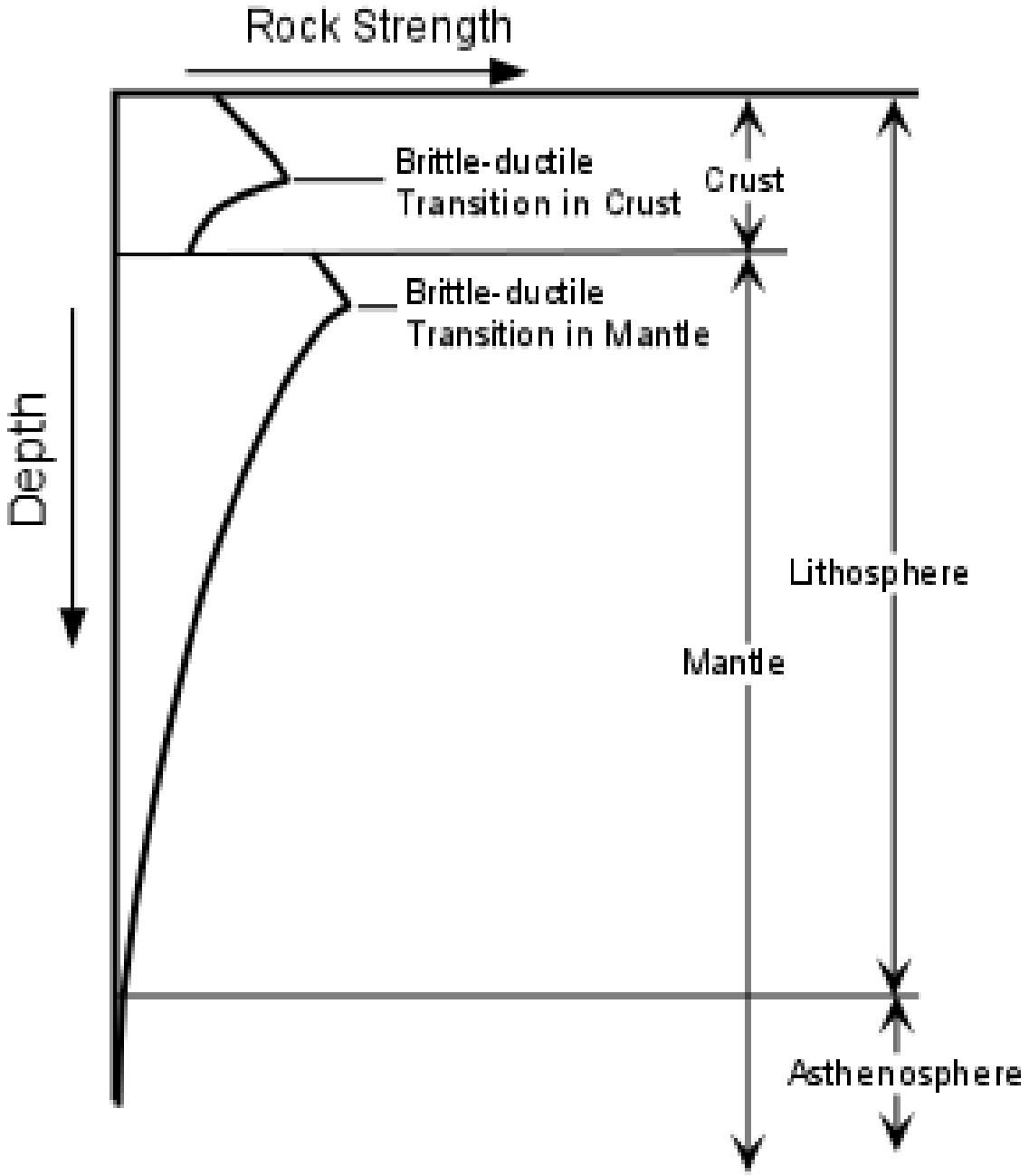
- **Composition**
- Some minerals, like quartz, olivine, and feldspars are very brittle.
- Others, like clay minerals, micas, and calcite are more ductile
- This is due to the chemical bond types that hold them together.
- Thus, the mineralogical composition of the rock will be a factor in determining the deformational behavior of the rock.

- Another aspect is presence or absence of water.
- Water appears to weaken the chemical bonds and forms films around mineral grains along which slippage can take place.
- Thus wet rock tends to behave in ductile manner, while dry rocks tend to behave in brittle manner.

Brittle-Ductile Properties of the Lithosphere

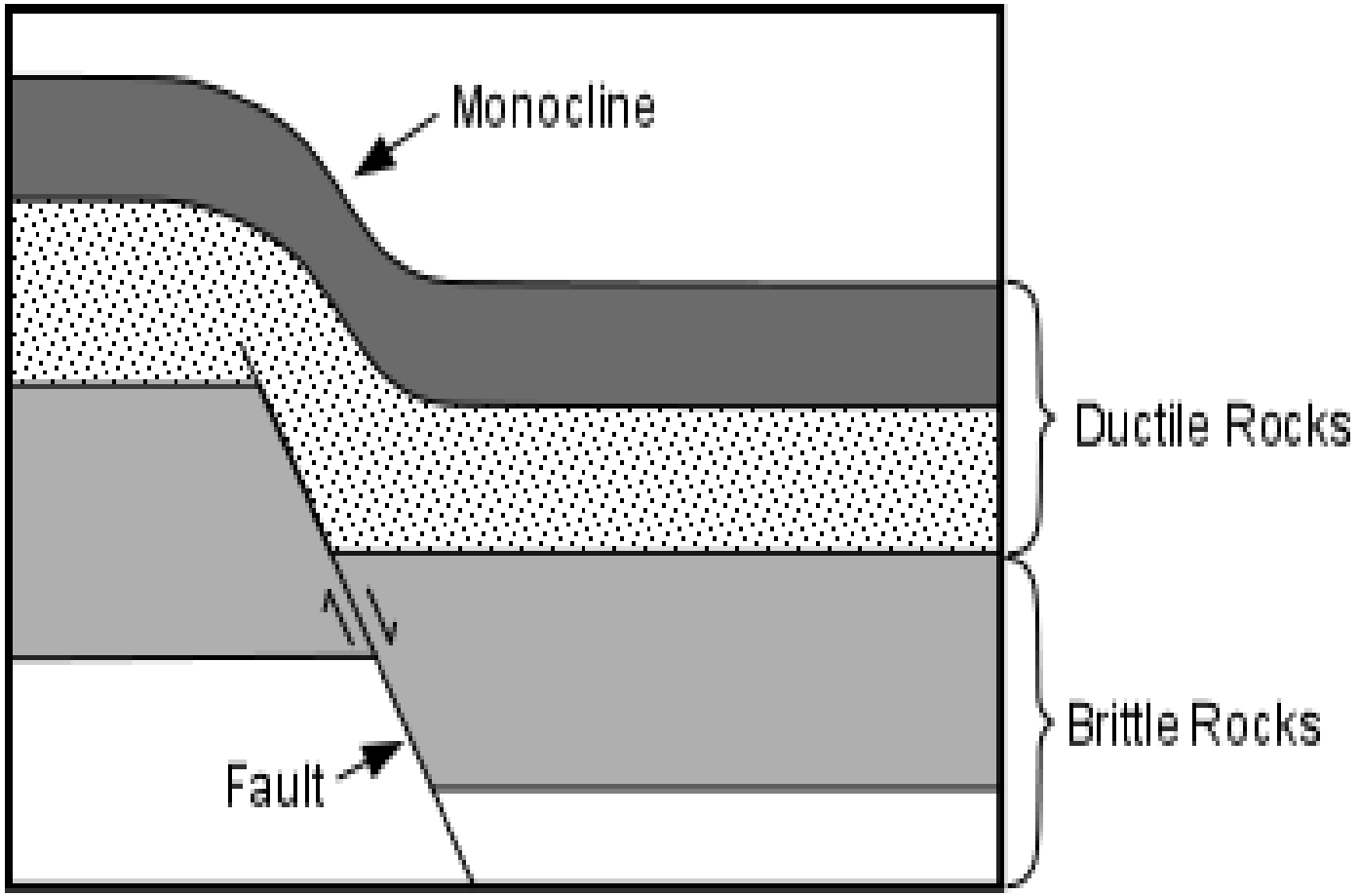
- We all know that rocks near the surface of the Earth behave in a brittle manner.
- Crustal rocks are composed of minerals like quartz and feldspar which have high strength, particularly at low pressure and temperature. As we go deeper in the Earth the strength of these rocks initially increases.
- At a depth of about 15 km we reach a point called the brittle-ductile transition zone.
- Below this point rock strength decreases because fractures become closed and the temperature is higher, making the rocks behave in a ductile manner.

- At the base of the crust the rock type changes to peridotite which is rich in olivine. Olivine is stronger than the minerals that make up most crustal rocks, so the upper part of the mantle is again strong.
- But, just as in the crust, increasing temperature eventually predominates and at a depth of about 40 km the brittle-ductile transition zone in the mantle occurs. Below this point rocks behave in an increasingly ductile manner.


Rock Strength
Brittle-ductile
Transition in Crust
Crust
Brittle-ductile
Transition in Mantle
Depth
Lithosphere
Mantle
Asthenosphere

The Relationship Between Folding and Faulting

- Because different rocks behave differently under stress, we expect that some rocks when subjected to the same stress will fracture or fault, while others will fold.
- When such contrasting rocks occur in the same area, such as ductile rocks overlying brittle rocks, the brittle rocks may fault and the ductile rocks may bend or fold over the fault.


Monocline
Ductile Rocks
Brittle Rocks
Fault

Folds and Topography

- Since different rocks have different resistance to erosion and weathering, erosion of folded areas can lead to a topography that reflects the folding.
- Resistant strata would form ridges that have the same form as the folds, while less resistant strata will form valleys

Mountain Ranges - The Result of Deformation of the Crust

- One of the most spectacular results of deformation acting within the crust of the Earth is the formation of mountain ranges. Mountains originate by three processes, two of which are directly related to deformation. Thus, there are three types of mountains:

Fault Block Mountains

- As the name implies, fault Block Mountains originate by faulting.
- As discussed previously, both normal and reverse faults can cause the uplift of blocks of crustal rocks.
- The Sierra Nevada Mountains of California, and the mountains in the Basin and Range province of the western U.S., were formed by faulting processes and are thus fault Block Mountains.

Fold & Thrust Mountains

- Large compressional stresses can be generated in the crust by tectonic forces that cause continental crustal areas to collide.
- When this occurs the rocks between the two continental blocks become folded and faulted under compressional stresses and are pushed upward to form fold and thrust mountains.
- The Himalayan Mountains (currently the highest on Earth) are mountains of this type and were formed as a result of the Indian Plate colliding with the Eurasian plate. Similarly the Appalachian Mountains of North America and the Alps of Europe were formed by such processes

Volcanic Mountains

- The third type of mountains, volcanic mountains, are not formed by deformational processes, but instead by the outpouring of magma onto the surface of the Earth.
- The Cascade Mountains of the western U.S., and of course the mountains of the Hawaiian Islands and Iceland are volcanic mountains.