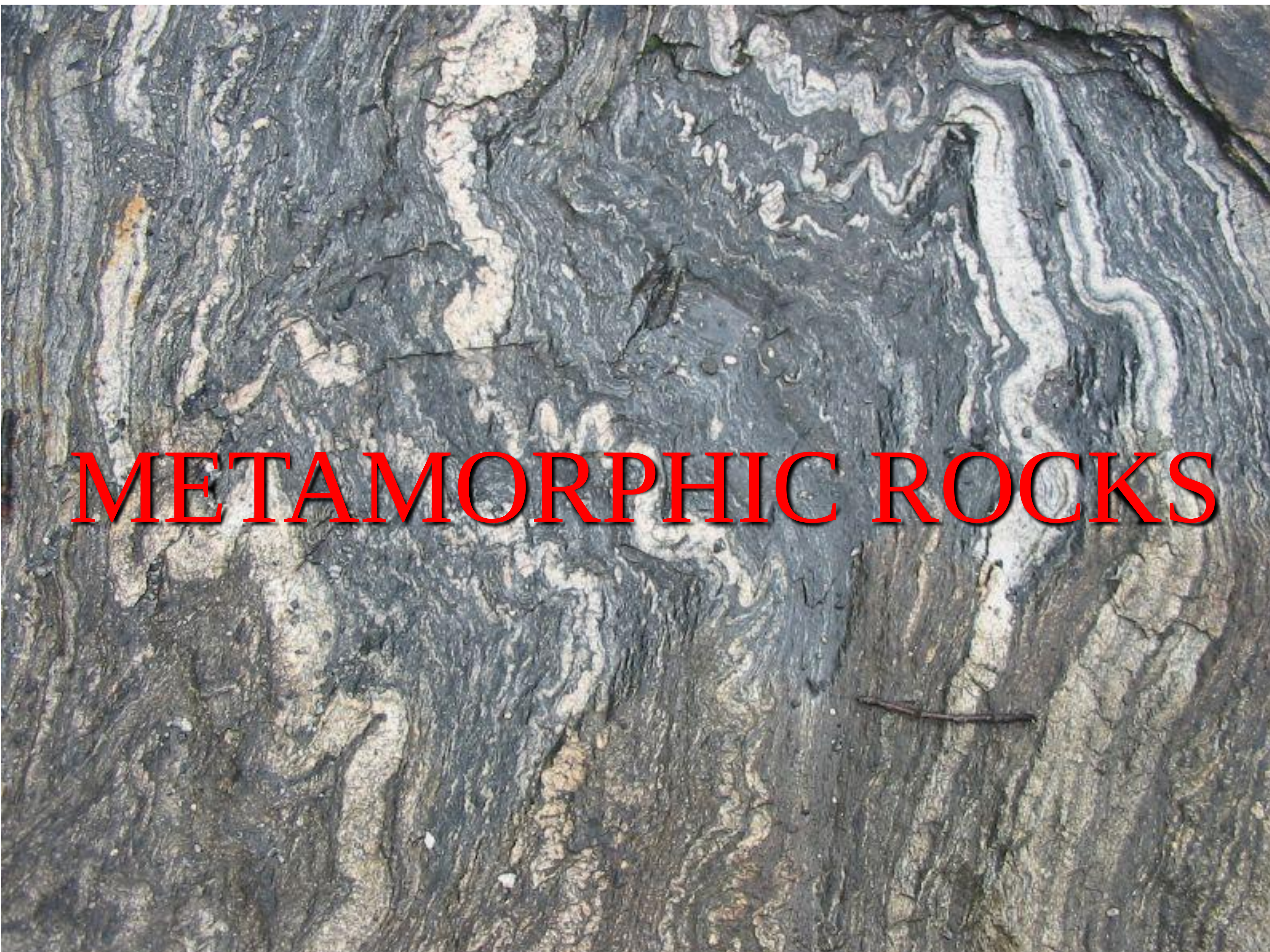


METAMORPHIC ROCKS

Definition

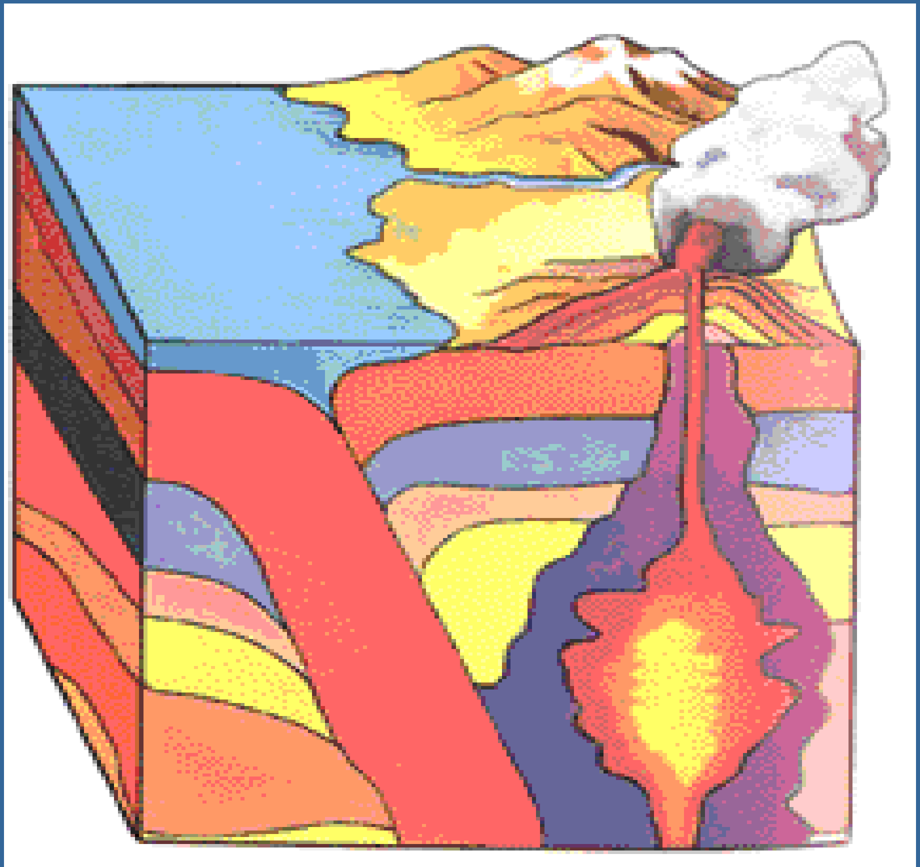
- Meta means **'change'**, Morph means **'form'**
- A change in form of pre-existing rocks of all types. **Sedimentary**, **igneous** and **metamorphic**
- By the action of **Heat** alone (**Contact**)
- By the action of **Pressure** alone (**Dynamic**)
- By the action of **Heat and Pressure** in combination (**Regional**)

Metamorphism Excludes:

- **Weathering, Diagenesis and Lithification**
- Environments where temperatures are below 200 – 300 degrees centigrade
- Melting Of Rocks - environments where temperatures are above 650 degrees centigrade
- Environments less than 2km depth and at pressures below 1000 bars

Metamorphic Rocks

What are They?

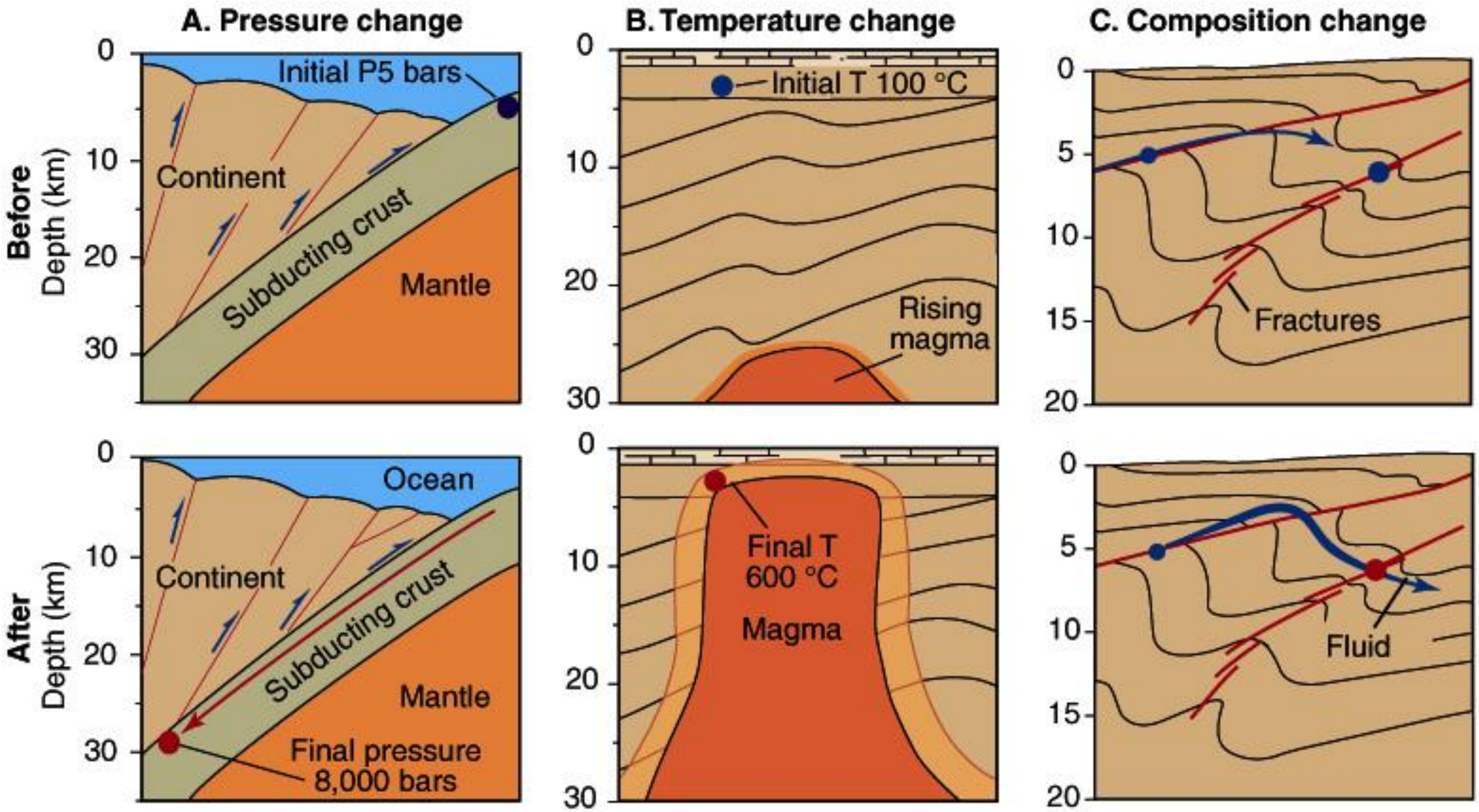


- Forms when rocks are changed into different kinds of rocks by great heat and/or pressure.
- They are heated, squeezed, folded, or chemically changed by contact with hot fluids.

Controlling Factors influencing of Metamorphism

- **Temperature**
- **Pressure**
- **Fluid**
- **Time**

Agents of Metamorphism


A. Pressure change
B. Temperature change
C. Composition change
Before
After
Depth (km)
Initial P5 bars
Continent
Subducting crust
Mantle
Ocean
Final pressure
8,000 bars
Initial T 100 °C
Rising
magma
Final T
600 °C
Magma
Fractures
Fluid
0
10
20
30
5
15

Factors influencing Metamorphism

Temperature

- **Below about 150°C, most minerals are stable (little or no metamorphism)**
- **Above 150°C, reaction rate increases as temperature increases, new minerals begin to form**
- **Above 600°C, some minerals begin to melt (transition to igneous rocks)**
- **Temperature a function of depth within the Earth and the presence of a magma**

Factors influencing Metamorphism

Pressure

- As pressure increases, pore spaces reduced and density increases, pore fluids are expelled

- Minerals recrystallize and begin to realign

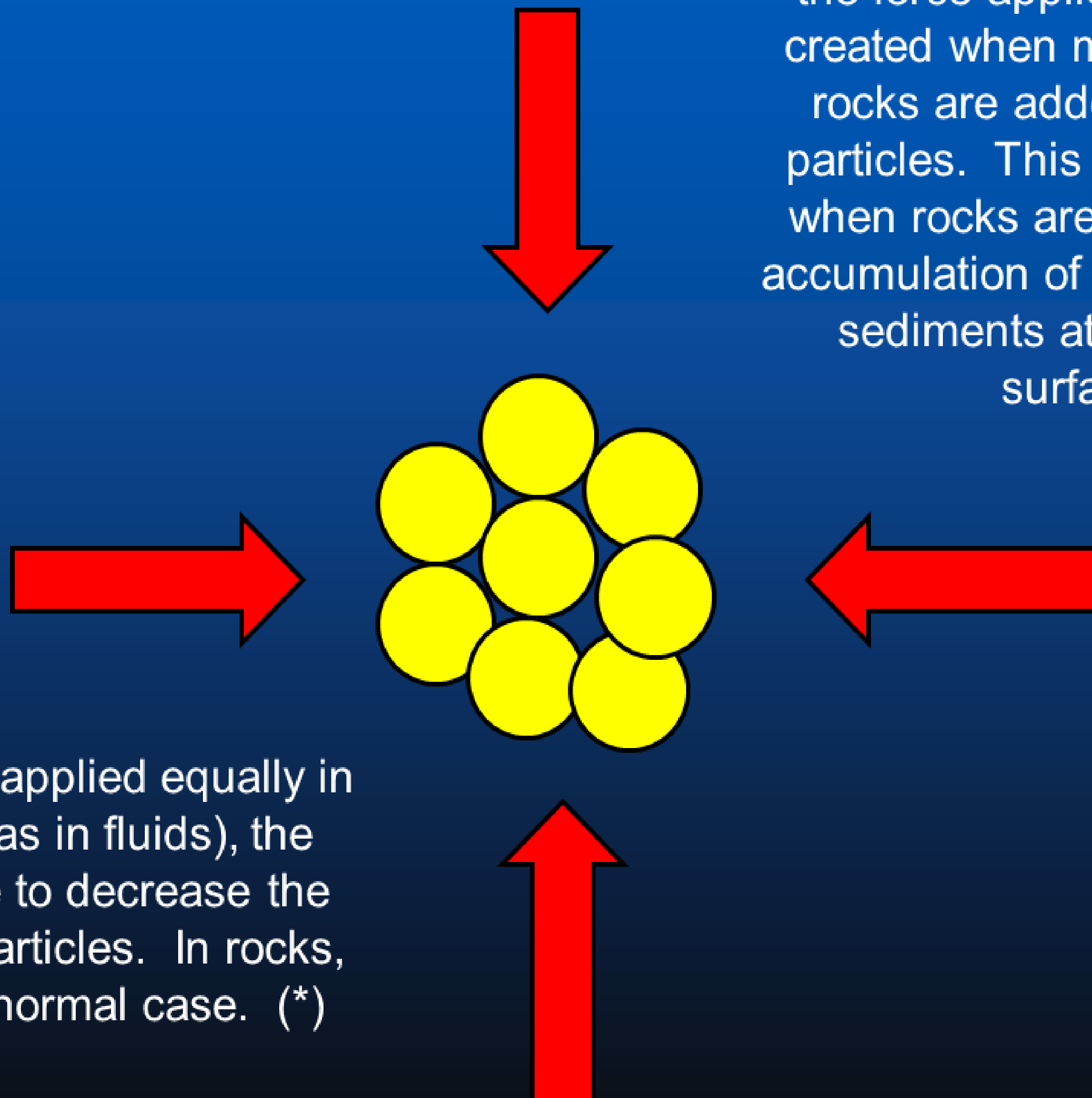
Differential stress

- Pressure is greater in one direction than in another

AGENT OF METAMORPHISM -- PRESSURE

Confining Pressure

In terms of metamorphic geology, confining pressure is the force applied to particles created when more and more rocks are added above the particles. This would happen when rocks are buried by the accumulation of more and more sediments at the Earth's surface.



If pressures are applied equally in all directions (as in fluids), the result would be to decrease the volume of the particles. In rocks, this is **not** the normal case. (*)

AGENT OF METAMORPHISM -- PRESSURE

Differential Pressure (Stress)

Instead, pressures are more directed. In this example, the principle stresses are from top and bottom. This would be an example of sediments being buried 1000's of feet below the surface. The force creating the pressure is simply gravity.

The particles are distorted. They have become elongate. Note that their long axis (shown by the red line on the single yellow particle) is oriented perpendicular to the maximum pressures (the red arrows). (*)

AGENT OF METAMORPHISM -- PRESSURE

Differential Pressure (Stress)

In this example the primary force is horizontal. This force could be created by the collision of continents during plate motions.

Here again you can see the distortion of the grains. They are flattened with their long axis perpendicular to the principle forces. (*)

AGENT OF METAMORPHISM --PRESSURE - Low

DEFORMATION

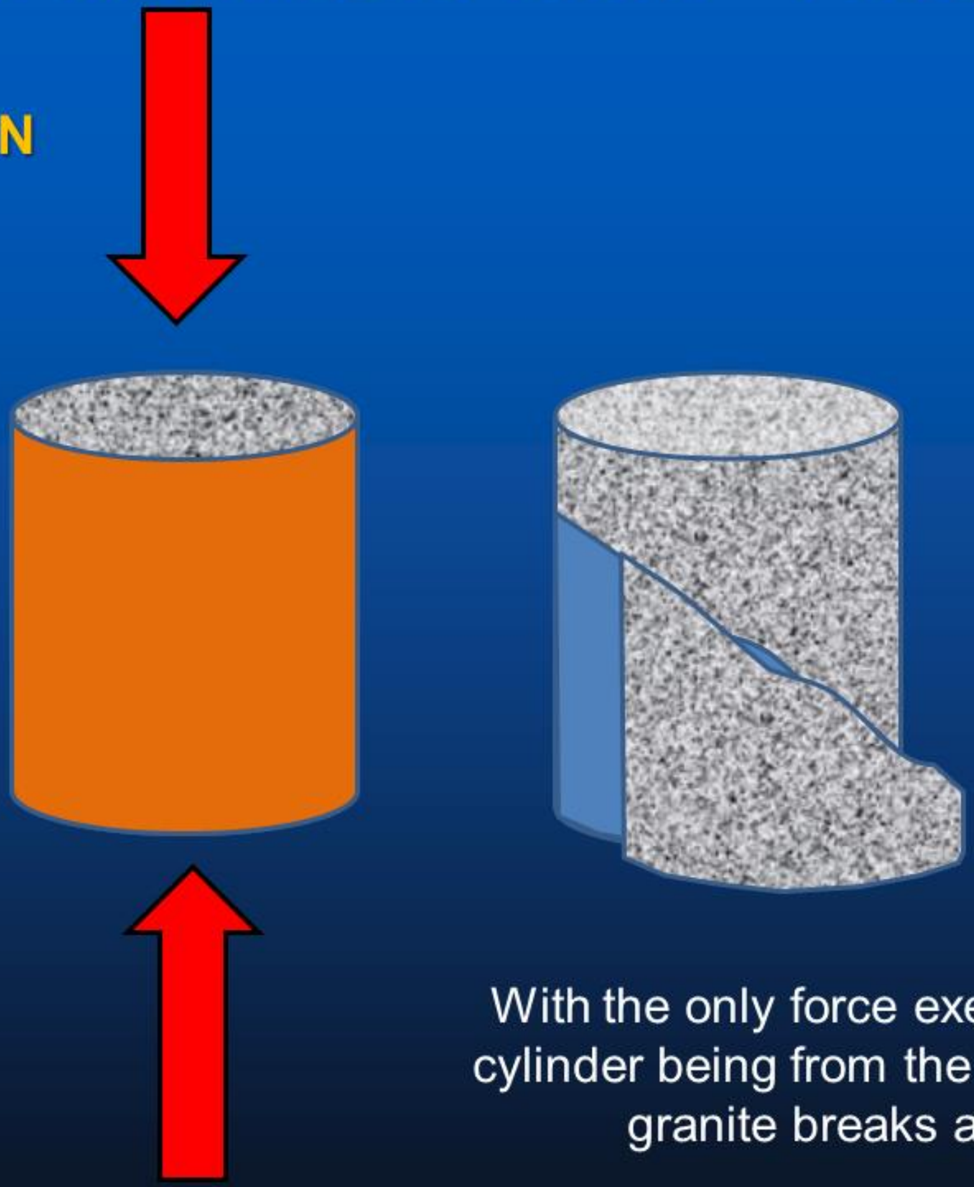
The next series of pages shows what happens when a brittle rock, like granite, is put under pressure. Low pressure at first and then greater pressures.

Each cylinder of granite is compressed in a copper jacket (shown in orange) so if there is an explosive failure, the pieces do not damage the equipment.

The principle force is applied from top and bottom. (*)

AGENT OF METAMORPHISM -- PRESSURE - Low

DEFORMATION

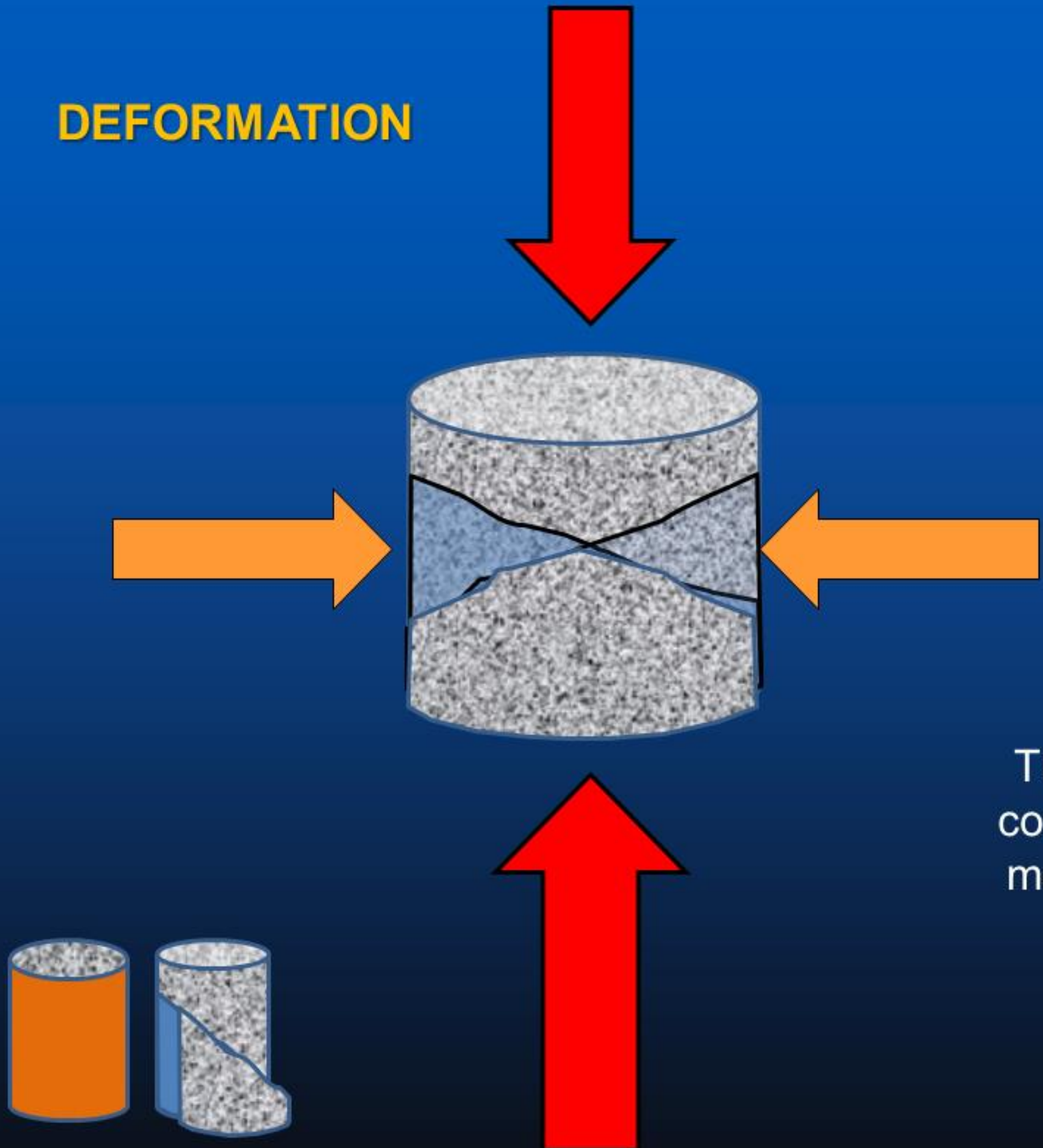


With the only force exerted on the granite cylinder being from the top and bottom, the granite breaks as shown. (*)

AGENT OF METAMORPHISM -- PRESSURE - Medium

DEFORMATION

In this example, medium confining pressure is added. This is shown by the orange arrows at the sides.

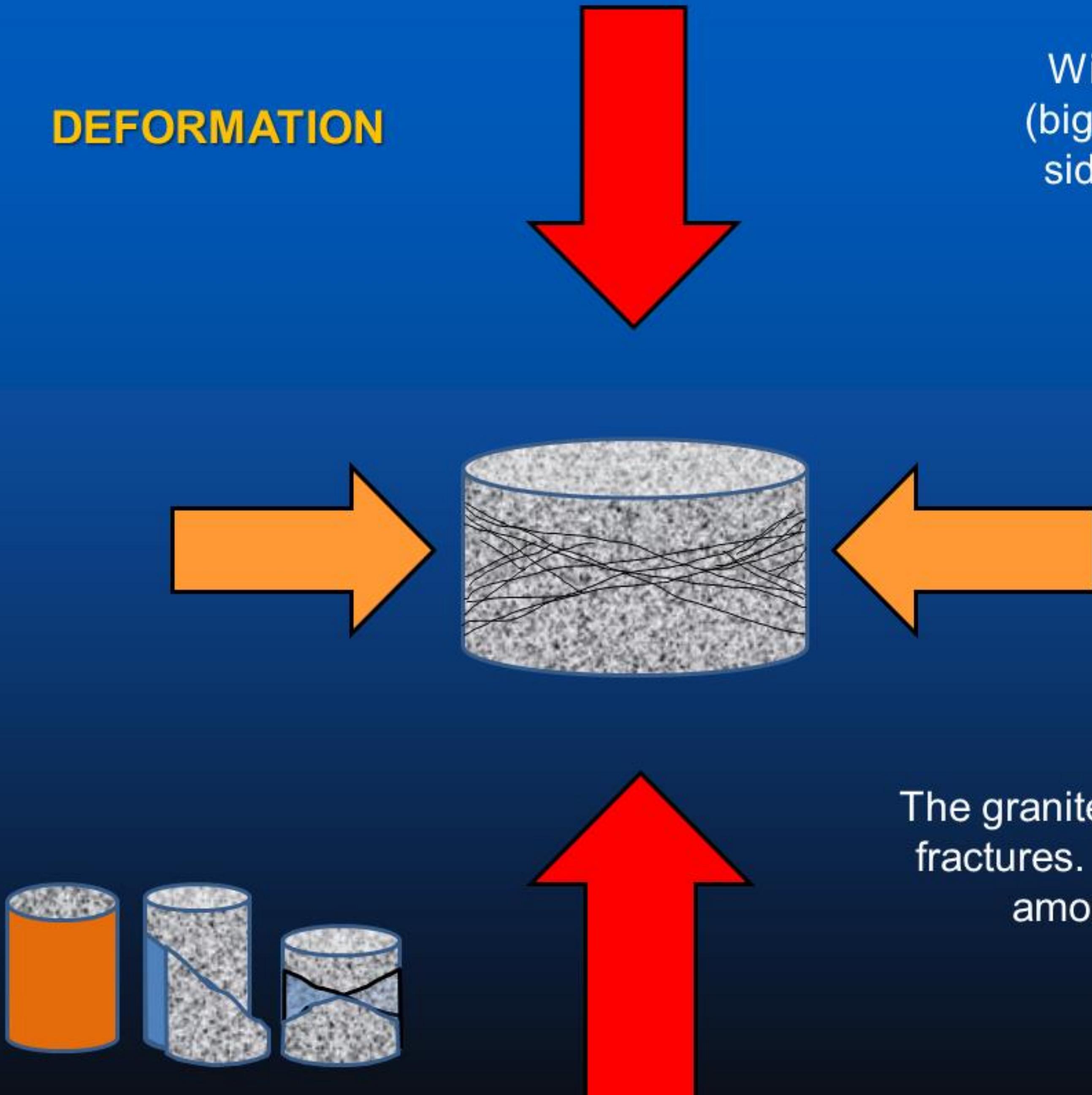


The granite breaks, but it is also compressed a little. There is also more than one main fracture. (*)

AGENT OF METAMORPHISM -- PRESSURE - HIGH

DEFORMATION

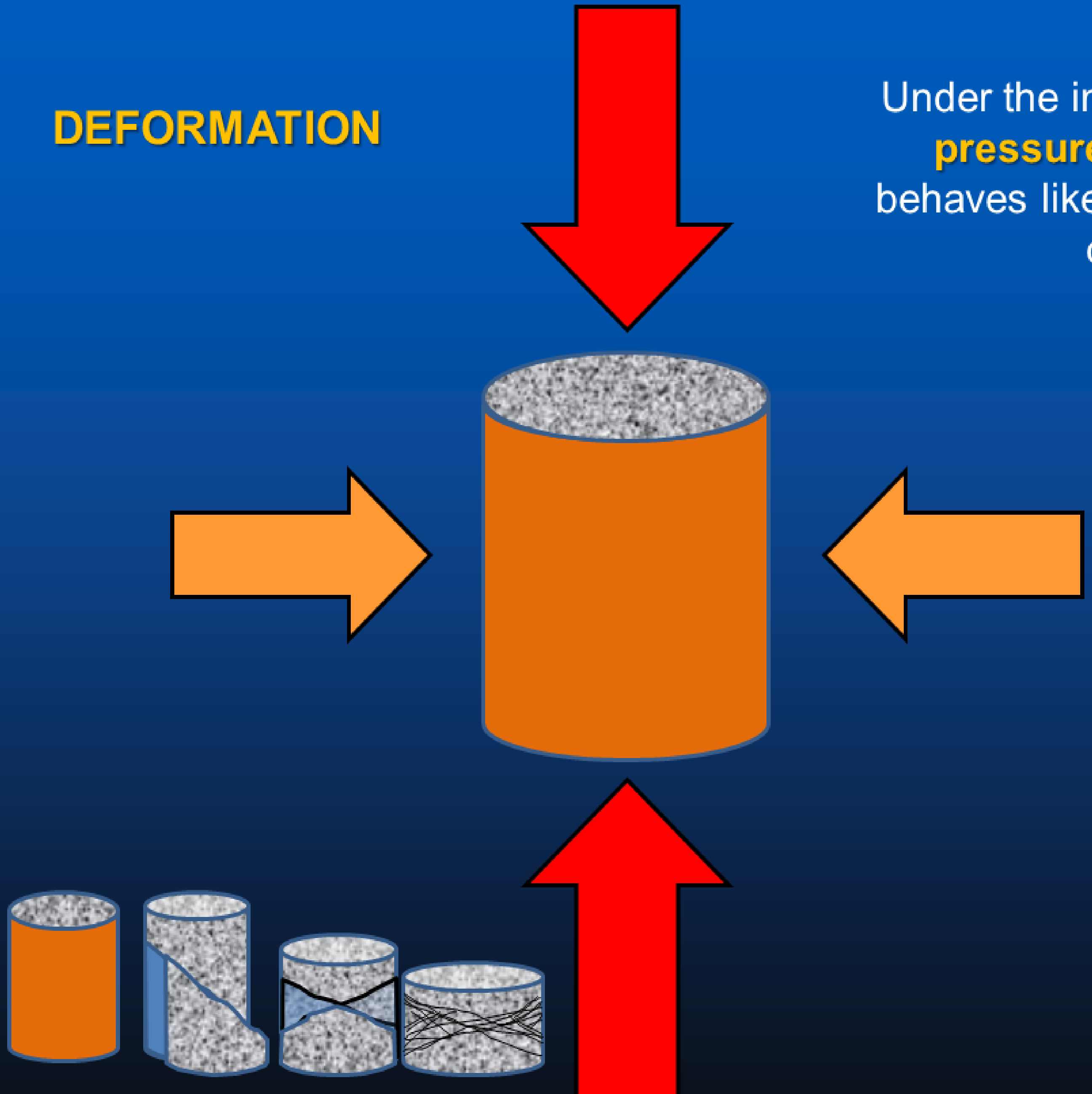
With high confining pressure (bigger orange arrows from the sides), the granite behaves a little differently.



The granite is broken with many small fractures. There is also a significant amount of shortening. (*)

AGENTS OF METAMORPHISM -- PRESSURE and HEAT

DEFORMATION

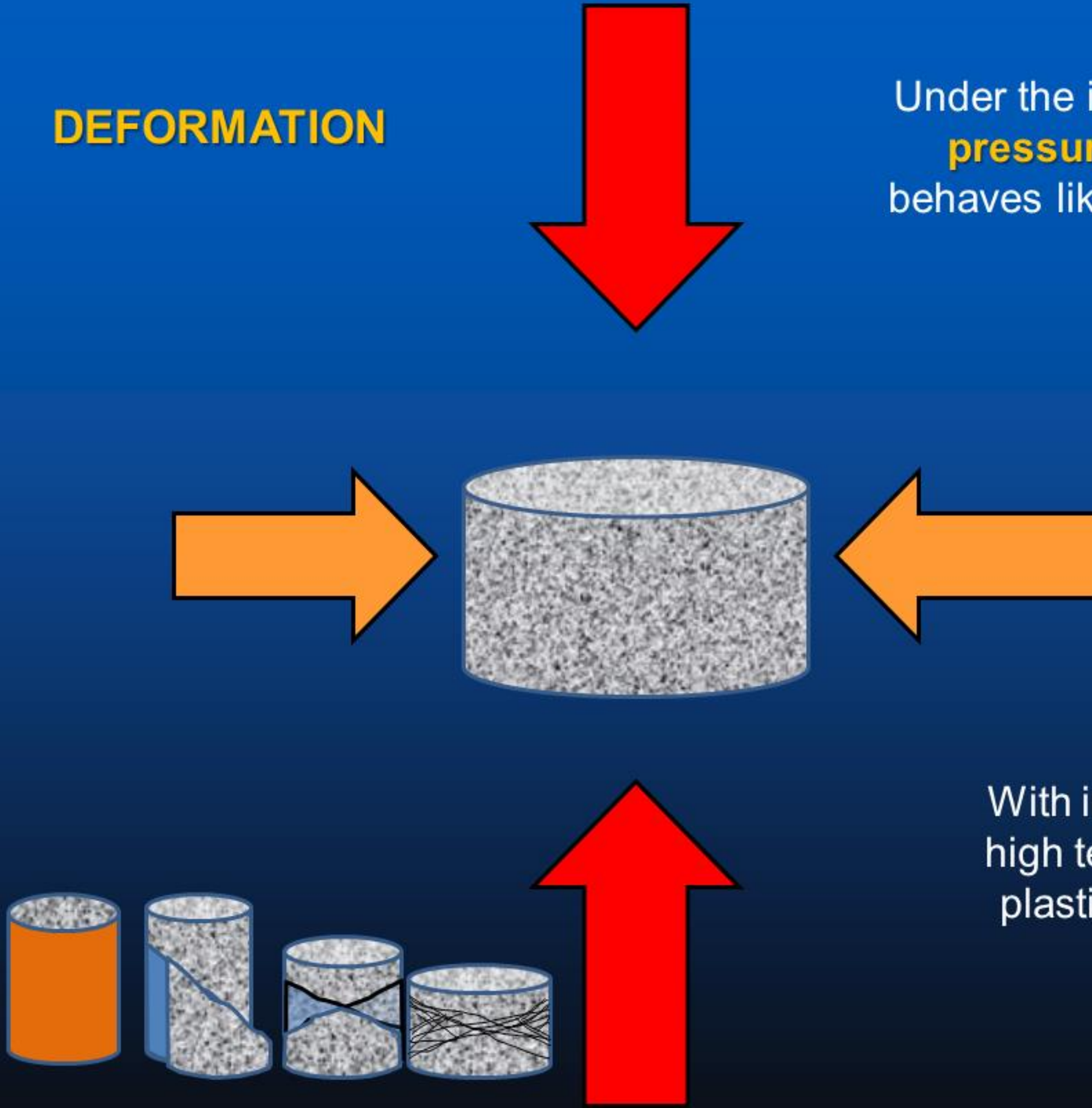


Under the influence of **high confining pressure AND heat**, the granite behaves like a plastic material, instead of a brittle rock.

AGENTS OF METAMORPHISM -- PRESSURE and HEAT

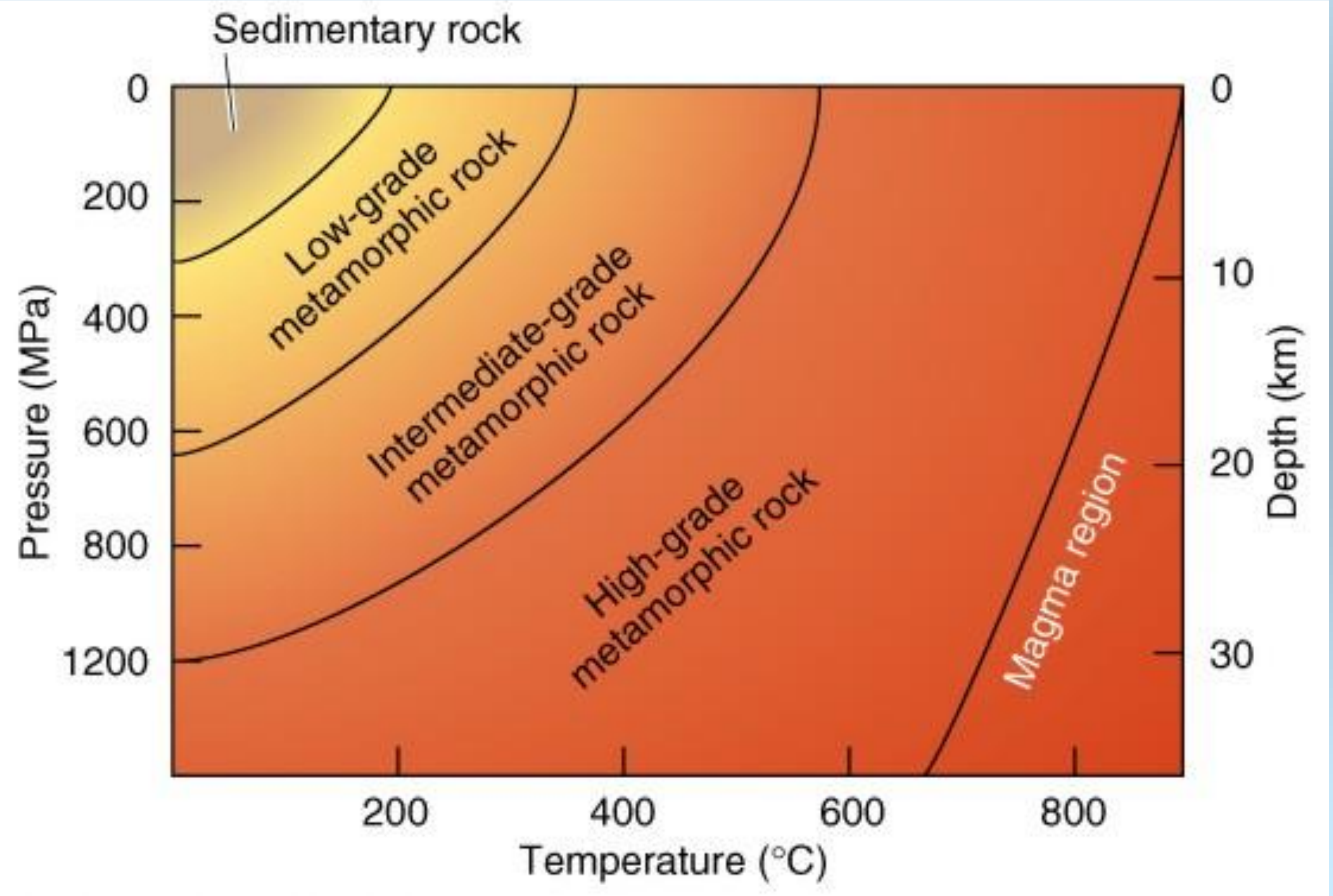
DEFORMATION

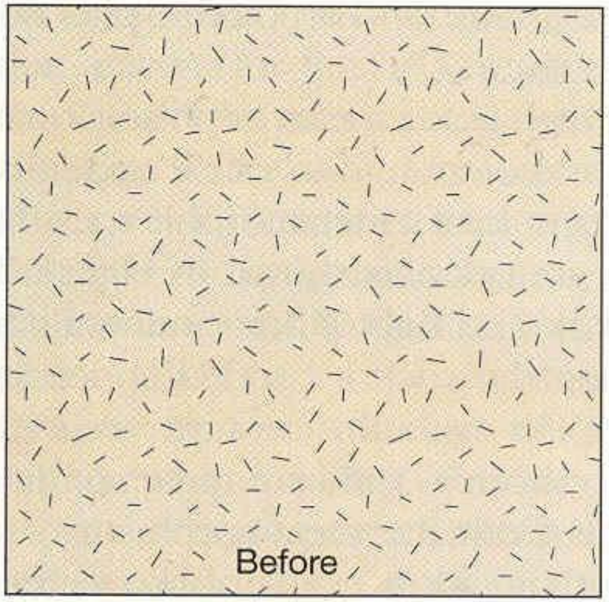
Under the influence of **high confining pressure AND heat**, the granite behaves like a plastic material, instead of a brittle rock.

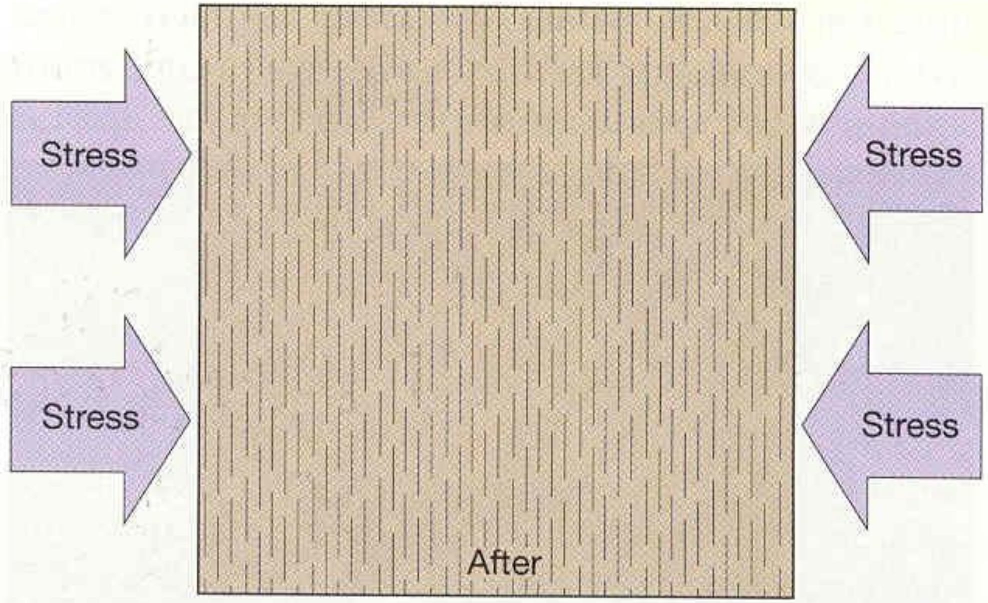


With increase in burial and under high temperatures, this leads to a plastic flow of rocks, rather than brittle failure. (*)

Temperature, Pressure and Rock Type

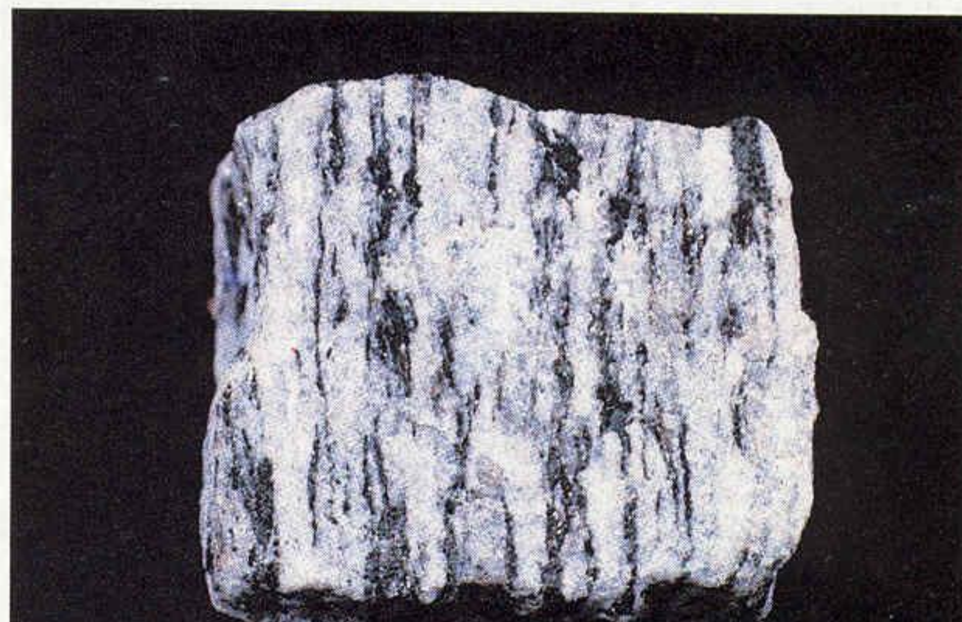






Granite

Gneiss



Effects of Stress

Uniform

Differential

Factors influencing Metamorphism

Pore fluids (water and carbon dioxide)

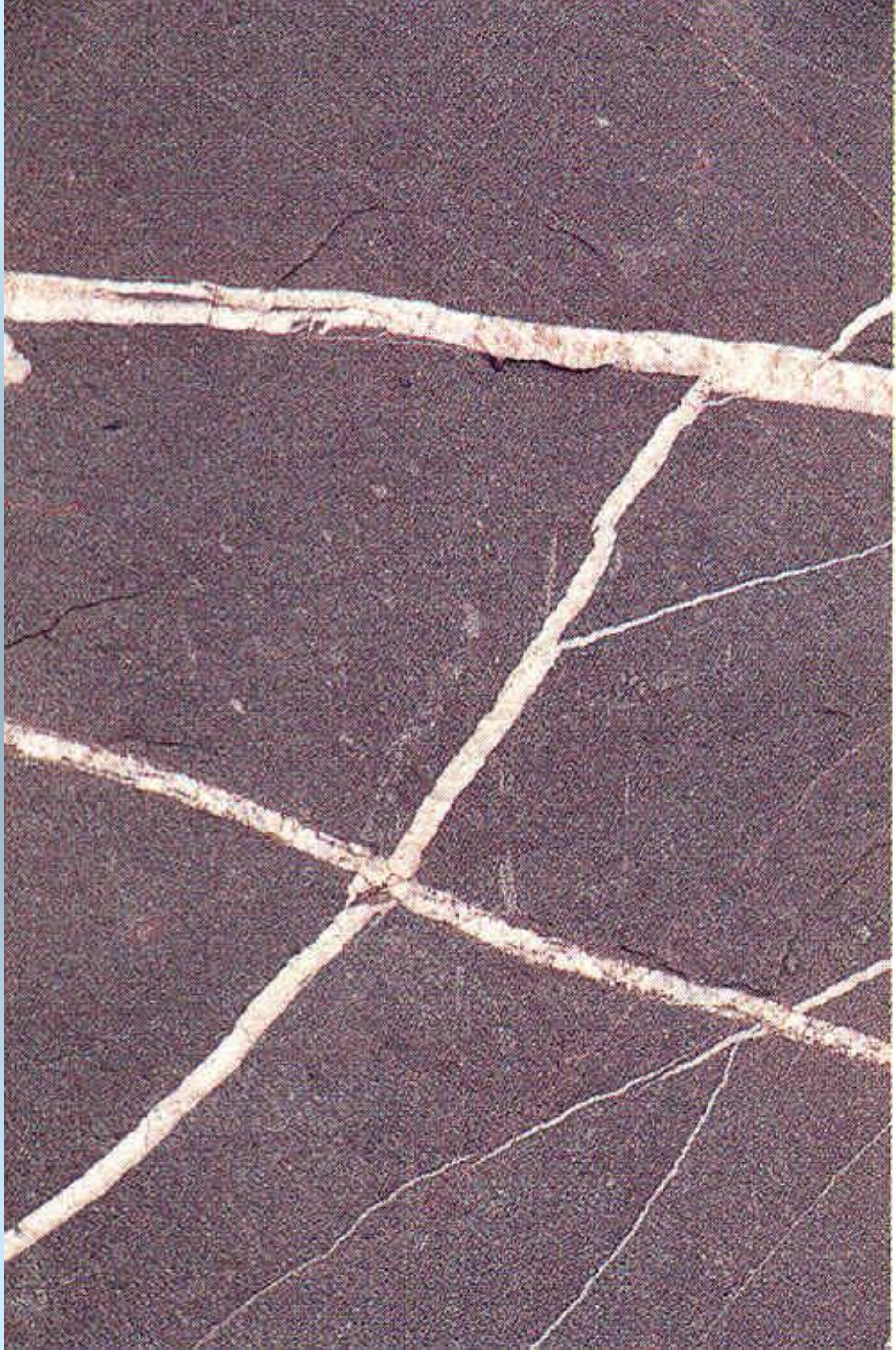
- As pressure increases, pore fluids are expelled
- Pore fluids increase the rate of metamorphic reactions by:
  - storing ions involved in reactions
  - moving ions from one place to another

Chemical Fluids from Magmas

- Carry ions from the melt
- Fluids increase the temperature in the rock

Veins

Solutions are deposited in fractures and joints



Factors influencing Metamorphism

Time

- Solid state recrystallization is a slow process
- In general, size of minerals increases with time

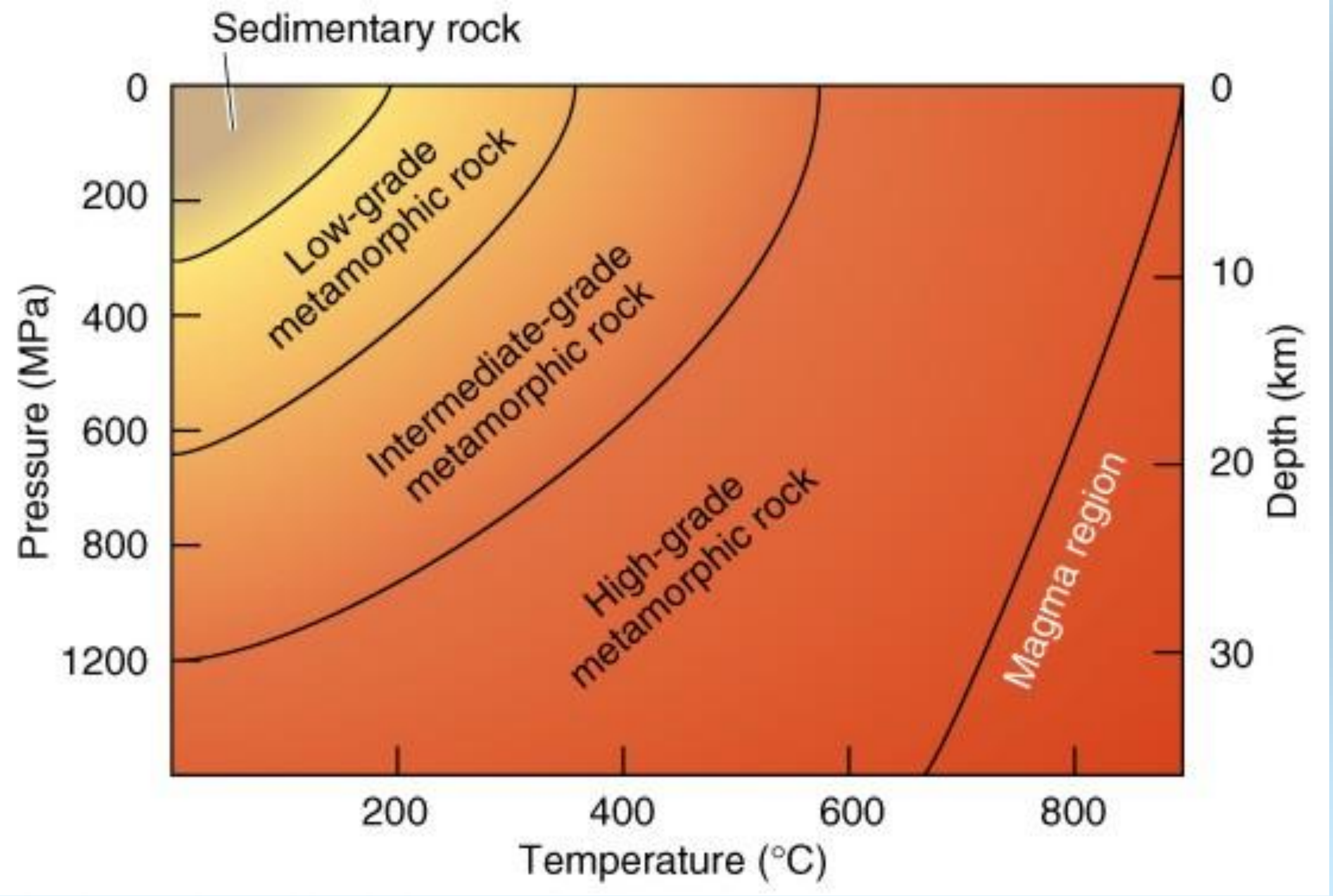
Metamorphic Grade

- The extent to which the pre-existing rocks have been changed in form/altered
  - **Low Grade – slight alteration**
  - **Medium Grade – significant alteration**
  - **High Grade – extensive/total alteration**

Metamorphic Grades

- Degrees of metamorphism
  - Low-grade (where ***shale*** becomes ***slate***)
  - Medium-grade (where ***granite*** becomes ***gneiss***)
  - High-grade (rock partially melts → ***migmatite***)

Metamorphic Grade



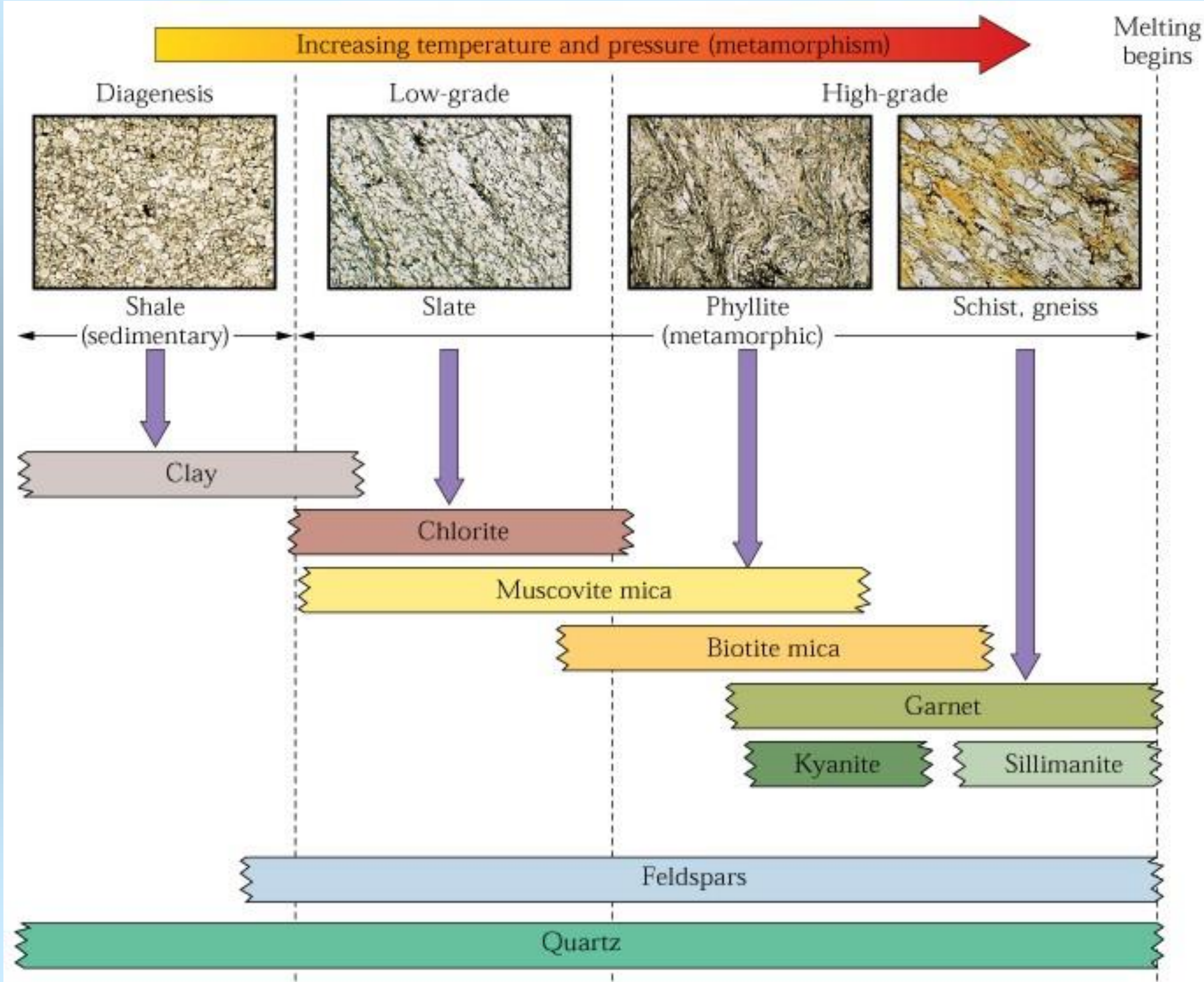
Low Grade Metamorphism

Example: SLATE

- **Rocks become more dense and compact**
- **Forms at low temperature and pressure**
- **Microscopic crystals**
- **Dull luster**
- **Clay and mica minerals**
- **Foliated**

Low Grade - Slate

Metamorphic Grade



Intermediate Grade Metamorphism

Example: PHYLLITE

- **Intermediate temperature and pressure**
- **Small crystals**
- **Shiny luster**
- **Mostly mica minerals**
- **Foliated**

Intermediate Grade – Phyllite

High Grade Metamorphism

Example: SCHIST

- **High temperature and pressure**
- **Large crystals**
- **Mica-rich**
- **Foliated**

High Grade - Schist

High Grade Metamorphism

Example: GNEISS

- **High temperature and pressure**
- **Large crystals**
- **Mica-poor**
- **foliated**

High Grade - Gneiss

- Shale forms slate. In slate, foliation layers are microscopically thin.

Shale → slate

(sedimentary rock)

Granite → Gneiss

gneiss

METAMORPHISM OF SHALE

schist

phyllite

slate

shale

METAMORPHISM OF COAL

Anthracite Coal

Bituminous Coal

Lignite

Peat

The Role of Parent Rocks in Metamorphism

- Parent rocks provide the minerals and ion sources that are transformed into new minerals and rocks.

- In most cases the new metamorphic rock has the same chemical composition as the parent rock that they formed from.

Examples of parent rocks and their metamorphic products:

Sandstone → Quartzite
Sedimentary → Metamorphic

Granite → Gneiss
Igneous → Metamorphic

Limestone → Marble
Sedimentary → Metamorphic

Sandstone → Quartzite

Limestone $\longrightarrow$ marble

Kinds or Types of Metamorphism

Three Major kinds of Metamorphism differentiated on the basis of factors most dominant in causing it area:

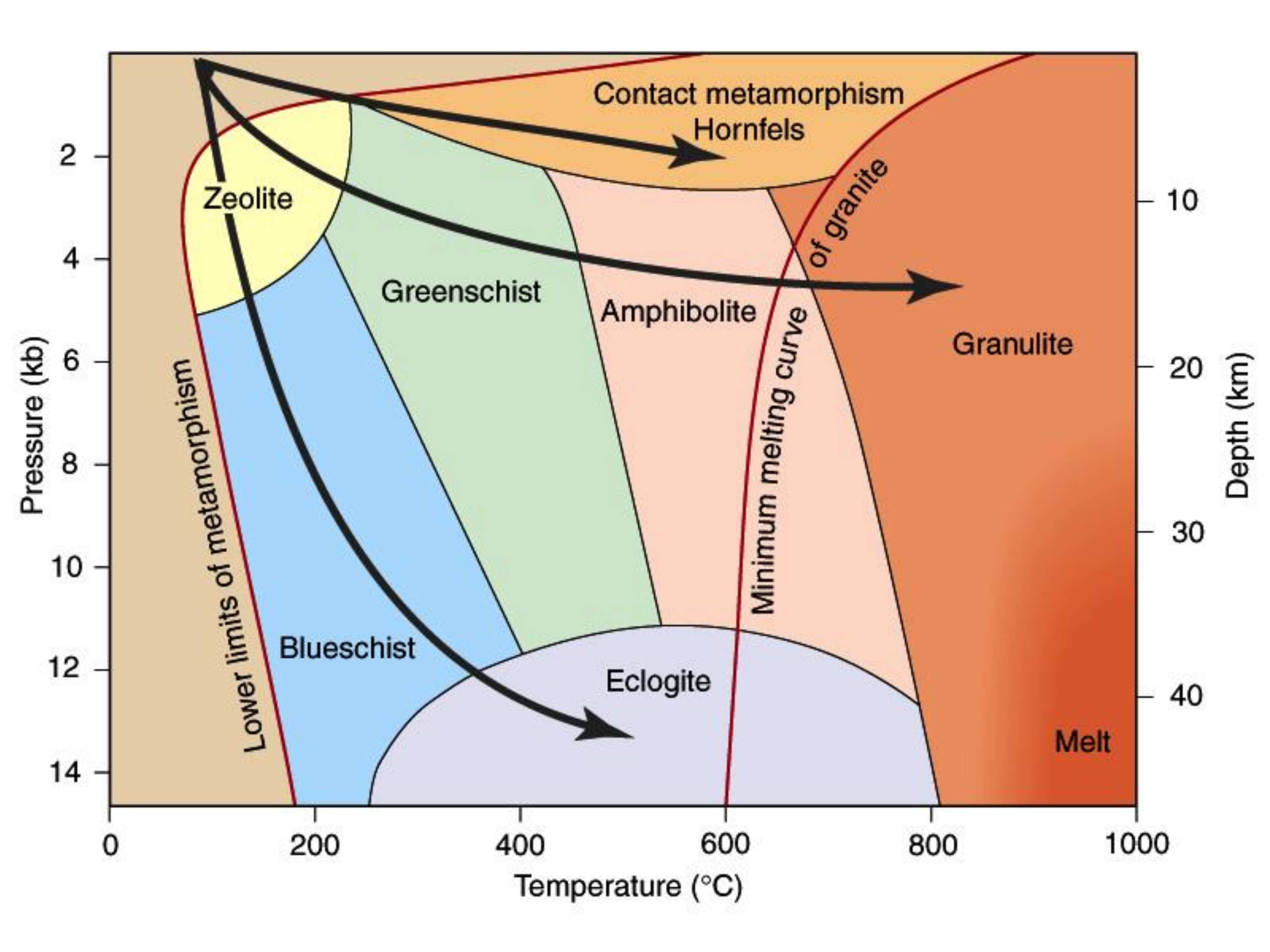
1. Thermal Metamorphism
   - Contact Metamorphism
   - Pyro-metamorphism
   - Plutonic Metamorphism
2. Dynamic or Cata-clastic Metamorphism
3. Dynamo-thermal Metamorphism
   - Regional Metamorphism
   - Orogenic Metamorphism
   - Burial Metamorphism
   - Ocean Floor Metamorphism

Hydrotheraml Metamorphism

Fault zone and Impact Metamorphism

Metamorphic Facies

- Different minerals form at different temperatures and pressures
- Group of stable minerals define a facies

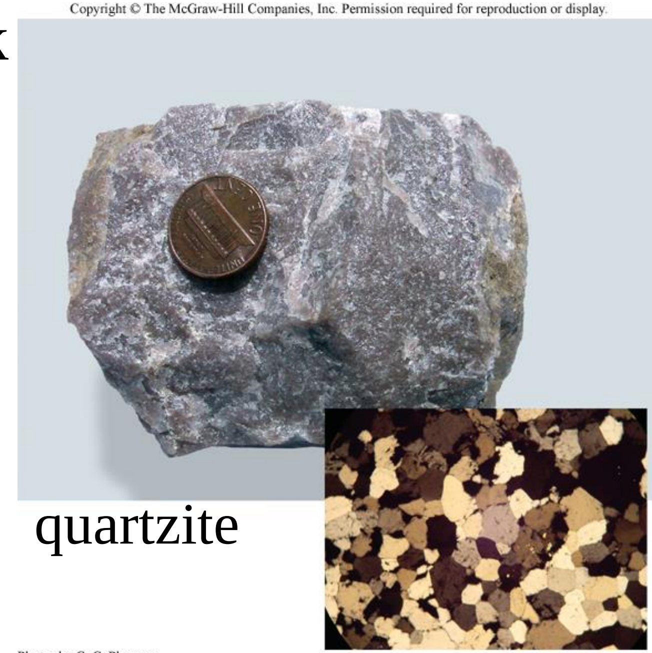


Types of Metamorphism

- ***Contact metamorphism***
  - High temperature
  - Produces *non-foliated* rocks
  - Rocks come in contact with magma bodies intruding cooler country rock

Photo A by C. C. Plummer

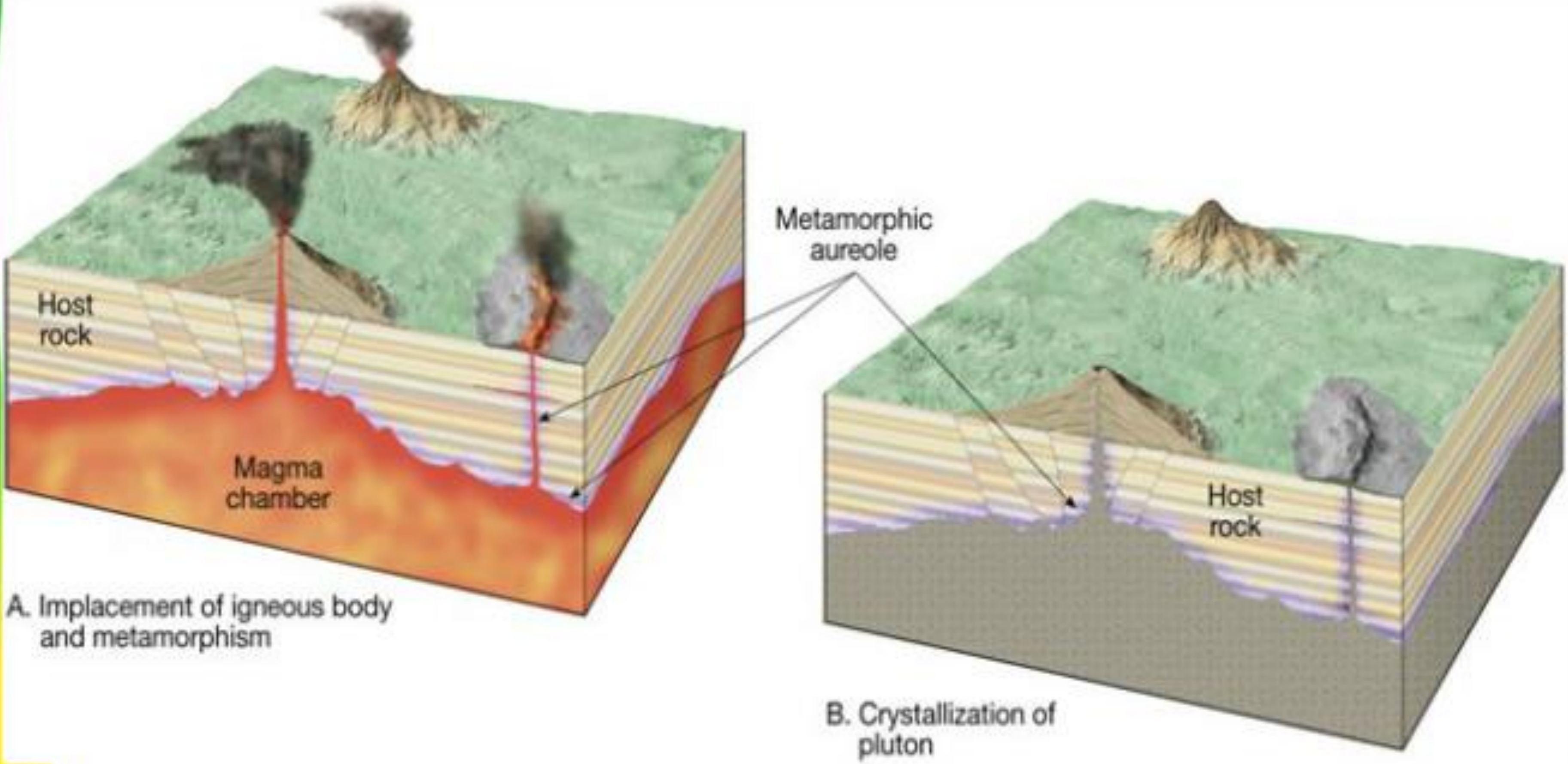
marble



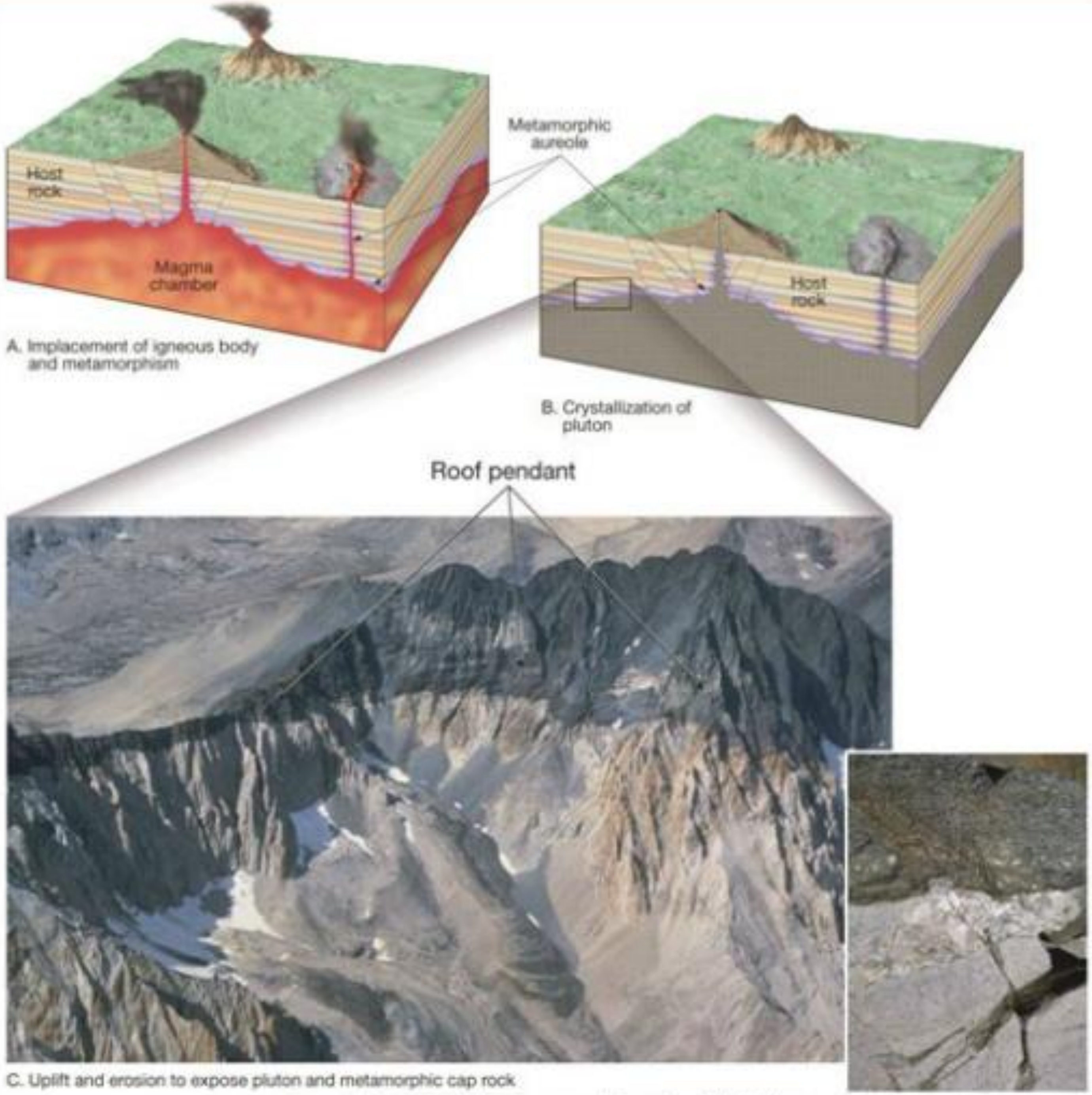
quartzite

Photos by C. C. Plummer

Contact metamorphism



Two principal types of contact metamorphism

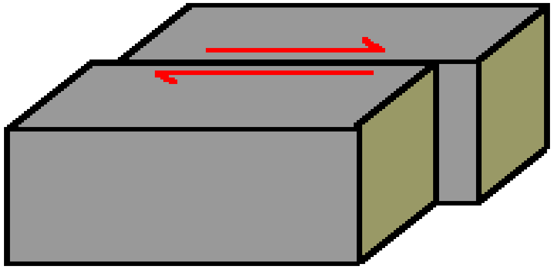

Metamorphic aureole
Host rock
Magma chamber
A. Implacement of igneous body and metamorphism
Host rock
B. Crystallization of pluton
Roof pendant
C. Uplift and erosion to expose pluton and metamorphic cap rock

Pyrometamorphism

- A minor type of **contact metamorphism**
- **Very high temperatures at very low pressures, generated by a volcanic or sub-volcanic body**
- **Also developed in xenoliths (pieces of solid rocks carried up by magma)**
- **Pyro-metamorphism may be accompanied by various degrees of partial melting**

Type of Metamorphism

- **Cataclastic Metamorphism**
- This type of metamorphism occurs mainly due to direct pressure
- eg. when two bodies of rock slide past one another along a fault zone. Heat is generated by the friction of sliding along the zone, and the rocks tend to crushed and pulverized due to the sliding.
- Cataclastic metamorphism is mere mechanical breakdown of rocks without any new mineral formation, however, sometime due to intense shearing few new minerals are formed.

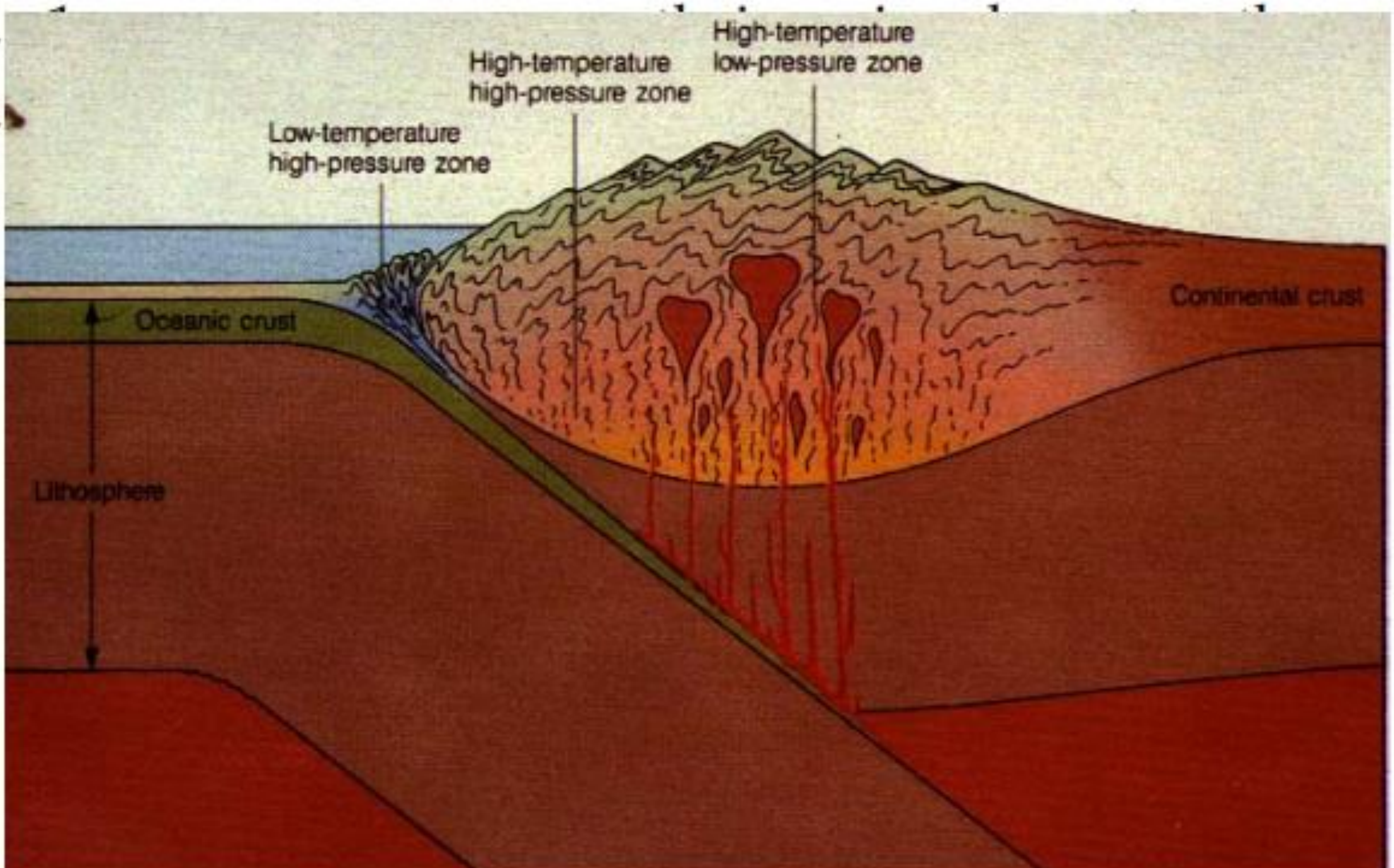


Right lateral

Hornfels

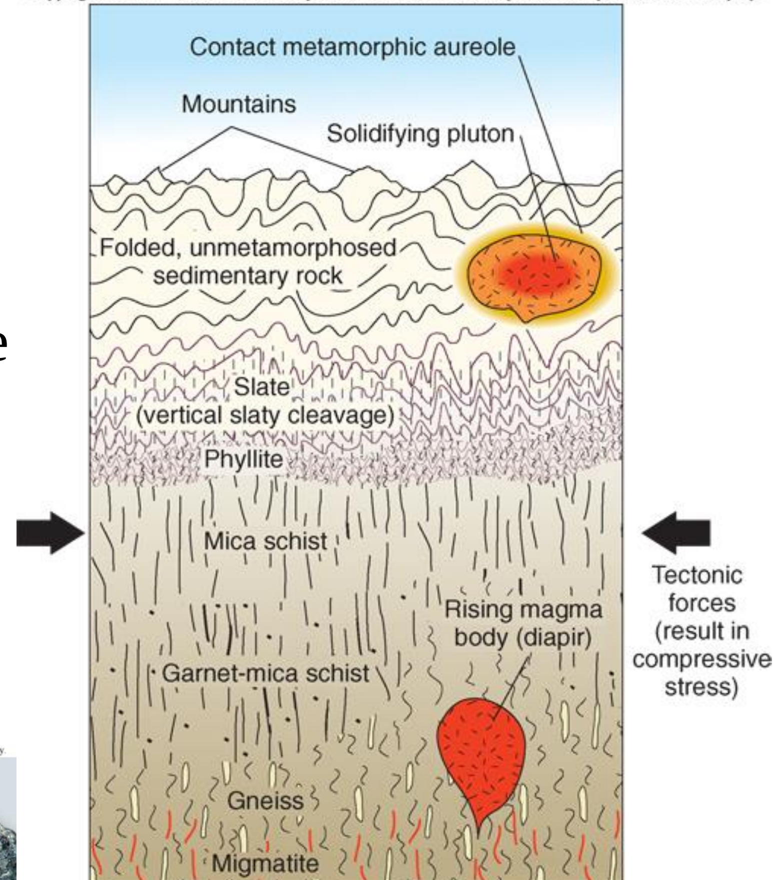
This is a metamorphic rock created by contact metamorphism when molten rock (like the peridotite) comes into contact with something like a mudstone. The mudstone is completely re-crystalised into a rock which has crystals all roughly the same size, but their colours vary depending on the type of mineral, so the rock looks more like a mosaic.

A. Regional Metamorphism- Regional metamorphism occurs when large areas of rock are under intense heat and pressure, it causes rocks to change form



Types of Metamorphism

- ***Regional metamorphism***
  – High pressure
  – Results in rocks with *foliated* textures
  – Can deform in mountain ranges
  – May occur over wide temperature range



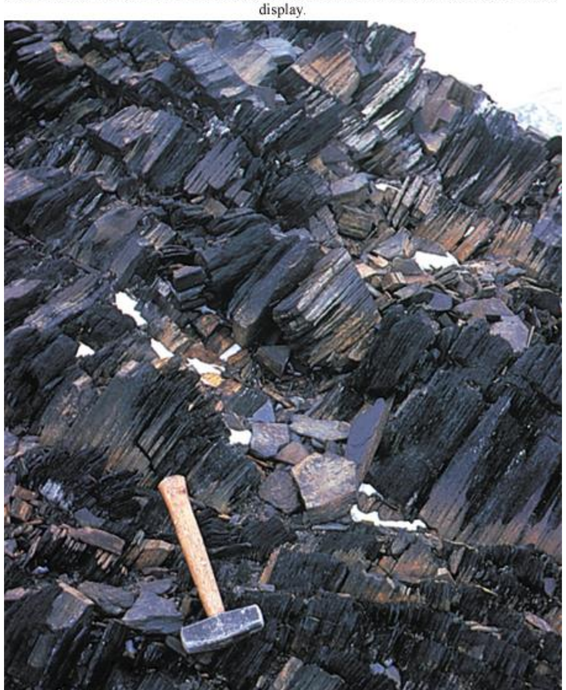


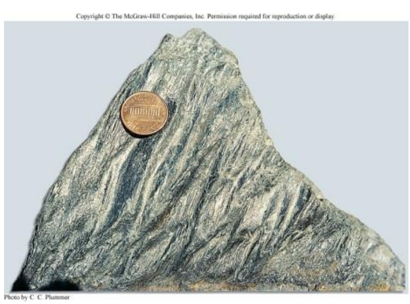
Photo by P. D. Rowley, U.S. Geological Survey

Photo by C. C. Plummer

Photo by C. C. Plummer

Types of Metamorphism

- ***Regional metamorphism***
  - Higher pressure *and* temperature will produce increased *metamorphic grade*
  - Prograde metamorphism of shale produces:
    - *slate*
    - *phyllite*
    - *schist*
    - *gneiss*

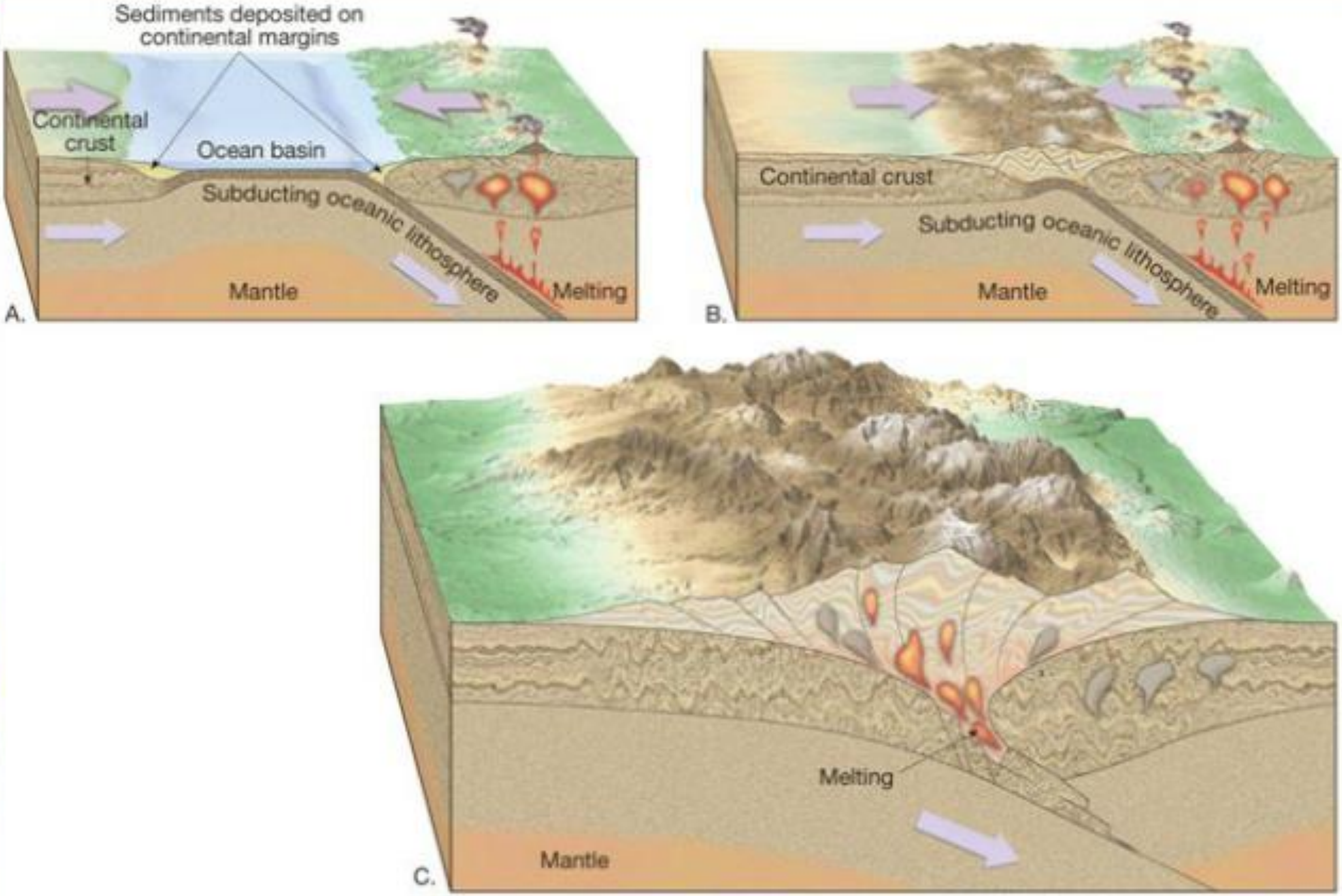


slate → phyllite → schist → gneiss

Metamorphic environments

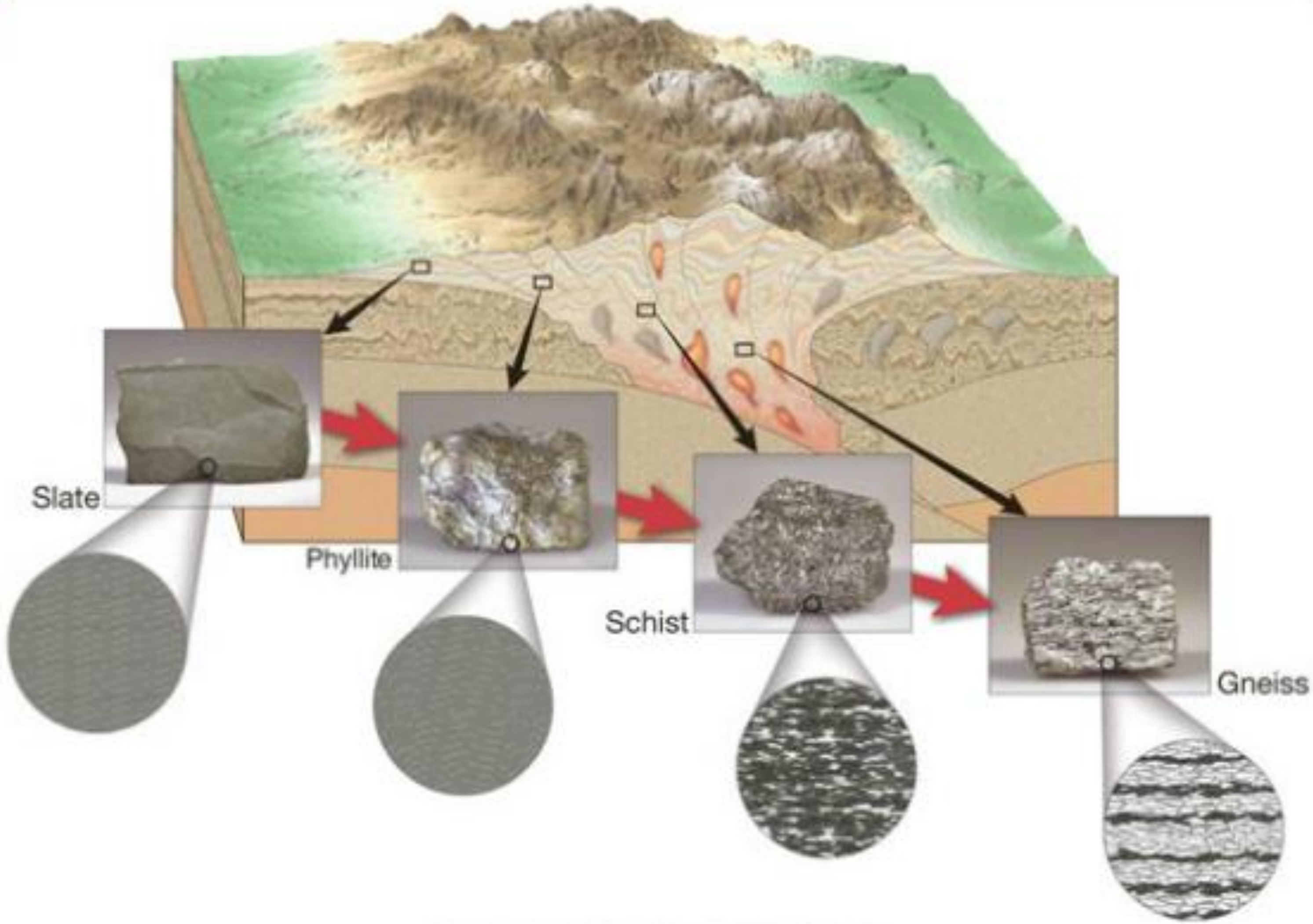
- Regional metamorphism
  - Produces the greatest quantity of metamorphic rock
  - Usually associated with mountain building

UMR



- **Regional metamorphism occurs when rocks are squeezed between converging plates during mountain building**

UMR



- **Progressive regional metamorphism: from low grade (slate); to high grade (gneiss)**

UMR

Regional Metamorphism *sensu lato*: **metamorphism that affects a large body of rock, and thus covers a great lateral extent**

Three principal types:

- **Orogenic metamorphism**
- **Burial metamorphism**
- **Ocean-floor metamorphism**

The term, "Regional Metamorphism" is often used synonymously with "orogenic metamorphism" (OROGENY=mountain building)

Orogenic Metamorphism is the type of metamorphism associated with **convergent plate margins**

- **Dynamo-thermal: one or more episodes of orogeny with combined elevated geothermal gradients and deformation (differential stress)**

- **Foliated rocks are a characteristic product**

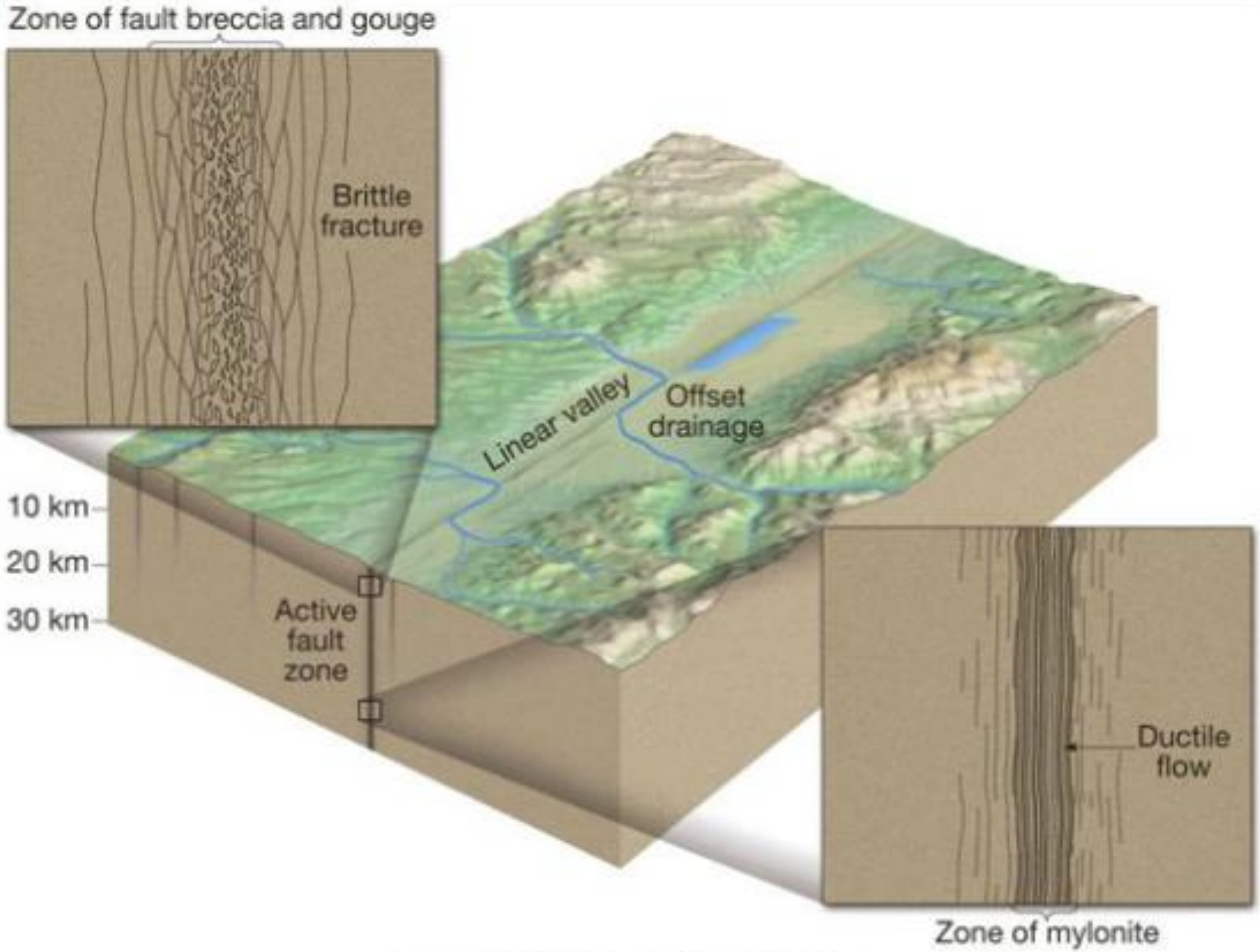
Burial metamorphism = low-grade metamorphism in sedimentary basins

- **Metamorphic effects attributed to increased temperature and pressure due to burial**
- **Occurs in areas that have not experienced significant deformation or orogeny**
- **Mild deformation, no igneous intrusions discovered**

Metamorphic environments

- Other metamorphic environments
  - Burial metamorphism
    - Associated with very thick sedimentary strata
    - Required depth varies depending on the prevailing geothermal gradient
  - Metamorphism along fault zones
    - Occurs at depth and high temperatures
    - Pre-existing minerals deform by ductile flow

UMR



- **Metamorphism along a fault zone**

UMR

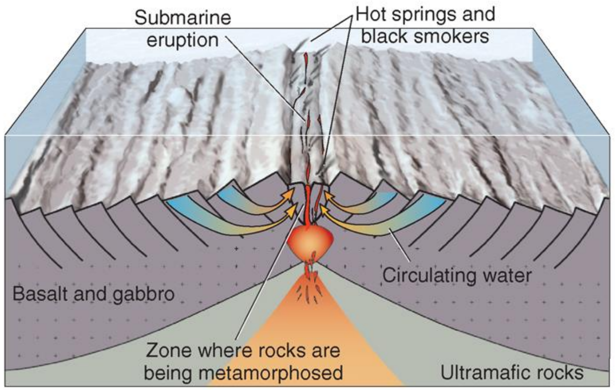
Ocean-Floor Metamorphism affects the oceanic crust at ocean ridge spreading centers

- **A wide range of temperatures at relatively low pressure**
- **Seawater penetrates down fracture systems, where it becomes heated, and leaches metals and silica from the hot basalts**
- **Considerable metasomatic alteration, notably loss of Ca and Si and gain of Mg and Na**

- **Fault breccia** exposed in Titus Canyon, a tributary leading down into Death Valley, CA
- **Breccia** is comprised of very angular fragments

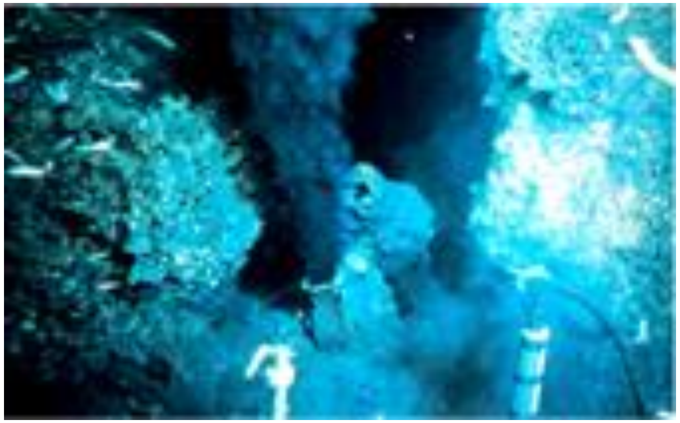
UMR

Hydrothermal Processes



- Rocks precipitated from or altered by hot water are referred to as *hydrothermal*
  - Common at spreading centers (under water)
- Hydrothermal processes add water for metamorphic reactions

- Formation of *hydrothermal rocks*
    - Water passes through rocks and *precipitates new minerals* on walls of cracks and in pore spaces
    - *Metallic ore deposits* often form this way (*veins*)

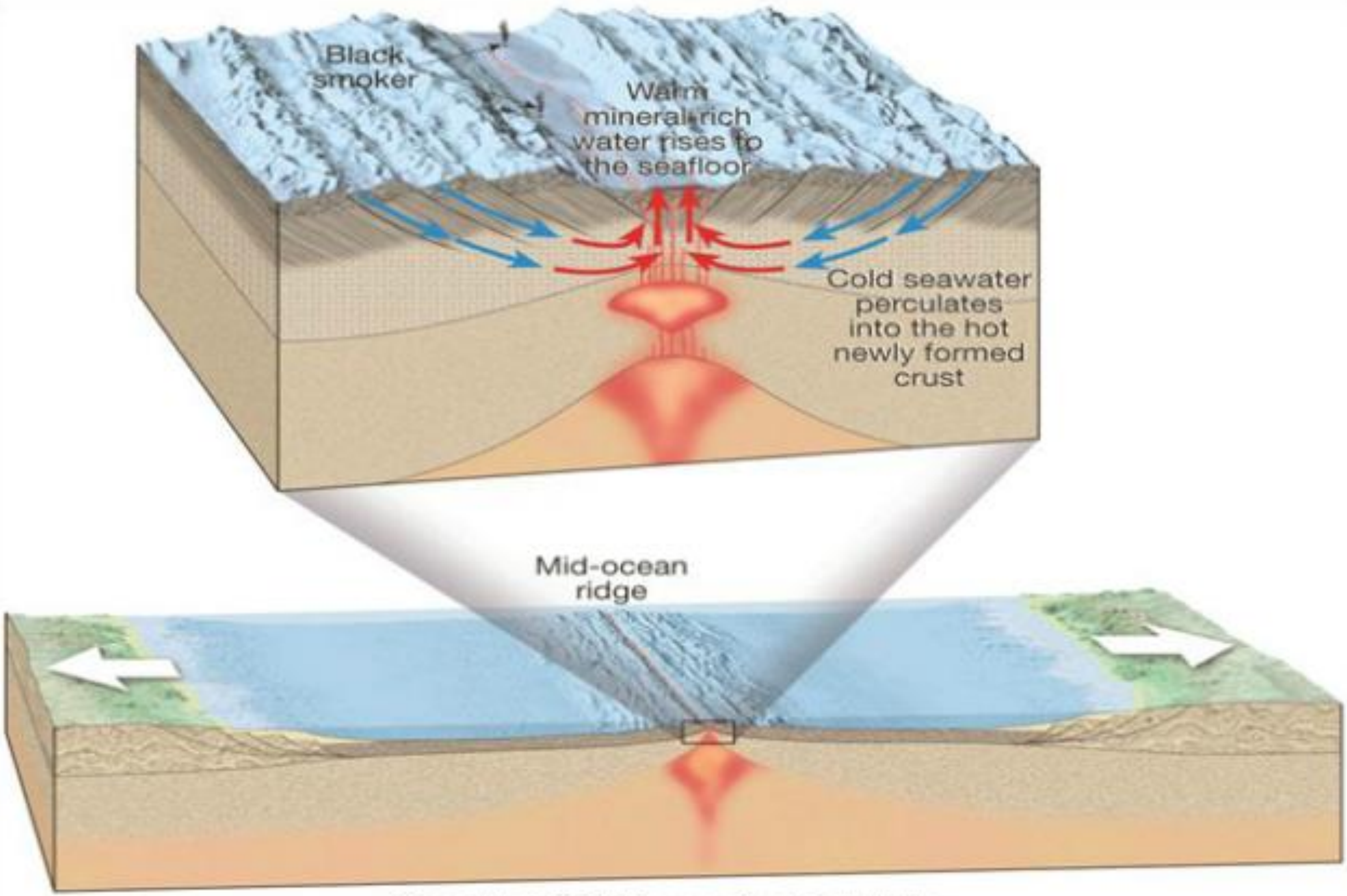


Metamorphic environments

- Hydrothermal metamorphism
  - Chemical alteration caused when hot, ion-rich fluids, called hydrothermal solutions, circulate through fissures and cracks that develop in rock
  - Most widespread along the axis of the mid-ocean ridge system

UMR

Hydrothermal metamorphism



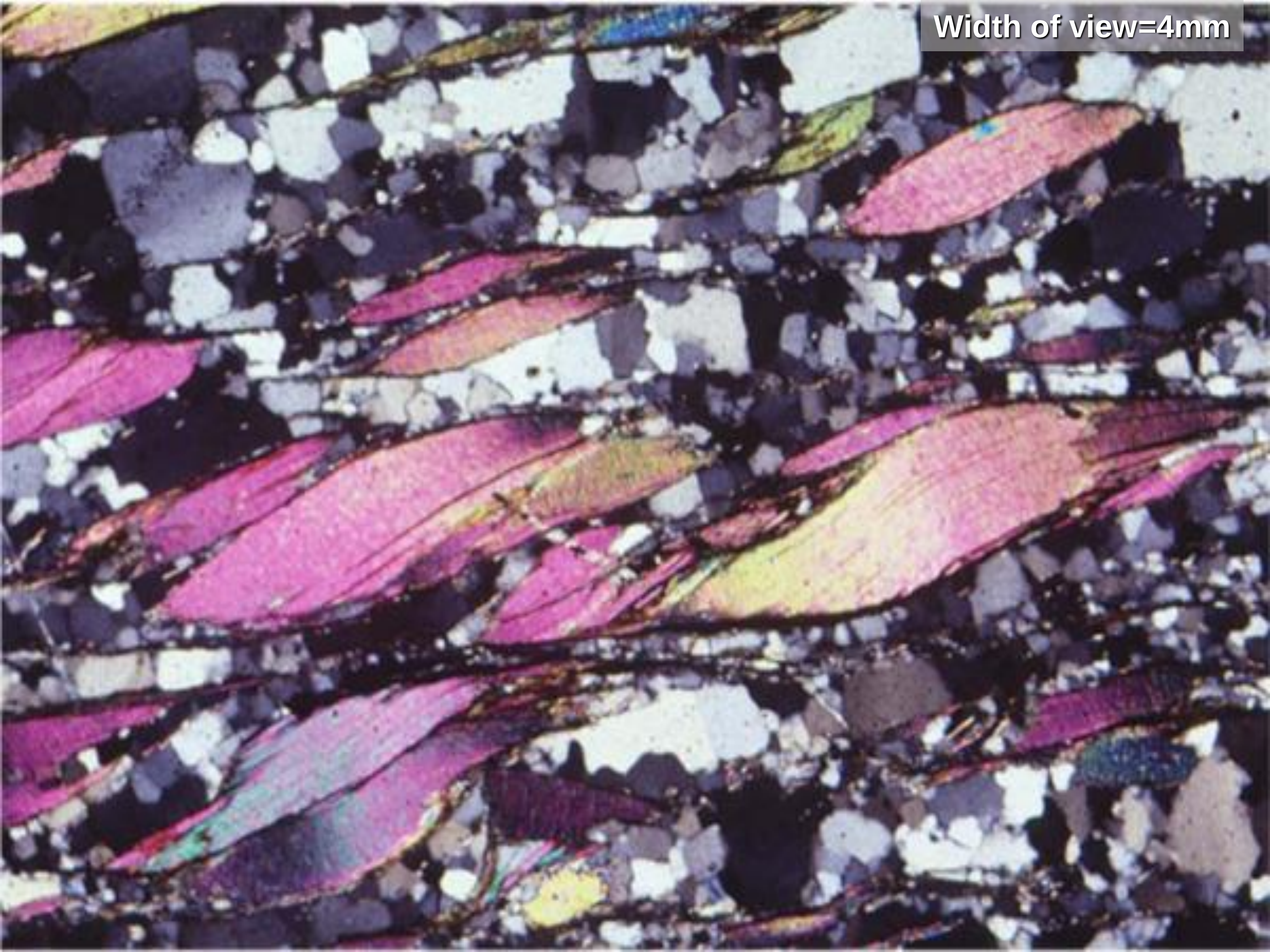
UMR

Fault-Zone and Impact Metamorphism

– High rates of deformation and strain with only minor recrystallization

(a) Shallow fault zone with fault breccia

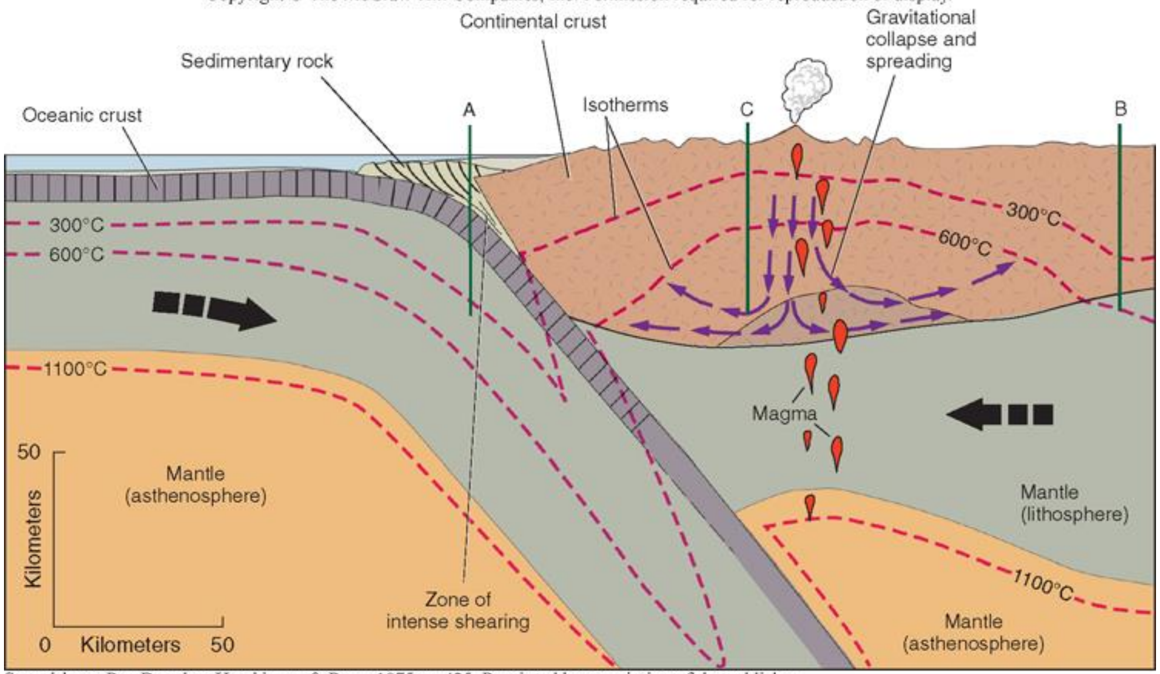
(b) Slightly deeper fault zone (exposed by erosion) with some ductile flow and fault mylonite


Width of view=4mm

Fault-Zone and Impact Metamorphism

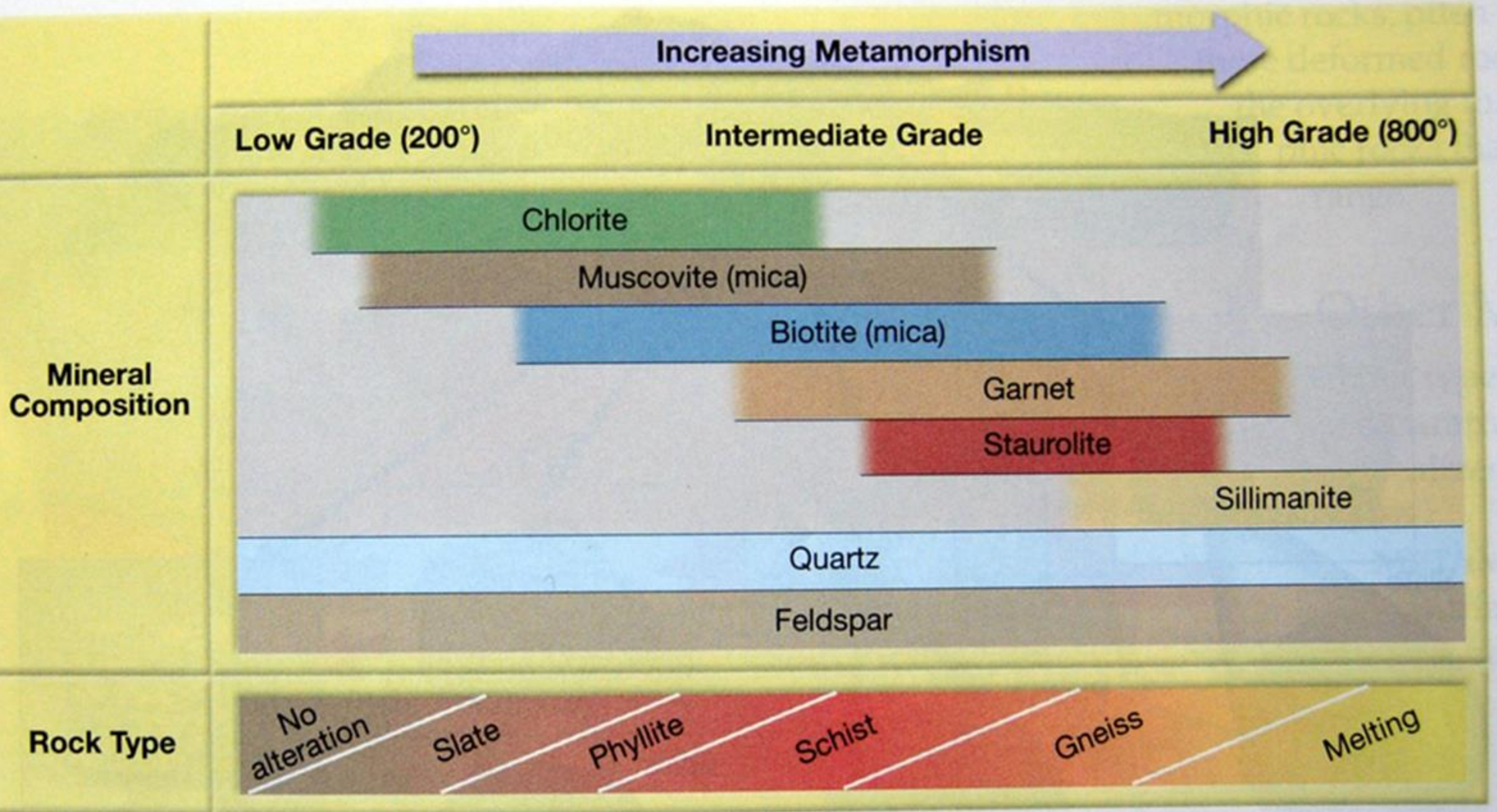
- **High rates of deformation and strain with only minor recrystallization**
- **Impact metamorphism at meteorite (or other bolide) impact craters**
- **Both correlate with dynamic metamorphism, based on process**

Plate Tectonics and Metamorphism



Stroudsberg, Pa.: Dowden, Hutchinson & Ross, 1975; p. 425. Reprinted by permission of the publisher

- Regional metamorphism associated with ***convergent plate boundaries***
  - Pressure proportional to depth
  - Temperature varies laterally at convergent boundaries
    - *Isotherms* bow down in sinking oceanic plate and bow up where magma rises



The typical transition in mineralogy that results from progressive metamorphism of shale.

METAMORPHIC ENVIRONMENTS

Contact metamorphism of shale yields hornfels, while contact metamorphism of quartz sandstone and limestone produces quartzite and marble, respectively.

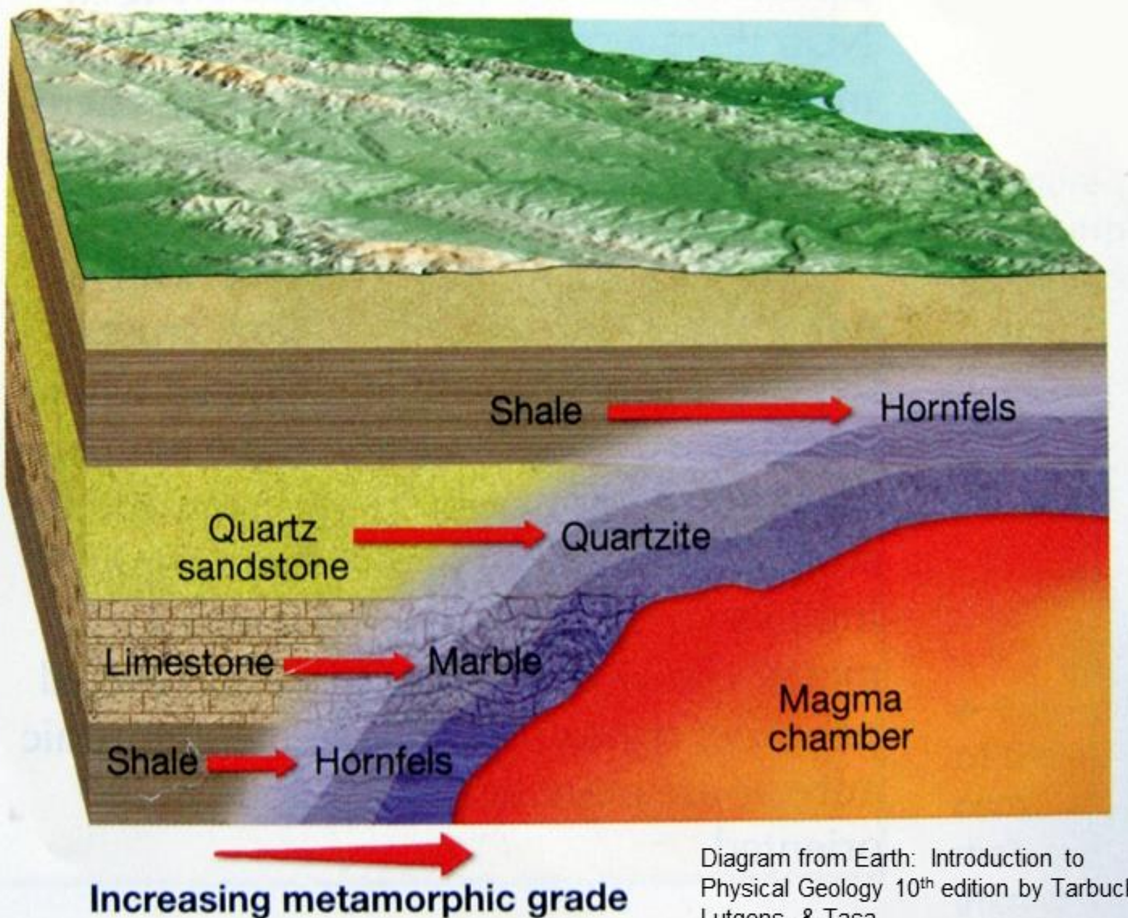


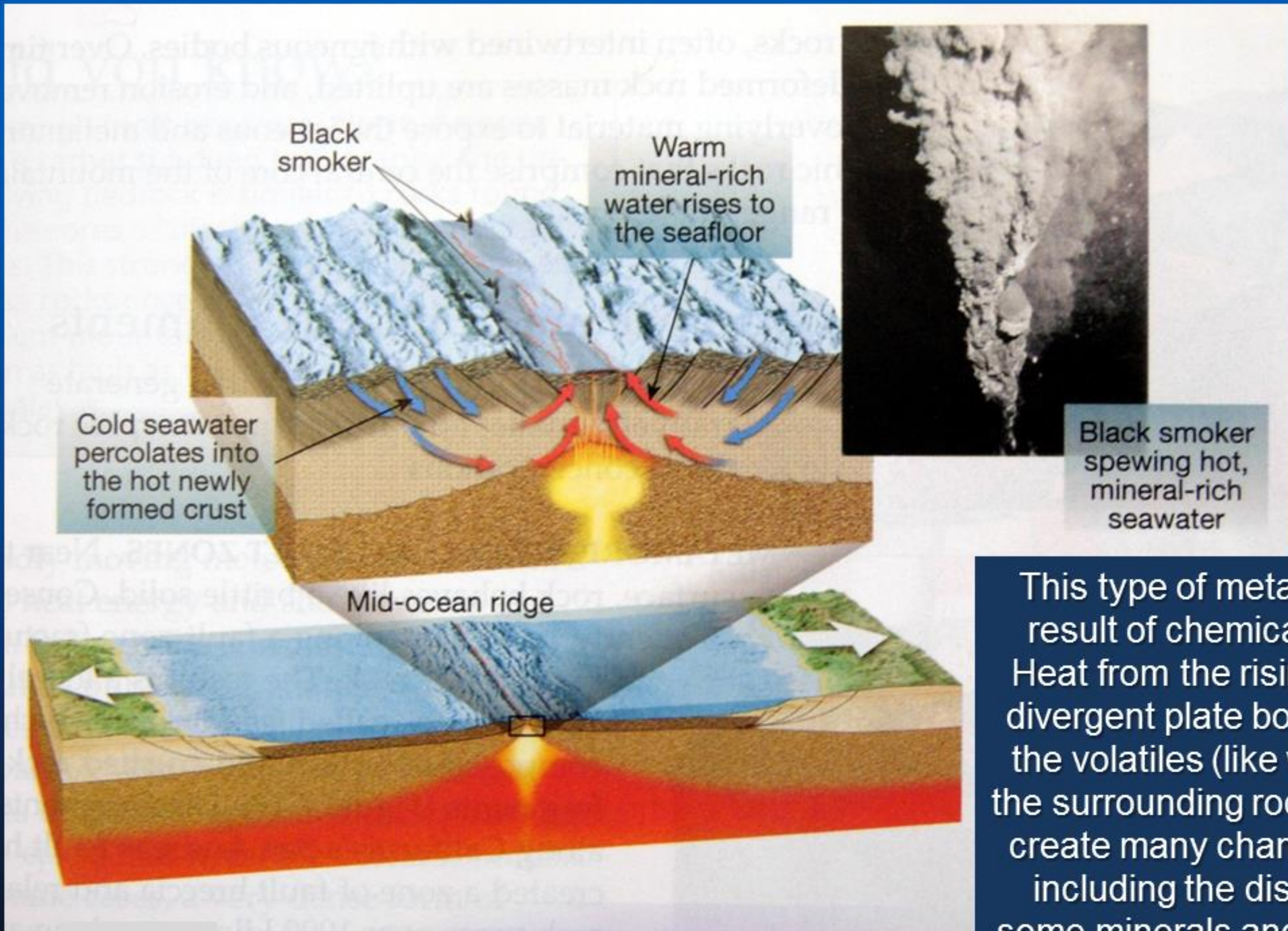
Diagram from Earth: Introduction to Physical Geology 10th edition by Tarbuck, Lutgens, & Tasa

CONTACT METAMORPHISM

Contact metamorphism is perhaps the most straightforward. The rocks are simply heated. This is commonly the result of the intrusion of a magma body nearby. Closest to the magma body, the rocks are changed the most. In this diagram, the original rocks are sedimentary. Heating changes them by recrystallization to their metamorphic equivalents. (Hornfels is a collective term for any dark, fine-grained metamorphic rock. (*)

METAMORPHIC ENVIRONMENTS

HYDROTHERMAL METAMORPHISM



Hydrothermal metamorphism along a mid-ocean ridge.

(Photo by R., Ballard/Woods Hole)

Diagram from Earth: Introduction to Physical Geology 10th edition by Tarbuck, Lutgens, & Tasa

This type of metamorphism is the result of chemically active fluids. Heat from the rising magma at the divergent plate boundary mobilizes the volatiles (like water) that are in the surrounding rocks. This fluid can create many changes in the rocks, including the dissolving away of some minerals and the deposition of others, in some cases economically important minerals, like copper. (*)

METAMORPHIC ENVIRONMENTS

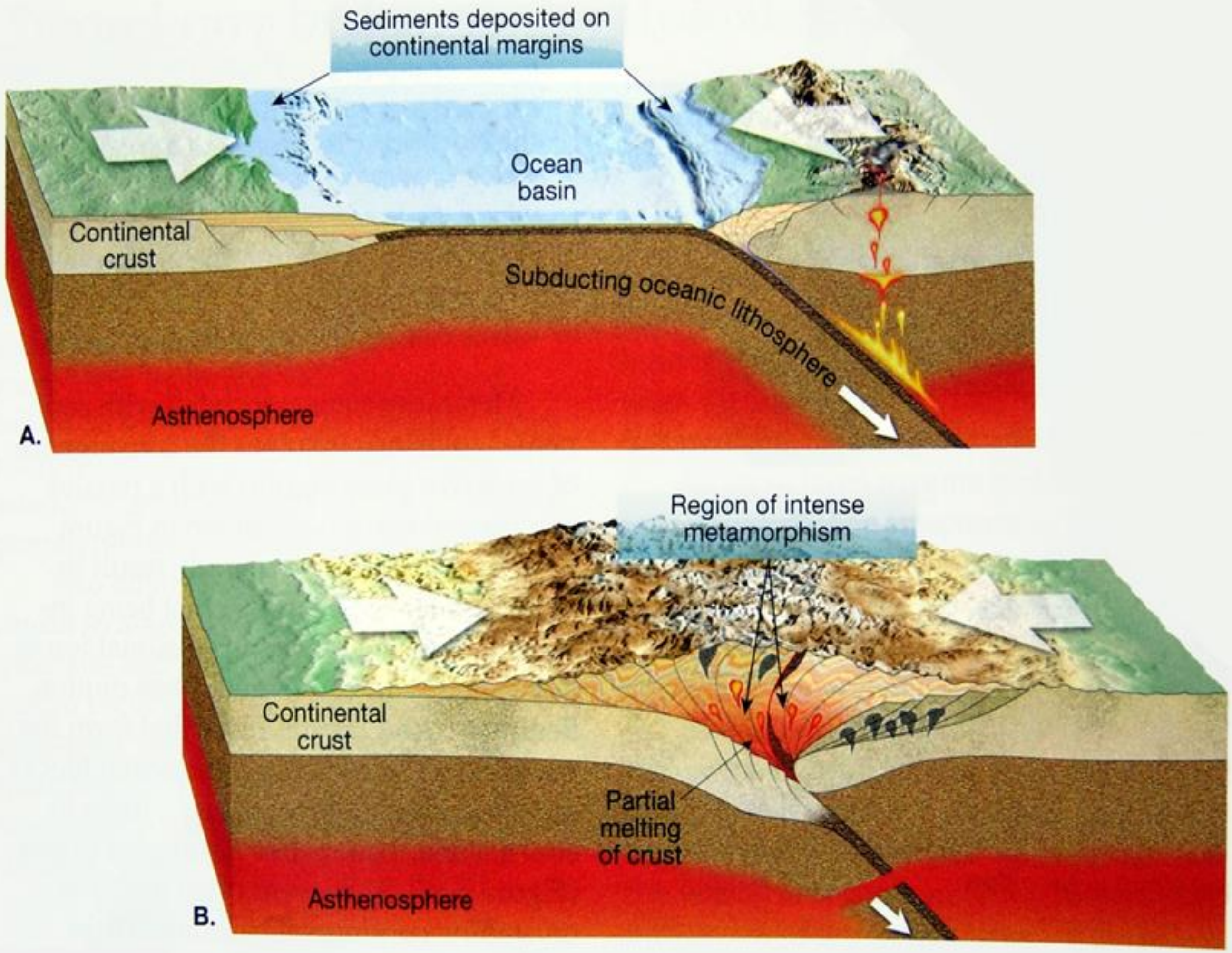
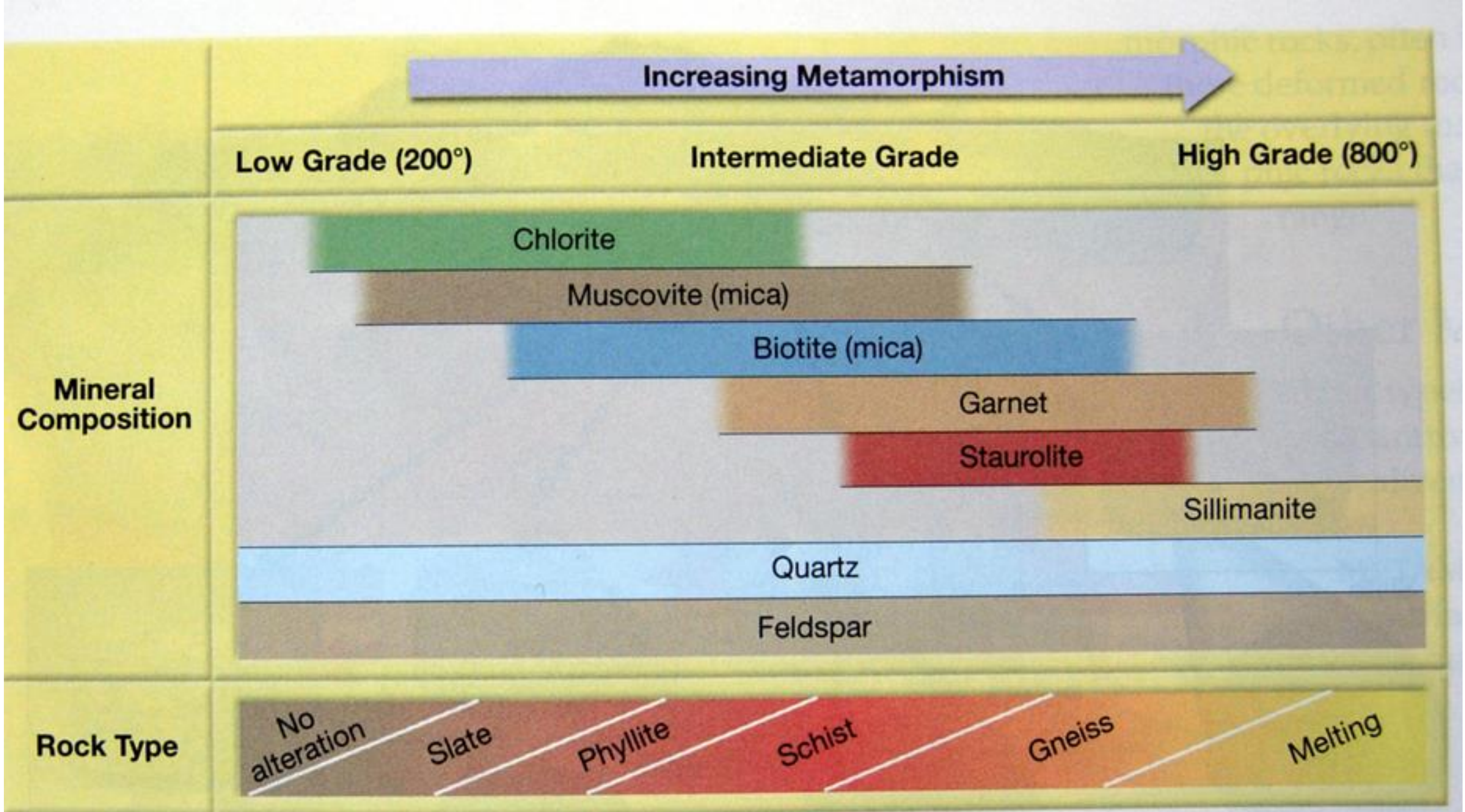


Figure 8.26 Regional metamorphism occurs where rocks are squeezed between two converging lithospheric plates during mountain building.

Diagram from Earth: Introduction to Physical Geology 10th edition by Tarbuck, Lutgens, & Tasa

REGIONAL METAMORPHISM

This is the most geographically extensive. It covers millions of square miles, because it involves the collision and heat generated by plate tectonics. Within the realm of regional metamorphism, all of the other forms of metamorphism can be found (except impact which is due to meteorite or asteroid collisions). (*)



The typical transition in mineralogy that results from progressive metamorphism of shale.

Textures of Metamorphic Rocks

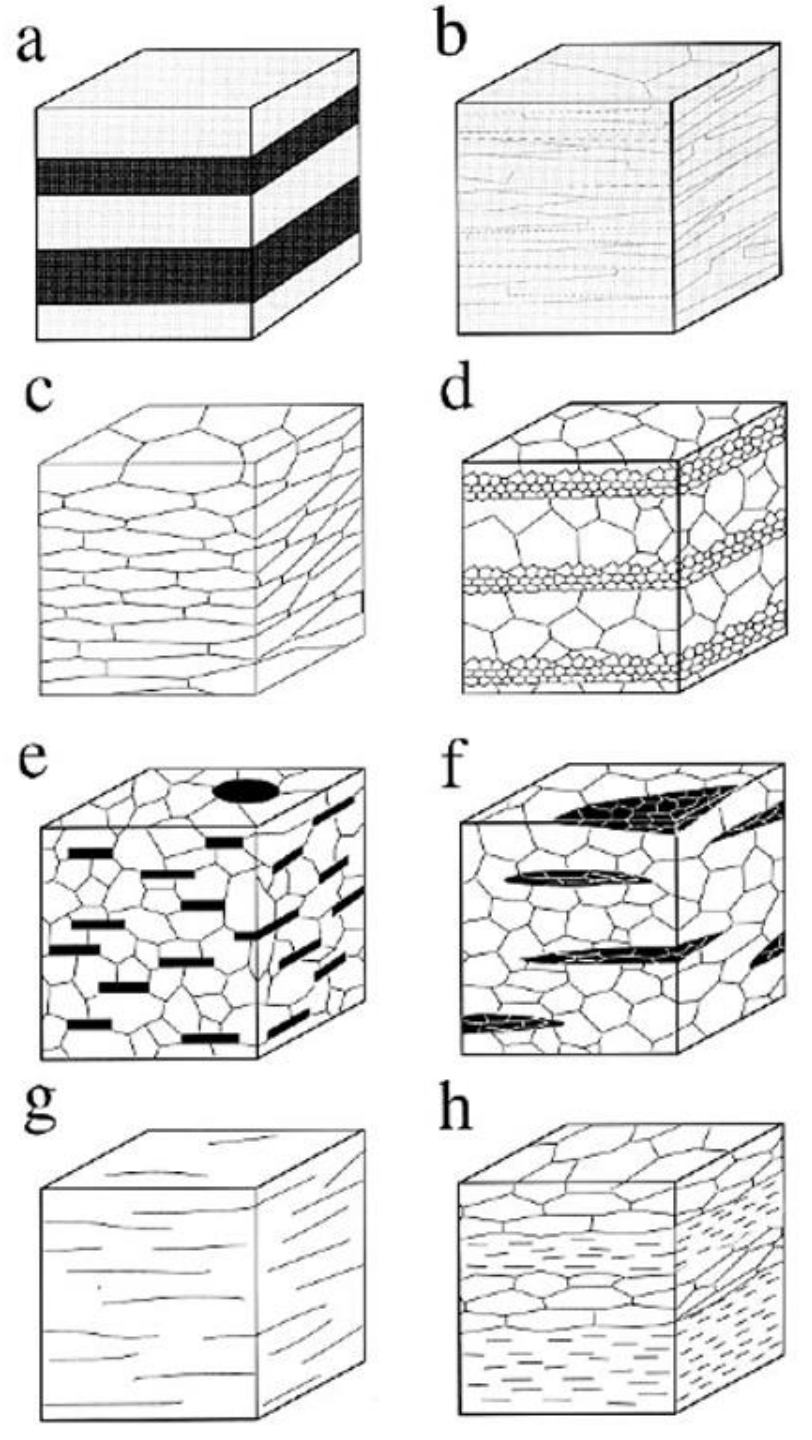
Foliated Metamorphic Rocks

- What is Foliation:

  General term that describes a planar fabric; typically defined by platy minerals such as mica or flattened grains such as quartz.

Fig. 4.1a–h. Diagrammatic presentation of various fabric elements that may define a foliation (after Fig. 5.1 in Hobbs et al. 1976). **a** Compositional layering. **b** Preferred orientation of platy minerals (e.g. mica). **c** Preferred orientation of grain boundaries and shape of deformed grains (e.g. quartz, carbonate). **d** Grain-size variation. **e** Preferred orientation of platy minerals in a matrix without preferred orientation (e.g. mica in micaceous quartzite or gneiss). **f** Preferred orientation of lenticular mineral aggregates. **g** Preferred orientation of fractures or microfaults (e.g. in low-grade quartzites). **h** Combination of fabric elements **a, b** and **c;** such combinations are common in metamorphic rocks

Passchier & Trouw, 1996



Foliated Metamorphic Rocks

Foliated Metamorphic Rocks

Schistosity

- A preferred orientation of inequant and platy mineral grains or grain aggregates
- Aligned minerals are coarse grained enough to see with the unaided eye
- Most commonly used to describe medium-grade rocks such as schists of nearly any bulk composition.

Foliated Metamorphic Rocks

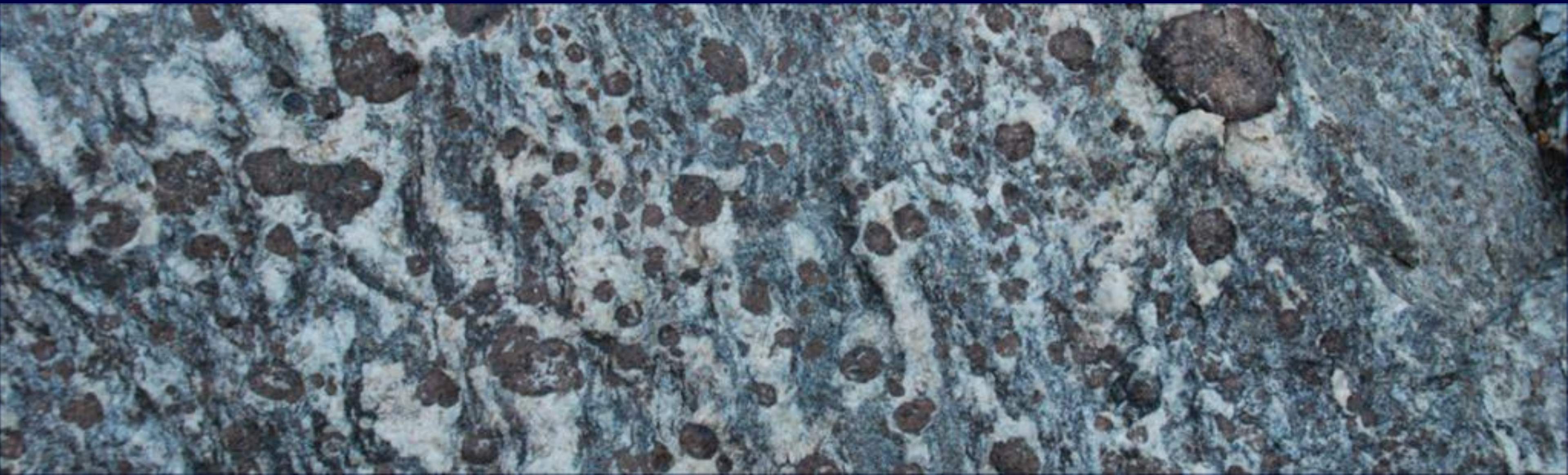
Gneissose structure/Gneissic Layering

- Segregated into layers by metamorphic processes
- Tends to involve equant minerals such as feldspar and quartz.
- Gneissic rocks are generally coarse grained
- Most commonly used to describe high-grade metamorphic rocks such as gneisses.

Classification of Metamorphic Rocks

Porphyroblastic means that a metamorphic rock has one or more metamorphic minerals that grew much larger than the others.

Each individual crystal is a porphyroblast



Foliated Metamorphic Rocks (pelitic protolith)

Slate: compact, very fine-grained, metamorphic rock with a well-developed cleavage. Freshly cleaved surfaces are dull

Phyllite: a rock with a schistosity in which very fine phyllosilicates (sericite/phengite and/or chlorite), although rarely coarse enough to see unaided, impart a silky sheen to the foliation surface. Phyllites with both a foliation and lineation are very common.

Figure 22-1. Examples of foliated metamorphic rocks. **a.** Slate. **b.** Phyllite. Note the difference in reflectance on the foliation surfaces between a and b: phyllite is characterized by a satiny sheen. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Foliated Metamorphic Rocks (pelitic protolith)

Schist: **a metamorphic rock exhibiting a schistosity. By this definition schist is a broad term, and slates and phyllites are also types of schists. In common usage, schists are restricted to those metamorphic rocks in which the foliated minerals are coarse enough to see easily in hand specimen.**

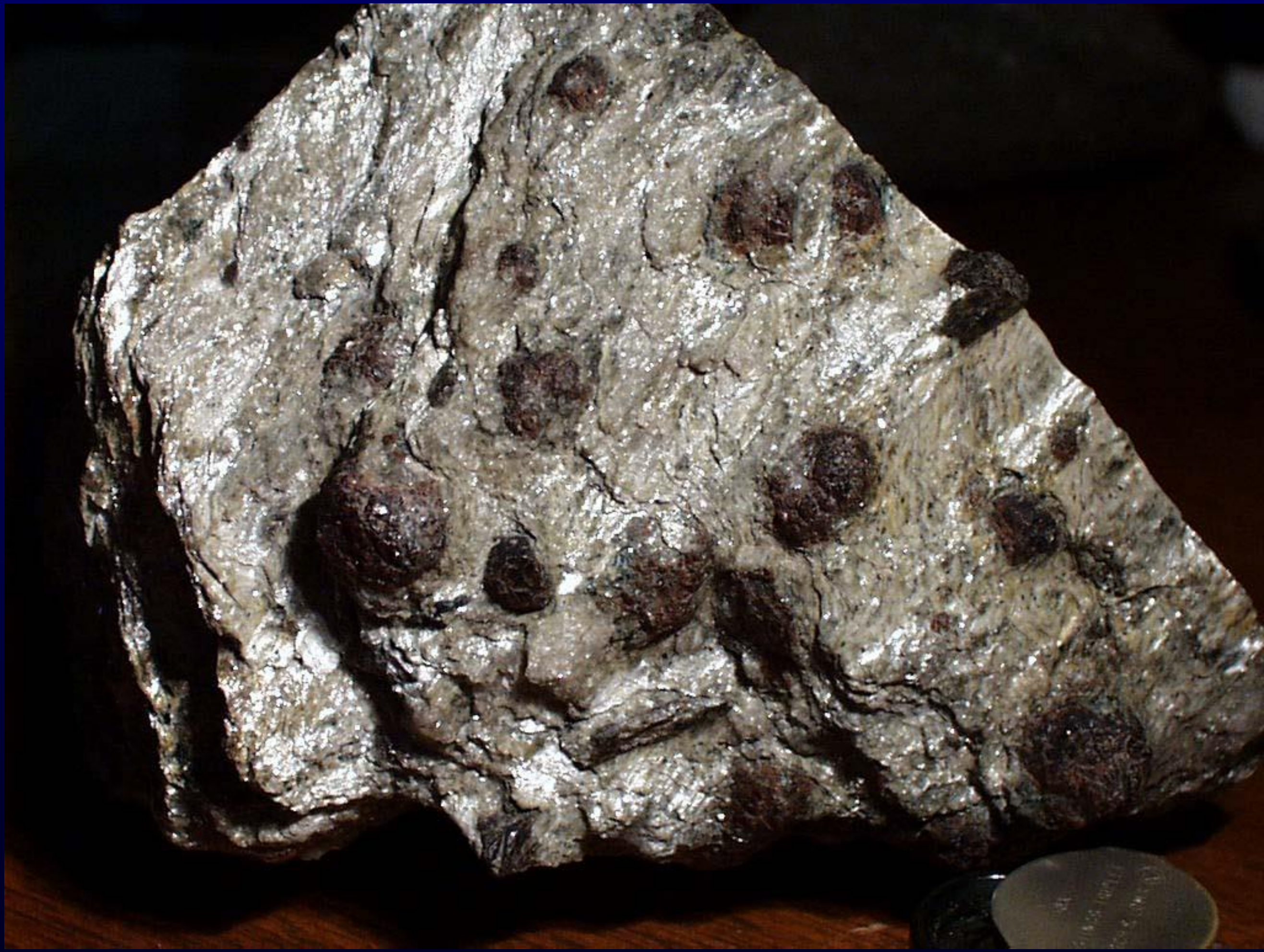


Figure 22-1c. Garnet muscovite schist. Muscovite crystals are visible and silvery, garnets occur as large dark porphyroblasts. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Foliated Metamorphic Rocks (pelitic protolith)

Gneiss: **a metamorphic rock displaying gneissose structure. Gneisses are typically layered (also called banded), generally with alternating felsic and darker mineral layers. Gneisses may also be lineated, but must also show segregations of felsic-mineral-rich and dark-mineral-rich concentrations.**

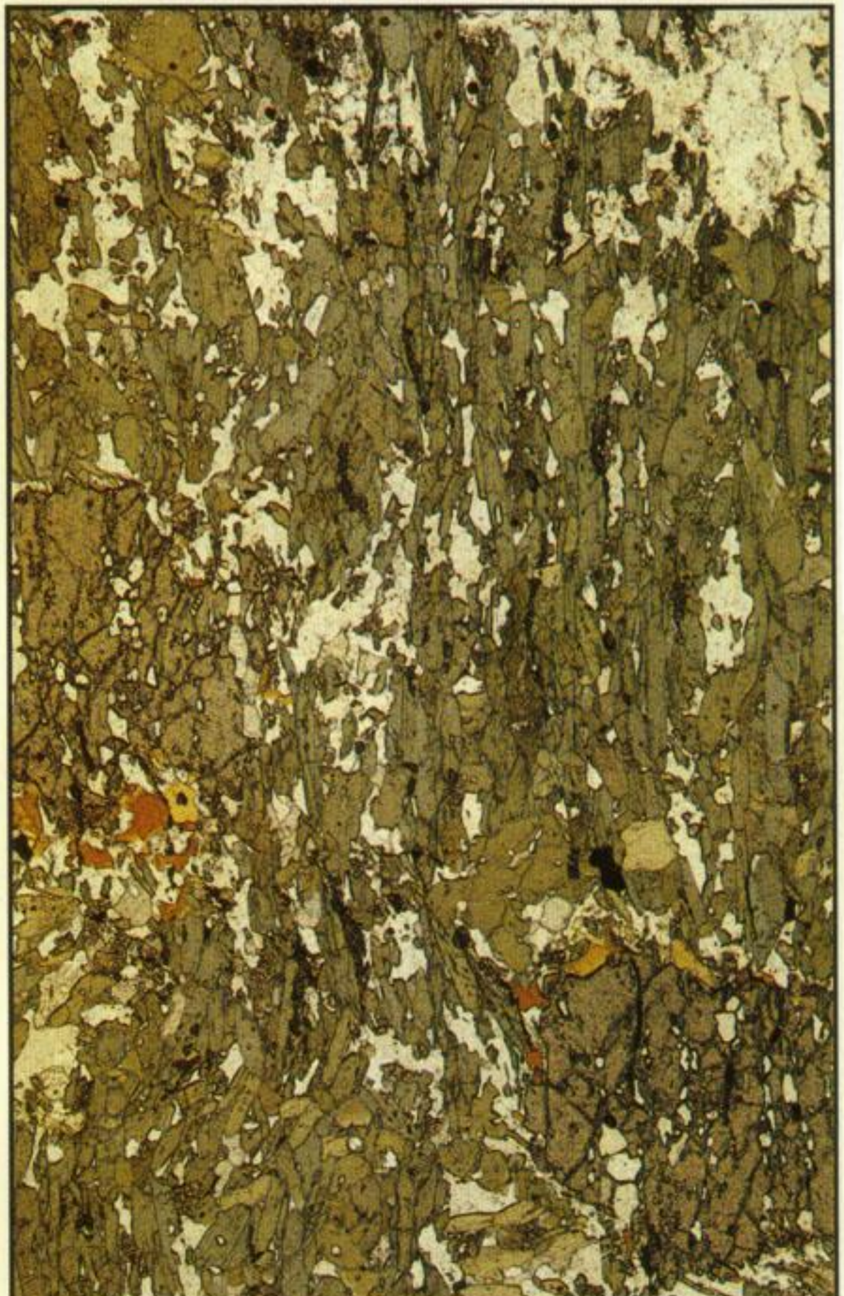
Figure 22-1d. **Quartzo-feldspathic gneiss with obvious layering. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.**

Calcareous and Quartzo-feldspathic
ns

M
omposed
dolomite (calcareous

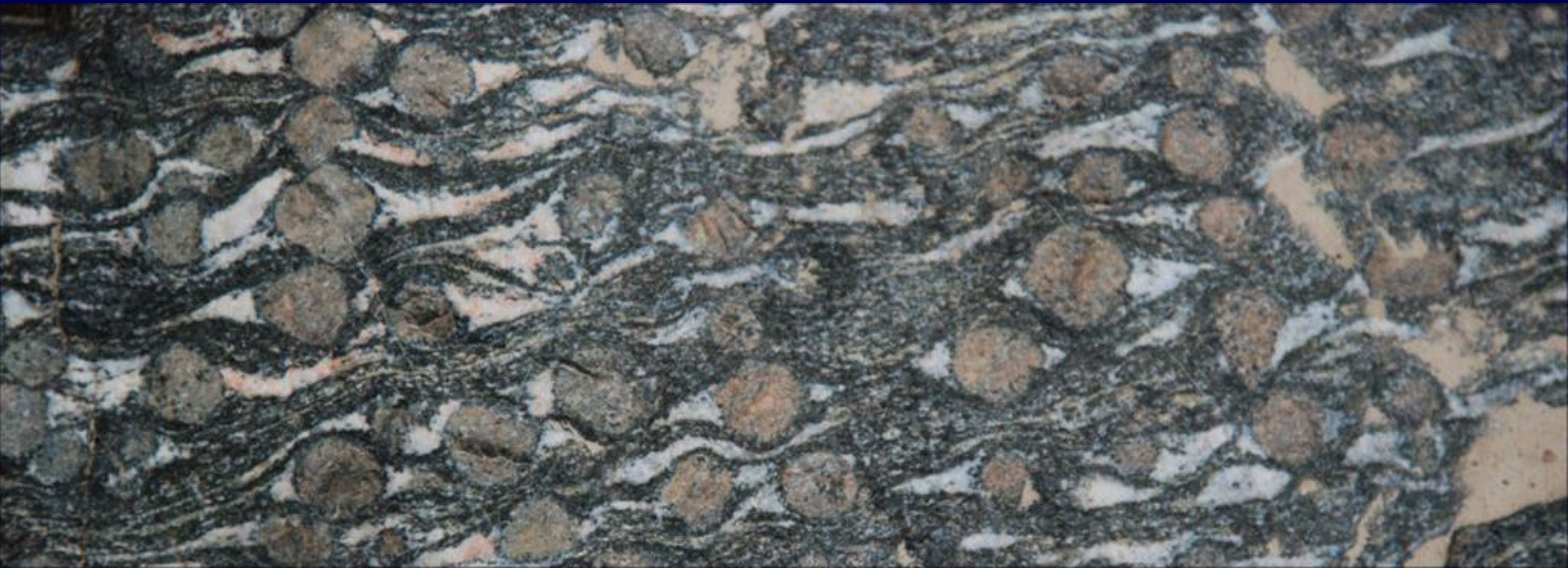
Quartzite: a metamorp
predominantly of qu
typically sandstone.

What textures do you see?



Basic Protoliths (mafic igneous or sedimentary rocks)

Amphibolite: a metamorphic rock dominated by hornblende + plagioclase. Amphibolites may be foliated or non-foliated. The protolith can be a mafic igneous or sedimentary rock.



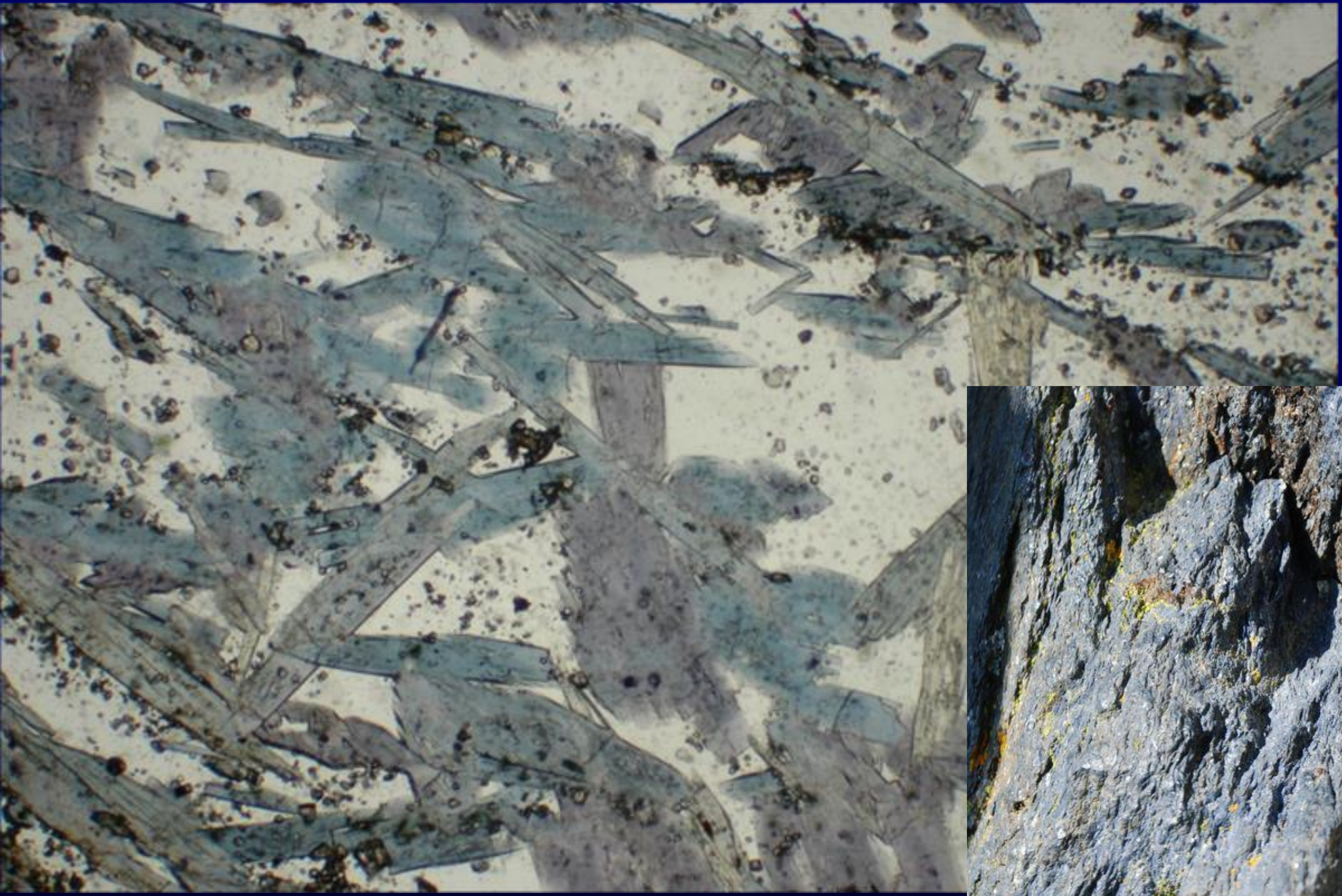
Basic Protoliths (mafic igneous or sedimentary rocks)

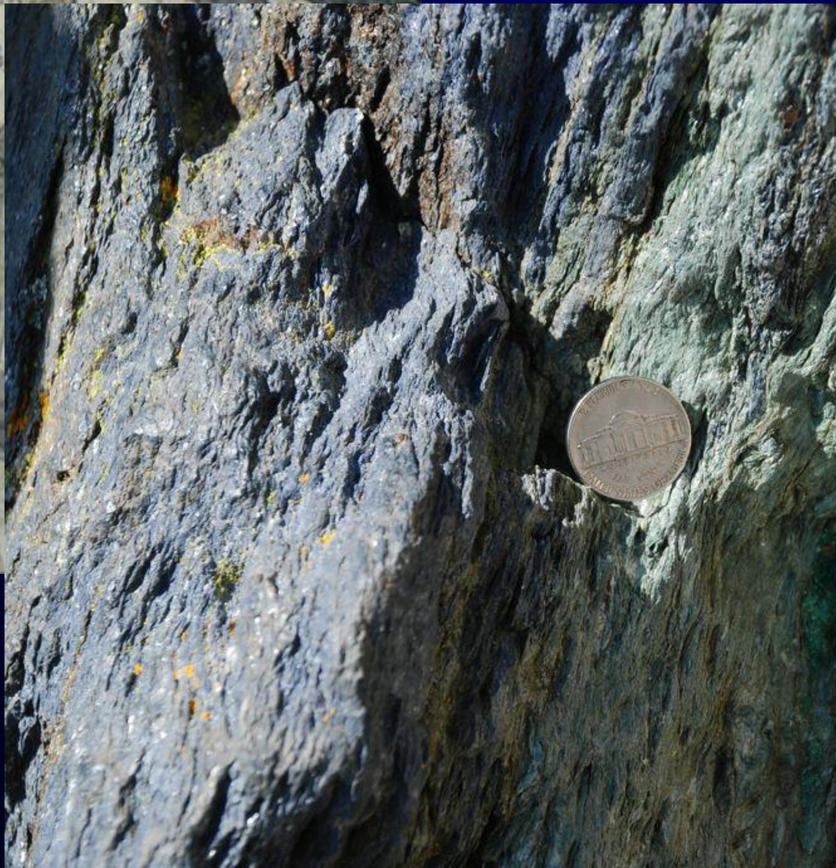
Serpentinite: an ultramafic rock metamorphosed at low grade, so th

Blueschist: a blue metamorphosed sedimentary roc

Eclogite: a green contains clinopy pyrope). The pr

Blueschist: blue amphibole = Glaucophane





Basic Protoliths (mafic igneous or sedimentary rocks)

Greenschist: a low-grade metamorphic rock that typically contains chlorite, actinolite, epidote, and albite. Note that the first three minerals are green, which imparts the color to the rock. The protolith is either a mafic igne

sedimentary rock.

Non-Foliated

Hornfels is … cally very fine-grai … n contact aureoles. … d to splinter w …

A Classification of Metamorphic Rocks

Additional Modifying Terms:

Ortho- a prefix indicating an igneous parent, and

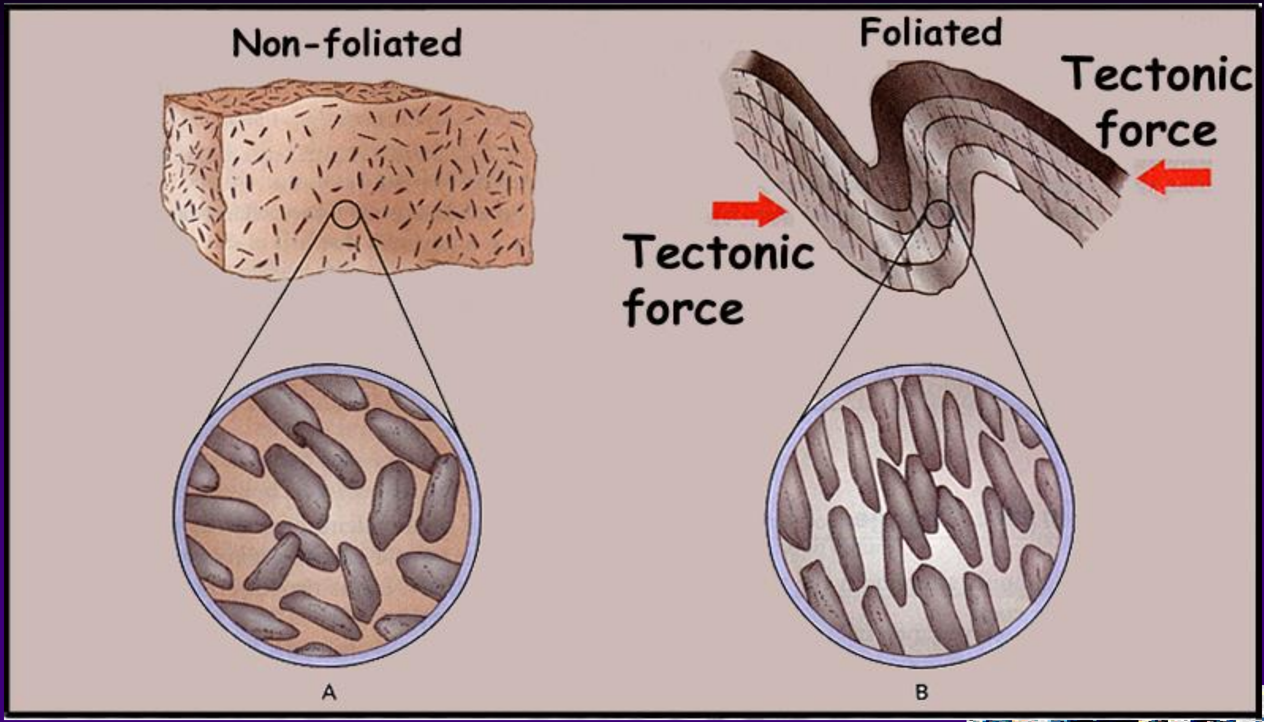
Para- a prefix indicating a sedimentary parent

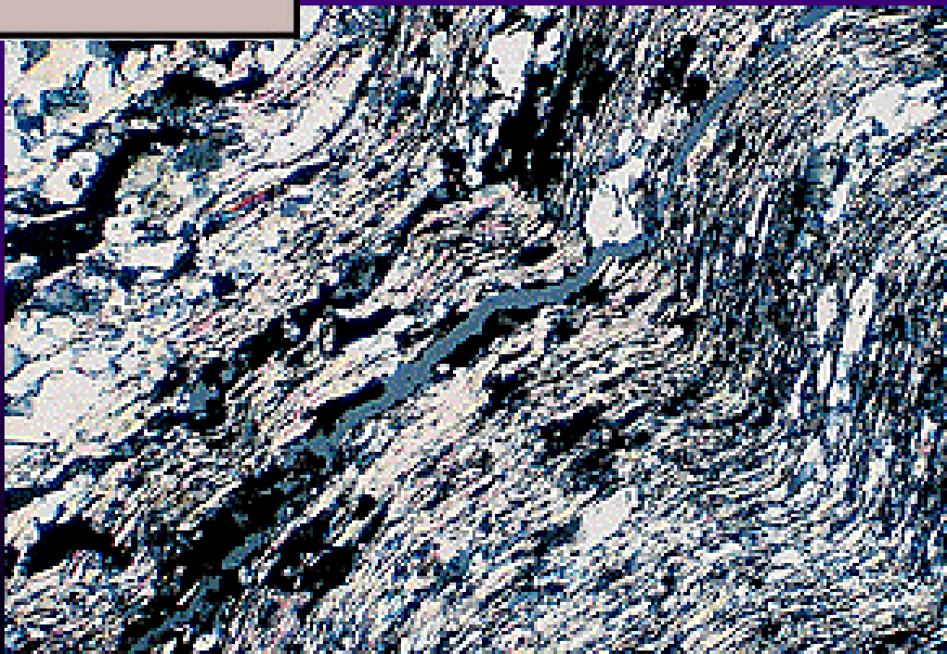
Metamorphic Textures

- Foliated
  - Folios = page or leaf-like
  - rock has distinct banding or layering
    - often not smooth like in sedimentary rocks
  - formed under directed pressure

- Non-foliated
  - no distinct layering character
  - often a massive crystalline texture
  - formed under uniform pressures

Foliated Texture





Foliated Textures

- **Slatey**
  - looks like blackboard
    - dull surface
  - smooth, thin layering
  - breaks into flat slabs
    - referred to as slatey cleavage
  - no mineral grains visible
- **Phyllitic**
  - looks like waxed surface
    - has a "sheen" to it
  - may have little "waves" on surface
    - referred to as *crenulations*
  - some small grains visible
- **Schistose**
  - distinct bands of minerals
  - visible mineral grains
    - garnets, staurolites
  - may have shiny appearance
    - due to mica minerals
- **Gneissic**
  - larger grains
  - may look like igneous rock
  - may have crude banding
    - intensely distorted
  - different minerals than schistose

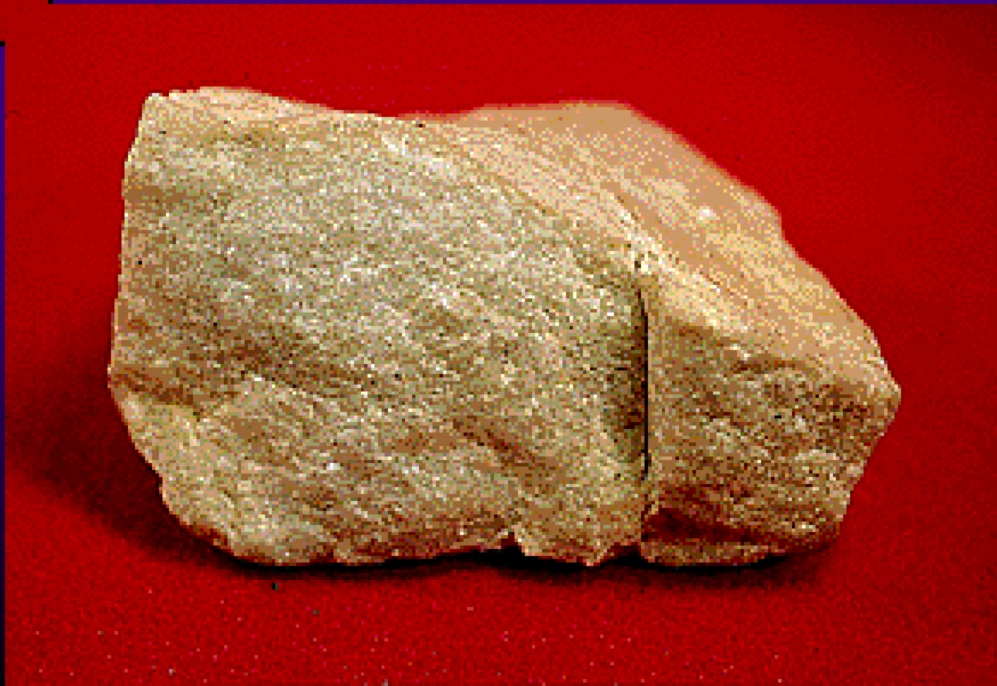
Foliated MM Rocks

MM Rocks that could form as a shale (sedimentary) parent rock is exposed to increasing directed pressure and temperature

Non-foliated Rocks

- **Marble:**
  - metamorphosed limestone

- **Quartzite:**
  - metamorphosed quartz sandstone



STRUCTURES OF METAMORPHIC ROCKS

- The term Structure in a broad sense to include both **small scale** and **large scale features** seen in metamorphic rocks.

- Structures of metamorphic rocks developed in a solid medium by growth of crystals which recrystallize simultaneously.

Structures of Metamorphic rocks

1. Cataclastic structure
2. Schistose structure
3. Gneissose structure
4. Maculose structure
5. Granulose structure

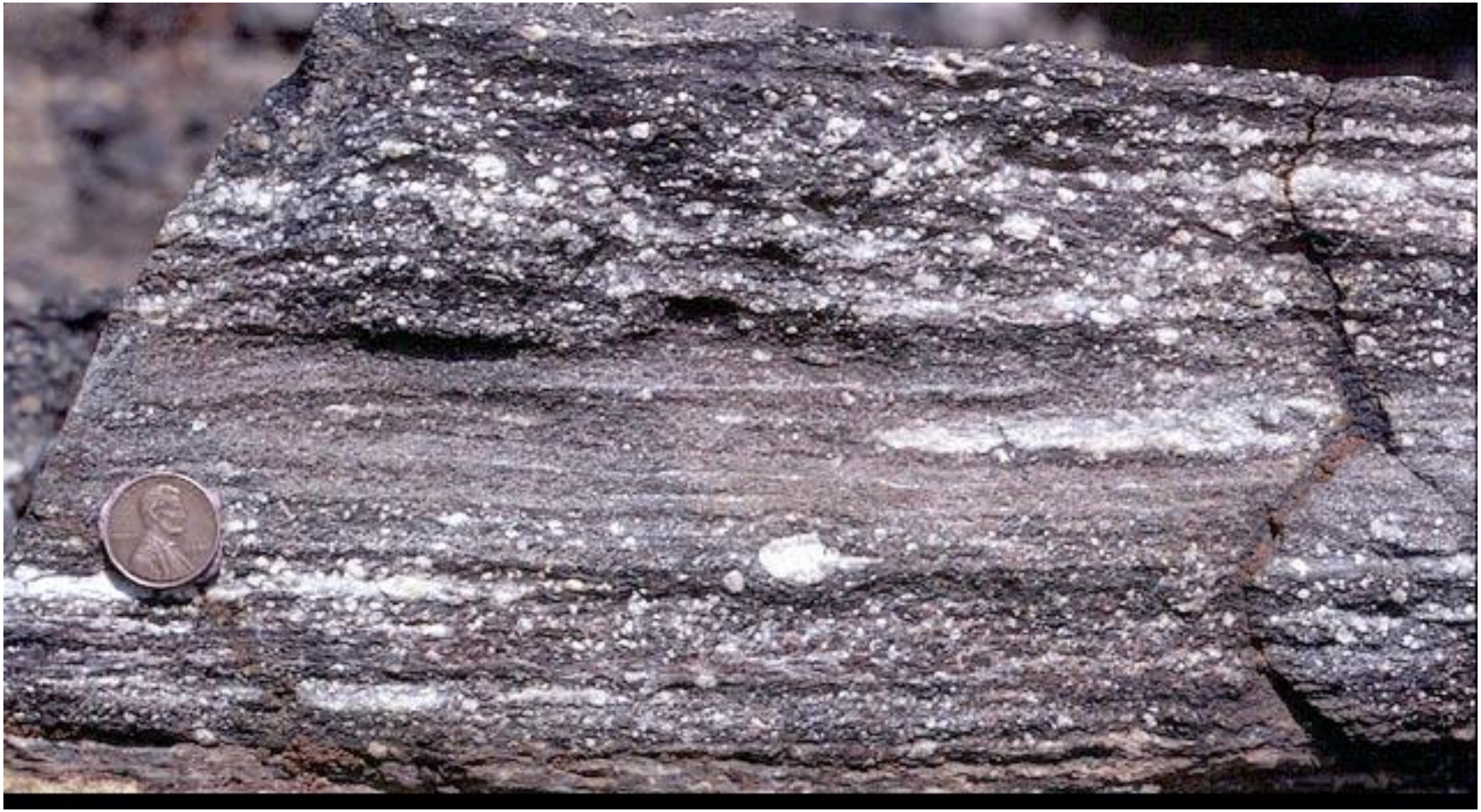
1. Cataclastic Structure :

- Cataclastic structures are those of broken and fragmented rocks developed by mechanical deformation of hard brittle rocks due to cataclastic metamorphism.

- There is almost no new mineral formation.

- Initial stages of deformation simple crushing of rocks takes place producing structuraless aggregates, continued intense movement under stress results in the rolling of grains and finally the rock becomes a more or less streaky, pulverized rock.

Mylonitic and cataclastic rock in the southeastern San Bernardino Mountains



2. Hornfelsic Structure :

- Hornfelsic structures also known as Maculose structure. It is one in which porphyroblasts of strong minerals like Andalusite, Cordierite, Chloritoid Biotite etc are well developed.

- An incipient banding or foliaform this stage there exit transitions to Granulose, Schistose and Gneissose structures.

- Hornfelsic structure is typically developed in Argillaceous rocks under Contact or Thermal Metamorphism.

3. **Granular Structure :**

- This structures is developed largely in rocks with Granoblstic and equidimentional minerals like Quartz, Feldspar, Pyroxene, Granet, Calcite, Dolomite etc.
- Flaky or platy and linear minerals are either absent or present only in small quantities.
- Some times parallel, banded or streaky structures may be present due to alternation of patches differing in mineral composition or granularity.
- Granulose structures are common in products of Thermal and Plutonic metamorphism.

4. **Foliated Structure :**

- Foliated structures are by far the most common and important among metamorphic structures.

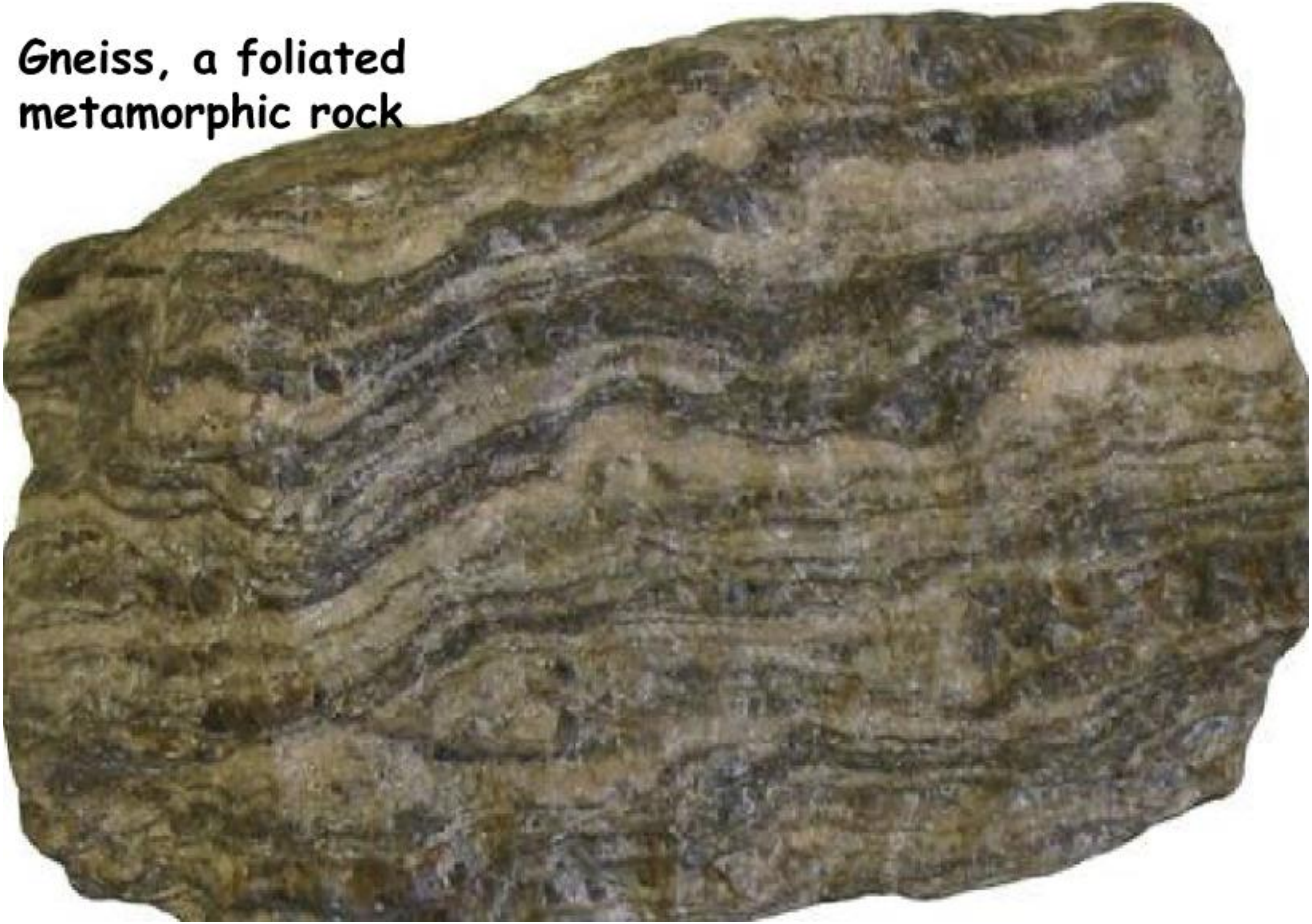
- The term Foliation or Schistosity is applied to cleavage or facility due to paralleism of platy or linear minerals in metamorphic rocks.

- Foliation may be subdivided according to the degree of perfection of the parallel surface as **Staty Cleavage** *(most perfect*) Schistosity and Gneissic structures *(least perfect)*.

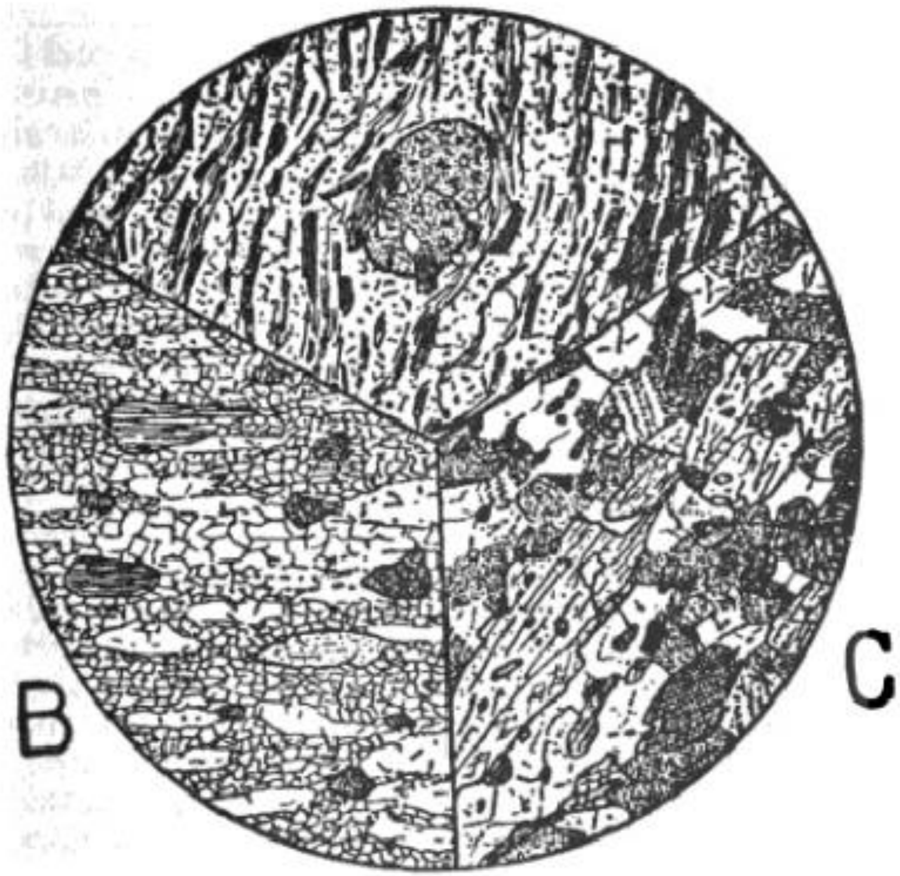
- Foliation results from the parallel or subparallel arrangement of tabular, flaky and linear minerals.

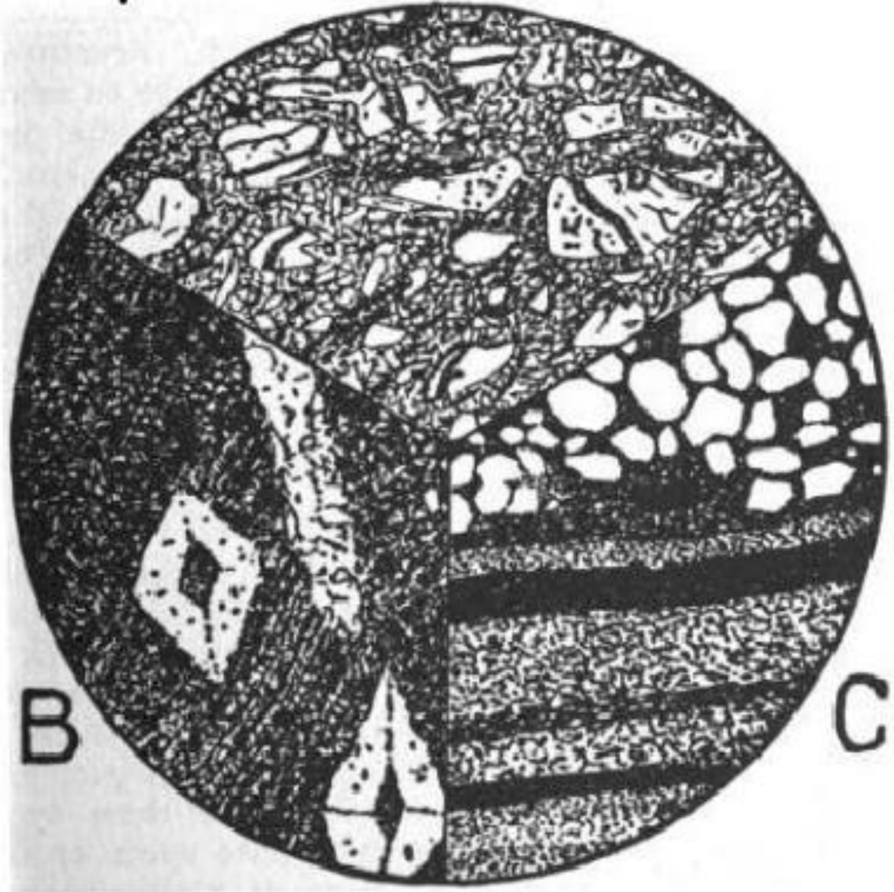
Foliated gabbro showing weak banding structure, which is cut by leucocratic vein in the right part

Gneiss, a foliated metamorphic rock



A Structures of Metamorphic rocks A





A. Schistose structure

B. Granulose structure

C. Gneissose structure

A. Cataclastic structure

B. Maculose structure

C. Palimpsest structure

Large scale structural features

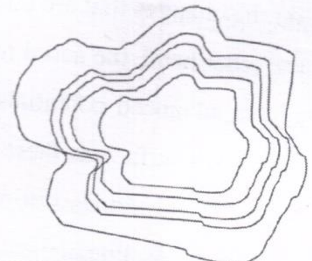
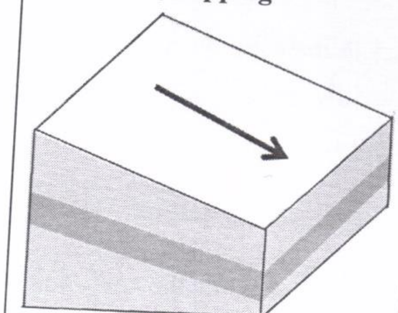
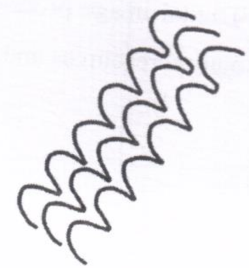
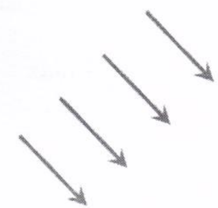
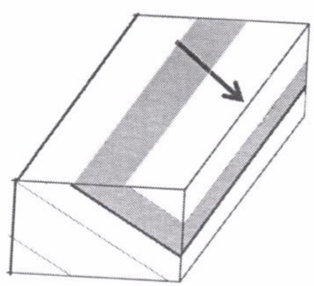
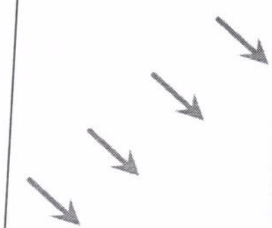
- Rock cleavage
  - Flow cleavage
  - Fracture cleavage
- Schistosity
- Foliation

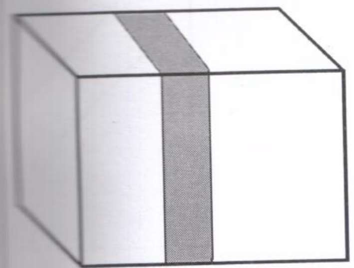
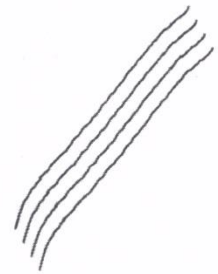
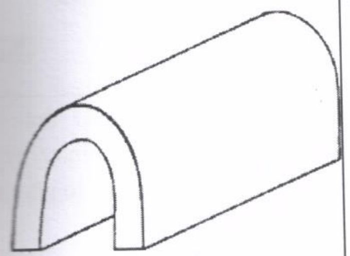
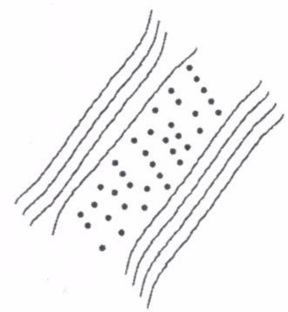
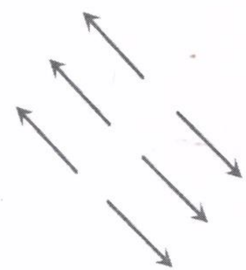
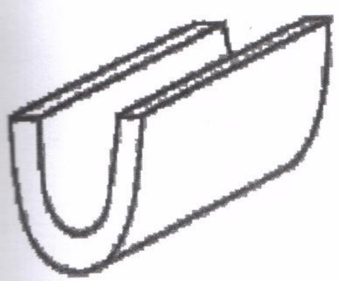
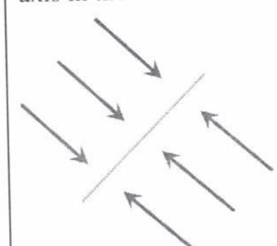
Classification of Metamorphic rocks

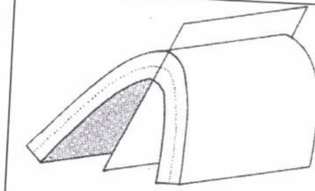
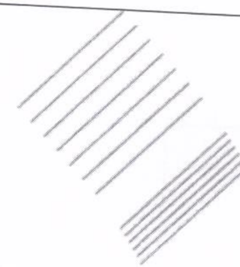
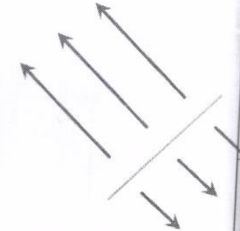
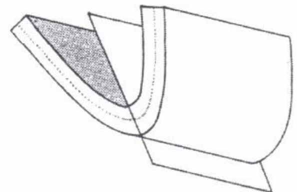
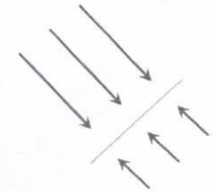
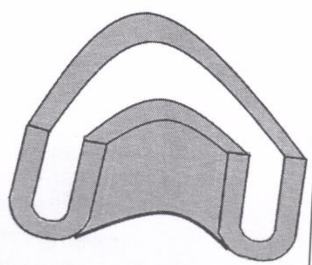
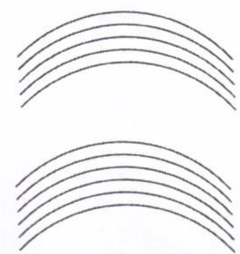
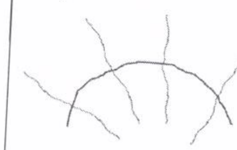
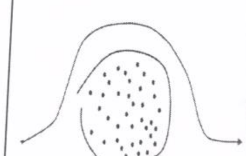
- Foliated rocks – rocks that show parallelism in their mineralogical and structural constitution e.g. slates, phyllites
- Non-foliated rocks – characterized by the absence of foliation

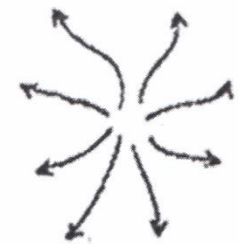
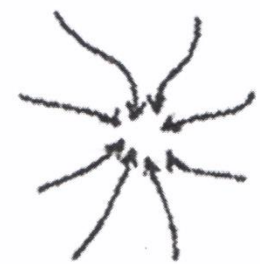
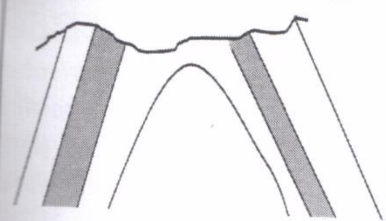
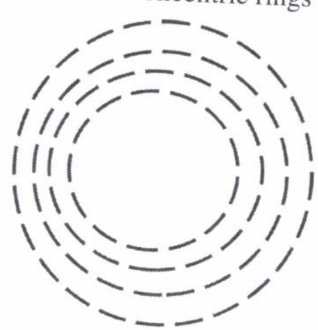
Mapping of Metamorphic Rocks Through Remote Sensing Data

Table:1. Folds in field and remotely sensed data

Sl. No	Expression of folds in field	Expression of folds in Remote Sensing	
		Structural Trends	Drainages
1.	**Flat lying**	Absence in the Centre and Wavy in the boundaries 	
2.	**Marginally dipping** 	Wavy in the up dip boundary 	Parallel drainages with equal length and near equidistant 
3.	**Moderately dipping** 	Broad wavy in up dip boundary 	Parallel and comparatively short distance 

4.	**Steep / vertical dipping beds** 	Long and linear 	
5.	**Symmetrical anticline** 	Sub parallel sets with the gap in the Centre marked by coarser texture 	Parallel set of divergent drainage with equal length 
6.	**Symmetrical syncline** 	Same as in 5.	Parallel and equal length drainages but converging towards the axis in the centre 
7.	**Asymmetrical Anticline**	Linear and parallel, closely spaced sets and sparsely spaced sets with a gap in the Centre	Parallel drainages long on one side and short on other side – divergent

			
8.	**Asymmetrical Syncline** 	Do	Do – but convergent 
9.	**Refolded Folds** 	Arcuate with gap in the Centre 	Annular drainage with subordinate trellis (may be due to plunging fold also) 
10.	**Topo high / anomalous dry lands amidst irrigated land (subsurface domes)**	Broken circular trends 	Anomalous annular drainage 

Do	Do	Radial centrifugal drainage 
Subsurface Basins	Do	Radial centripetal drainage 
Domes with encircled circular rings of hard and soft rocks 	Circular and concentric rings 	Inner centripetal, with outer centripetal with annular drainages in berween