Geology 12 - Metamorphic Rocks Outline:

1. General Information
2. Factors in Metamorphism
3. The Two Major Categories of Metamorphic Rocks
4. Environments of Metamorphism
5. Metamorphic Grade
6. Classification of Metamorphic Rocks

General Information:

"*Metamorphism*"

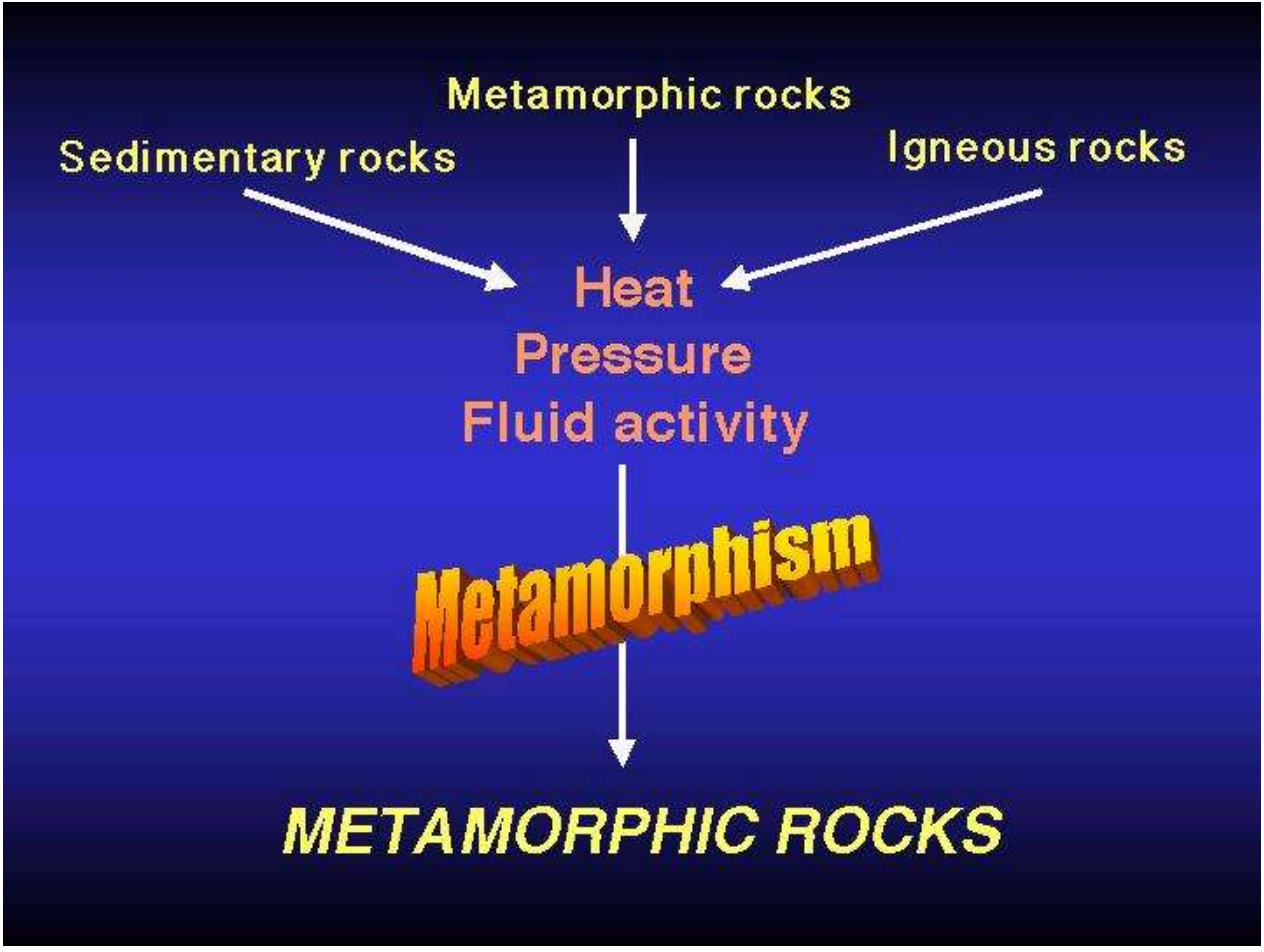
Comes from Greek:

Meta = change & Morph = form so…

Metamorphism means to change form.

- **In geology this refers to the changes in mineral assemblage and texture.**

- **These changes result from subjecting a rock to pressures and temperatures different from those under which the rock originally formed.**



Metamorphic rocks
Sedimentary rocks
Igneous rocks
Heat
Pressure
Fluid activity
Metamorphism
METAMORPHIC ROCKS

Factors
In
Metamorphism:

Four Main Factors to Consider:

Temperature

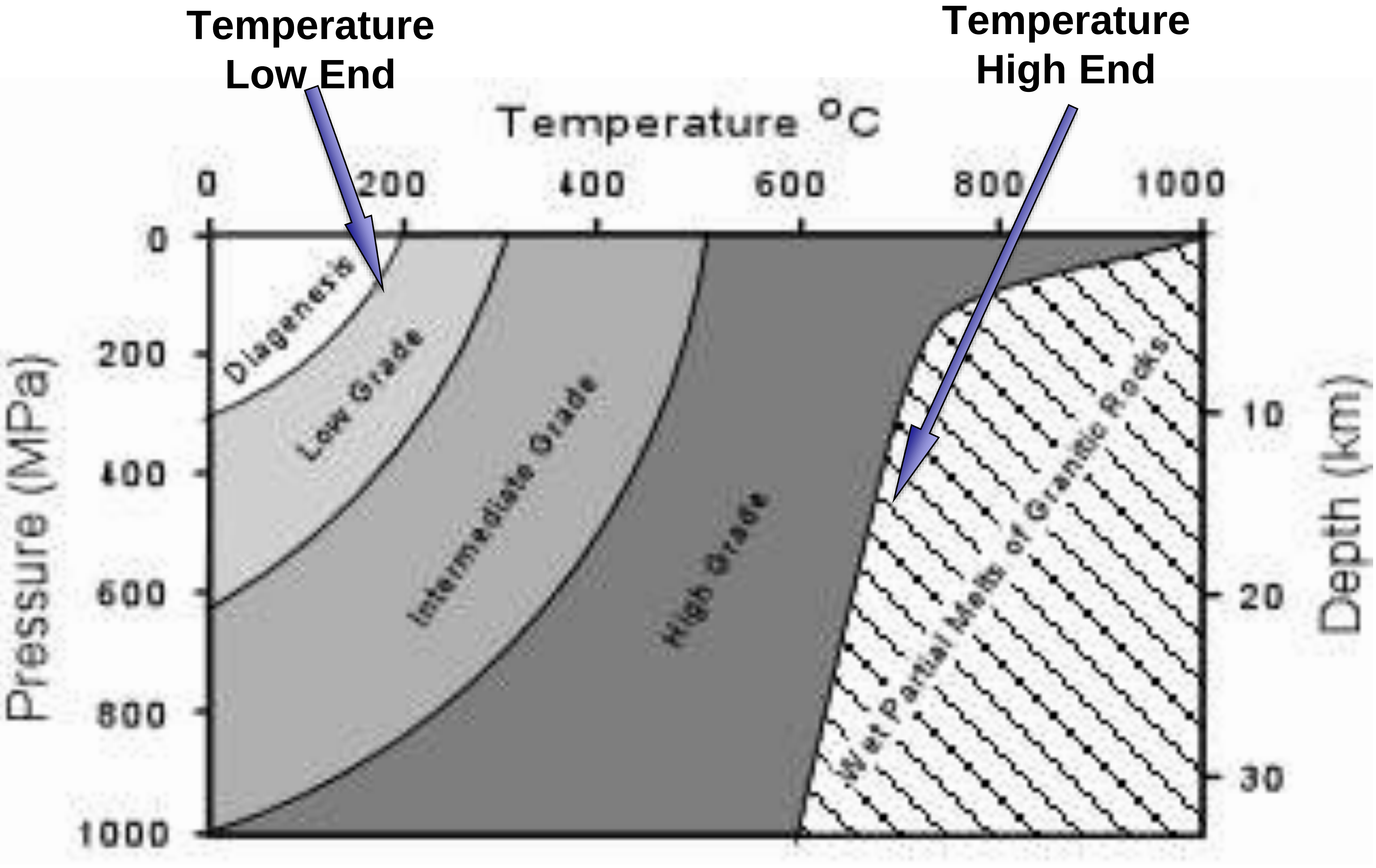
Pressure

Chemical Reactions

Parent Rocks

Temperature:

- Limited on Low end by **Diagenesis (Sedimentary process)**.
- Limited on High end by **Melting (becomes magma)**.
- Range of Temperatures between these two is the **metamorphic temperature range**
- Typically between **100** Degrees Celsius & **800** Degrees Celsius.
- As temperature increases **minerals become unstable & breakdown** to form new minerals; therefore, temperatures in metamorphic range result in **new rock types** with new mineral assemblages!
- Increase in temperature can be from:
    - » **Normal heat due to Geothermal Gradient.**
    - » **Intense Plate Tectonic Activity.**
    - » **Proximity to a nearby Magma Body.**

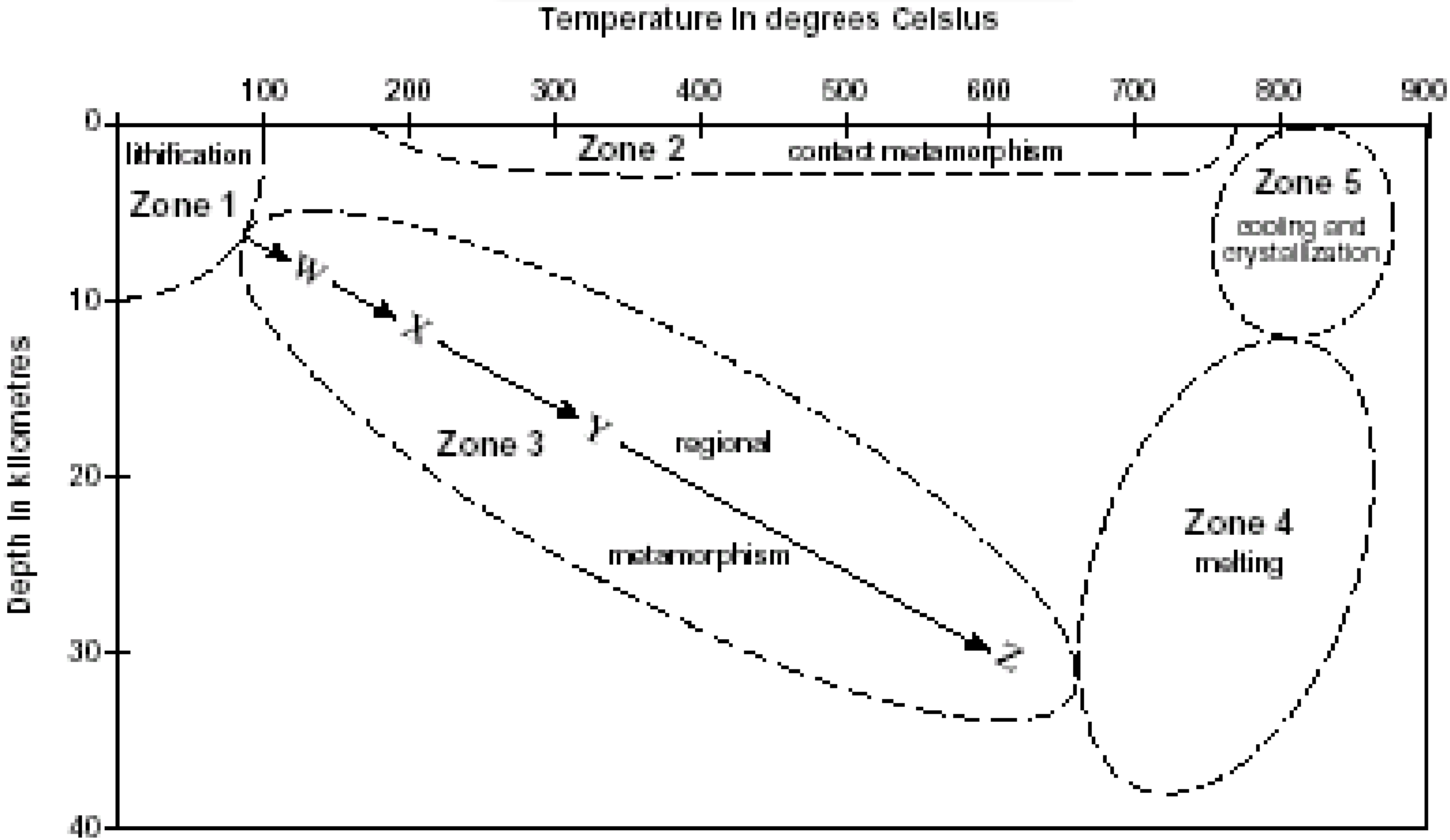


Notice: *GRADE*.

low grade, intermediate grade, high grade metamorphism

The starting materials for the rock cycle shown are the sediments clay, silt and mud.

NOTICE: *Zone 2 and 3...*



Pressure:

- Two Types of pressure:

A. *Confining Pressure*

B. *Directed Pressure*

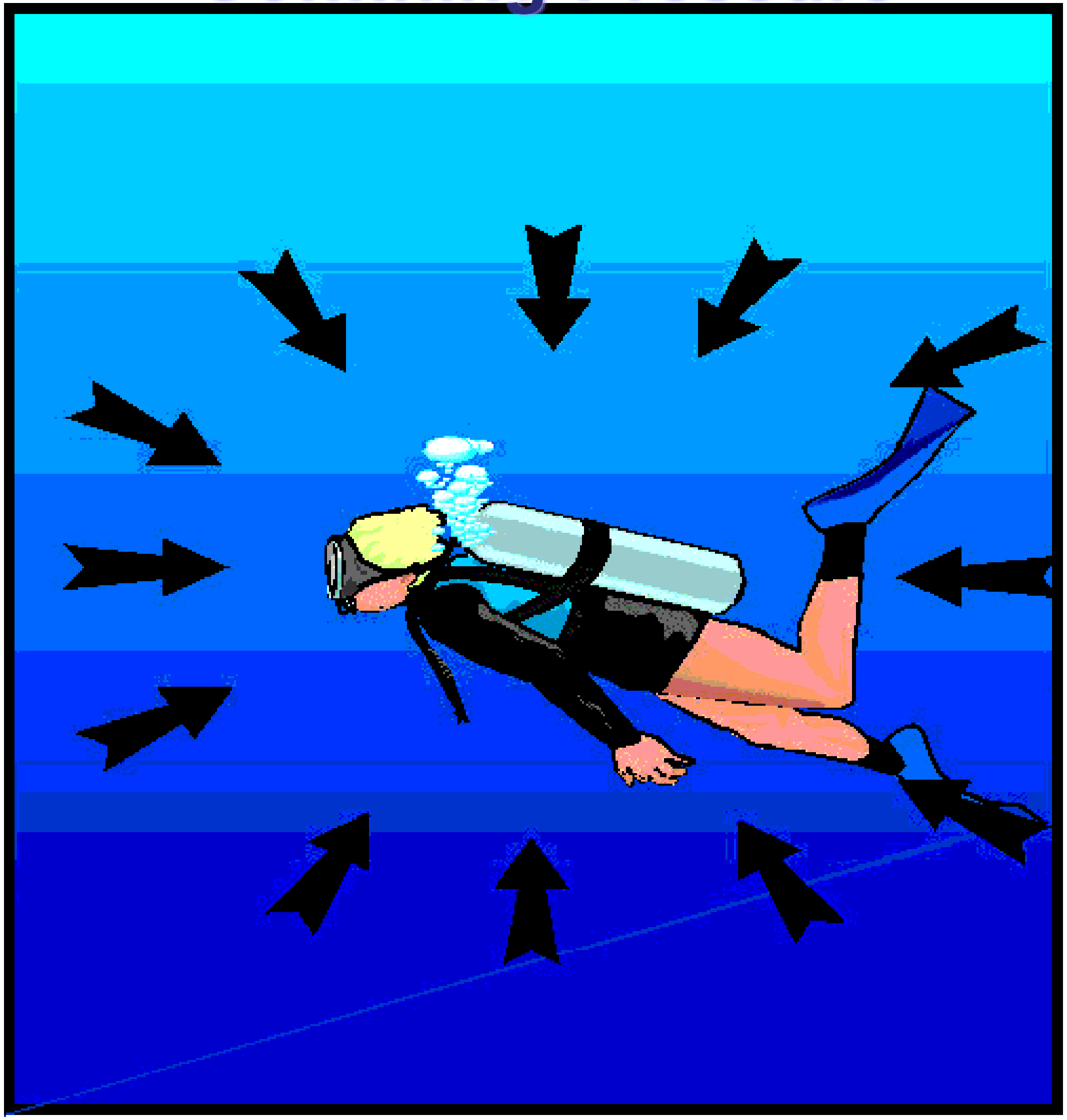
A. **Confining Pressure:**

Imposed by Surrounding Rocks,

Increases with Depth.

<u>Uniform in All Directions.</u>

This diver is experiencing "Confining Pressure"

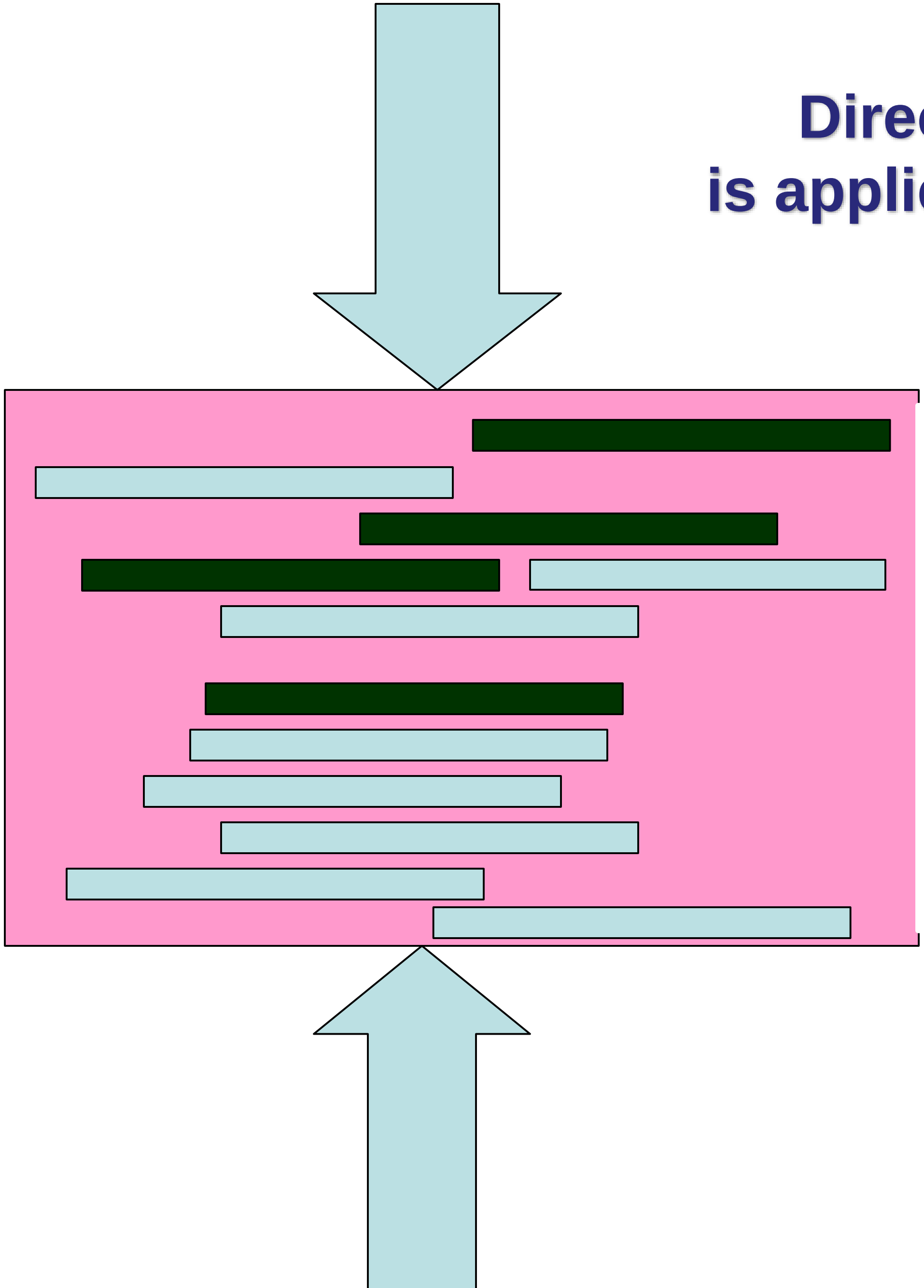


B. **Directed Pressure / Stress**

Connected to plate tectonics & mountain building processes.

<u>NOT Uniform in All Directions.</u>

Results in Deformation.



Directed Pressure / Stress
is applied in a specific direction!

...it causes mineral crystals to align **PERPENDICULAR** to the **stress**!

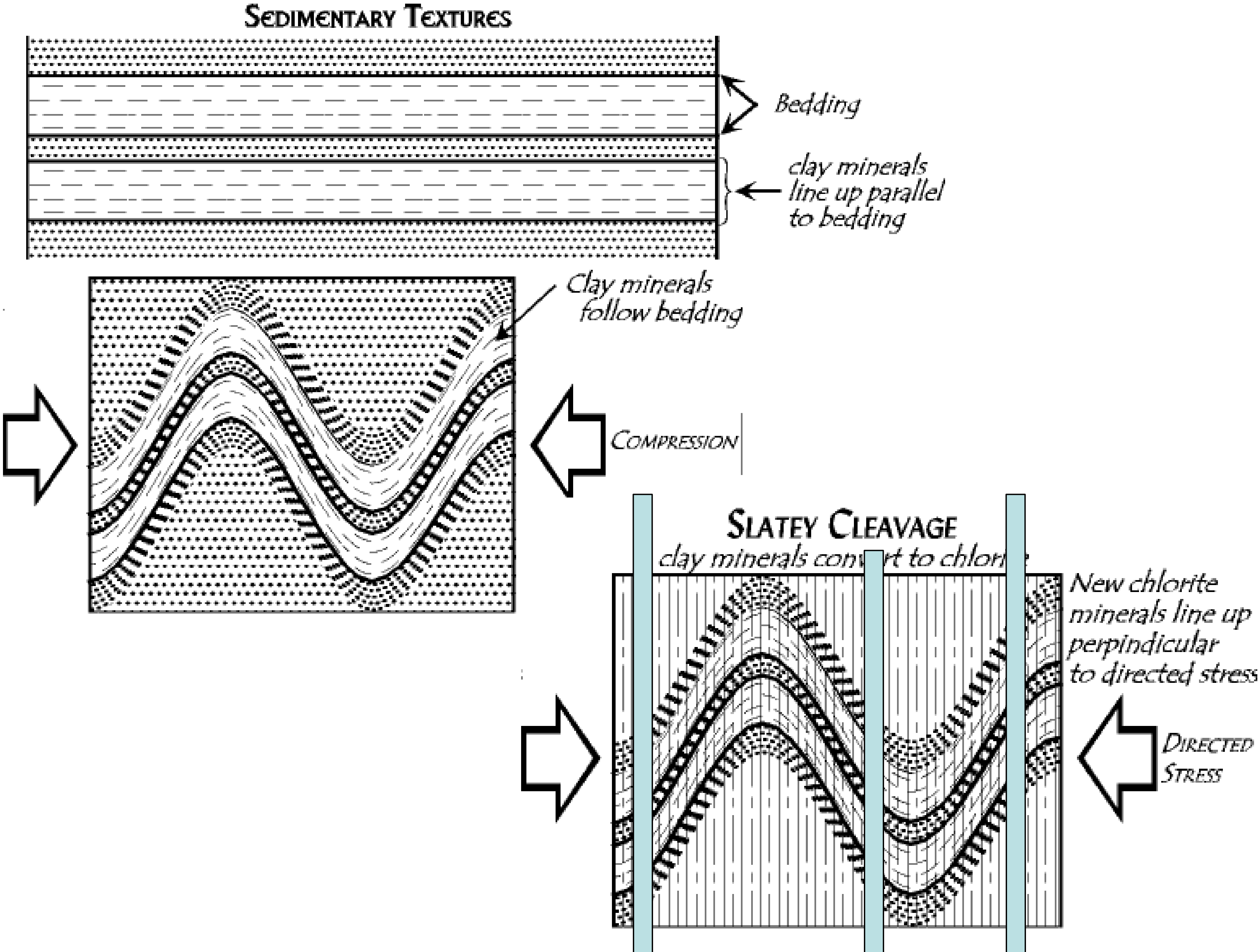
Results of Pressure!

- As pressure increases rocks become more compact & dense.

- Mineral Crystals become aligned parallel to each other.

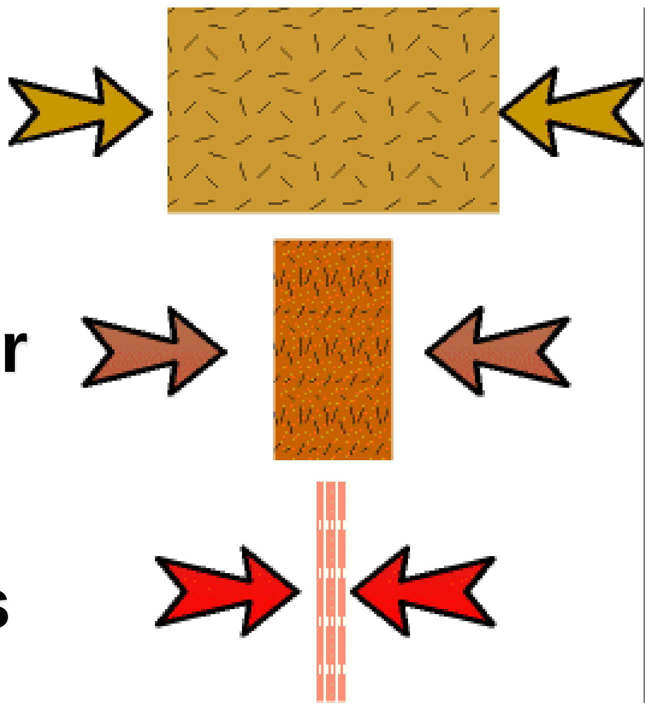
- Mineral crystals line up perpendicular to the stress.

- Results in compositional & textural banding
  ex. *Schistocity* & *Gneissic Banding*


SEDIMENTARY TEXTURES
Bedding
clay minerals line up parallel to bedding
Clay minerals follow bedding
COMPRESSION
SLATEY CLEAVAGE
clay minerals con rt to chlori
New chlorite minerals line up perpindicular to directed stress
DIRECTED STRESS

- Often creates "Rock Cleavage"
  ex. *Slate breaks easily into flat layers*!

- Mineral crystals & rock/fossil fragments become stretched & deformed.
- Mineral crystals INCREASE in SIZE due to recrystallization!



- Porosity is greatly reduced.
- Net result is significantly altered or METAMORPHOSED rocks.
- Recrystallization of many minerals occurs = Porphyroblasts!

Porphyroblasts

Large mineral crystals in a fine grained groundmass

Chemical Reaction:

- **Permeable rocks allow fluids to flow through pore space.**
- **Fluids (or materials dissolved in them) which flow through pore spaces can react with the original rock.**
- **Reaction produces new mineral assemblages, and therefore new METAMORPHOSED rocks.**
- **Often fluids migrate away from an area of heating caused by the intrusion of magma.**

- **These fluids then leave one area and enter another.**

- **These fluids often carry various dissolved gasses and minerals.**

- **Areas that GAIN fluids & areas that LOSE fluids will end up being changed chemically = METAMORPHOSED!**

- **This change can be brought about without the help of pressure/stress =**

Contact Metamorphism…

i.e. an area of "Country rock" surrounding a magma is altered simply by the heat from the magma

Parent Rocks: - PROTOLITH

- **Simply enough…the metamorphic changes that will/can occur in a rock depend on the original mineral composition of the "Parent Rock".**
- **This initial "Parent Rock Composition" interacts in a complex way with temperature, pressure, and chemical reactions.**
- **The result is a Metamorphic rock which is a complex relationship between these four factors:**
  - Ex. *A parent rock of **shale** can become **slate, phyllite, schist,** or **gneiss**, depending on the temperature, pressure, and chemical reactions it undergoes!!*

The Two
Main Categories
of
Metamorphic Rock:

There Are Two Main Categories of Metamorphic Rocks:

#1 FOLIATED **Page #193 Lab Manual**

#2 NON-FOLIATED **Page #194 Lab Manual**

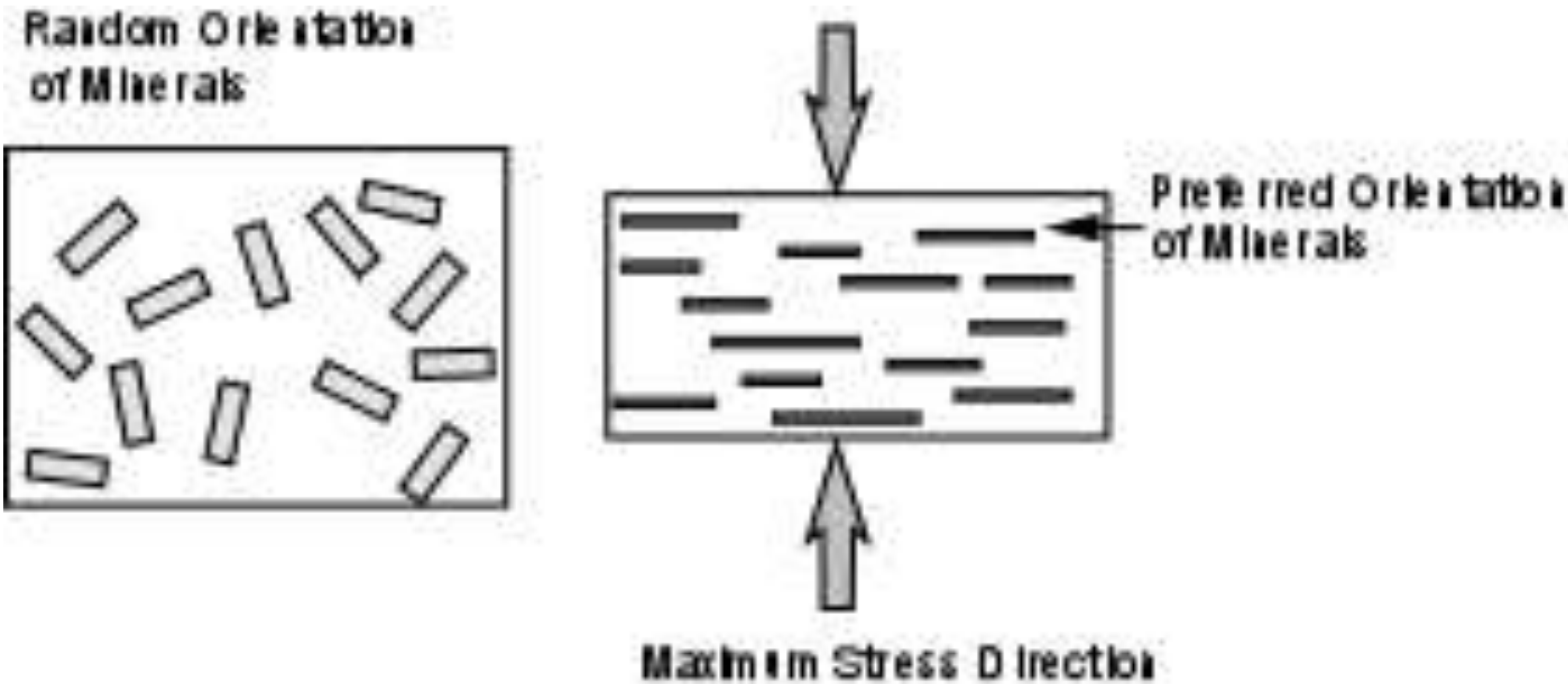
#1 FOLIATED:

•Foliation forms when pressure squeezes the flat or elongate minerals within a rock so they **become aligned**.

•These rocks develop a platy or sheet-like structure that reflects the direction that **pressure** was applied.

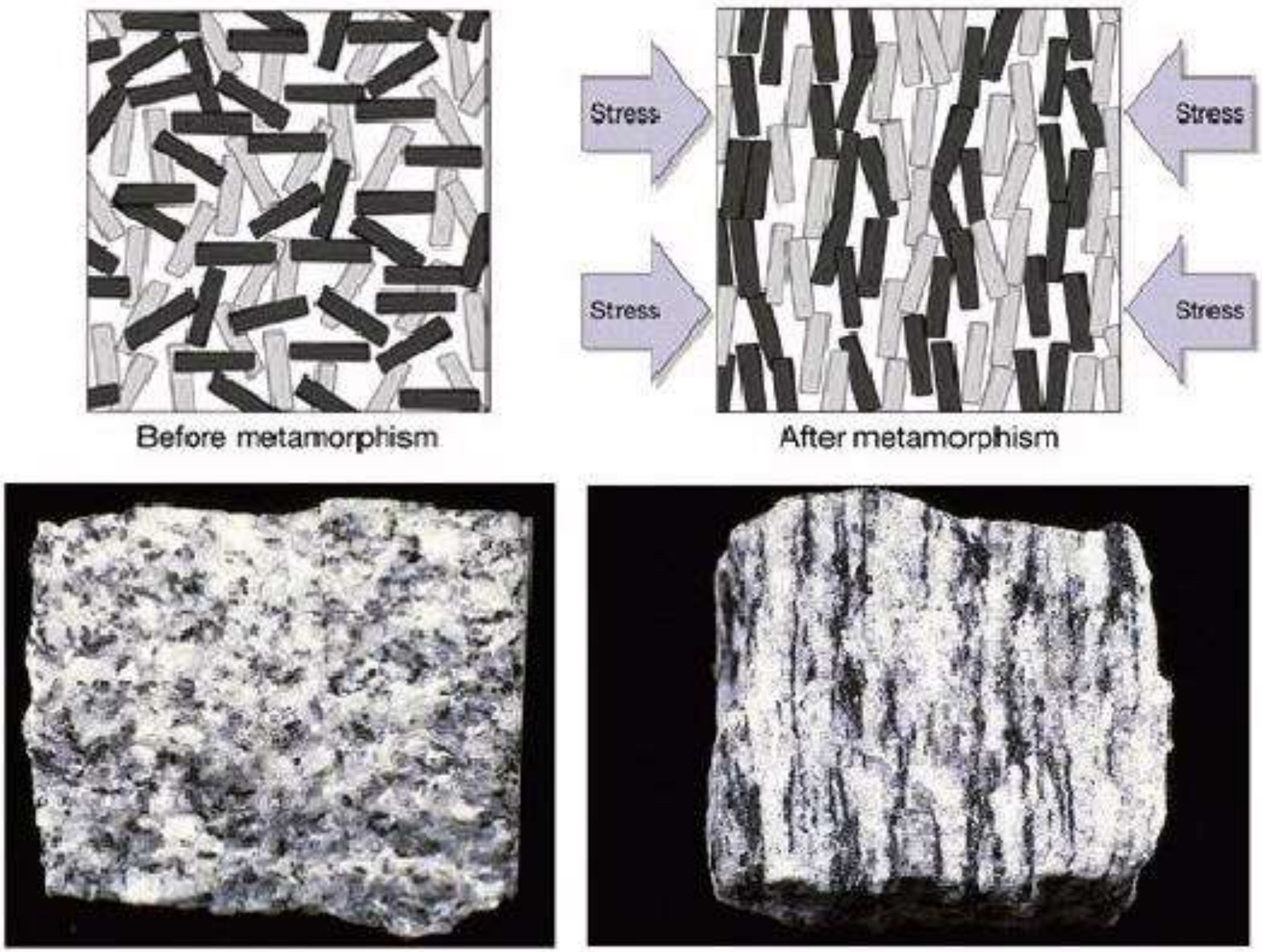
Which direction was pressure applied?

Diagram showing application of stress resulting in alignment of mineral crystals...

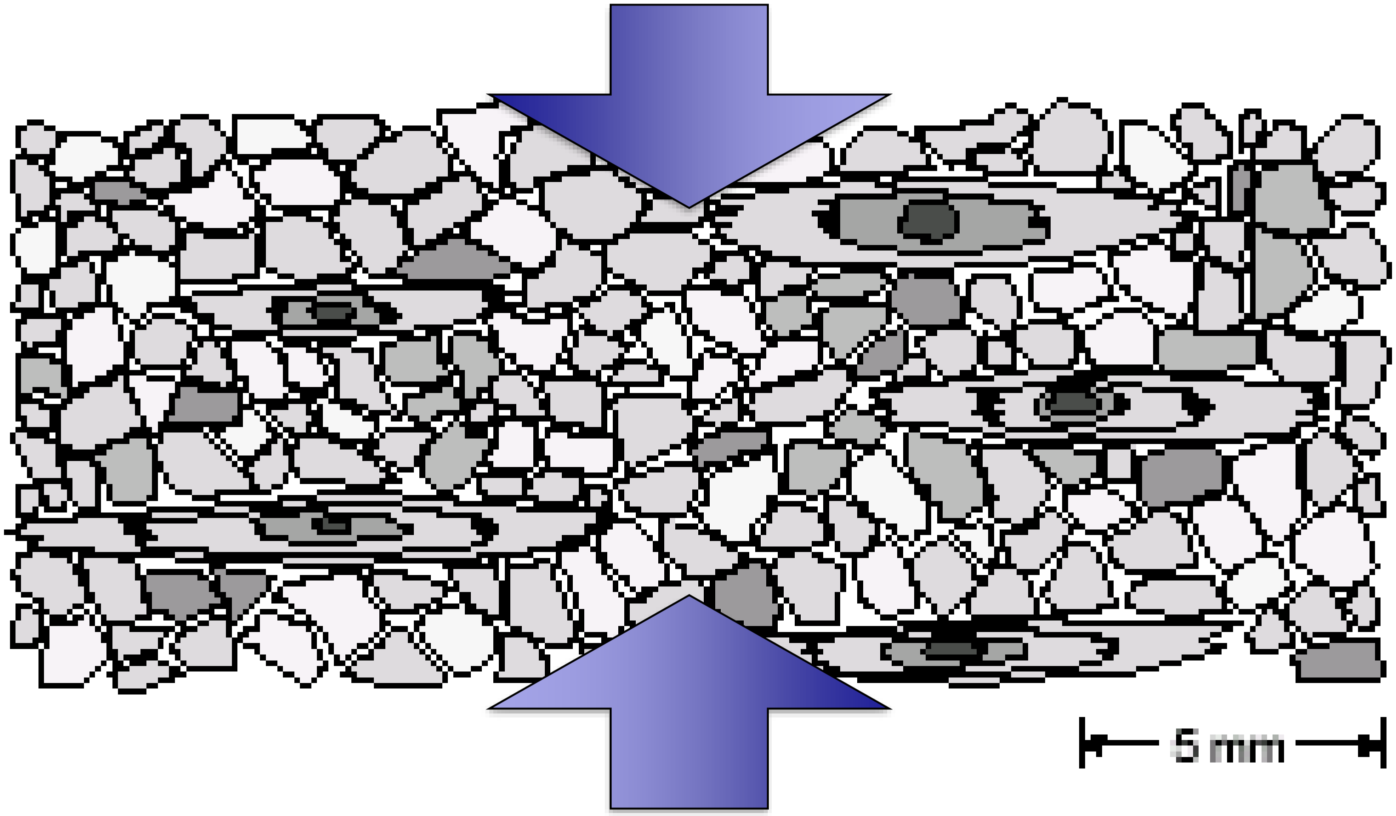


What is "metamorphosed"?

Texture



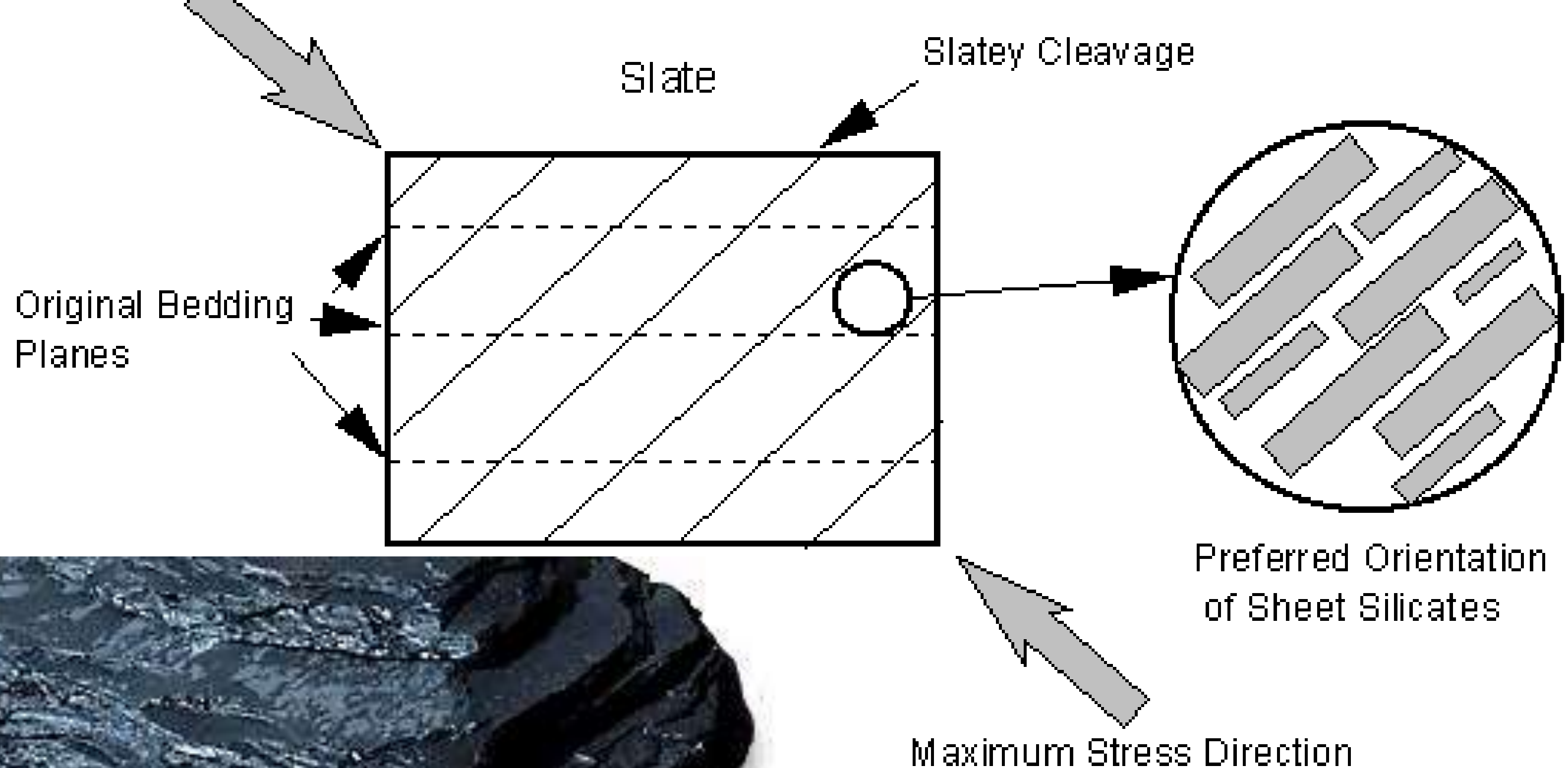
In this old exam question, they asked which direction the force that aligned the mineral crystals was applied from.



This is an example of foliation…caused by directed stress/pressure…found in areas of **REGIONAL METAMORPHISM**!

Foliated Metamorphic Grade - Stage #1:

Slate has a **SIMPLE & FLAT** foliation in which the rock will break into hard flat sheets…called **SLATEY CLEAVAGE!!**



Slate

Foliated Metamorphic Grade - Stage #2:

Phyllite has a slightly more complex WAVY / WRINKLED foliation.

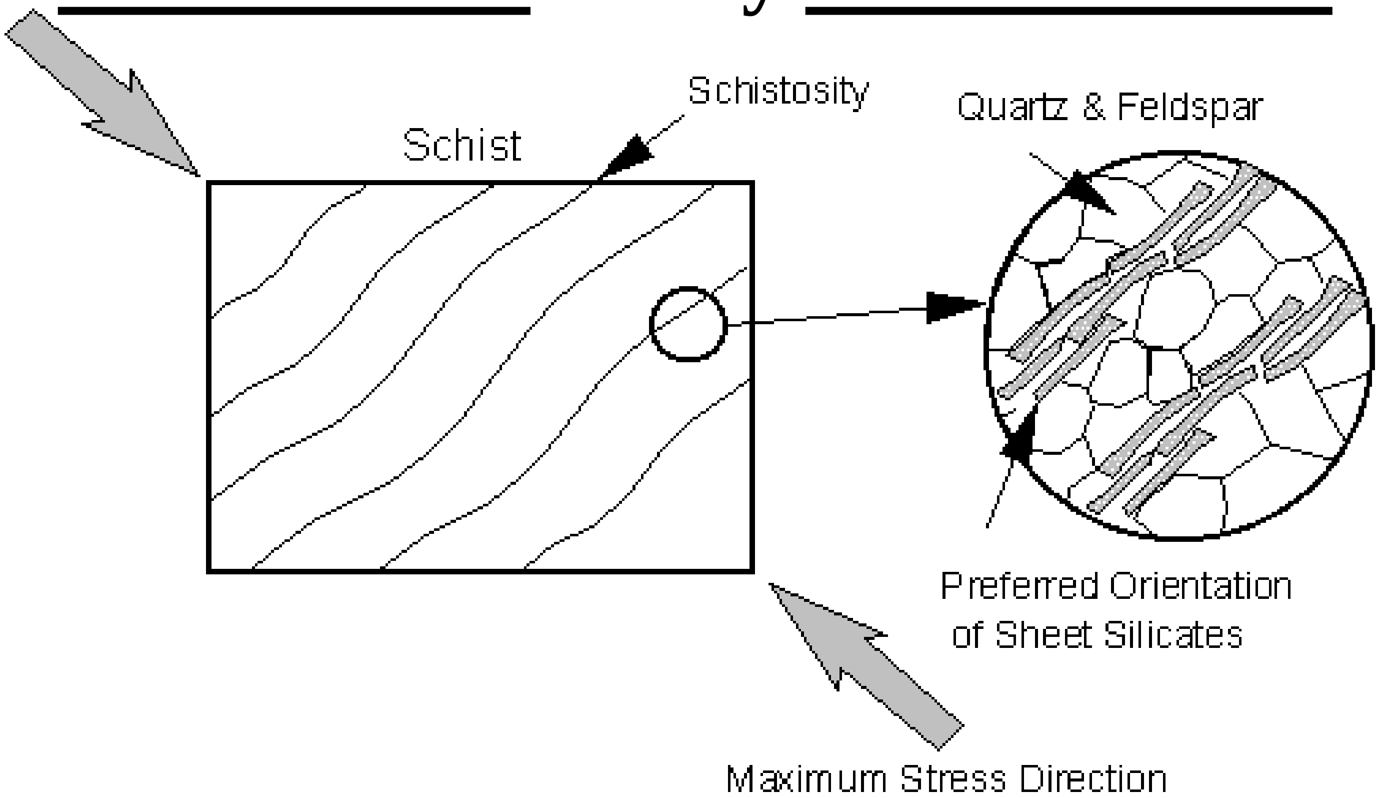
The minerals are altered in such a way that they appear to have a somewhat shiny "METALLIC LUSTER"

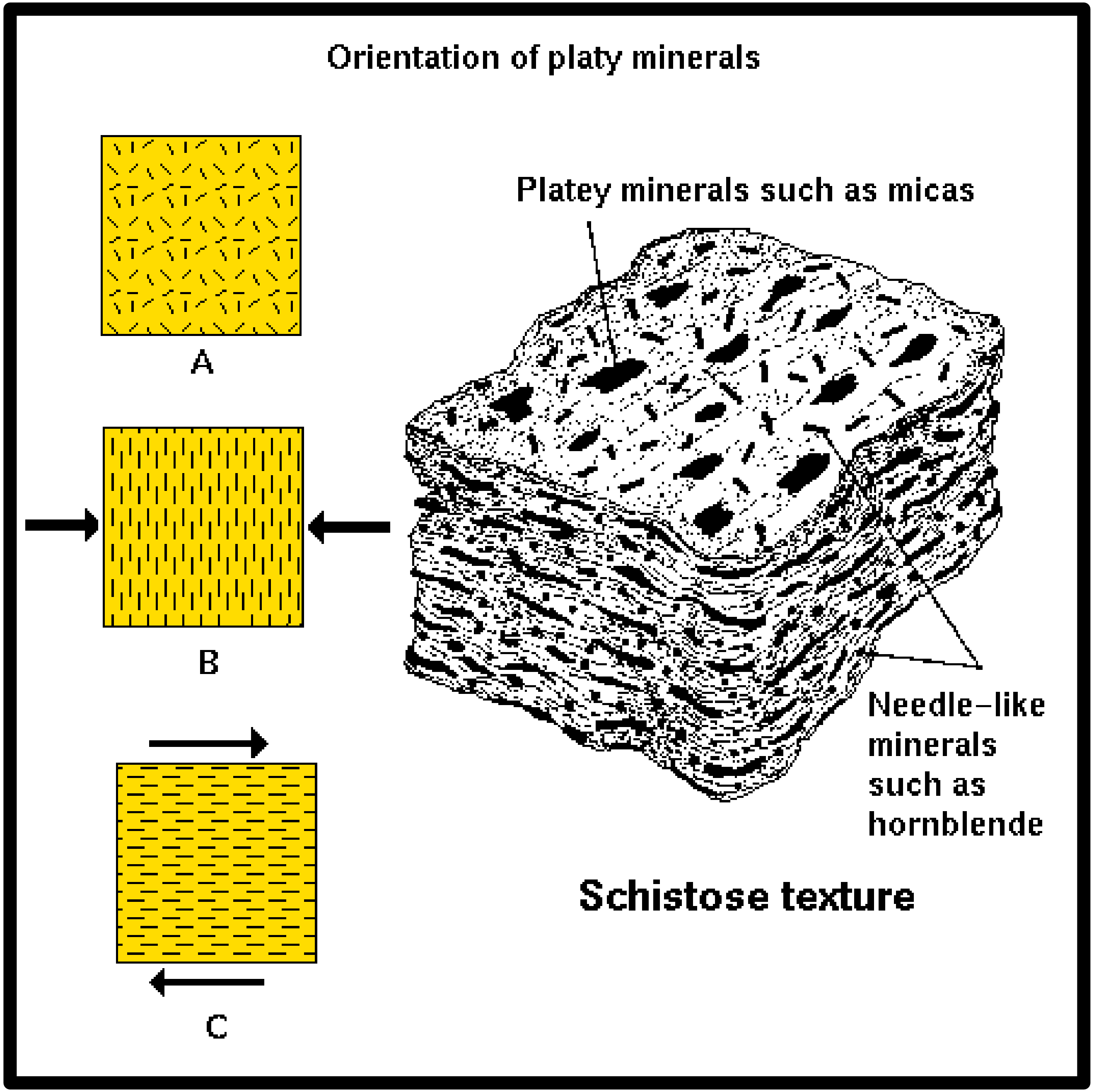
Phyllite

Foliated Metamorphic Grade - Stage #3:

Schists have a more complex foliation in which the rock will break into SCALY sheets … called SCHISTOSITY!!

They appear GLITTERY & very CRYSTALLY!



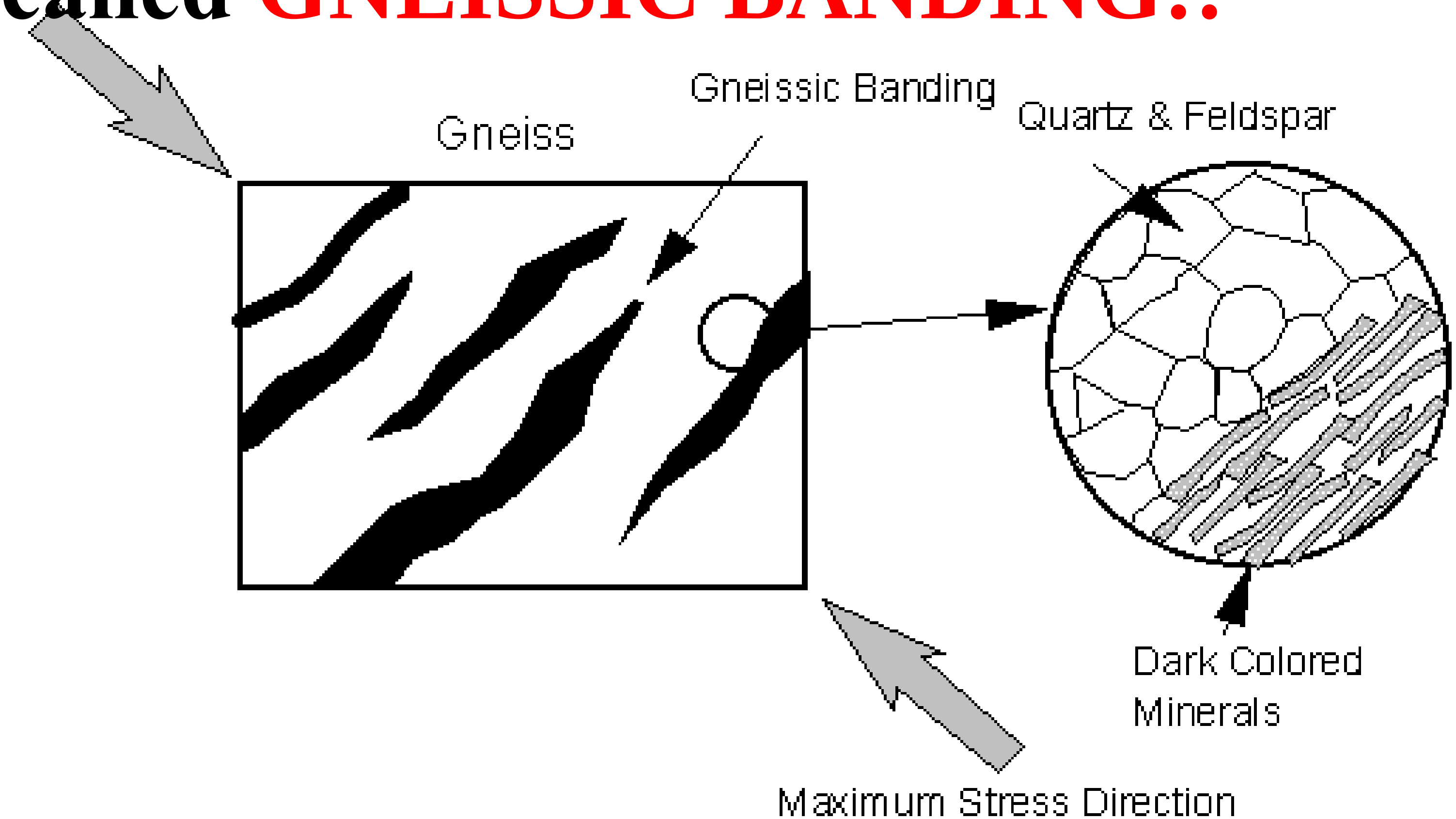


Notice how it is more *wavy* than Phyllite!

Schist

Foliated Metamorphic Grade - Stage #4:

Gneiss has a still more complex foliation in which the minerals in the rock segregate into alternating <u>LIGHT</u> & <u>DARK</u> layers…called GNEISSIC BANDING!!





Gneiss

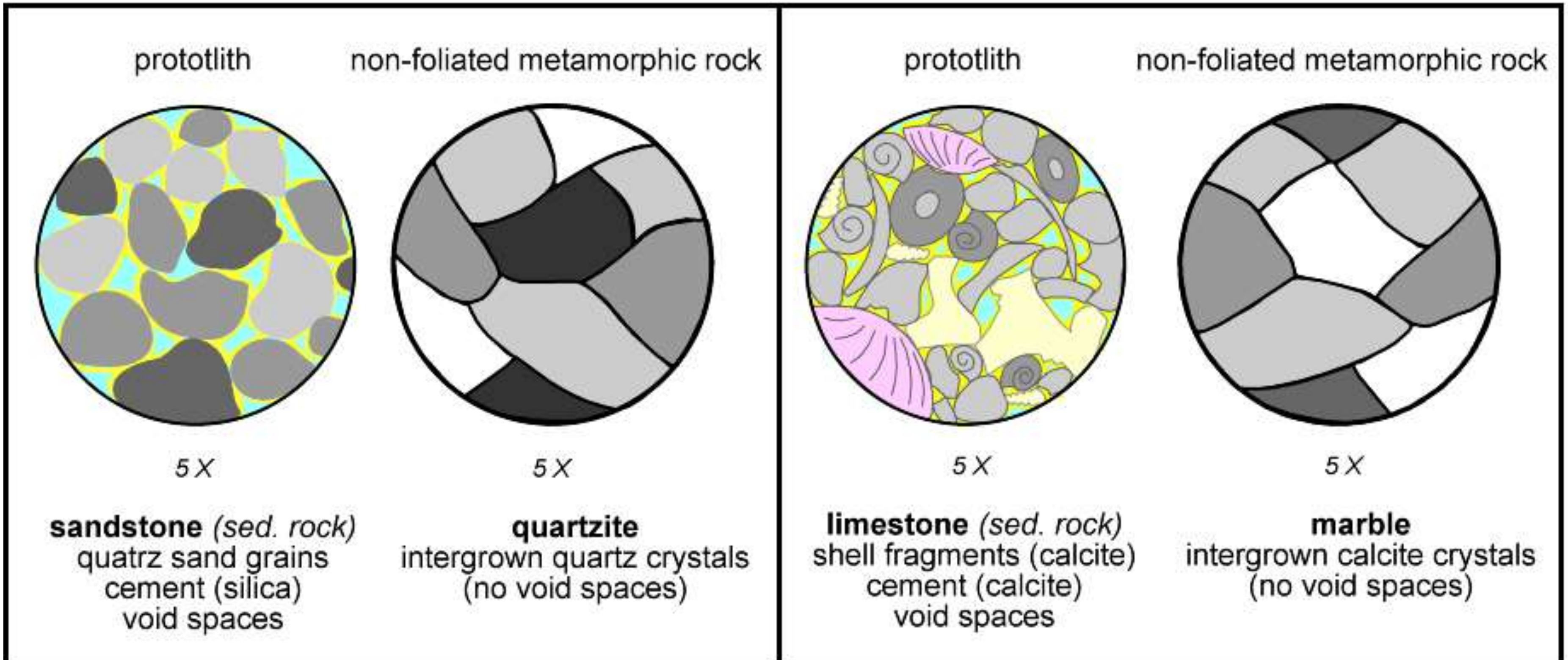

#2 NON-FOLIATED:

Non-foliated metamorphic rocks do **not** have a platy or sheet-like structure.

Crystals are NOT ALIGNED!

There are a couple of reasons that non-foliated metamorphic rocks are produced:

- **Some rocks, such as limestone are made of minerals that are not flat or elongate.**
- **No matter how much pressure you apply, the crystals will not align!**



- **In the process of Contact Metamorphism, hot igneous rock intrudes into some pre-existing rock.**

- **The pre-existing rock is essentially baked by the heat, changing the mineral structure of the rock without addition of pressure.**

- **If no pressure is applied, there can be no alignment of mineral crystals and therefore no foliation!**

Environments of Metamorphism:

There are <u>two</u> Environments of Metamorphism:

#1 Regional Metamorphism

#2 Contact Metamorphism

1. Regional Metamorphism:

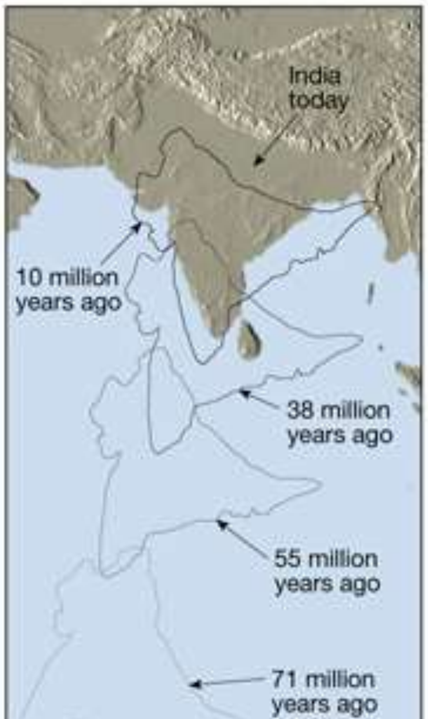
- occurs on a **large scale**, typically involving **hundreds of square kilometers** of surface area.

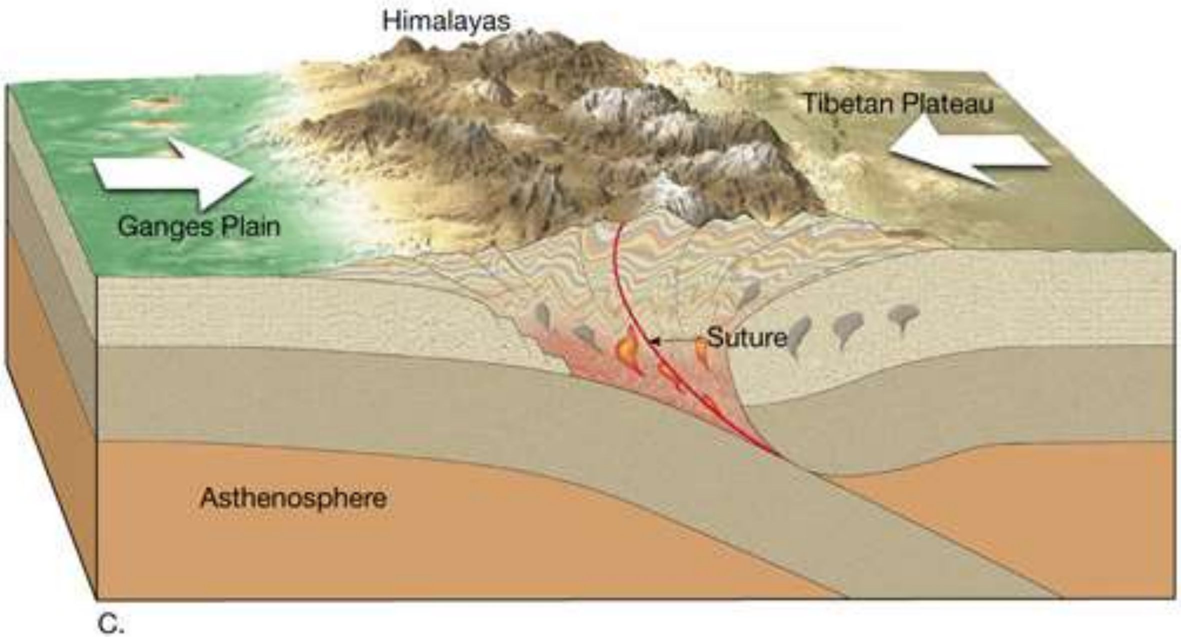
- It is the **most widespread of the metamorphic types** and is typical of the major fold-mountain belts such as the Appalachians, Himalayas, Alps or Rocky Mountains.

- Results from **faulting and folding associated with mountain building** processes and therefore lots of **STRESS**.

- A process that is usually **associated with convergent plate tectonic boundaries**.

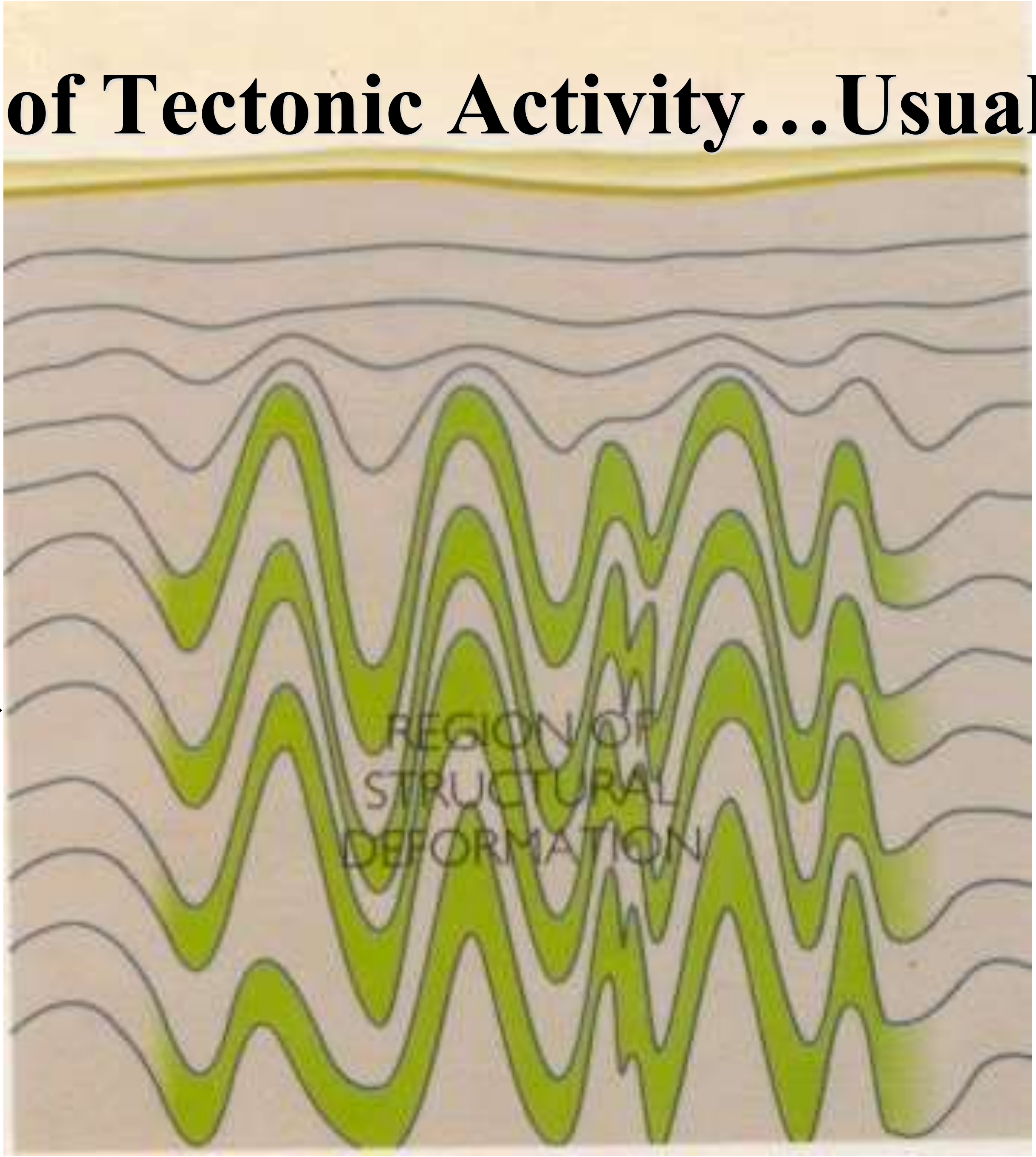
- In this type of environment, folding and differential stress are common; consequently **foliation is a common feature of regionally metamorphosed rocks**.





Regional Metamorphism

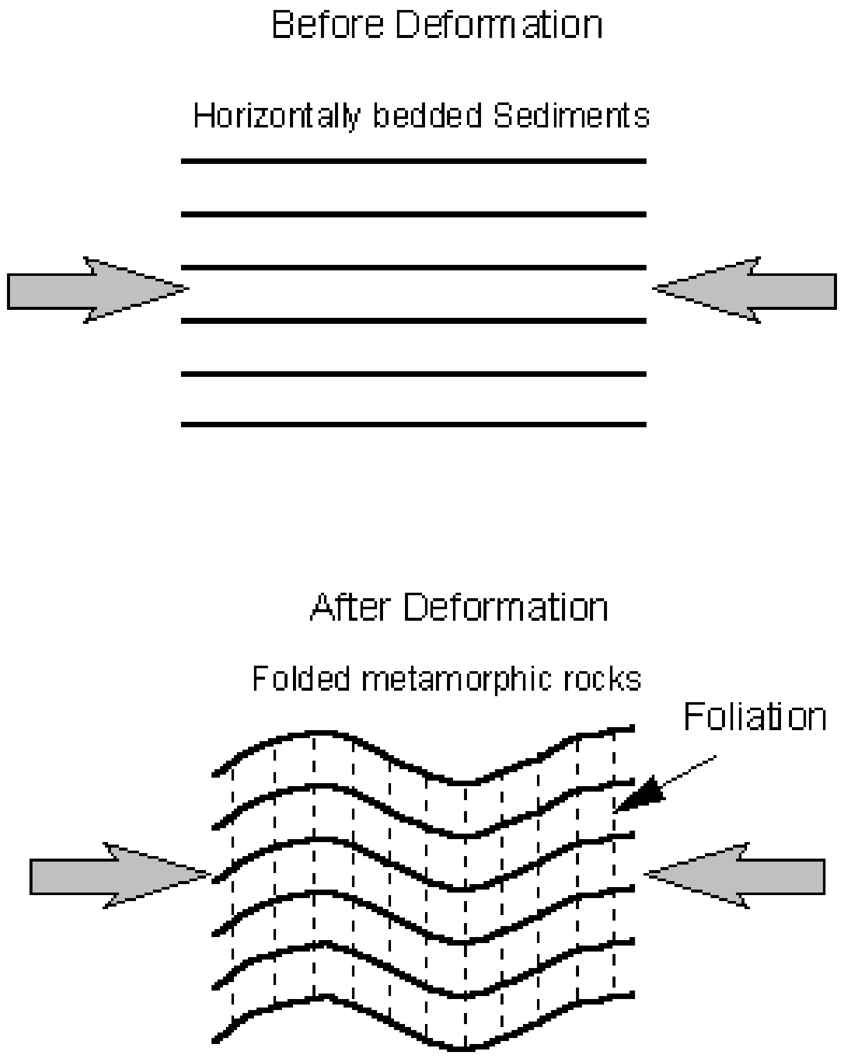
le Area of Tectonic Activity…Usually Collid



Directed Stress

Compressive stresses involved in plate collisions result in folding of the rock & increased PRESSURE & TEMPERATURE.

The result is large areas of FOLIATED Metamorphosed rock!

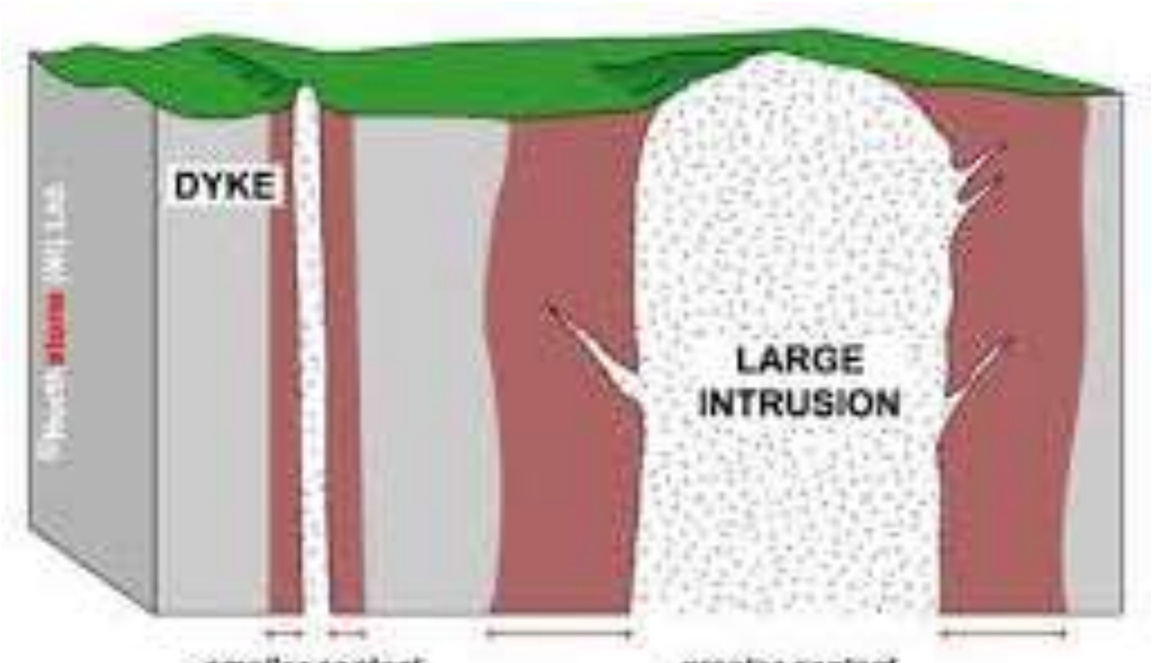


2. Contact Metamorphism:

- Is a **local type of metamorphism** that develops at the "**contact" of hot igneous intrusions** and the surrounding rocks.

- The contact metamorphism is **driven entirely by addition of heat** into the surrounding rocks.

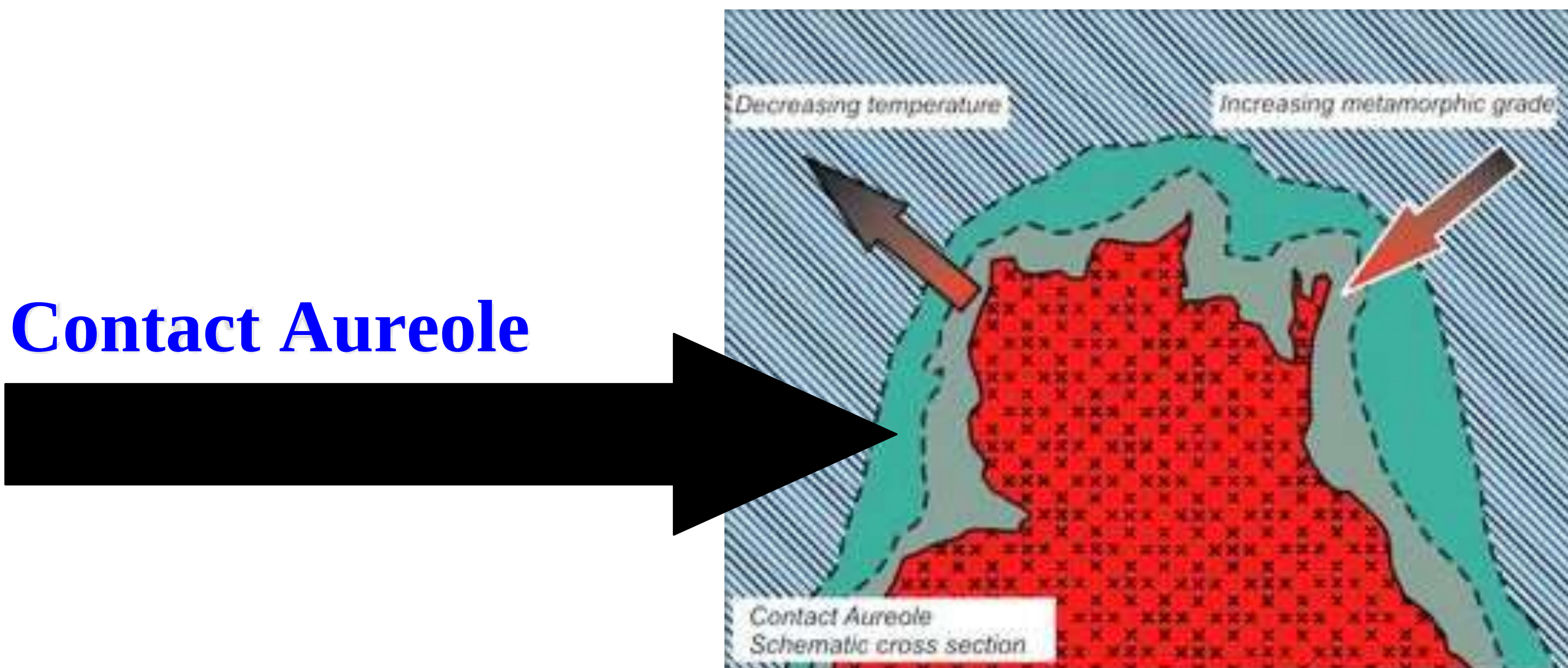
- Consequently this type of metamorphism is also referred to as **thermal metamorphism**.

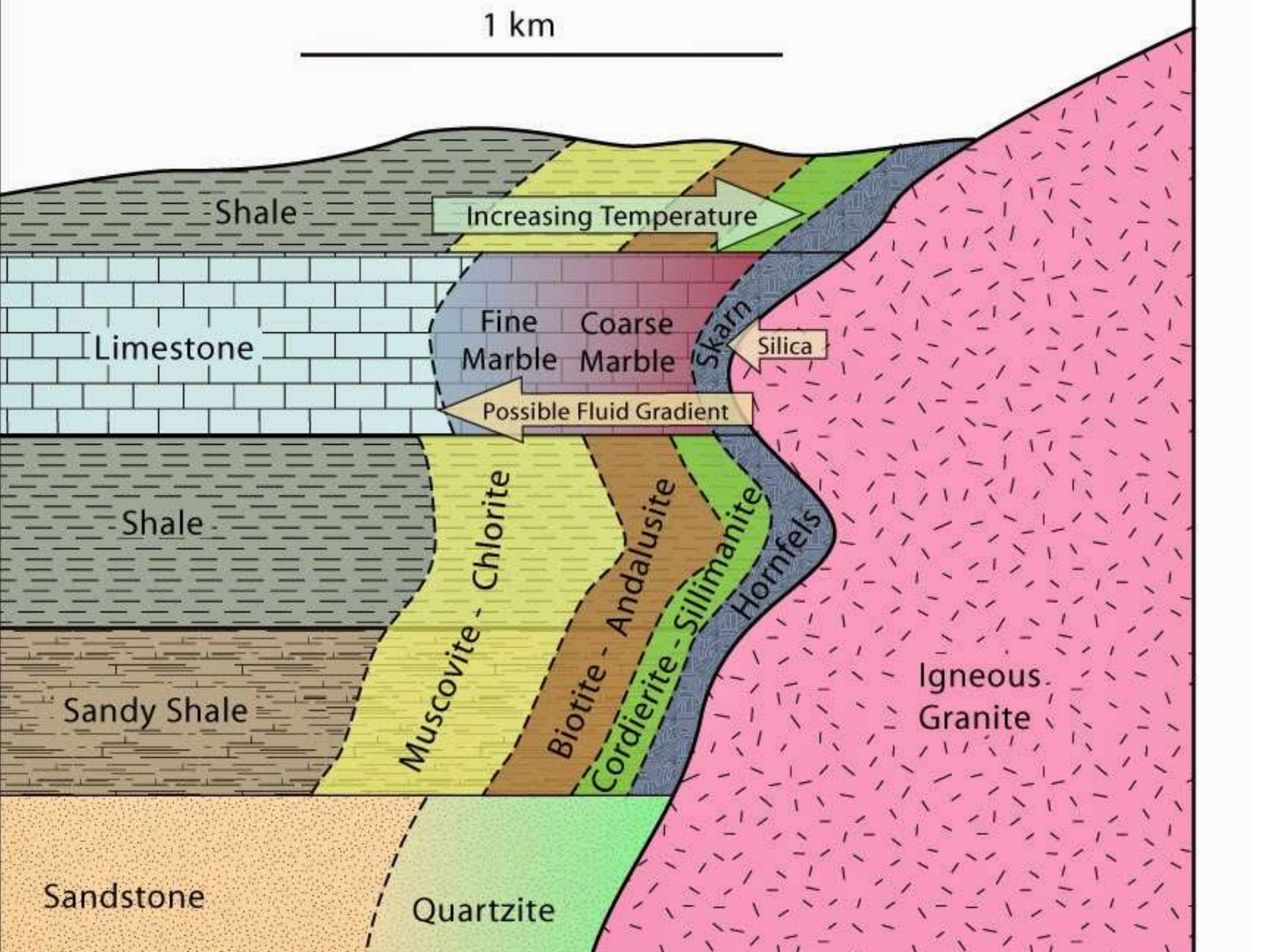


- Metamorphism is typically **restricted to a thin layer or "<u>aureole</u>"** between 1 - 2 km wide adjacent to the place where the igneous rock was.

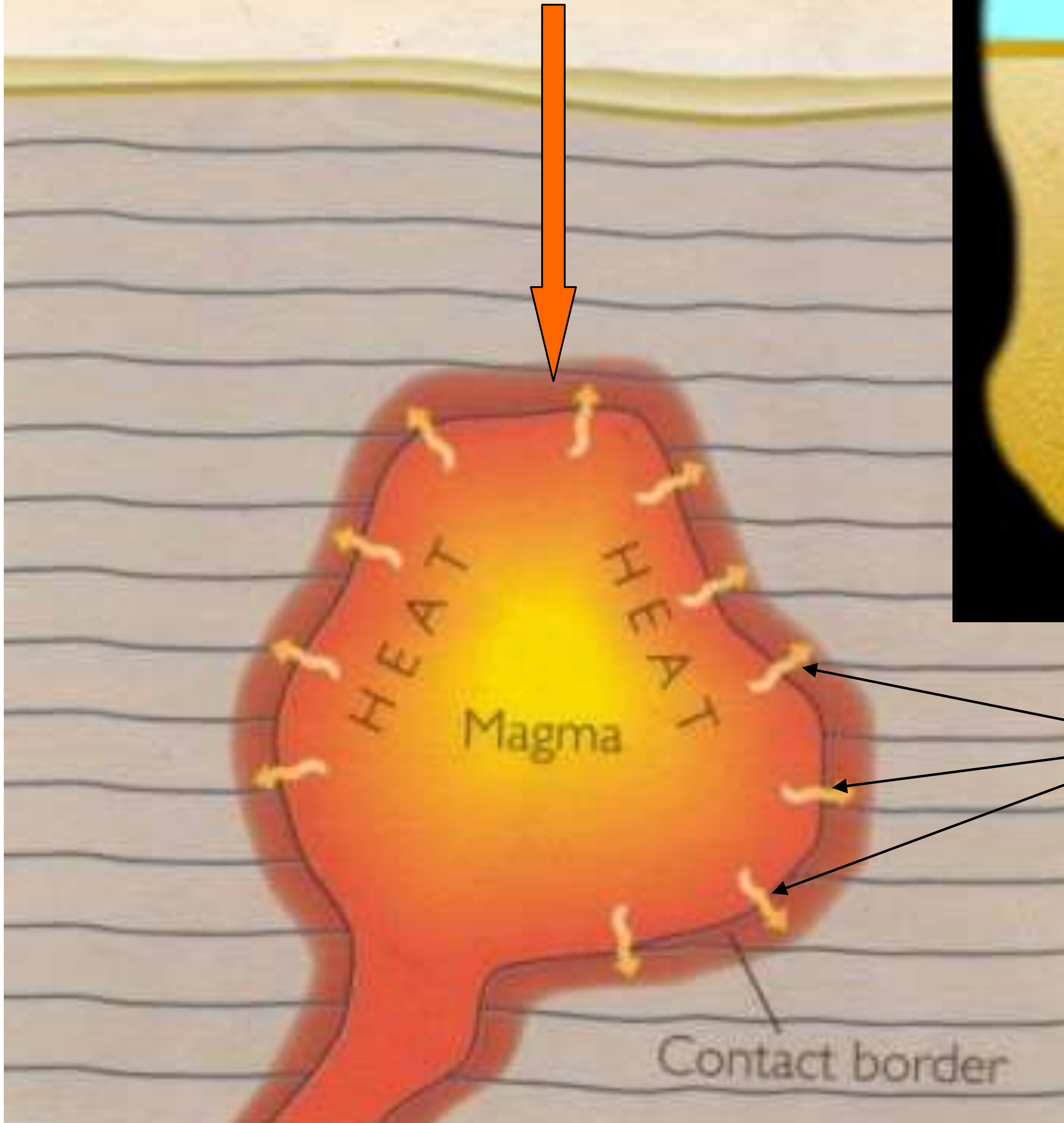
- Since this environment is not associated with application of direct stress, the metamorphic rocks in contact aureoles **usually <u>do not exhibit foliation</u>**.

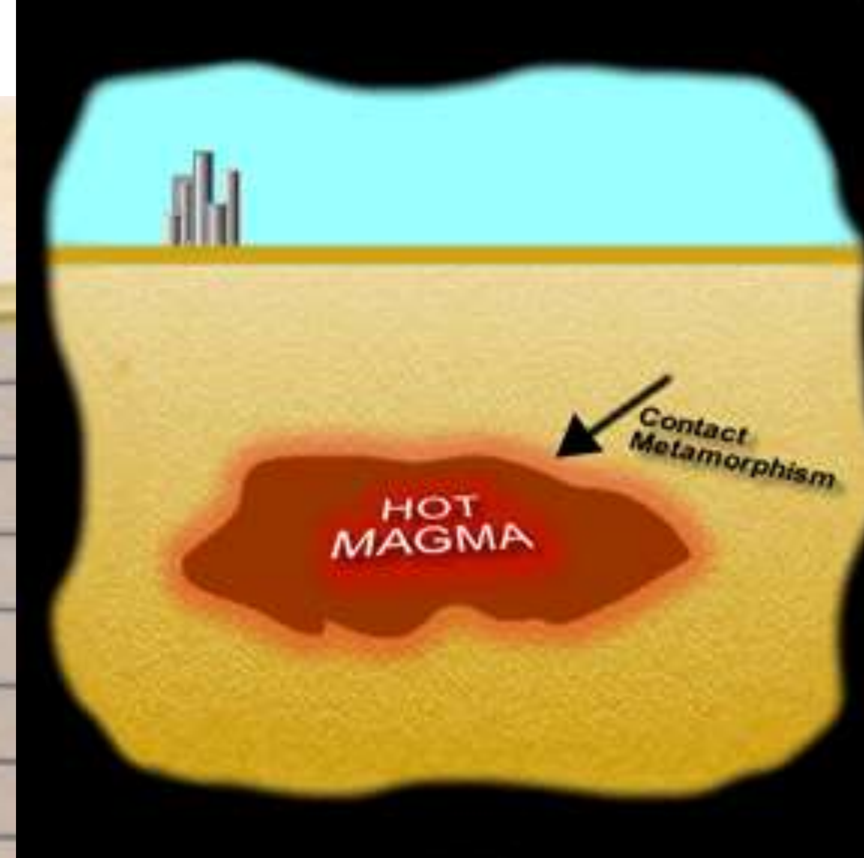
Contact Aureole




1 km
Shale
Increasing Temperature
Limestone
Fine Marble
Coarse Marble
Skarn
Silica
Possible Fluid Gradient
Shale
Muscovite - Chlorite
Biotite - Andalusite
Cordierite - Sillimanite
Hornfels
Sandy Shale
Igneous Granite
Sandstone
Quartzite

Called “Contact Aureole”...





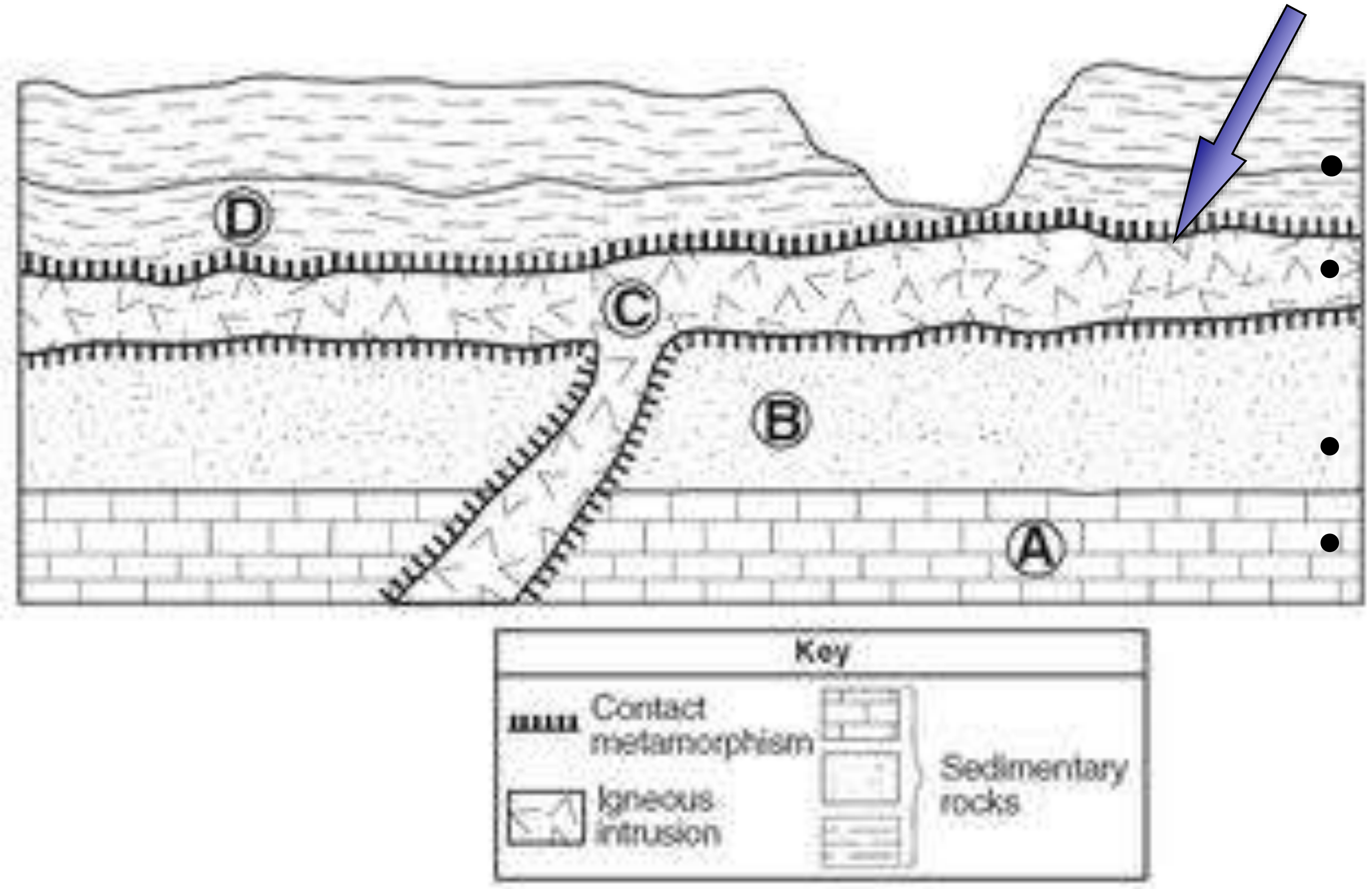
Hot magma drives mineral rich fluids away =

Chemical Change

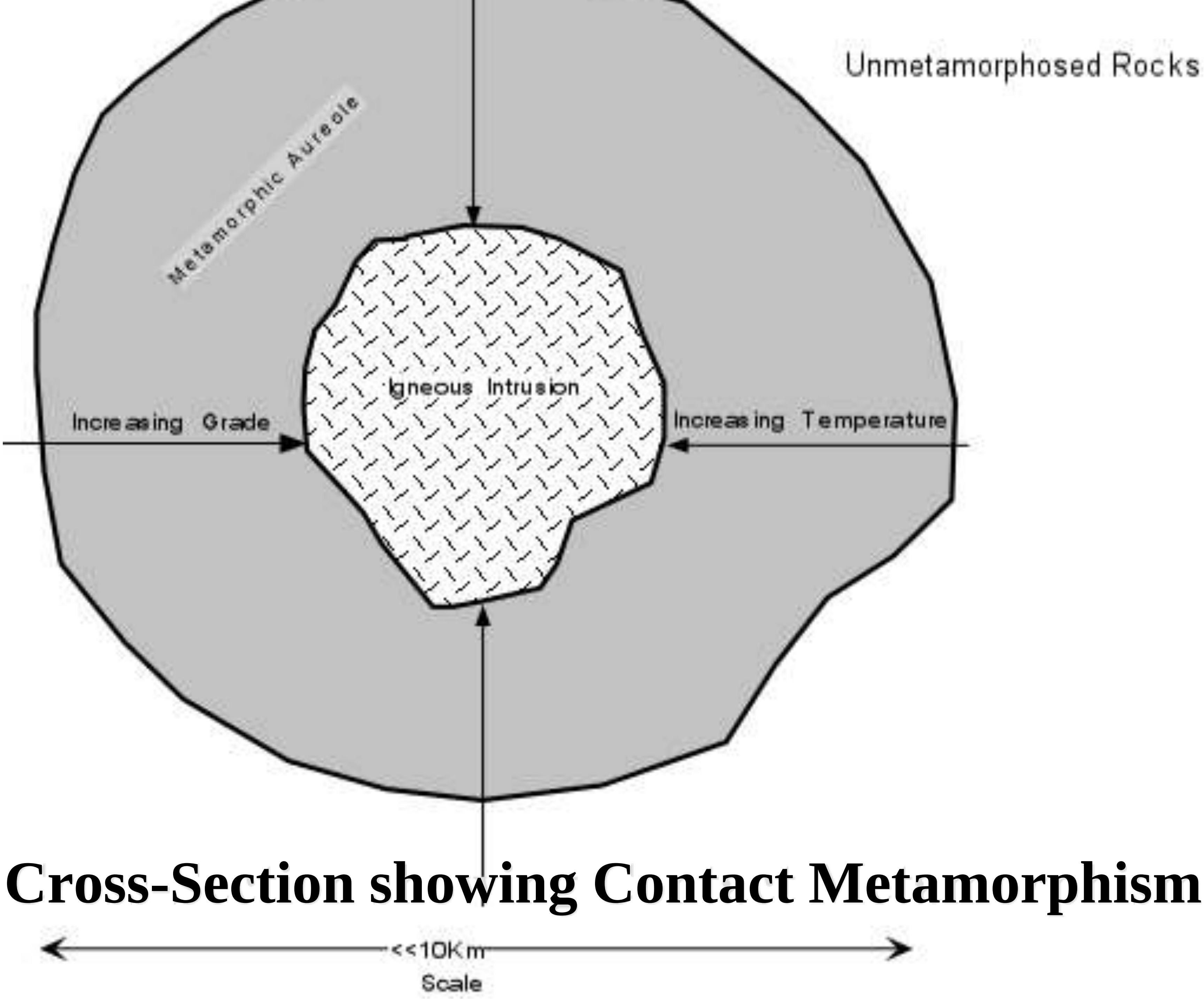
Contact metamorphism

What do these crosshatch marks represent?

Contact metamorphism



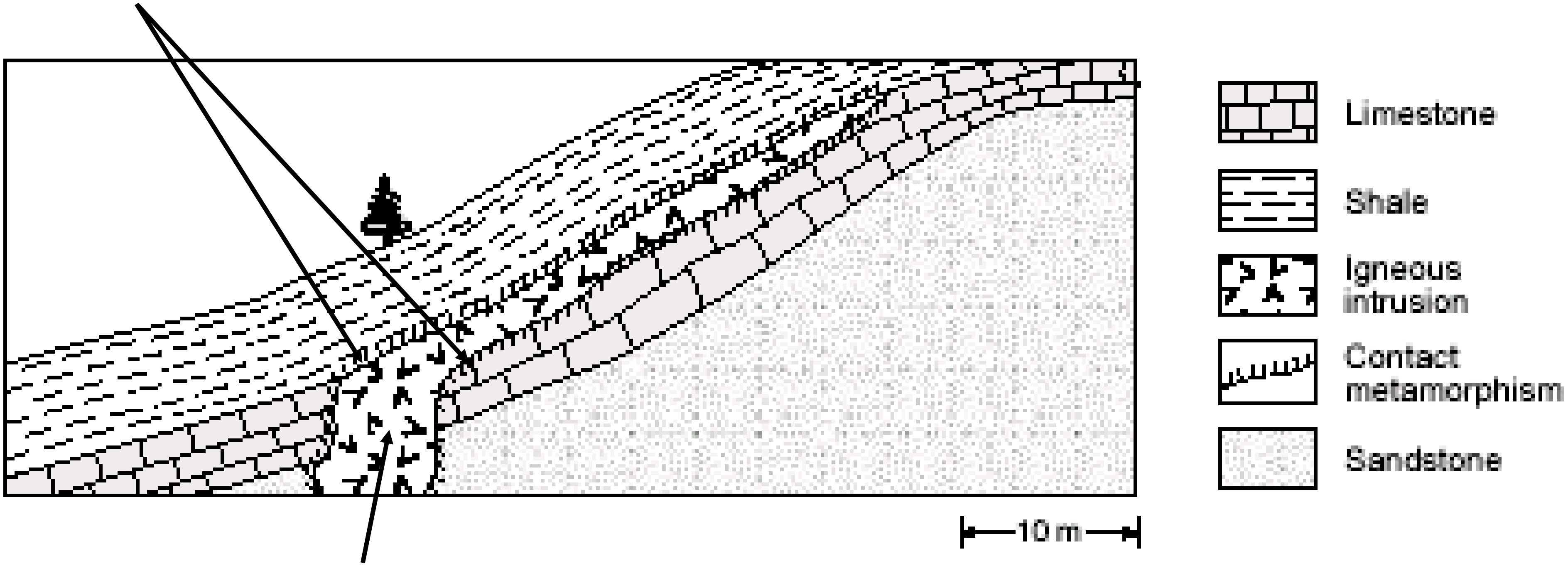
- D)Shale
- C) Igneous intrusion
- B) Sandstone
- A) Limestone



A Cross-Section showing Contact Metamorphism...

Which Rock Is the **Youngest** & How Do You Know?

Notice the zone of Contact Metamorphism Here...



Igneous Intrusion = **Hot** = Cooks the Rock = **Contact Metamorphism**

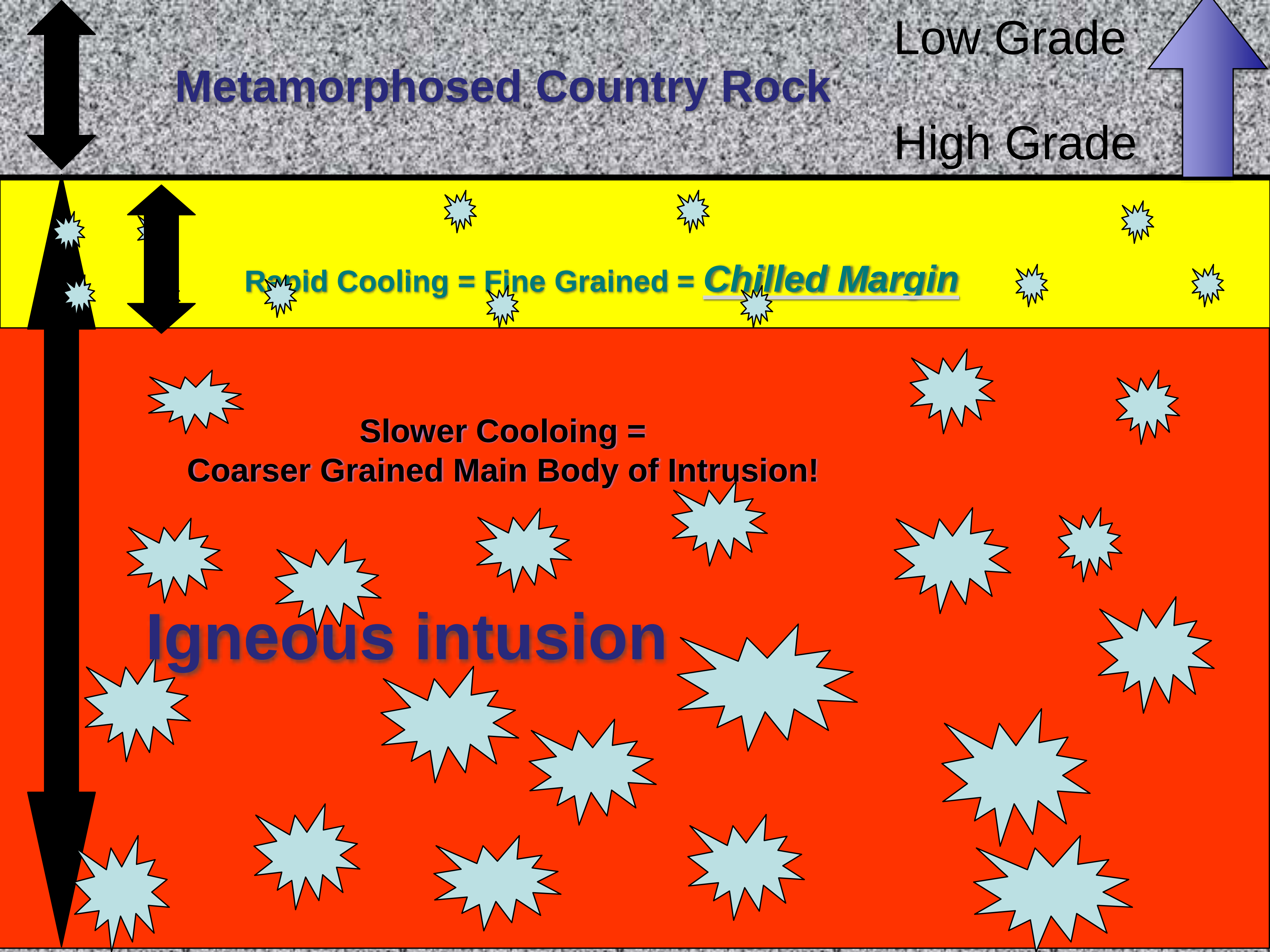
Changes To Country Rocks & Intrusions:

Country Rock:

- Country rock touches against hot igneous intrusions.
- Country rock will be **altered** by the contact with the magma.
- This is an example of Contact Metamorphism.
- Rock **closest** to the intrusion is altered or **METAMORPHOSED the MOST**!
  - » **Therefore, the "Highest Grade" metamorphic rocks will be closest to the magma, and the "Lowest Grade" metamorphic rocks will be furthest from it.**

Intrusions:

- The magmatic intrusion will cool the fastest at the boundary where it touches the country rock.
- Therefore, the intrusion will have the smallest crystals near the country rock, and the largest crystals away from the country rock = ***Chilled Margins***!


Low Grade
Metamorphosed Country Rock
High Grade
Rapid Cooling = Fine Grained = Chilled Margin
Slower Cooloing =
Coarser Grained Main Body of Intrusion!
Igneous intusion

Metamorphic Grade:

What is Metamorphic Grade?

- **A measure of the INTENSITY of metamorphism to which a metamorphic rock was subjected**

i.e. how much heat, pressure, chemical reaction?

- **Low-Grade Metamorphic rocks experience the least temperature, pressure, & chemical reaction, and hence, the least amount of metamorphism.**
- **High-grade Metamorphic rocks experience the most!**
- ***We will apply it mostly to the Foliated Metamorphic Rocks.***

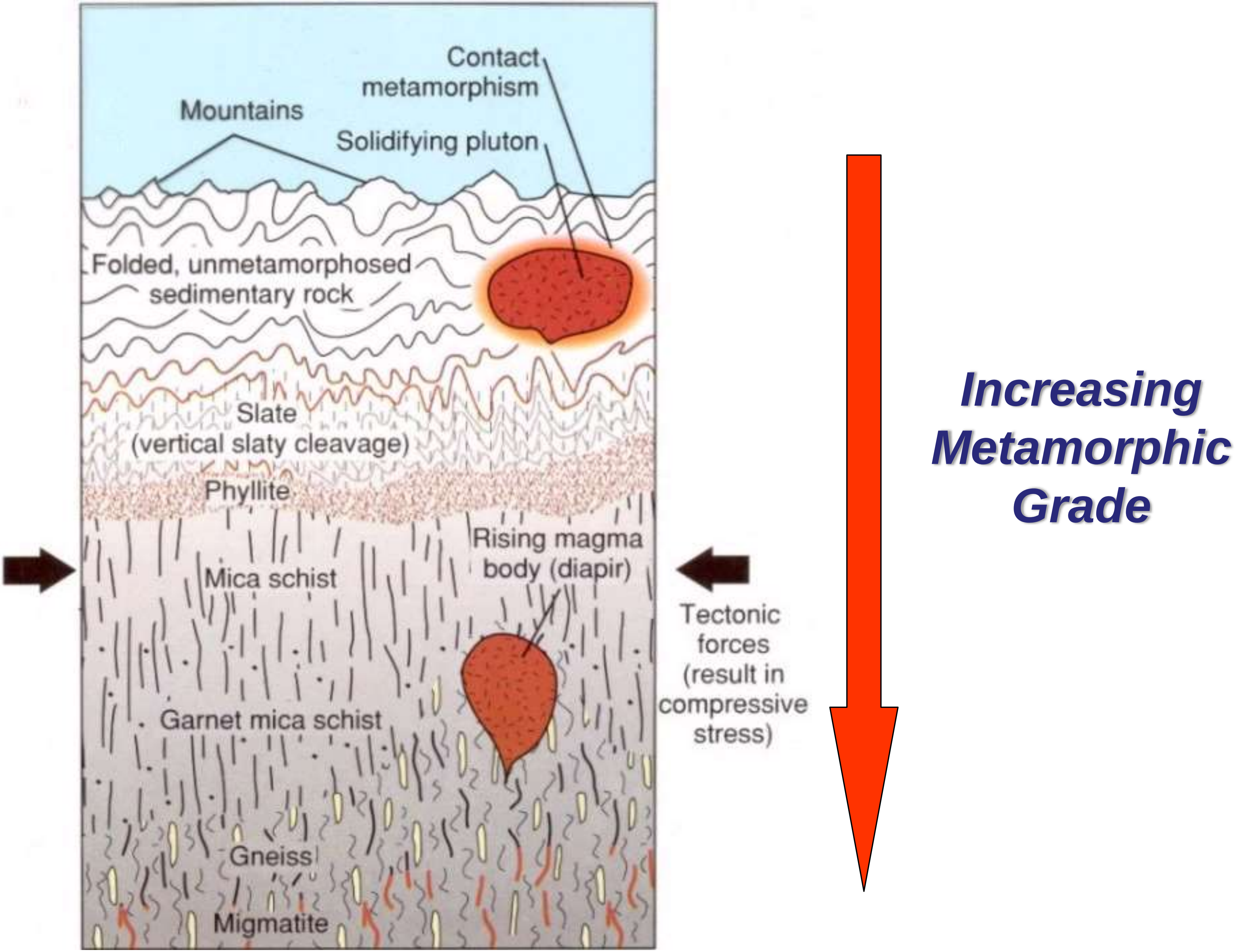
Order of Metamorphic Grade: In Foliated Rocks

The metamorphic grade is as follows (see **figure 7.15 Lab Manual**):

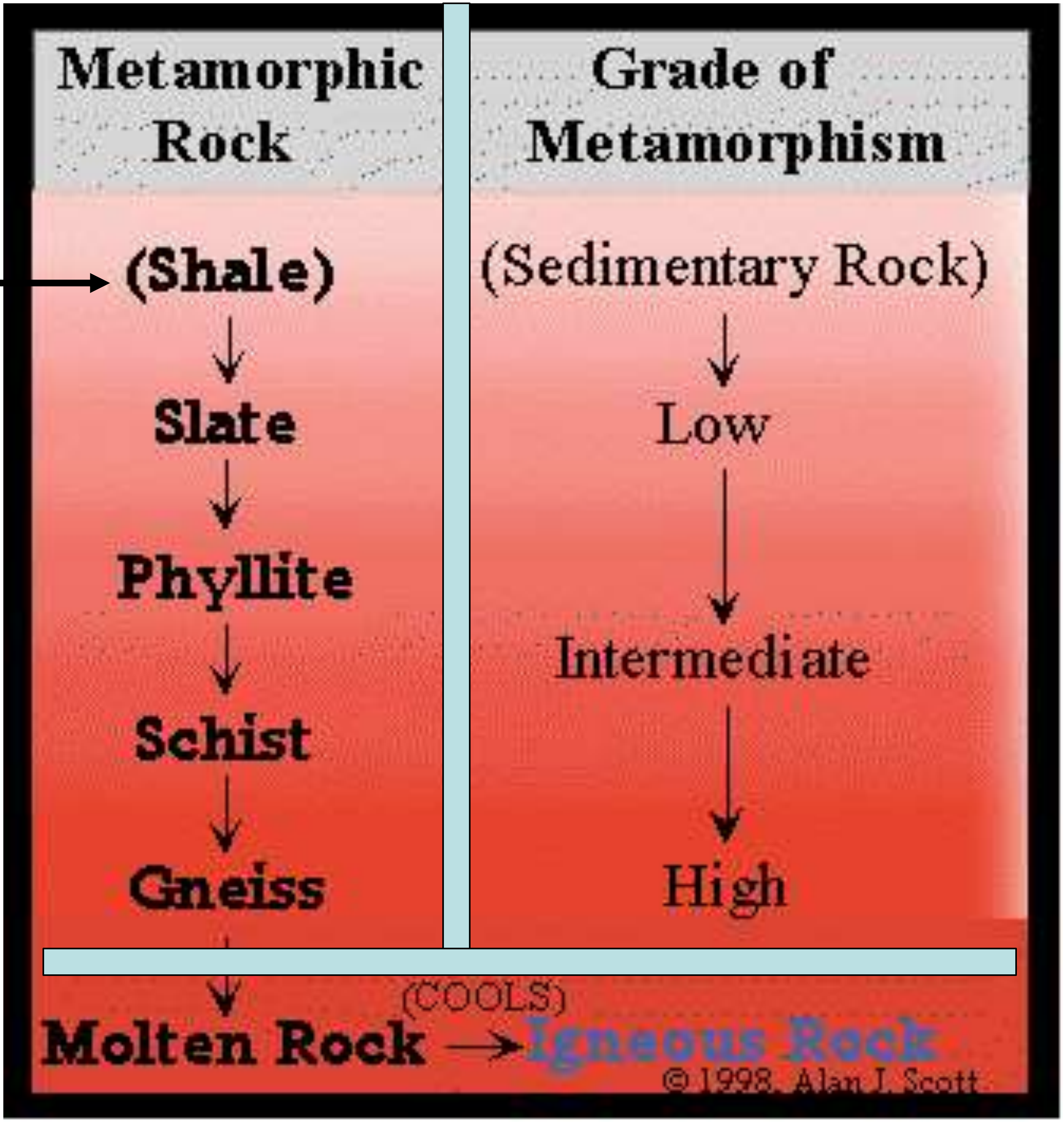
Shale → **Slate** → **Phyllite** → **Schist** → **Gneiss**

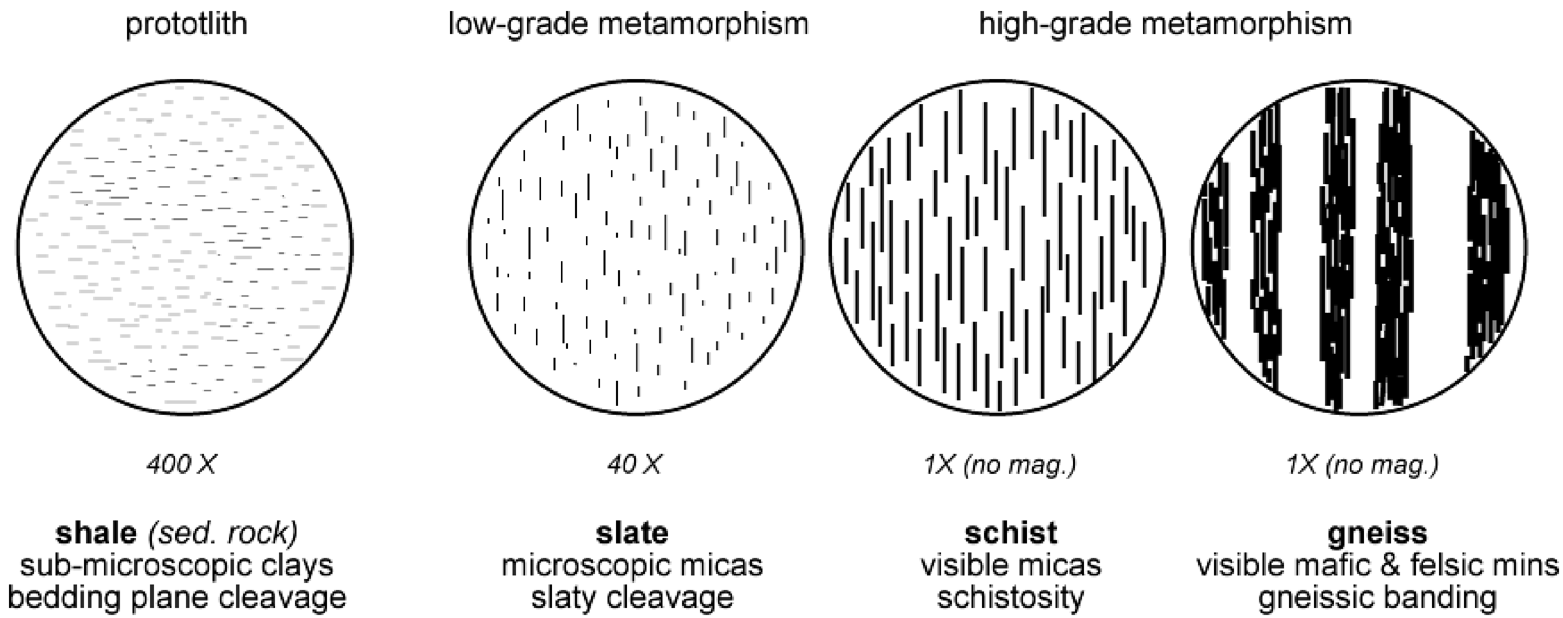
(Parent Rock) **(Low-Grade Met.)** **(Medium-Grade Met.)** **(High-Grade Met.)**

The next step after Gneiss is MELTING!


Contact
metamorphism
Mountains
Solidifying pluton
Folded, unmetamorphosed
sedimentary rock
Slate
(vertical slaty cleavage)
Phyllite
Rising magma
body (diapir)
Mica schist
Tectonic
forces
(result in
compressive
stress)
Garnet mica schist
Gneiss
Migmatite
Increasing
Metamorphic
Grade

All Mudstones!





- **Metamorphic Grade & Density:**

As we increase the metamorphic grade we **INCREASE** the density.

- **Metamorphic Grade & Porosity:**

As we increase the metamorphic grade we **DECREASE** the porosity.

- **Metamorphic Grade & Crystal Size:**

As we increase the metamorphic grade we **INCREASE** the crystal size.

= *Porphyroblasts!!!!*

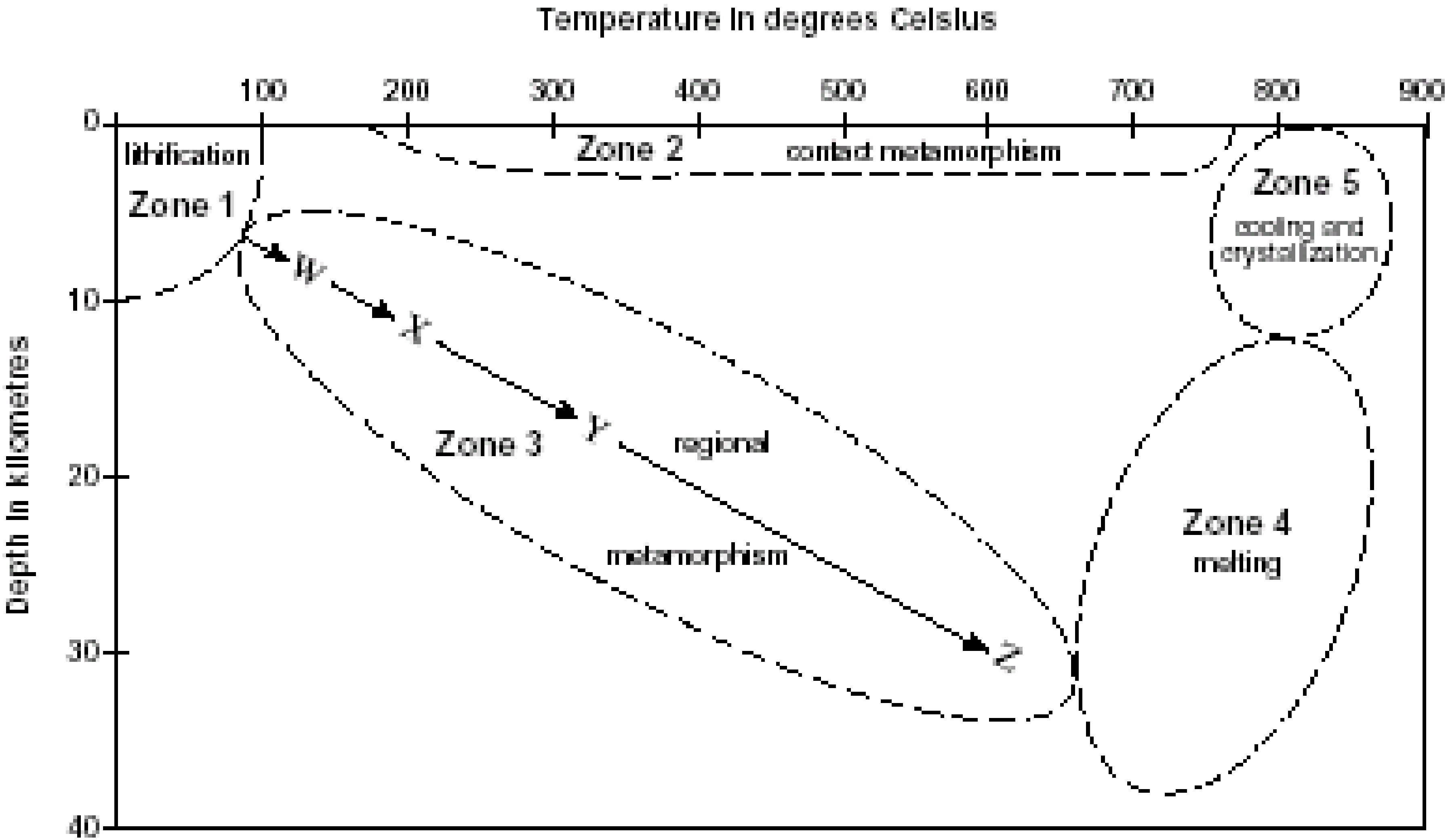
- **Metamorphic Grade & Foliation:**

As we increase the metamorphic grade the foliation moves from:

- SIMPLE SLATY to
- PHYLLITIC to
- SCHISTOSITY to
- GNEISSIC BANDING.

In the diagram below…what do W/X/Y/Z represent?

The starting materials for the rock cycle shown are the sediments clay, silt and mud.



Classification of Metamorphic Rocks:

Texture:

- Determine & record an unknown metamorphic rock's texture.
  - Is it **Foliated** or **Non-Foliated**?
  - Are there any other textural features such as ***Schistosity*** or ***Gneissic Banding***?

Mineralogical Composition & Other Features:

- Determine & record an unknown metamorphic rock's mineralogical composition.
  - Can you identify the basic **types** of minerals?
  - Are they **Felsic** or **Mafic**?
  - Are there any other distinct features such as deformed rock / fossil fragments?

Figure 7.16 Page #197 LAB MANUAL:

- Once you know the unknown rock's texture,mineral composition, and any other important features, you have already arrived at **step three** of metamorphic rock classification.
- Now all you have to do is **name the rock**.
- Once you know the name of the Metamorphic Rock, you can determine what the **PARENT ROCK** was!
- Now you can identify some **uses** of the Metamorphic Rock!
- That's it!!

Examples of Metamorphic Rocks:

The Metamorphic Rocks you will need to be familiar with are as follows:

- **Slate**
- **Phyllite**
- **Schist**
- **Gneiss**
- **Quartzite**
- **Marble**
- **Metaconglomerate**

Foliated

Non-Foliated

An example of Foliated SLATE.

Parent rock was a MUDSTONE!

This sample is rich in **biotite mica**!

An example of Foliated PHYLLITE.

Parent rock was a MUDSTONE!

This sample is rich in **mica, chlorite,** & **quartz!**

Close-up of foliated Phyllite...

An example of Foliated Schist…parent rock was also a MUDSTONE!

This sample is rich in mica and quartz!

Close-up of foliated Schist...

..If you look real close you can see the **SCHISTOCITY**!

An even closer, close-up!!!

An example of Gneiss showing gneissic banding:

Foliated!!

Parent rock was a MUDSTONE!!

Close up of Gneiss & gneissic banding

An example of a Non-Foliated Quartzite.

The parent rock was SANDSTONE!

This sample is rich in quartz!

A close-up of Quartzite...

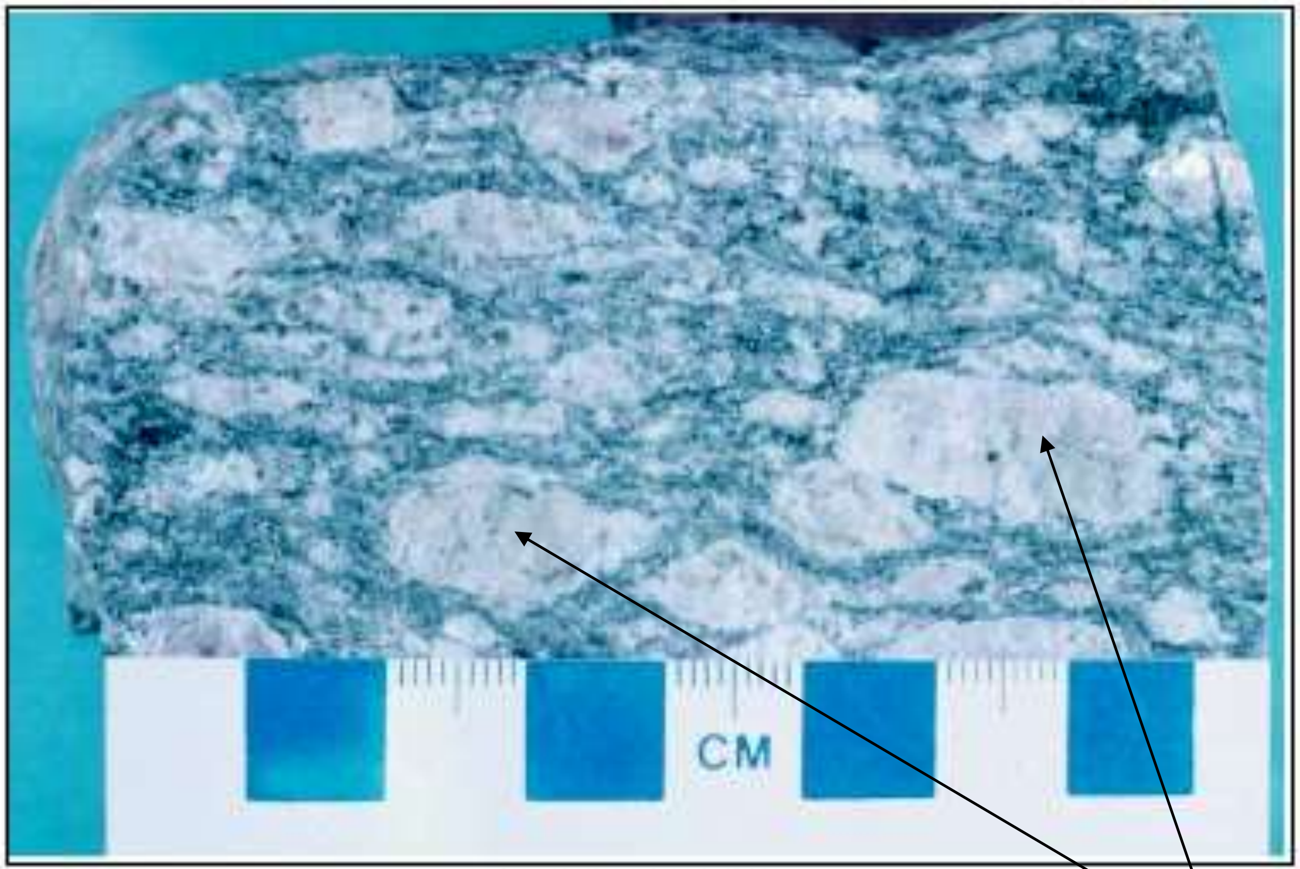
An example of Non-Foliated MARBLE!
Parent Rock was LIMESTONE

This sample was originally almost pure calcite!

A close-up of MARBLE...

An example of Non-Foliated **Meta-Conglomerate**!

Parent Rock was CONGLOMERATE



photograph 5

Notice the stretching & deformation of the individual CLASTS!

Another example of Non-Foliated Meta-Conglomerate!

Photograph 11

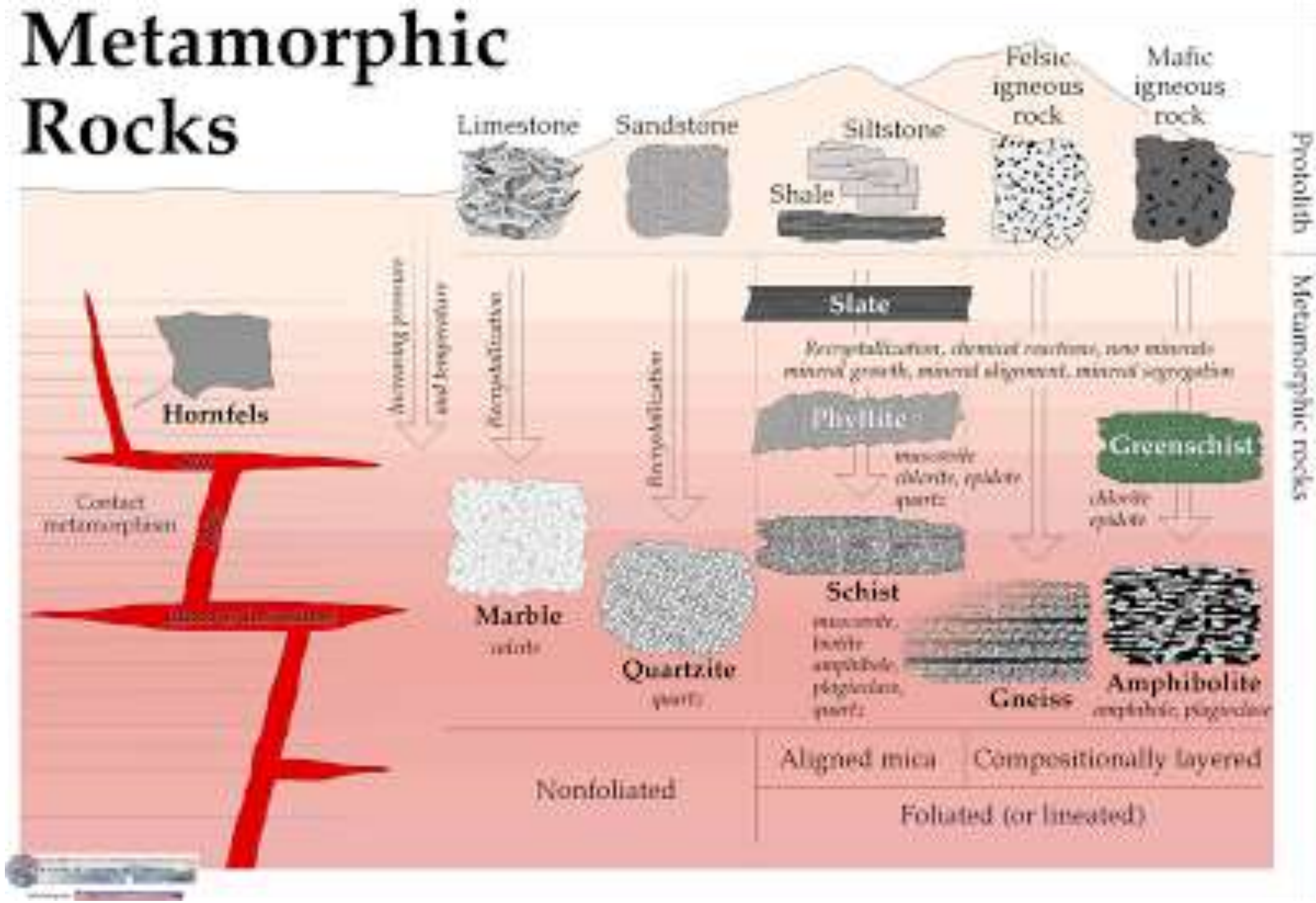
Notice the stretching & deformation of the individual CLASTS!

An example of a Non-Foliated **ANTHRACITE COAL**.

The parent Rock was Bituminous Coal!

This sample is almost pure Carbon!

A close-up of Anthracite Coal...


Metamorphic Rocks
Limestone
Sandstone
Siltstone
Shale
Felsic igneous rock
Mafic igneous rock
Protolith
Metamorphic rocks
Slate
Phyllite
Greenschist
Hornfels
Contact metamorphism
Marble
Quartzite
Schist
Gneiss
Amphibolite
Nonfoliated
Aligned mica
Compositionally layered
Foliated (or lineated)

Time for Metamorphic Rock ID Lab!