METAMORPHISM

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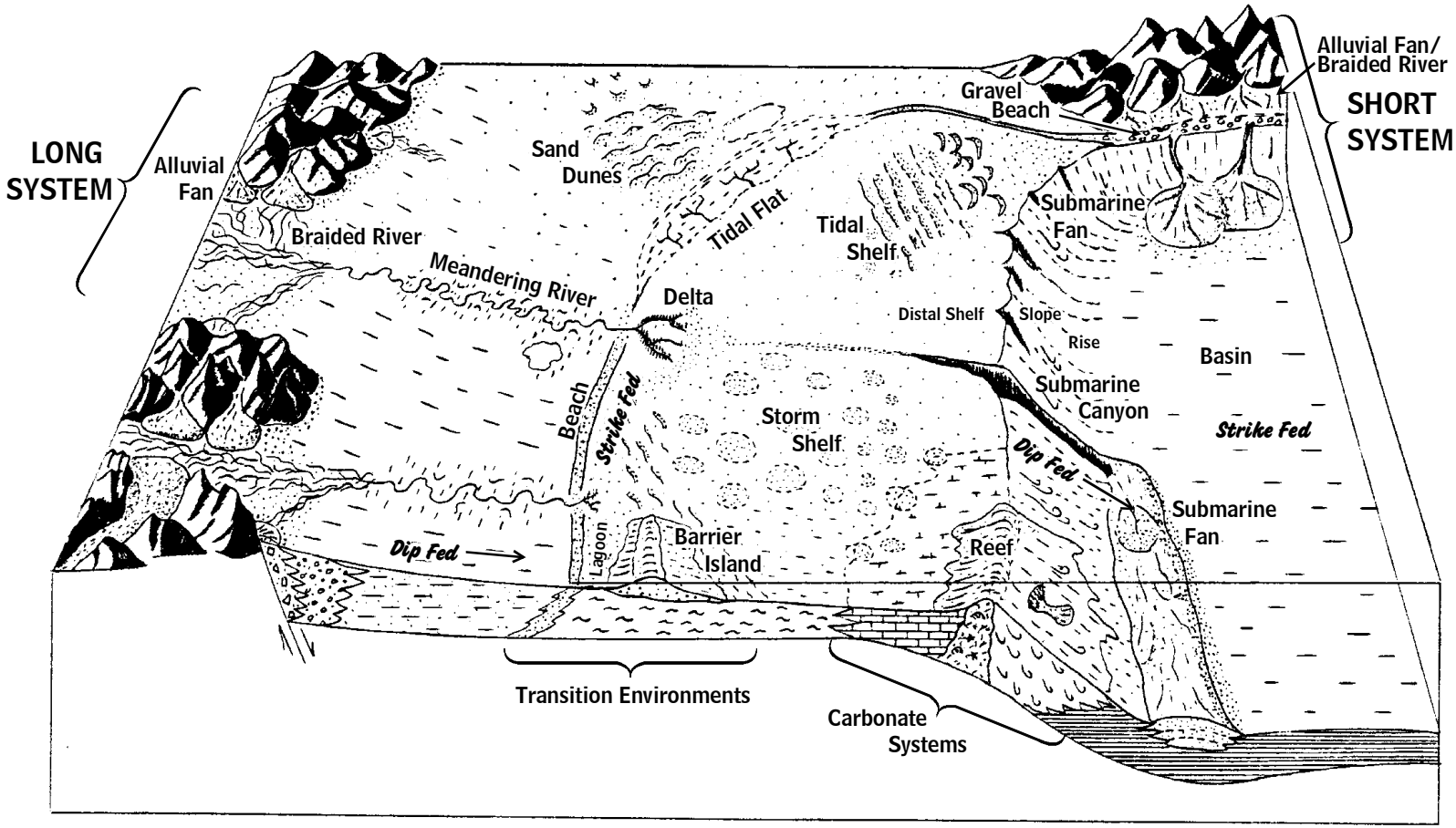
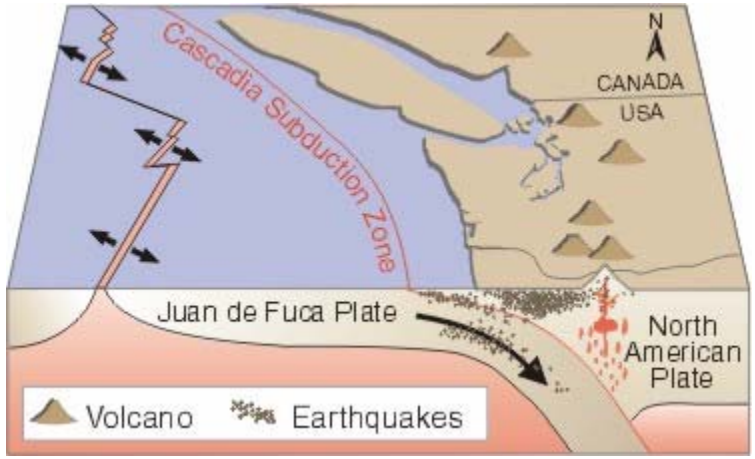
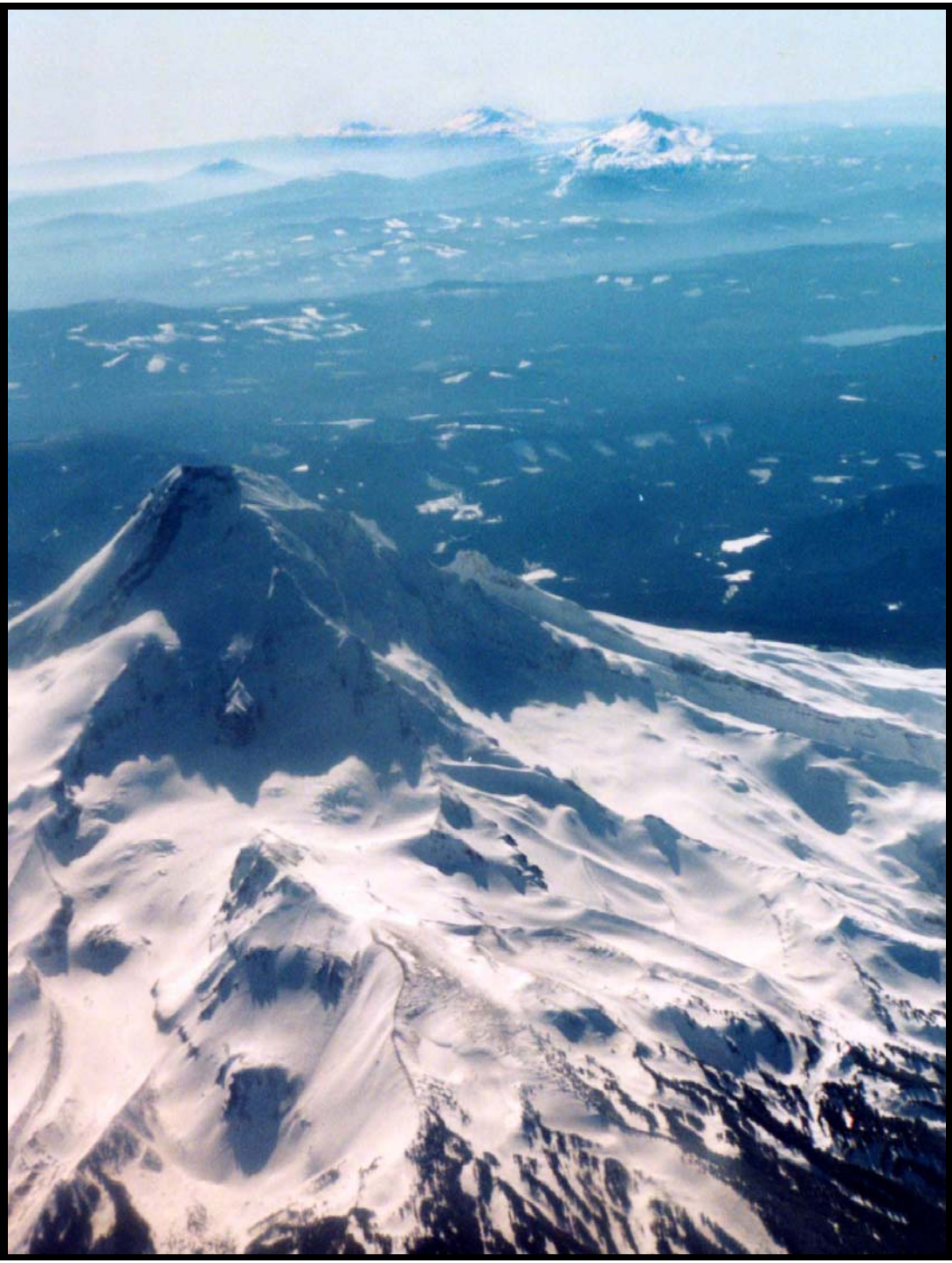
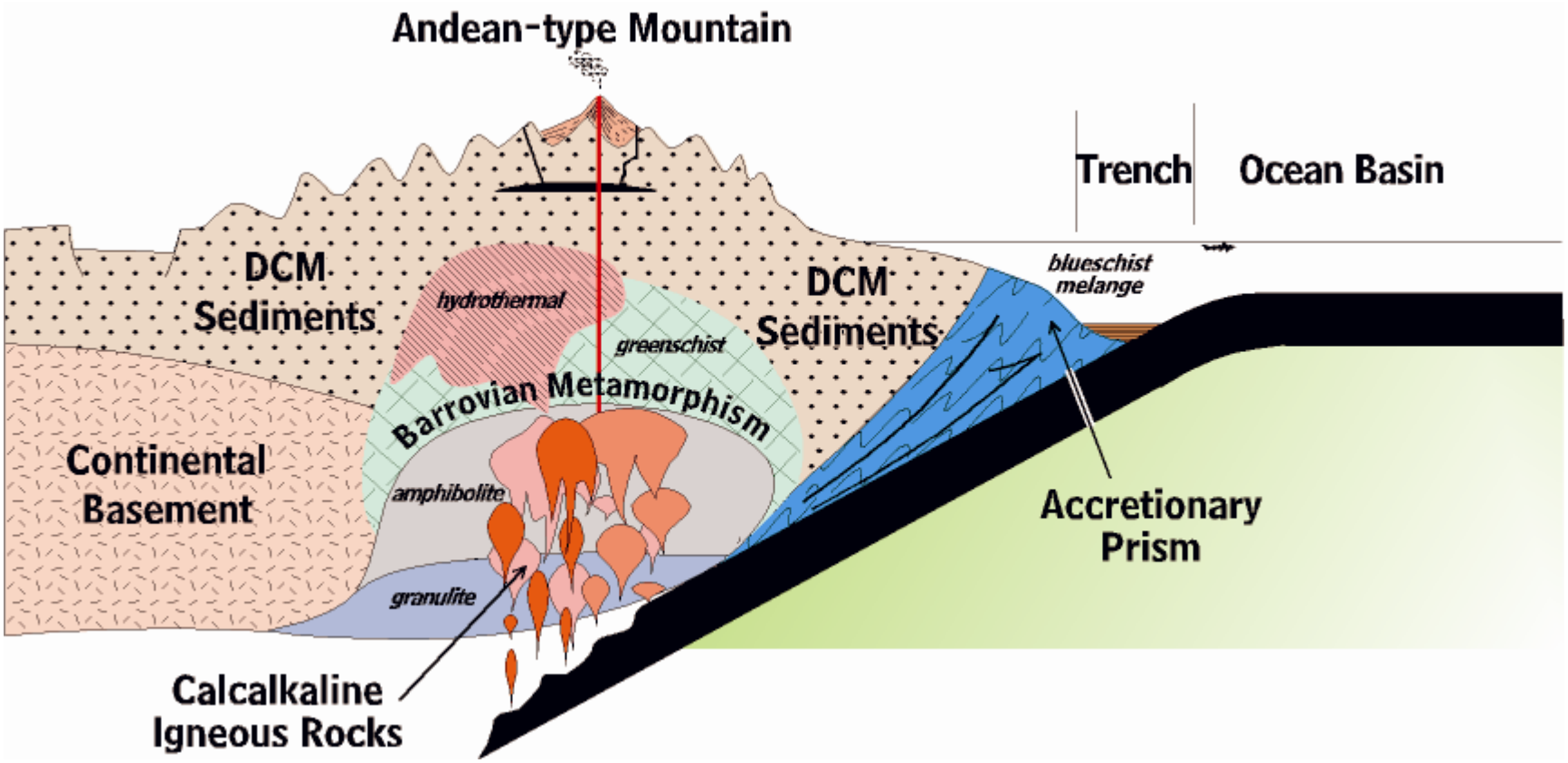
From sedimentary processes that take place at the Earth's surface . . . To metamorphic processes that take place below the surface.

Minerals and Rocks are stable only under the conditions at which they form.

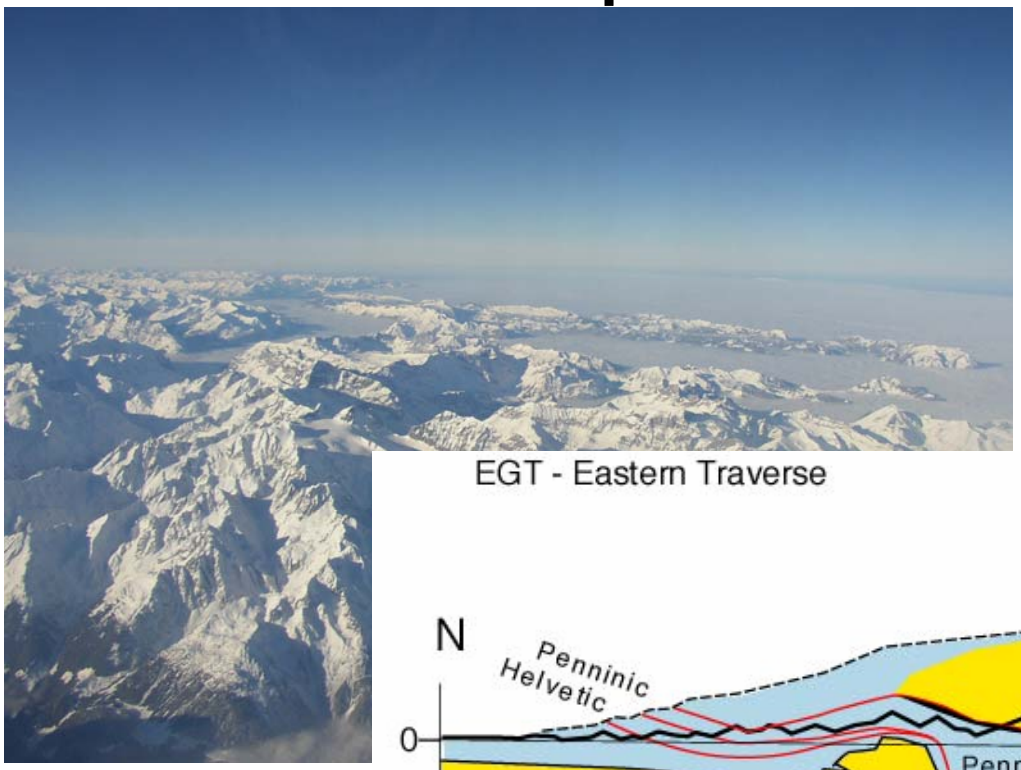



N
CANADA
USA
Cascadia Subduction Zone
Juan de Fuca Plate
North American Plate
Volcano
Earthquakes

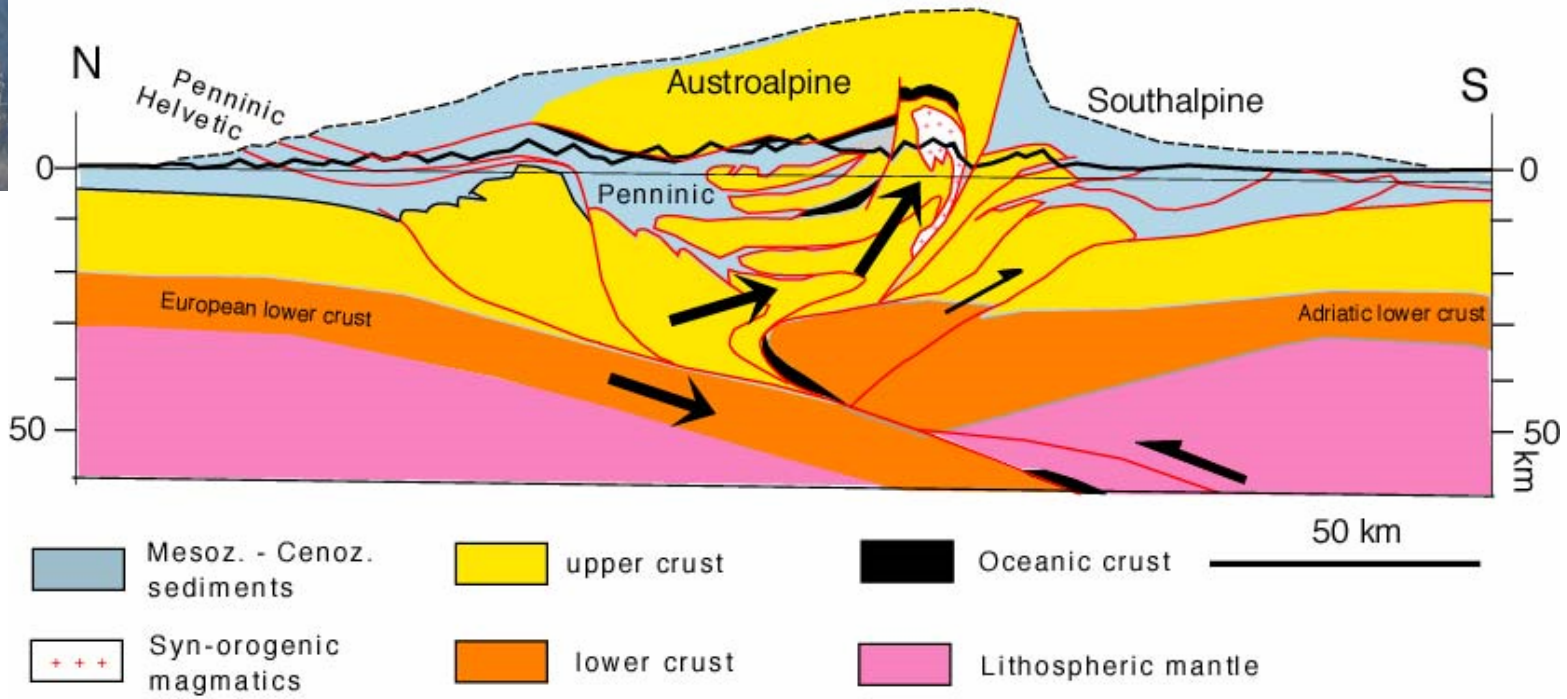



Andean-type Mountain
Trench
Ocean Basin
DCM
Sediments
hydrothermal
greenschist
Barrovian Metamorphism
DCM
Sediments
blueschist
melange
Continental
Basement
amphibolite
granulite
Accretionary
Prism
Calcalkaline
Igneous Rocks

Deep Structure of the Swiss Alps:



EGT - Eastern Traverse



http://www.earthsci.unibe.ch/people/pfiffner/NRP20.html

The Mechanisms of Metamorphism

- Heat
- Pressure
- Chemically active fluids

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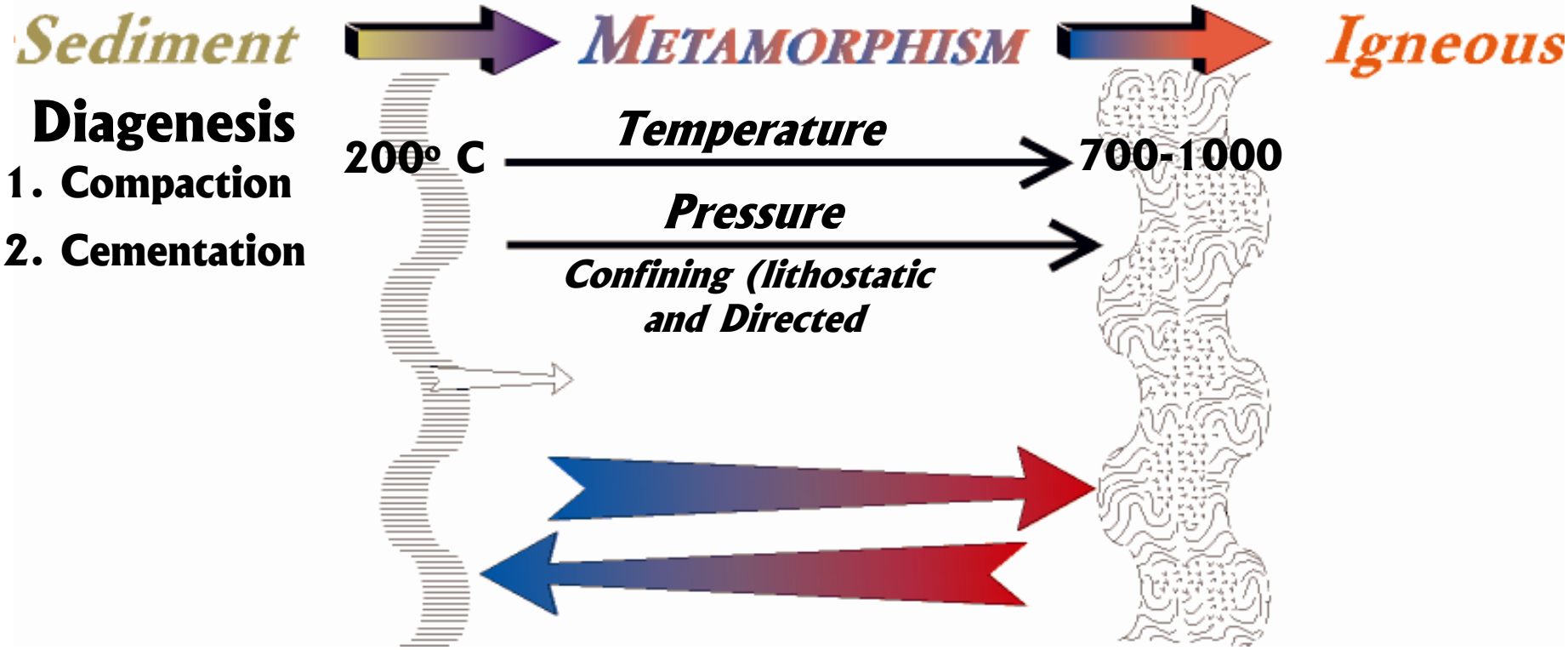
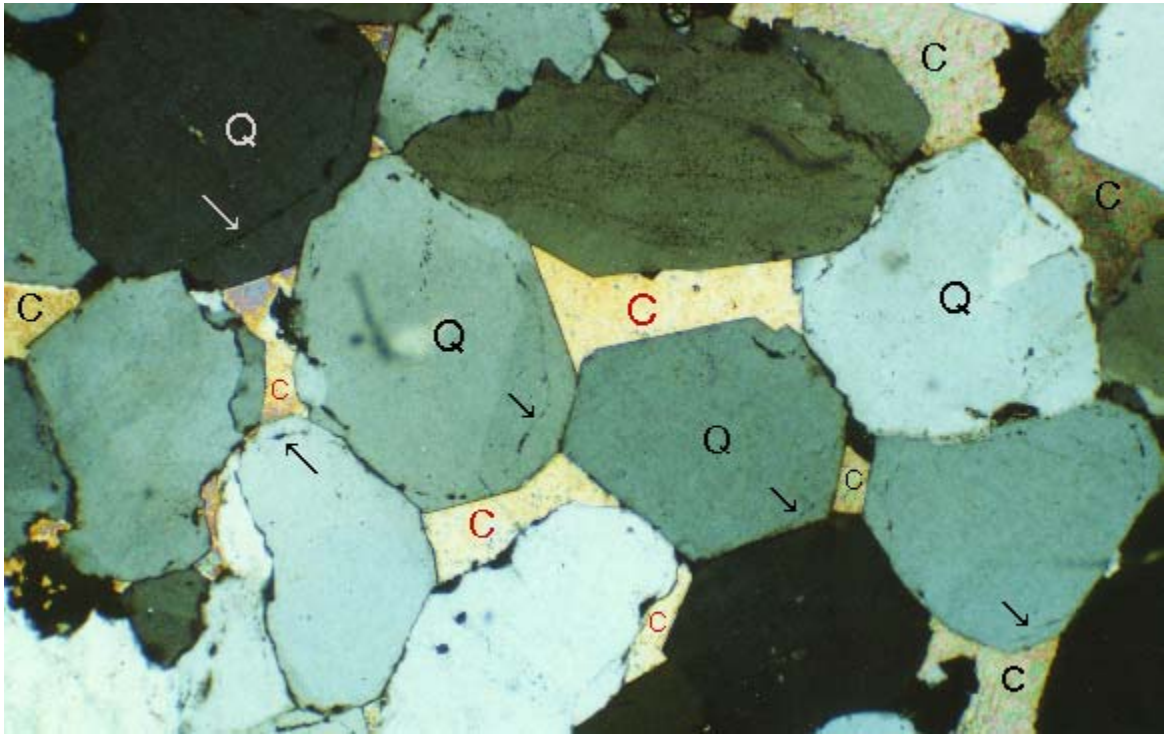


Calcite cemented sandstone (specifically, a quartz arenite)

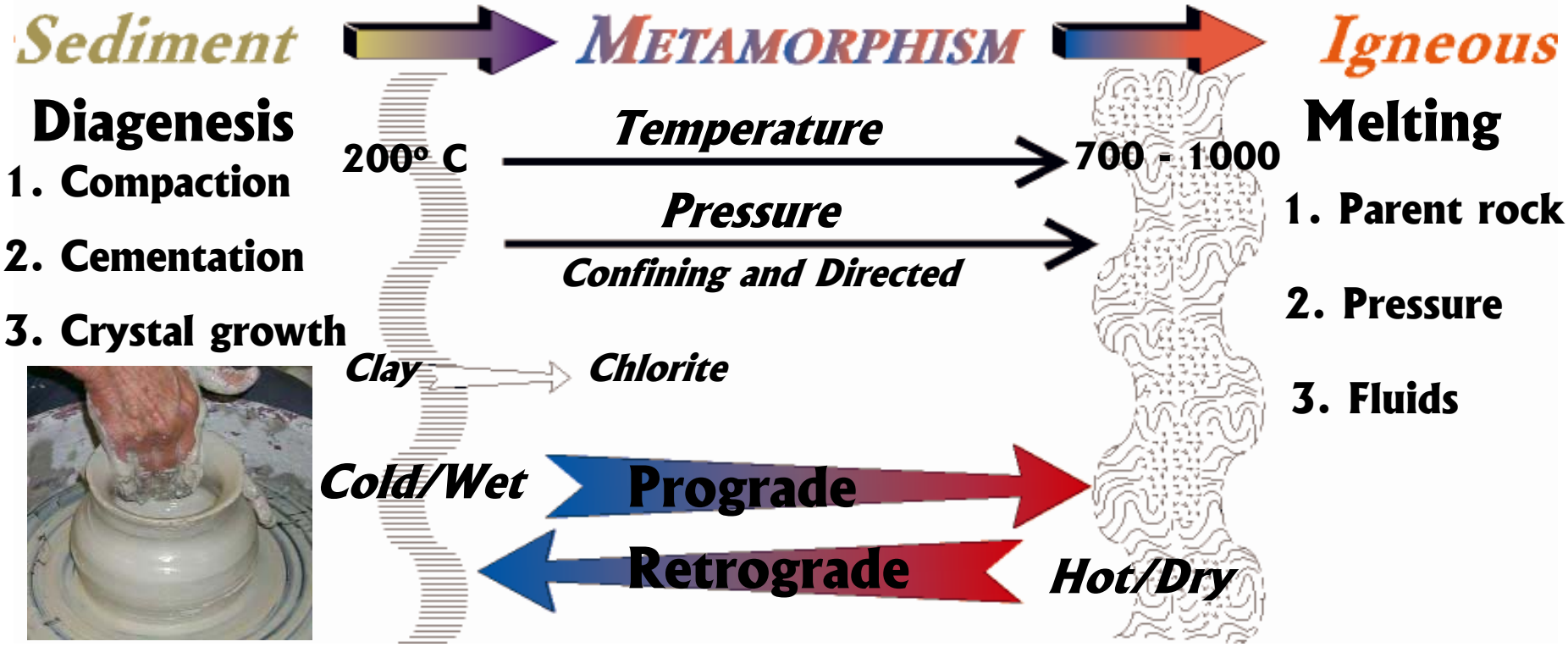


http://www.gly.uga.edu/railsback/speleoatlas/SAimage0223.html

The Mechanisms of Metamorphism

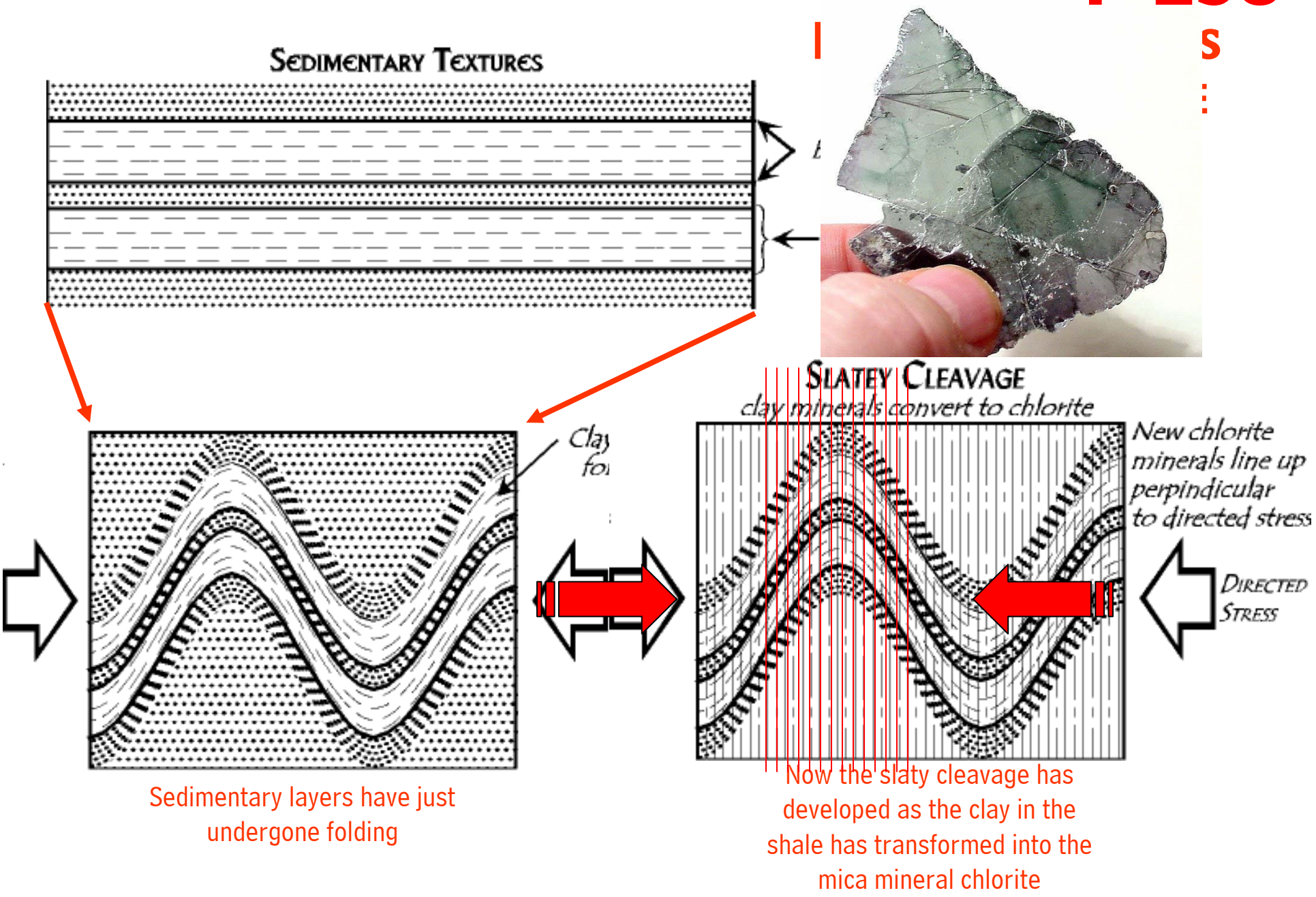
- Heat
- Pressure
- Chemically active fluids

photo to R.Weller/Cochise College.



Textural Responses to Changes in Metamorphic Temperature & Pressure

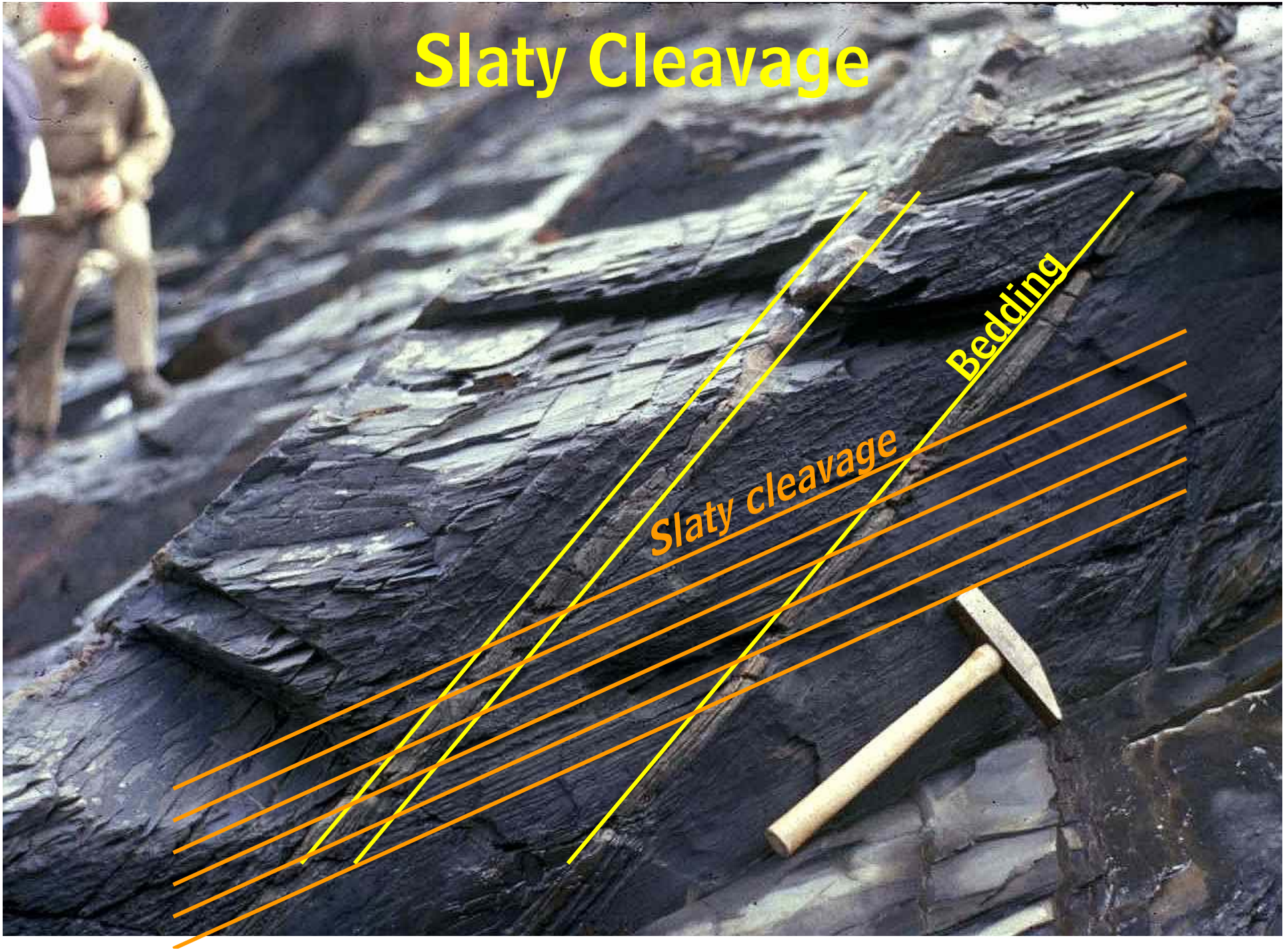
P 158



Sedimentary layers have just undergone folding

Now the slaty cleavage has developed as the clay in the shale has transformed into the mica mineral chlorite

Slaty Cleavage



Slaty Cleavage

Ductile Deformation

Chevron folds, Barnhardt Canyon, Arizona

Ductile Deformation

Ductile Deformation

Ductile Deformation

Ductile Deformation

Five Kinds of Metamorphism

The trouble with metamorphism is . . .

Any kind of rock, igneous, sedimentary, or metamorphic . . .

Can undergo any kind of metamorphism . . .

Producing every conceivable combination and permutation.

Metamorphic Rocks are Very Complex

Five Kinds of Metamorphism

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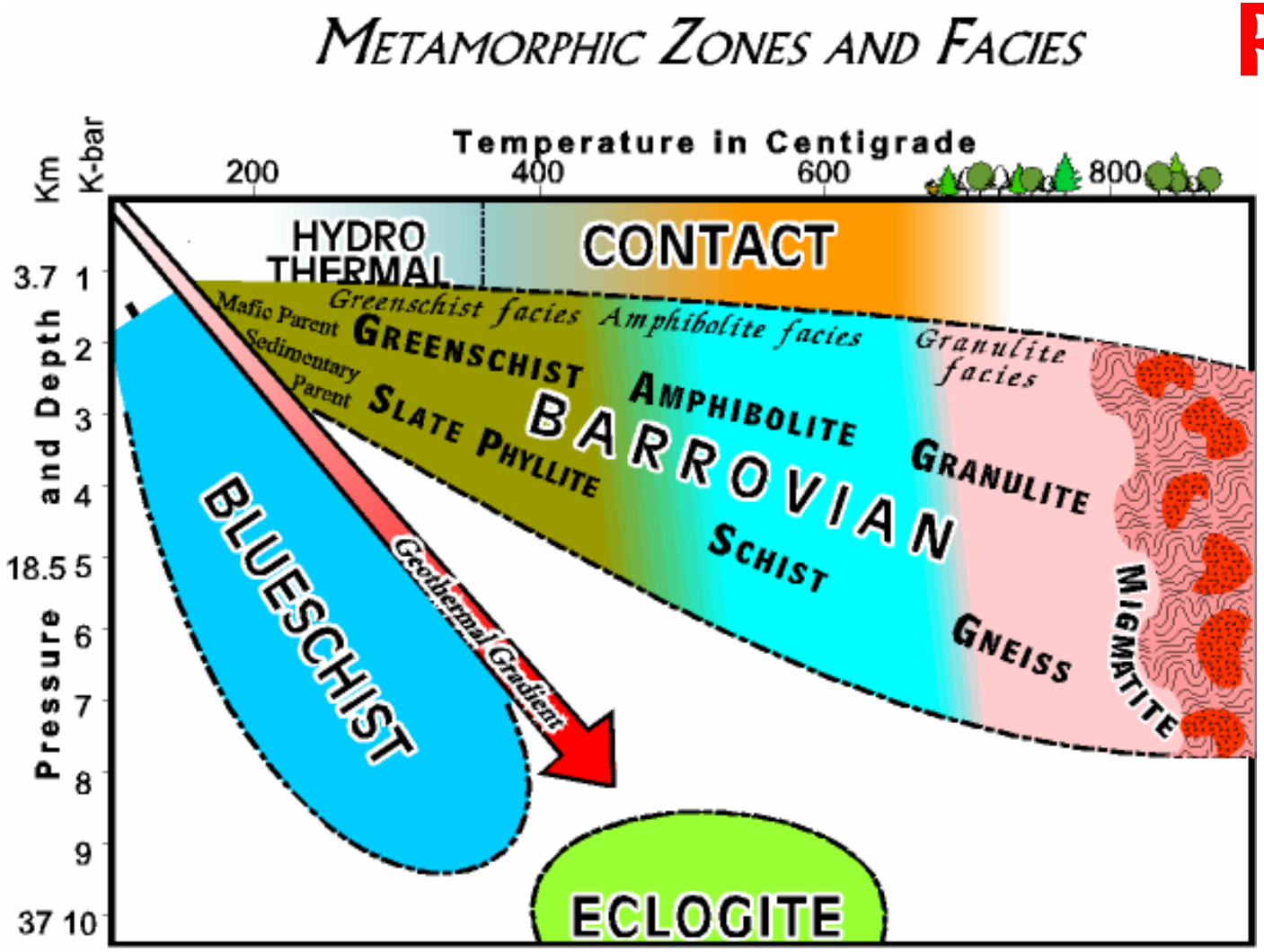
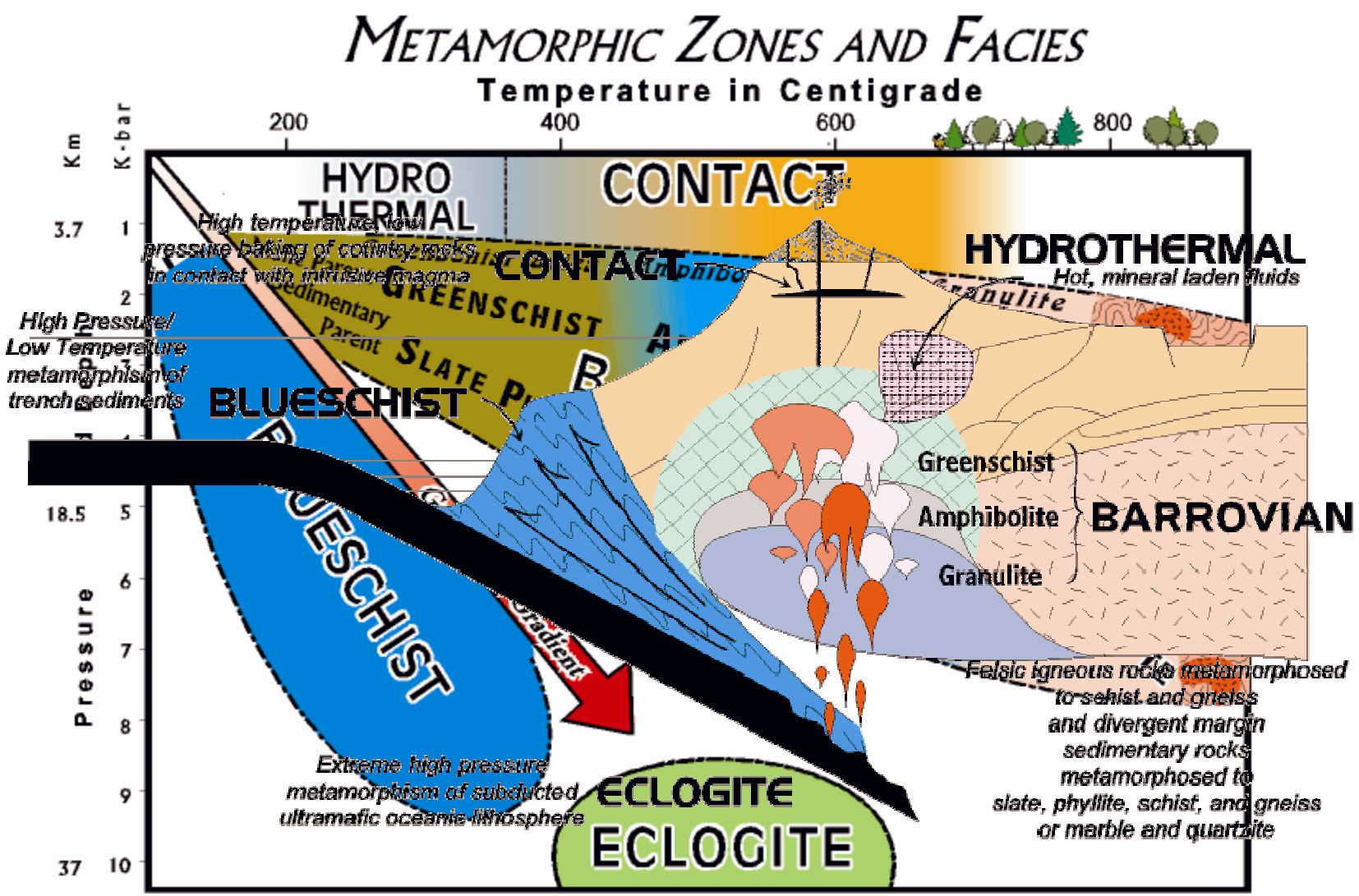
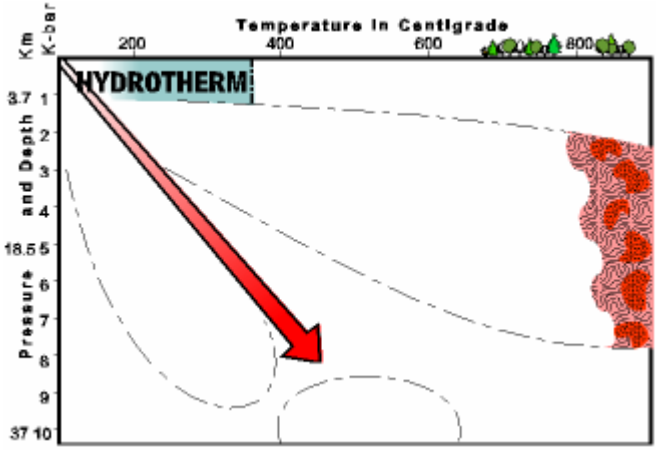


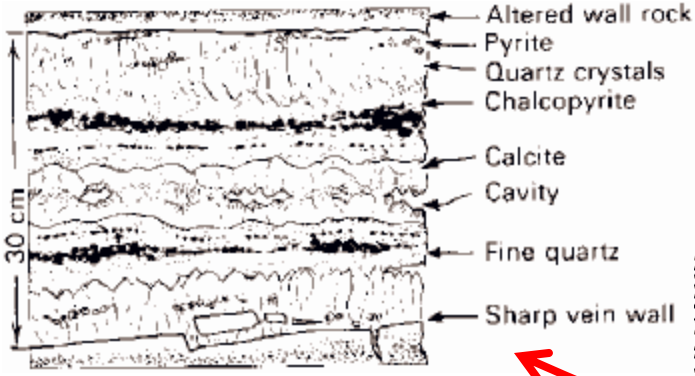

METAMORPHIC ZONES AND FACIES
Temperature in Centigrade
200
400
600
800
Km
K-bar
3.7
1
2
18.5
5
6
7
8
9
37
10
Pressure
HYDRO THERMAL
CONTACT
High temperature, low pressure baking of country rocks in contact with intrusive magma
CONTACT
HYDROTHERMAL
Hot, mineral laden fluids
High Pressure/ Low Temperature metamorphism of trench sediments
GREENSCHIST
Sedimentary Parent
SLATE
BLUESCHIST
BLUESCHIST
Greenschist
Amphibolite
Granulite
BARROVIAN
Felsic igneous rocks metamorphosed to schist and gneiss and divergent margin sedimentary rocks metamorphosed to slate, phyllite, schist, and gneiss or marble and quartzite
Extreme high pressure metamorphism of subducted ultramafic oceanic lithosphere
ECLOGITE
ECLOGITE

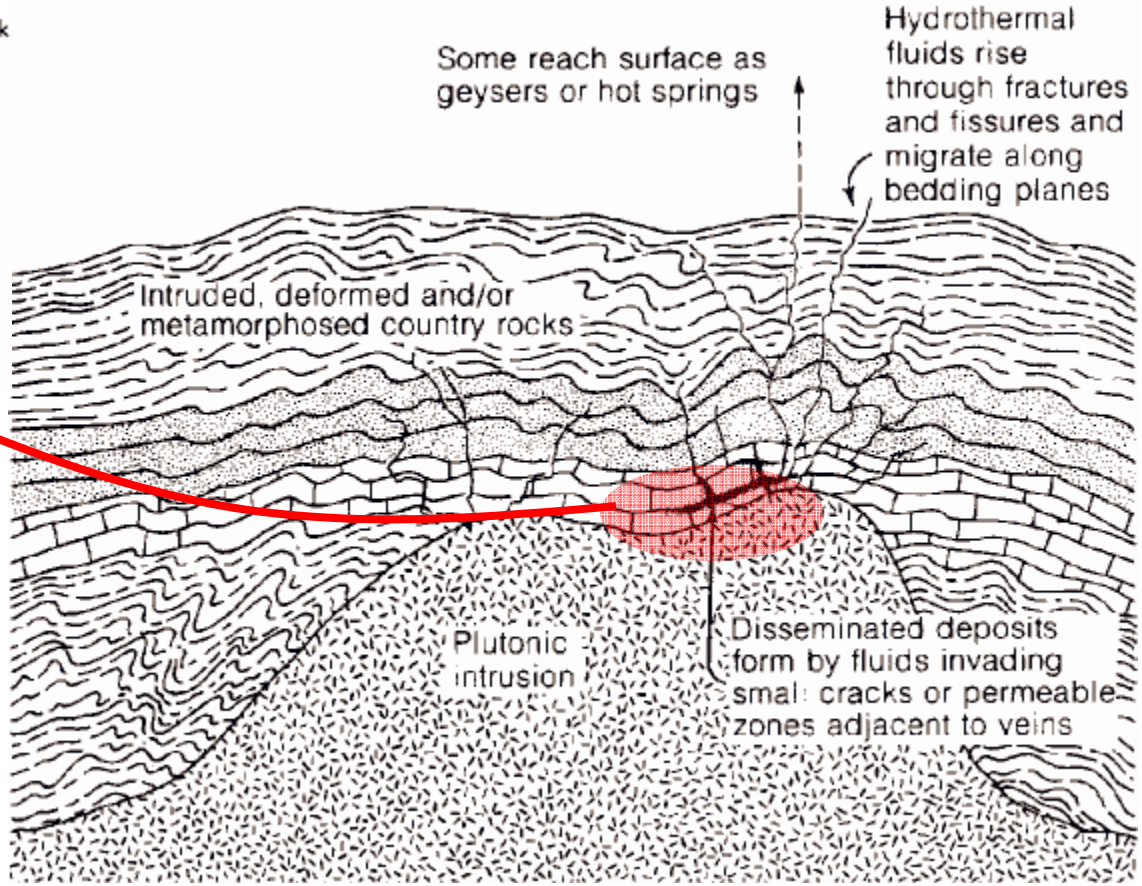
Hydrothermal Metamorphism

Hot fluids from cooling magma

Hot fluids driven from a cooling magma that penetrates into the country rock carrying dissolved minerals that precipitate in the veins and cracks in the rock.







Hydrothermal Metamorphism

Hot fluids from cooling magma

Any chemical that cannot crystallize into a rock forming mineral is driven out of the magma as it crystallizes. In this case water (steam) is escaping through a fumarole precipitating the yellow sulfur it is carrying.

http://vulcan.wr.usgs.gov/Imgs/Jpg/Baker/baker_fumarole_sampling.jpg

Hydrothermal Metamorphism

Hot fluids from cooling magma

Hydrothermal minerals precipitated in veins in a rock.

Veins in cores from the basement rocks of the Savannah River Plant in South Carolina. In these two cores you can see two different vein complexes cutting the rock. To the left the white and green material obliquely cutting the core is quartz and epidote the precipitated in the fractures when they opened up. If you look carefully you can see how the quartz is in the interior, and the epidote tends to be on the exterior of the vein suggesting an evoluton of the fluids moving through these cracks. You can also see that multiple cracks exist suggesting this complex opened up and sealed with hydryothermal precipitates several time. In the core to the right you see pink zeolite crystals in the vein that point inwards to the void which is still left. Note how this vein is discordant to the layering in the enclosing gneiss. Zeolites are hydrothermal index minerals giving some idea to the conditions of formation. They also have useful industrial filtering properties.

http://maps.unomaha.edu/Maher/geol17/veins.jpeg

Hydrothermal Metamorphism

On the ocean floor

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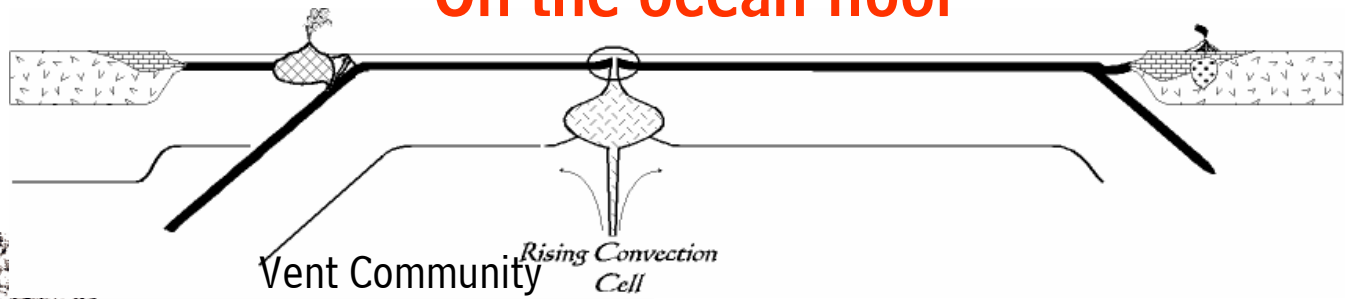
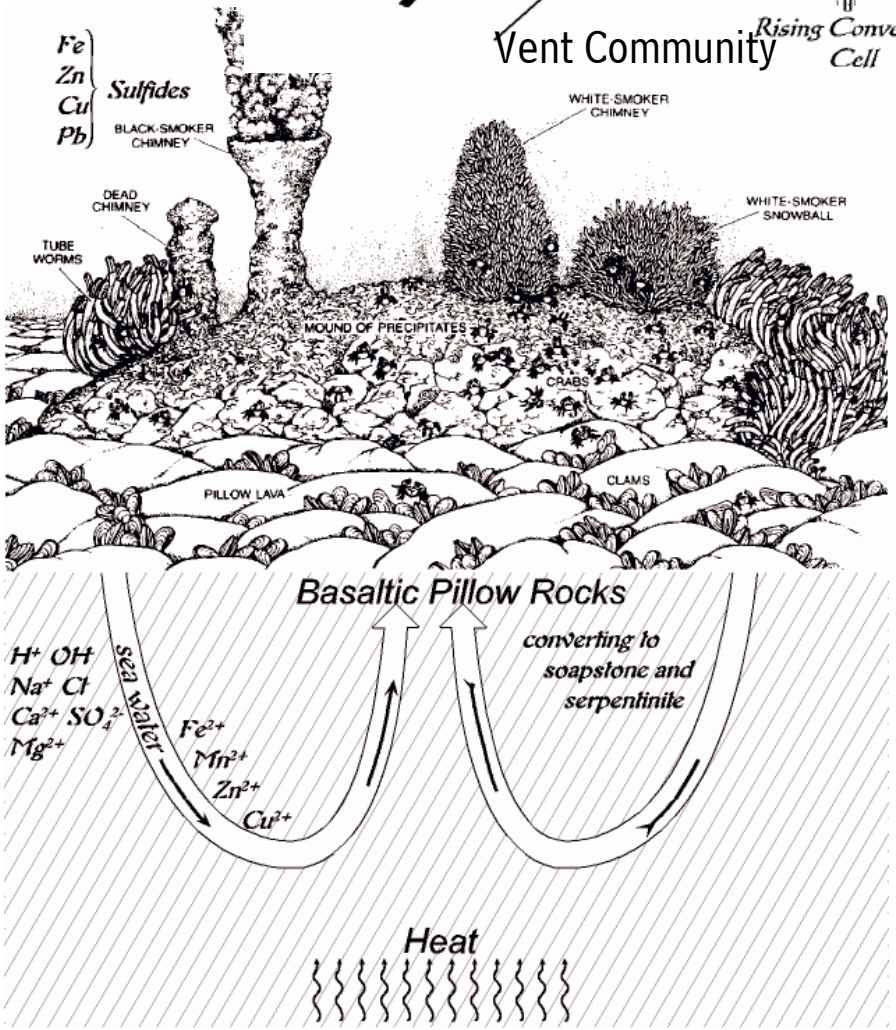
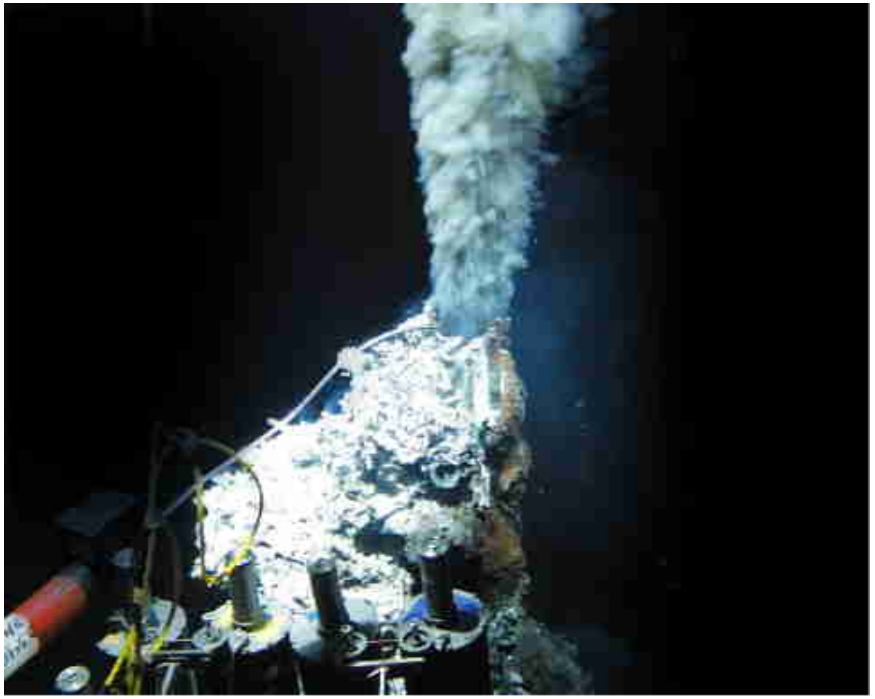


Vent Community



Ocean floor fumeroles and gysers (smokers)



Hydrothermal Metamorphism

On the ocean floor

Basalt under the influence of hydrothermal metamorphism turns into two of the softer rocks – soapstone (composed of the mineral talc) and serpentinite (composed on the mineral serpentine).

SERPENTINITE

http://www.rafa.com/soapstone.htm

SOAP-STONE

http://www.sandycline.com/sculpture/soapstone.html

Soapstone, which is also known as steatite is a metamorphic rock having a talc base ("metamorphic" means changing from one type of stone to another through time and pressure). It occurs as a secondary mineral formed as a result of the alteration of olivine, pyroxene,and amphibole. The purest talc is used commercially to make talcum powder. Soapstone can be distinguished by its' ease of carving, soapy feel, and vibrant colour, which is obtained by the associated minerals leaching into the talc.

Because of its malleability, it has been used as a carving material for centuries. Egyptians carved figures and bowls of soapstone to be put into the tombs of pharaohs. Soapstone seals of Indian origin have been found in Bahrain and Ur. Paleoeskimos were mining the stone to make bowls and lamps on the Baie Verte Peninsula 1600 years ago. Native American Indians throughout North America carved soapstone into ornamental pipes and bowls.

http://www.rafa.com/soapstone.htm

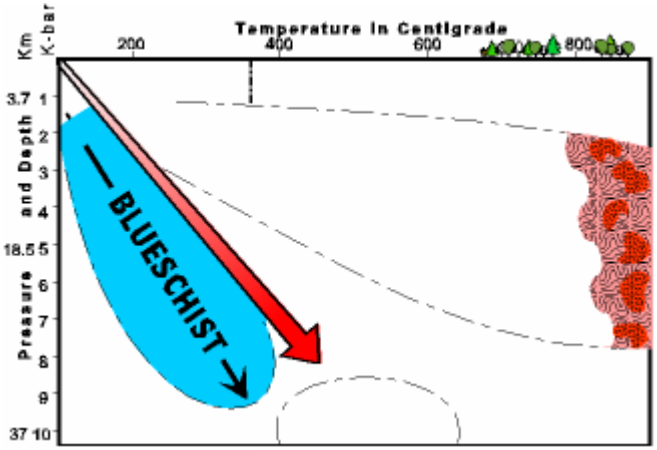
http://www.sandycline.com/sculpture/soapstone.html

http://www.sandycline.com/sculpture/soapstone.html

Practical Uses of Soapstone and Serpentinite

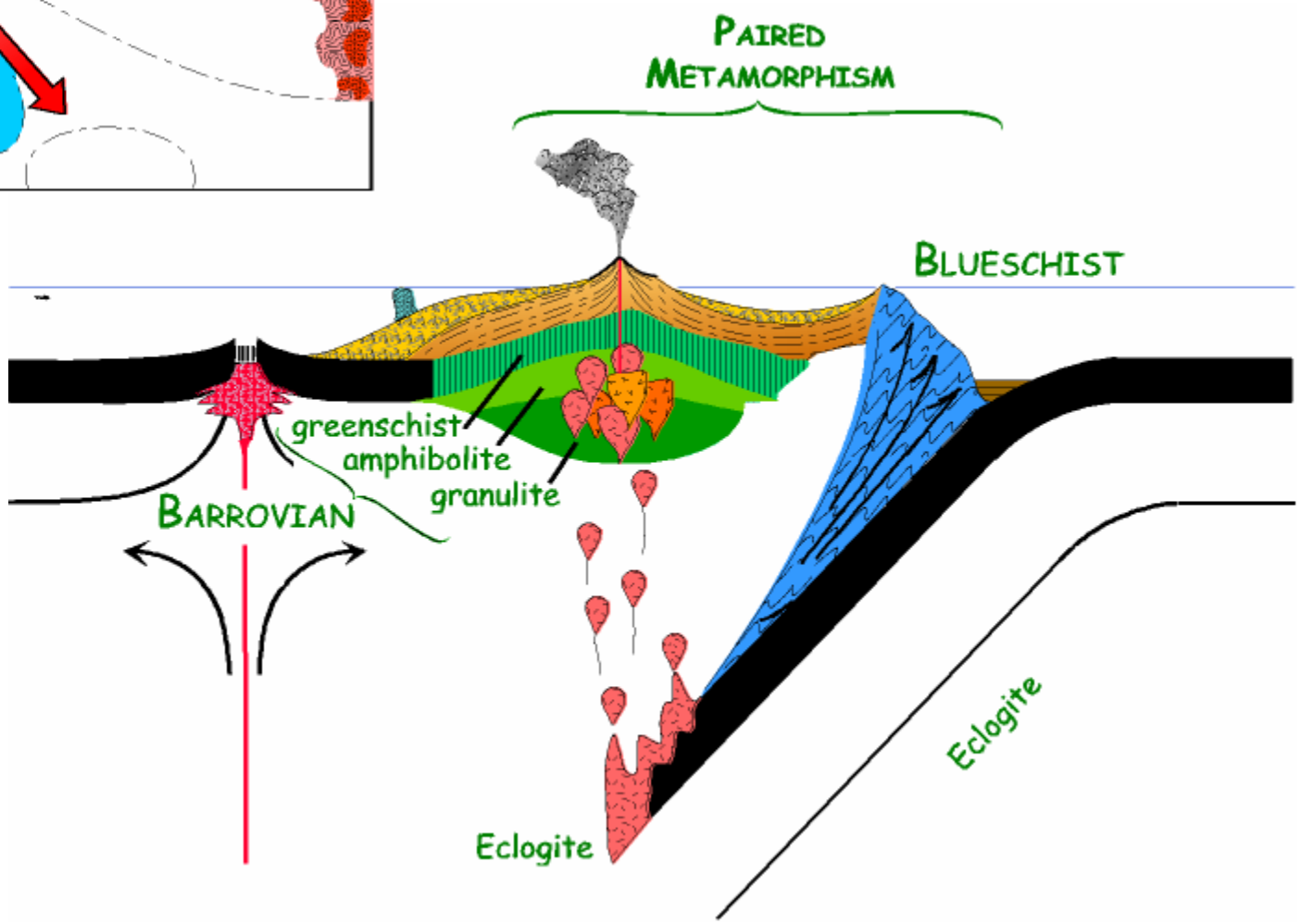
http://www.kadi.com/bb2004.asp

http://www.kadi.com/bb2004.asp

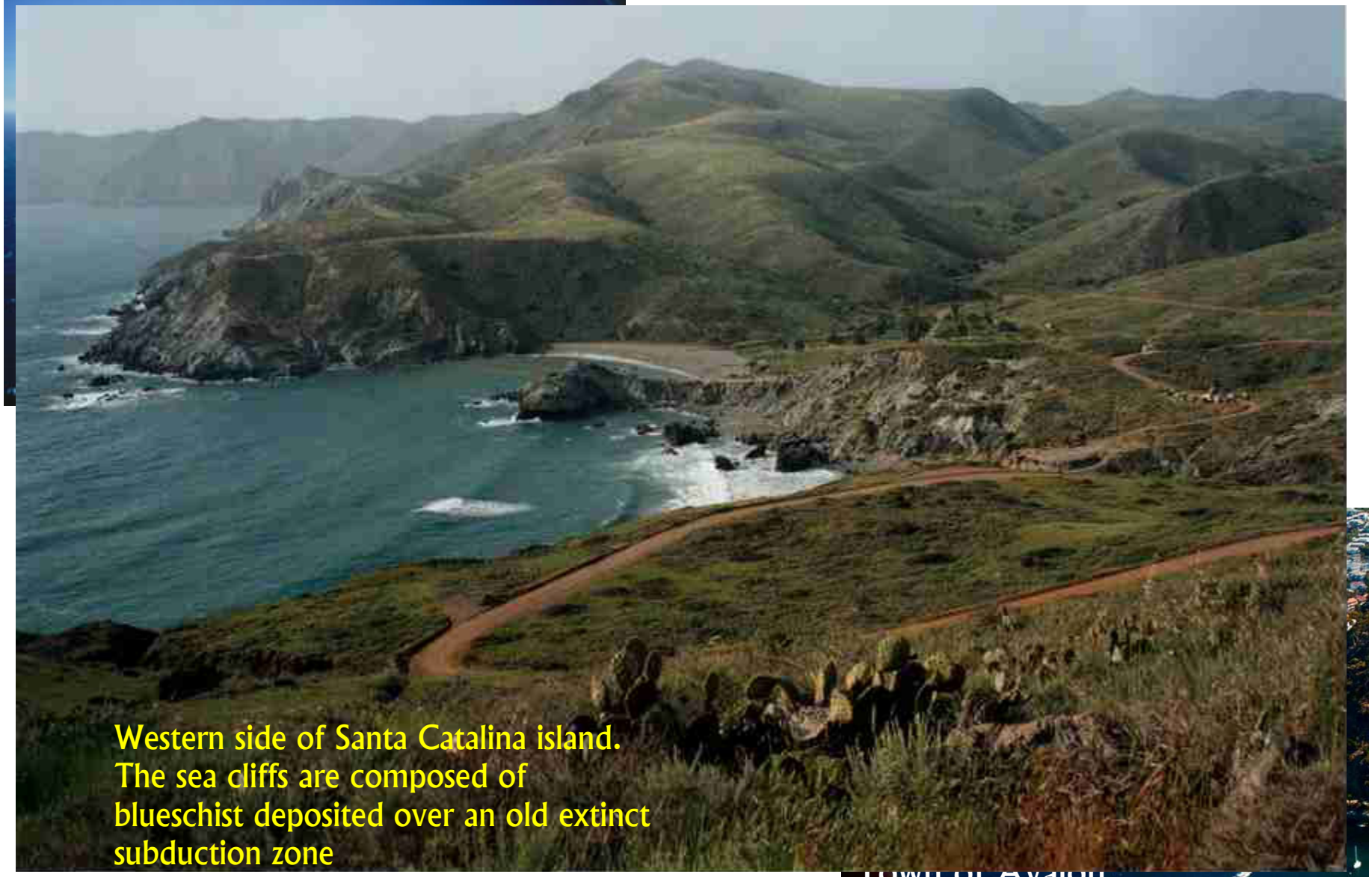


Blueschist Metamorphism

High Pressure – Low Temperature



Santa Catalina Island Blueschist Metamorphism



Western side of Santa Catalina island. The sea cliffs are composed of blueschist deposited over an old extinct subduction zone

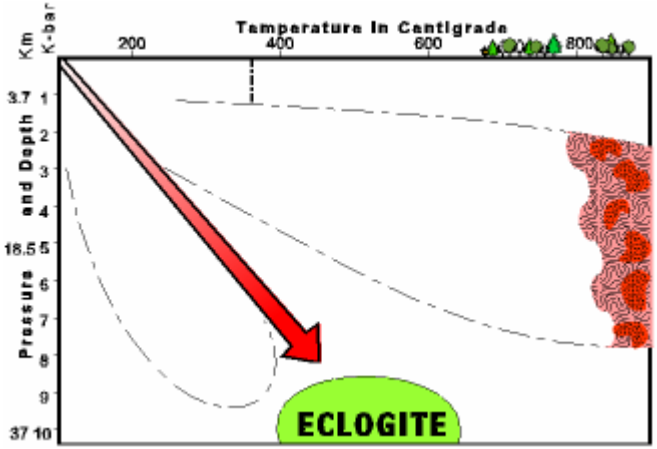
http://quezst.arc.nasa.gov/neuron/team/journals/oyung/catland.jp

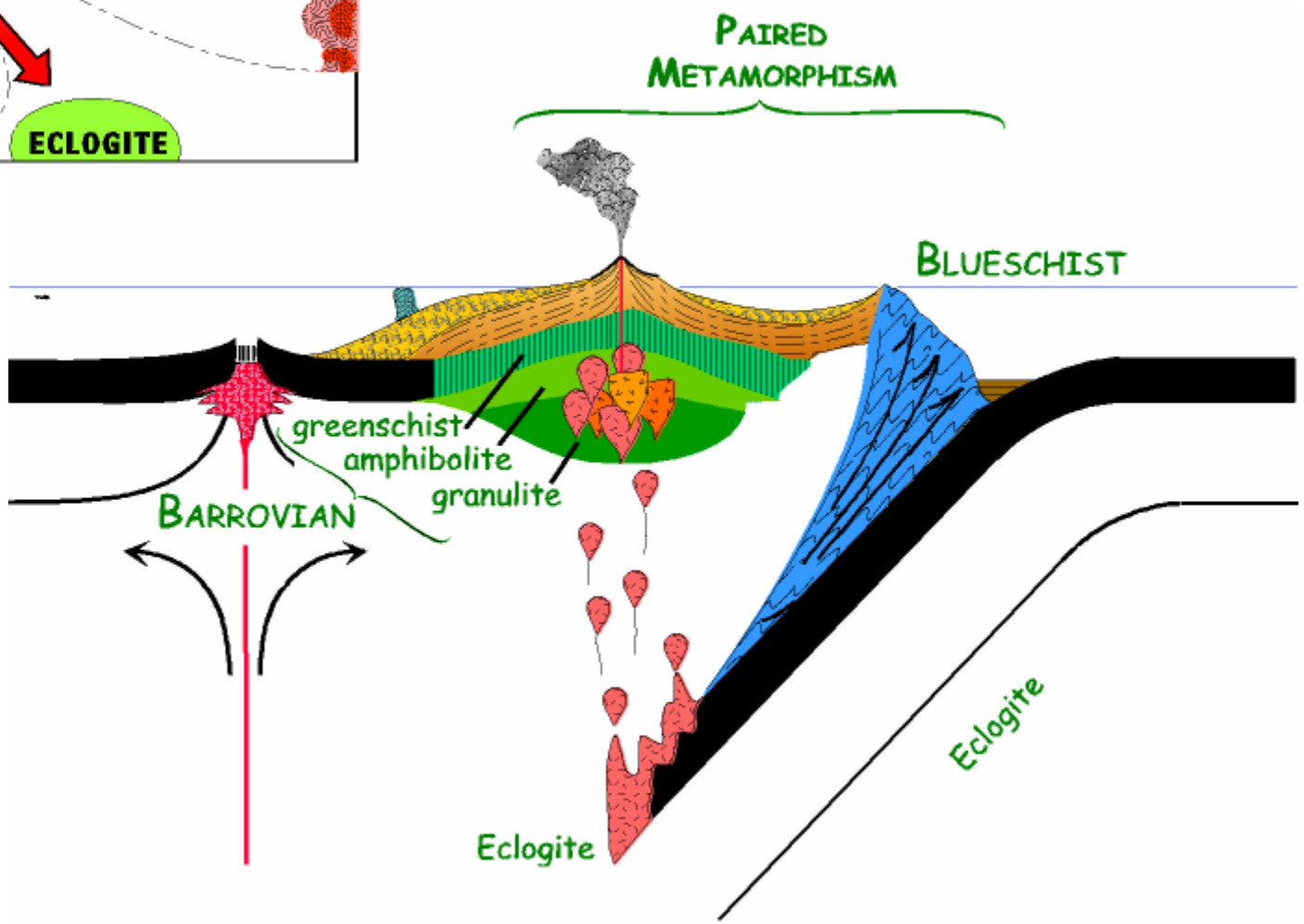
http://wings-travel.de/avalonopt.jpg

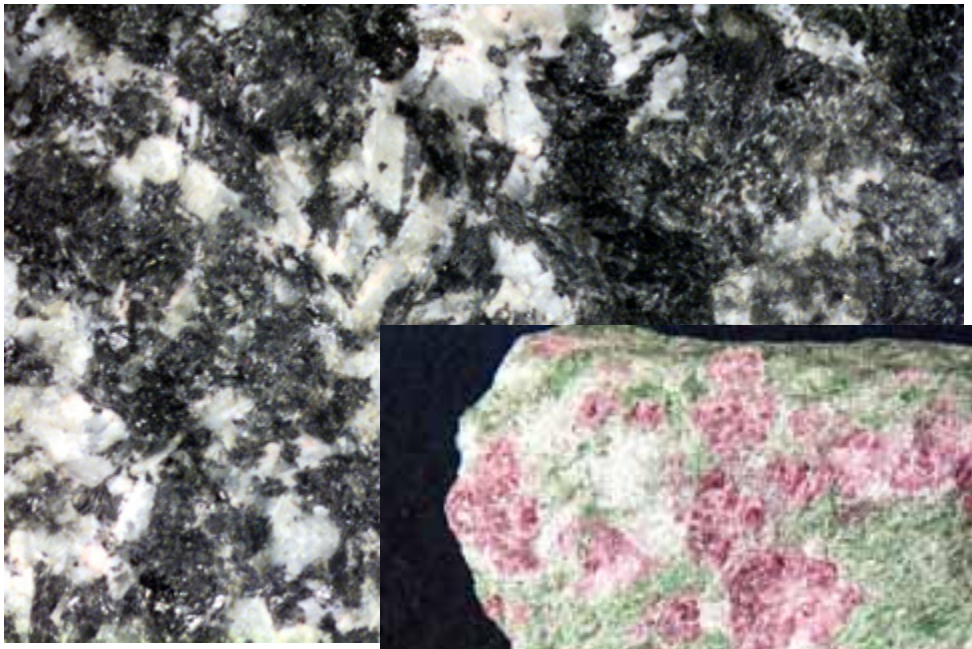
Blueschist Metamorphism

Petrologists prefer to talk about the glaucophane-schist facies, because not all blueschist is all that blue. Consider this hand specimen, which displays many different shades. Glaucophane and lawsonite are the major blue species in this rock type, but jadeite, epidote, and quartz are also common. It's hard to tell what's what on this specimen without a microscope

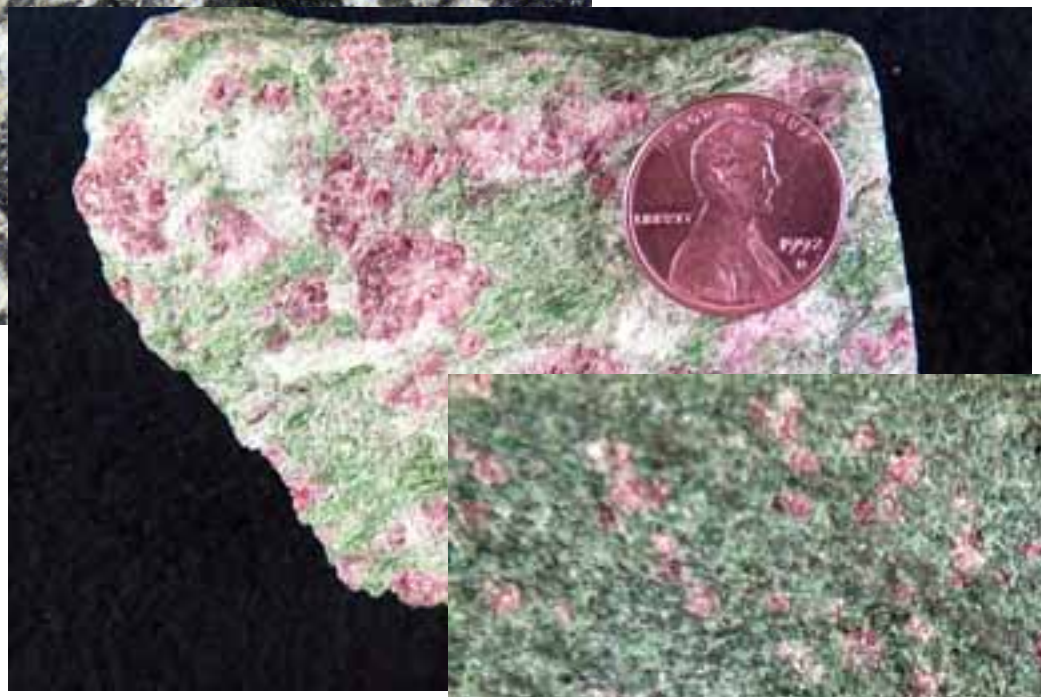
Eclogite Metamorphism

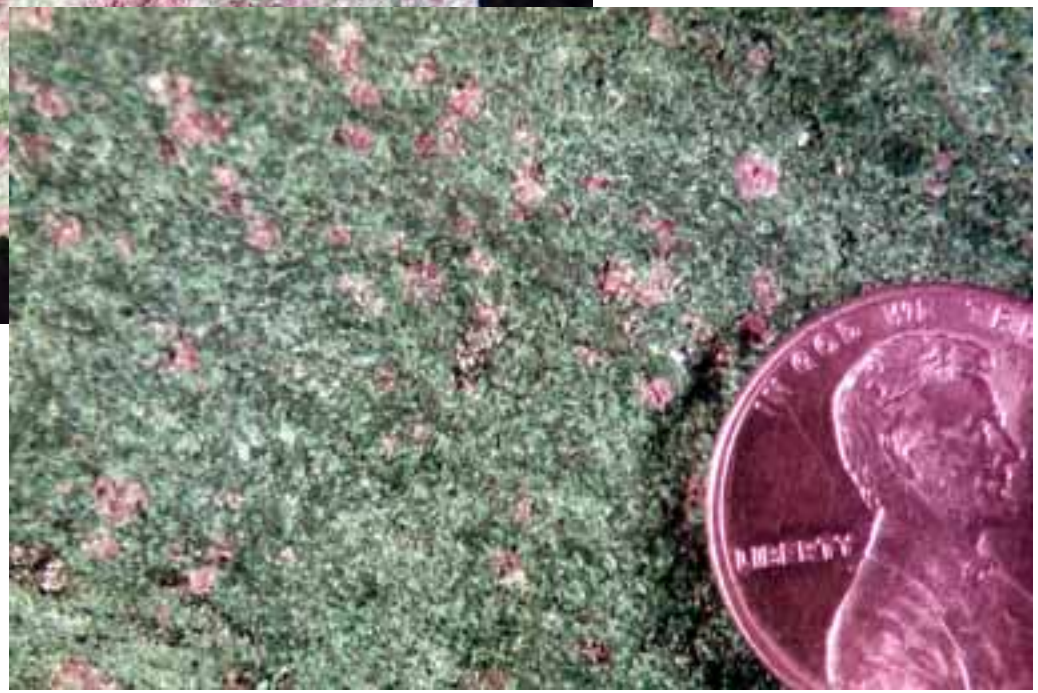






Gabbro





Eclogite

Barrovian Metamorphism

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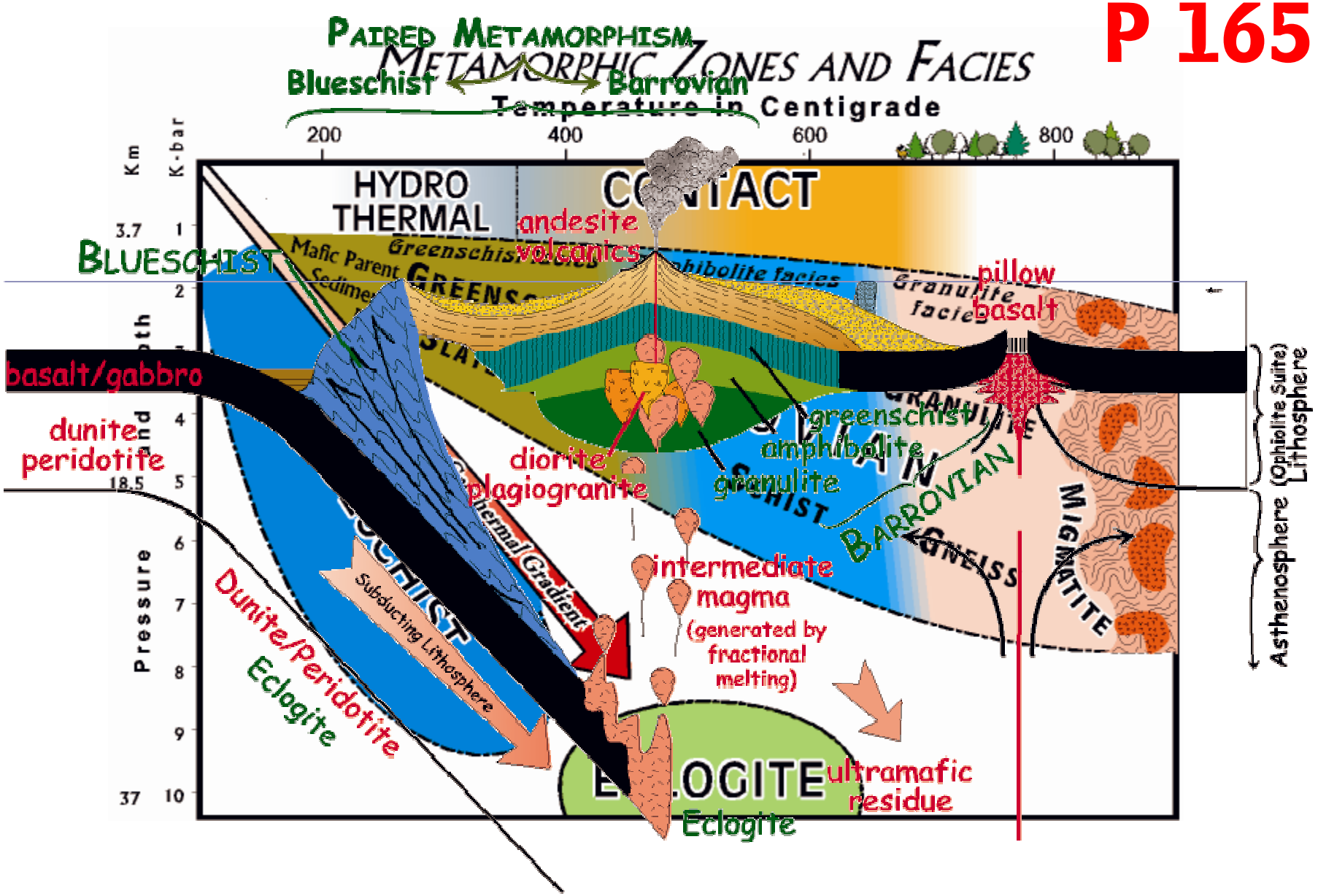
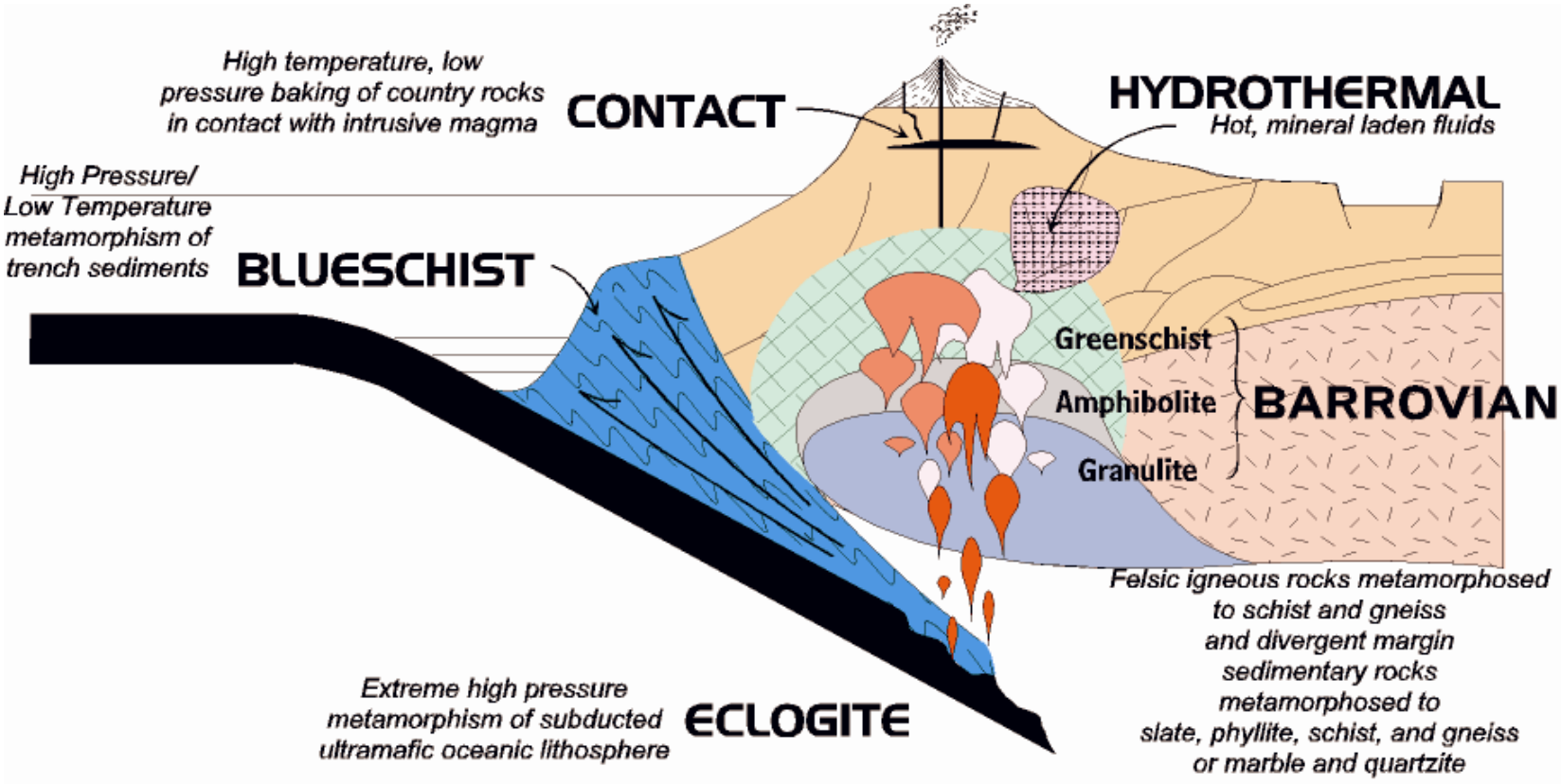


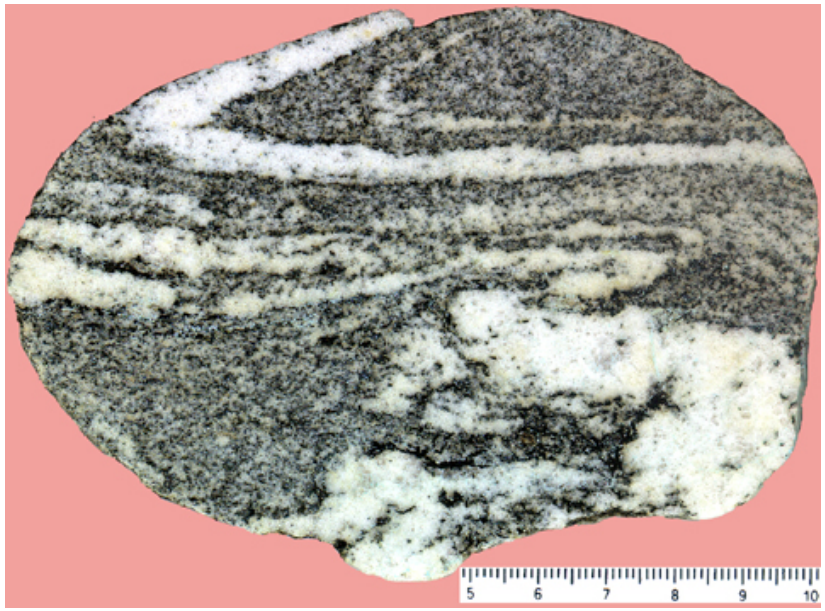
Barrovian Metamorphism



Barrovian Metamorphism sometimes called Regional Metamorphism

The kind of metamorphic rock you get depends on the parent rock

Granite goes to . . .



Gneiss

The kind of metamorphic rock you get depends on the parent rock

Limestone goes to . . .

The kind of metamorphic rock you get depends on the parent rock

Limestone goes to . . .

The kind of metamorphic rock you get depends on the parent rock

Limestone goes to . . .

Marble

The kind of metamorphic rock you get depends on the parent rock

Shale goes to . . .

Well, a lot of things.

Development of Barrovian Metamorphic Rocks From a Shale Parent

	Sedimentary Processes	⇨ Greenschist Facies ⇨		Amphibolite Facies ⇨	Granulite Facies ⇨	Igneous Processes
	Shale	**Slate**	**Phyllite**	**Schist**	**Gneiss**	**Magma**
Composition	Clay SiO_2 Fe oxides Organic matter	Very small crystals of chlorite	Larger chlorite crystals. Fine grained quartz and feldspar	Chlorite gone. Qtz, feldspar, mica common. New Minerals include: garnet, staurolite, kyanite, andalusite, etc.	Quartz, feldspar mica dominate. Other minerals break down.	Rock melts to produce Felsic magma.
Texture	Sedimentary bedding	Slatey cleavage Fine grained foliation leading to good, flat cleavage.	Slatey cleavage Coarser grained foliation due to enlarging chlorite crystals	Schistosity Minerals completely intermixed, but with micas (biotite or muscovite) all aligned.	Mineral Banding Quartz and feldspar migrate into separate bands from micas.	Migmatite Partial (fractional) melting. Highly deformed rock with swirls of granite within banded gneiss.
Distinguishing Features	Dull sound when struck; it "thunks"	Rings like a bell. More dense than shale. More luster than shales, less than phyllite.	Has definite sheen in reflected light. Foliation begins to produce an undulating surface.	Minerals large enough to be easily identified. Index minerals important: biotite ⇨ garnet ⇨ staurolite ⇨ kyanite ⇨ sillimanite	Defining bands of light and dark colored minerals	

Barrovian Metamorphism

Mineral Changes: clay → chlorite → quartz/feldspar/mica

Texture Changes: bedding → slaty cleavage → schistosity → mineral banding

Rock Changes: shale → slate → phyllite → schist → gneiss

Shale

Clay
Silica
Iron oxides

Sedimentary
Bedding

Dull “thunk” sound when struck

Metamorphoses Into →

Slate

Small chlorite crystals

Slaty cleavage

Rings like a bell when struck

Barrovian Metamorphism

Mineral Changes: clay → chlorite → quartz/feldspar/mica

Texture Changes: bedding → slaty cleavage → schistosity → mineral banding

Rock Changes: shale → slate → phyllite → schist → gneiss

Slate

Small chlorite crystals

Slaty cleavage

Rings like a bell when struck

Metamorphoses Into

Phyllite

http://geology.about.com/library/bl/images/blphyllite.htm

Large chlorite crystals

Slaty cleavage – coarser grained foliation

Has a definite sheen in reflected light; back to dull “thunk” sound

Foliated Textures

Slaty Cleavage

http://www.env.duke.edu/eos/geo41/ims2.htm

http://www.accd.edu/sac/EARTHSCI/1301.090/Lecture□202.htm

Slaty Cleavage and its Practical Applications

http://www.creativeroofsystems.com/services.htm

http://www.restorationtrades.com/articles/roofslatetile.shtml

Slaty Cleavage and its Practical Applications

http://www.peartree12.freeserve.co.uk/topics/roofing.html

http://www.bingleystone.com/stoneslate/indian-p1.htm

Barrovian Metamorphism

Mineral Changes: clay → chlorite → quartz/feldspar/mica

Texture Changes: bedding → slaty cleavage → schistosity → mineral banding

Rock Changes: shale → slate → phyllite → schist → gneiss

Phyllite

http://geology.about.com/library/bl/images/blphyllite.htm

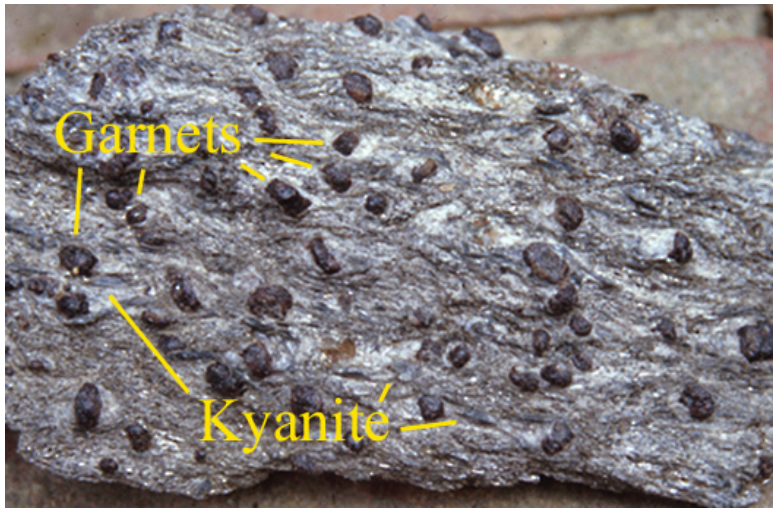
Large chlorite crystals

Slaty cleavage – coarser grained foliation

Has a definite sheen in reflected light; back to dull "thunk" sound

Metamorphoses Into

Schist



Chlorite gone. Quartz, feldspar, mica, and many new minerals

Schistosity; minerals completely intermixed

Minerals large enough to be easily identified

Foliated Textures

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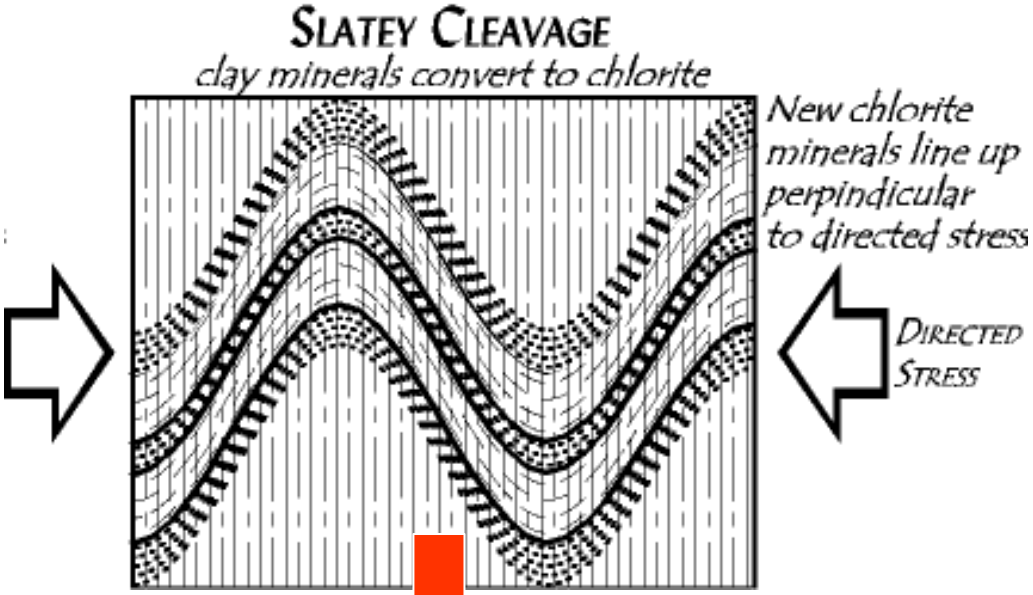
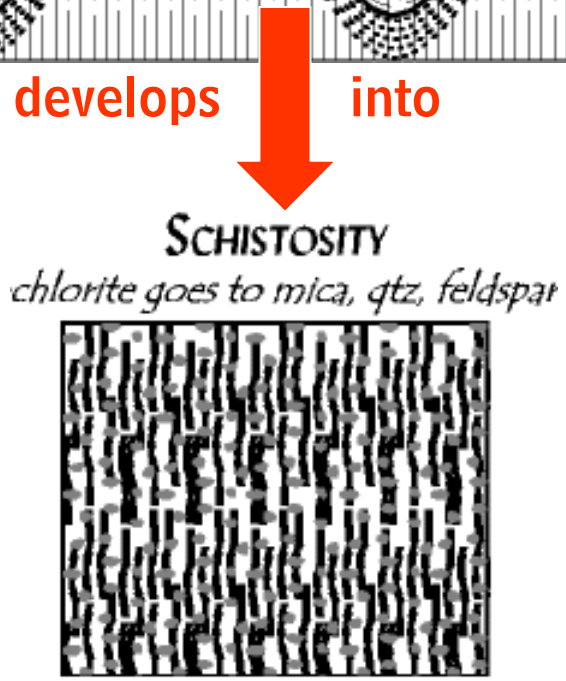
Schistosity and Mineral Banding

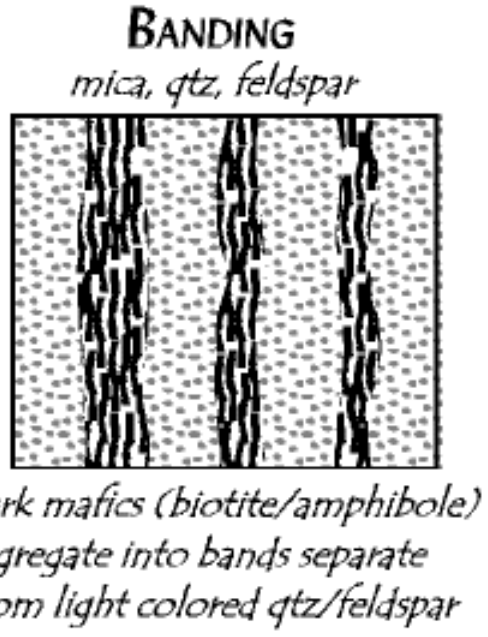


develops into



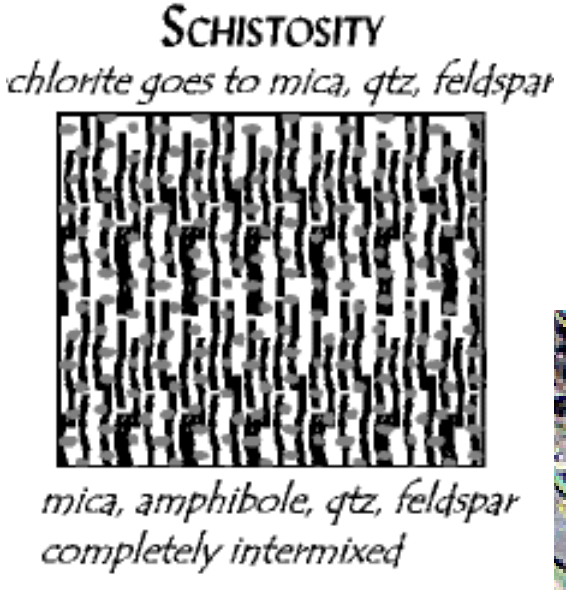
Which then

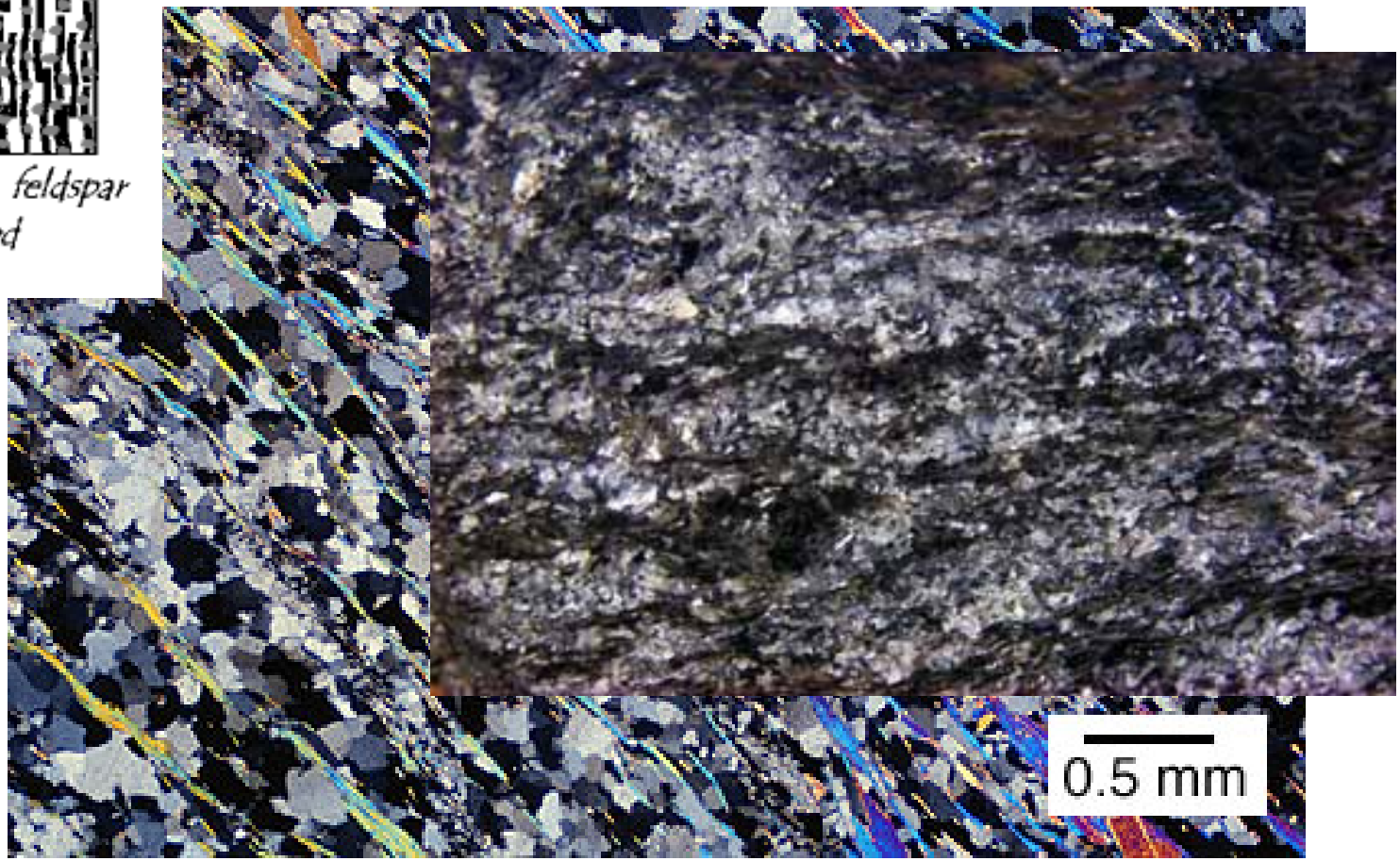
Develops into



Foliated Textures – Schistosity

A foliation is any planar fabric in a metamorphic rock. In this case, the foliation is defined by aligned sheets of muscovite sandwiched between quartz grains.





http://www.geolab.unc.edu/Petunia/IgMetAtlas/meta-micro/quartzmicaschist.X.html

Foliated Textures – Schistosity

Schist

http://www.accd.edu/sac/EARTHSCI/1301.090/Lecture□202.htm

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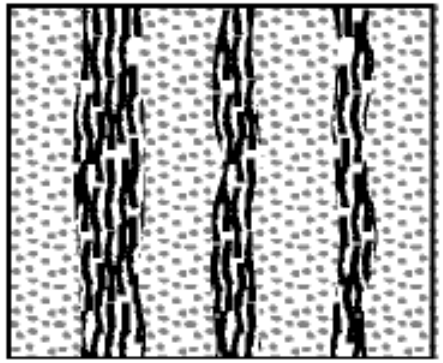
	Sedimentary Processes	⇨ Greenschist Facies		⇨ Amphibolite Facies	⇨ Granulite Facies	⇨ Igneous Processes
	Shale	**Slate**	**Phyllite**	**Schist**	**Gneiss**	**Magma**
Composition	Clay SiO2 Fe oxides Organic matter	Very small crystals of chlorite	Larger chlorite crystals. Fine grained quartz and feldspar	Chlorite gone. Qtz, feldspar, mica common New Minerals include: garnet, staurolite, kyanite, andalusite, etc.	Quartz, feldspar mica dominate. Other minerals break down.	Rock melts to produce Felsic magma.
Texture	Sedimentary bedding	Slatey cleavage Fine grained foliation leading to good, flat cleavage.	Slatey cleavage Coarser grained foliation due to enlarging chlorite crystals	Schistosity Minerals completely intermixed, but with micas (biotite or muscovite) all aligned.	Mineral Banding Quartz and feldspar migrate into separate bands from micas.	Migmatite Partial (fractional) melting. Highly deformed rock with swirls of granite within banded gneiss.
Distinguishing Features	Dull sound when struck; it "thunks"	Rings like a bell. More dense than shale. More luster than shales, less than phyllite.	Has definite sheen in reflected light. Foliation begins to produce an undulating surface.	Minerals large enough to be easily identified. Index minerals important: biotite ⇨ garnet ⇨ staurolite ⇨ kyanite ⇨ sillimanite	Defining bands of light and dark colored minerals	

Foliated Textures – Mineral Banding

Banding

mica, qtz, feldspar



dark mafics (biotite/amphibole) segregate into bands separate from light colored qtz/feldspar

Gneiss

http://www.uwlax.edu/faculty/stoelting/Intro/Guides/Images2/gneiss_8X6.jpg

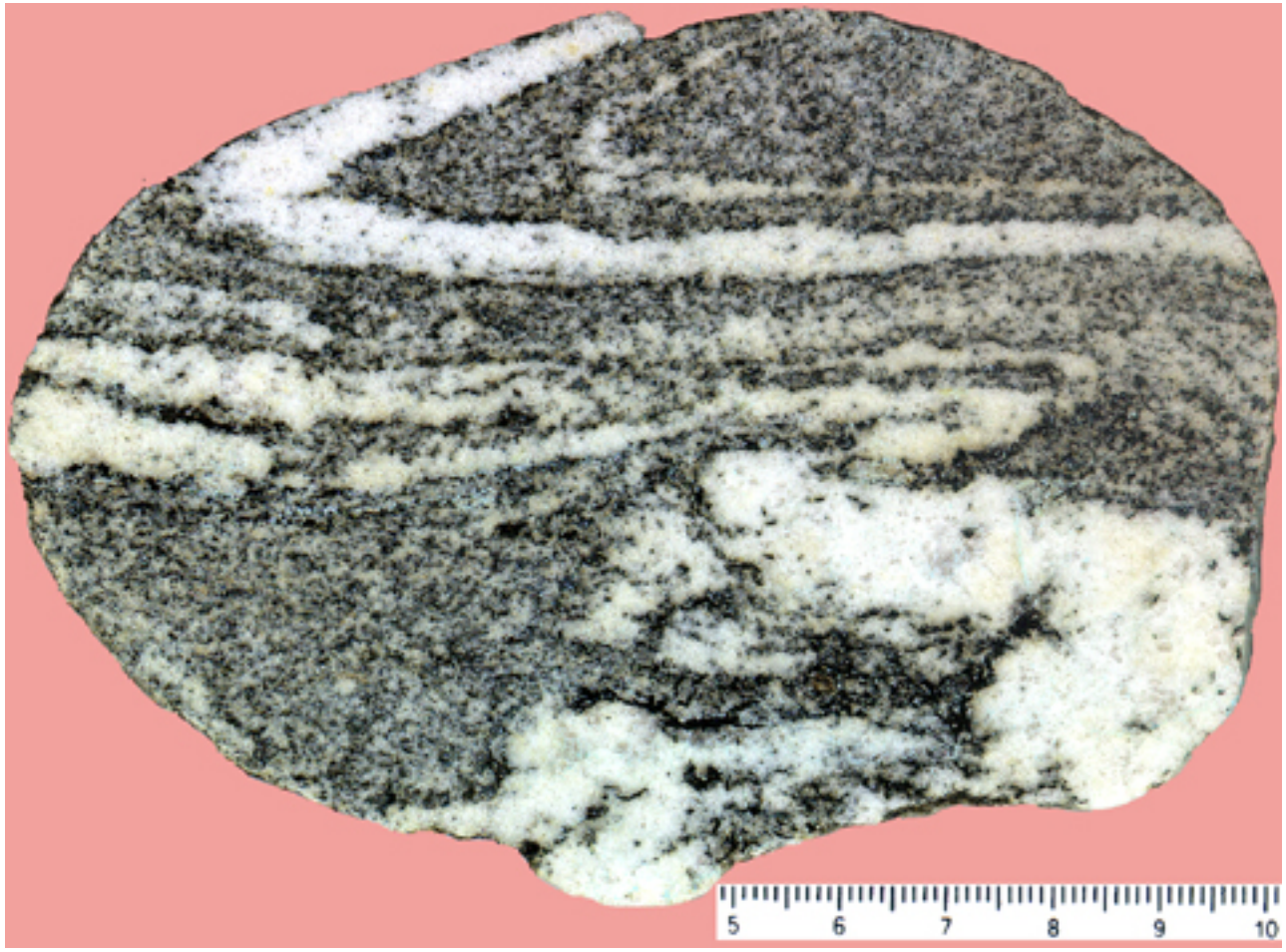
Foliated Textures – Mineral Banding

Gneiss

http://www.library.csi.cuny.edu/dept/as/meta/fol.htm

Foliated Textures – Mineral Banding

Gneiss



http://www.ut.ee/BGGM/miner/para_gneiss1.jpg

Foliated Textures – Mineral Banding

Gneiss

http://www.eas.slu.edu/Photos/3_2_Ga_gneiss.html

Foliated Textures – Mineral Banding P 156

Gneiss

http://www.gly.uga.edu/railsback/FieldImages/BountifulFolds.jpeg

The kind of metamorphic rock you get depends on the parent rock

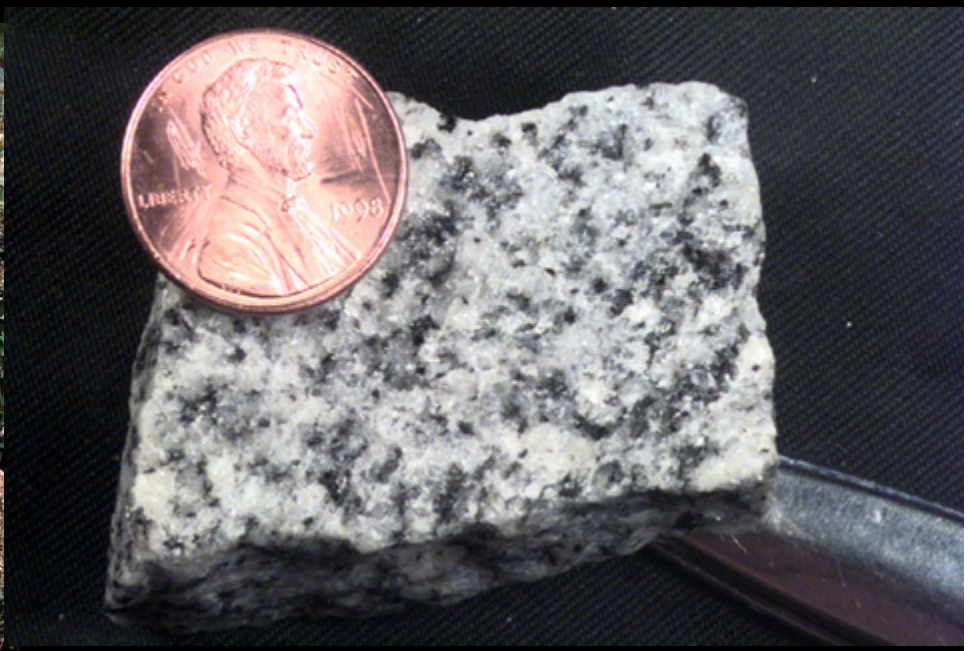
Gneiss goes to . . .

Migmatite

The kind of metamorphic rock you get depends on the parent rock

Which goes to . . .

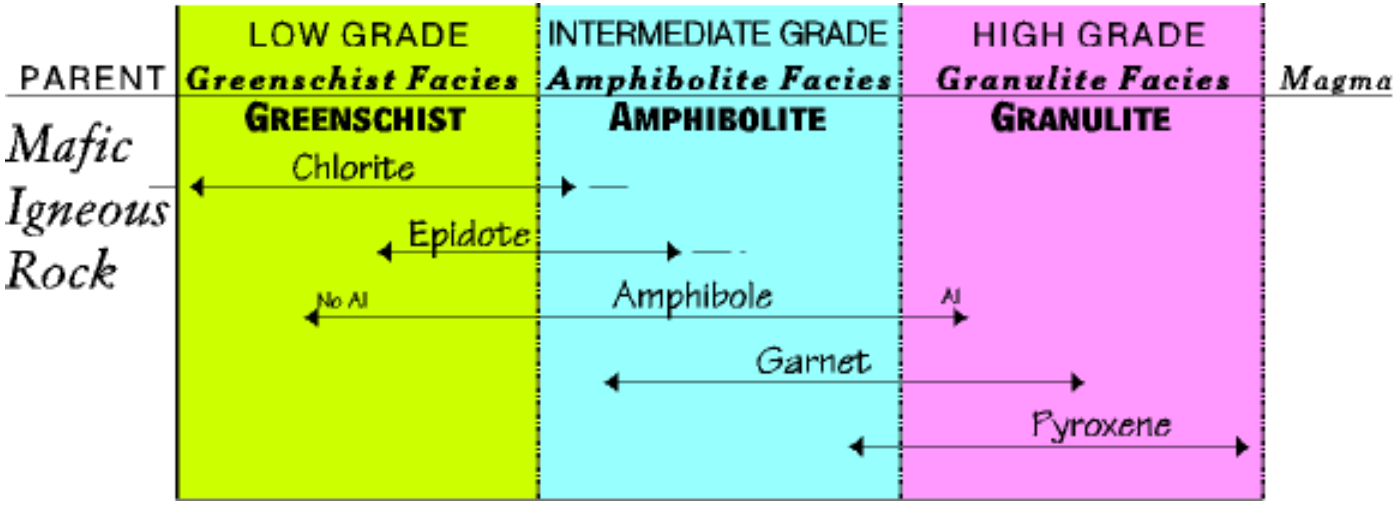
Granite



The kind of metamorphic rock you get depends on the parent rock

Basalt/Gabbro goes to . . .

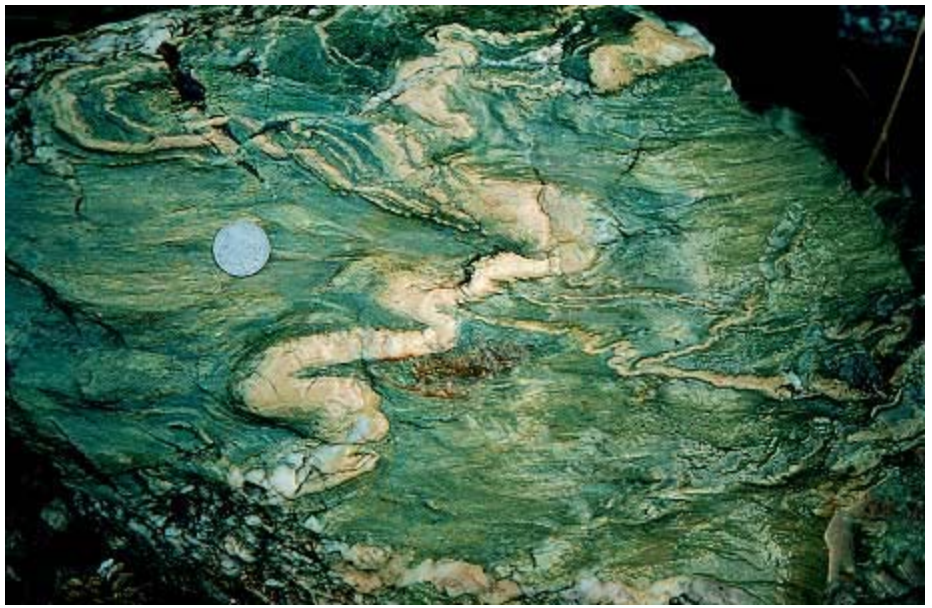
Barrovian Metamorphism of Mafic Igneous Rocks



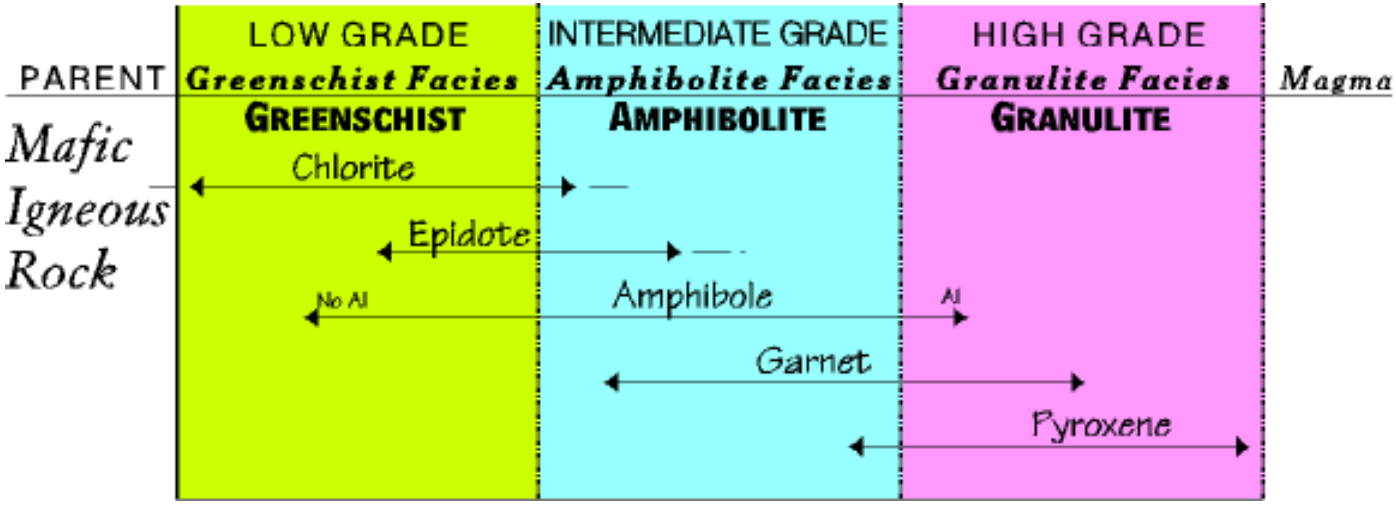
Greenschist

Gabbro

Metamorphoses Into



Barrovian Metamorphism of Mafic Igneous Rocks

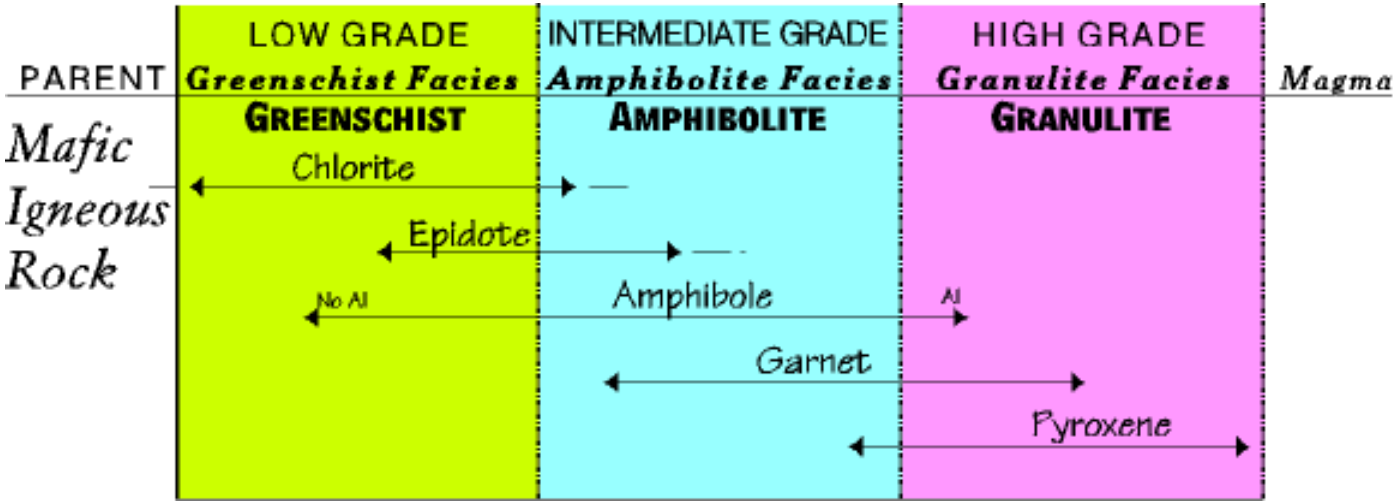


Greenschist

Metamorphoses Into

Amphibolite

Barrovian Metamorphism of Mafic Igneous Rocks



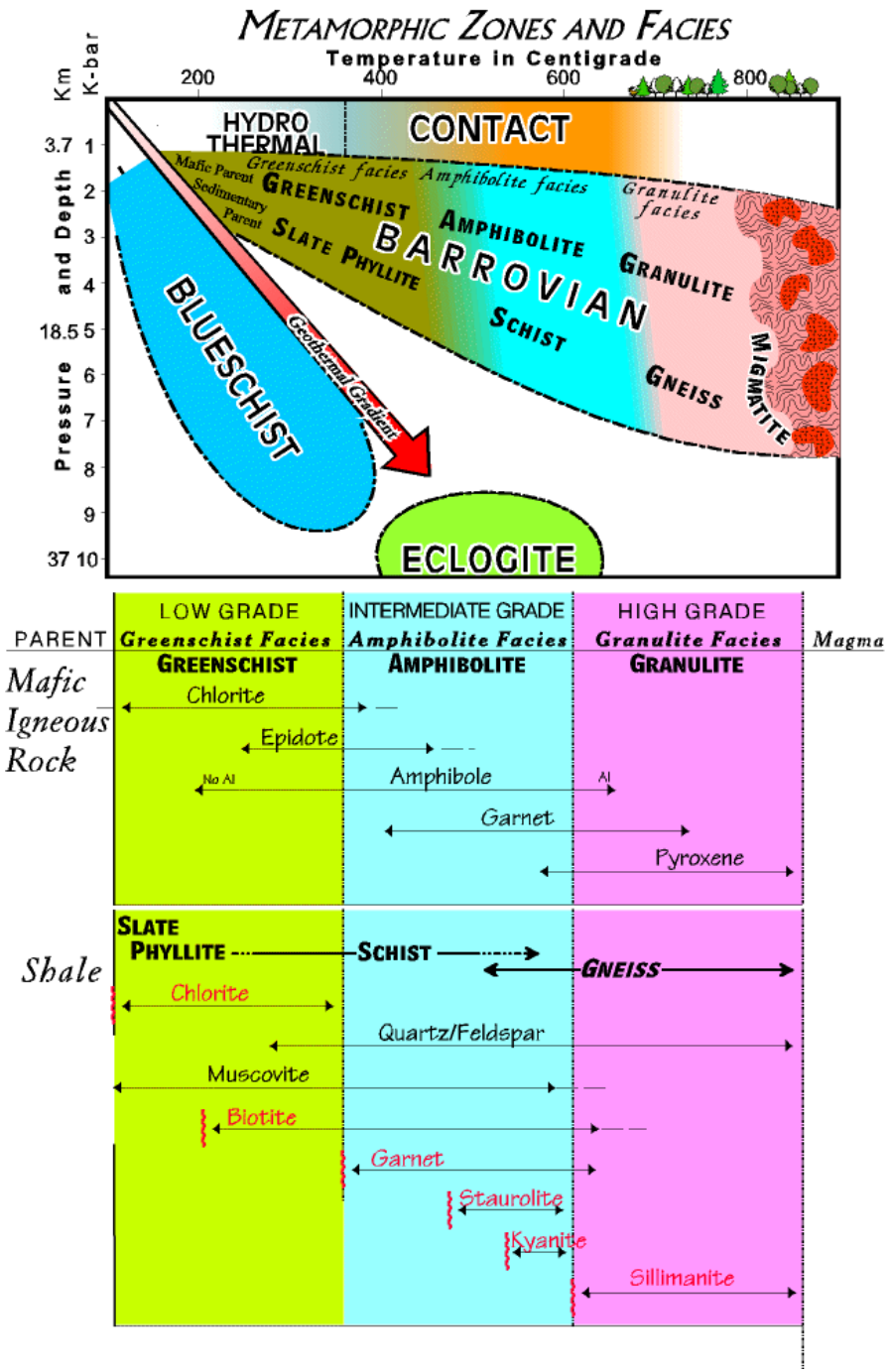
Amphibolite

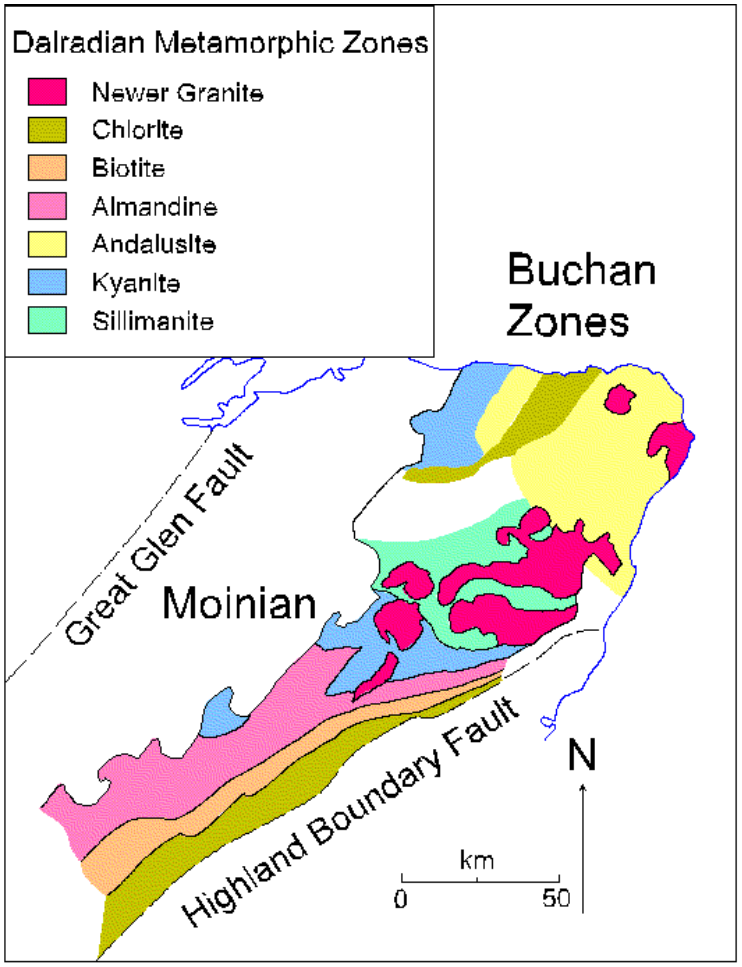
Metamorphoses Into

Granulite

Measuring the Intensity Of Barrovian Metamorphism

Zones and Facies



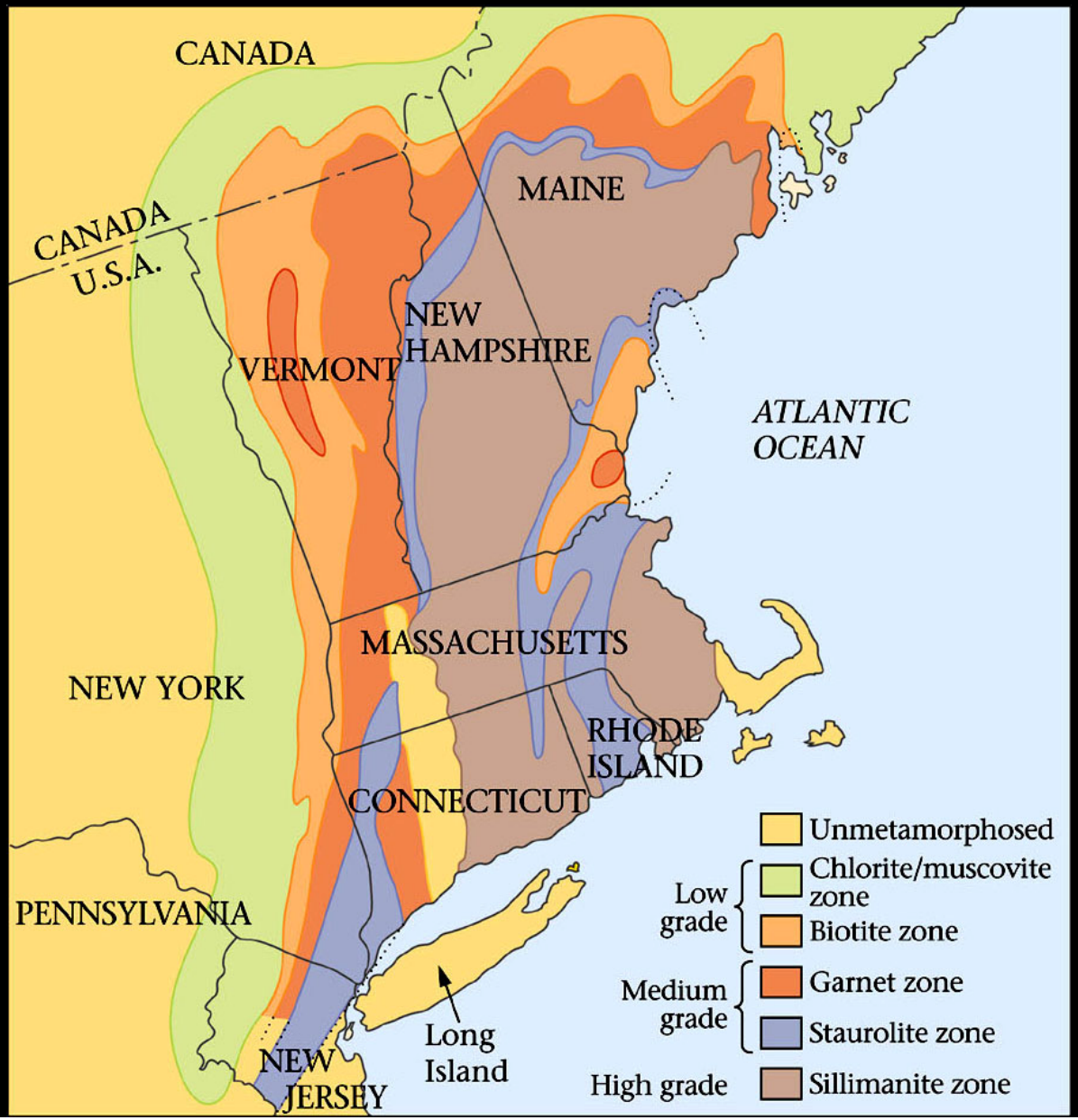


The extension of Barrow's zones of regional metamorphism along the length of the Dalradian sequence in the Scottish Highlands (from Turner, 1968).

(File-absrcesh.ds4)

http://www.brocku.ca/earthsciences/people/gfinn/petrology/barrow1.htm

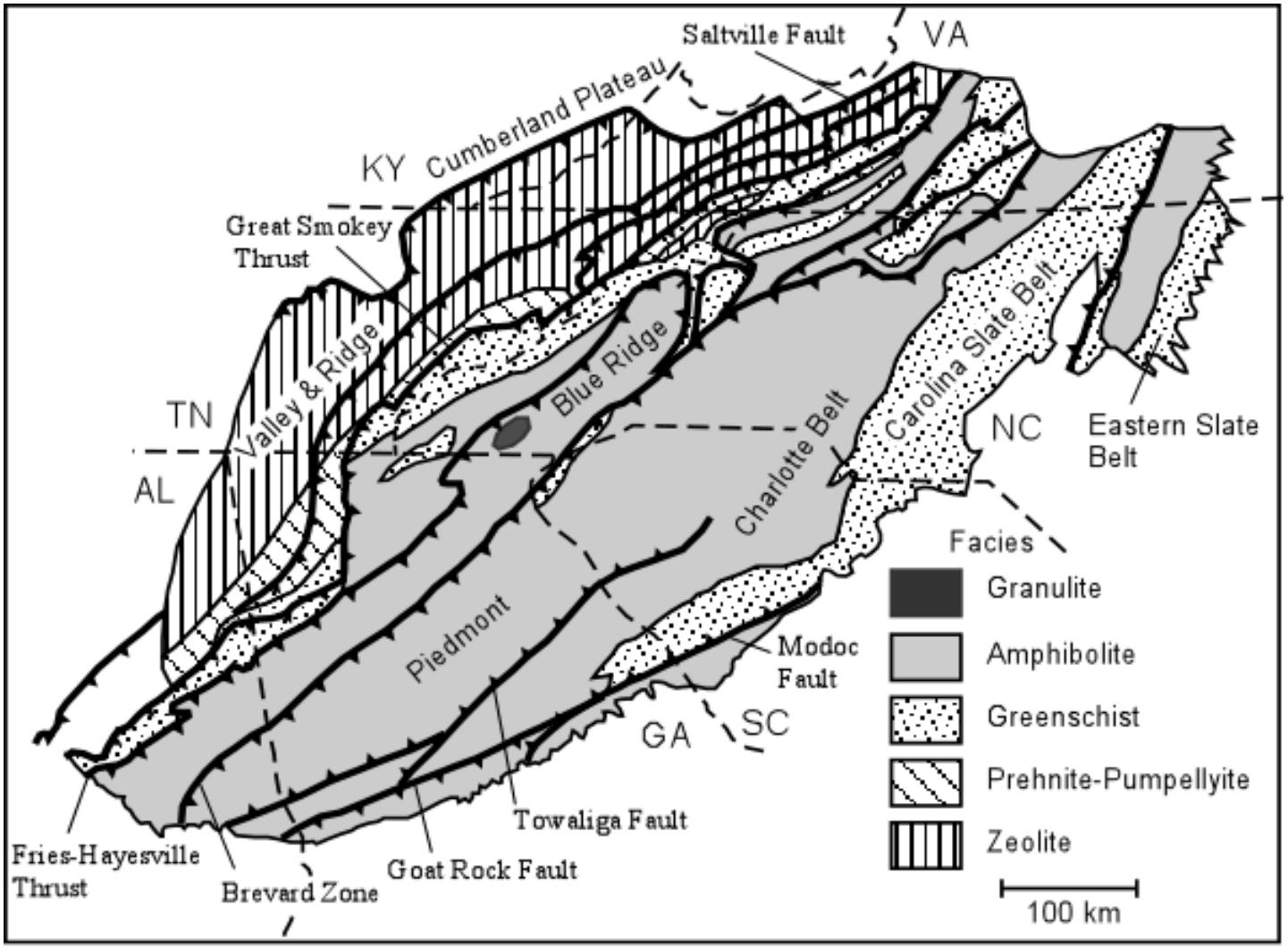
Metamorphic grade in New England



(Acadian in New England)

Barrovian Facies Series of the Southern Appalachians

The Barrovian Facies Series occurs in the southern Appalachians, extending from Central Virginia to Alabama. Interpretation of the relationship between deformation and metamorphism is complicated by the fact the region has experienced at least three mountain building events, and thrust faults cut the area.



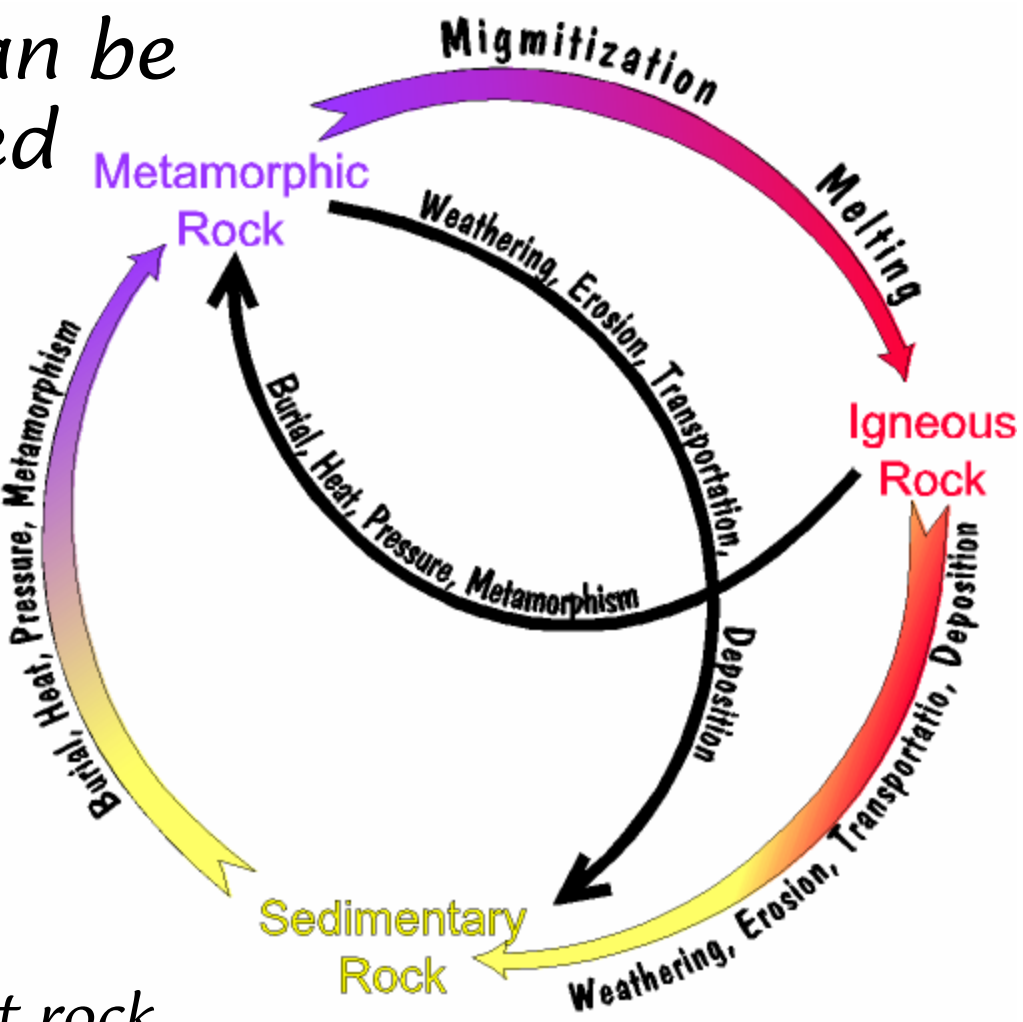
After Raymond, 1995

http://www.tulane.edu/~sanelson/eens212/regionalmetamorph.htm

Cycles Within Cycles

The Rock Cycle

All rocks can be transformed Into other rocks



But, all rocks originate and evolve from the parent rock

Thus endith

Our study of the Geological Earth

It is time for the first test

What day would work best for the test? Wednesday? Thursday?

When we do the test we can do it one of two ways.

Decision is by majority vote.

Option One:

- Test begins at 9:00.
- You have 50 minutes to take the test.
- Class begins at 10:00.

Option Two:

- Class begins at 9:00 and ends at 11:00.
- You may begin the test anytime between 11:00 and 1:30.
- You may have a much time as you wish to take the test.