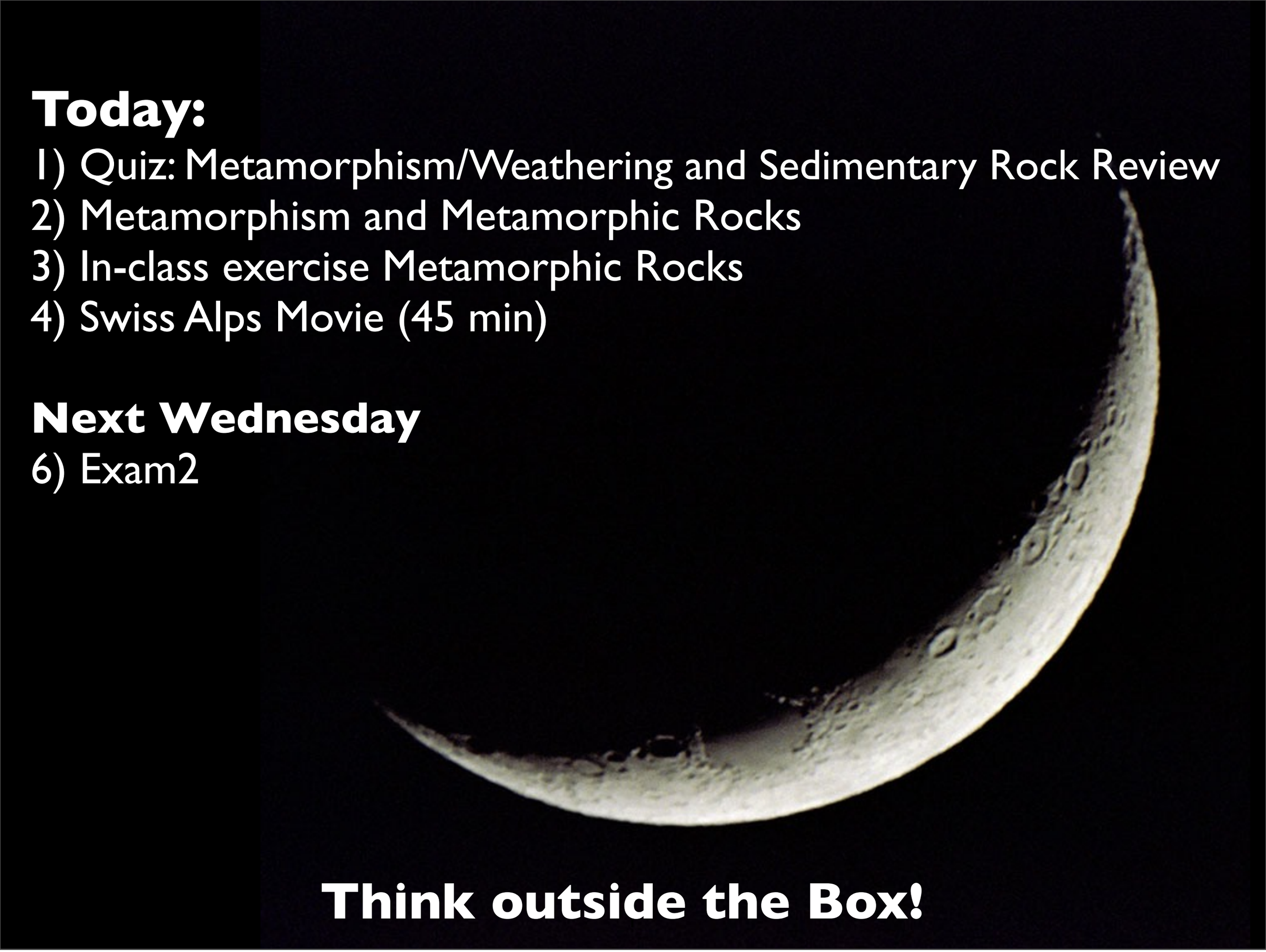
Today:

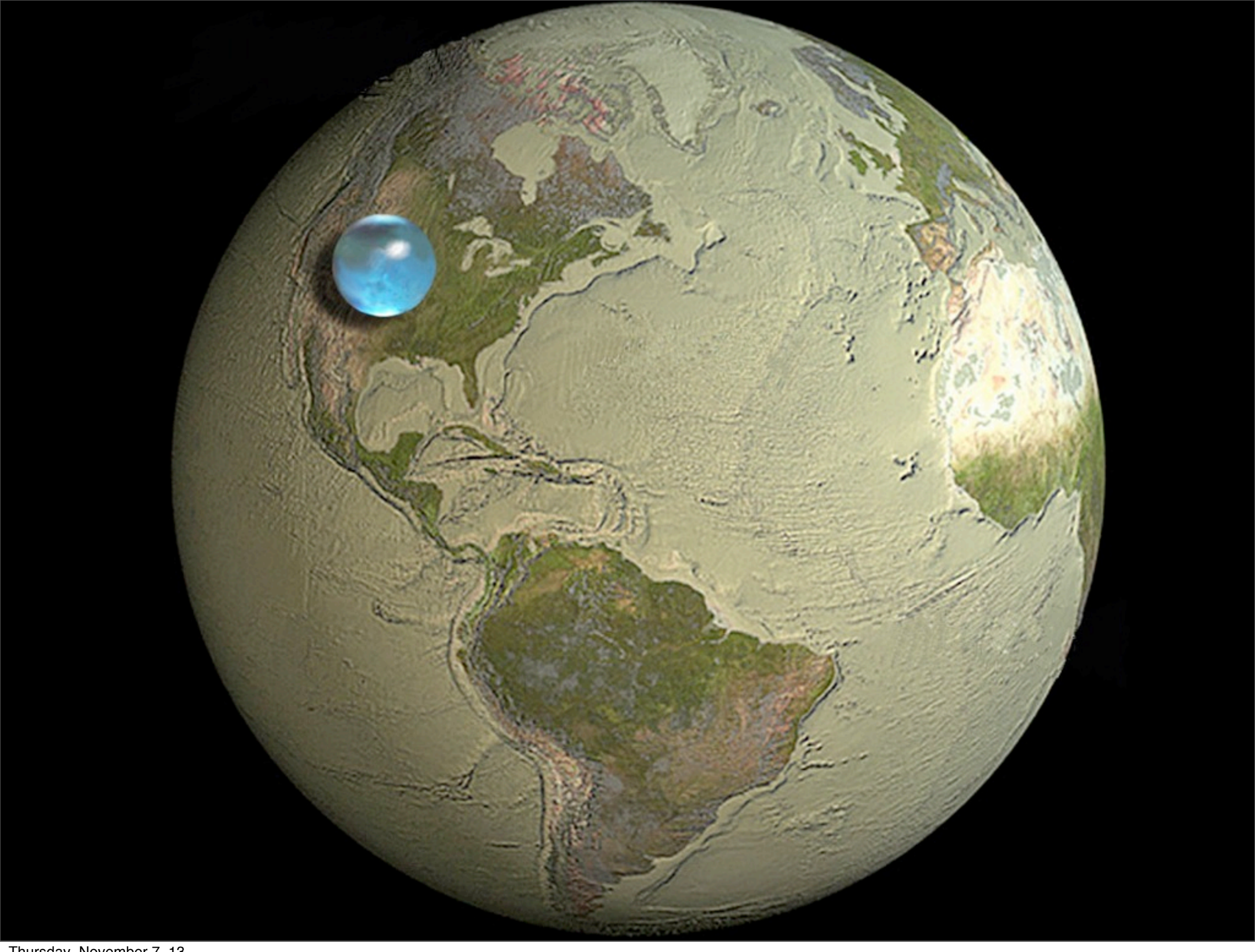
1) Quiz: Metamorphism/Weathering and Sedimentary Rock Review
2) Metamorphism and Metamorphic Rocks
3) In-class exercise Metamorphic Rocks
4) Swiss Alps Movie (45 min)

Next Wednesday

6) Exam2



Think outside the Box!



Metamorphism

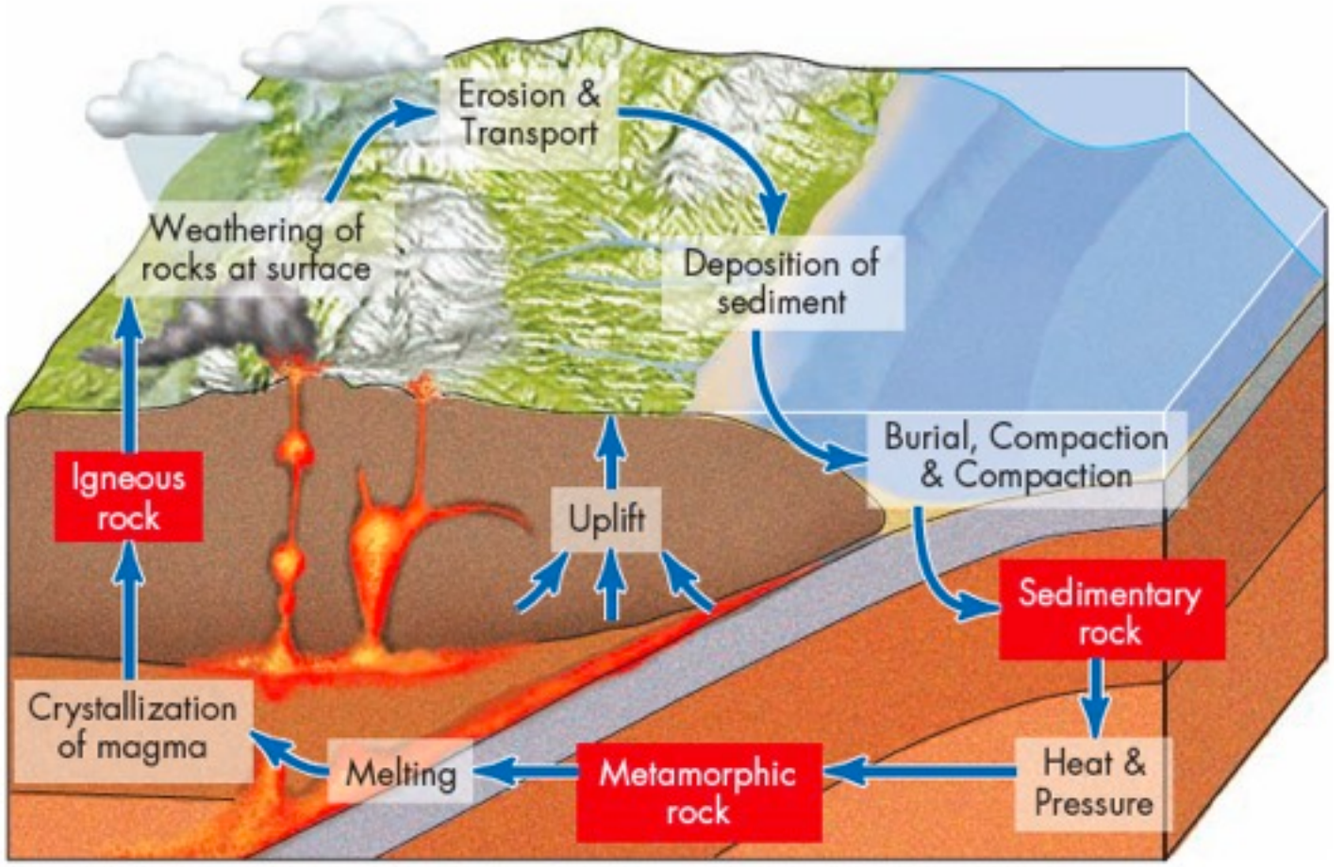
Meta- Greek word, meaning Change.

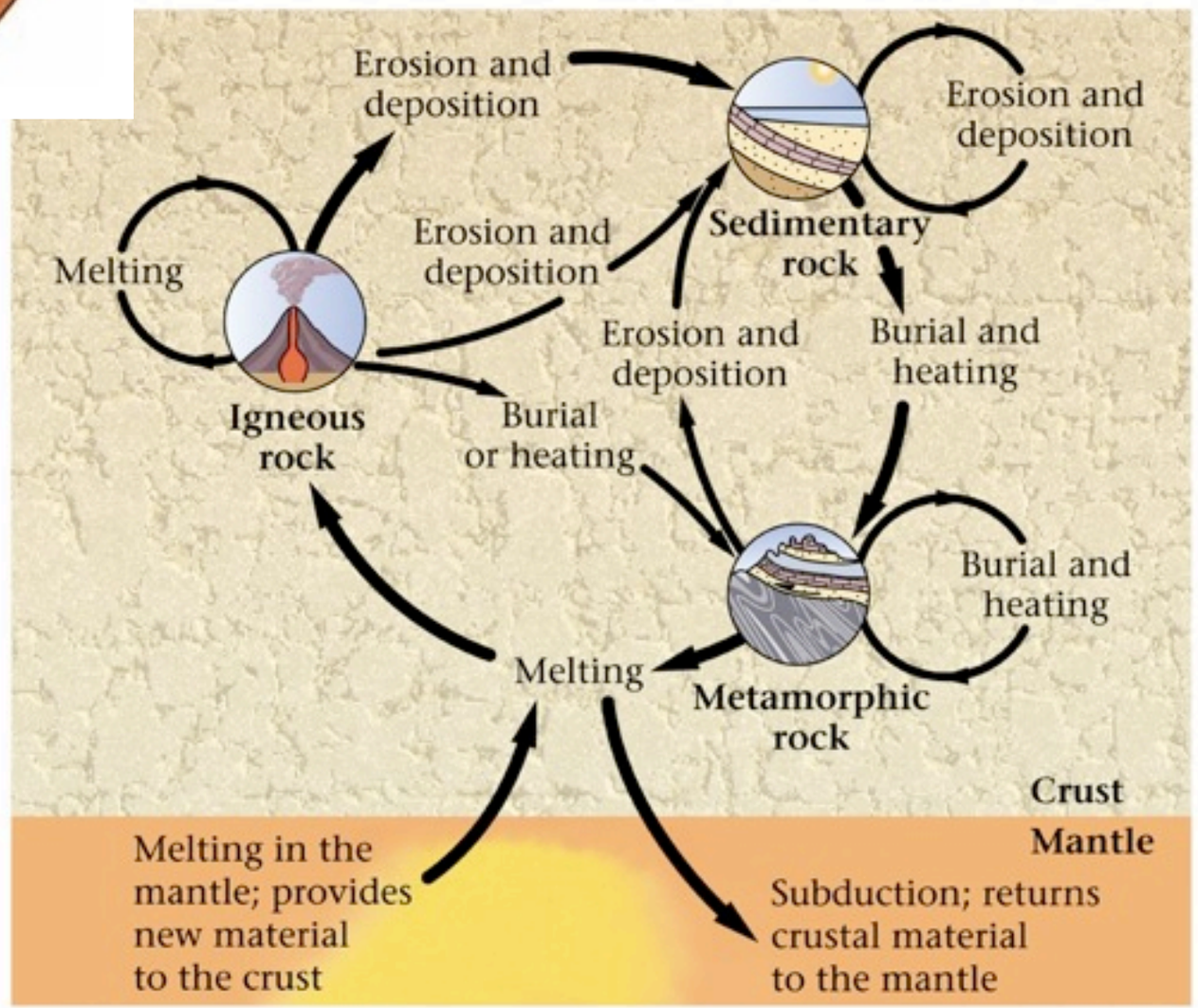
Morph is from the Greek *morphe* meaning *shape* or *form*

ism- the action or result of

Metamorphic Rock- forms when preexisting rock (parent rock), or protolith undergoes solid state change in response to the modification of its environment.

The Rock Cycle





Causes of Metamorphism

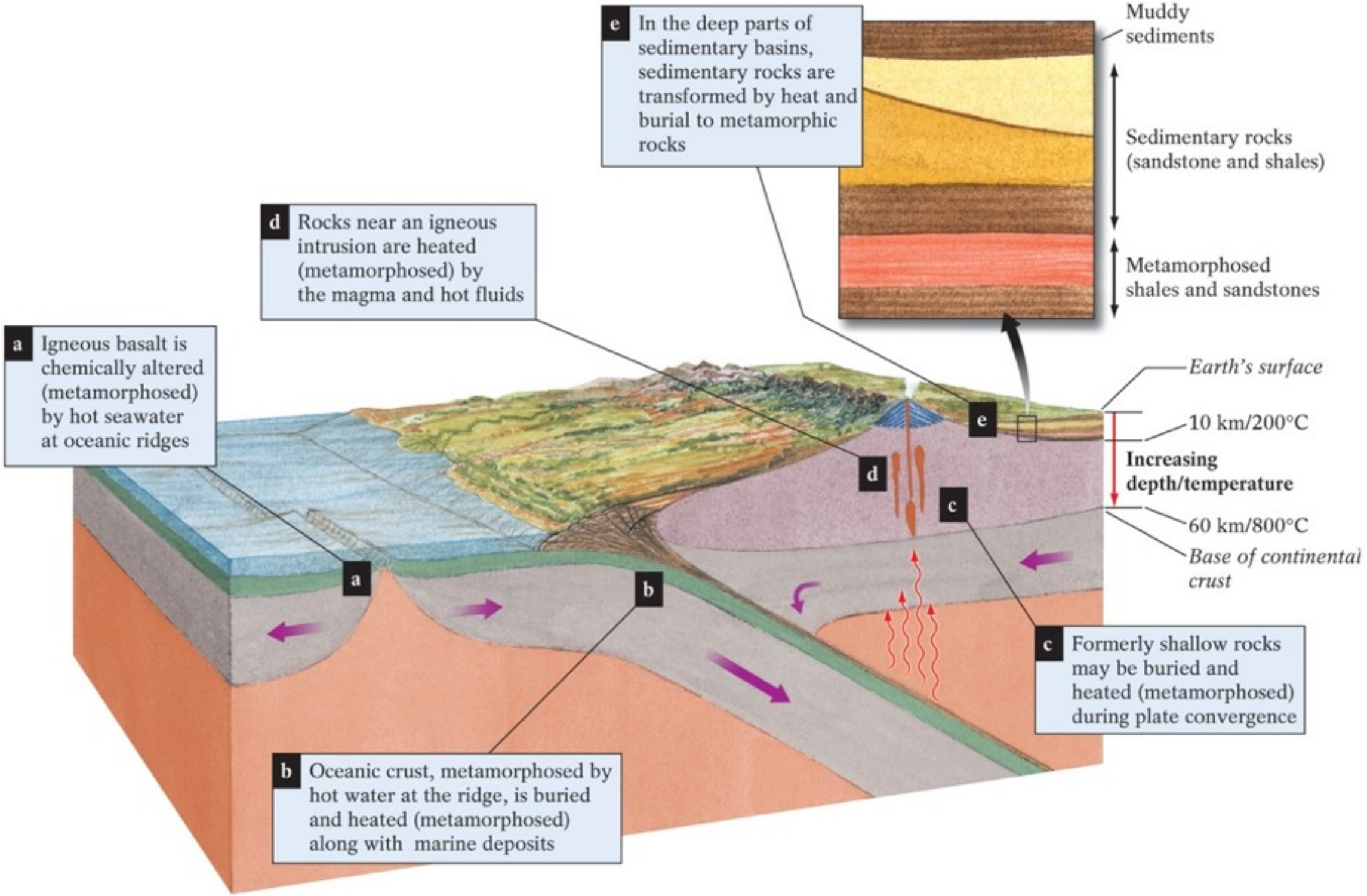
Metamorphism due to heating (200 - 800 C)

Metamorphism due to increased Pressure

Metamorphism due to increase Heat and Pressure

Metamorphism due to Hydrothermal Fluids

Where Metamorphic Rocks Form



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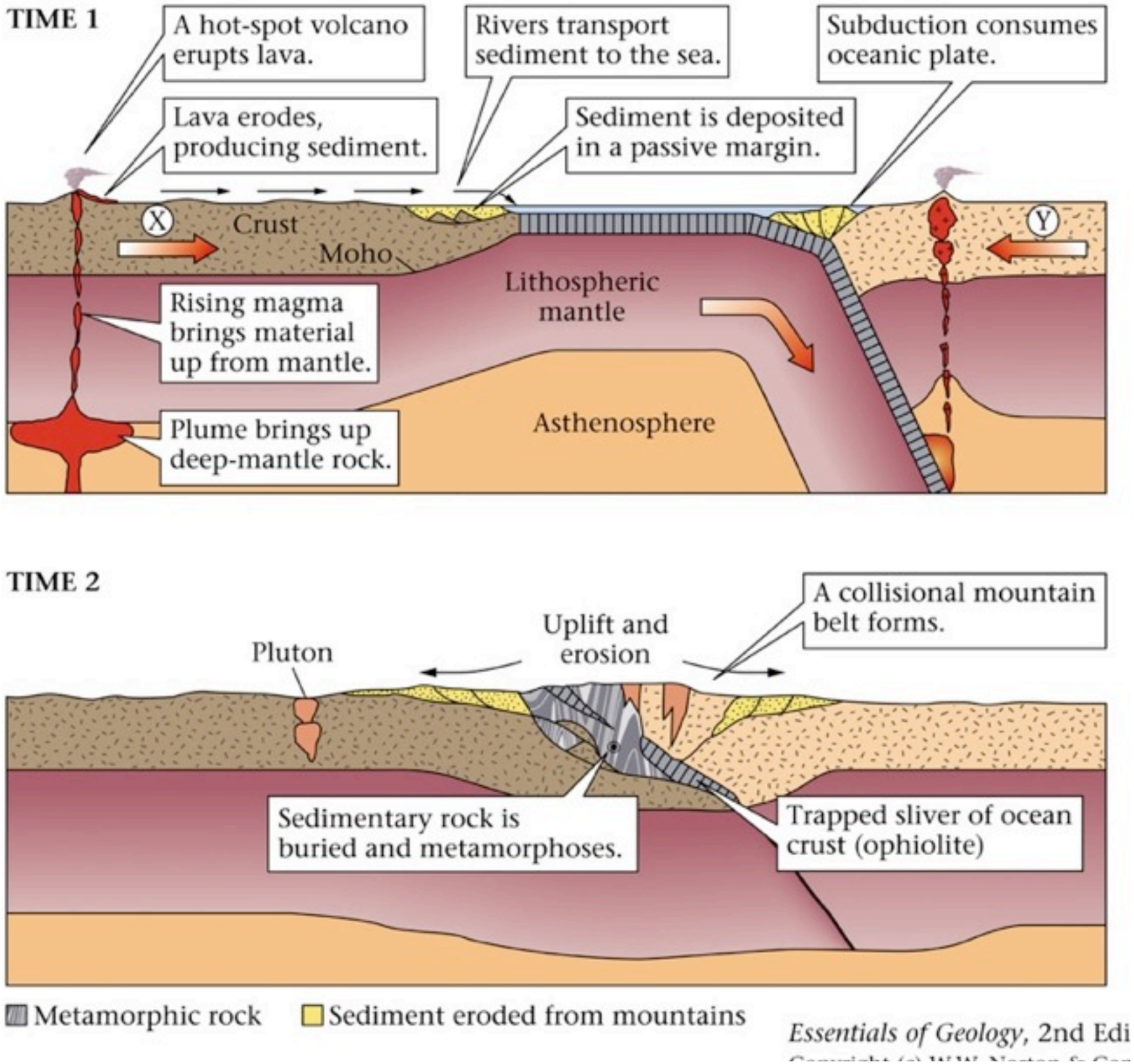

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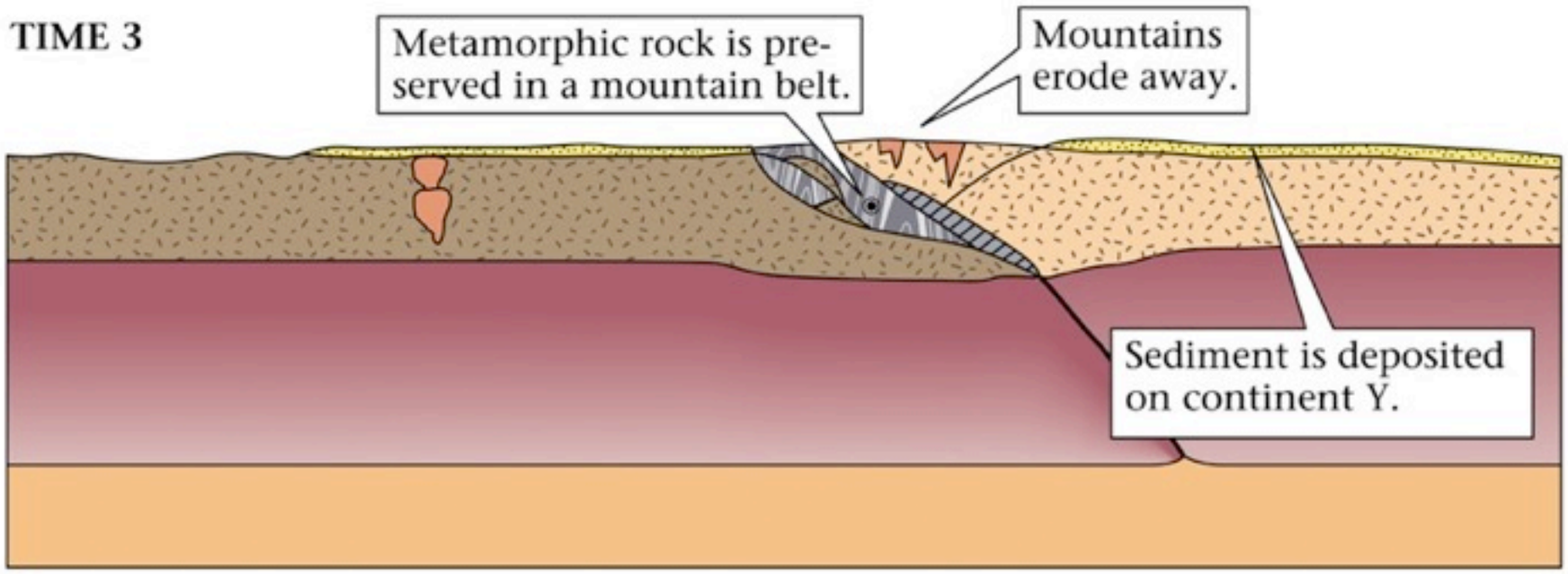
Where Metamorphic Rocks Form



Where Metamorphic Rocks are Exposed

Least abundant rock
at the Earths
Surface
Form at Temp
200-800 C and
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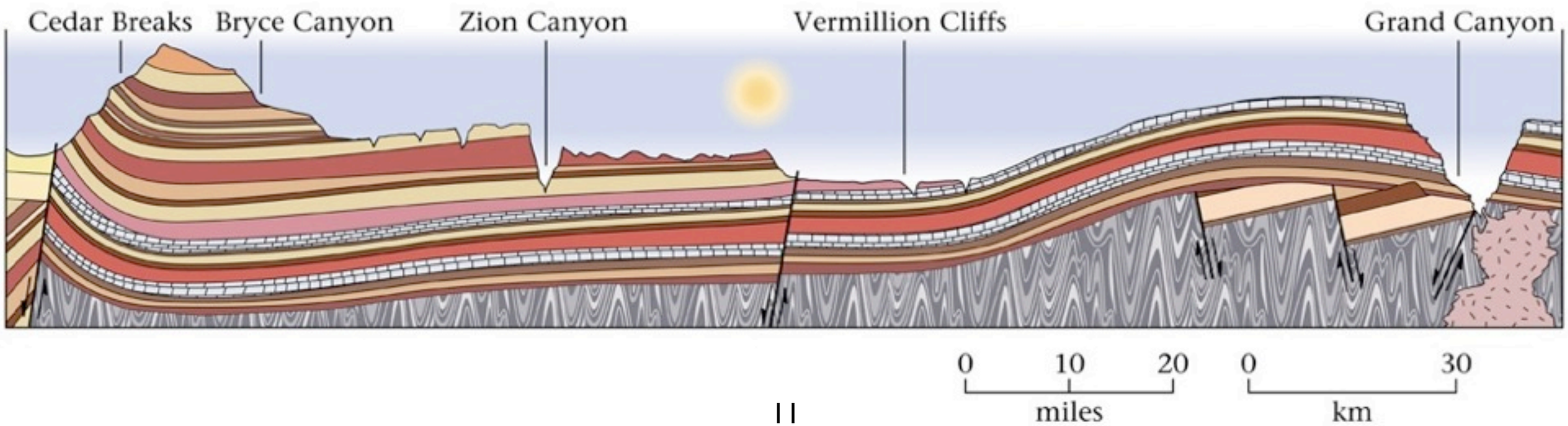
However, the continental curst is predominately composed of metamorphic rocks which underlie a thin veneer of sedimentary rocks



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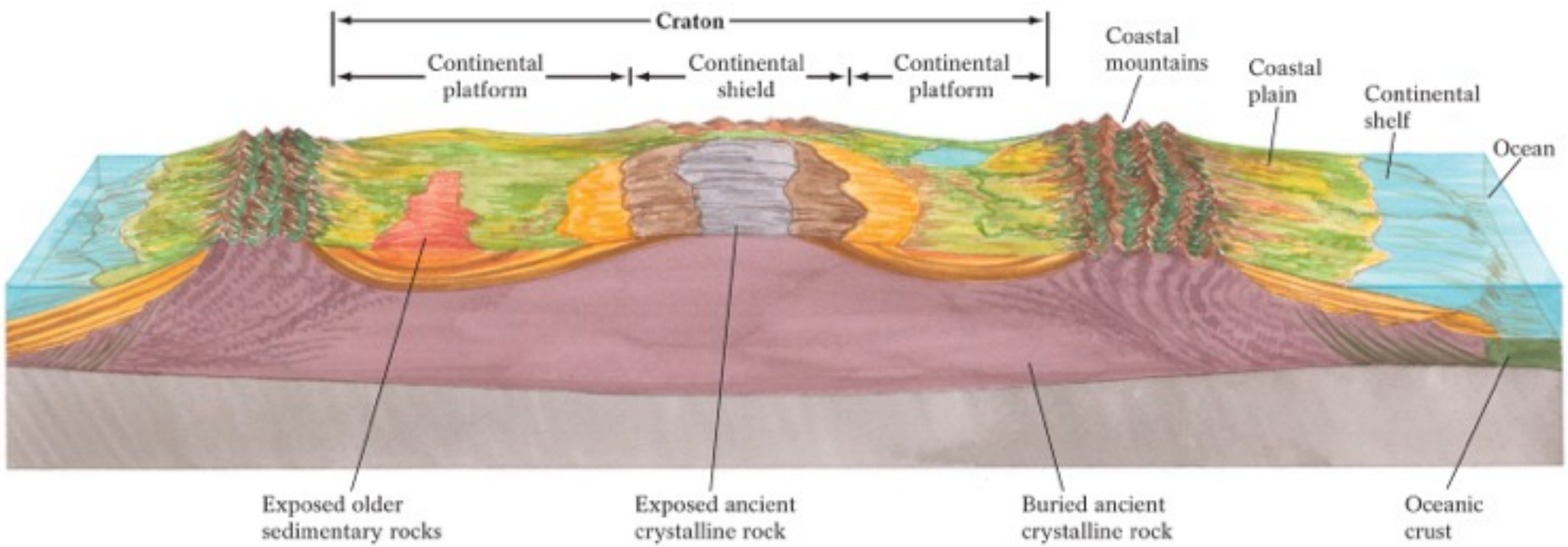

2 Types of Metamorphic Rocks

Foliated(layered) and Non-Foliated

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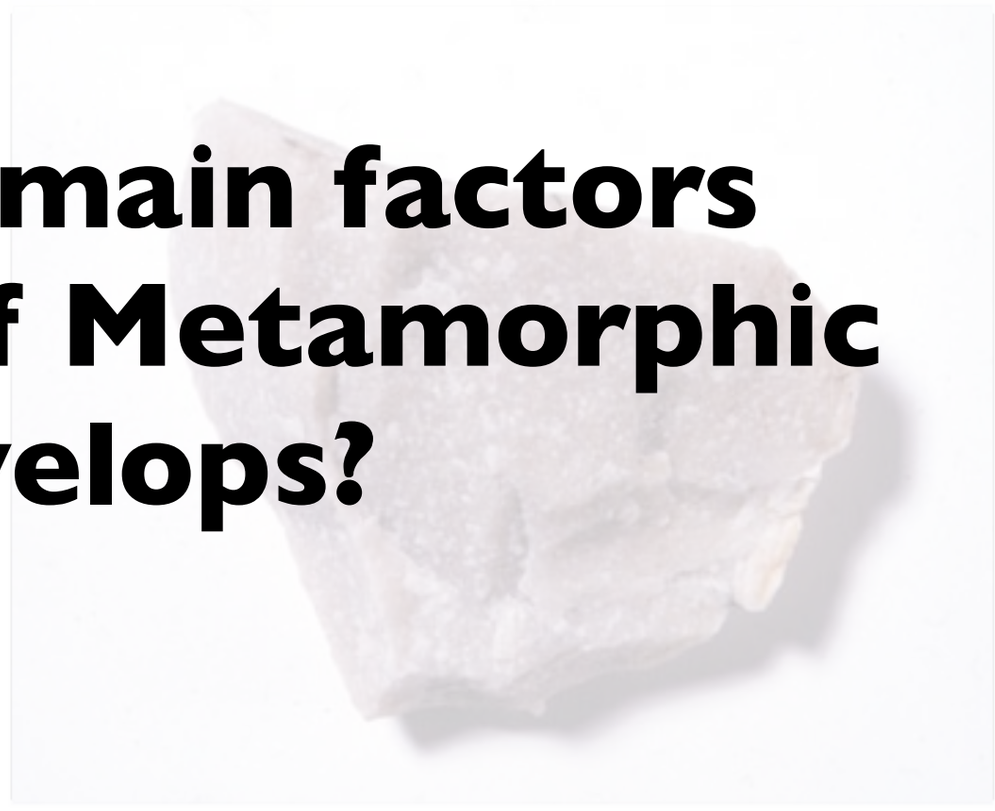
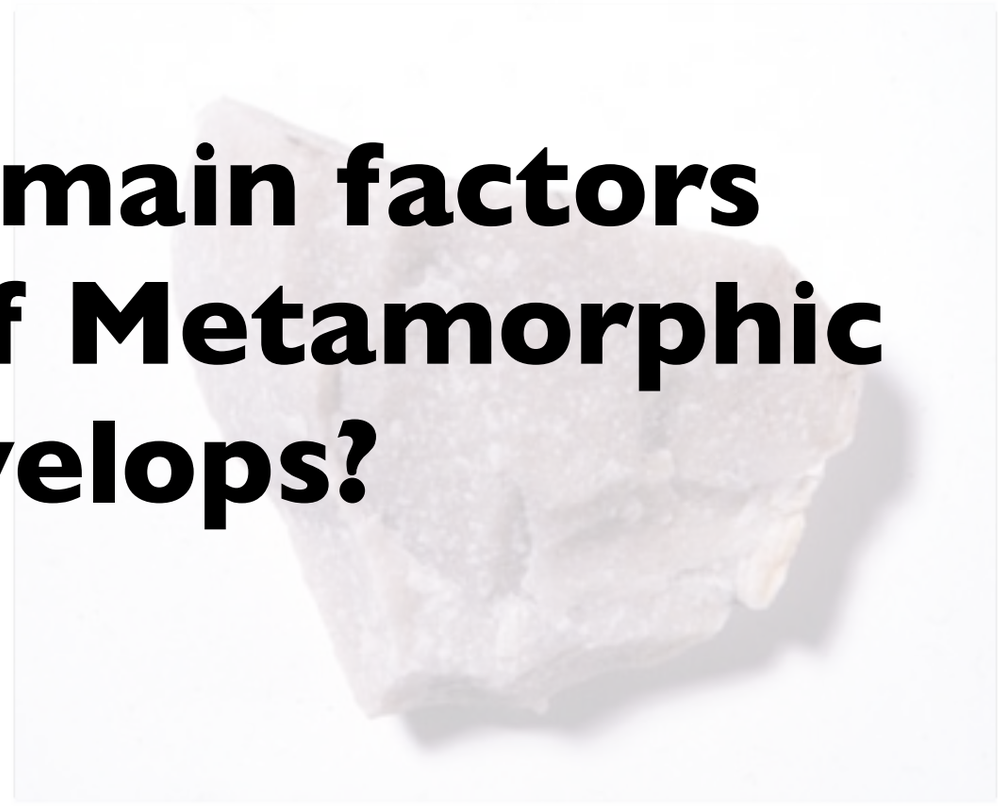
Foliated(layered) and Non-Foliated



What are the three main factors controlling the type of Metamorphic Rock that develops?

2 Types of Metamorphic Rocks

Foliated(layered) and Non-Foliated



What are the three main factors controlling the type of Metamorphic Rock that develops?

Temperature Pressure Composition

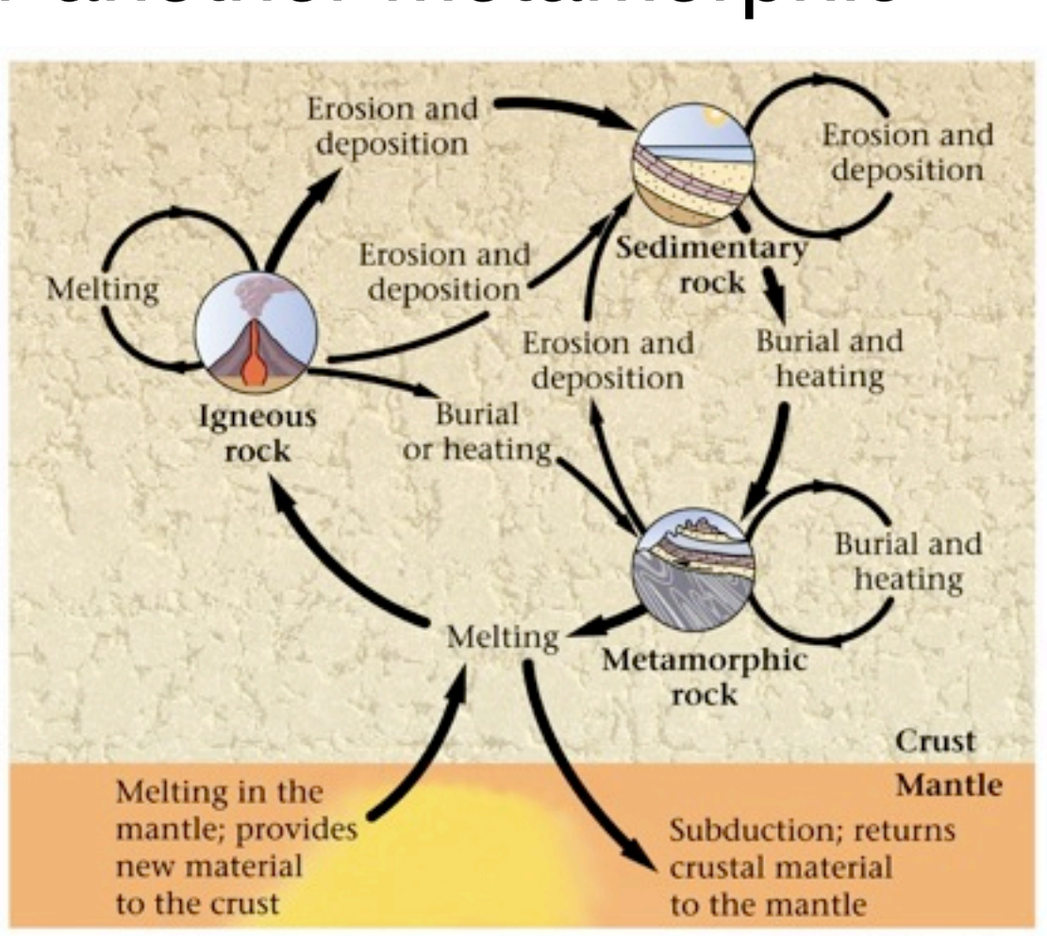
and Presence of Water

Protolith = Composition

Proto- means first in time; original.

lith is the Greek *word for stone*

Protolith refers to the original rock before metamorphism it could be an igneous, sedimentary, or another metamorphic rock.



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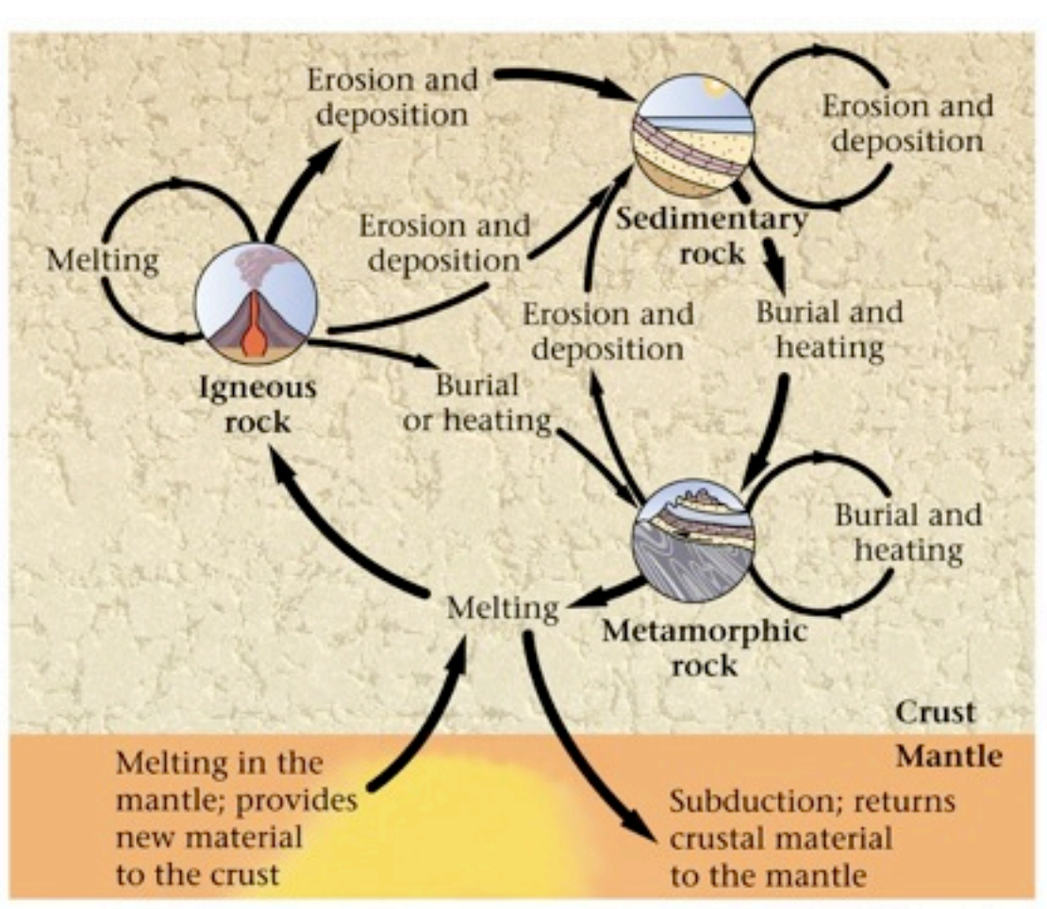
Igneous- **P**retty **G**ood **D**iet **G**ranola **BAR**



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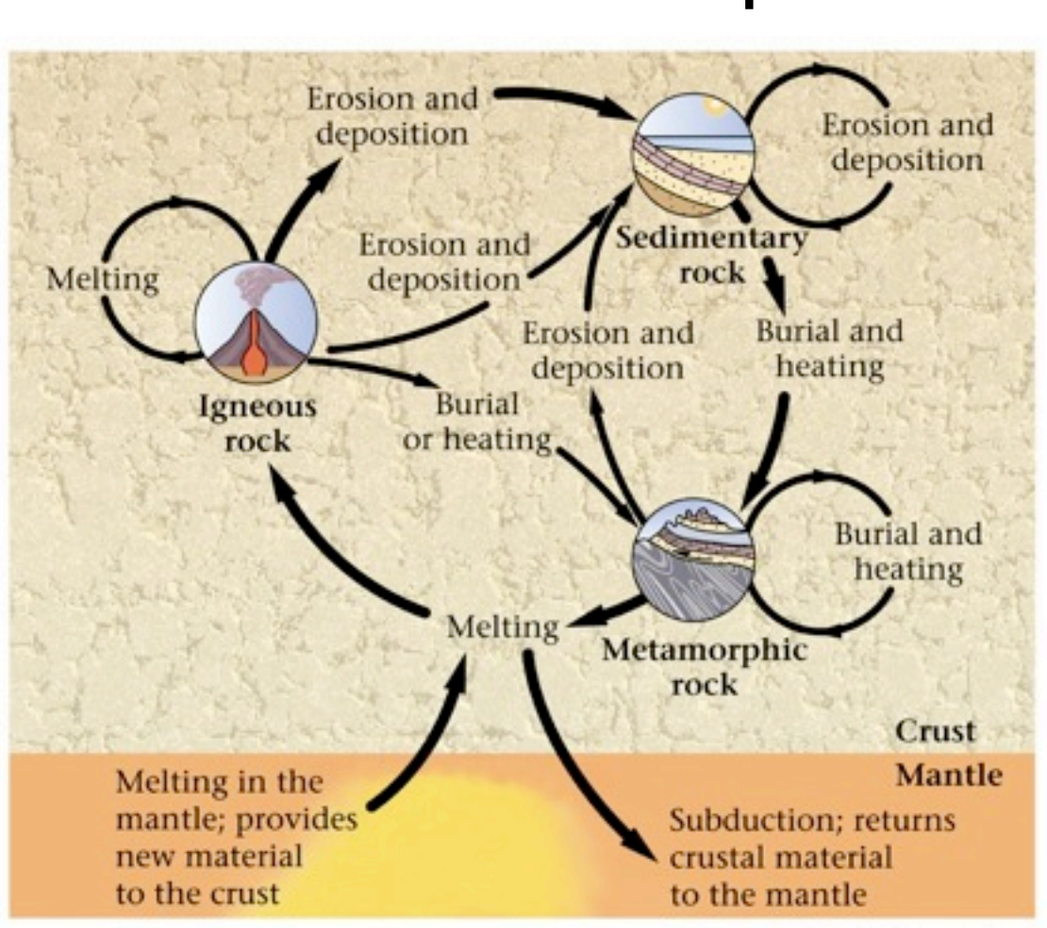
Sedimentary- **Conglomerate, Sandstone, mud/claystone, limestone**



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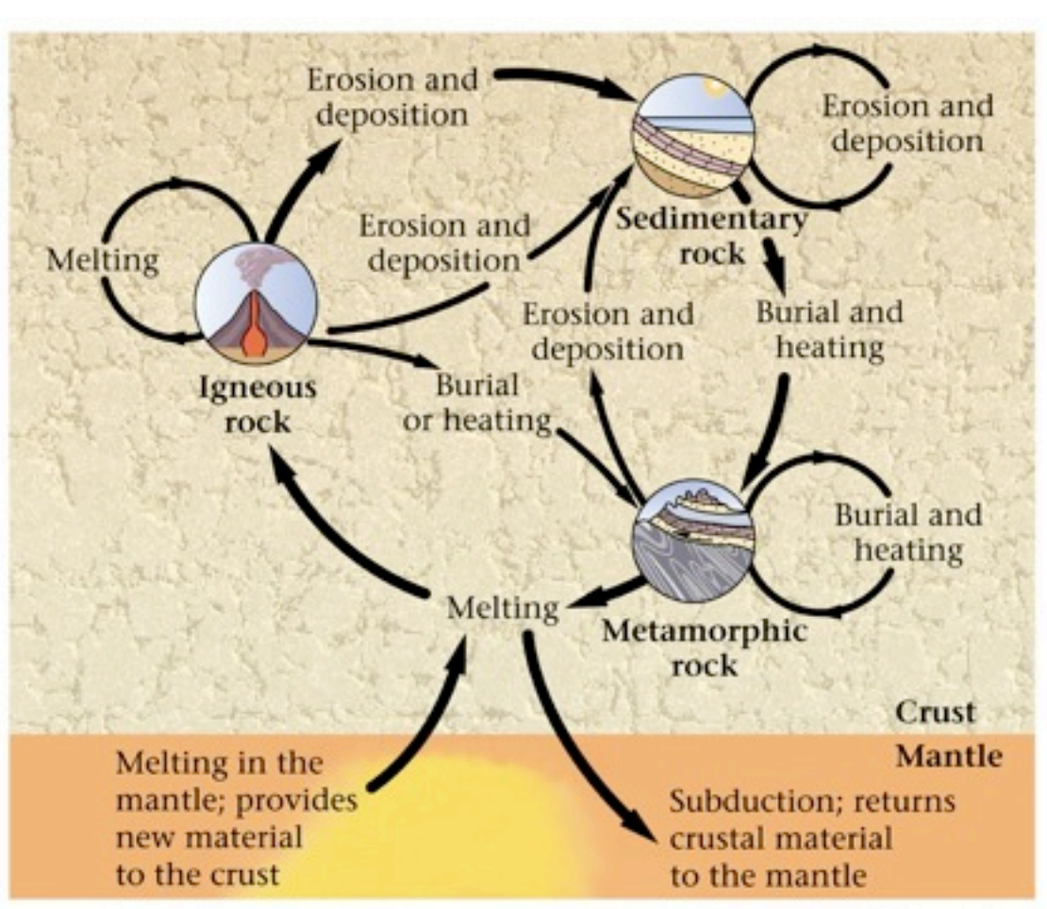
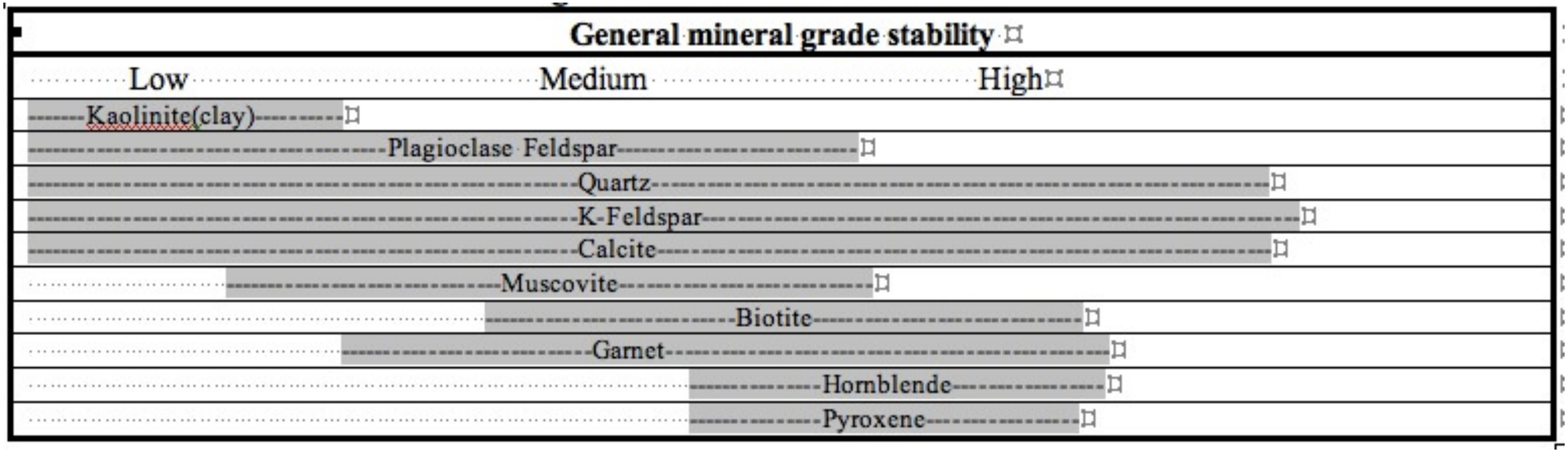
Metamorphic



Generalized Mineral Stability for Different Metamorphic Grades



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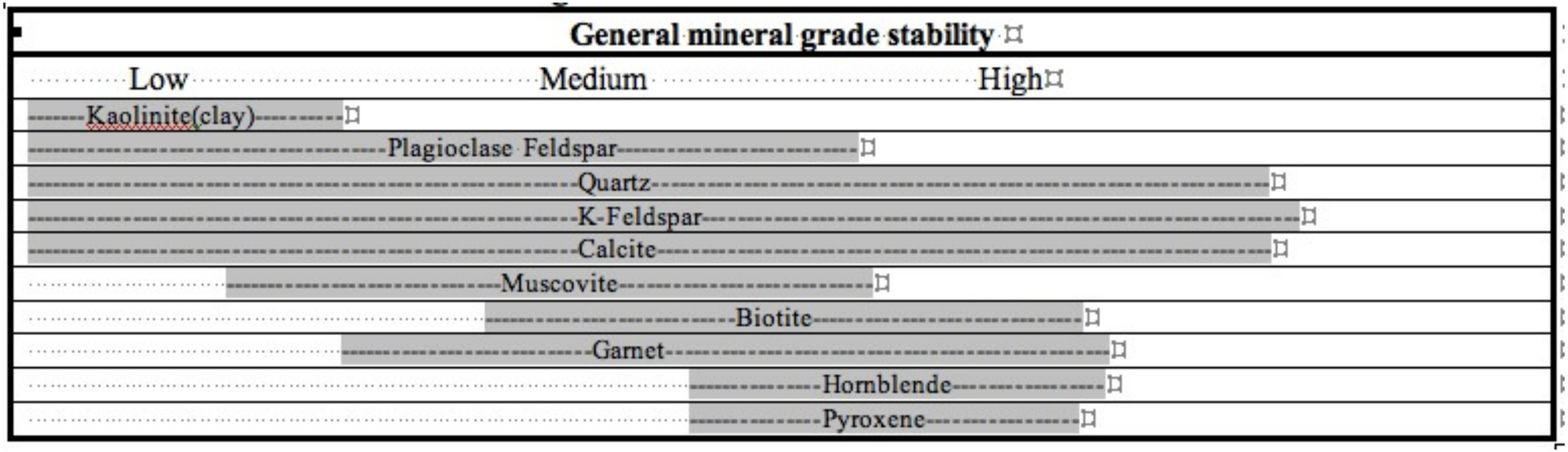

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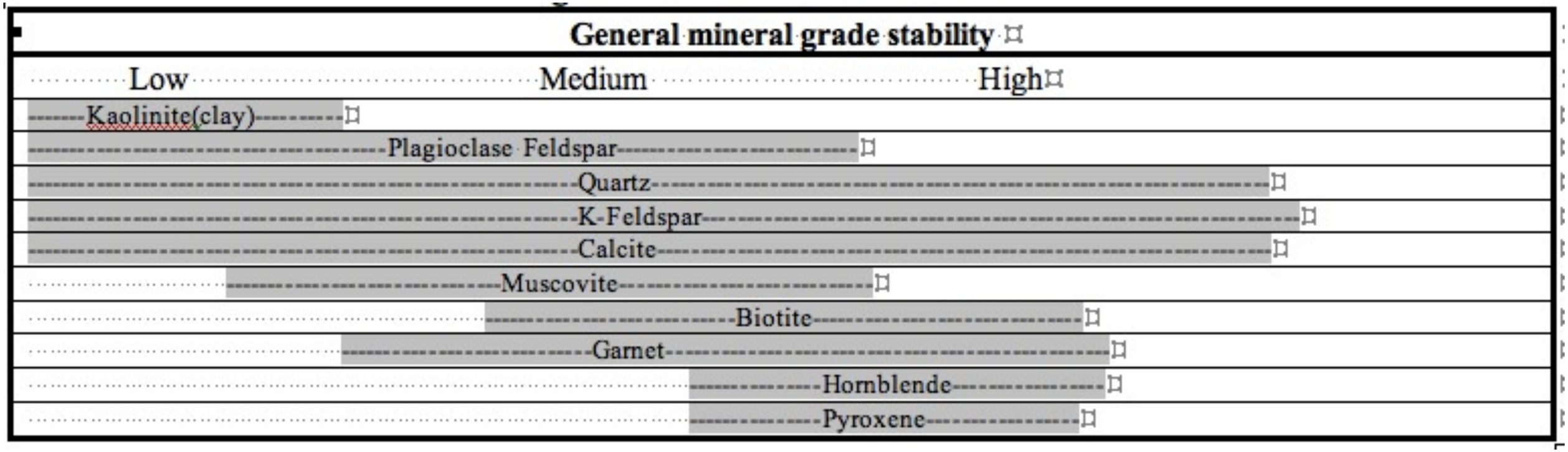

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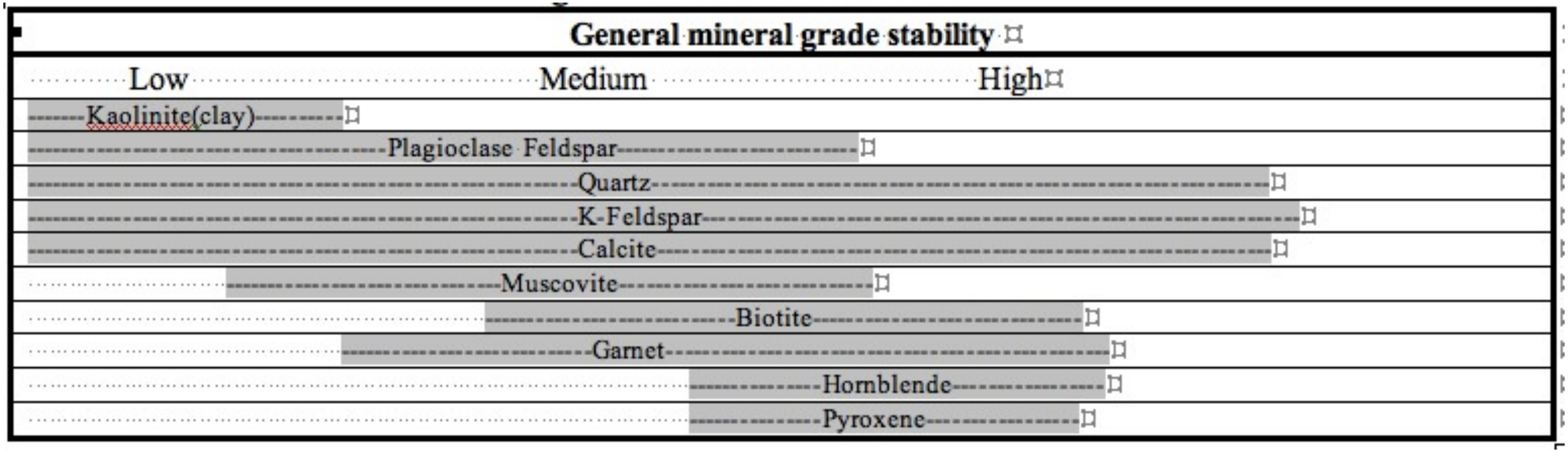

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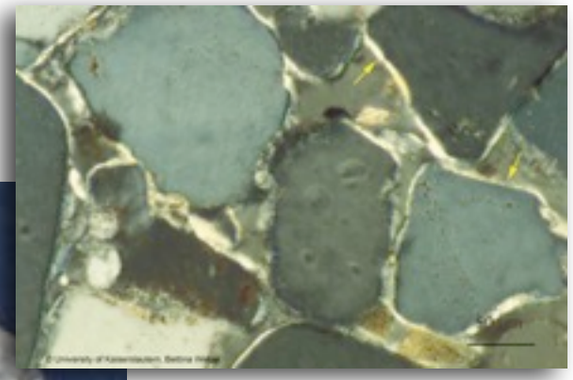
Temperature Pressure Composition

and Presence of Water

Non-Foliated Metamorphic Rocks

Protolith

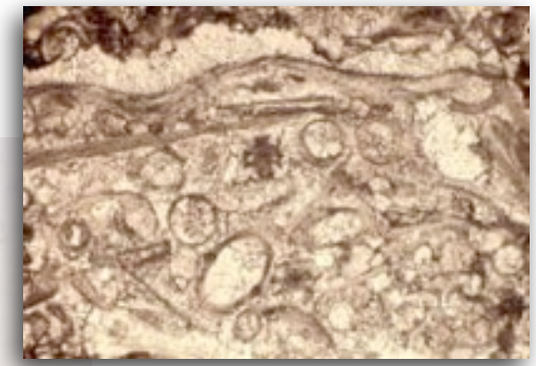
Sandstone



Meta Rx

Quartzite

Limestone

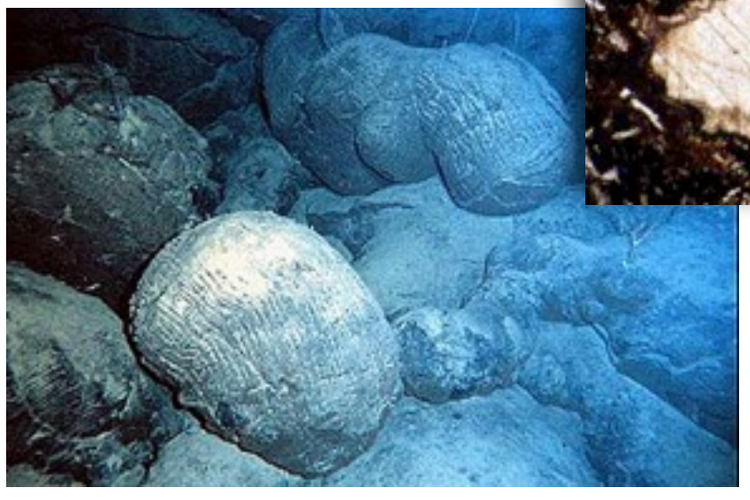


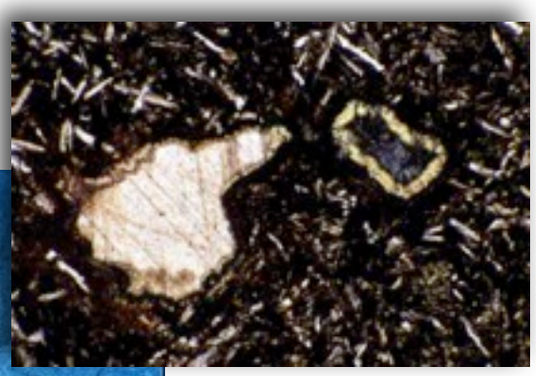
Marble

Non-Foliated Metamorphic Rocks

Protolith

Basalt





Plagioclase Feldspar

Medium-Grade

Meta Rx

Greenstone

Epidote
Actinolite
Chlorite

High Grade

Blue Schist

Very
High
Grade

Eclogite

Pyroxene
Garnet

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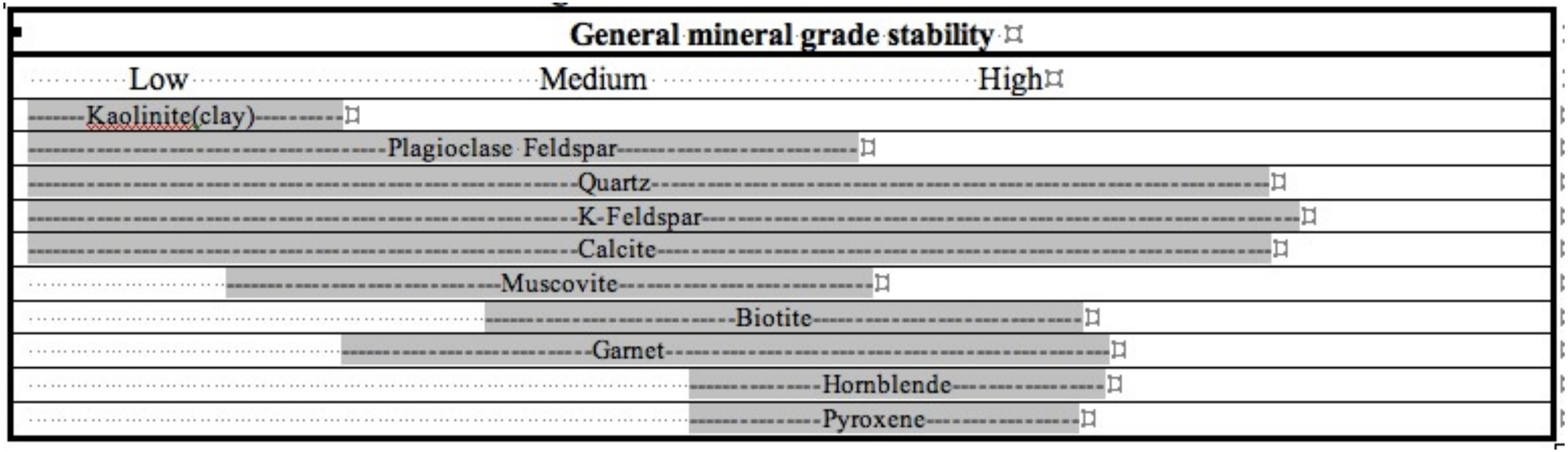

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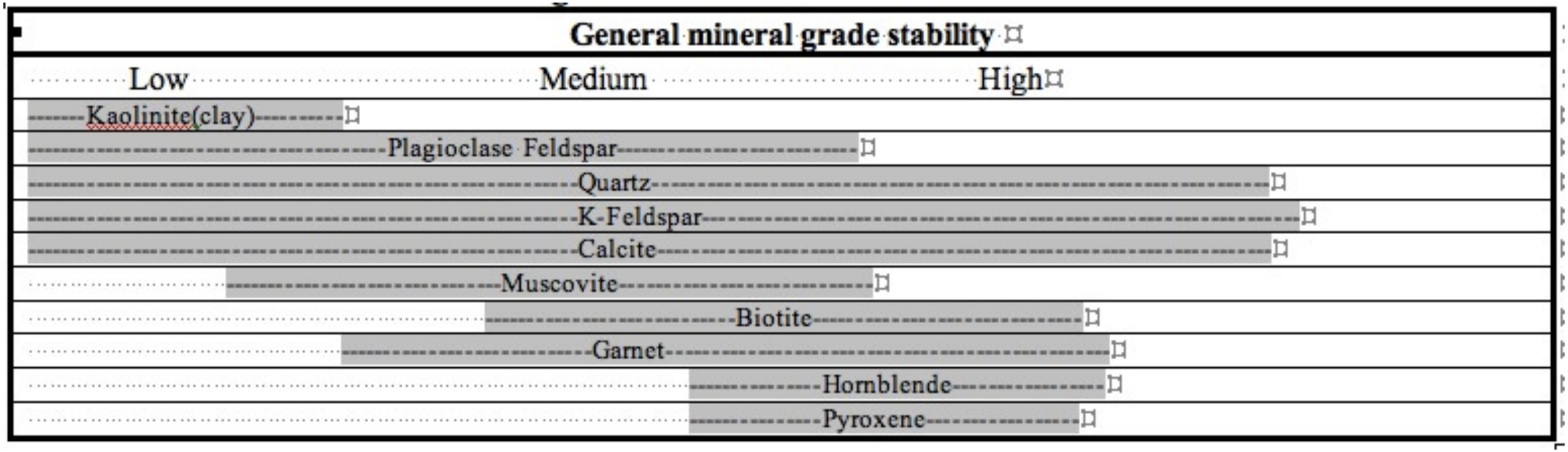

Igneous- **P**retty **G**ood **D**iet **G**ranola **BAR**

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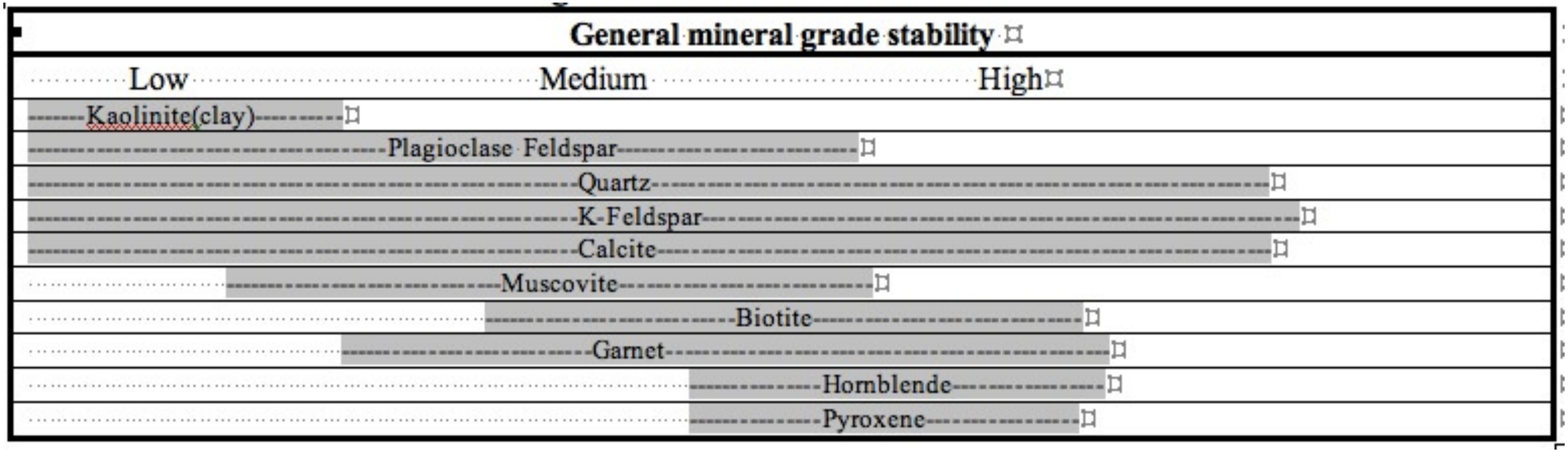


Igneous- **P**retty **G**ood **D**iet **G**ranola **BAR**

Sedimentary- **Conglomerate, Sandstone, mud/claystone, limestone**

Foliated Metamorphic Rocks

Sedimentary

Parent/Protolith

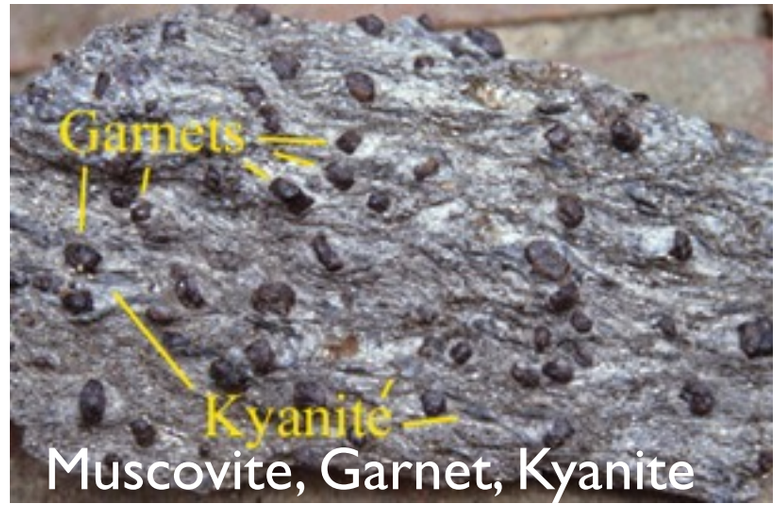
Mudstone/shale

Grain size Increasing

Slate

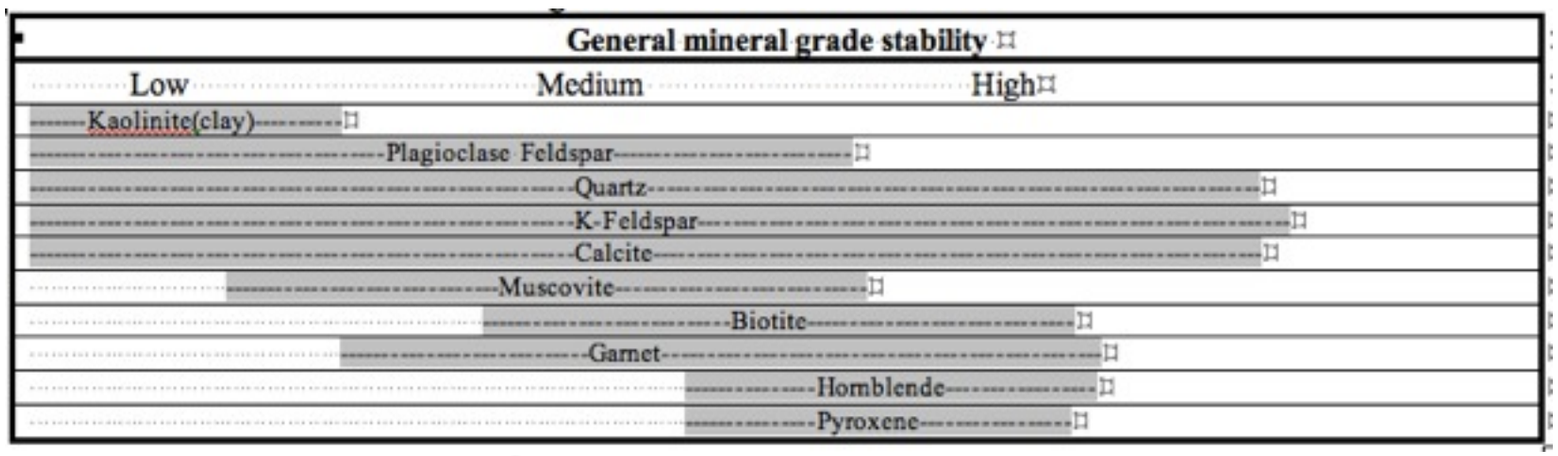
Phyllite

Schist



Mineral Differentiation

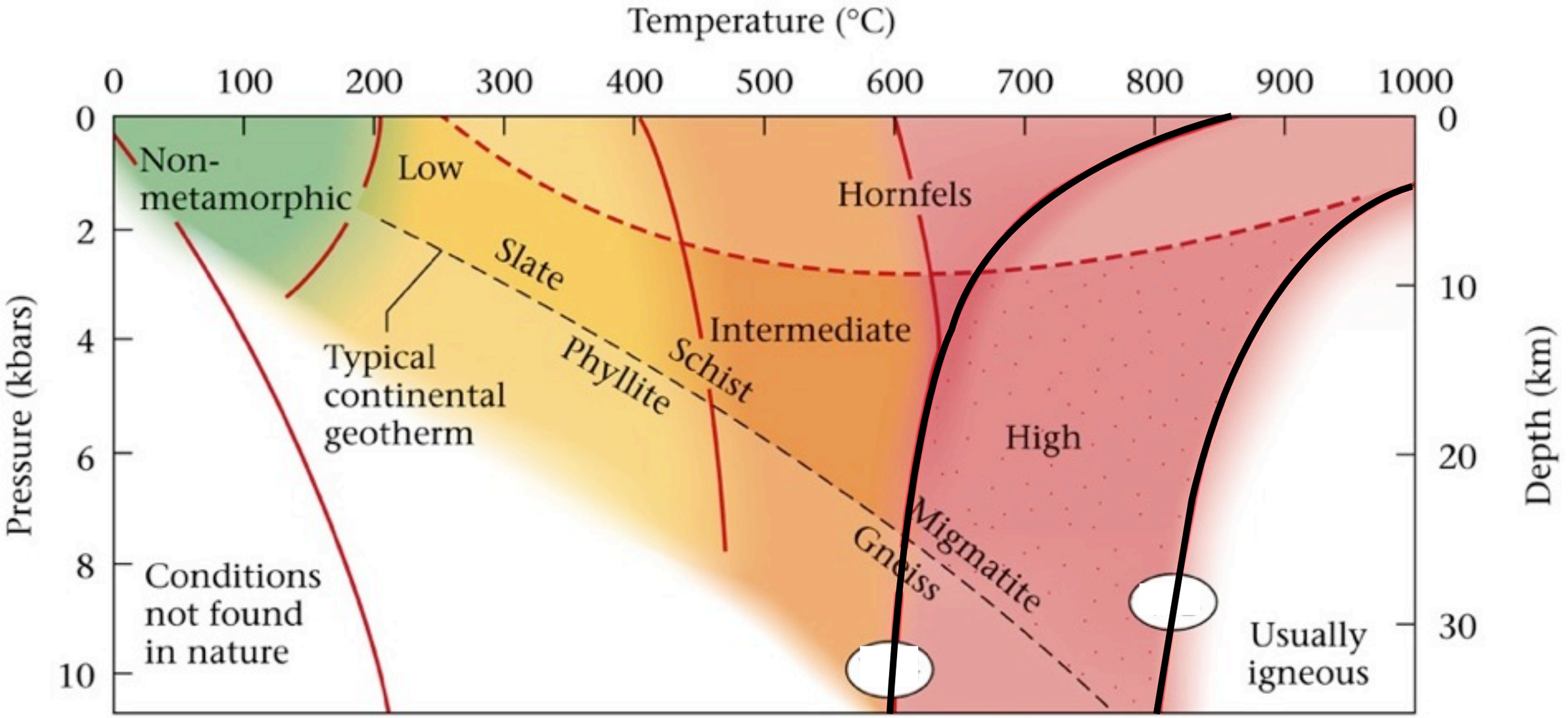
Gneiss



Degree of Metamorphism Increasing

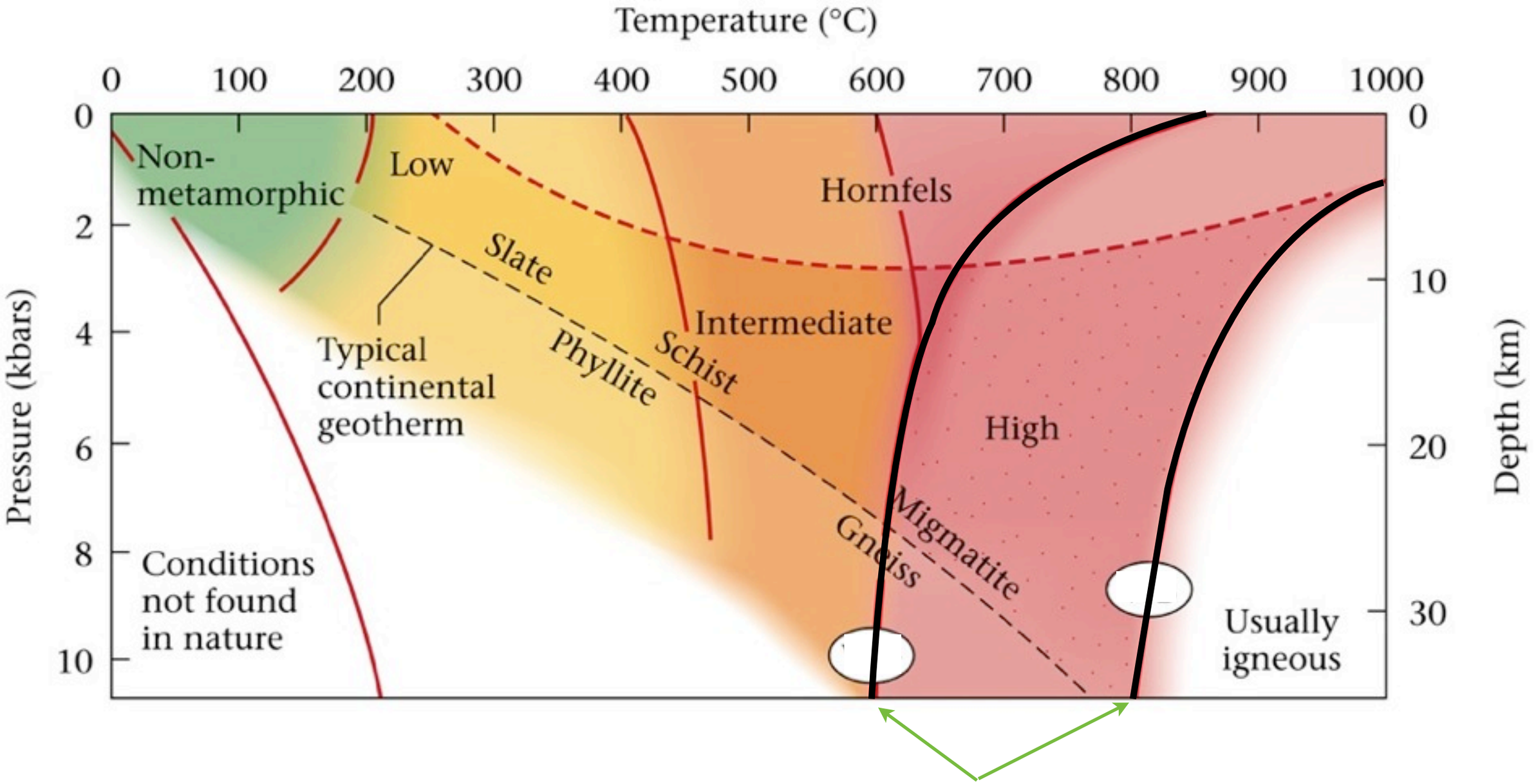
No Melting!

Metamorphic Rock Stability Diagram



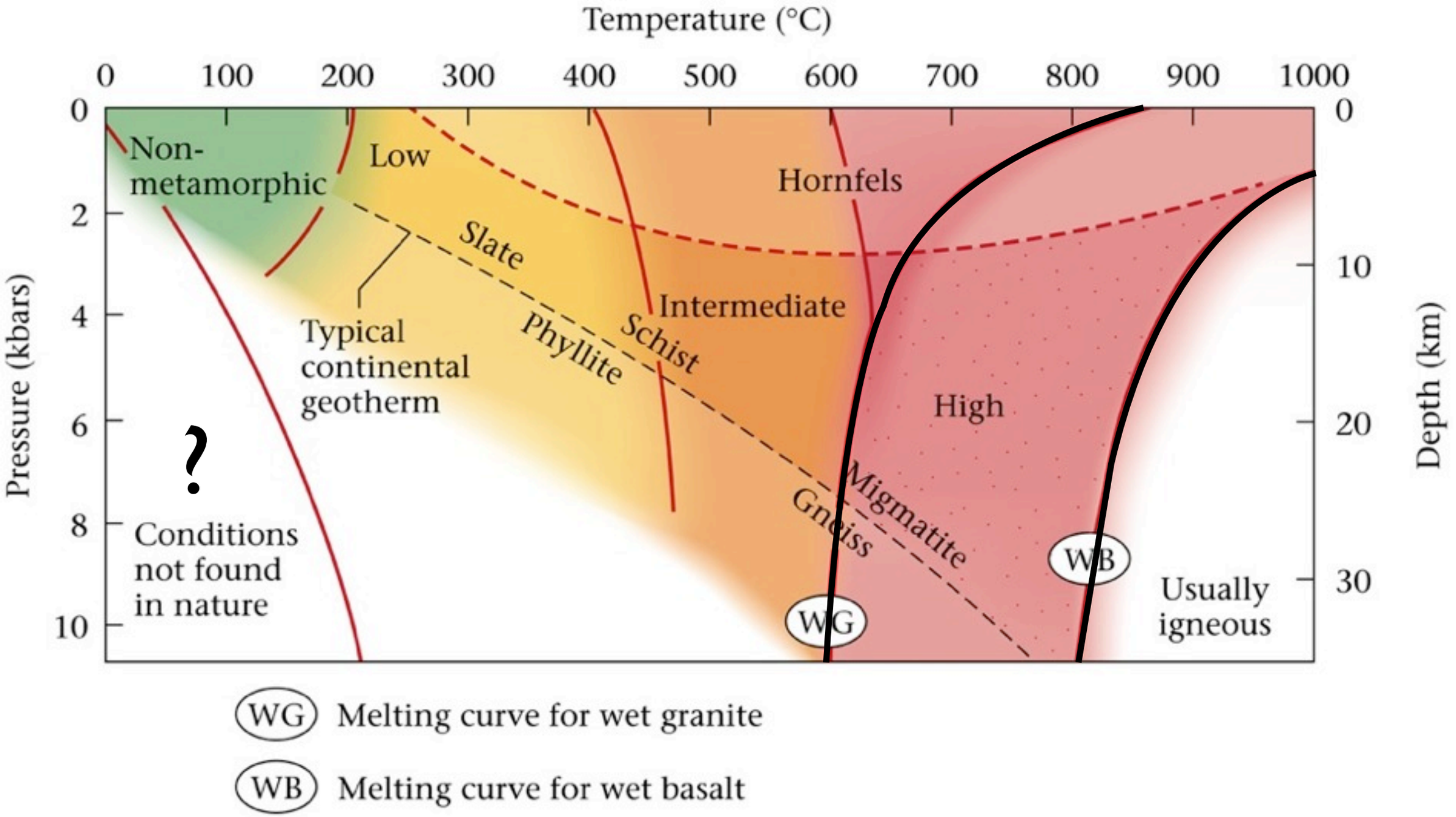
Does anything look familiar here?

Metamorphic Rock Stability Diagram



Melting Curves
Solidi for Granite and Basalt

Metamorphic Rock Stability Diagram



Causes of Metamorphism

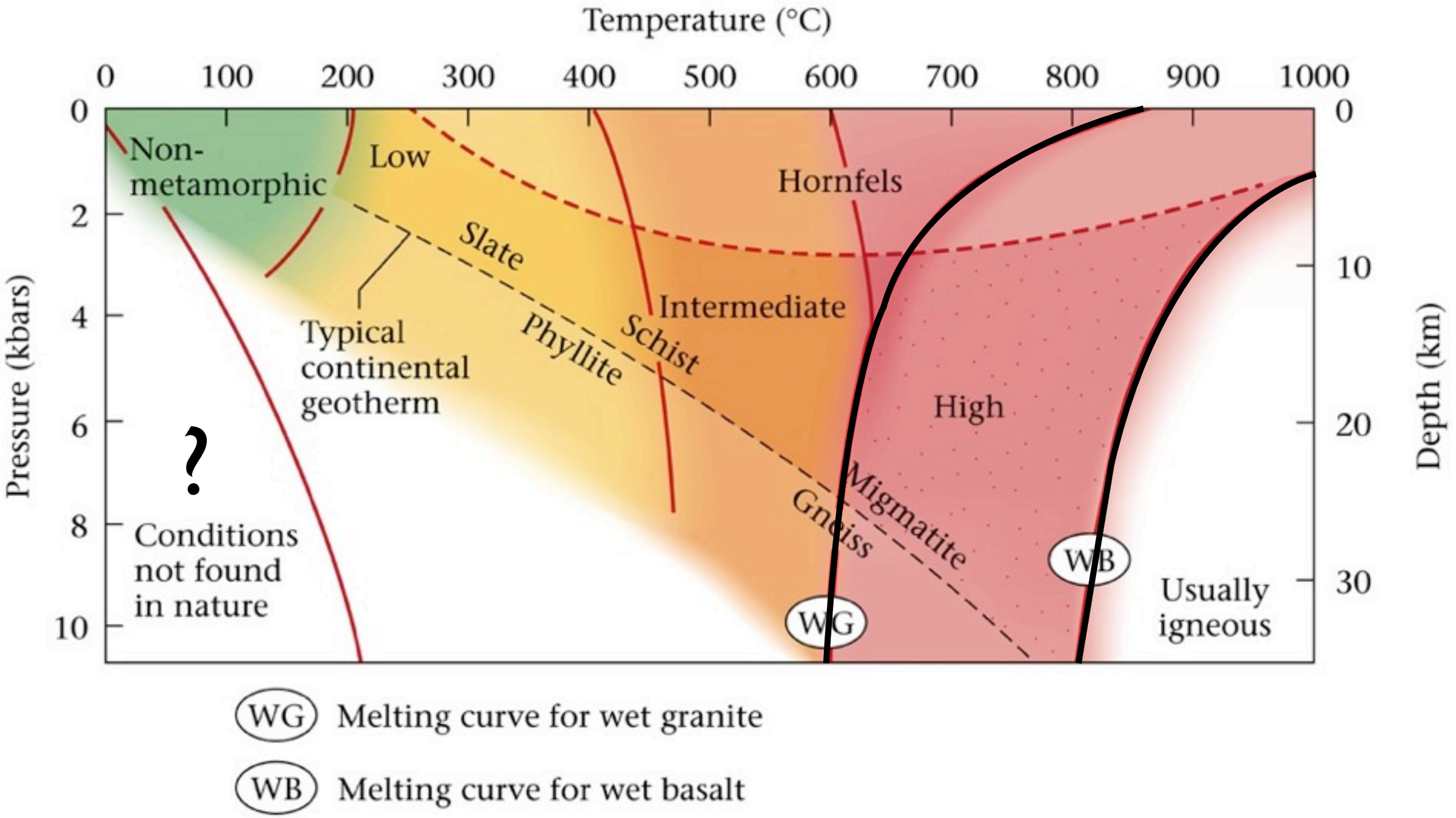
Metamorphism due to heating (200-800 C)

Metamorphism due to increased Pressure

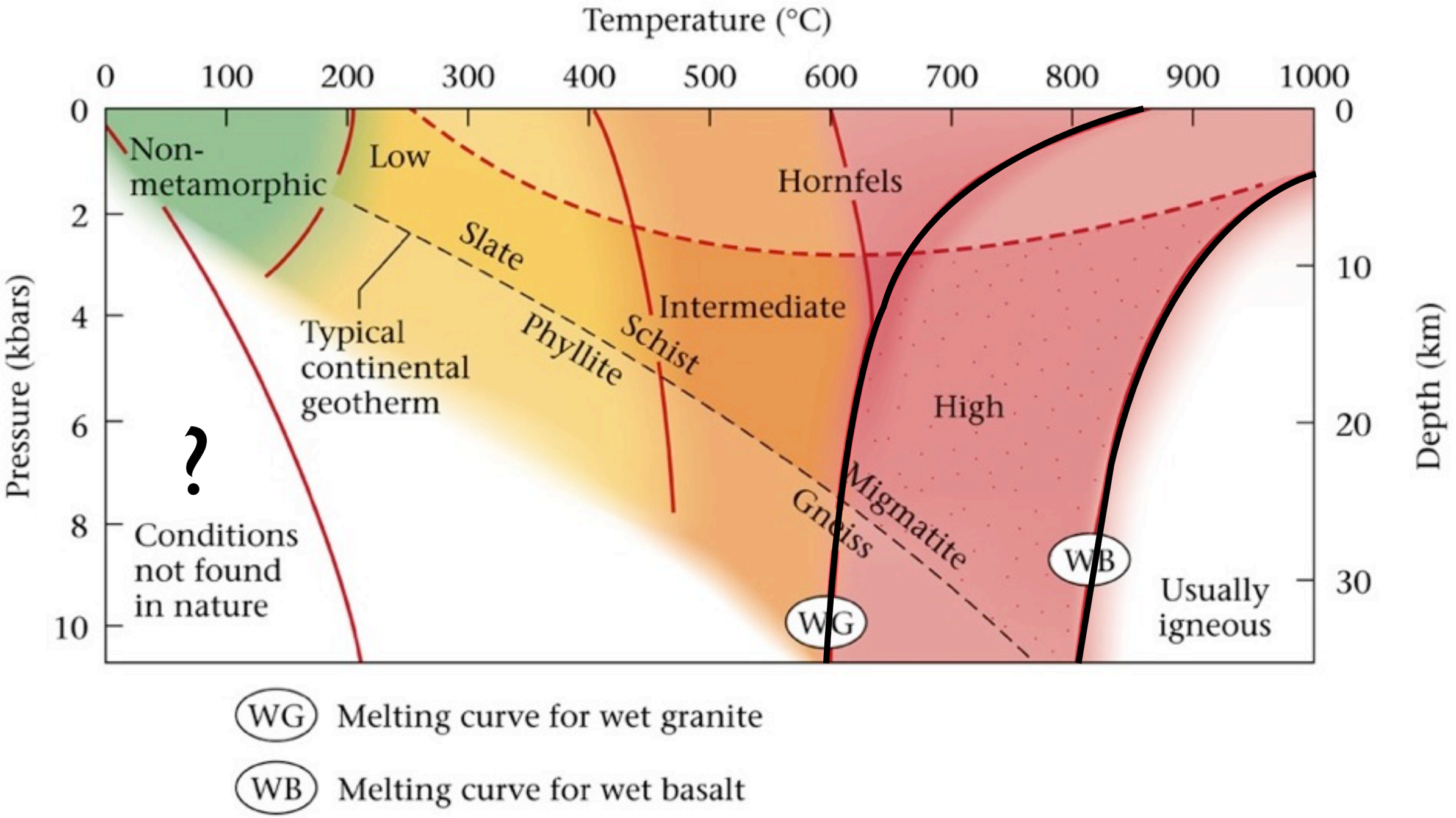
Metamorphism due to increase Heat and Pressure

Metamorphism to Hydrothermal Fluids

Increased Heat and Pressure



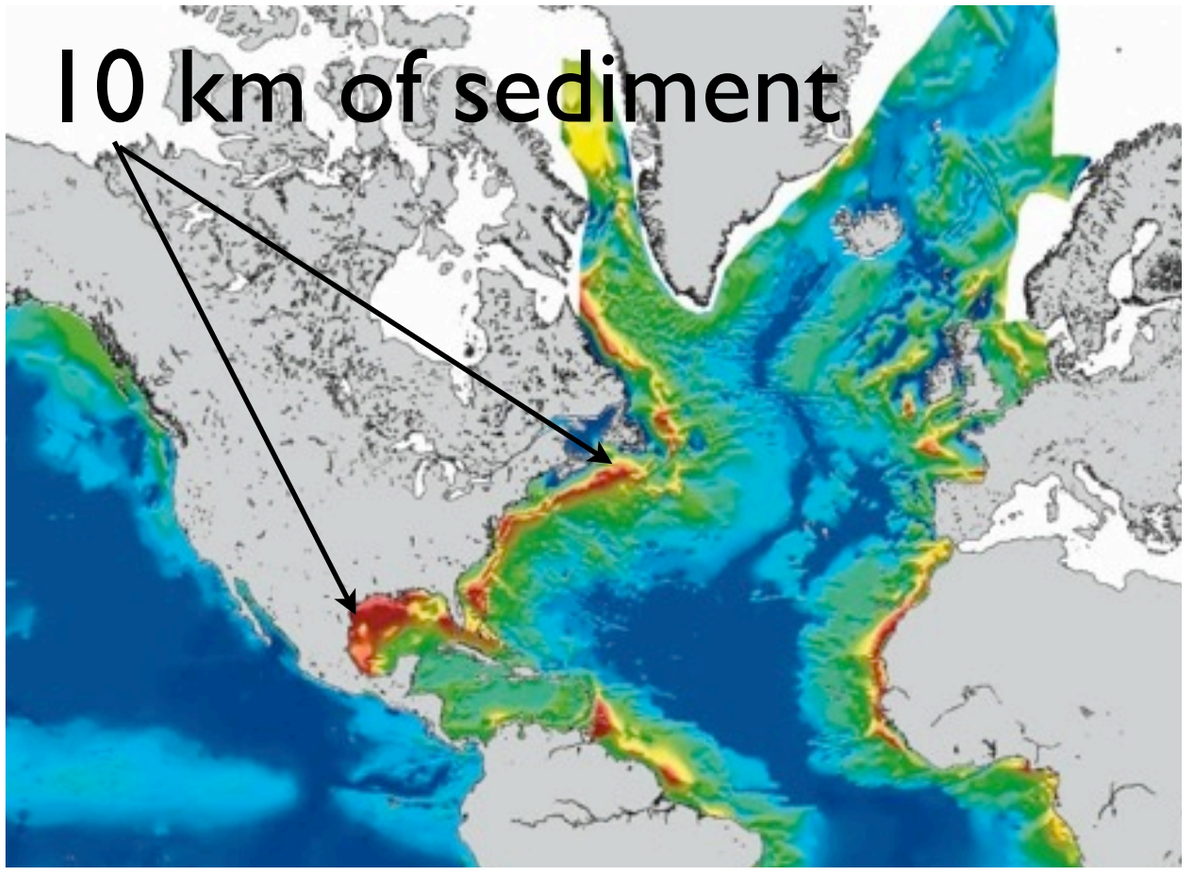
Increased Heat and Pressure

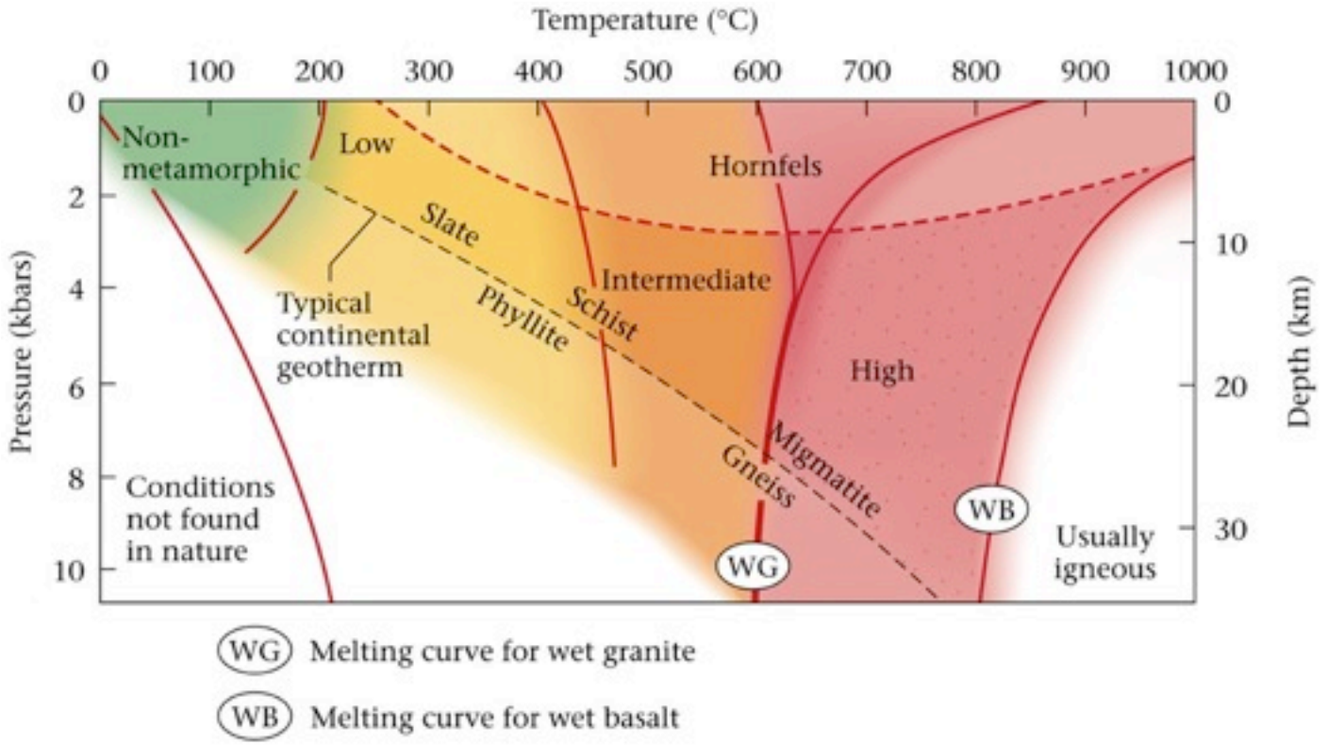


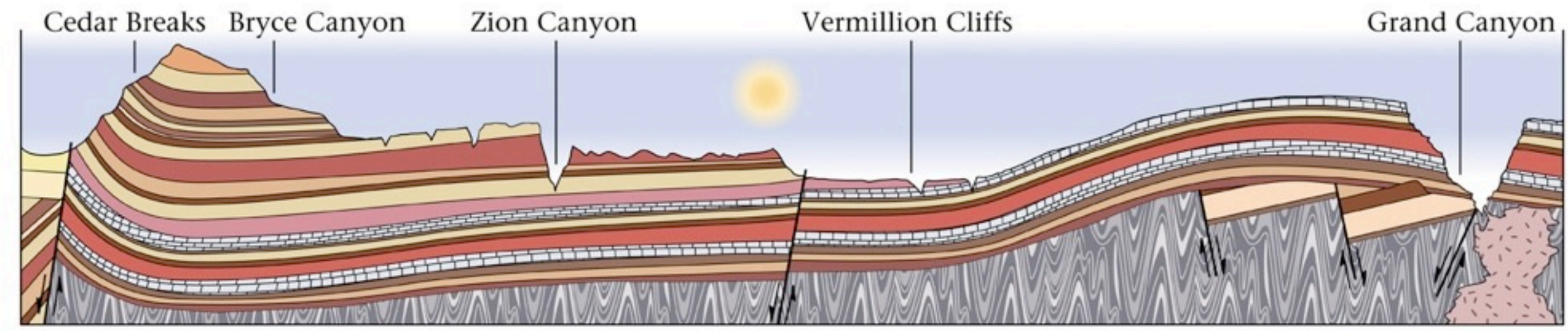
Burial by sedimentation - Burial by tectonics

Hydrostatic stress

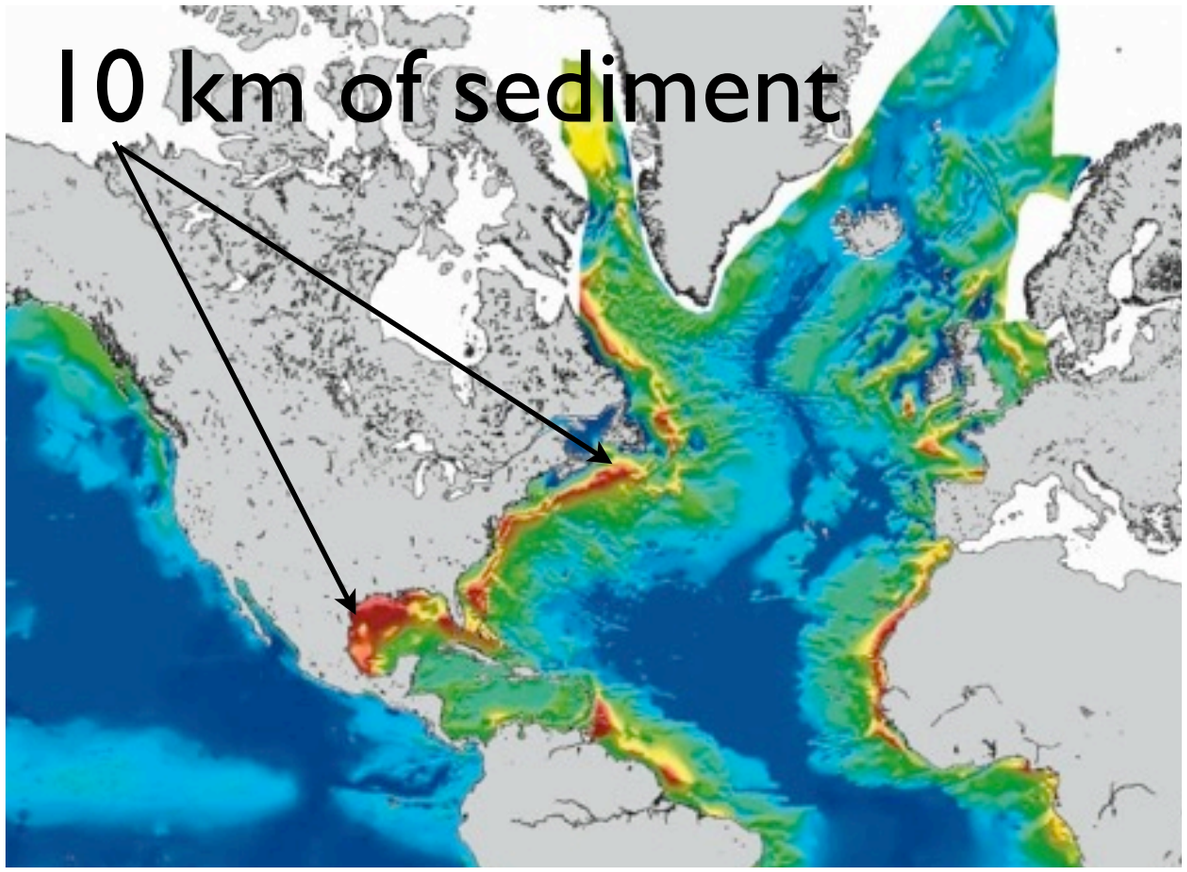
Deep Burial by accumulation of thick sequences of sedimentary rock

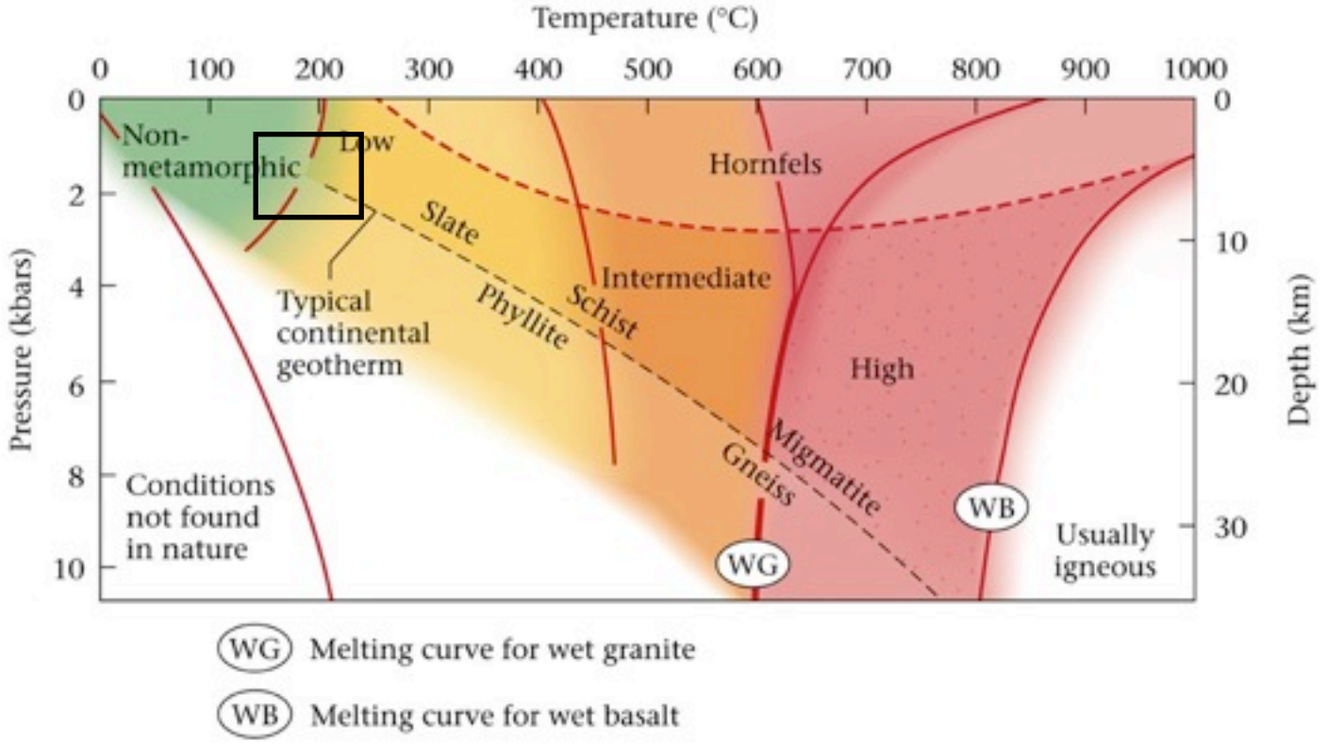




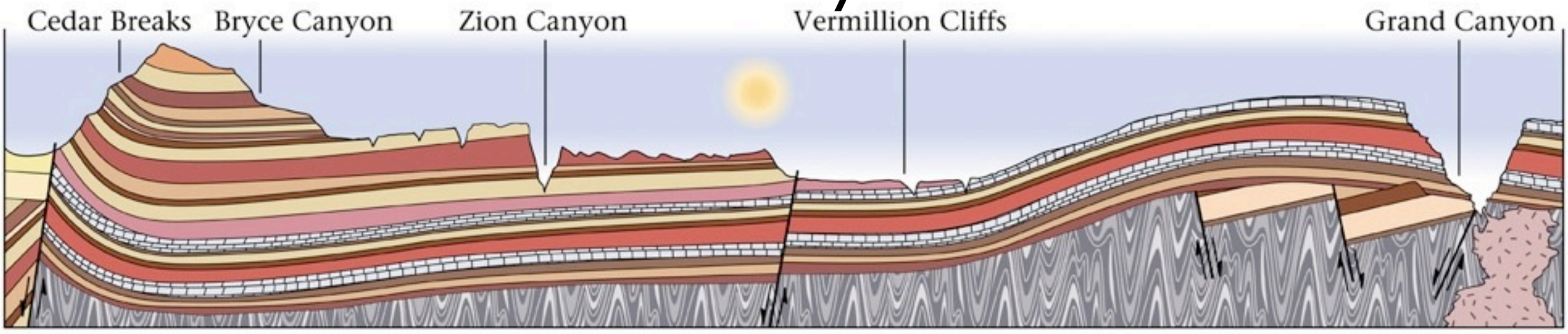


Deep Burial by accumulation of thick sequences of sedimentary rock





Hydrocarbon Generation



4 km of sediment

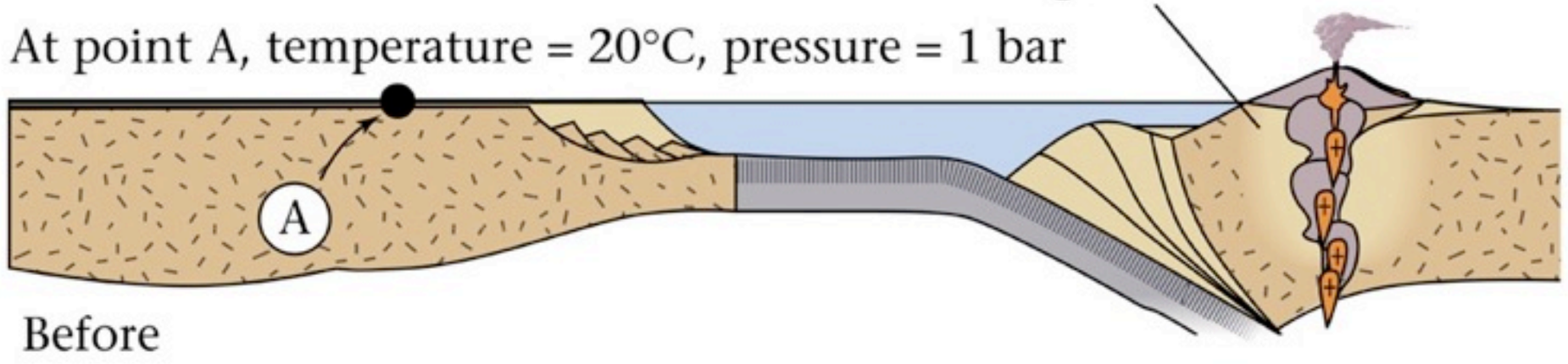
Dynamo-thermal Metamorphism

India

Convergent margin
metamorphosed rock

Asia

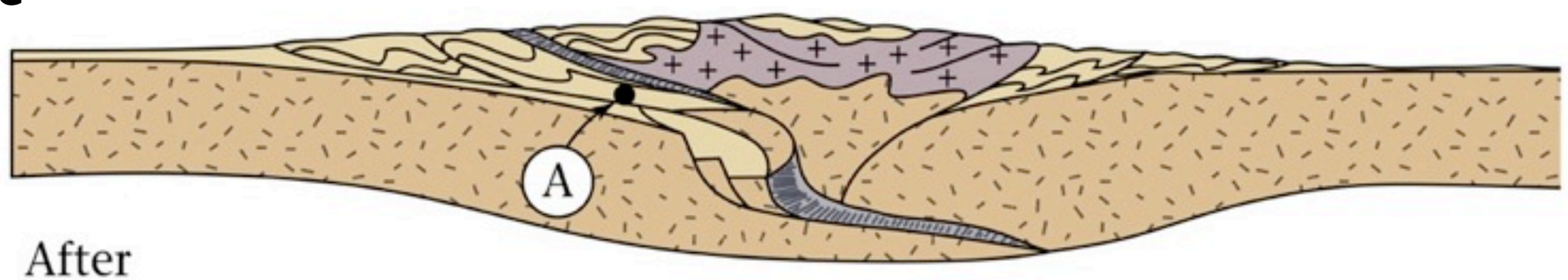
50 Ma



(a)

Present

Himalayan Mountains



(b)

FIGURE 6.19

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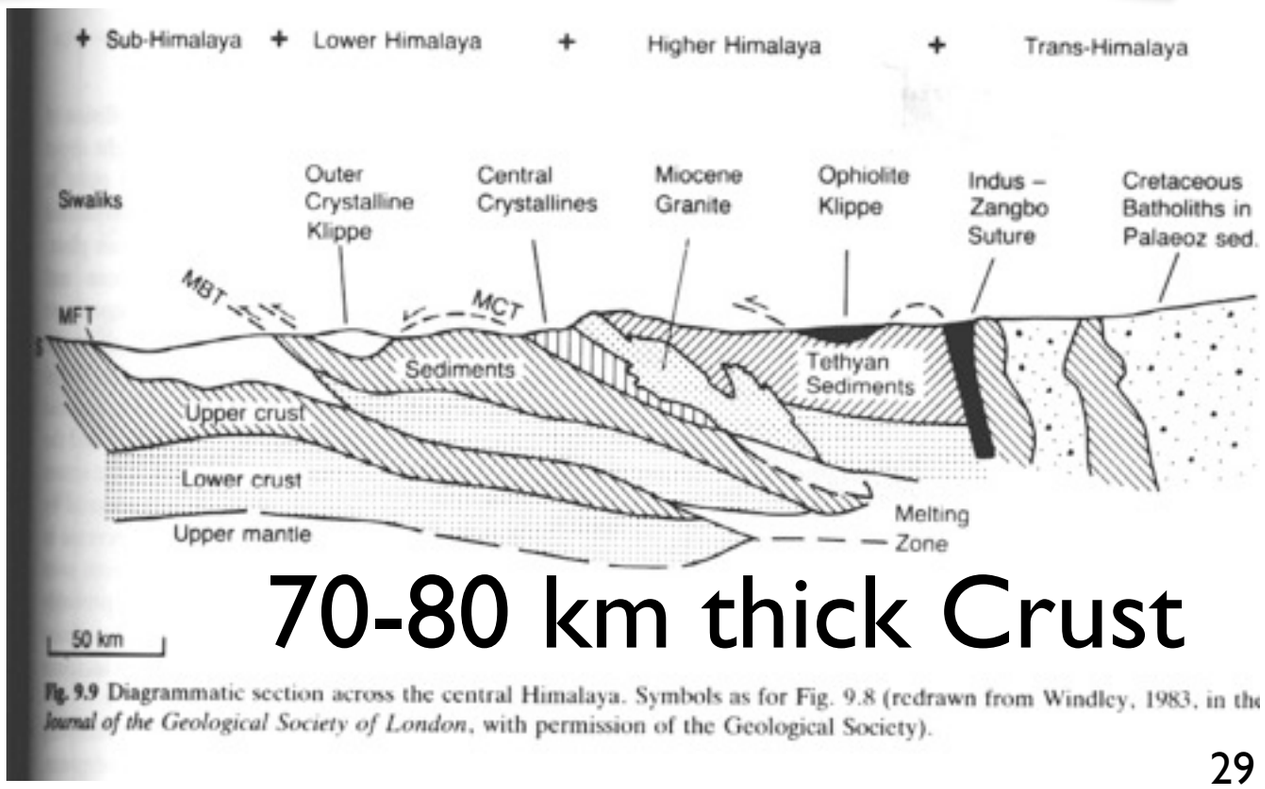
Himalayan Metamorphic core



70-80 km thick Crust

Fig. 9.9 Diagrammatic section across the central Himalaya. Symbols as for Fig. 9.8 (redrawn from Windley, 1983, in the *Journal of the Geological Society of London*, with permission of the Geological Society).

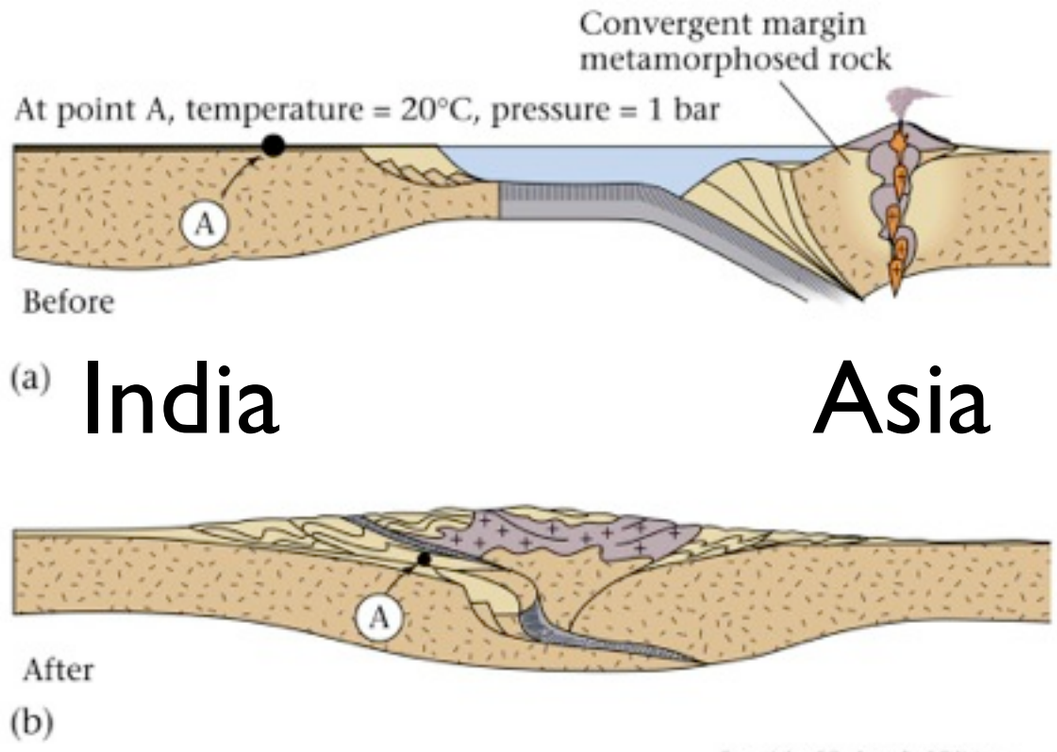


FIGURE 6.19

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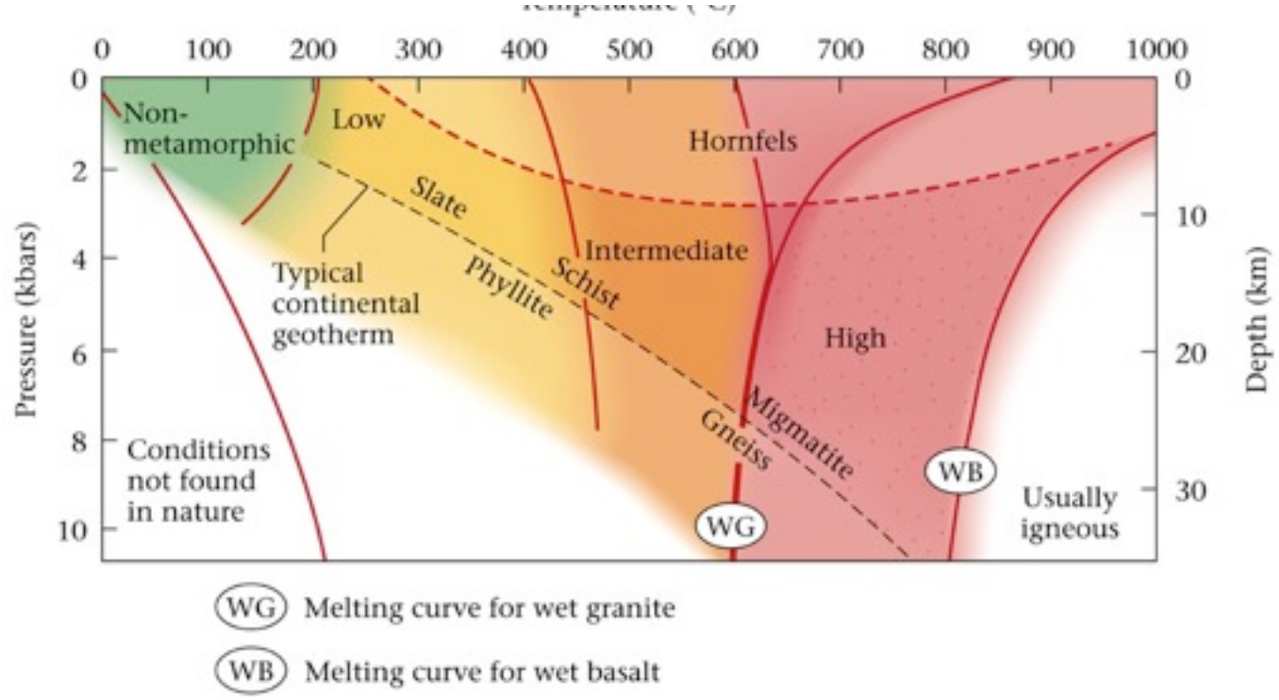
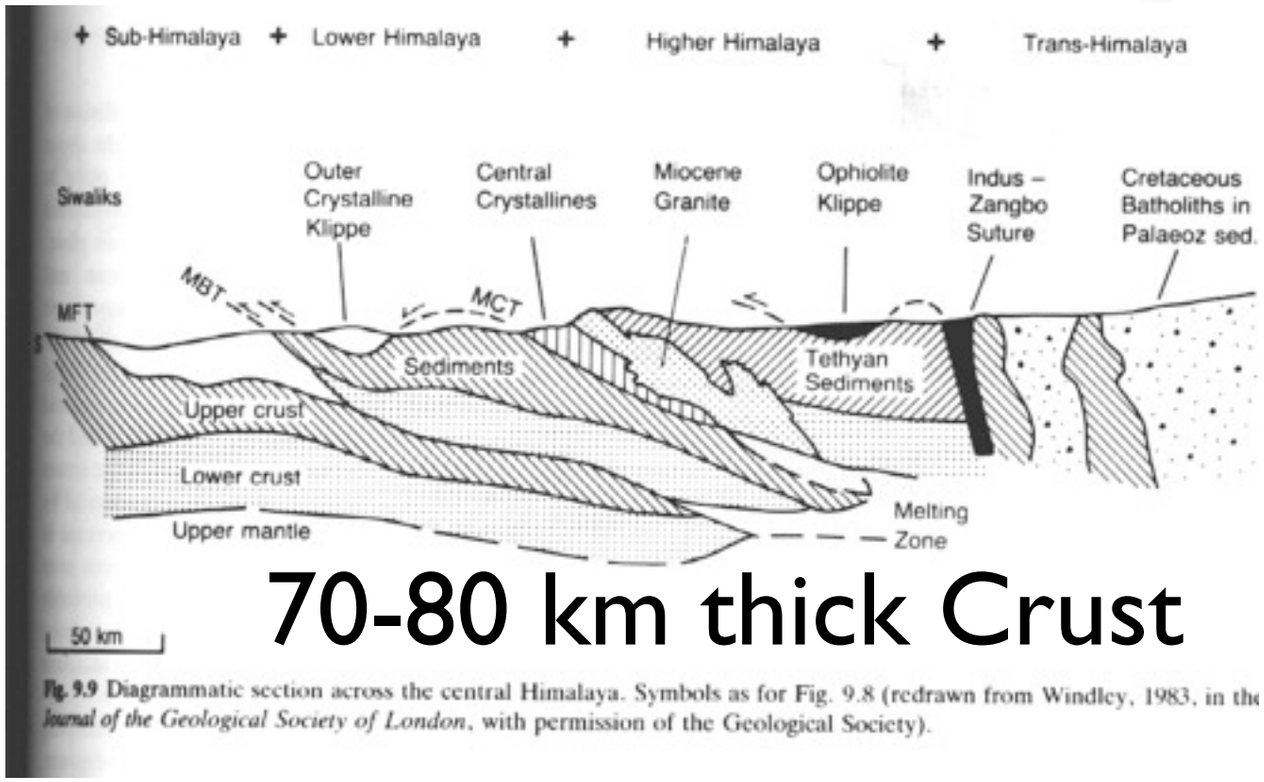
Himalayan Metamorphic core





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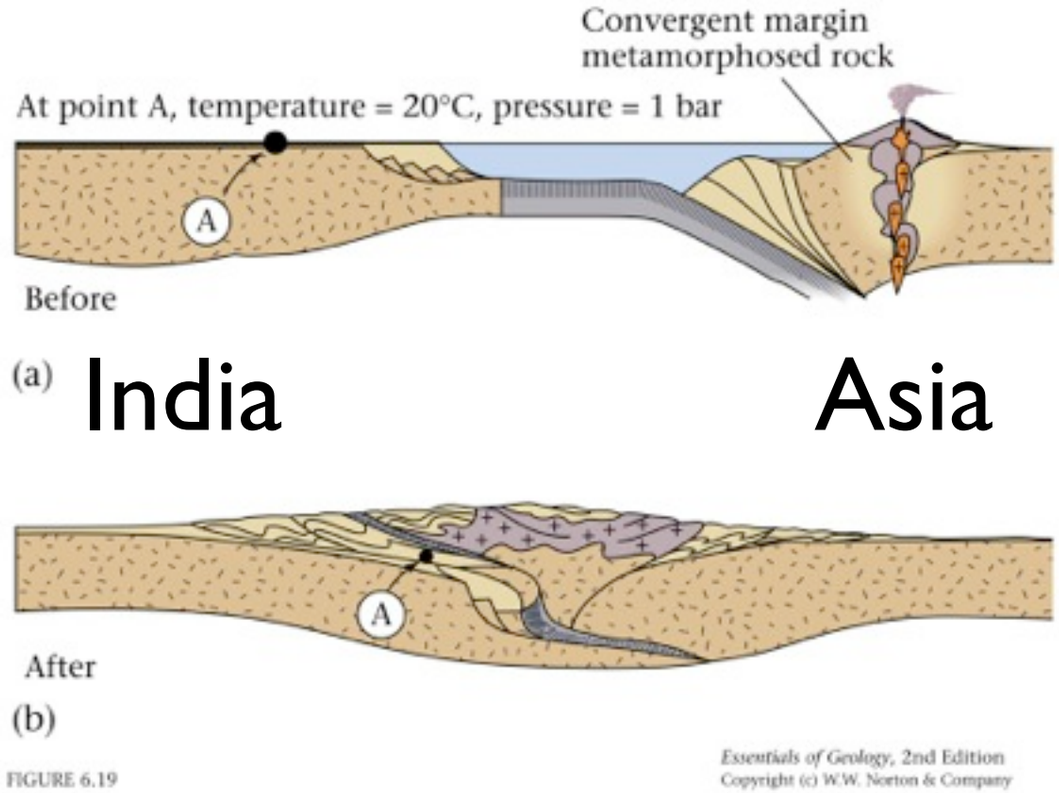

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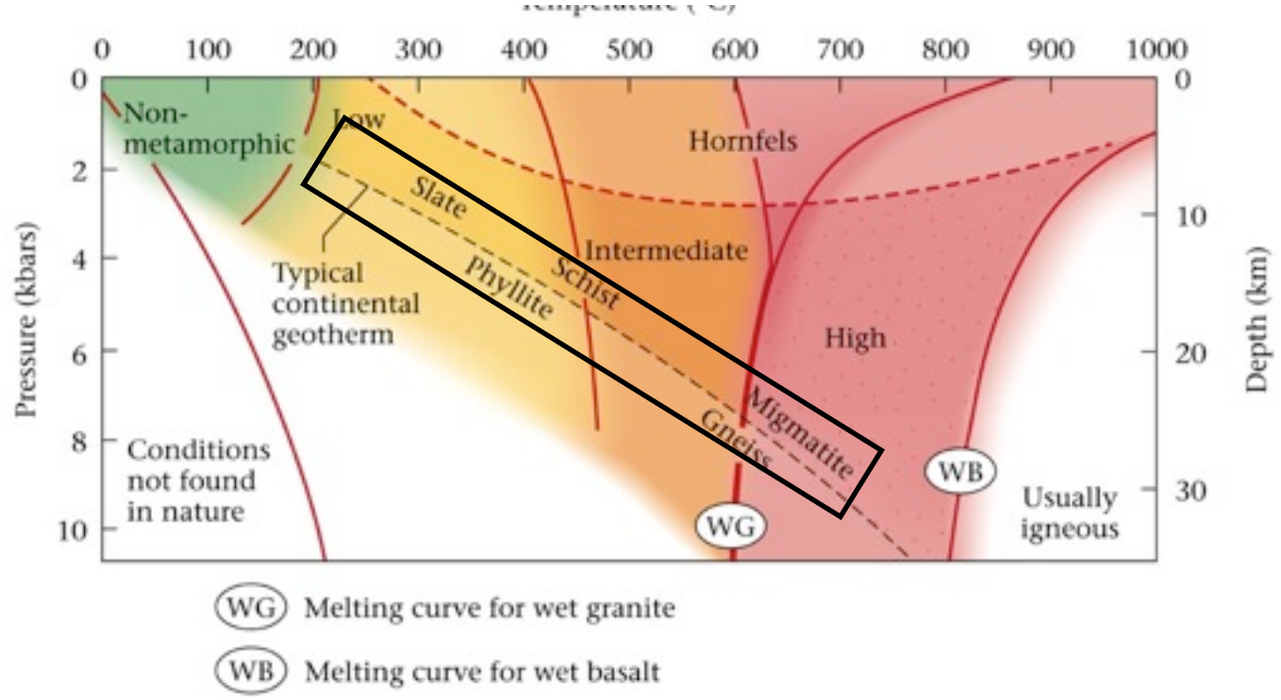
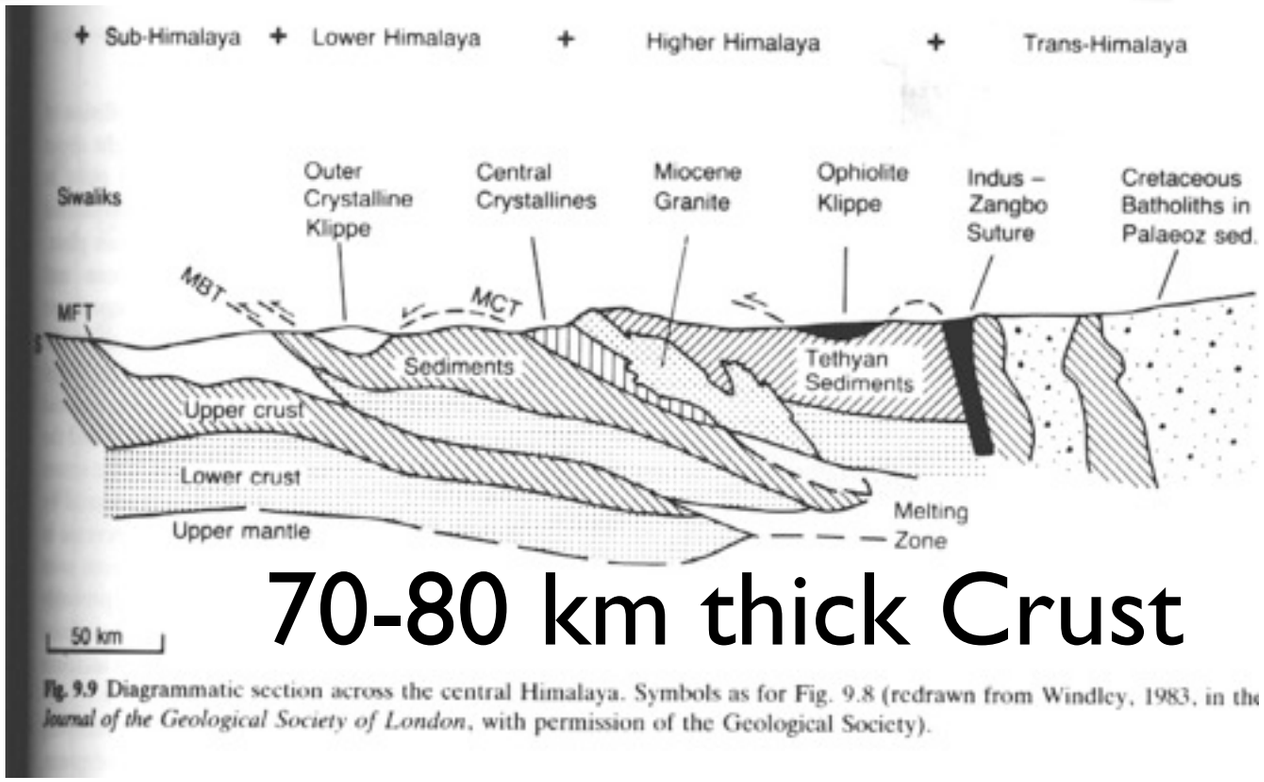
Himalayan Metamorphic core





70-80 km thick Crust

Fig. 9.9 Diagrammatic section across the central Himalaya. Symbols as for Fig. 9.8 (redrawn from Windley, 1983, in the *Journal of the Geological Society of London*, with permission of the Geological Society).

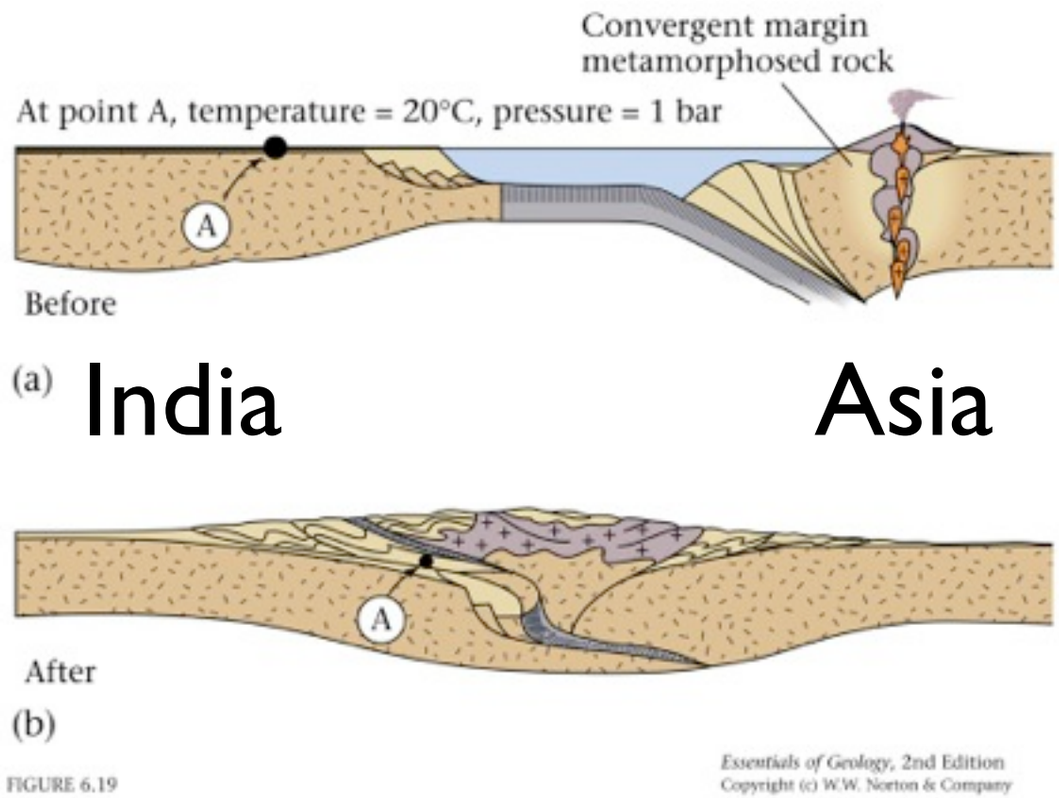


FIGURE 6.19

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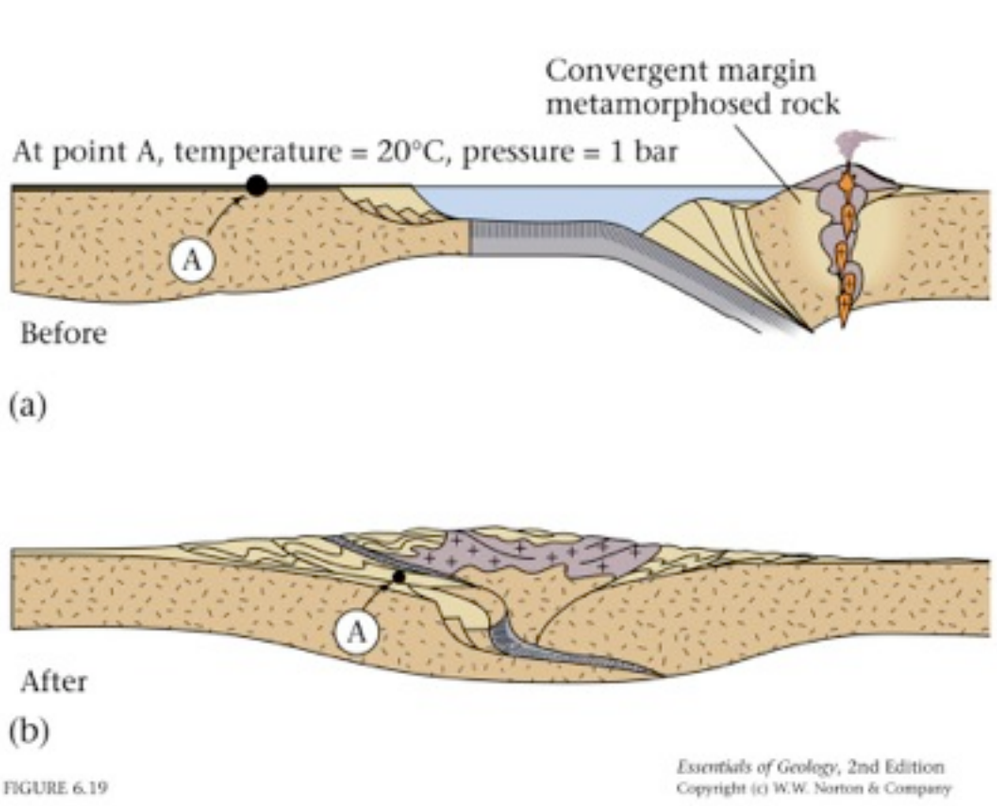
Where Metamorphic Rocks Form

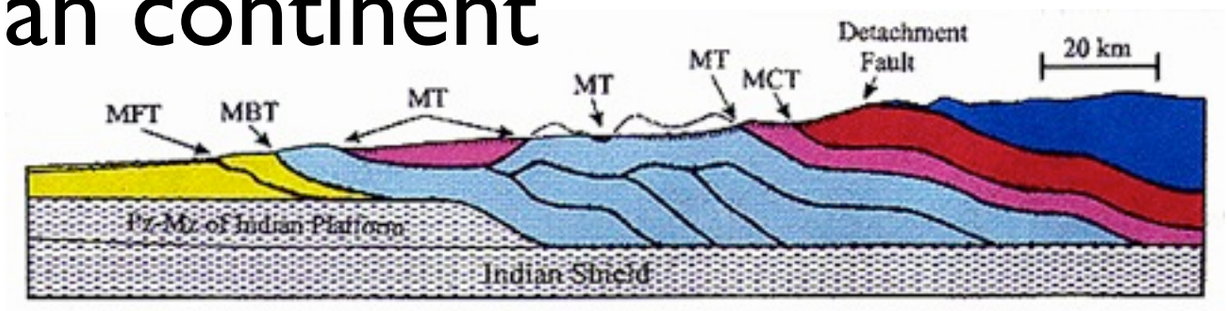
Indian continent

Asia



Asia

Indian continent

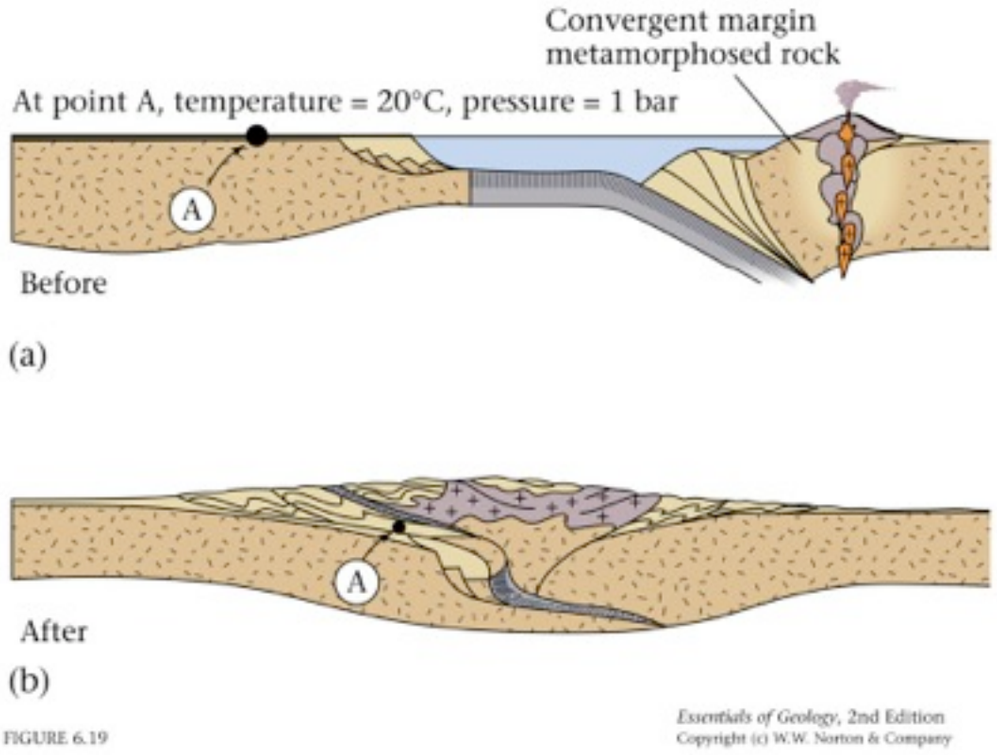


Bonnet et al. (2007) video

Where Metamorphic Rocks Form

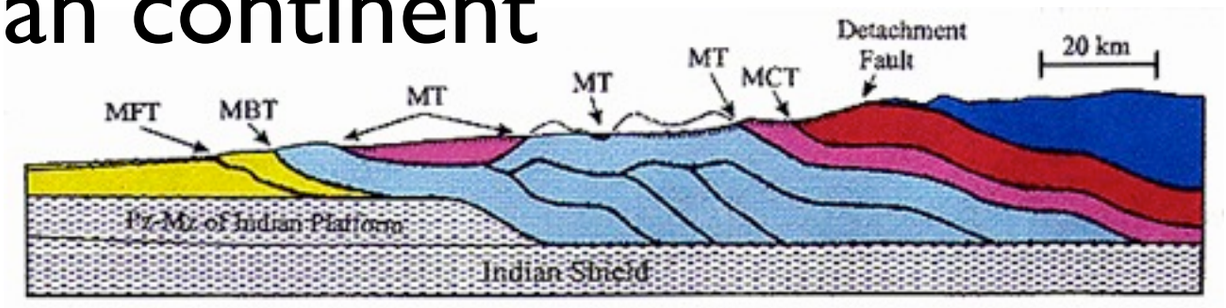
Indian continent

Asia



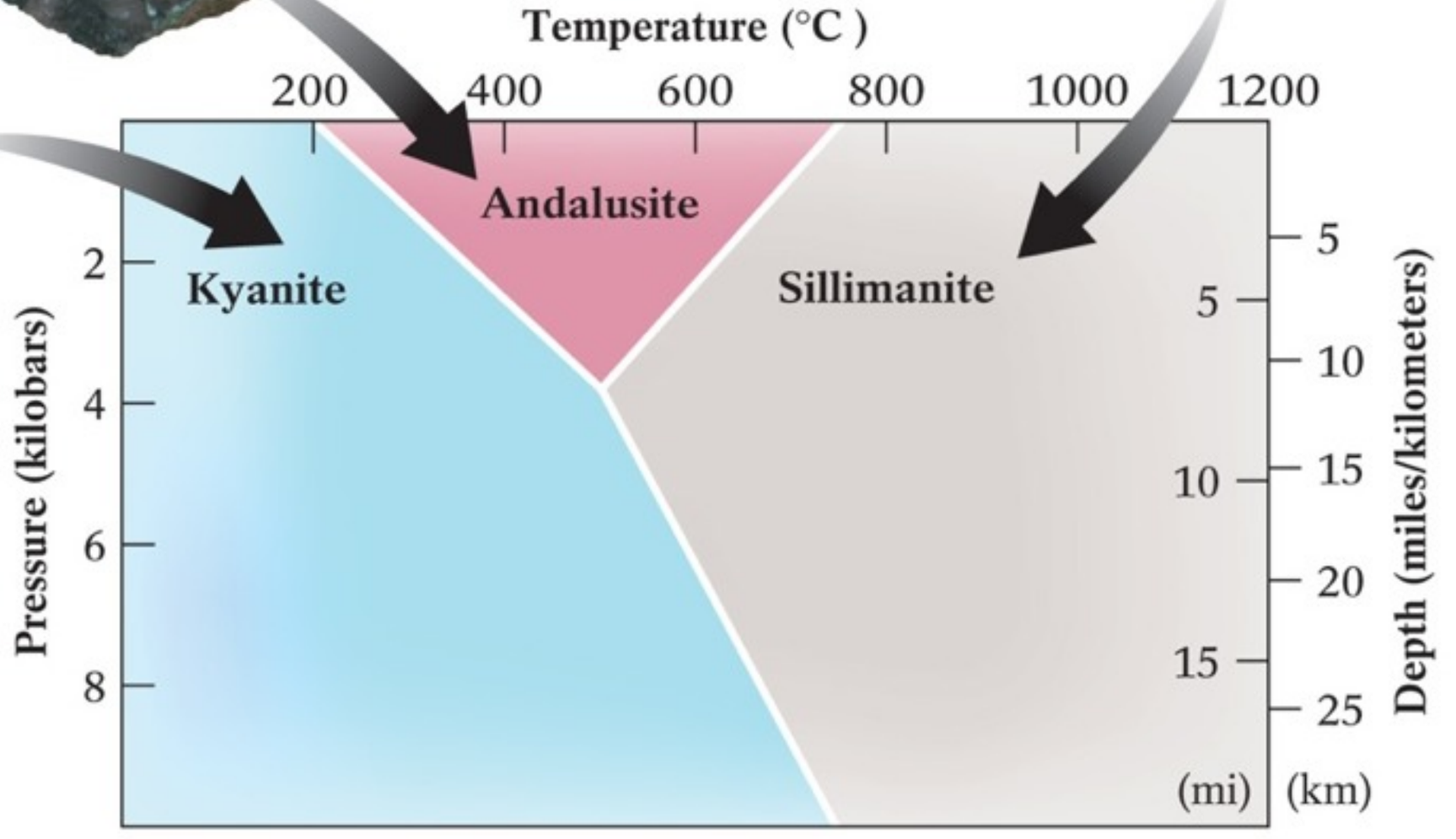
Indian continent

Asia

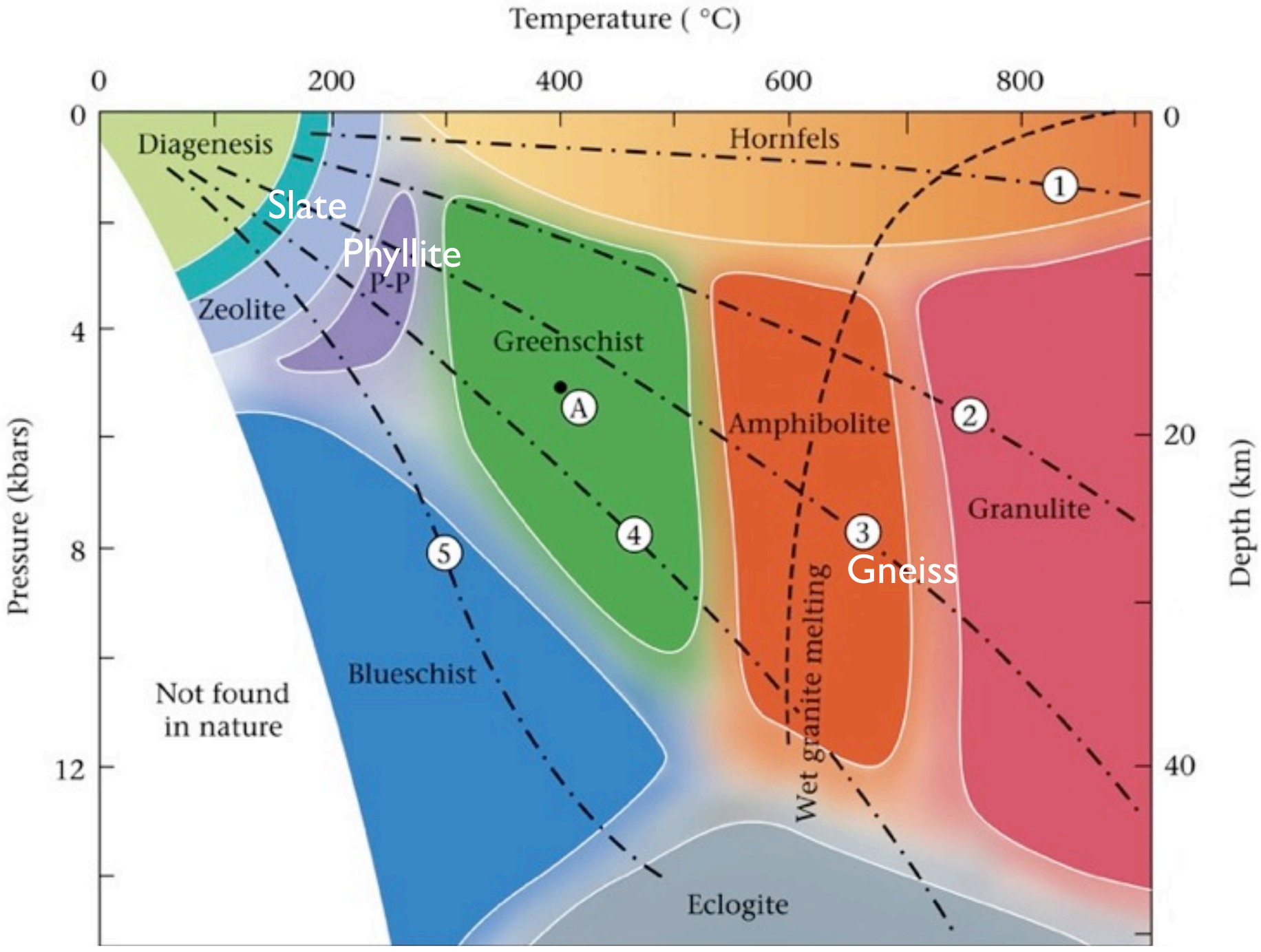


Bonnet et al. (2007) video

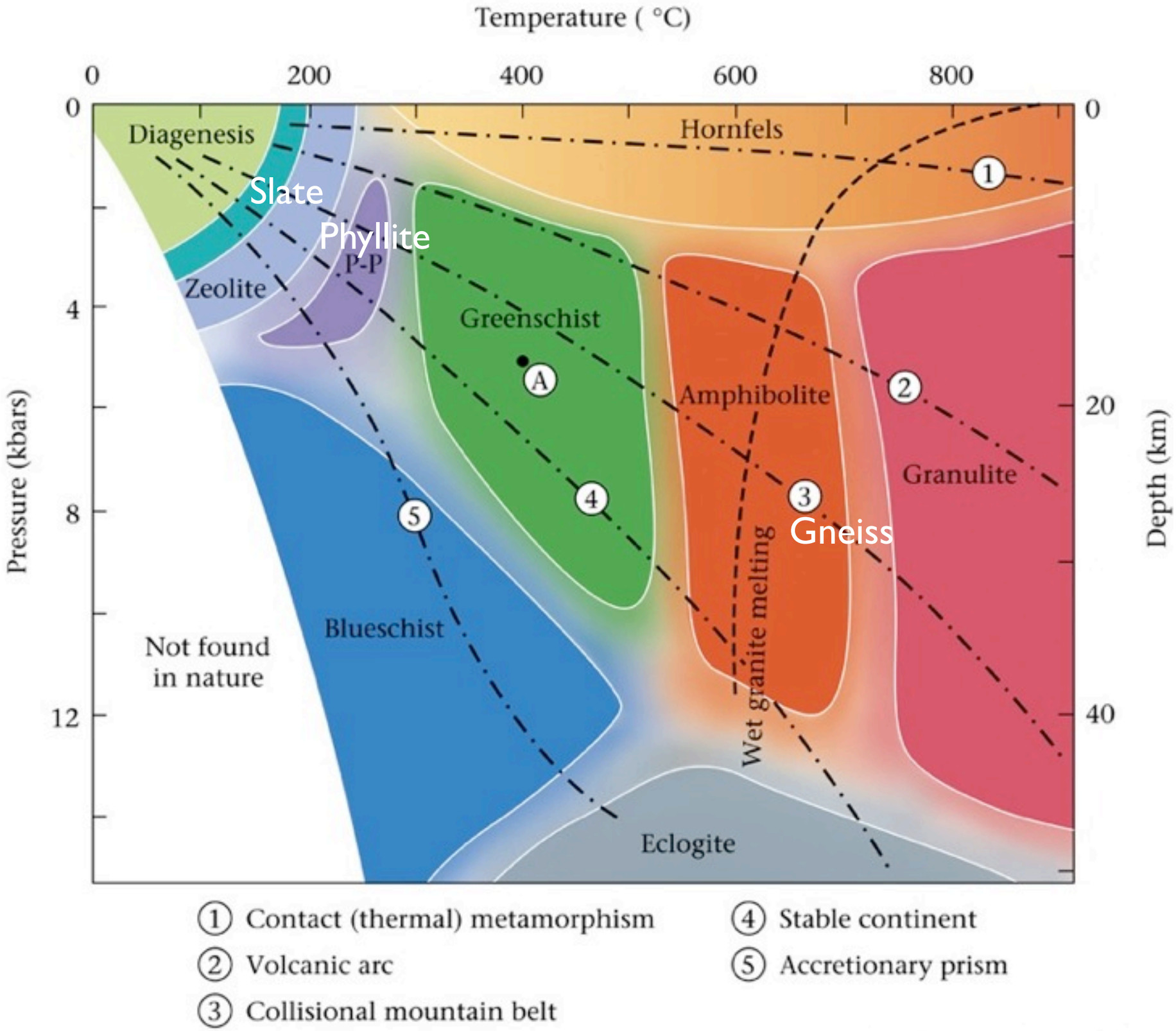
Metamorphic Mineral Stability Diagram



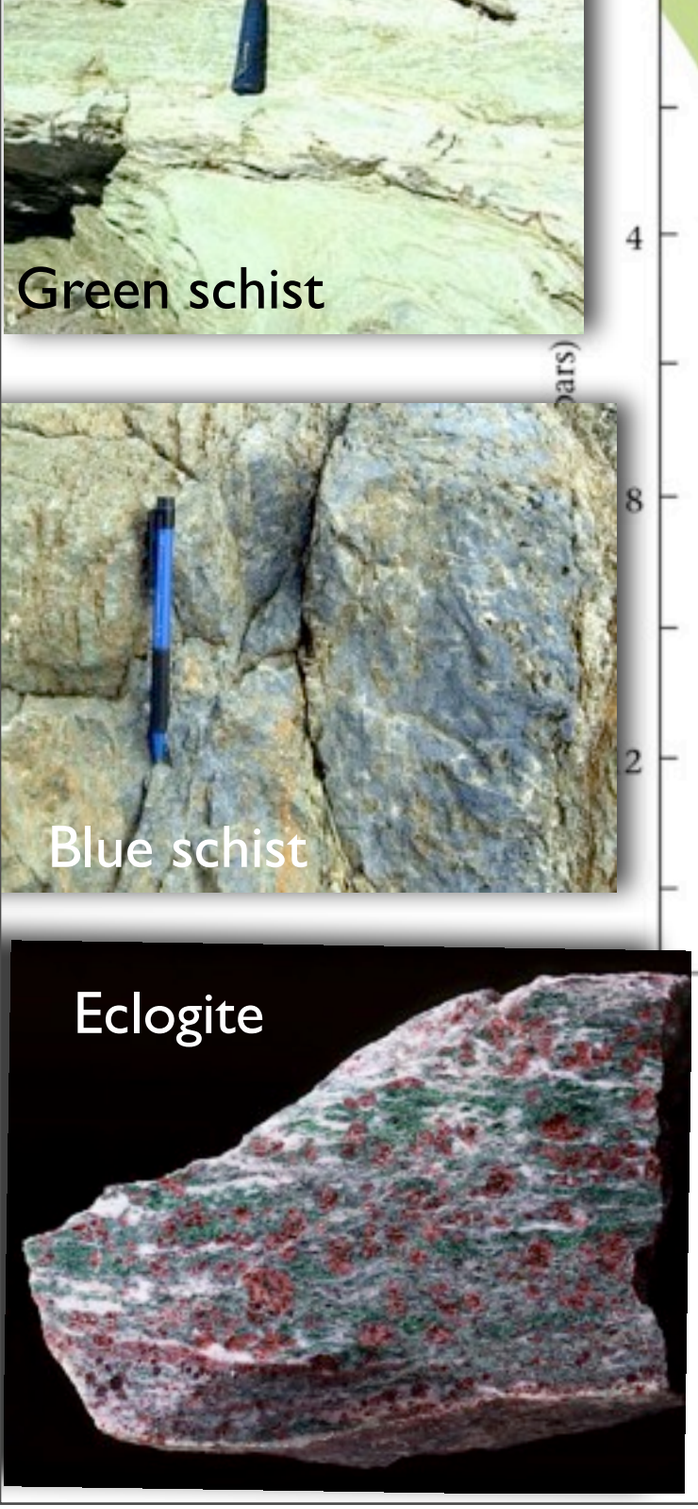
Earth's Temperature Profile is Variable

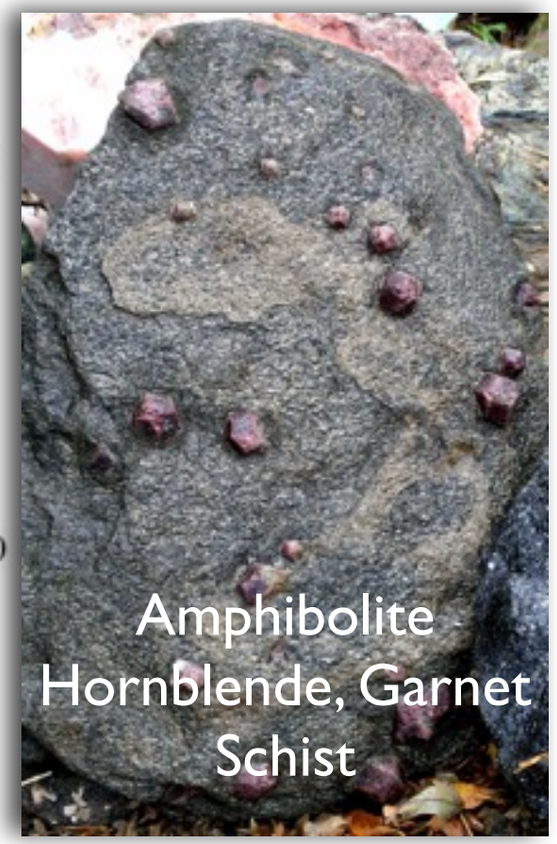


Earth's Temperature Profile is Variable



Metamorphic Mineral Phase Diagram





Causes of Metamorphism

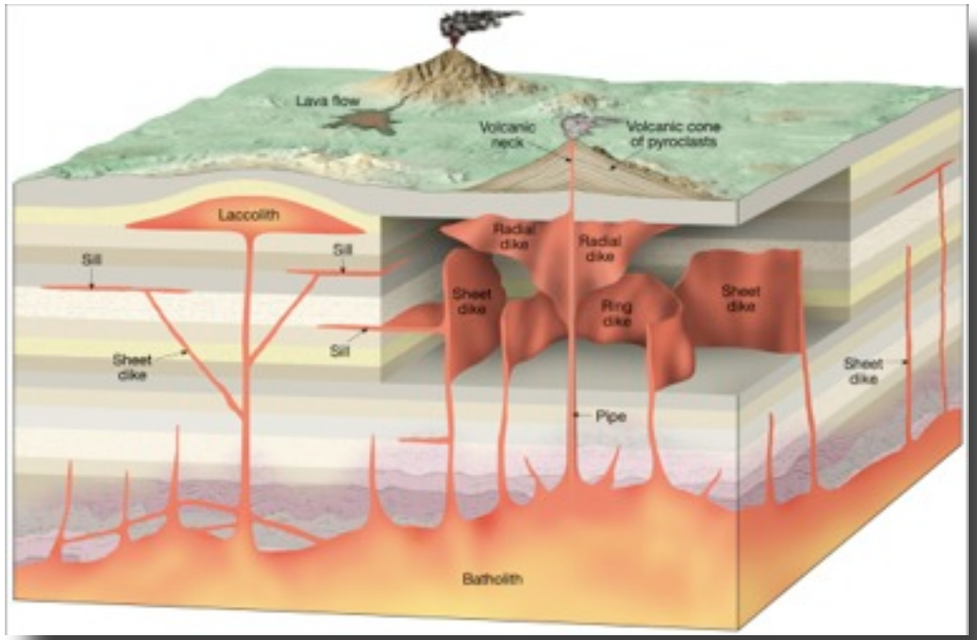
Metamorphism due to heating (200-800 C)

Metamorphism due to increased Pressure

Metamorphism due to increase Heat and Pressure

Metamorphism to Hydrothermal Fluids

Thermal or Contact Metamorphism



Contact metamorphism typically produces a fine-grained metamorphic rock

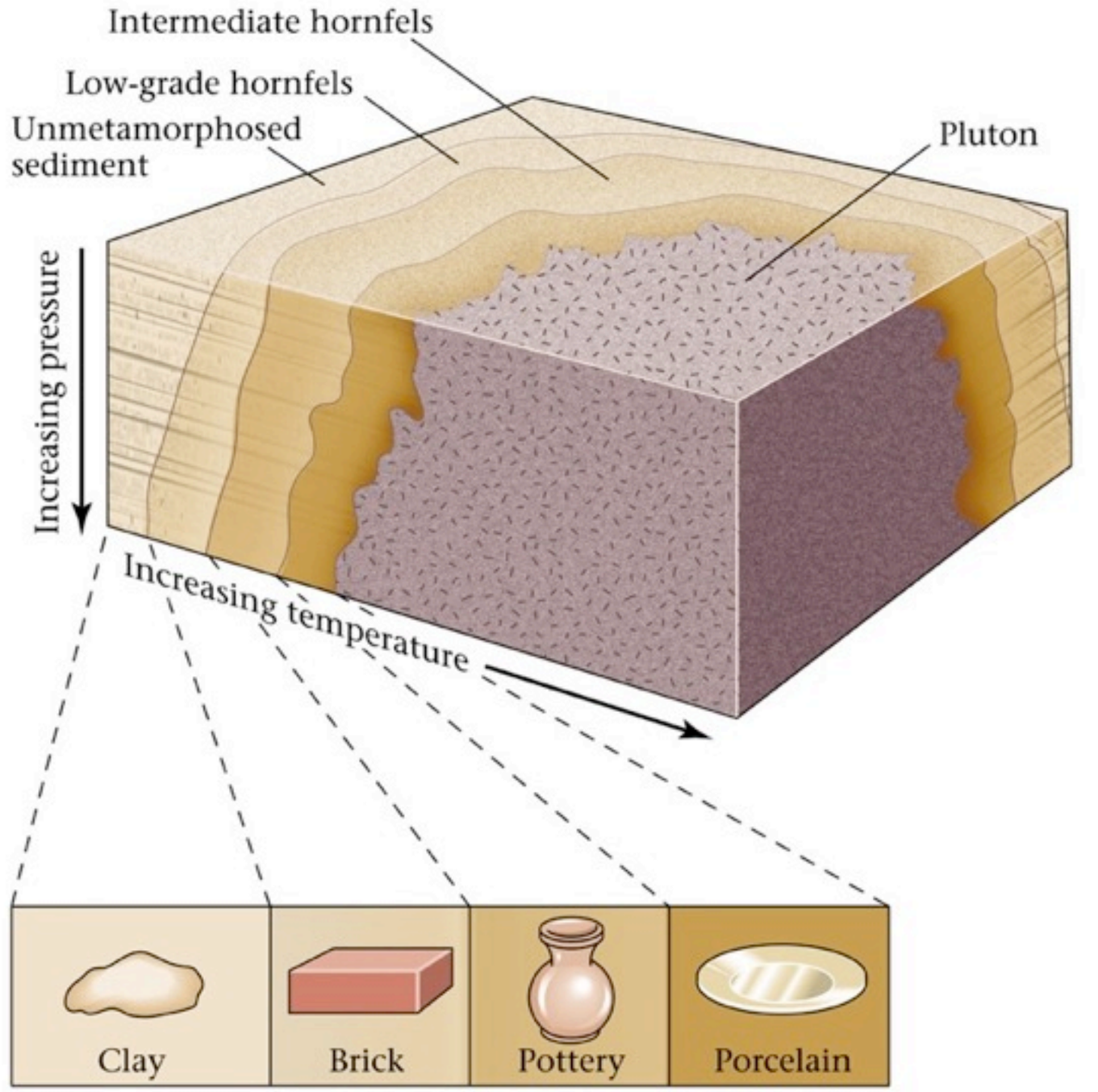
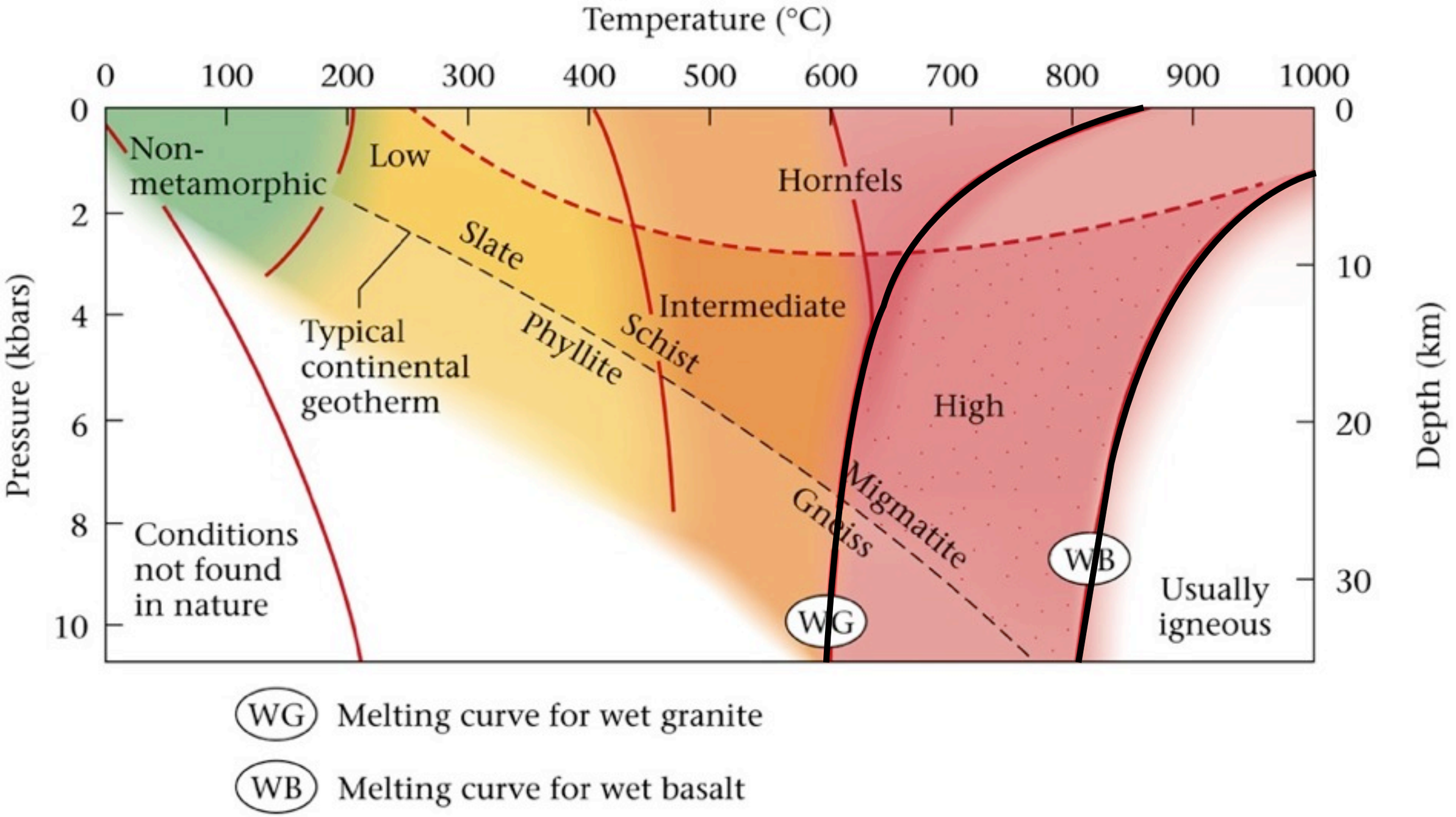


FIGURE 6.17

Metamorphic Rock Stability Diagram

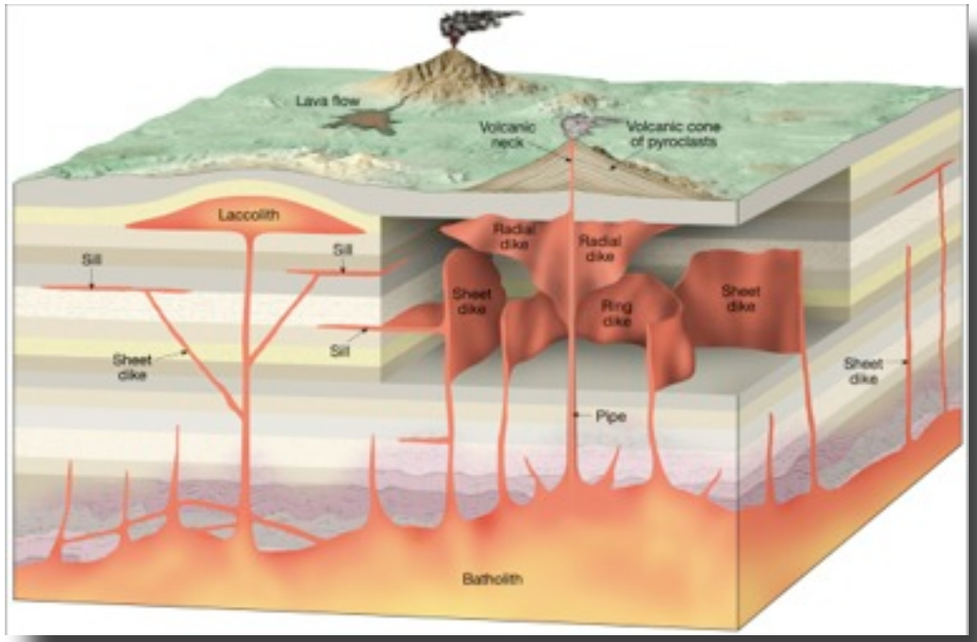


What kind of metamorphic Rock might you expect from Contact metamorphism?

Metamorphic Rock Stability Diagram

What kind of metamorphic Rock might you expect from Contact metamorphism?

Thermal or Contact Metamorphism



When hydrothermal fluids are present

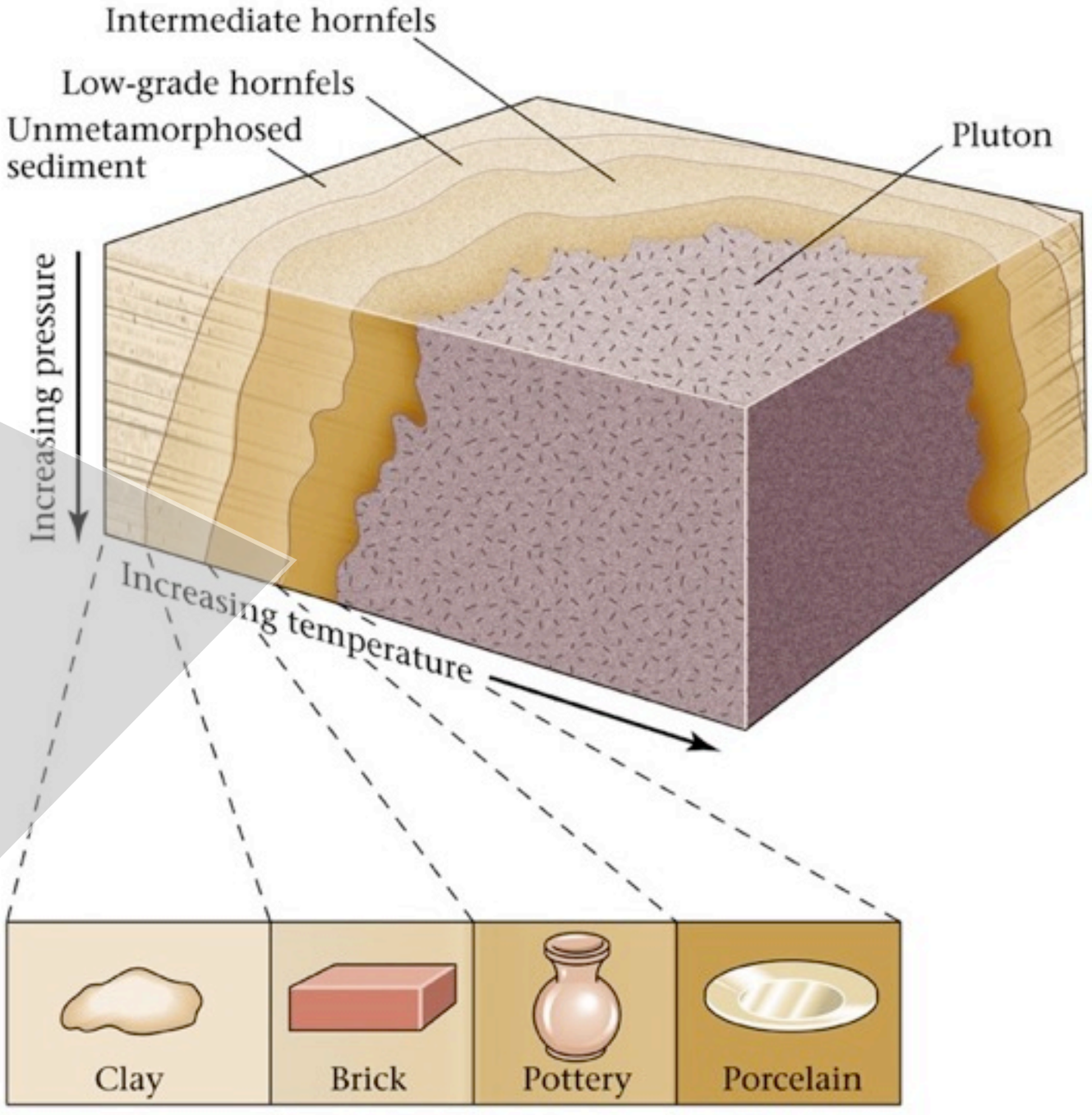


FIGURE 6.17

Causes of Metamorphism

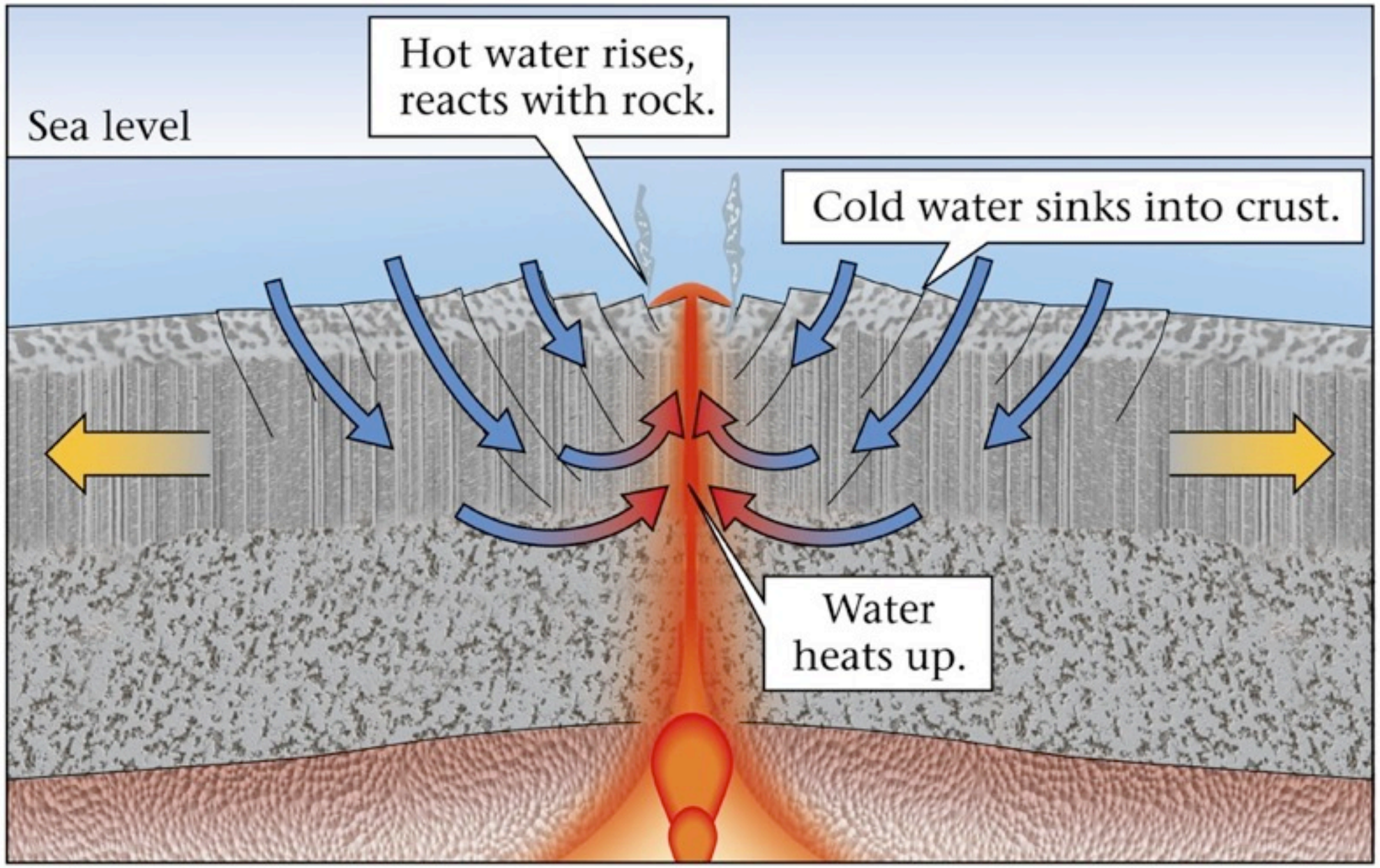
Metamorphism due to heating (200-800 C)

Metamorphism due to increased Pressure

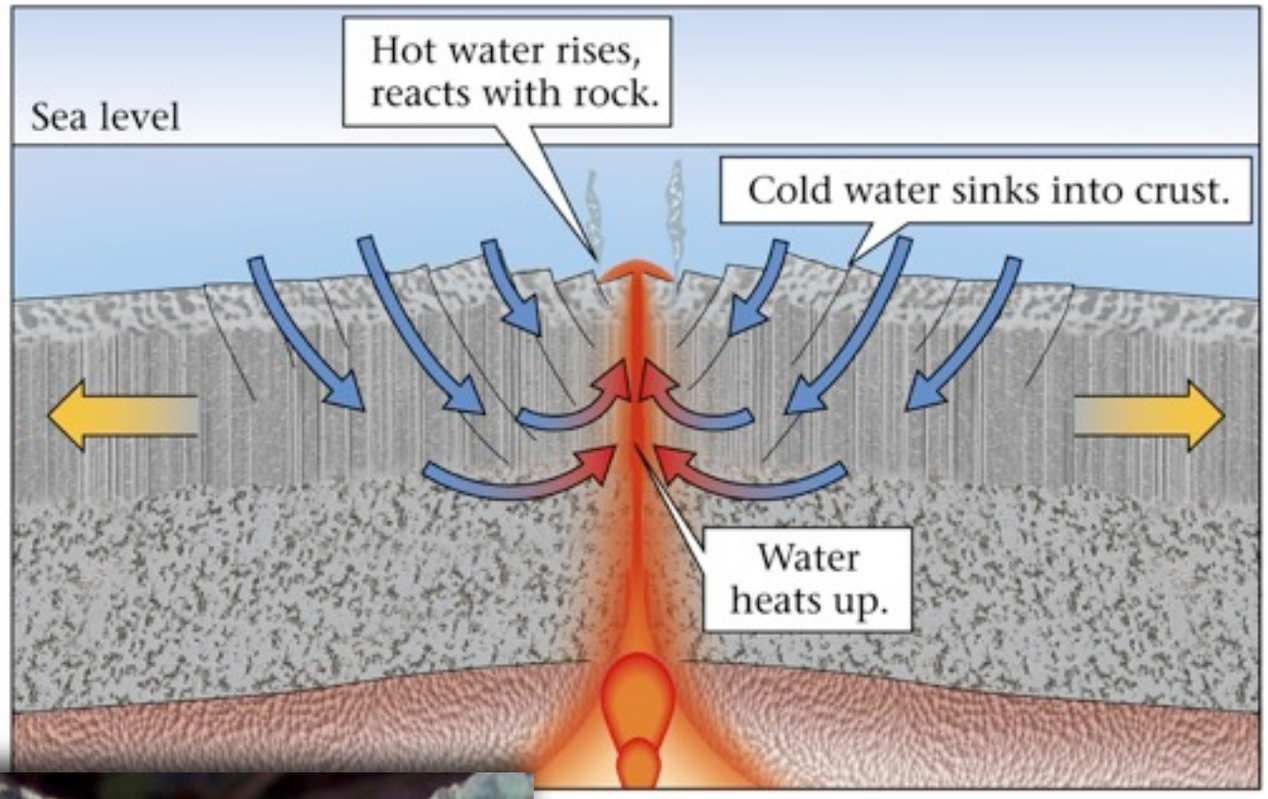
Metamorphism due to increase Heat and Pressure

Metamorphism to Hydrothermal Fluids

Hydrothermal Alteration



Hydrothermal Alteration



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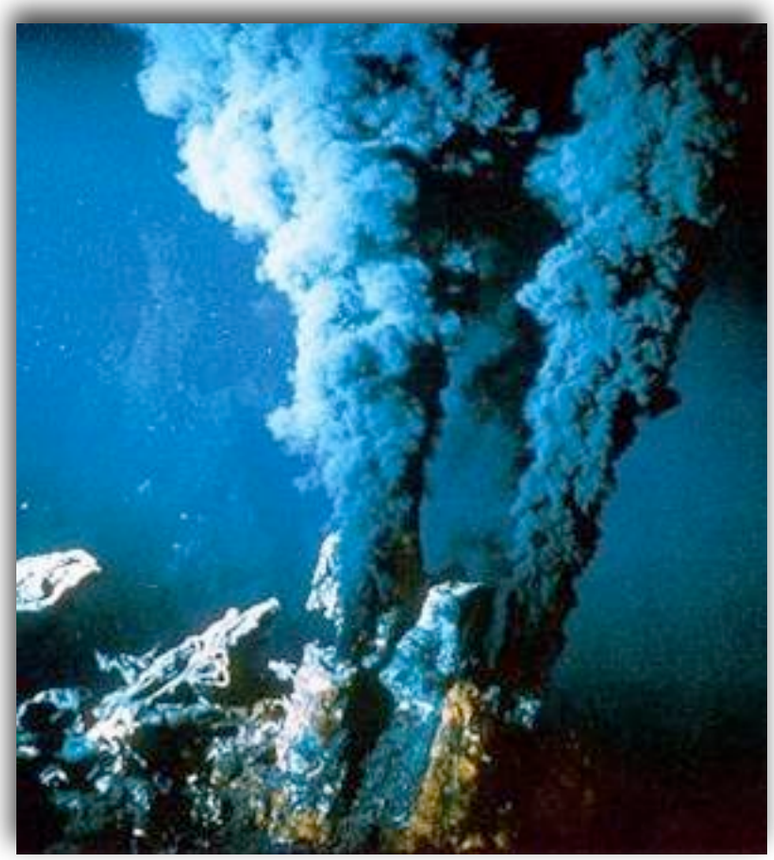
12% H2O by mass

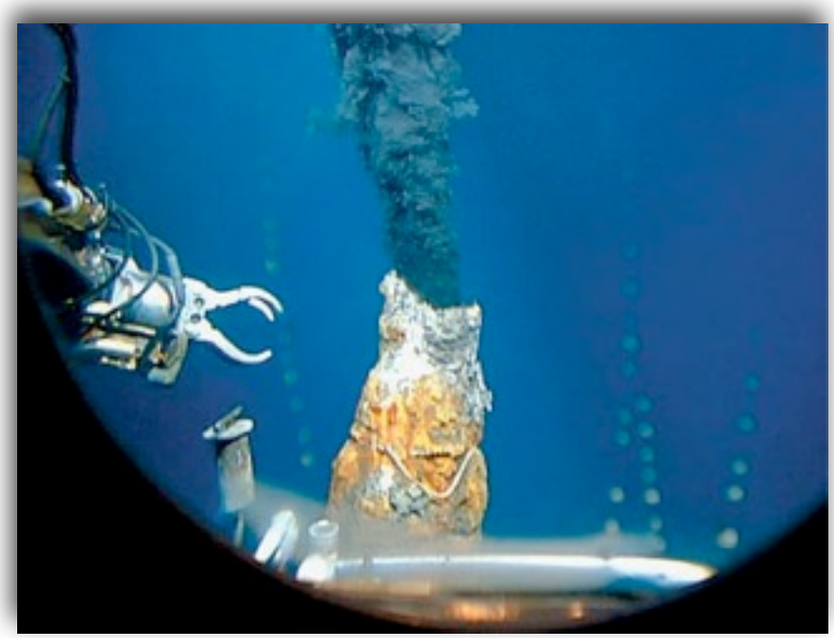
Olivine + Water + Carbonic acid → Serpentine + Magnetite + Methane

$$(Fe, Mg)_2SiO_4 + nH_2O + CO_2 \rightarrow Mg_3Si_2O_5(OH)_4 + Fe_3O_4 + CH_4$$

olivine — Serpentine — Magnetite

Hydrothermal Alteration





Black Smokers

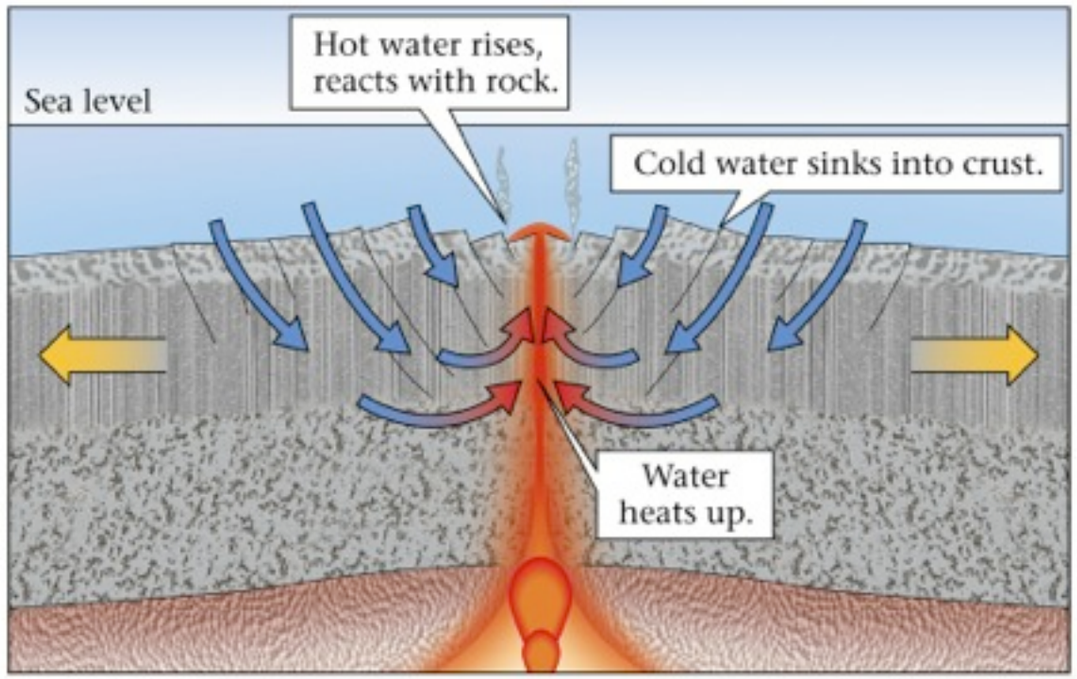
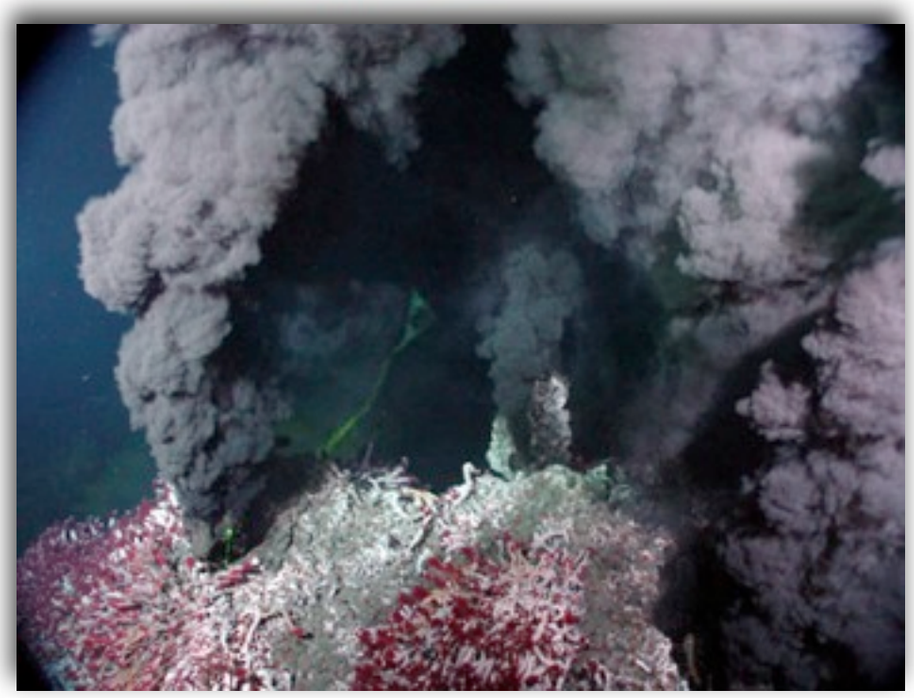


FIGURE 6.20



Olivine + Water + Carbonic acid → Serpentine + Magnetite + Methane

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olivine Serpentine Magnetite

Causes of Metamorphism

Metamorphism due to heating (200-800 C)

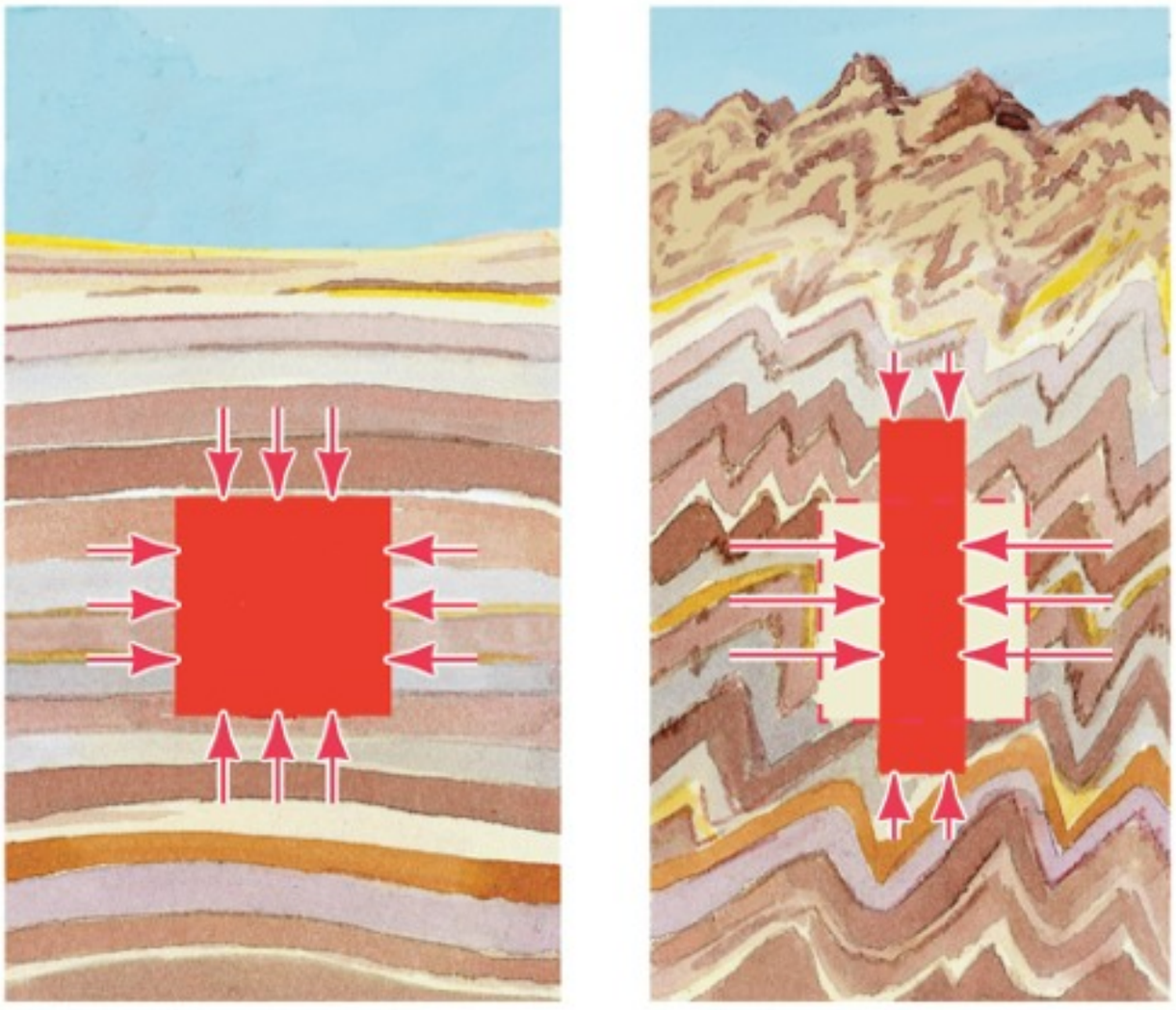
Metamorphism due to increased Pressure

Metamorphism due to increase Heat and Pressure

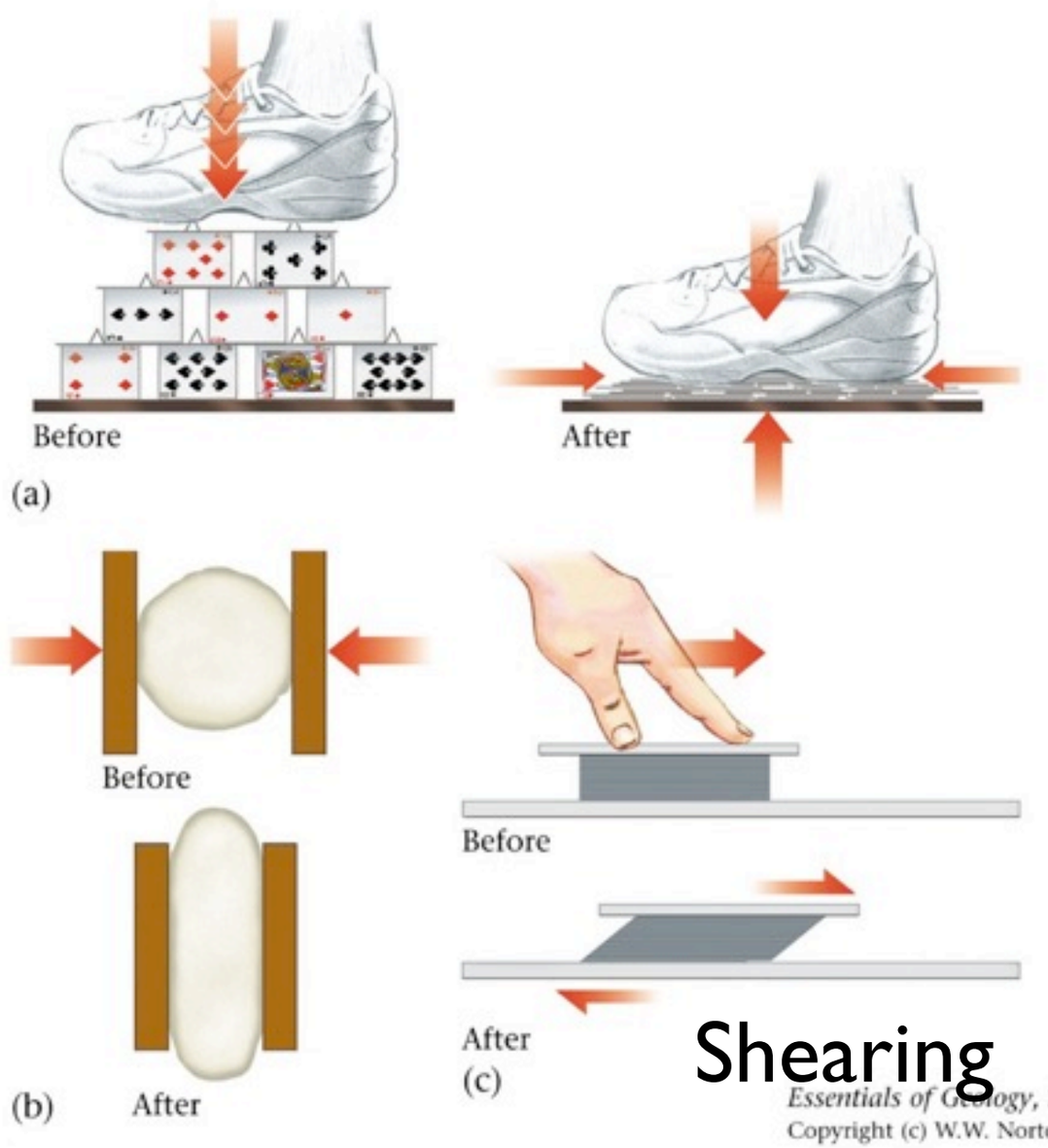
Metamorphism to Hydrothermal Fluids

Differential Stress and Development of Preferred Mineral Orientation

Directed Pressure

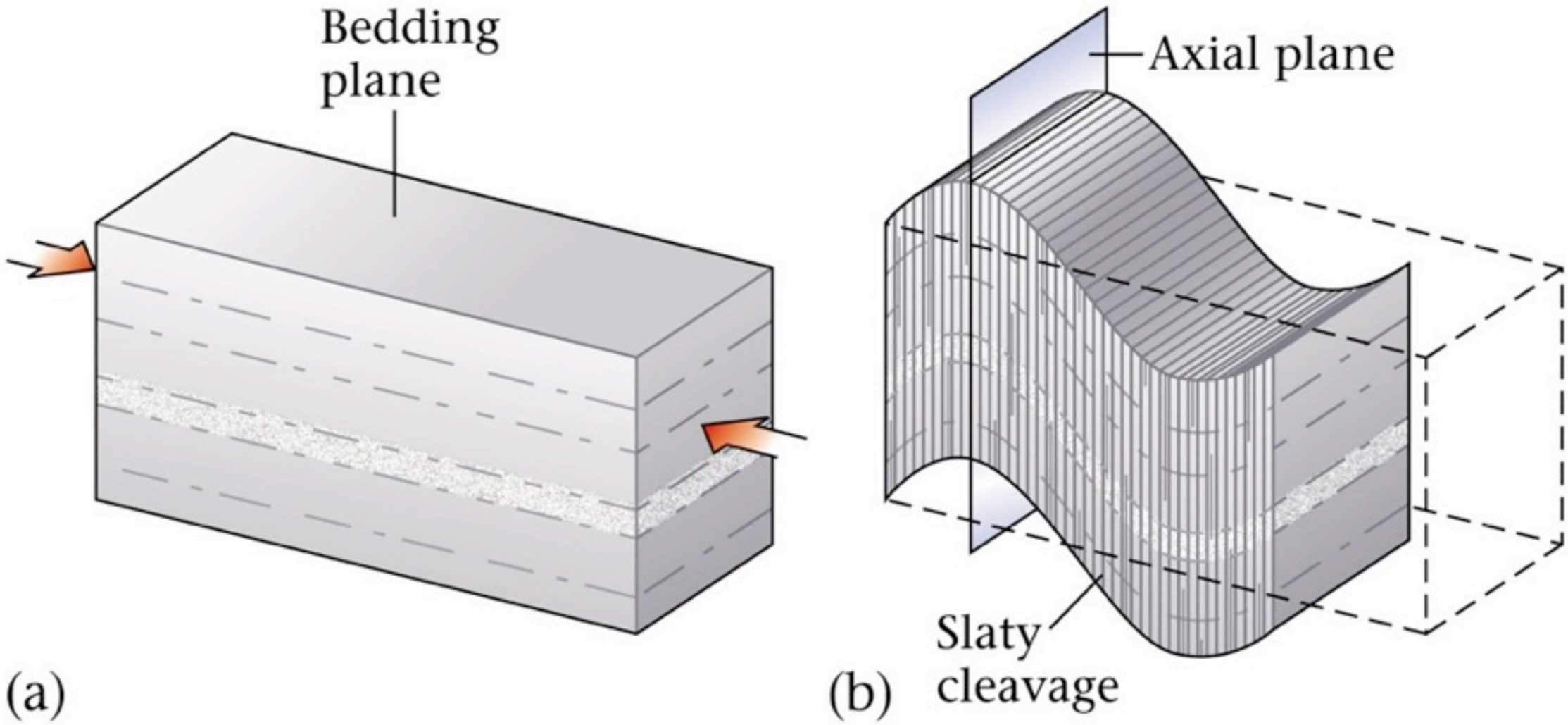


(b) Directed Pressure

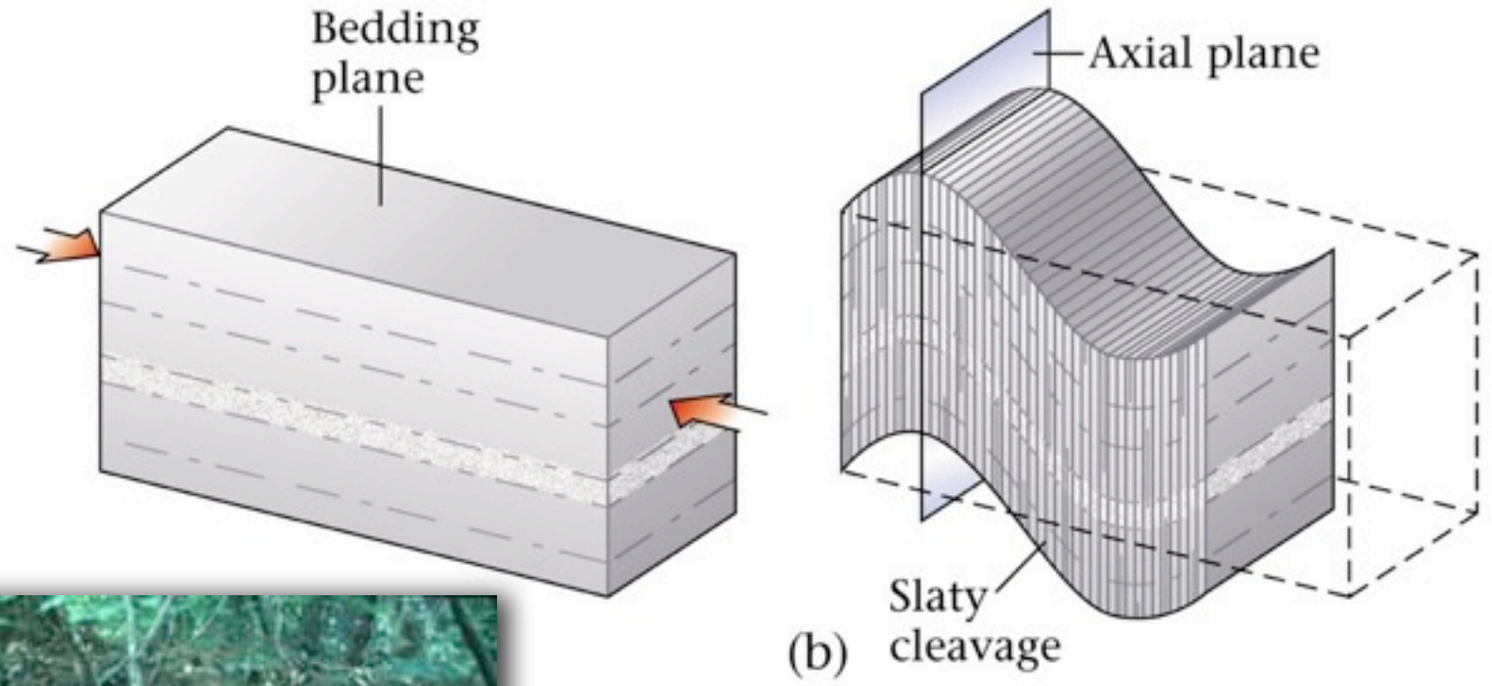


Shearing

Tectonic Fabric



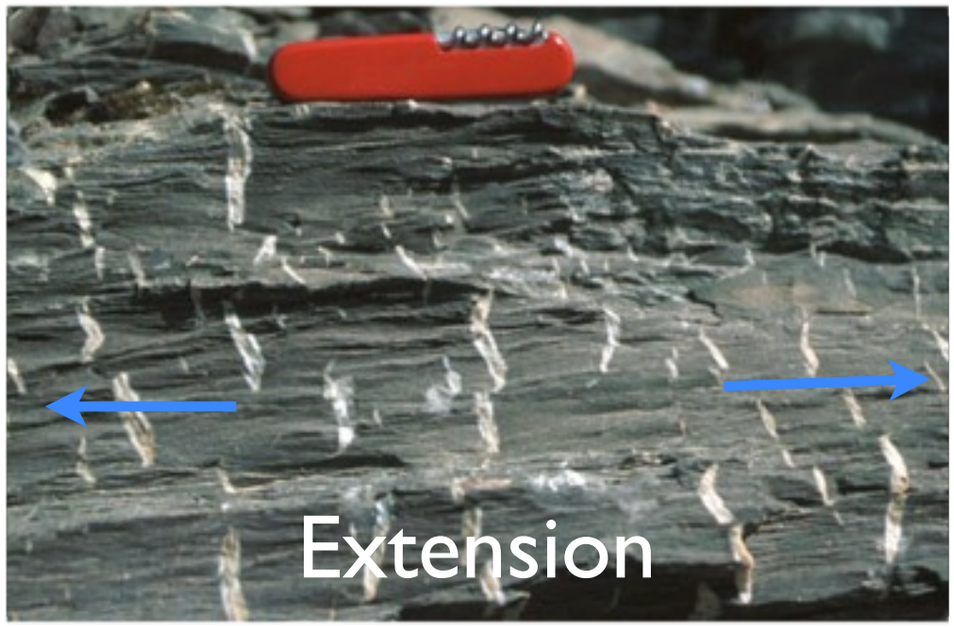
Tectonite

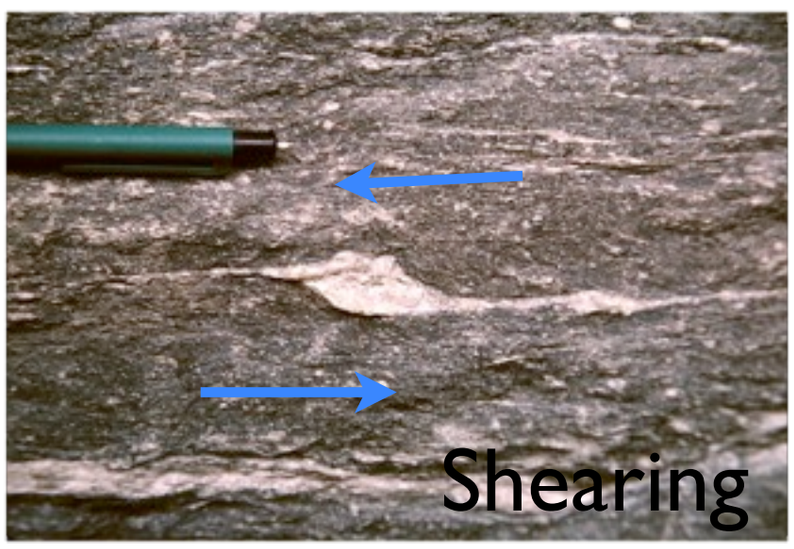


Axial Planar Cleavage

Other cool rocks that have something to say!

Tectonites





Today:

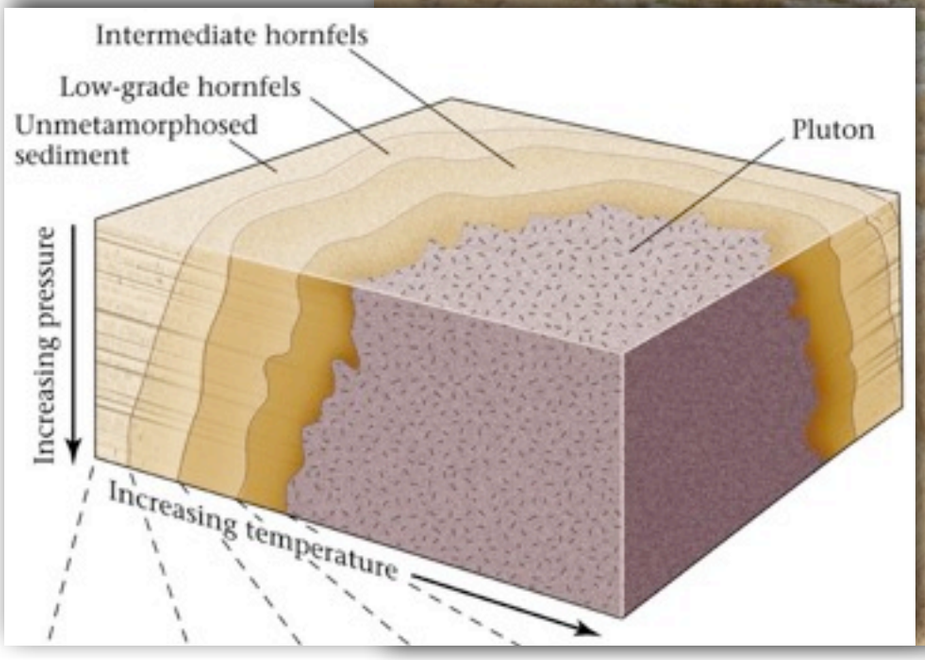
1) Case Study: Contact Metamorphism
2) Metamorphic Rx Identification (9:50)
3) Movie: The Alps (10:10)

Next Class:

4) Exam2
   -Minerals, Igneous Rx, Volcanoes, Weathering, Sedimentary Rx, Metamorphic Rx

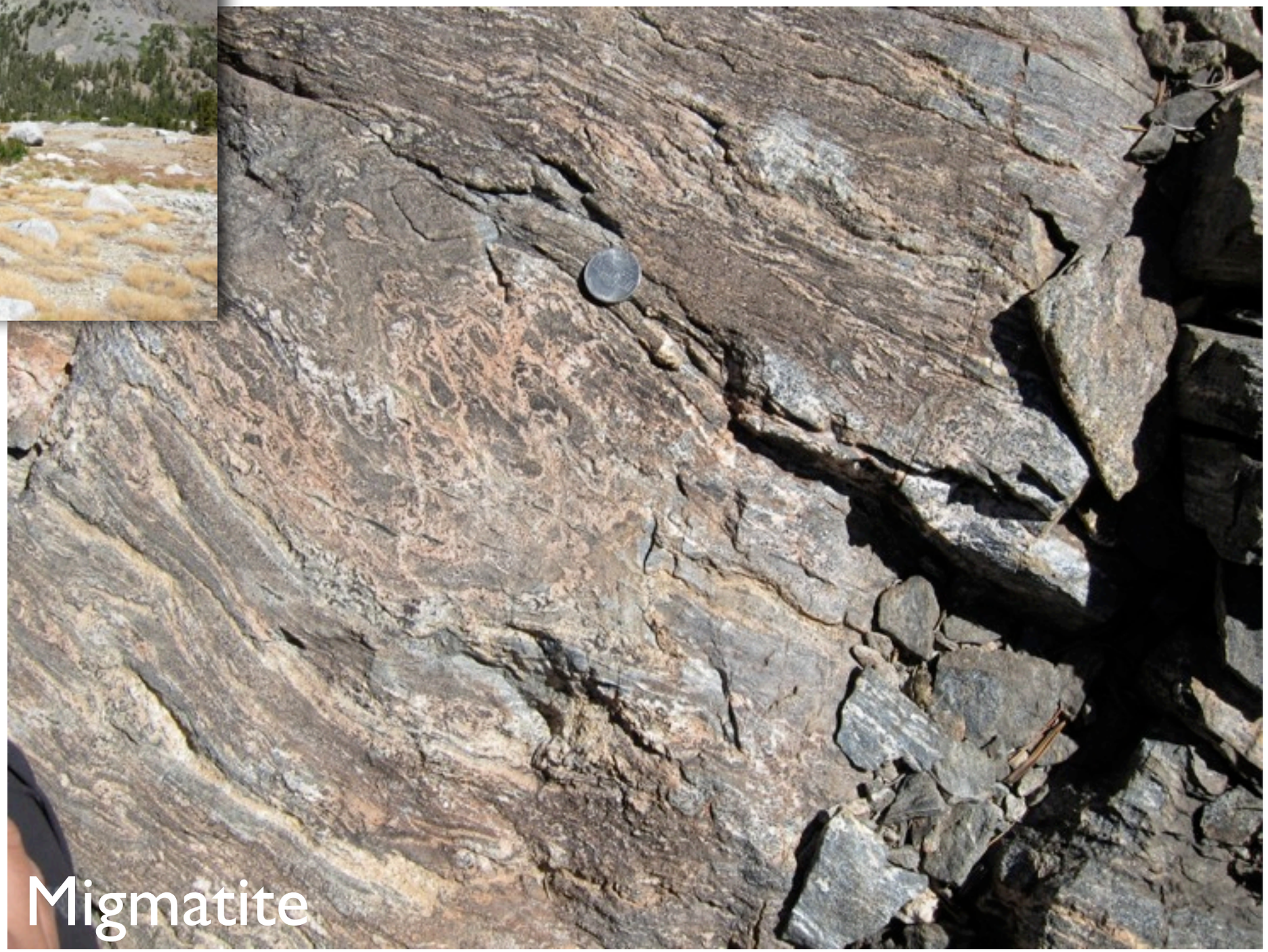
Think inside the Box!

Case Study : Contact Metamorphism
Sierra Nevada of California



Sierra Nevada of California

Sierra Nevada of California



Migmatite

Sierra Nevada of California

Stretch Pebble Conglomerate