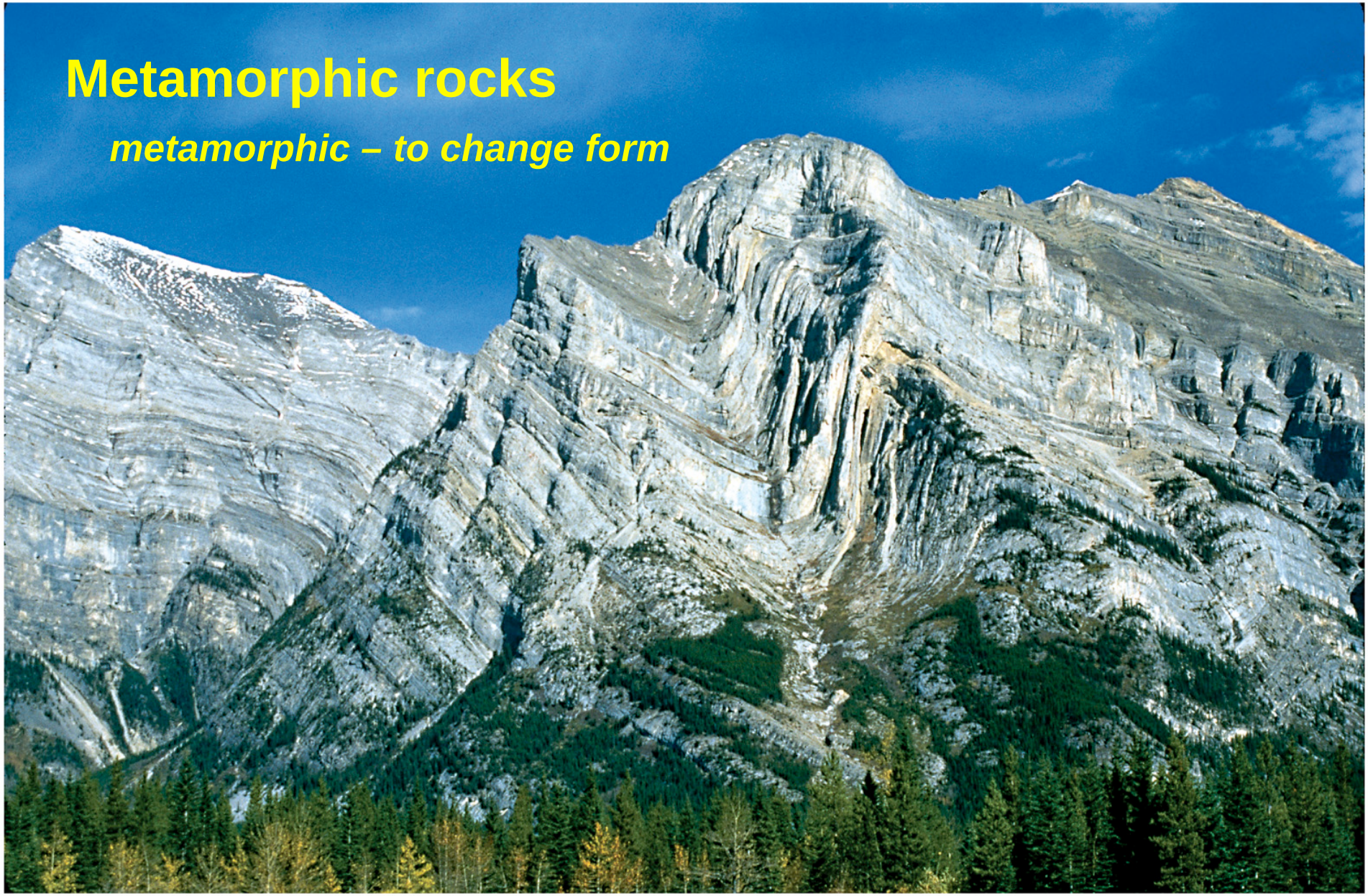
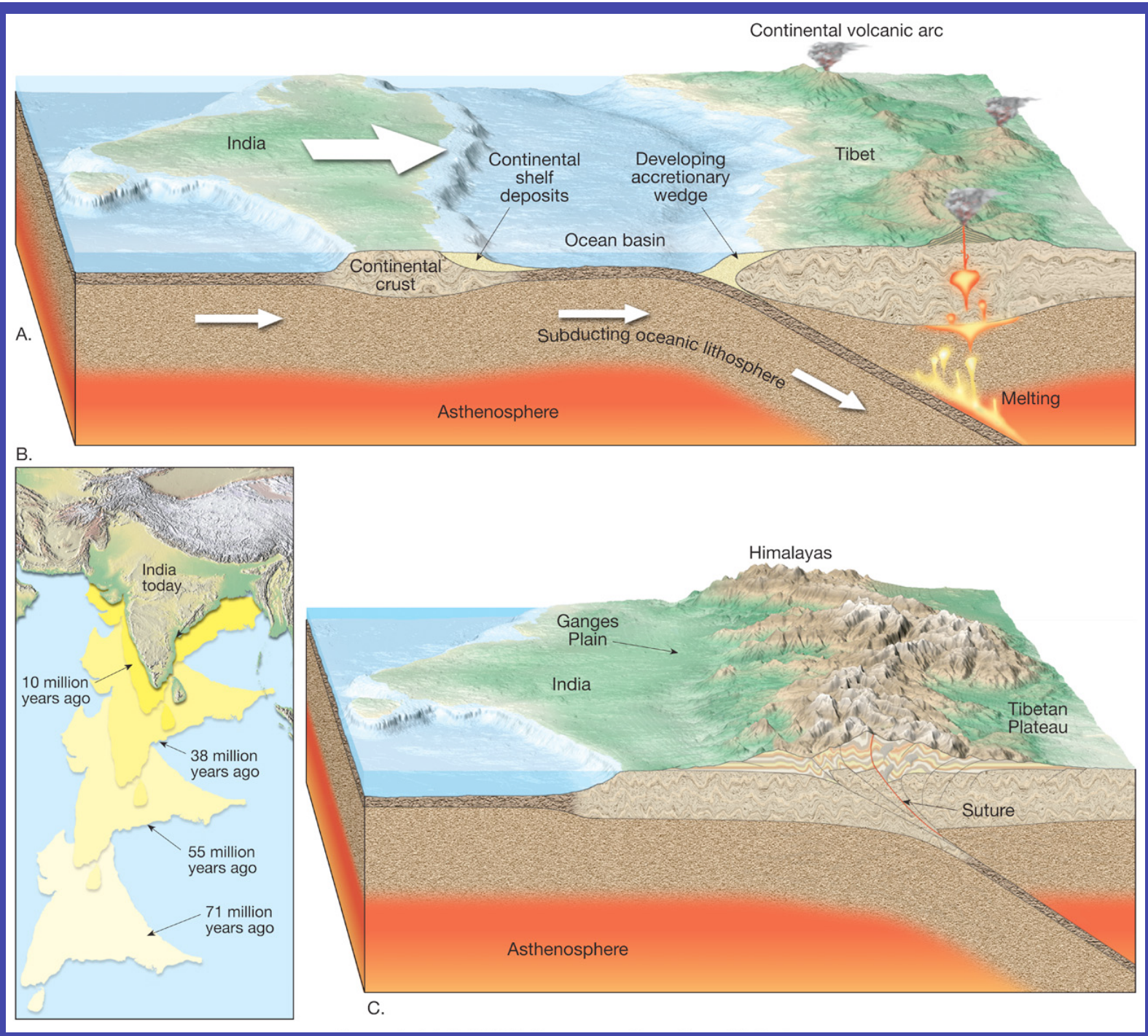
Metamorphic rocks

metamorphic – to change form



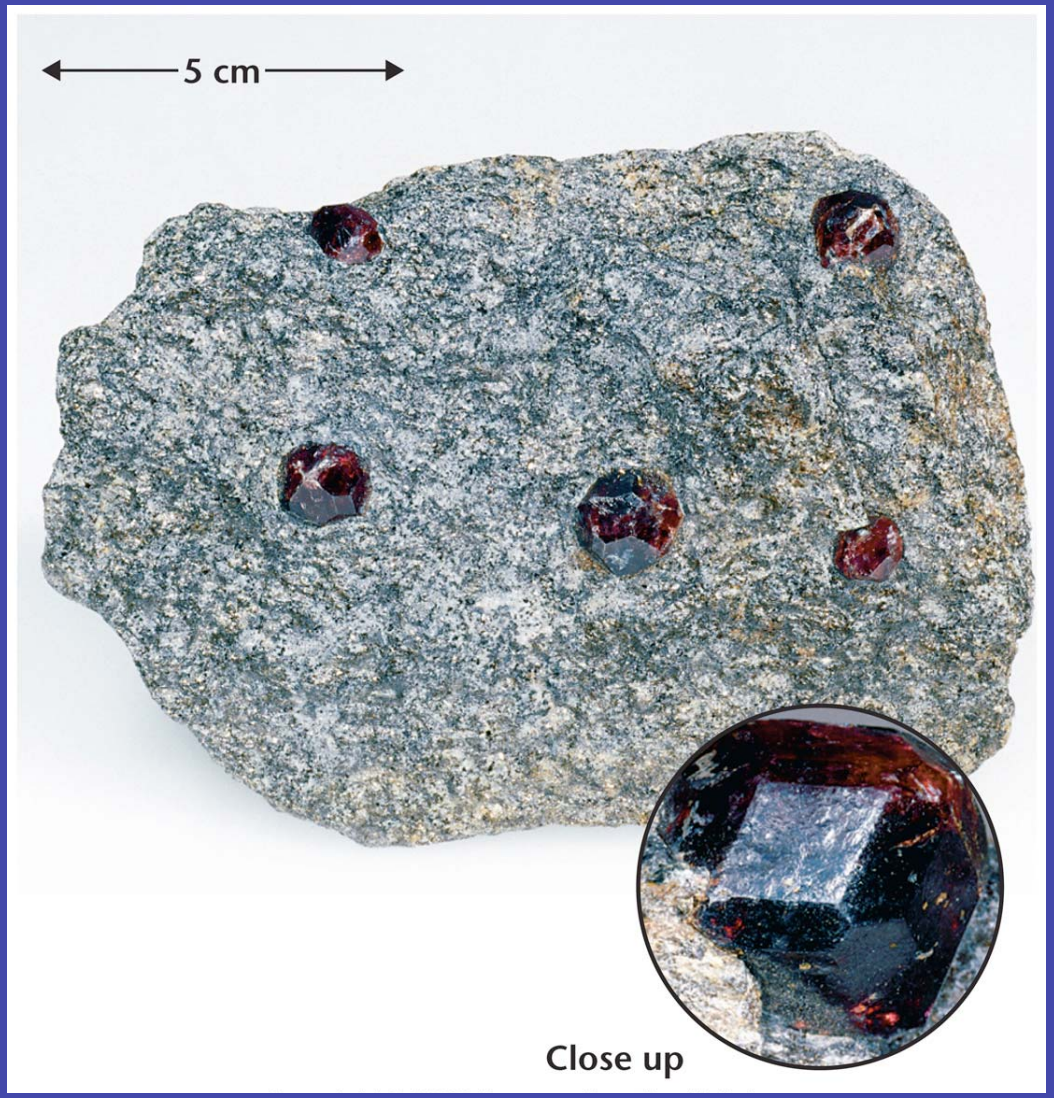
Mount Kidd, Alberta, Canada


Continental volcanic arc
India
Continental shelf deposits
Developing accretionary wedge
Tibet
Ocean basin
Continental crust
A.
Subducting oceanic lithosphere
Asthenosphere
Melting
B.
India today
10 million years ago
38 million years ago
55 million years ago
71 million years ago
Himalayas
Ganges Plain
India
Tibetan Plateau
Suture
Asthenosphere
C.

What forces/processes will change a rock's form?

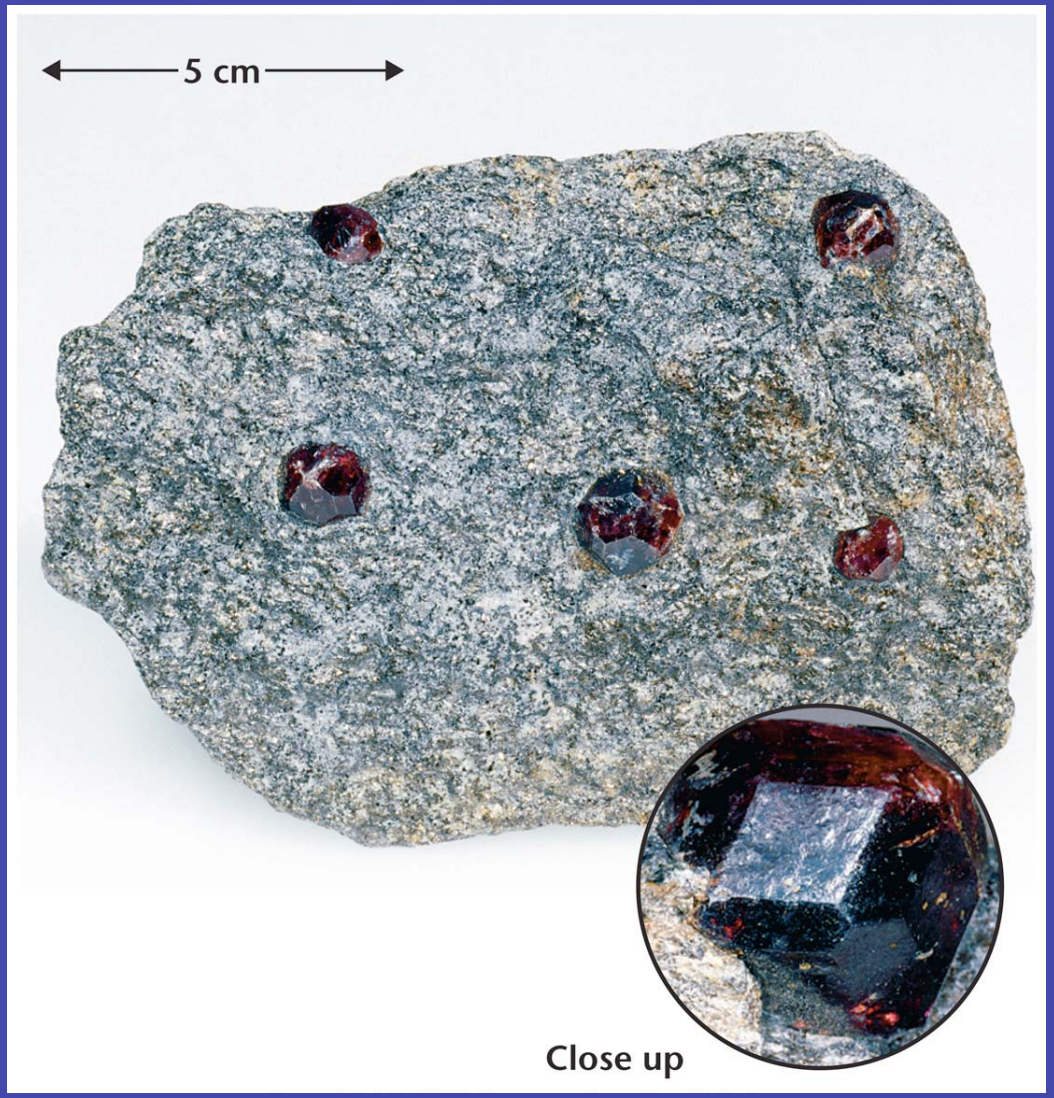


After - Schist





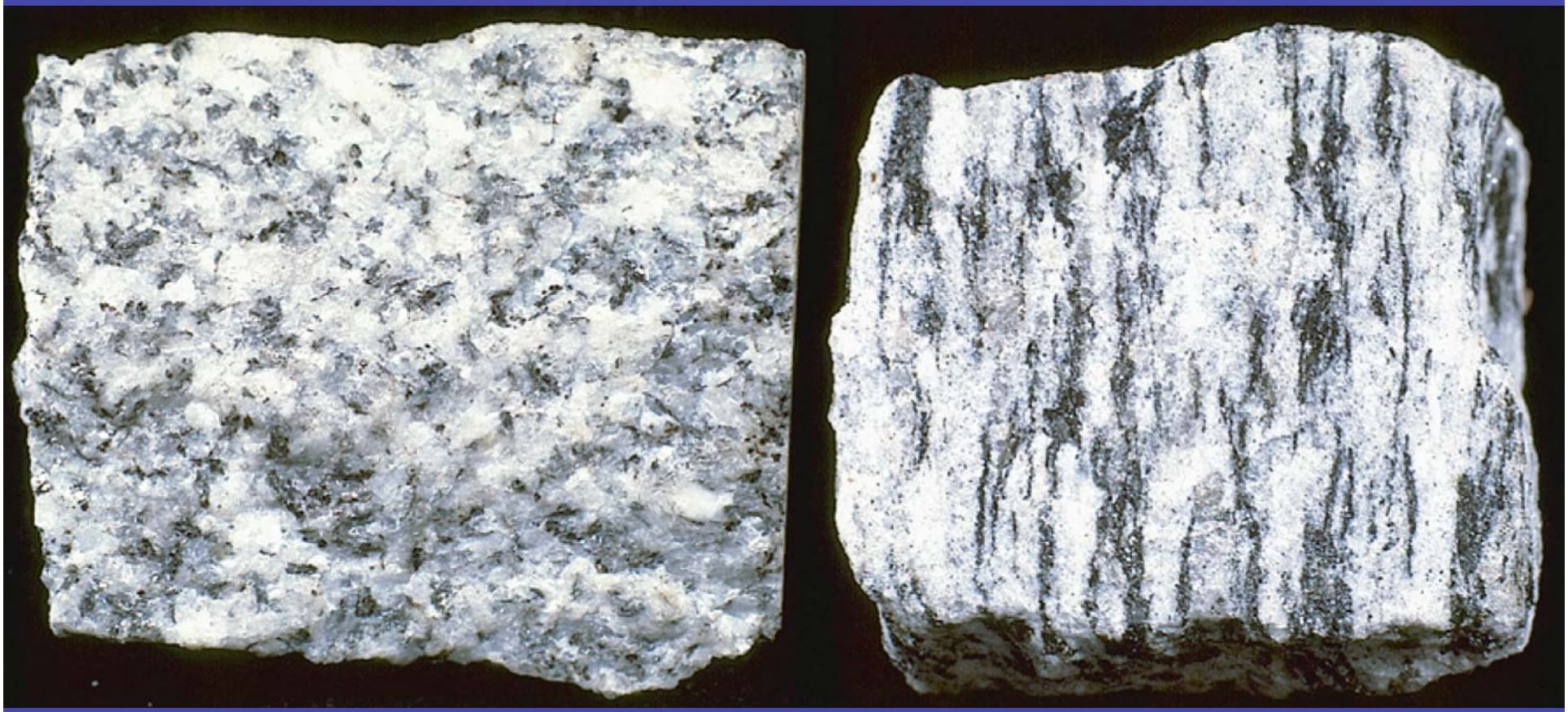
After - Schist



Heating causes recrystallization

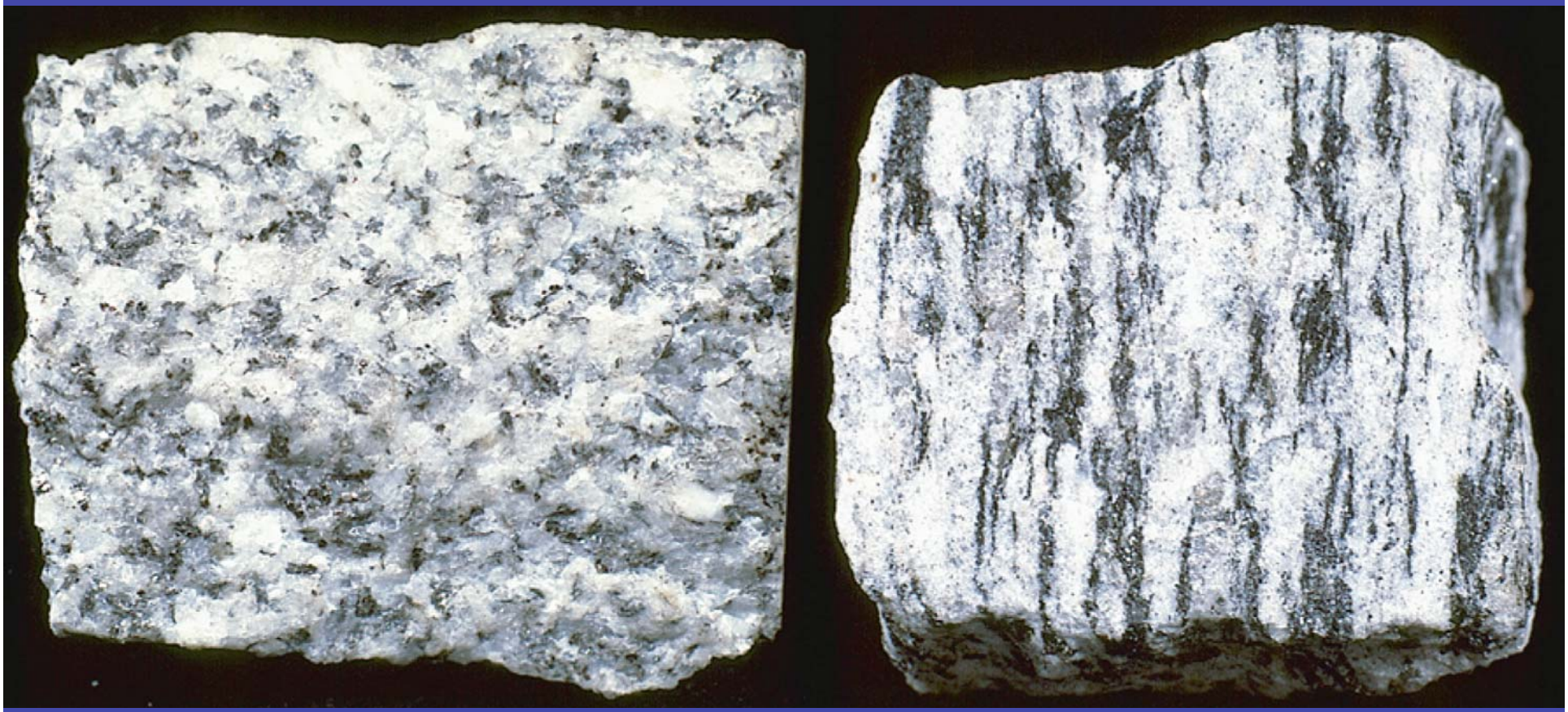
Before

After



Before - Granite

After - Gneiss

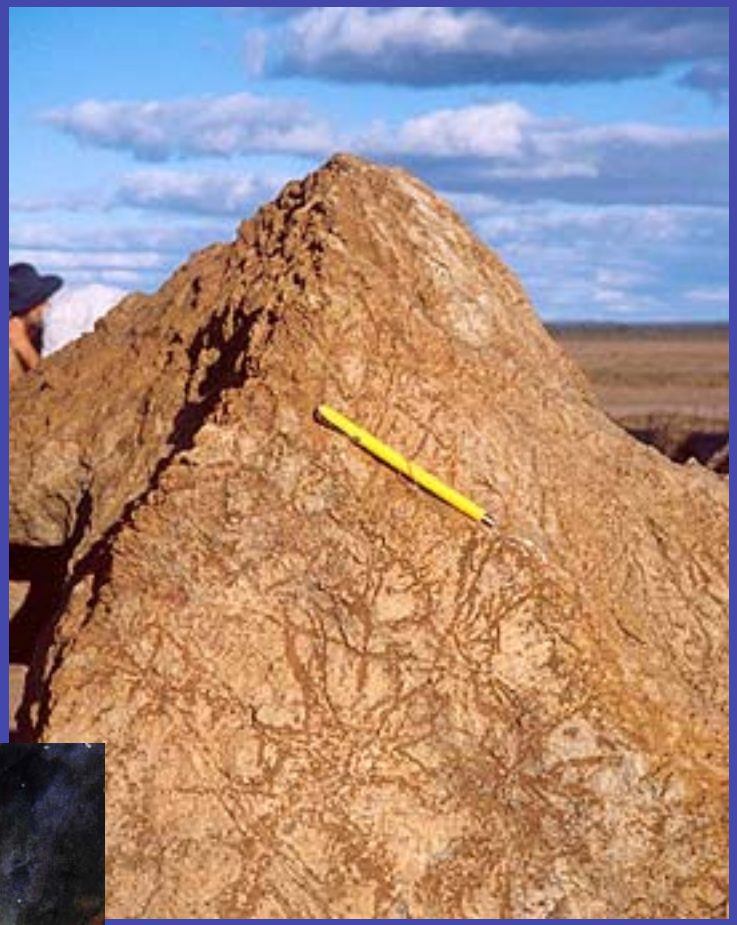


Pressure - mechanical rotation of grains results in alignment



Before





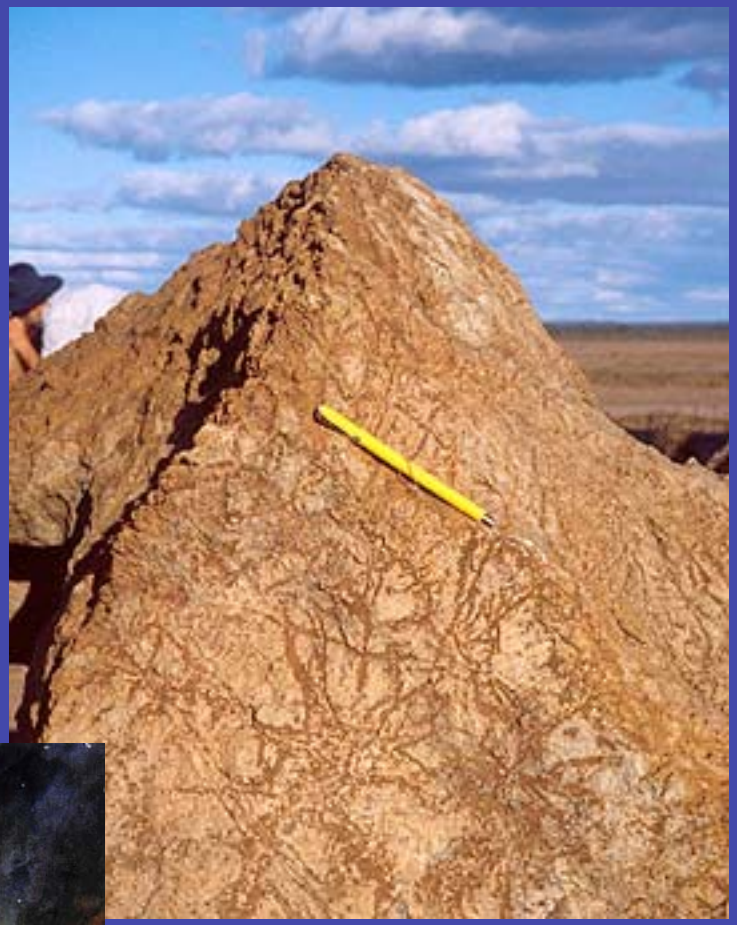
After



Before -
Pillow Basalt



Chemical fluid
circulation



After -
Sulfide deposits

What forces/processes will change a rock's form?

1. Heat



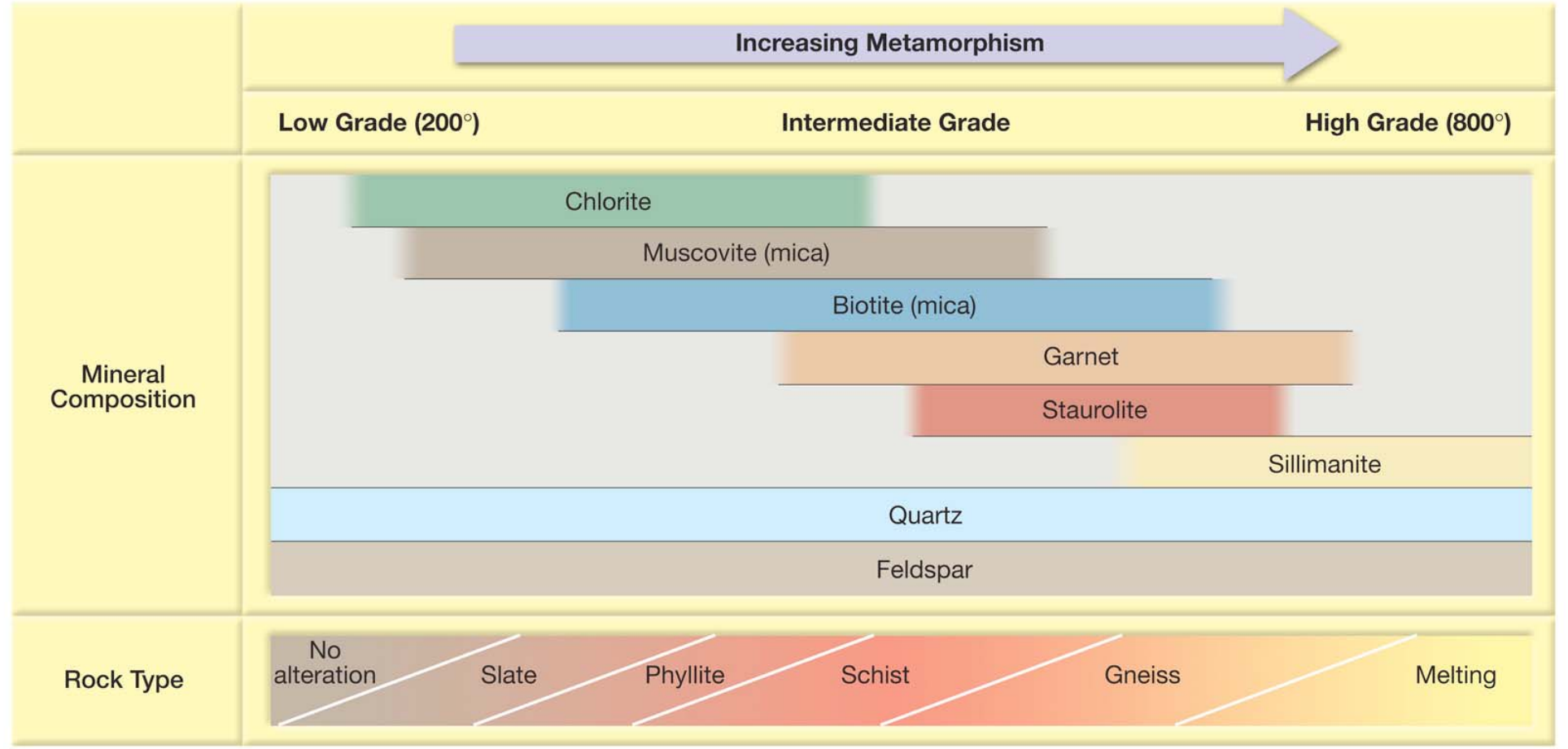
2. Pressure



3. Chemical Fluids



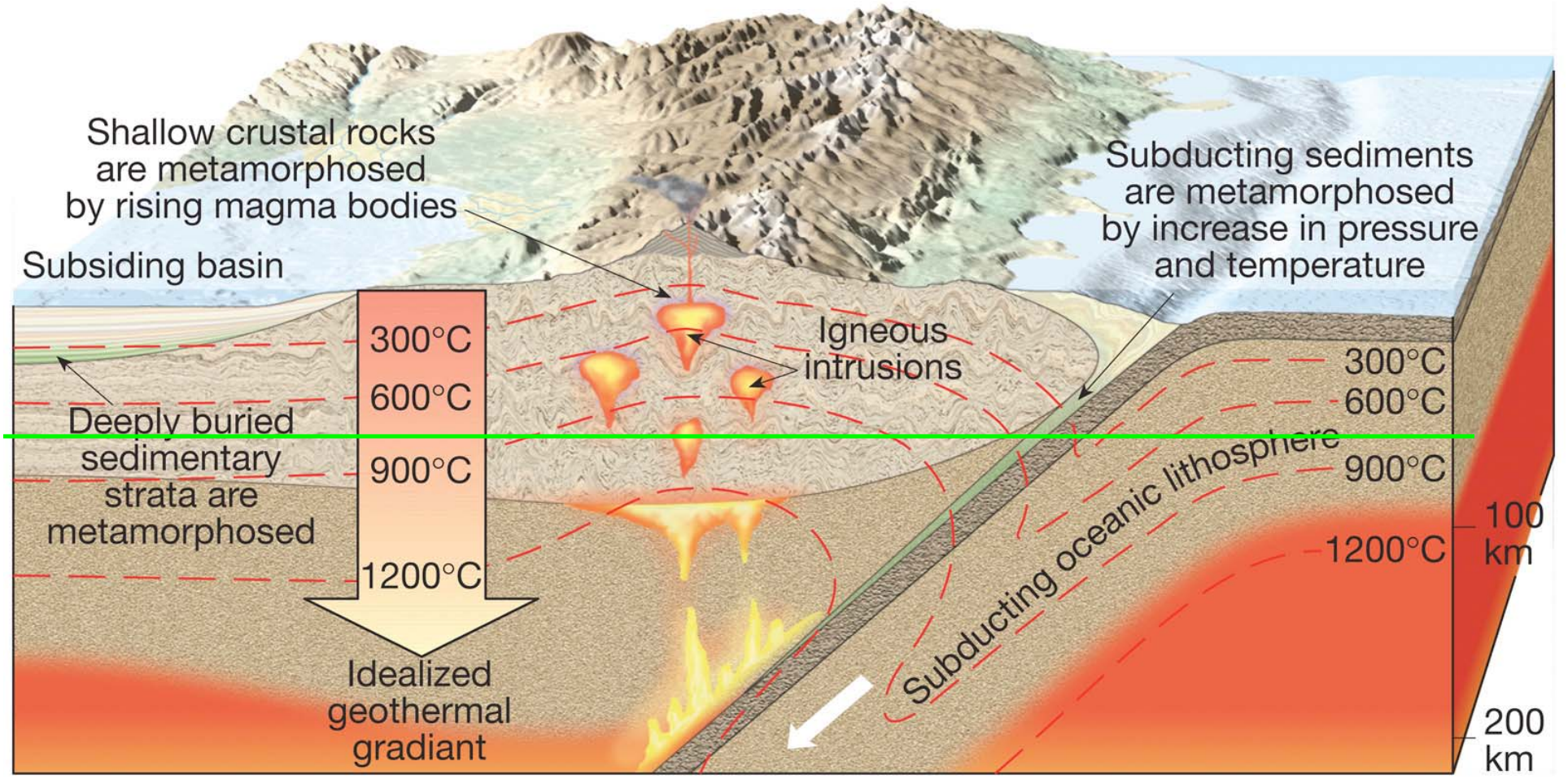
Metamorphic changes & temperature





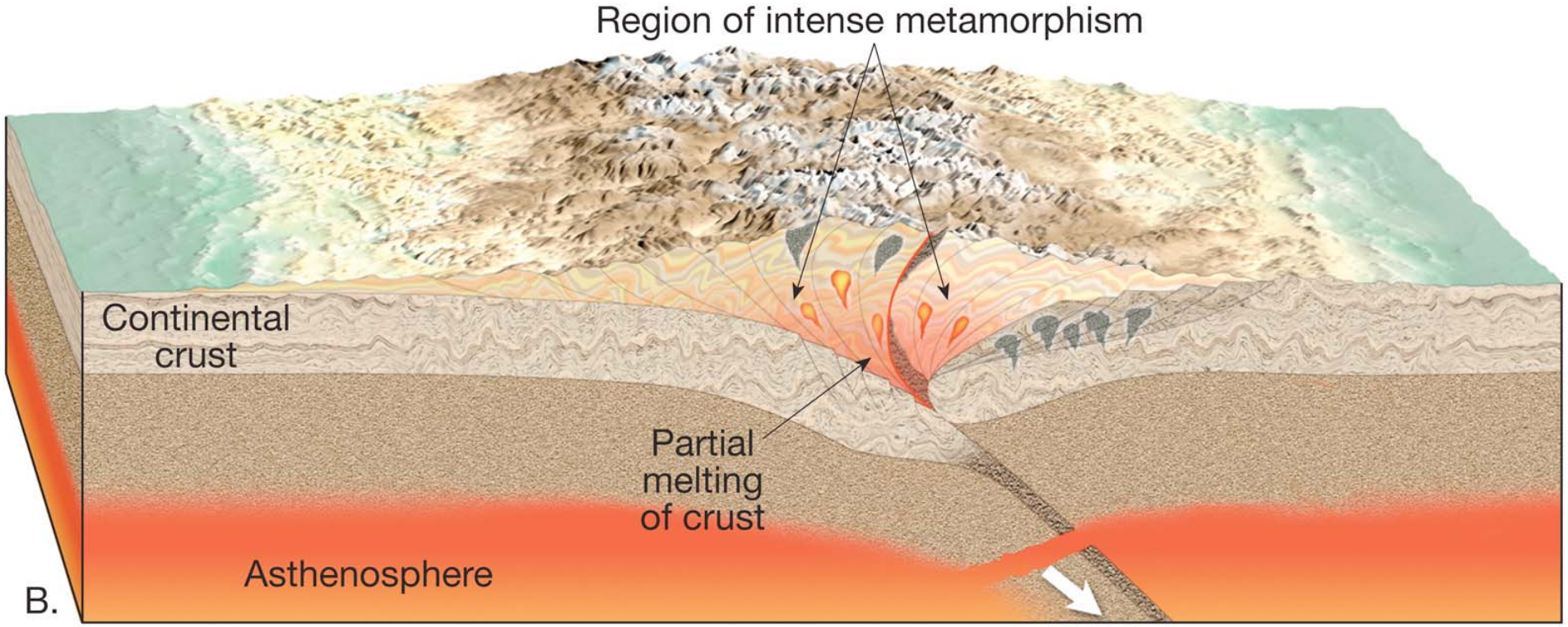
Where/how does heating occur naturally within Earth?

Earth's Geothermal Gradient

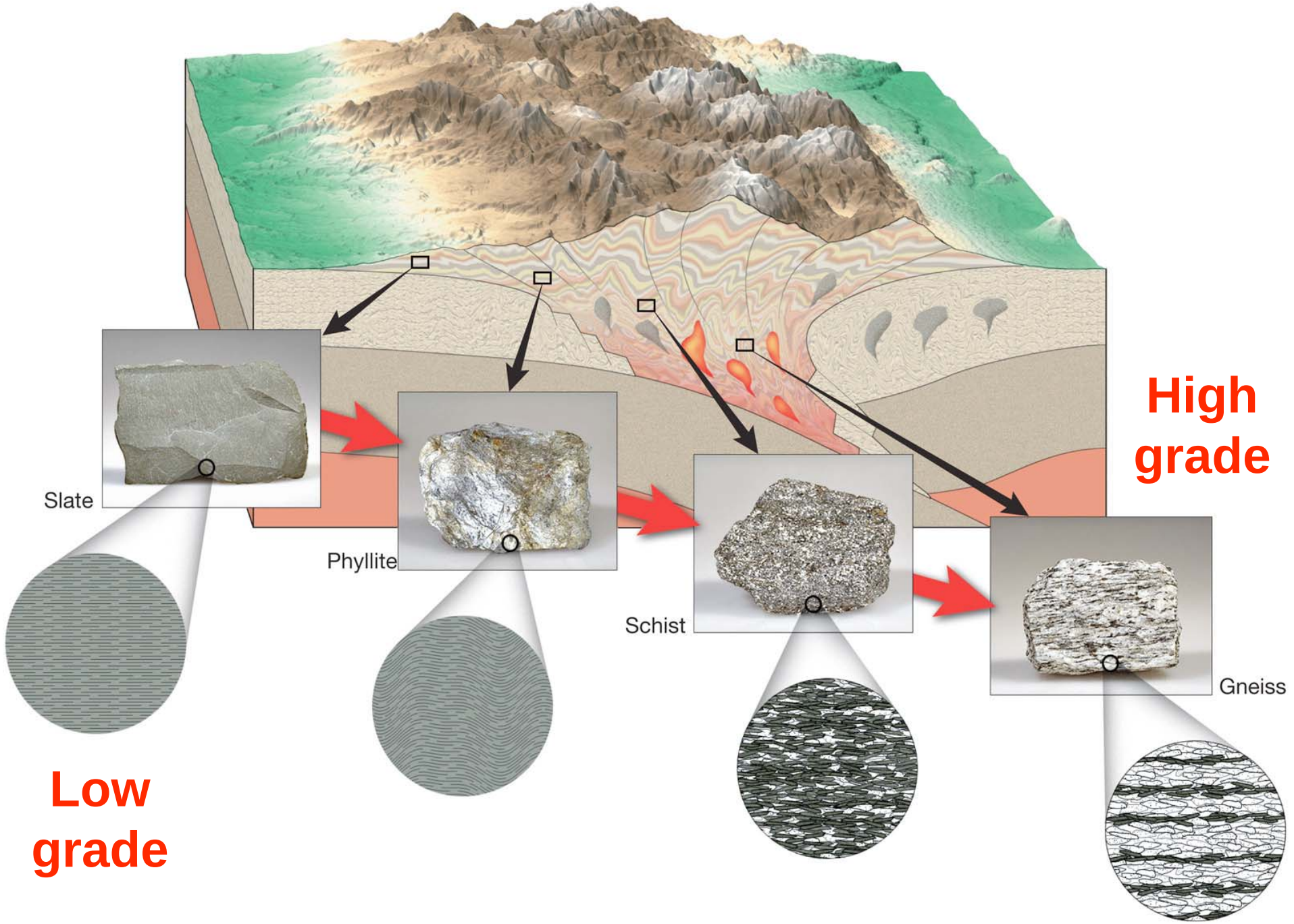


What kind of boundary is this?

How is temperature changing across this image?

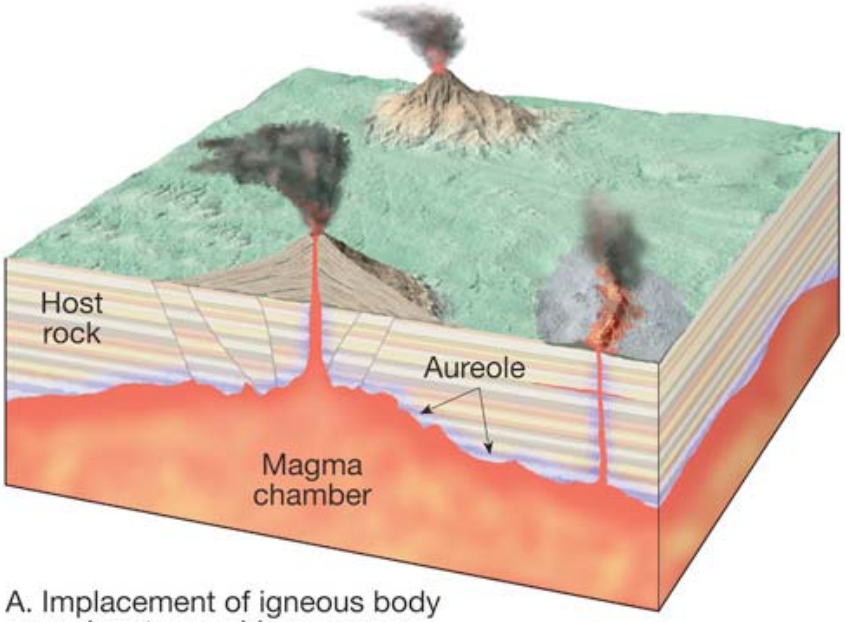


What kind of boundary is this?

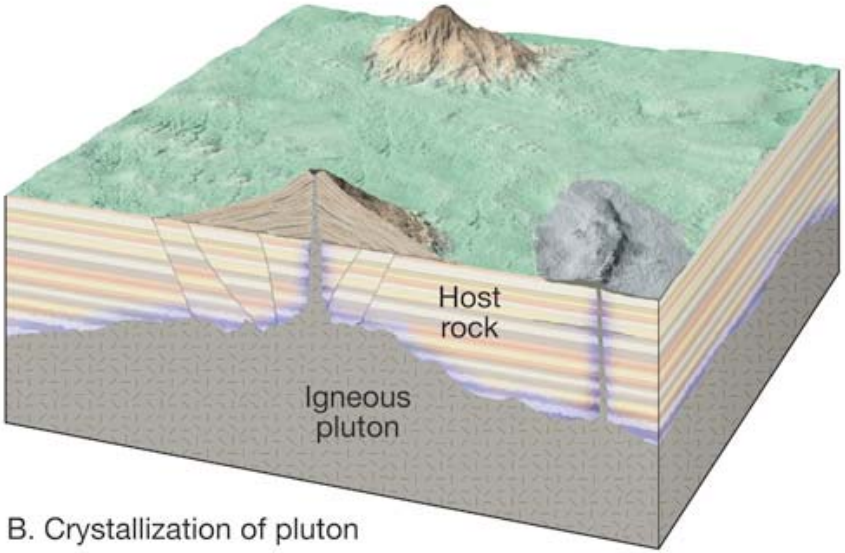

Slate
Phyllite
Schist
Gneiss
High grade
Low grade


Roof pendant
Igneous
pluton

Contact Metamorphism

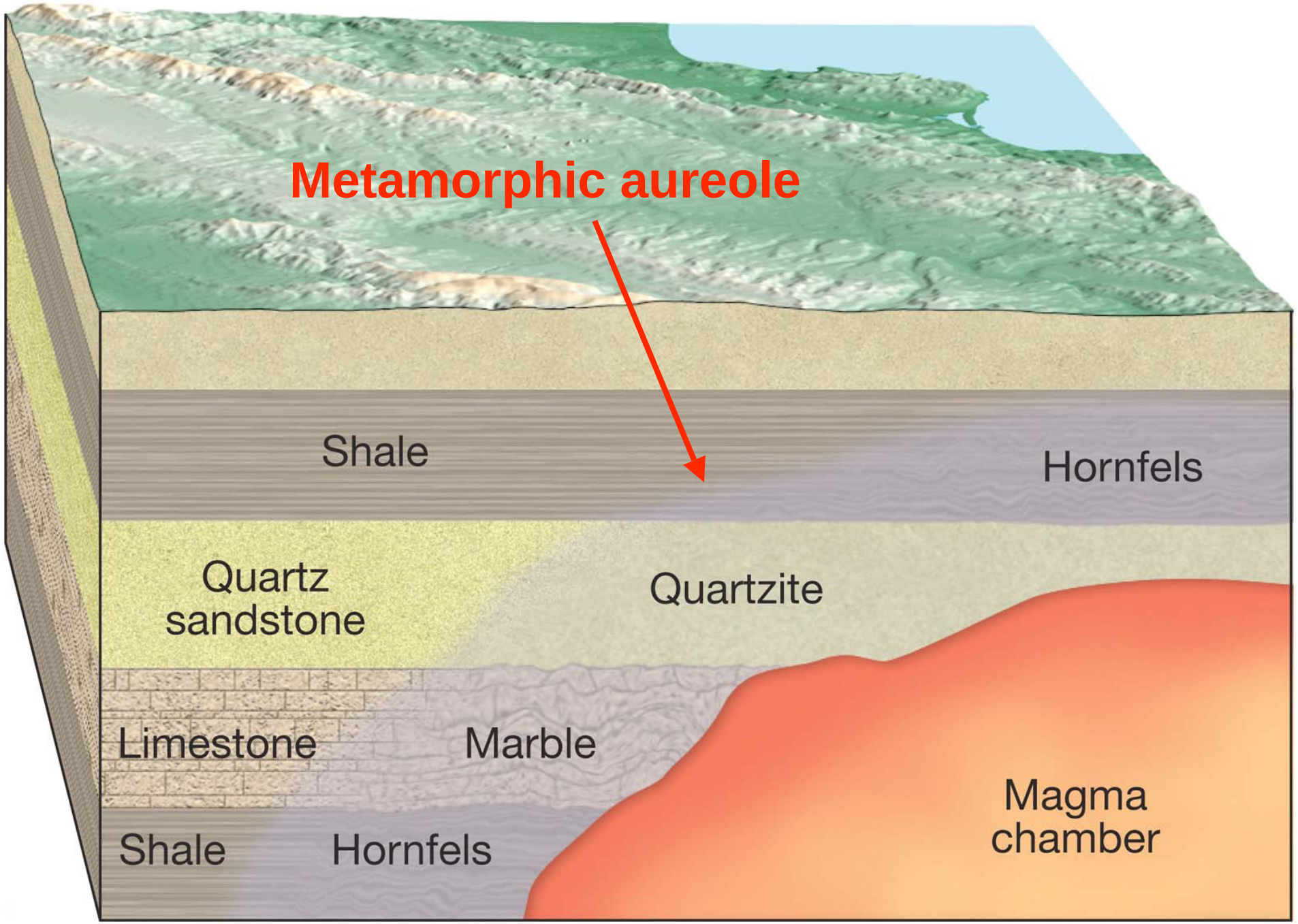


A. Implacement of igneous body and metamorphism



B. Crystallization of pluton

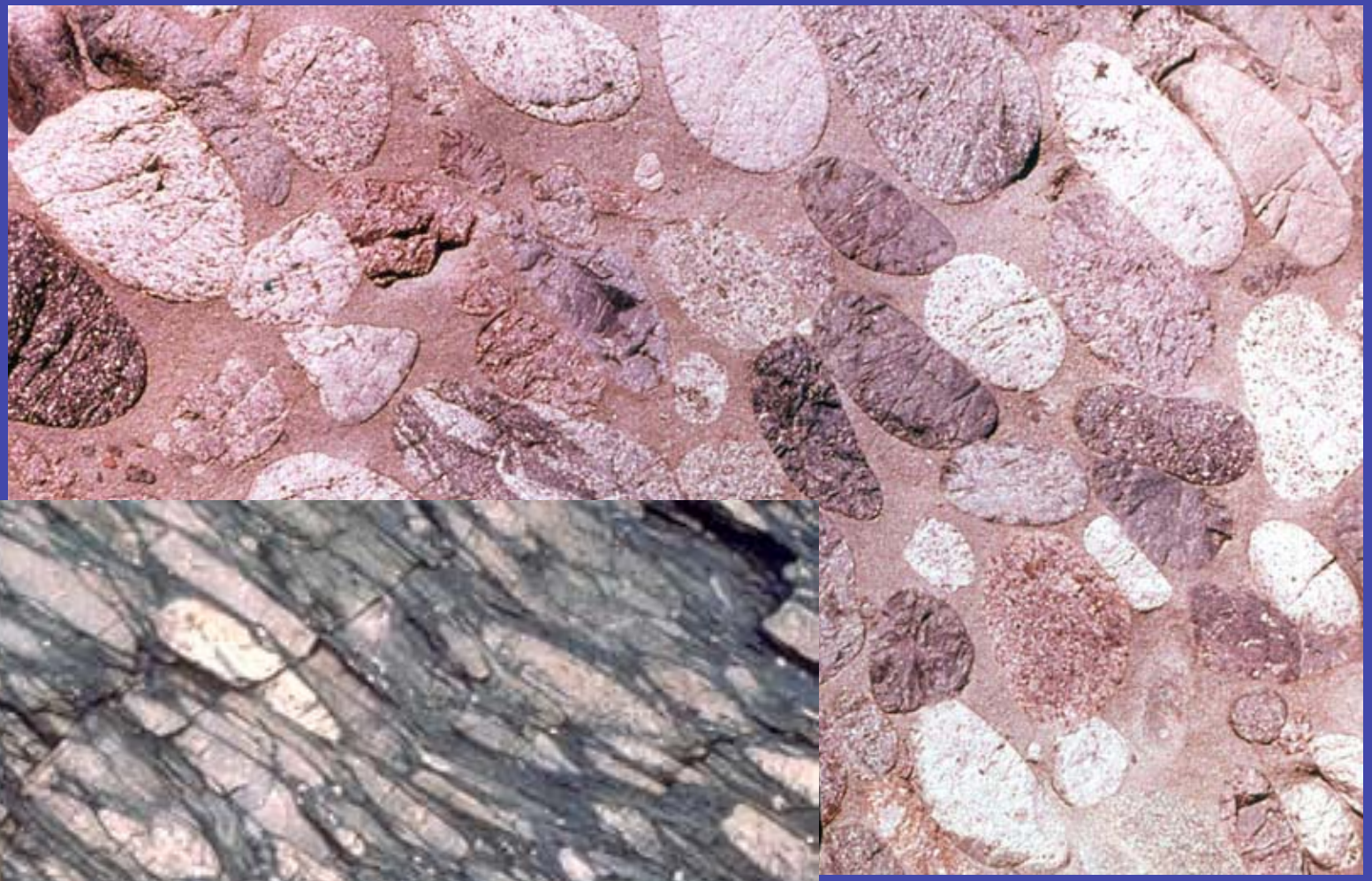



Metamorphic aureole
Shale
Hornfels
Quartz sandstone
Quartzite
Limestone
Marble
Shale
Hornfels
Magma chamber

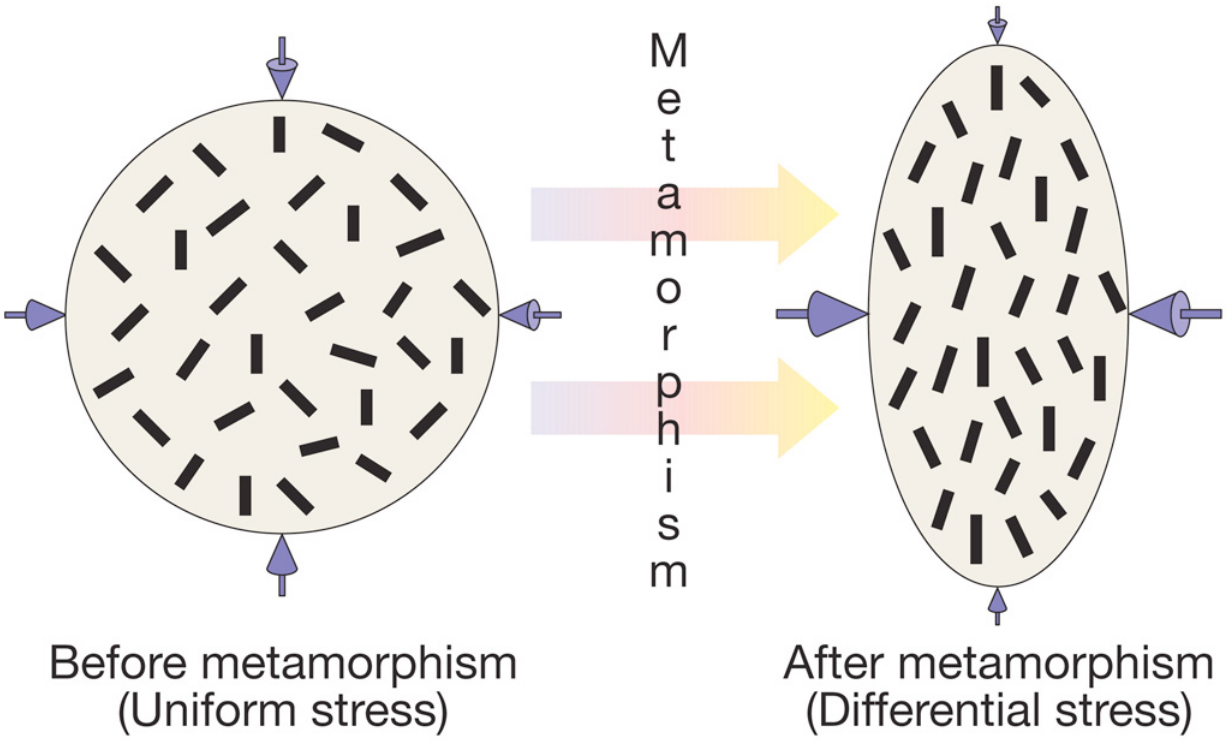
Metamorphic heating is the result of:

1. **Pressure**
2. **Burial**
3. **Volcanic activity**





Metaconglomerate

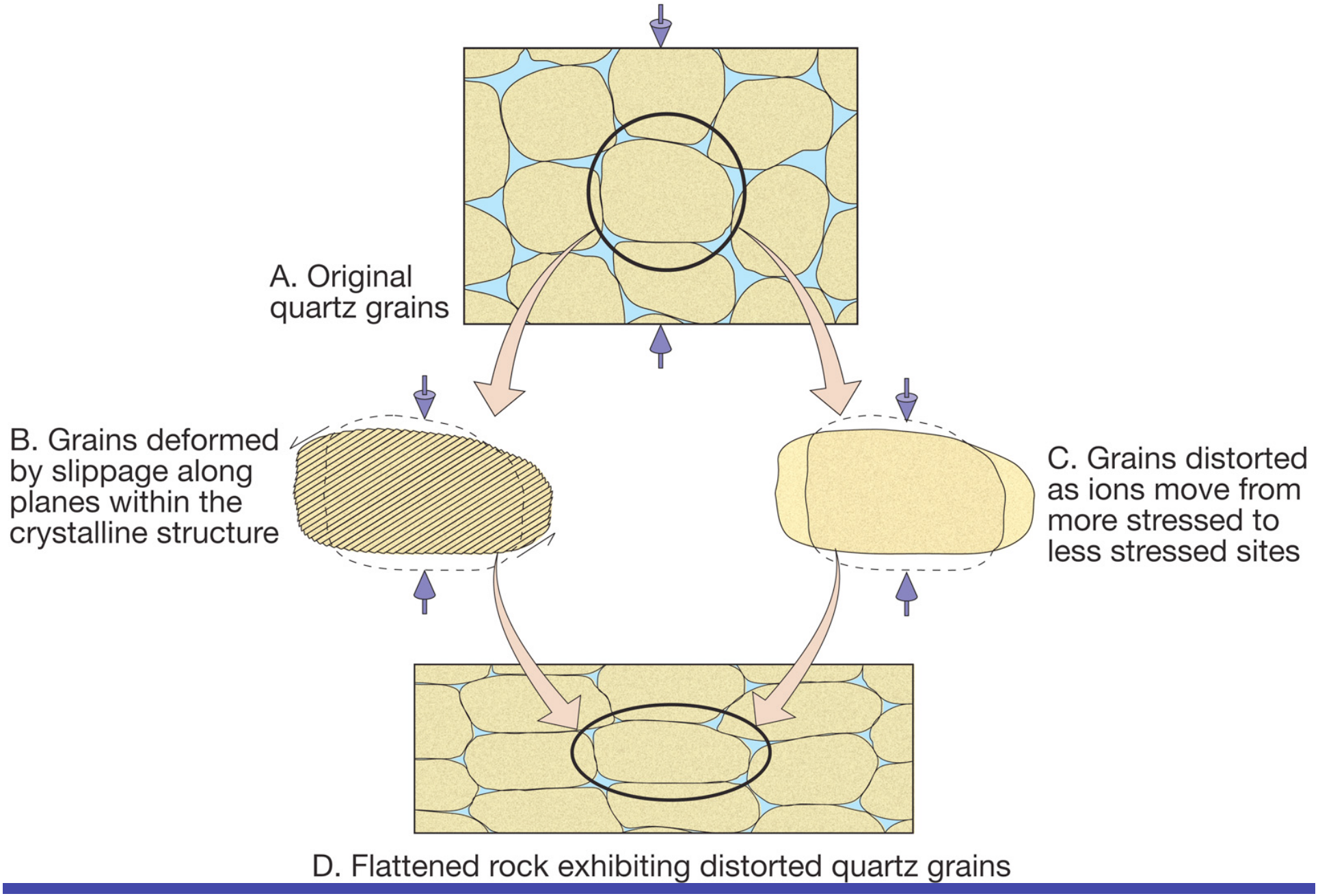


Granular reorientation





Pressure also deforms grains

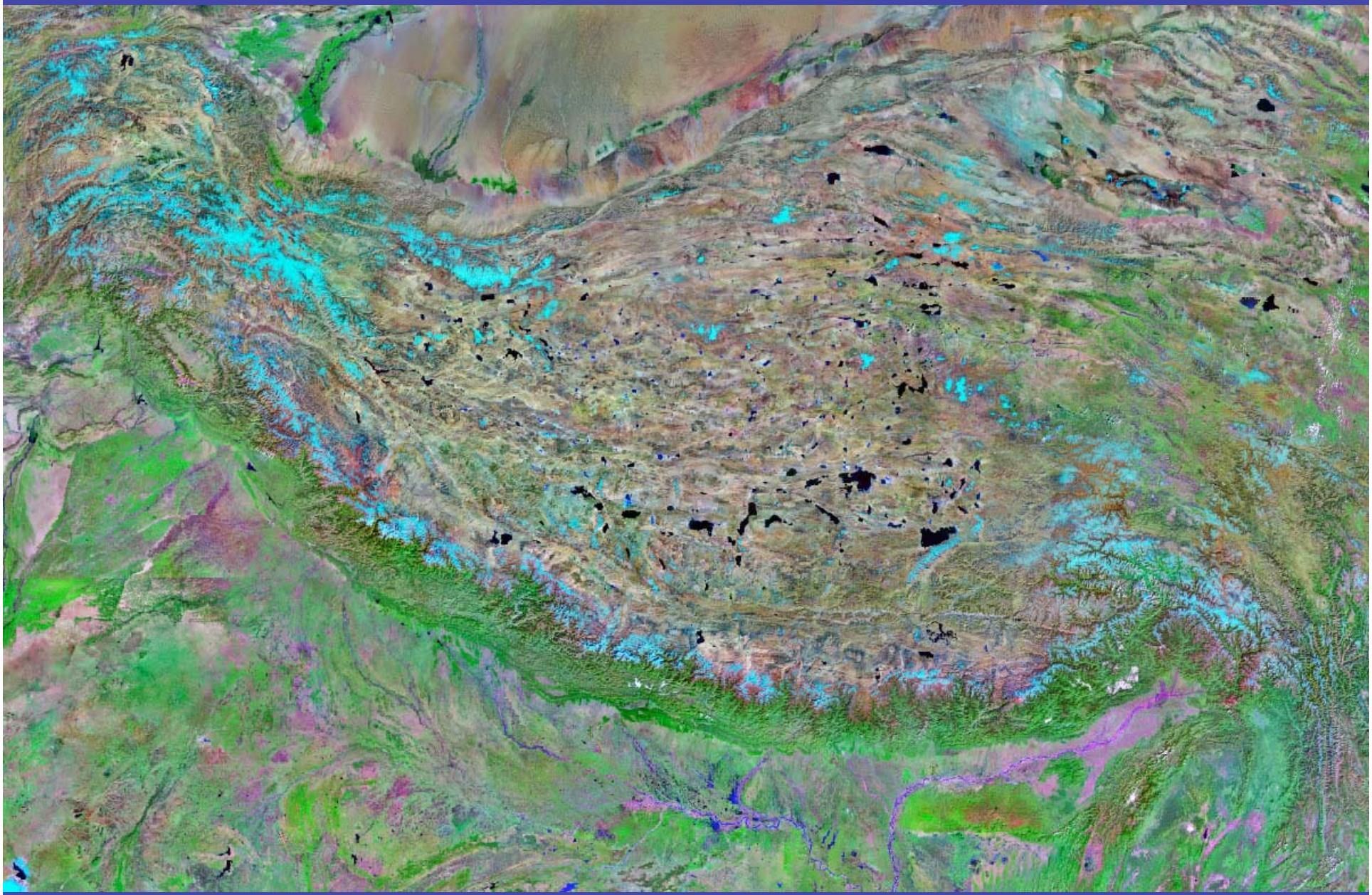


Foliation – reorganization of mineral grains into a planar orientation

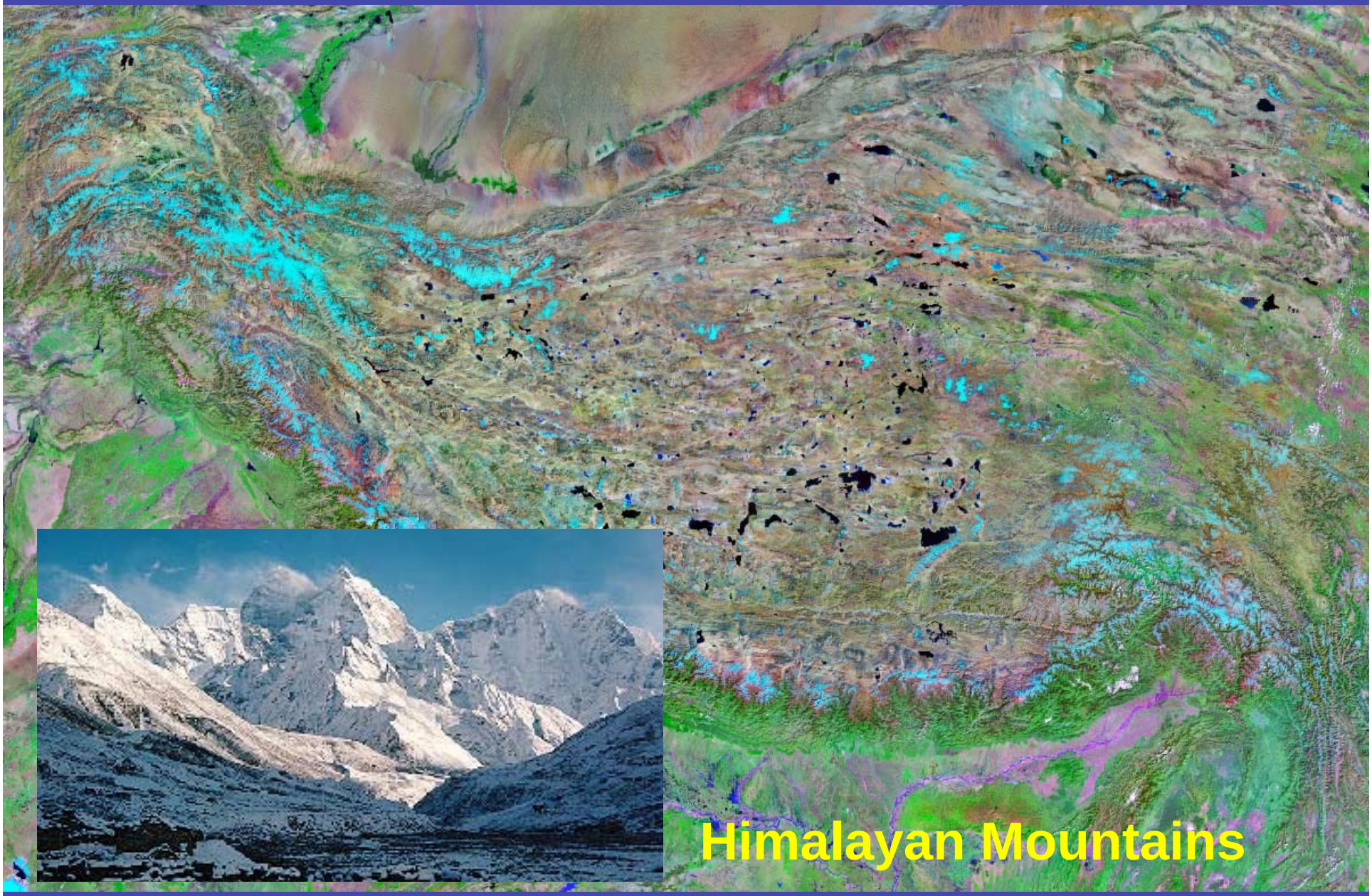


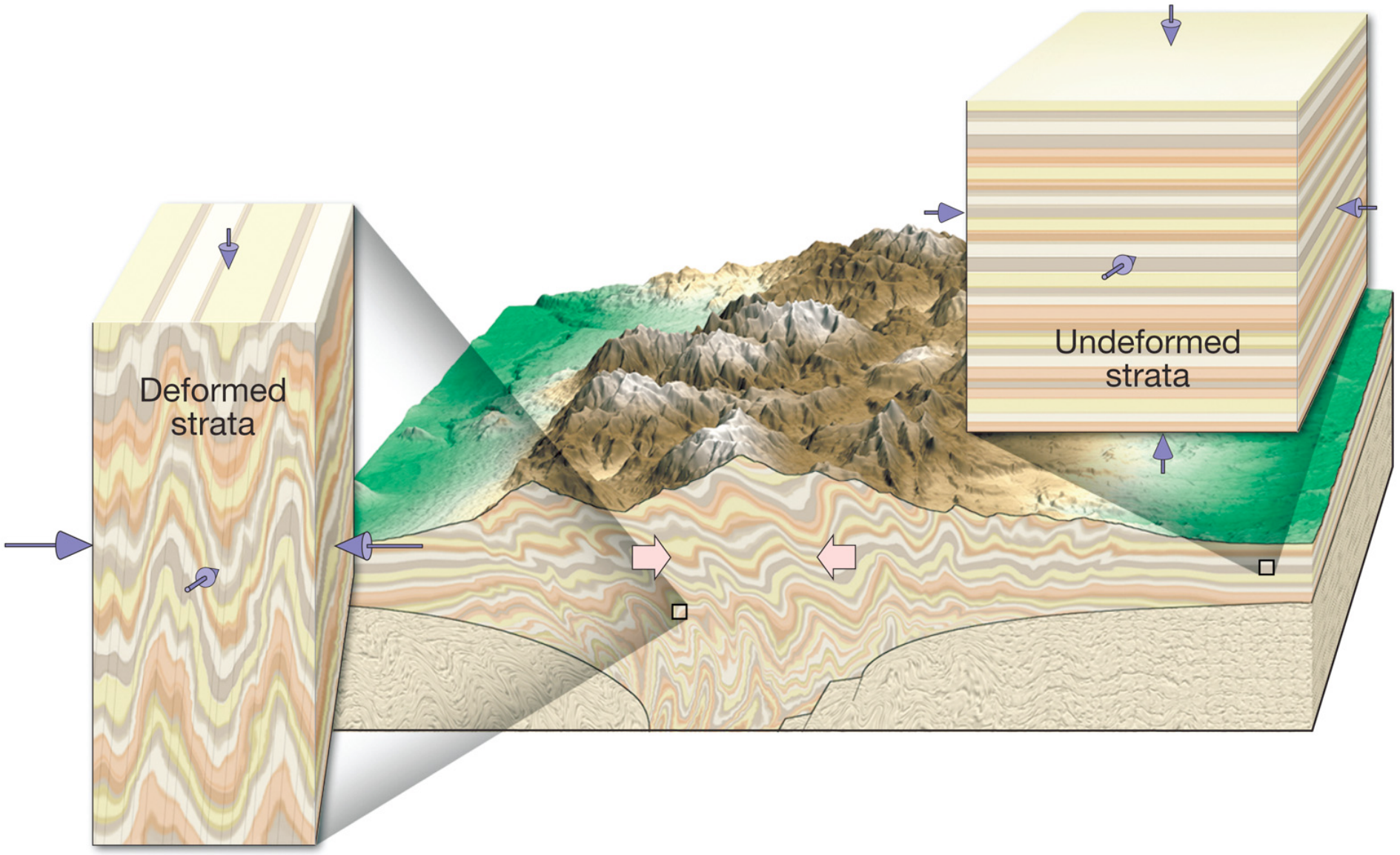
Where are these high pressure environments most common?

Regional metamorphism (modern)

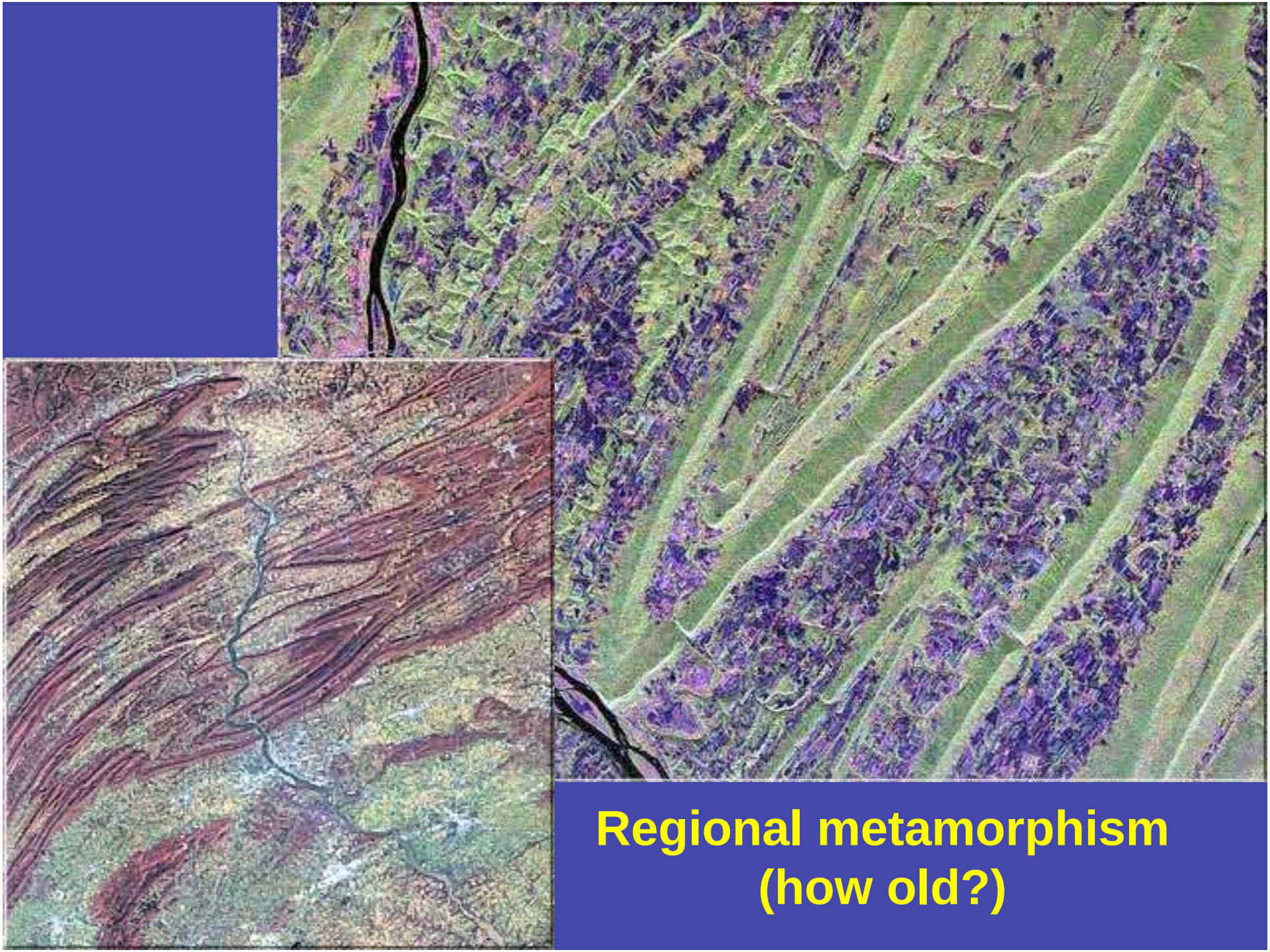


Regional metamorphism (modern)



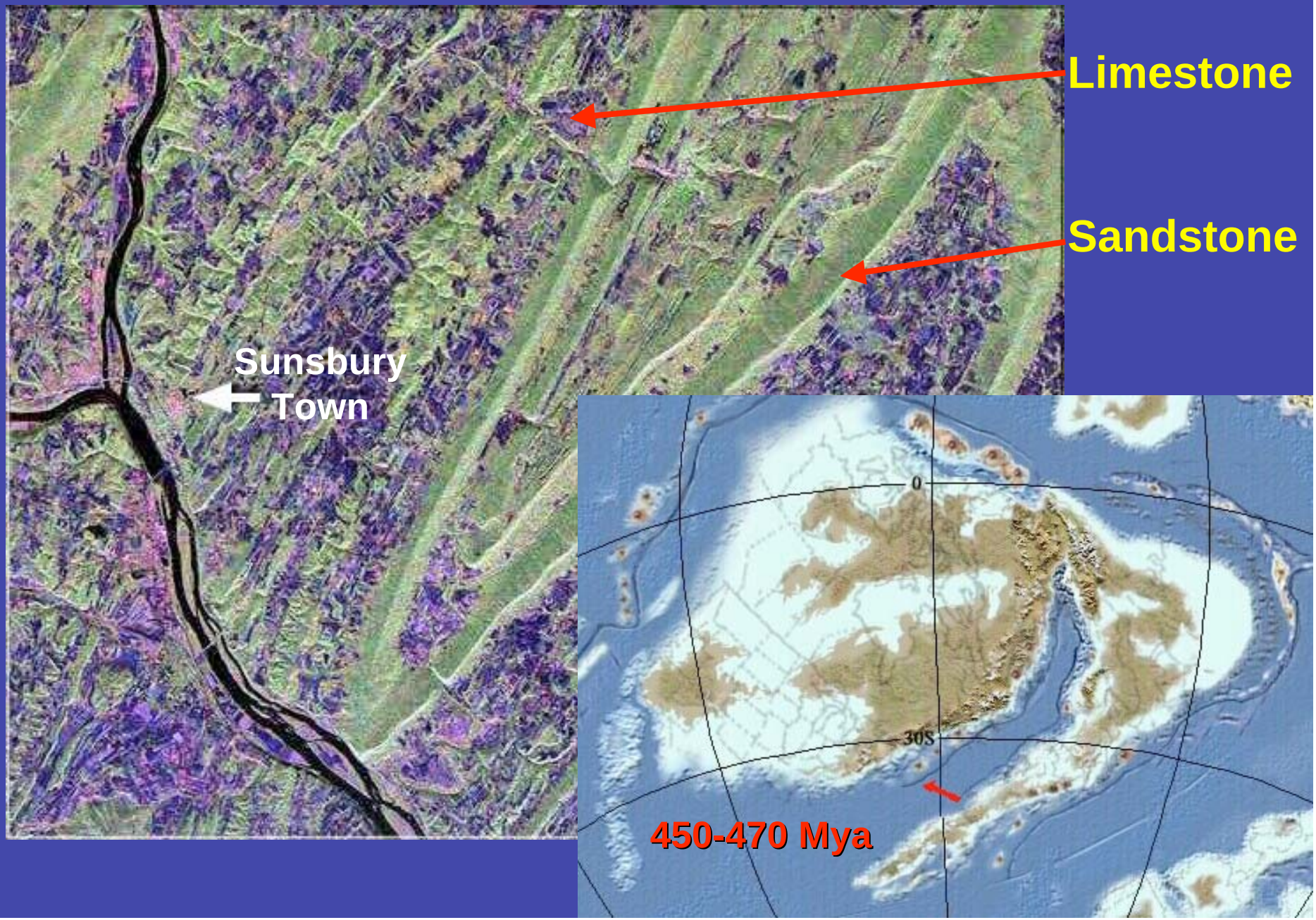


B. Differential stress



Regional metamorphism (how old?)

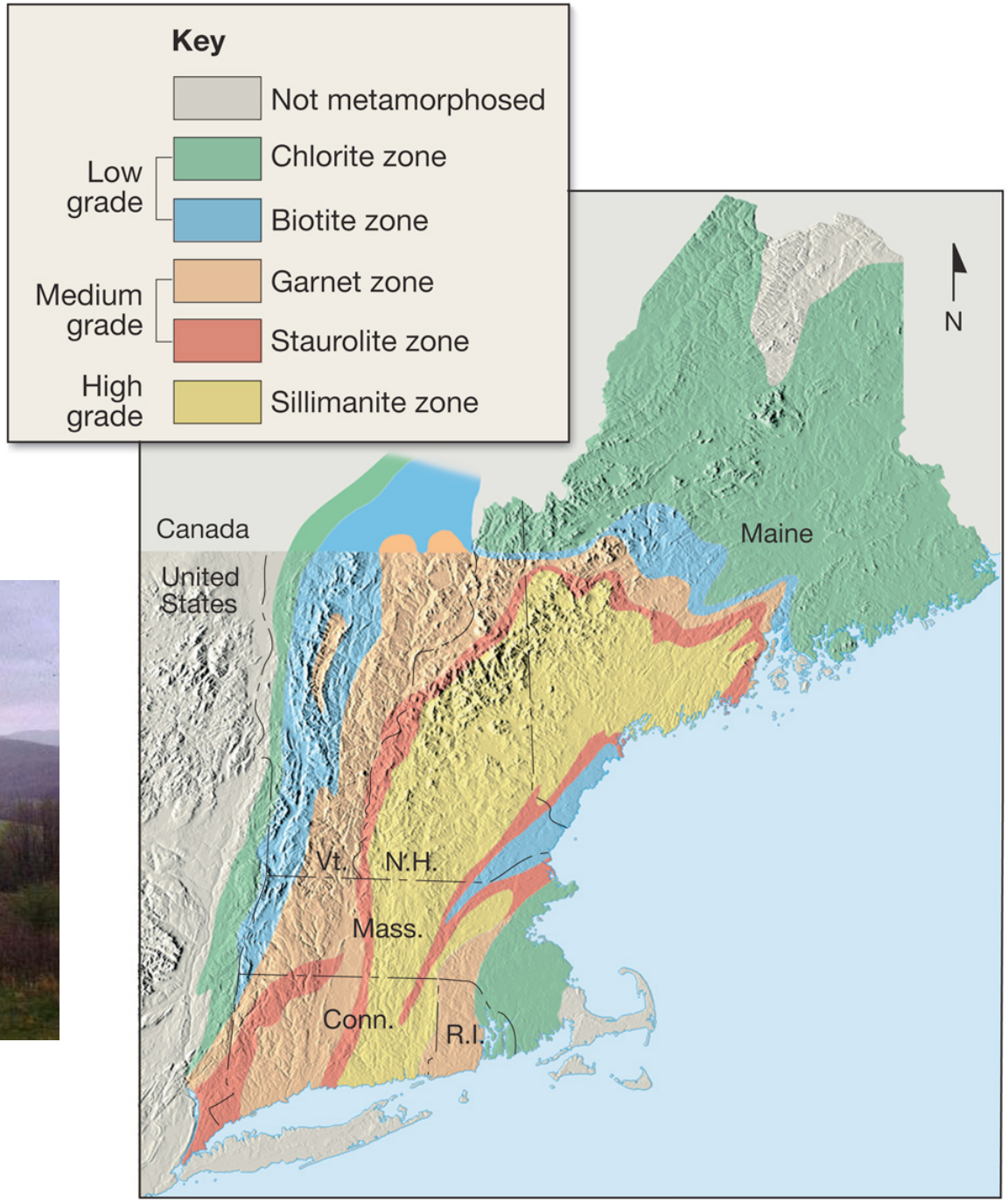
Regional metamorphism – Appalachian Mountains



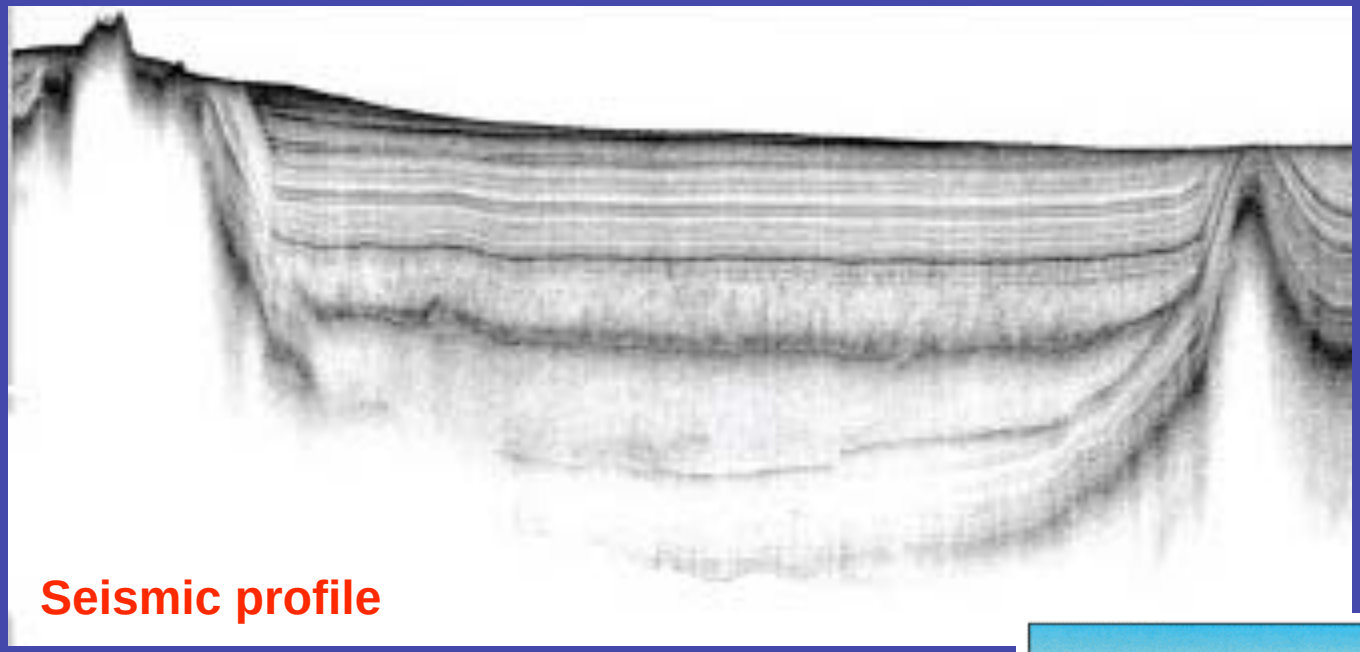




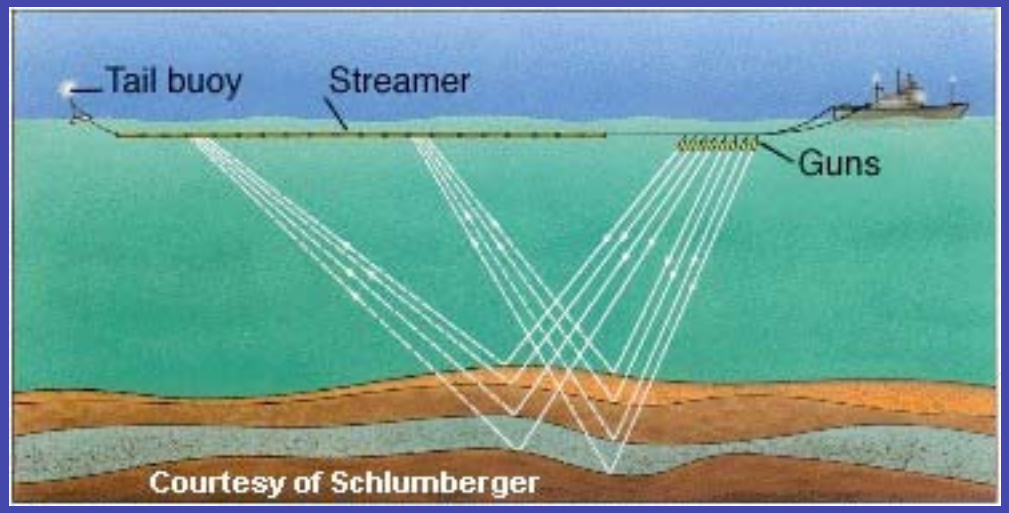
Appalachian Metamorphism

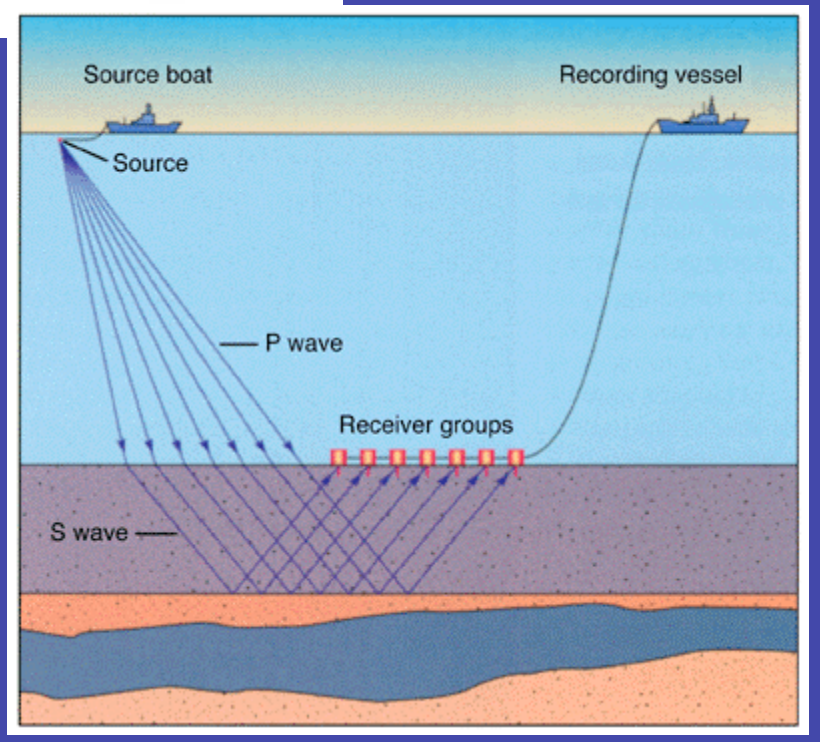


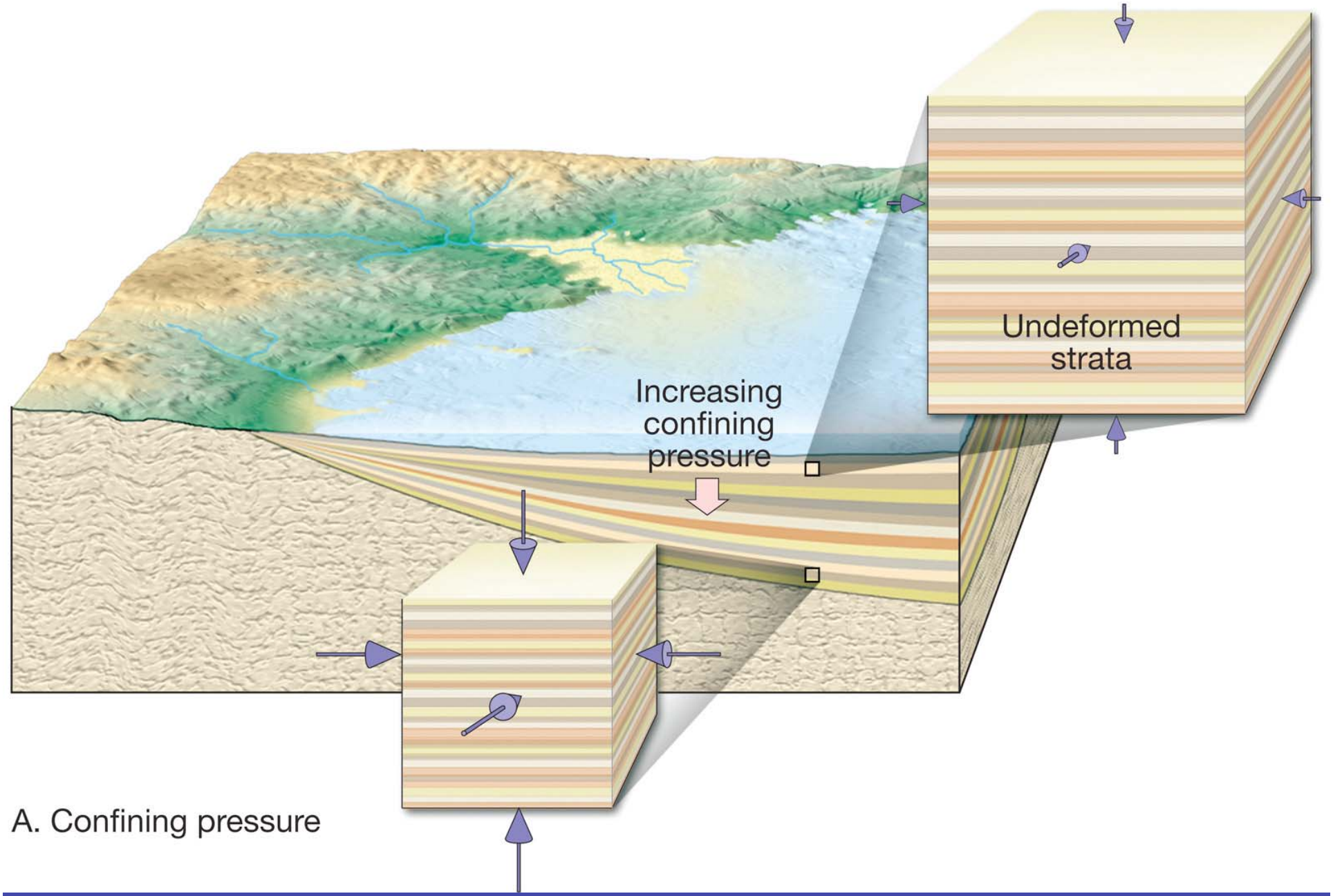
Burial Metamorphism



Seismic profile



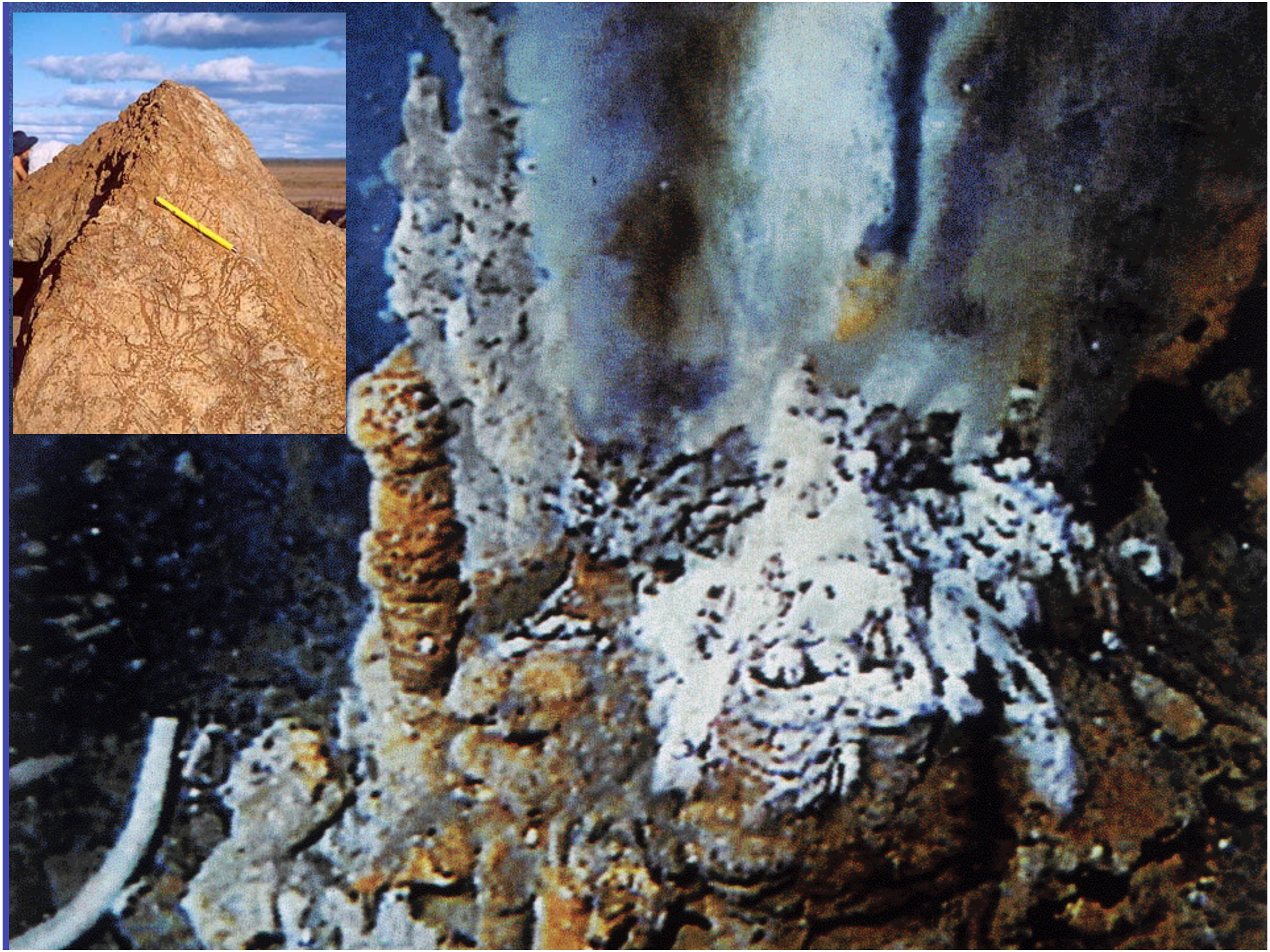


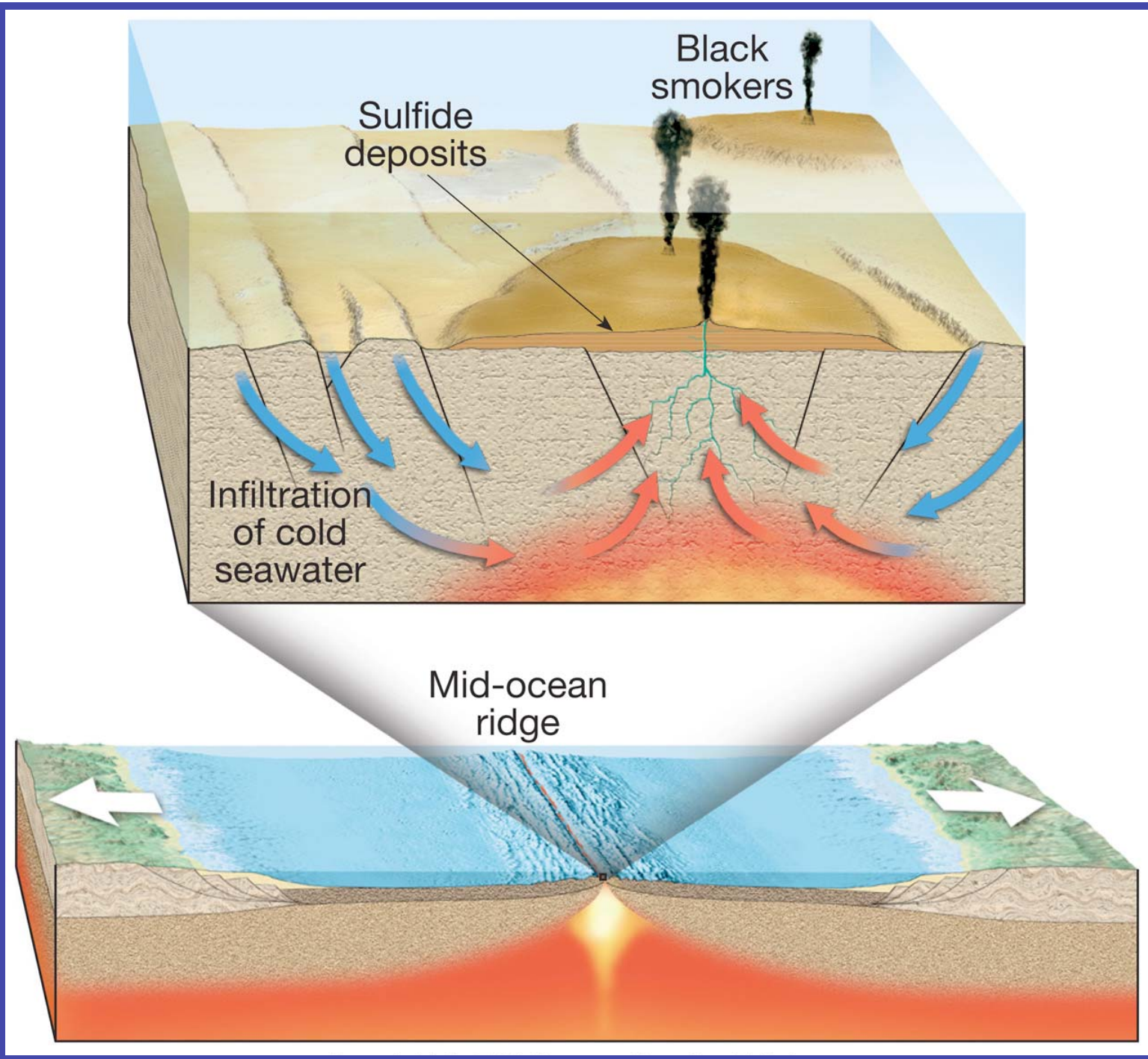


A. Confining pressure

Metamorphic pressure occurs due to:

1. **Tectonics**
2. **Burial**



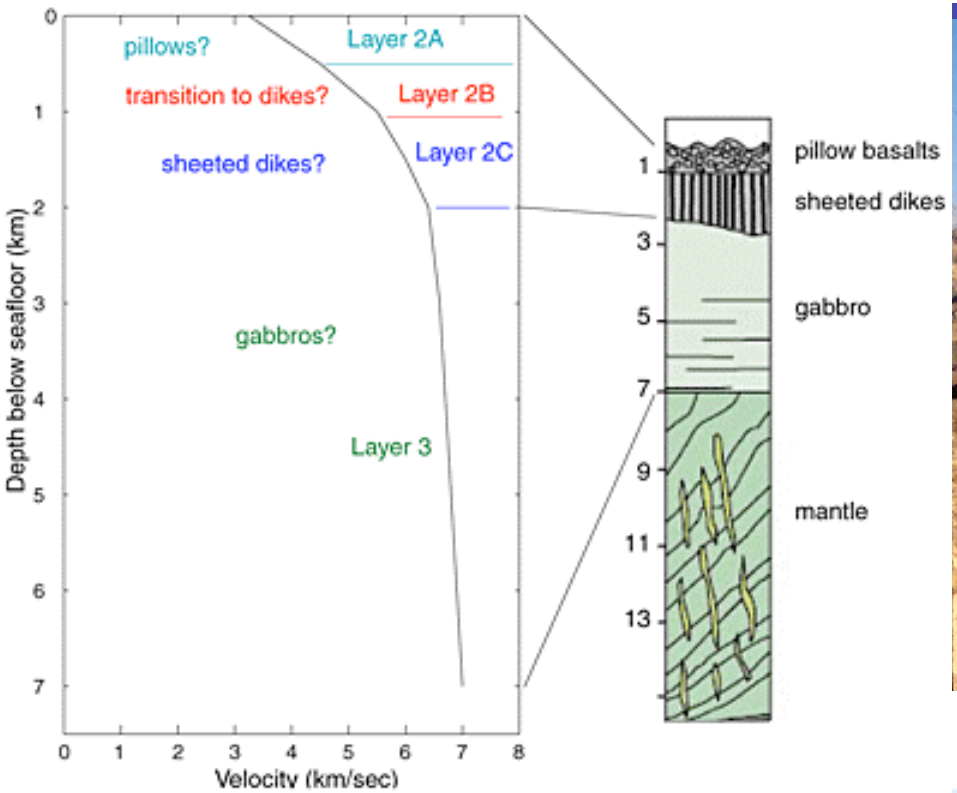

Black
smokers
Sulfide
deposits
Infiltration
of cold
seawater
Mid-ocean
ridge

Tethys Ocean
245-66 Mya



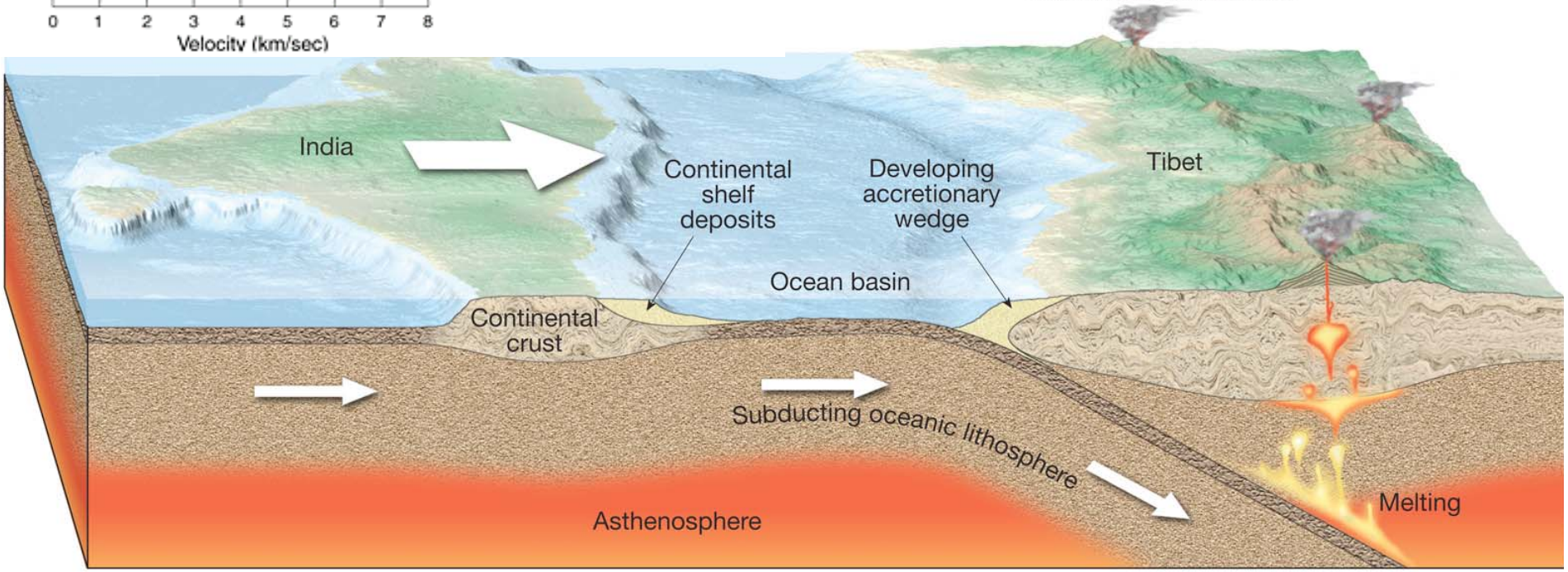
Countries that border the Mediterranean Sea







Continental volcanic arc









200,000 tons from 3,500-1,200 BC !

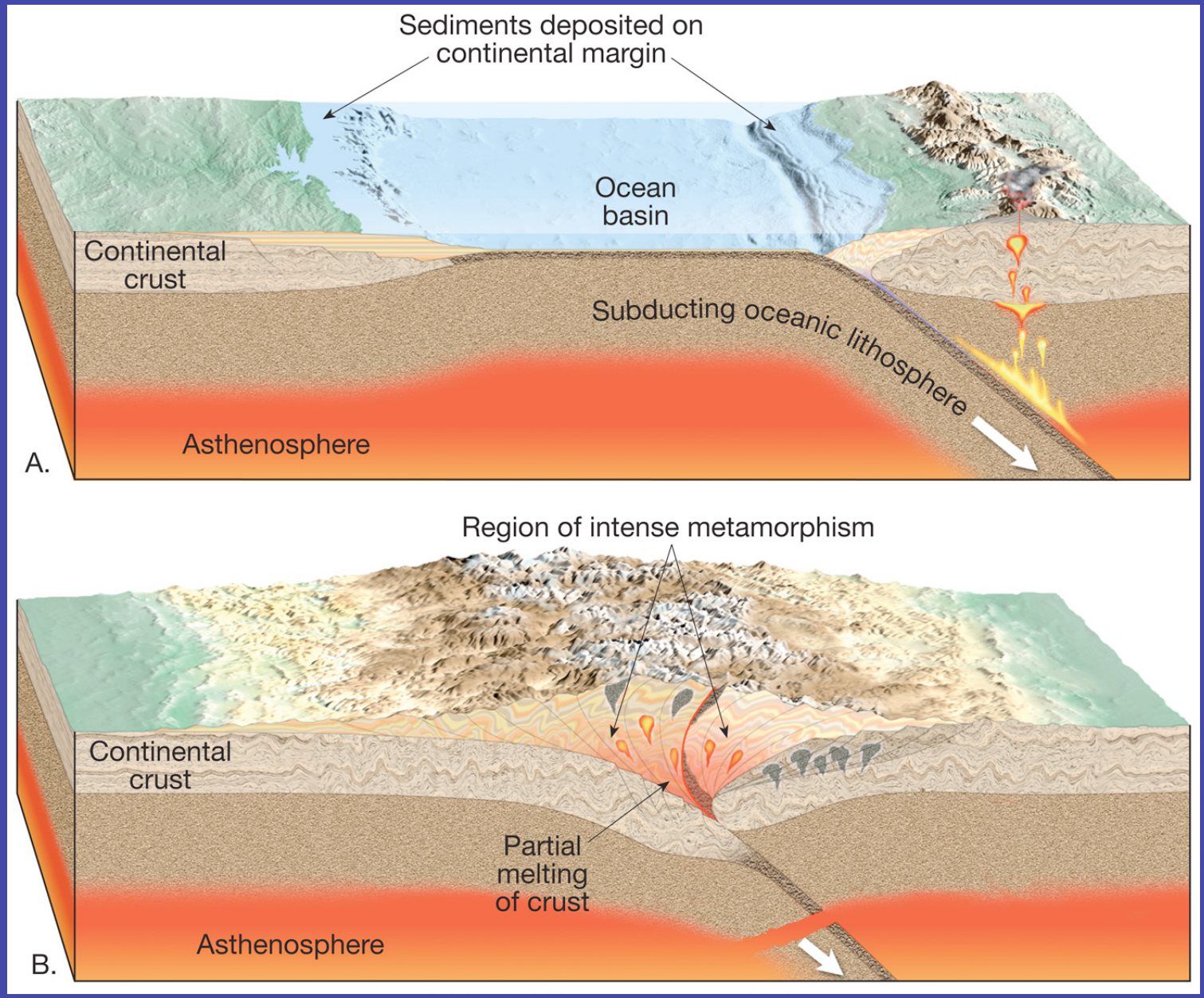
Metamorphic deposits related to chemical fluid circulation can be found:

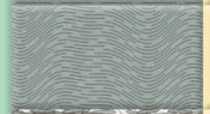
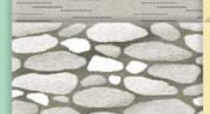
1. **At mid-ocean ridges**

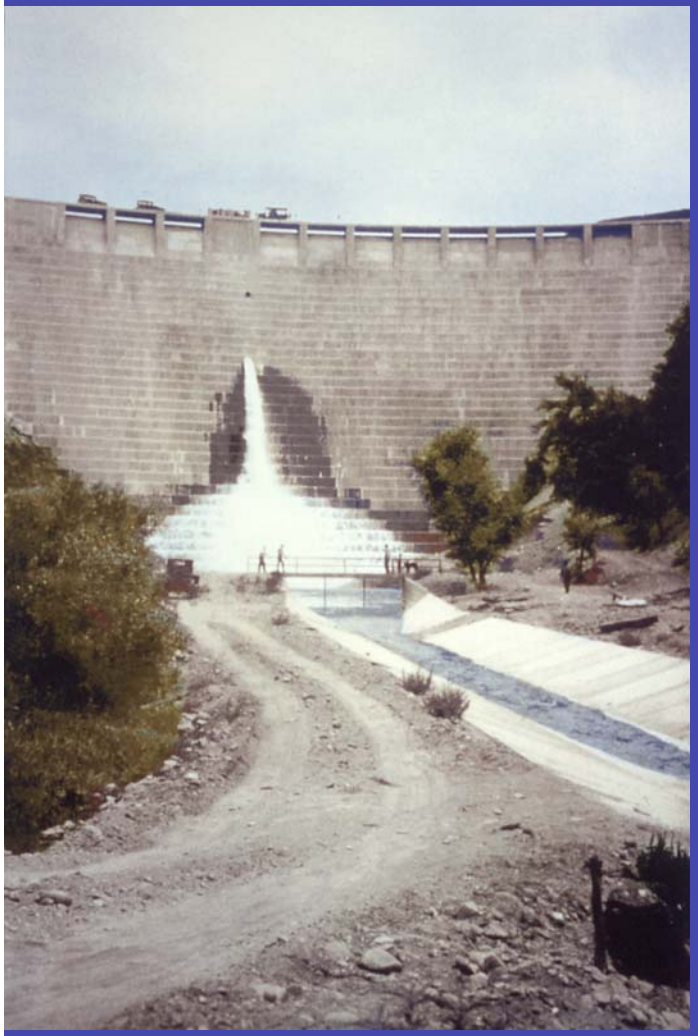
2. **In ophiolite complexes (uplifted MORs)**

3. **Anywhere hydrothermal fluids circulate (geysers, hot springs, other volcanic systems, etc.)**

Metamorphic processes work together



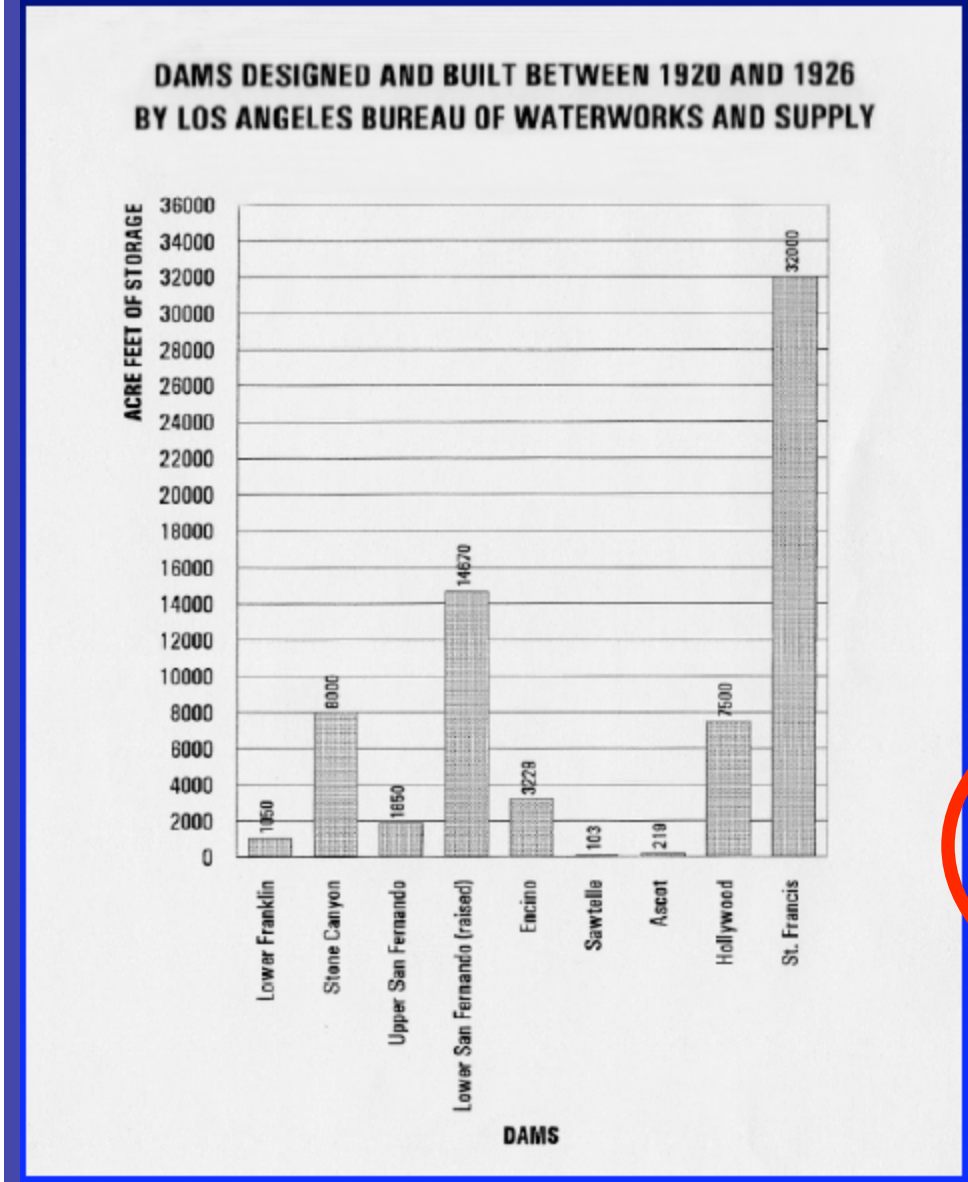
Rock Name		Texture		Grain Size	Comments	Parent Rock
Slate	Increasing Metamorphism	Foliated		Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite				Fine	Breaks along wavy surfaces, glossy sheen	Slate
Schist				Medium to Coarse	Micaceous minerals dominate, scaly foliation	Phyllite
Gneiss				Medium to Coarse	Compositional banding due to segregation of minerals	Schist, granite, or volcanic rocks
Migmatite				Medium to Coarse	Banded rock with zones of light-colored crystalline minerals	Gneiss, schist
Mylonite		Weakly Foliated		Fine	When very fine-grained, resembles chert, often breaks into slabs	Any rock type
Metaconglomerate				Coarse-grained	Stretched pebbles with preferred orientation	Quartz-rich conglomerate
Marble		Nonfoliated		Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite				Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Hornfels				Fine	Usually, dark massive rock with dull luster	Any rock type
Anthracite				Fine	Shiny black rock that may exhibit conchoidal fracture	Bituminous coal
Fault breccia				Medium to very coarse	Broken fragments in a haphazard arrangement	Any rock type



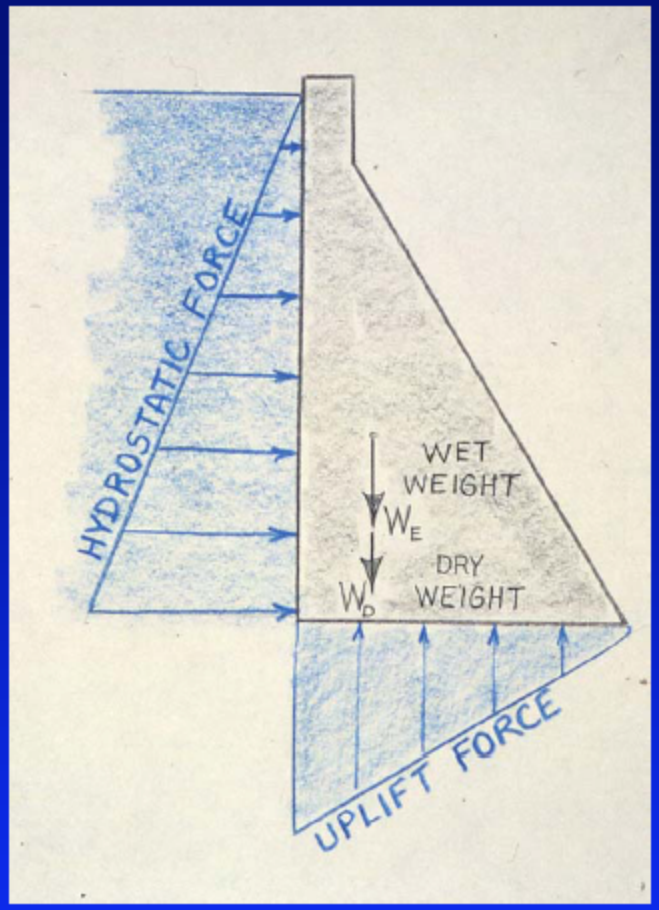


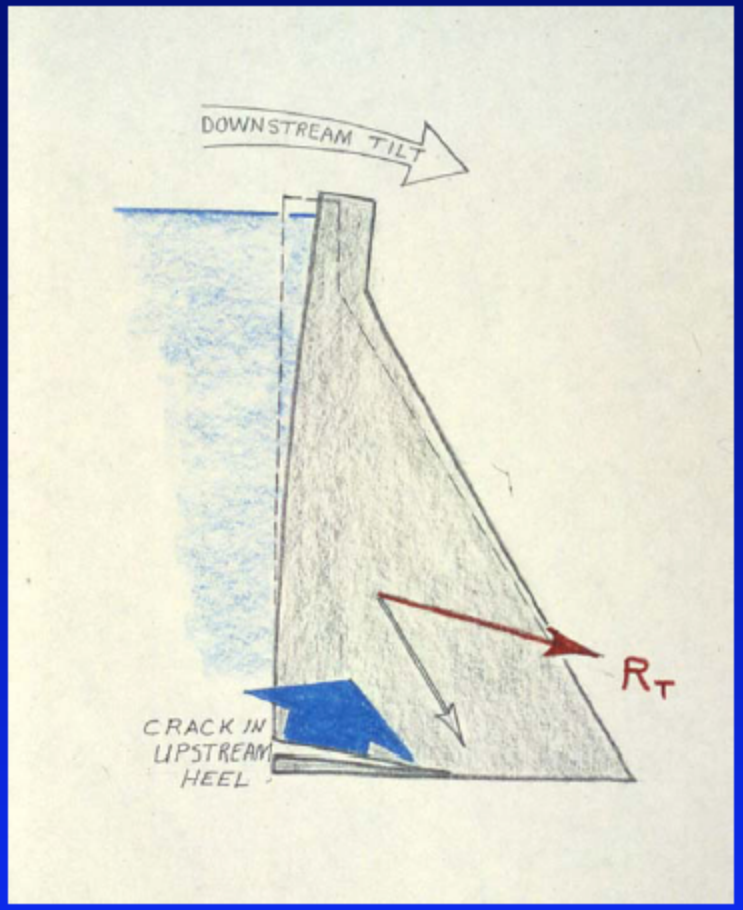
St. Francis Dam Failure, 1928

Another Water Crisis 1918-26



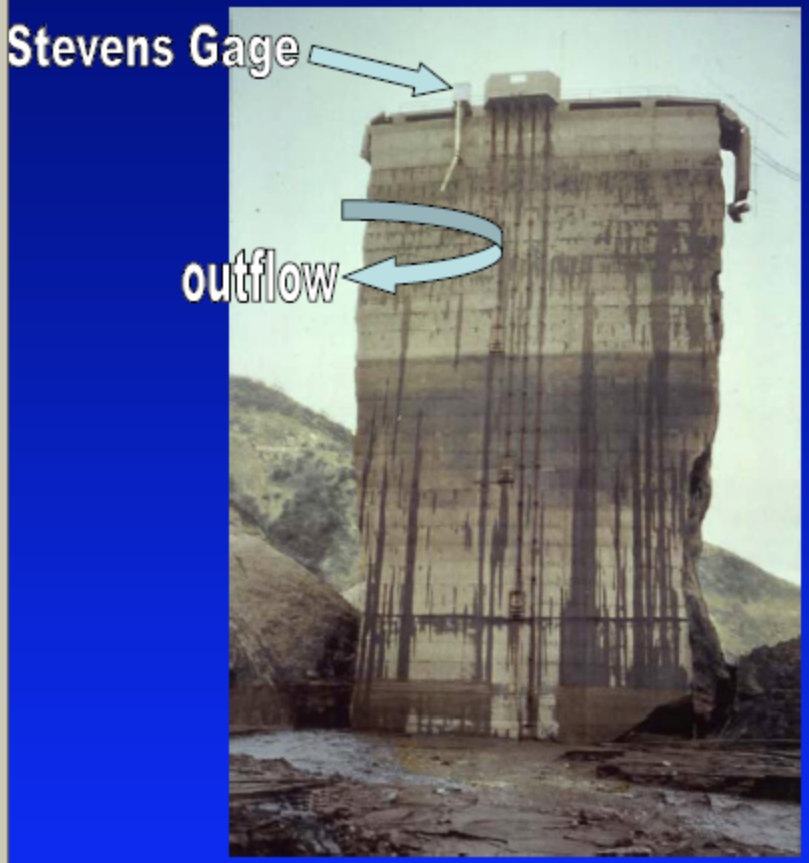
- While the aqueduct was under construction, the City's population grew from 284,000 to 425,000 people
- Near record-low rainfall beset the LA area, beginning in the winter of 1918-19, lasting till 1924-25
- Cultivation of the San Fernando Valley increased 567% from 1914-1923
- More water storage was needed in the Los Angeles vicinity for drought periods.
- St. Francis was the largest of 9 reservoirs built or enlarged between 1920-26

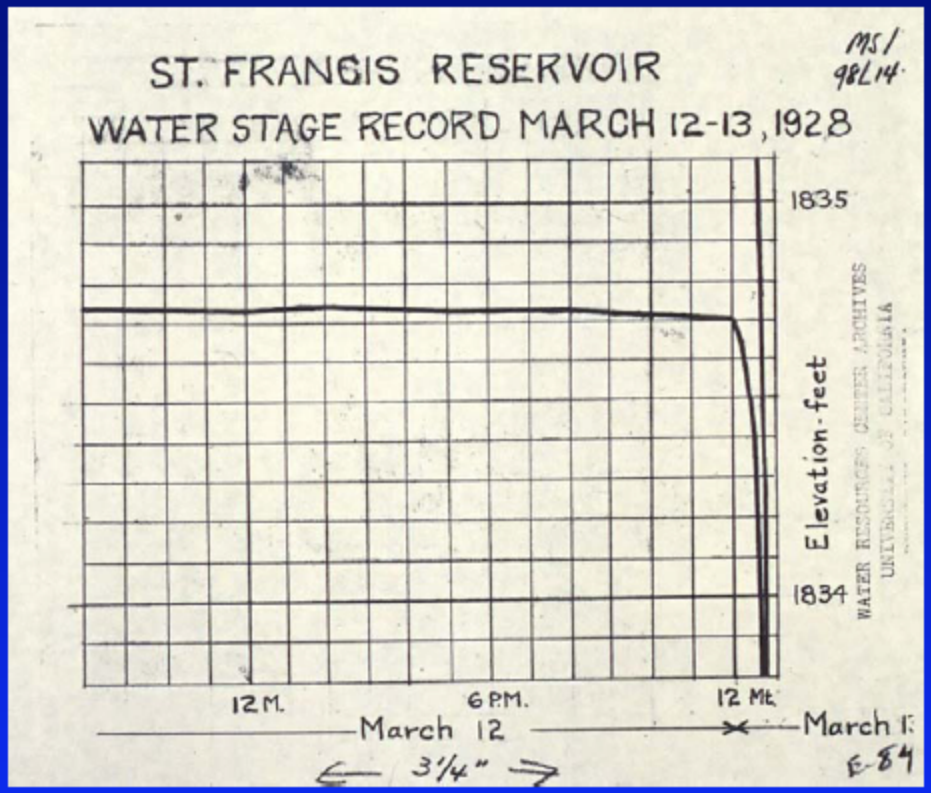




- **Hydrostatic forces act equally in all directions and can reduce the effective weight of the dam, causing it to become unstable.**
- **If the dam tilted forward ½ degree, this would explain the 3.67 inch drop of the reservoir recorded 40 minutes before the failure.**
- **When the dam cracked at its upstream toe, the resultant thrust would have been shifted 240 feet downstream, causing overturning.**

The Stevens Stage Record



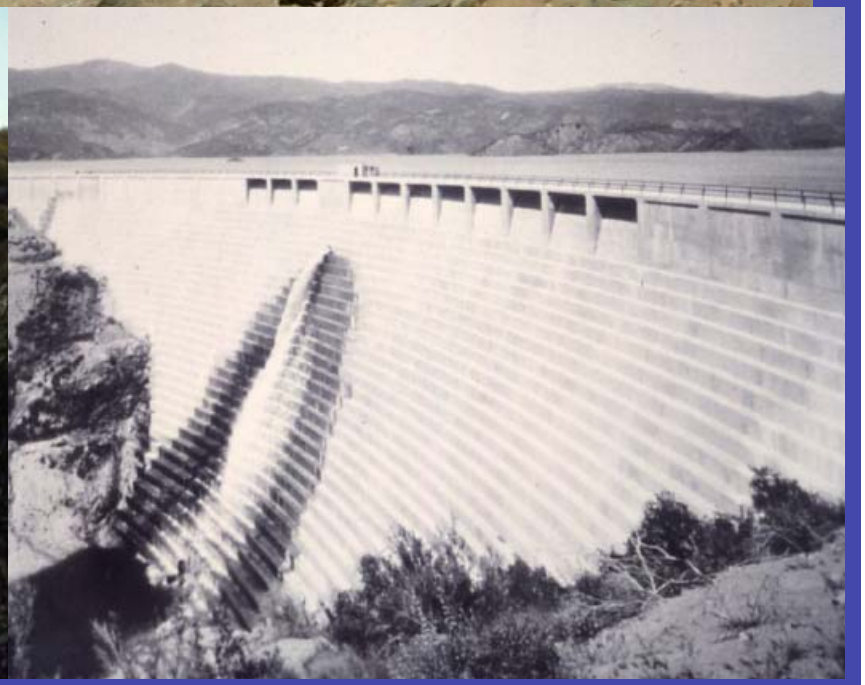


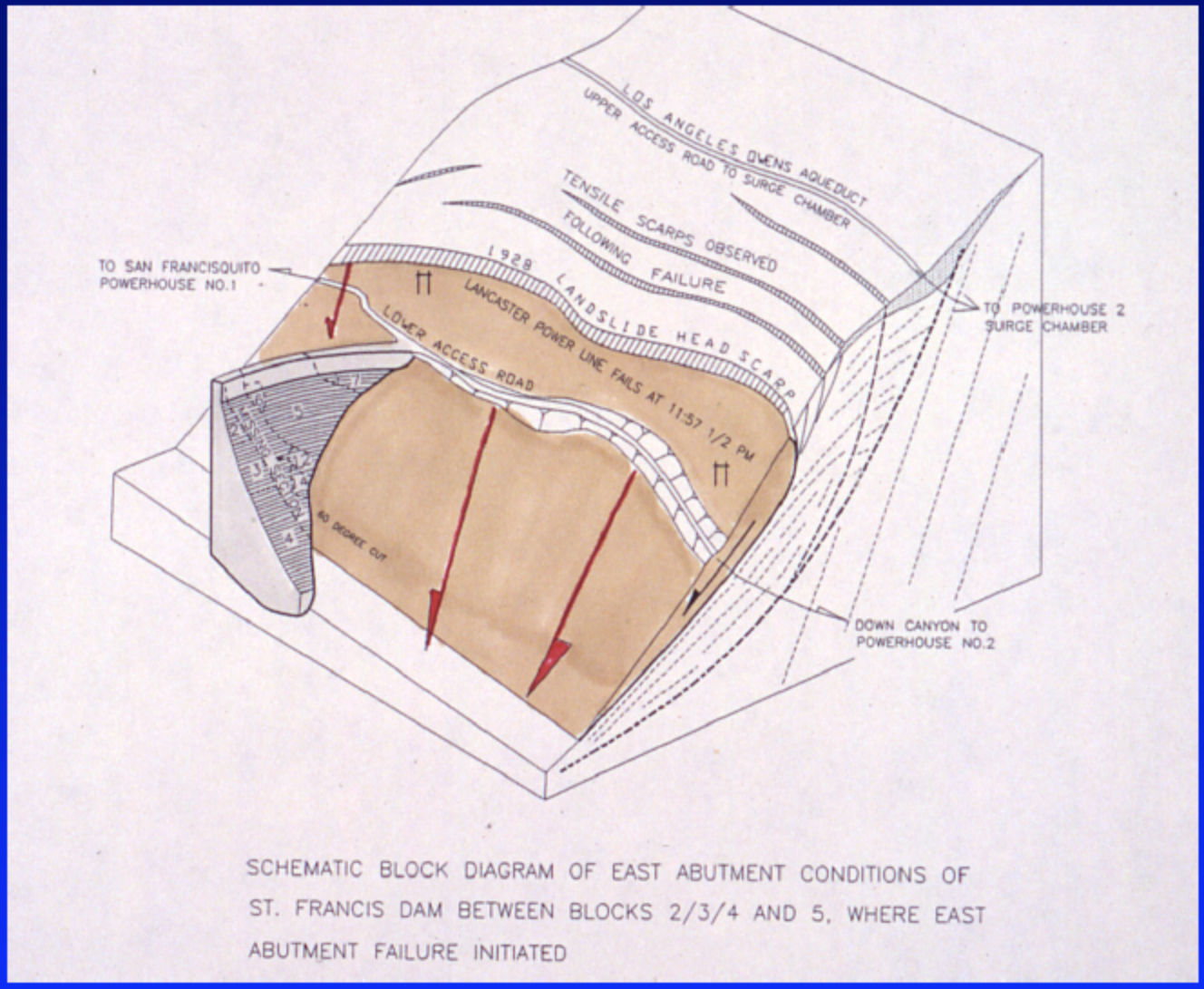
- A Stevens reservoir level recorder was mounted on the crest of Block 1 (left view). It recorded a slight drop of the reservoir beginning around 8 PM, then an increasingly sharp drop beginning around 12 Midnight. The timing mechanism may have been slightly ahead of schedule

Pelona Schist









SCHEMATIC BLOCK DIAGRAM OF EAST ABUTMENT CONDITIONS OF ST. FRANCIS DAM BETWEEN BLOCKS 2/3/4 AND 5, WHERE EAST ABUTMENT FAILURE INITIATED

- The landslide of March 12,1928 was only a portion of a much larger paleolandslide developed deep within the Pelona Schist.

The East Abutment Landslide





- The east abutment landslide involved about 700,000 cubic yards of Pelona Schist, removed in a short period of time. The landslide scar extended 130 feet above the reservoir water surface.



- The dam burst open at 11:57-1/2 PM on Monday evening March 12, 1928, sweeping everything in its path. The damkeeper, his wife and 6-year old son lived ¼ mile downstream. They became the flood's first victims. One passerby noted lights down in the canyon below the dam within an hour of the failure. There were no lights on the dam.


St Francis Dam



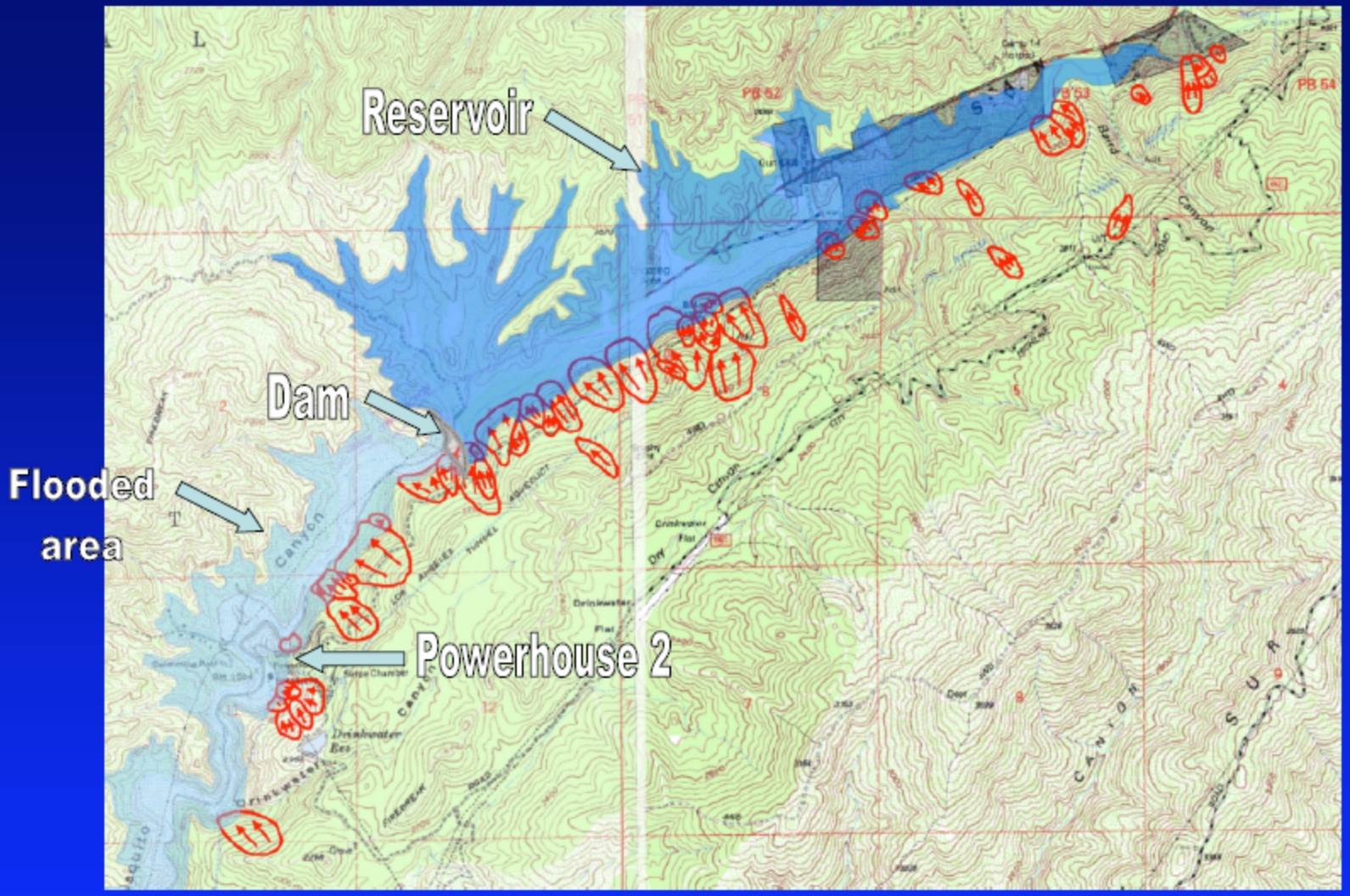


Tidal wave of destruction





- Just downstream of the dam the maximum depth of the flood was about 140 feet, shown at left.
- Almost a mile downstream the floodwaters spilled over a natural saddle 120 feet above the channel
- The average velocity in this reach was about 26 feet per second, around 18 miles per hour.



- The initial flooding reached a maximum depth of 140 feet filling all of San Francisquito Canyon. In the map shown here the reservoir is indicated in dark blue and the flood limits in light blue.

64 victims at Powerhouse 2



- 7300 feet downstream, the wave drowned 64 of the 67 City employees and their families who lived at Powerhouse No. 2, shown above

PATH OF DESTRUCTION





- The flood swept down San Francisquito Canyon and inundated the SoCal Edison Saugus substation, collapsing highway bridges at Castaic Junction, then swamped the SoCal Edison construction camp a few miles downstream at Kemp, drowning 84 of the 140 workers camped there.

INTO THE SEA



- The flood reached the Pacific Ocean at Montalvo around 5:30 AM. By this time the wave was only moving about 5 miles per hour, but was two miles wide. Both the railroad and highway bridges were washed out. A number of bodies were recovered from the ocean, as far south as the Mexican border