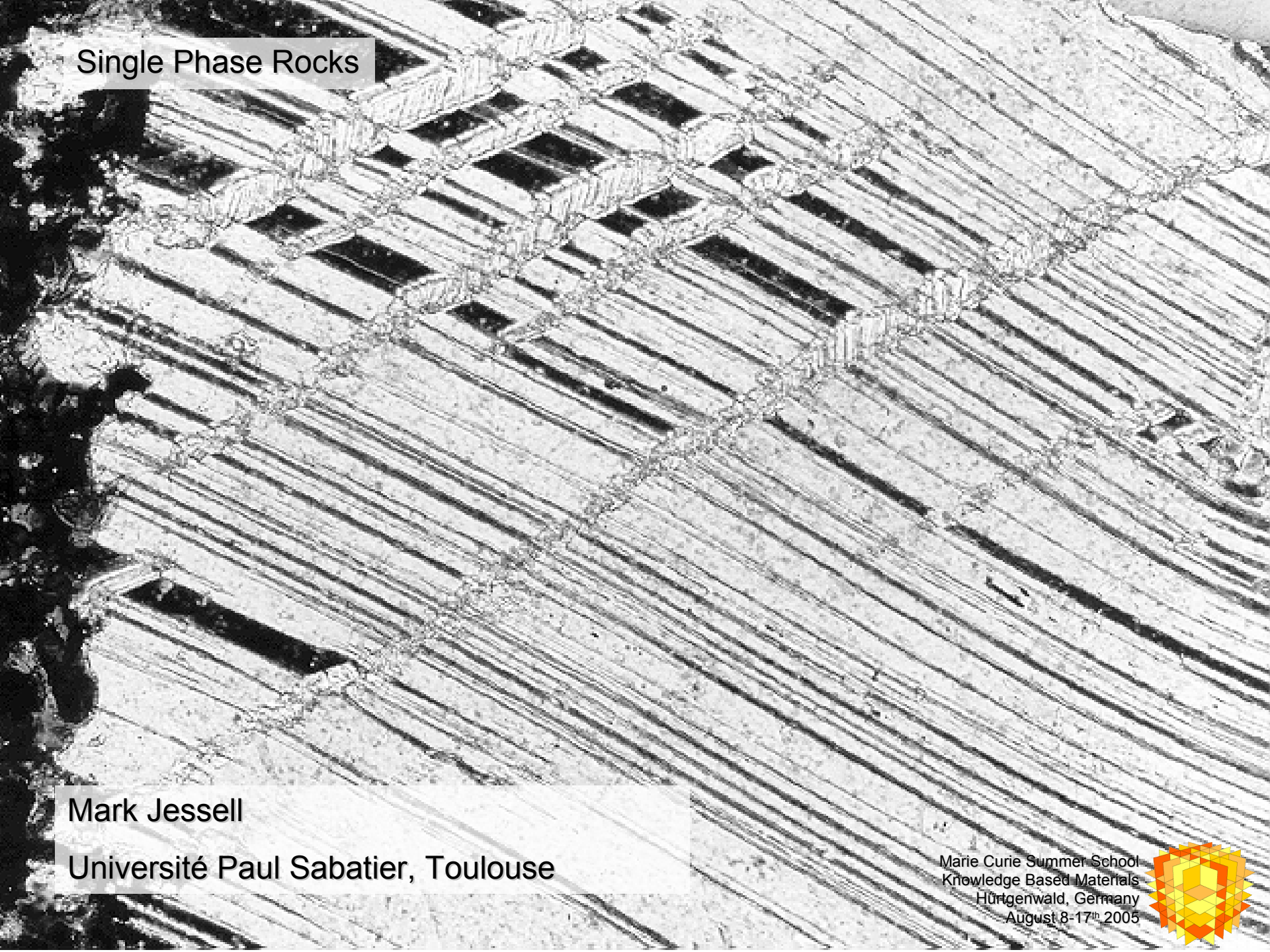
Single Phase Rocks



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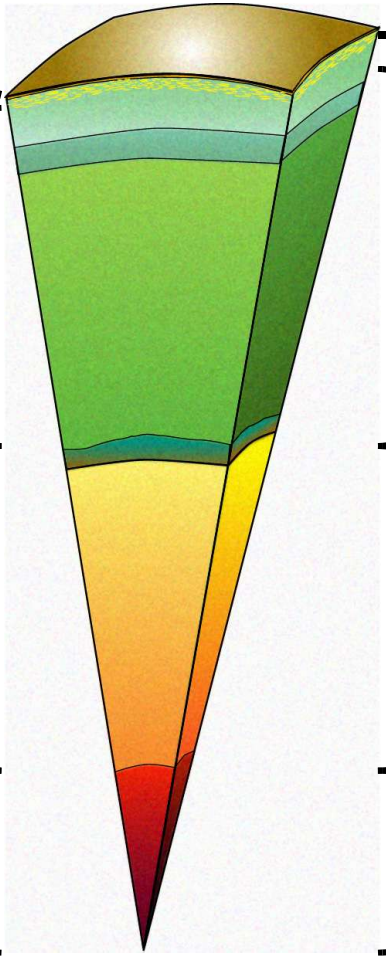
Knowledge Based Materials
Hürtgenwald, Germany
August 8-17th 2005

Compositional Structure of the Earth



thickness

0-50 km

2840 km

2260 km

1220 km

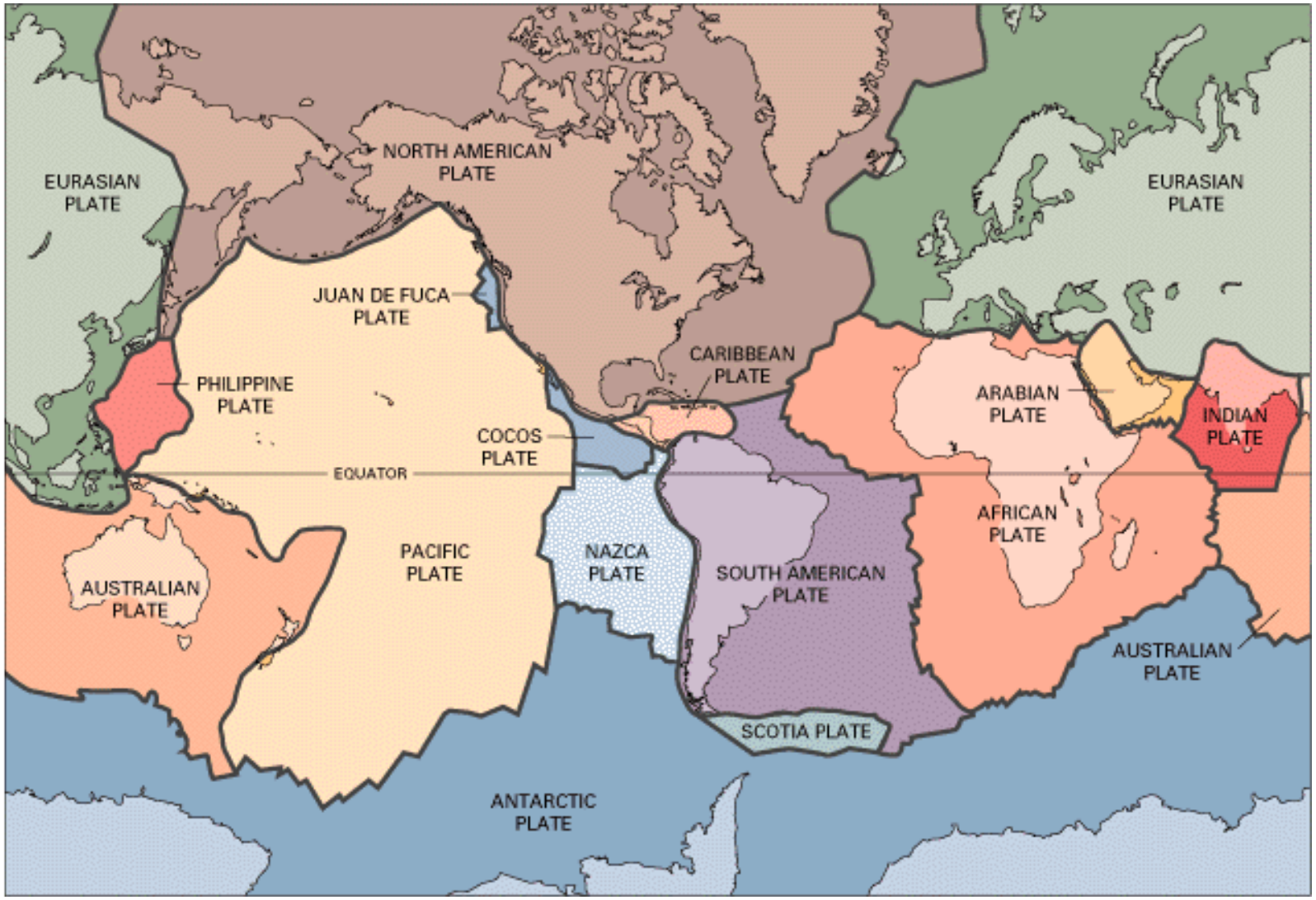
composition

Crust
O,Si, Na,Ca,K,Fe,Mg,Al
Silicates, Carbonates, Oxides, Halides

Mantle
O,Si, Fe,Mg Silicates & Oxides

Outer core
"Fe_2O", Sulfur, Nickel

Inner core
Pure Fe-Ni alloy, perhaps 6% Ni


EURASIAN PLATE
NORTH AMERICAN PLATE
EURASIAN PLATE
JUAN DE FUCA PLATE
CARIBBEAN PLATE
PHILIPPINE PLATE
ARABIAN PLATE
INDIAN PLATE
COCOS PLATE
EQUATOR
AFRICAN PLATE
PACIFIC PLATE
NAZCA PLATE
SOUTH AMERICAN PLATE
AUSTRALIAN PLATE
AUSTRALIAN PLATE
SCOTIA PLATE
ANTARCTIC PLATE

USGS

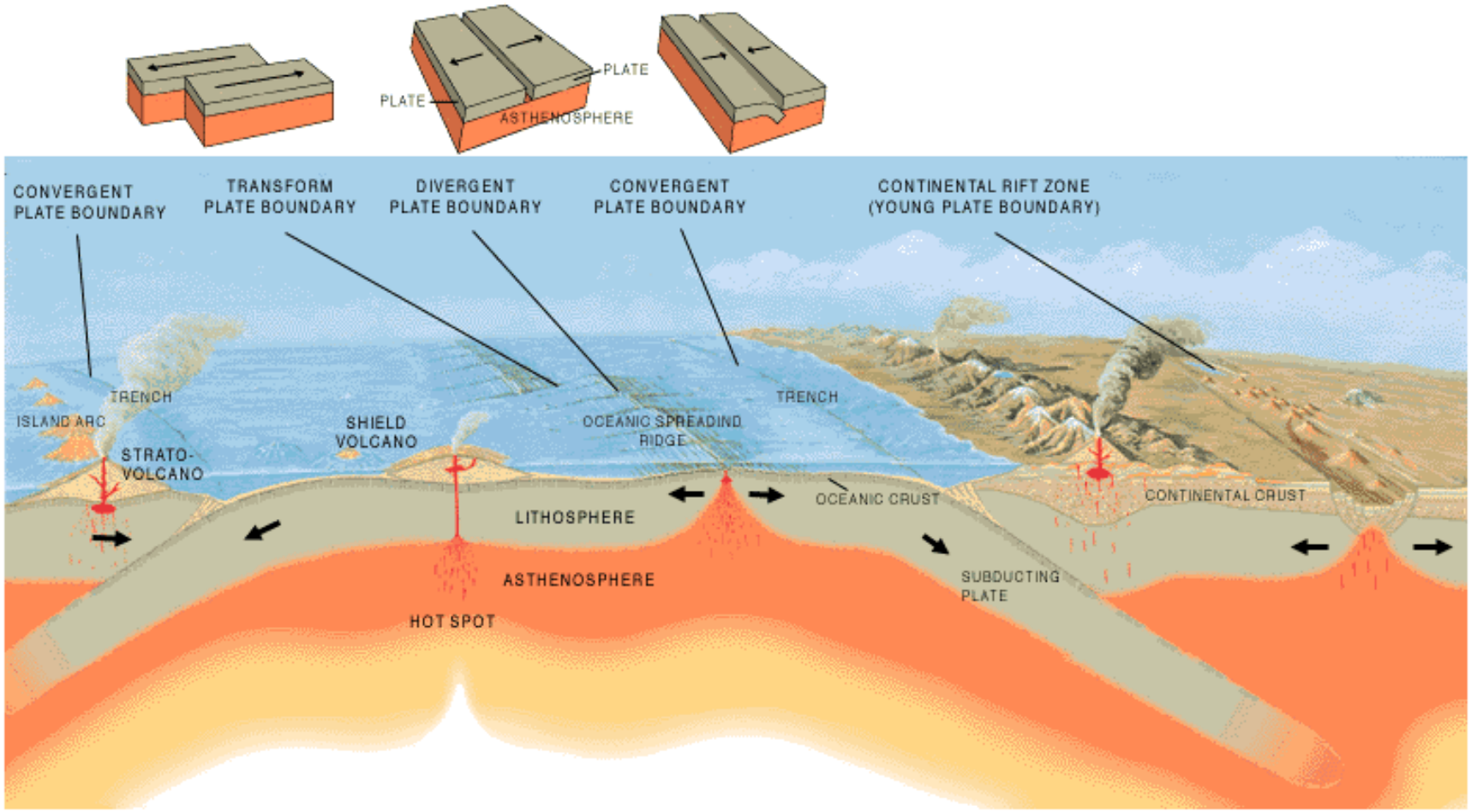
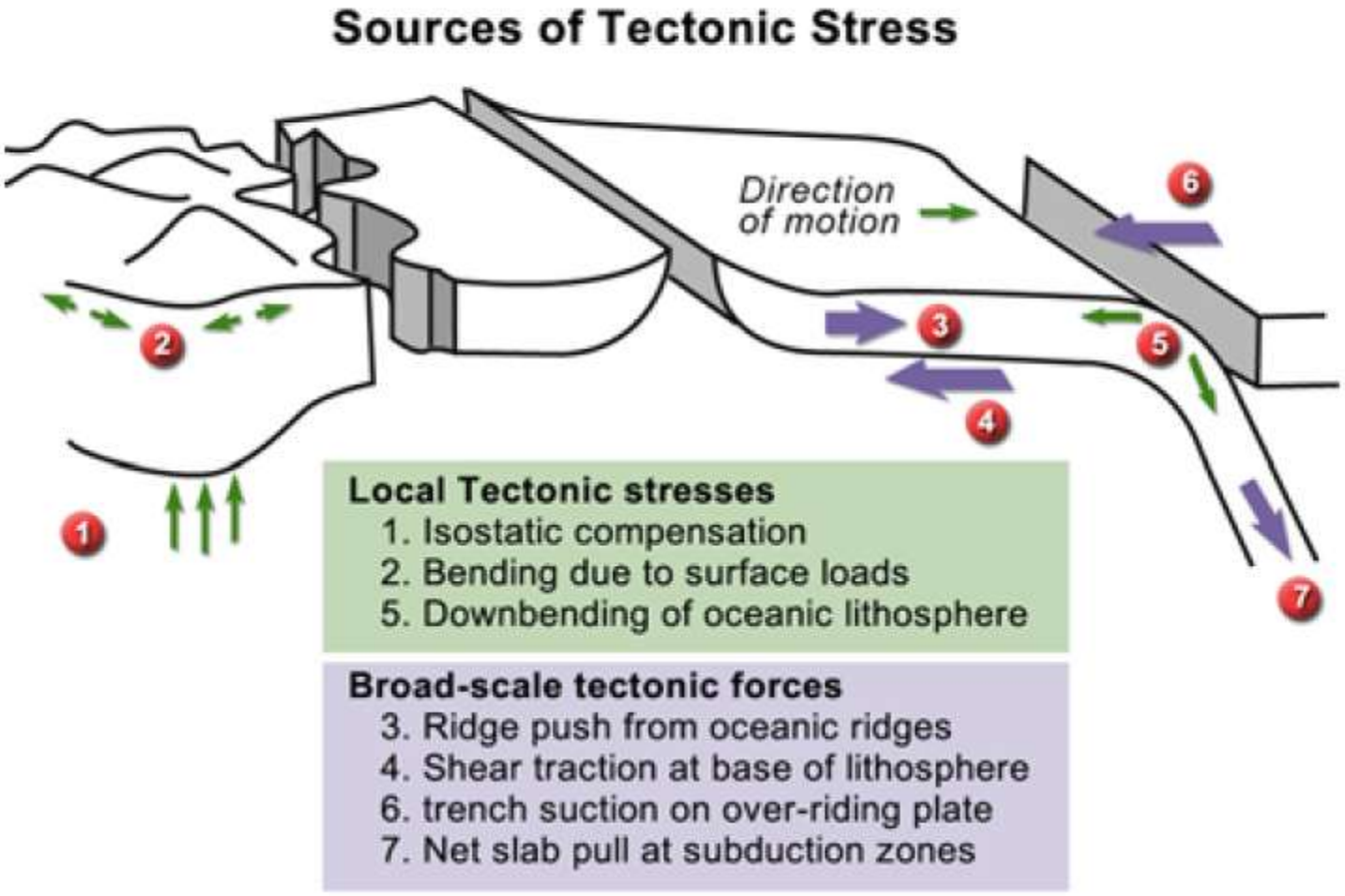


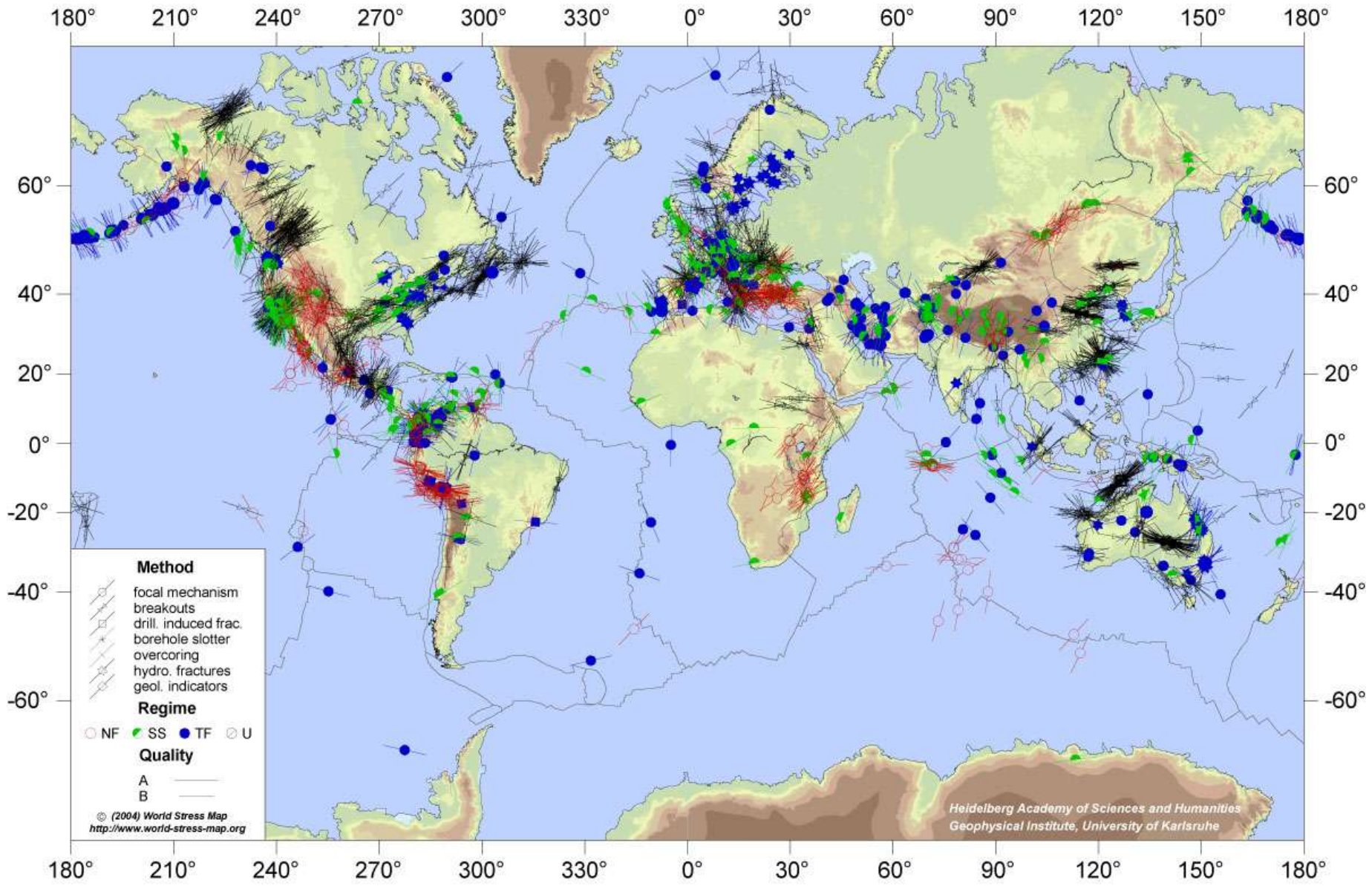
PLATE
PLATE
ASTHENOSPHERE
CONVERGENT PLATE BOUNDARY
TRANSFORM PLATE BOUNDARY
DIVERGENT PLATE BOUNDARY
CONVERGENT PLATE BOUNDARY
CONTINENTAL RIFT ZONE (YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-VOLCANO
SHIELD VOLCANO
OCEANIC SPREADING RIDGE
TRENCH
LITHOSPHERE
OCEANIC CRUST
CONTINENTAL CRUST
ASTHENOSPHERE
SUBDUCTING PLATE
HOT SPOT

USGS

Tectonic stresses



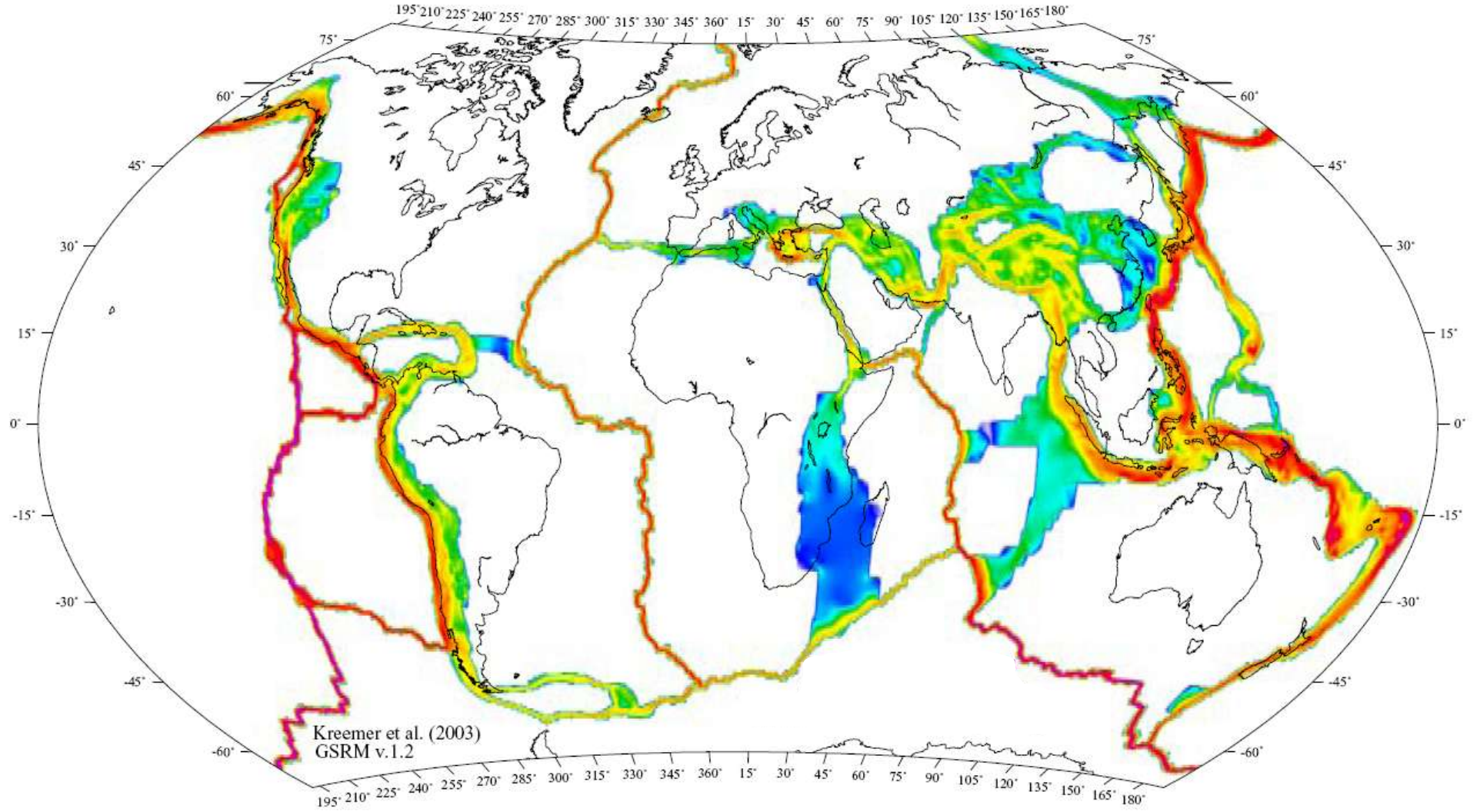
World stress map



Time scales

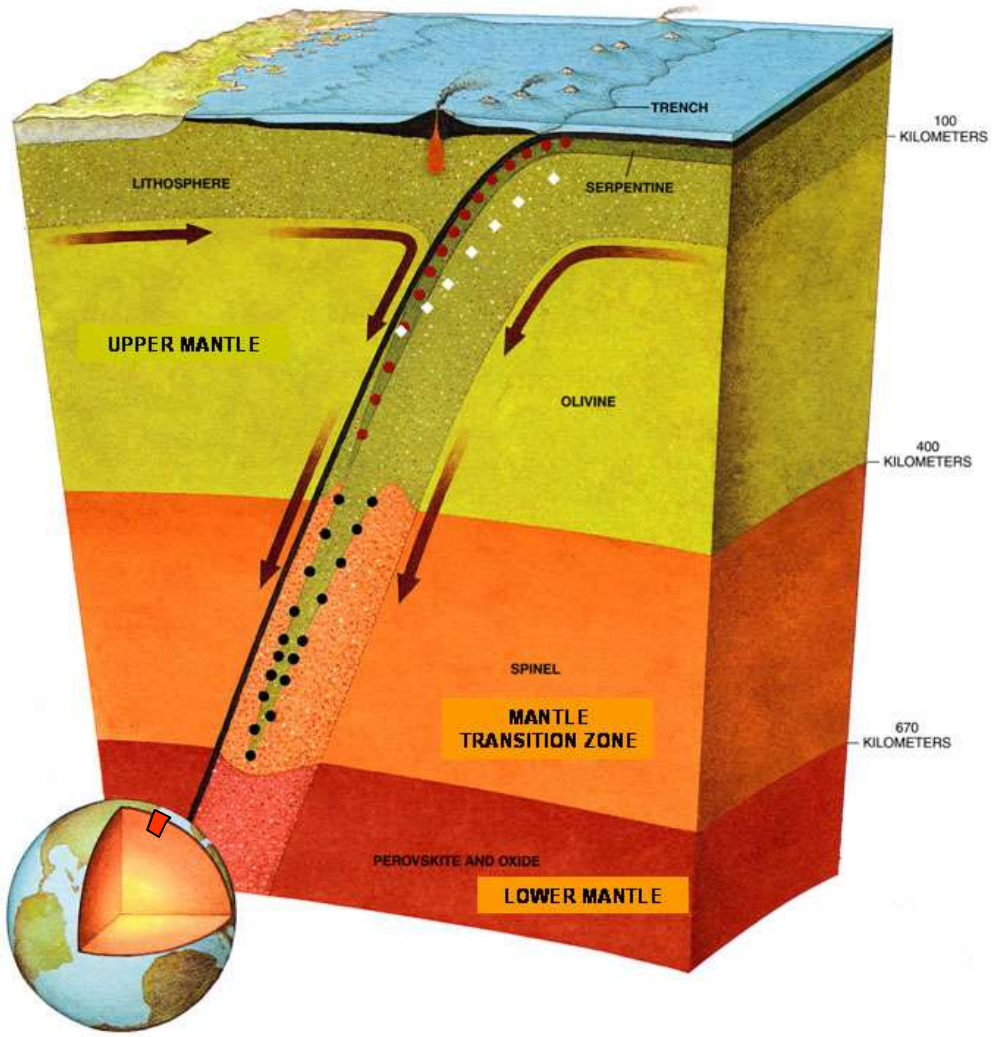
Absolute $10^{-9} \Rightarrow 10^{17}$s

Strain rates $10^{0} \Rightarrow 10^{-15}$ s^{-1}



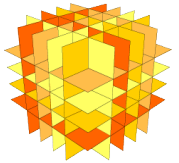
But: Earthquake slip =1ms^{-1}

Length scales



Location	Depth km	Lithostatic Pressure
ocean ridge crest	2.5	25 MPa
abyssal plain	4	40 MPa
deep sea trench	12	120 MPa
base of crust	30	1 GPa
transition zone	600	20 GPa
Core-mantle boundary	2900	140 GPa
Center of Earth	6400	360 GPa

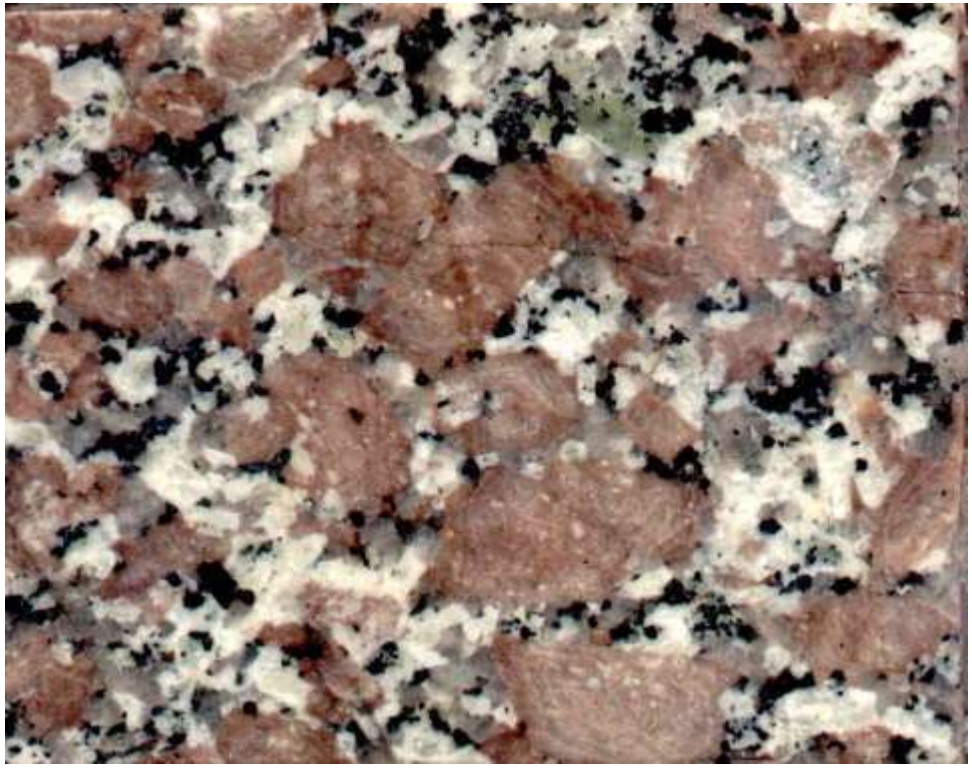
- Range $10^{-9} \Rightarrow 10^{7}$ m
- Crustal T gradient 0.02 ºC m^{-1}
- Pressure Gradient
- Rough concentric compositional layering
- Experimentally, 25 GPa possible (1mm^3 sample)
- Tectonic stresses probably of the order of 10-100 MPa



Earth Materials

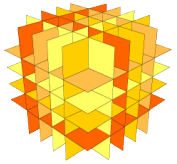
Crust & upper mantle:

Element	Weight %
O	44
Mg	22
Si	21
Fe	6
Ca	2.5
Al	2.3
Na	0.3

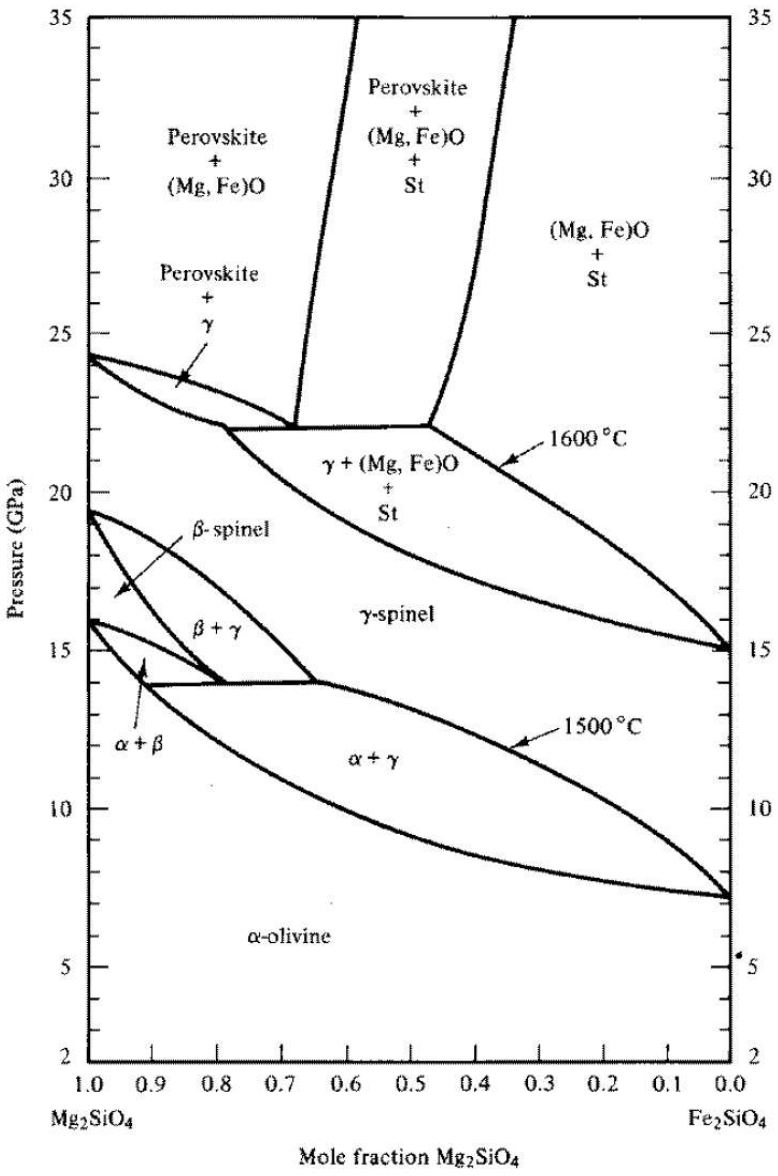


- Mostly Silicates:
  - >90 % Crust, >98% upper mantle
  - $KAlSi_3O_8$ Monoclinic
  - SiO_2 (Hexagonal, Trigonal)
  - $(Mg,Fe)_2SiO_4$ Orthorhombic

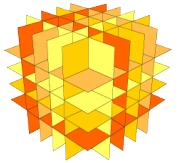
- Low symmetry $\Rightarrow$ high elastic, plastic, surface energy, electrical anisotropies
- Most rocks polyphase
- Fluid phases common (water, melt, CO_2)
- Complex loading histories



Mantle Phases



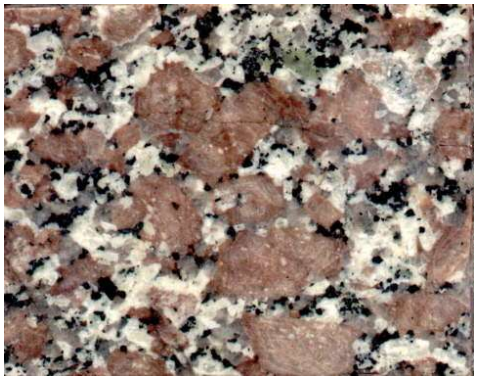
- Most of the Earth is dynamically recrystallising as we speak
- Phase changes important



How do rocks form:

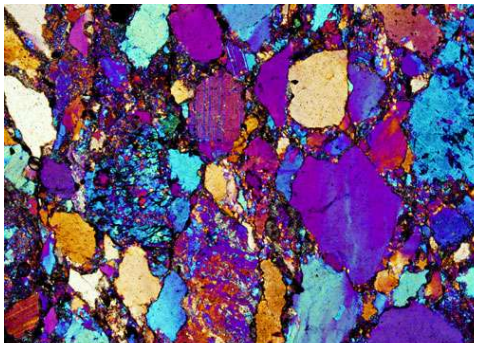
Igneous (solidifies from melts)

- Intrusive (Solidifies within an existing rock mass)
- Extrusive (Solidifies on Earth's surface)



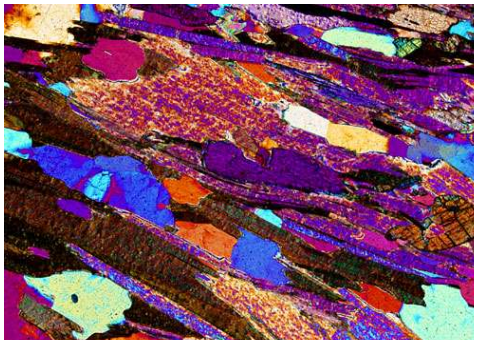
Sedimentary (destruction, transport & deposition)

- Mechanical
- Chemical
- Biological

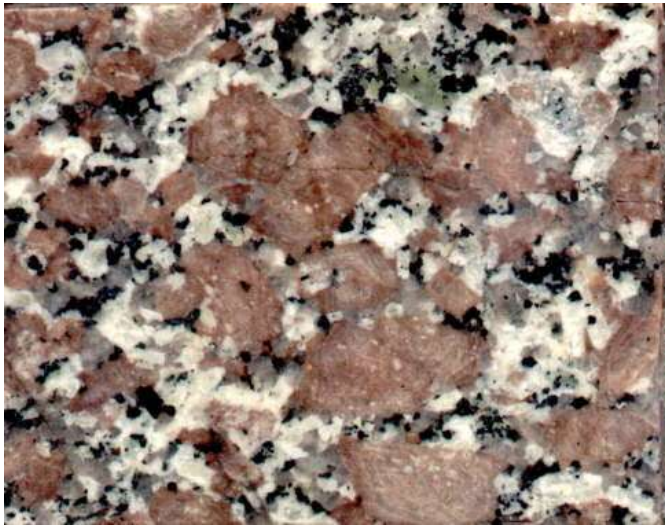


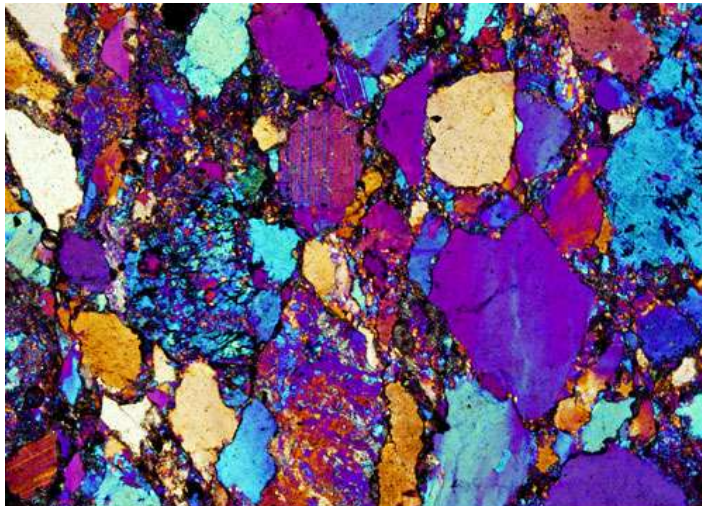
Metamorphism & Diagenesis

- Solid state (Nucleation, Chemical reaction, Phase change)
- Partial melt extraction
- Fluids (H_20, CO_2)



Cycle of rock formation

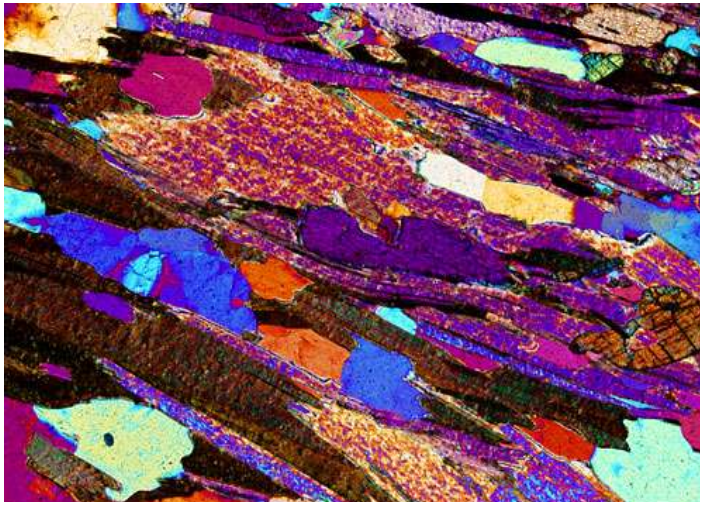




Igenous

Sedimentary

Metamorphic



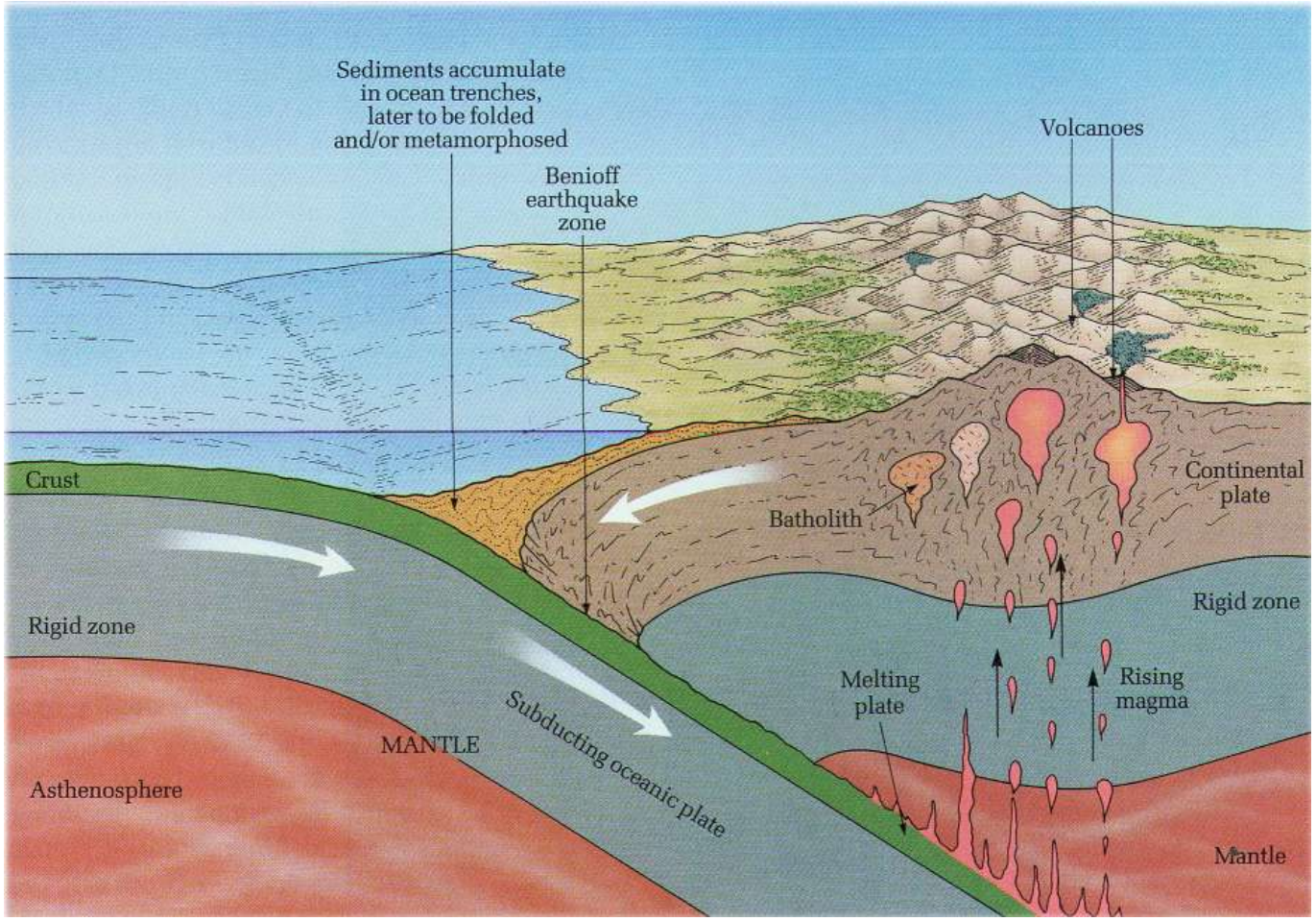
How do single phase rocks *(s.l.)* form?

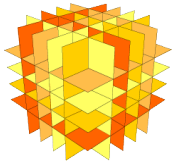
Solidification from melt (Na,Ca Silicate)

Fluid-Mechanical segregation (SiO_2)

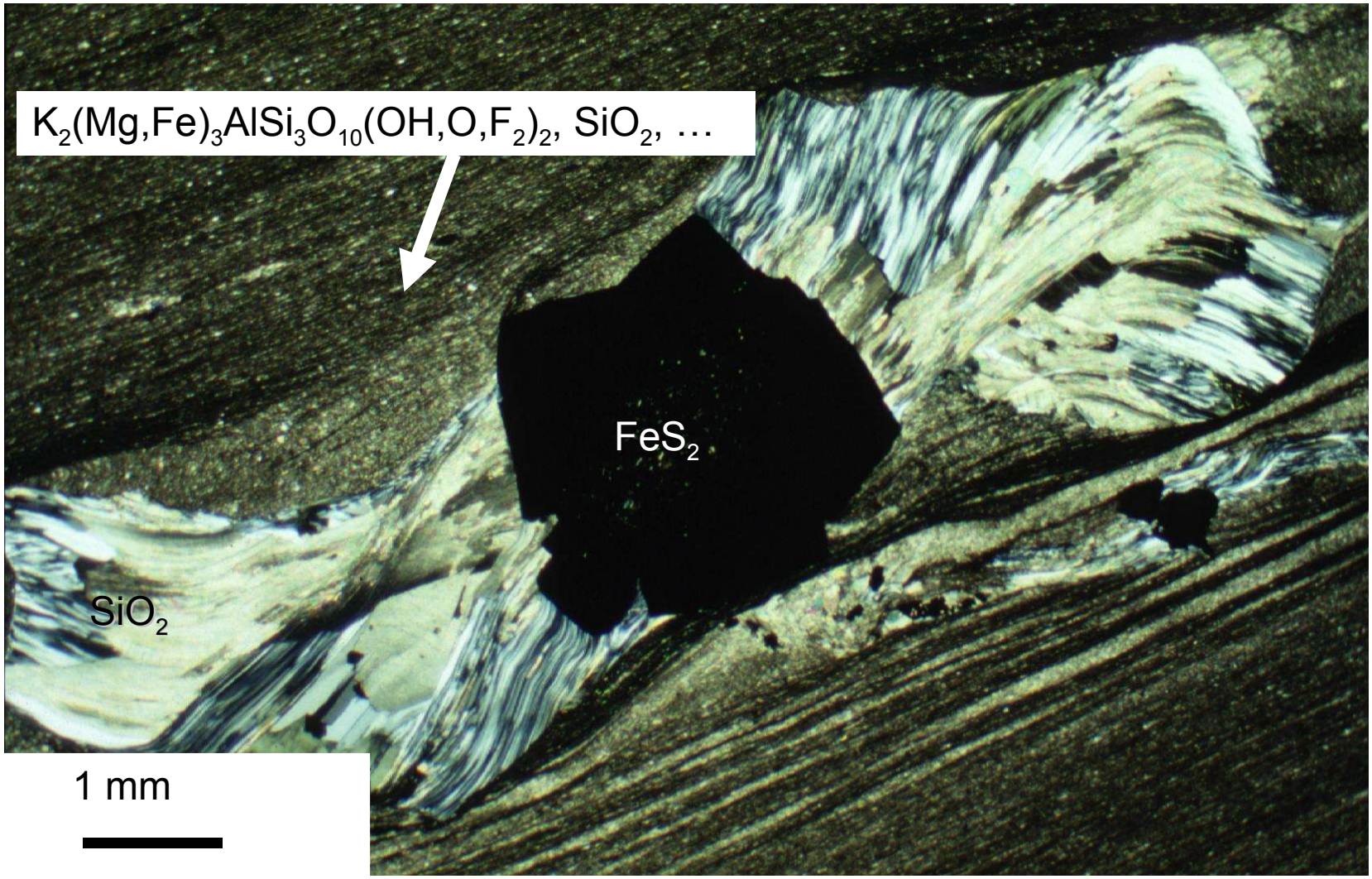
Chemical segregation ($CaCO_3$, NaCl, SiO_2)

Bio-deposition ($CaCO_3$, SiO_2)





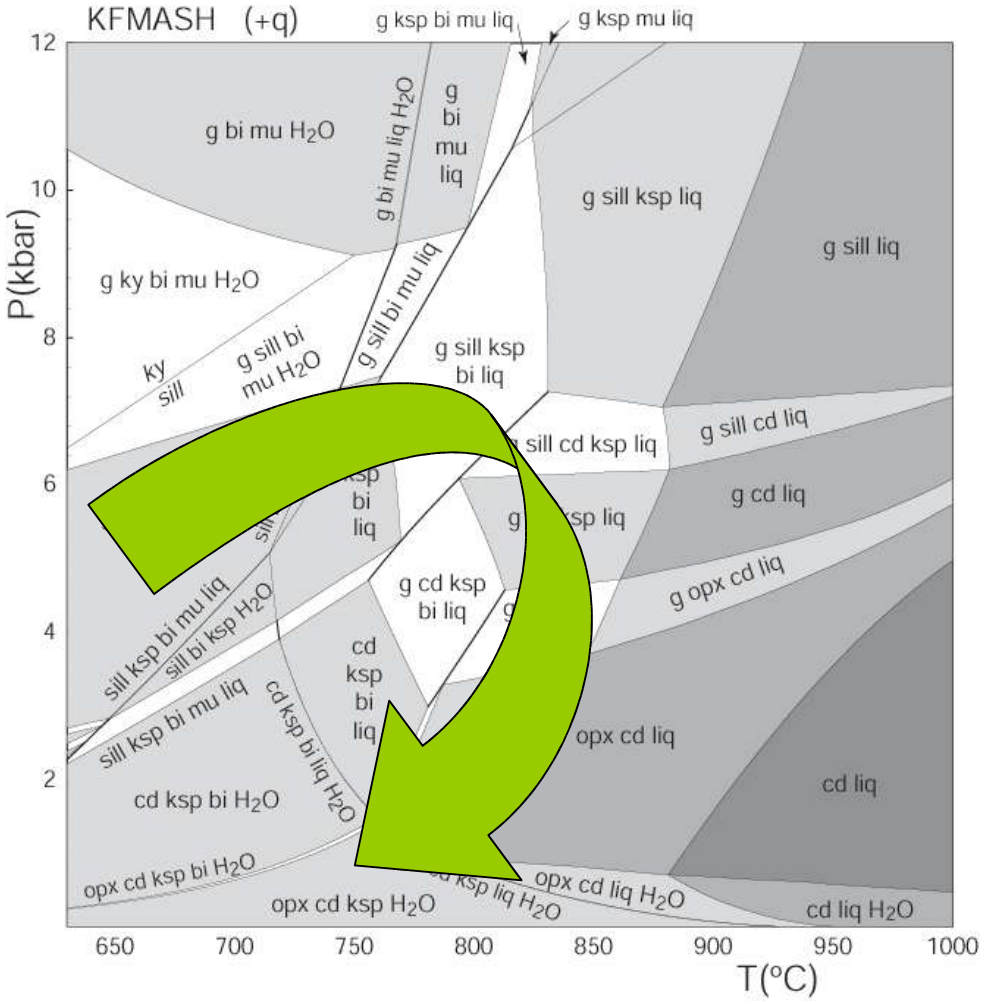
Chemical Segregation



Solid-state long-range reactions

chl-chlorite; bi-biotite; g-garnet; ky-kyanite; and-andalusite; sill-silliminite; st-stauralite; q-quartz

liq-liquid; opx-orthopyroxene; cd-cordierite; ksp-Potassium feldspar; mu-muscovite



chl = $(Mg,Fe,Al)_3(Si,Al)_4O_{10}(OH)_2*(Mg,Fe,Al)_3(OH)_6$

bi = $K_2(Mg,Fe)_3AlSi_3O_{10}(OH,O,F_2)_2$

g = $X_3Y_2(SiO_4)_3$ where

X = Ca, Mg, Fe^{2+}, Mn

Y = Al, Fe^{3+}, Cr

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Powell 1997, typical mudstone mineral stability fields