5. Rocks I: magmatic and metamorphic rocks

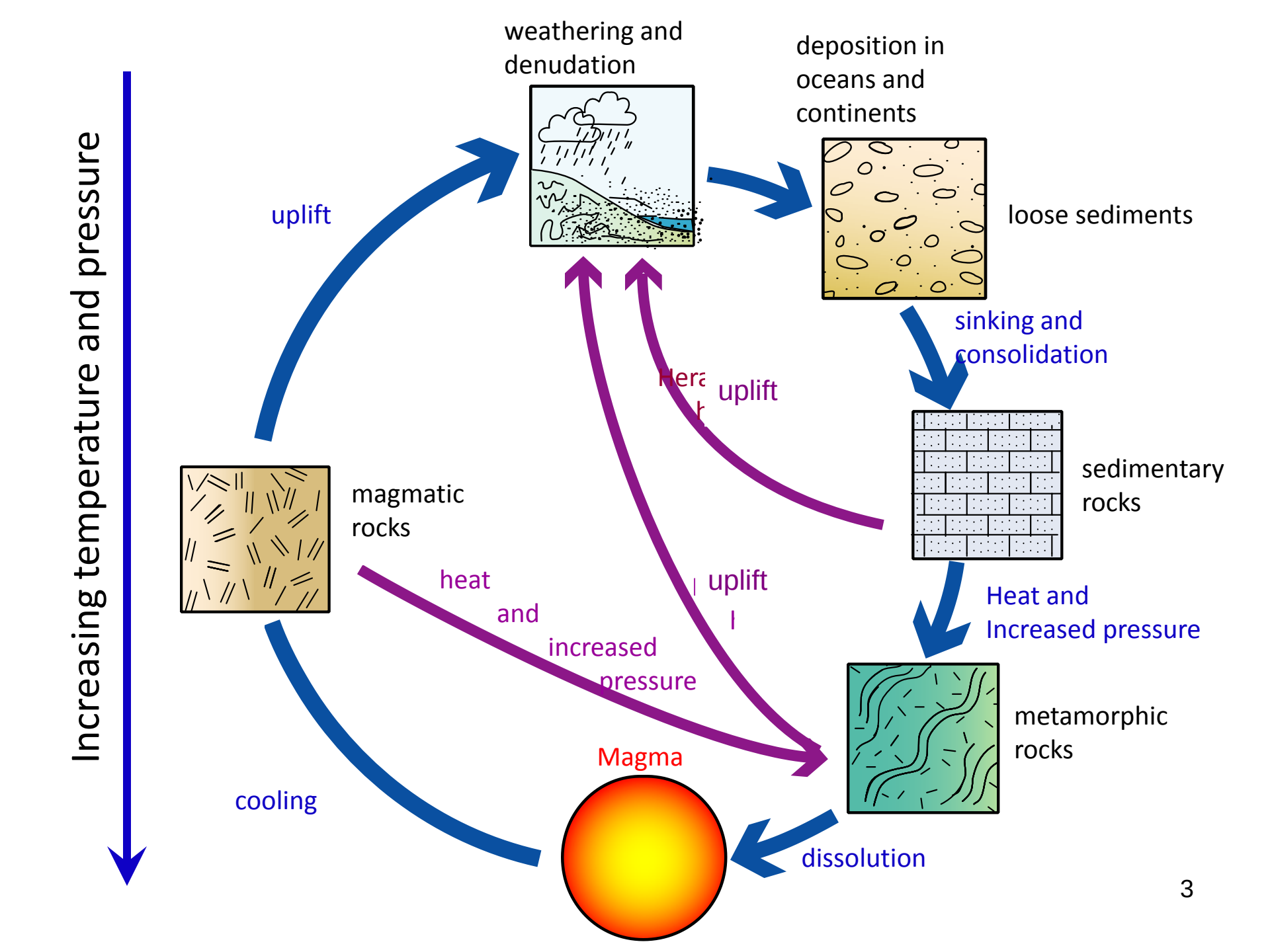
The manuscript is under construction. Please suggestions an kilian@uni-trier.de

Thank you,

Rolf Kilian

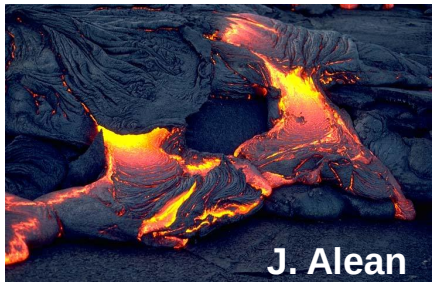
The rocks cycle (see next slide) begins at the Earth usually with magmatic rocks.

Paine intrusion (light) in dark cretaceous sediments (dark)


Increasing temperature and pressure
weathering and denudation
deposition in oceans and continents
loose sediments
sinking and consolidation
sedimentary rocks
Heat and Increased pressure
metamorphic rocks
dissolution
Magma
cooling
magmatic rocks
heat and increased pressure
uplift
uplift
uplift

Magmatic rocks

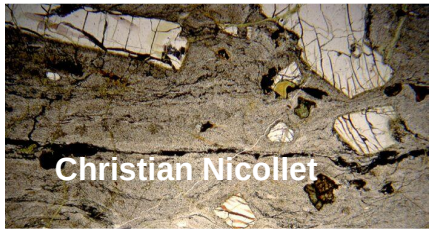
Magma-ascent



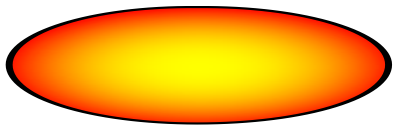
Effusive rocks
vulcanite

dike intrusions,
sub vulcanite

consolidation in the earth crust:
plutonites



differentiation by means of fractional
crystallization in magmatic hearths
of the earth crust



dissolution in earth matle
Or occasionally in the earth crust

Overview of the main magmatic minerals:

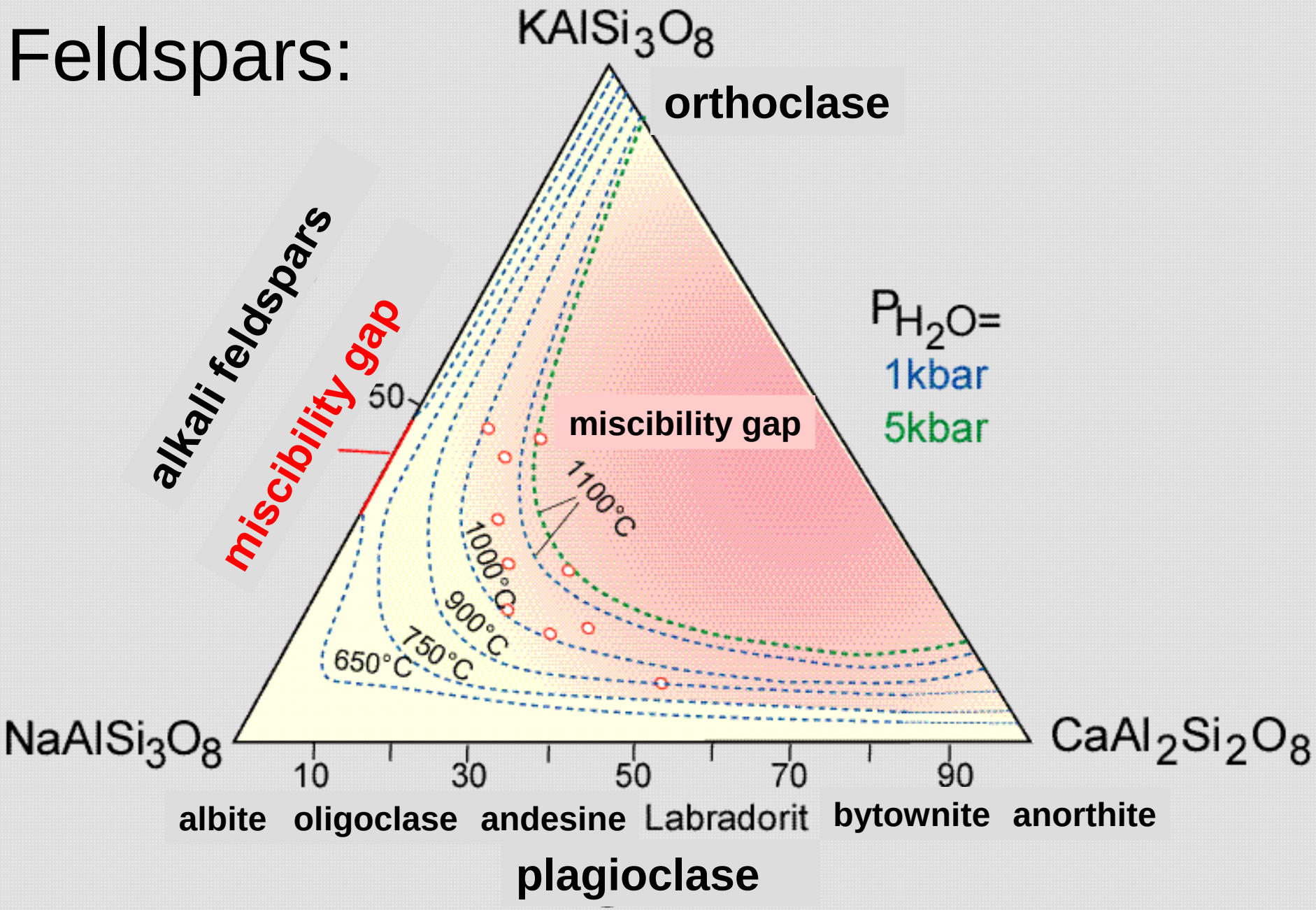
- **light, felsic minerals (K, Na, Ca, Si, Al):**
- quartz
- feldspars (sanidine and plagioclase)
- feldspathoids (foids) (leucite, nepheline, sodalite, melilitite)

- **dark, mafic minerales (Fe, Mn, Mg, Si):**
- olivine (only if siliceous-arm)
- pyroxene and hornblende
- biotite

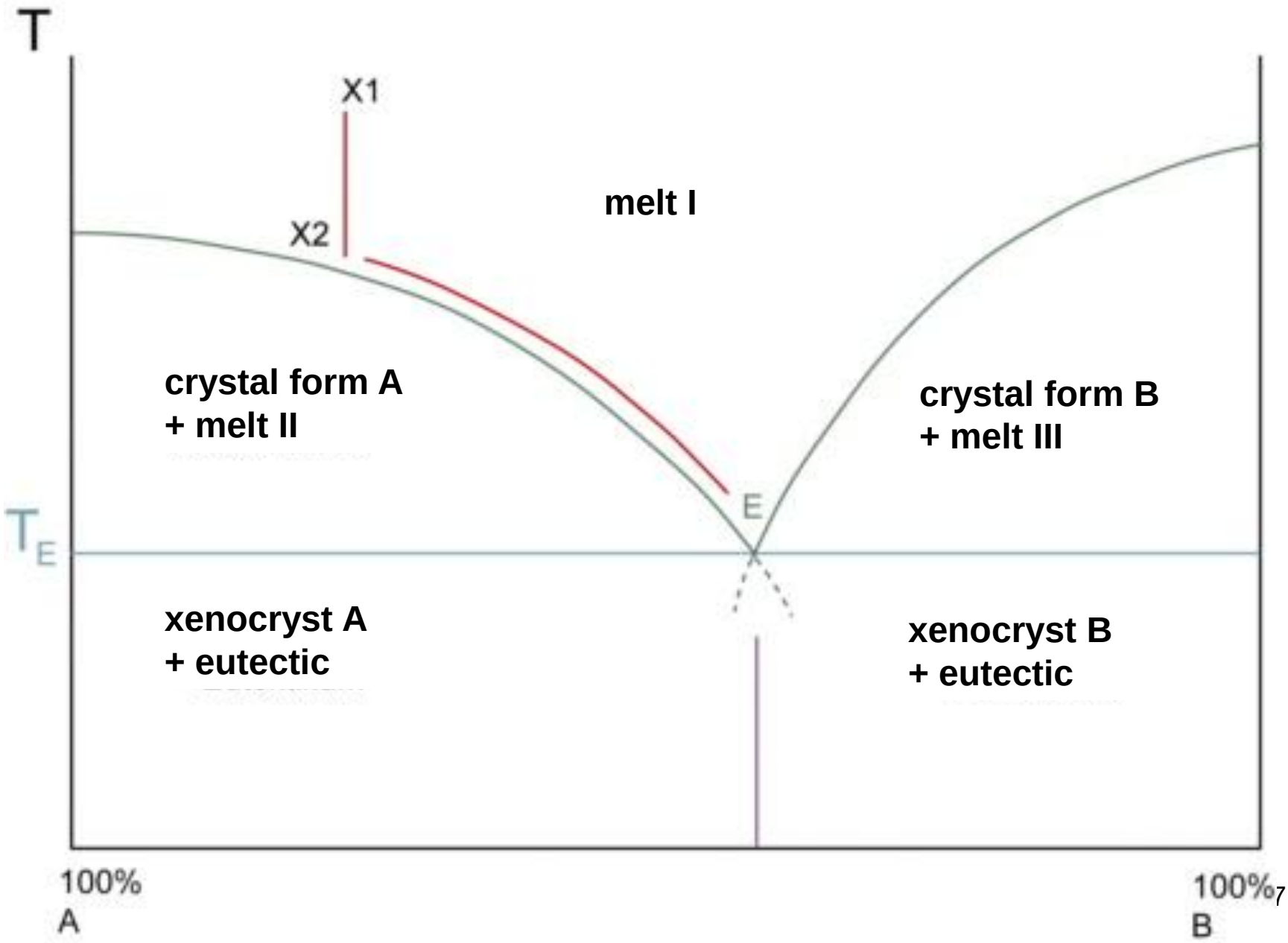
- **accessory minerals** (zircon, magnetite, apatite)

- **pegmatitic minerals** (quartz, beryl, tourmaline, apatite)

Feldspars:

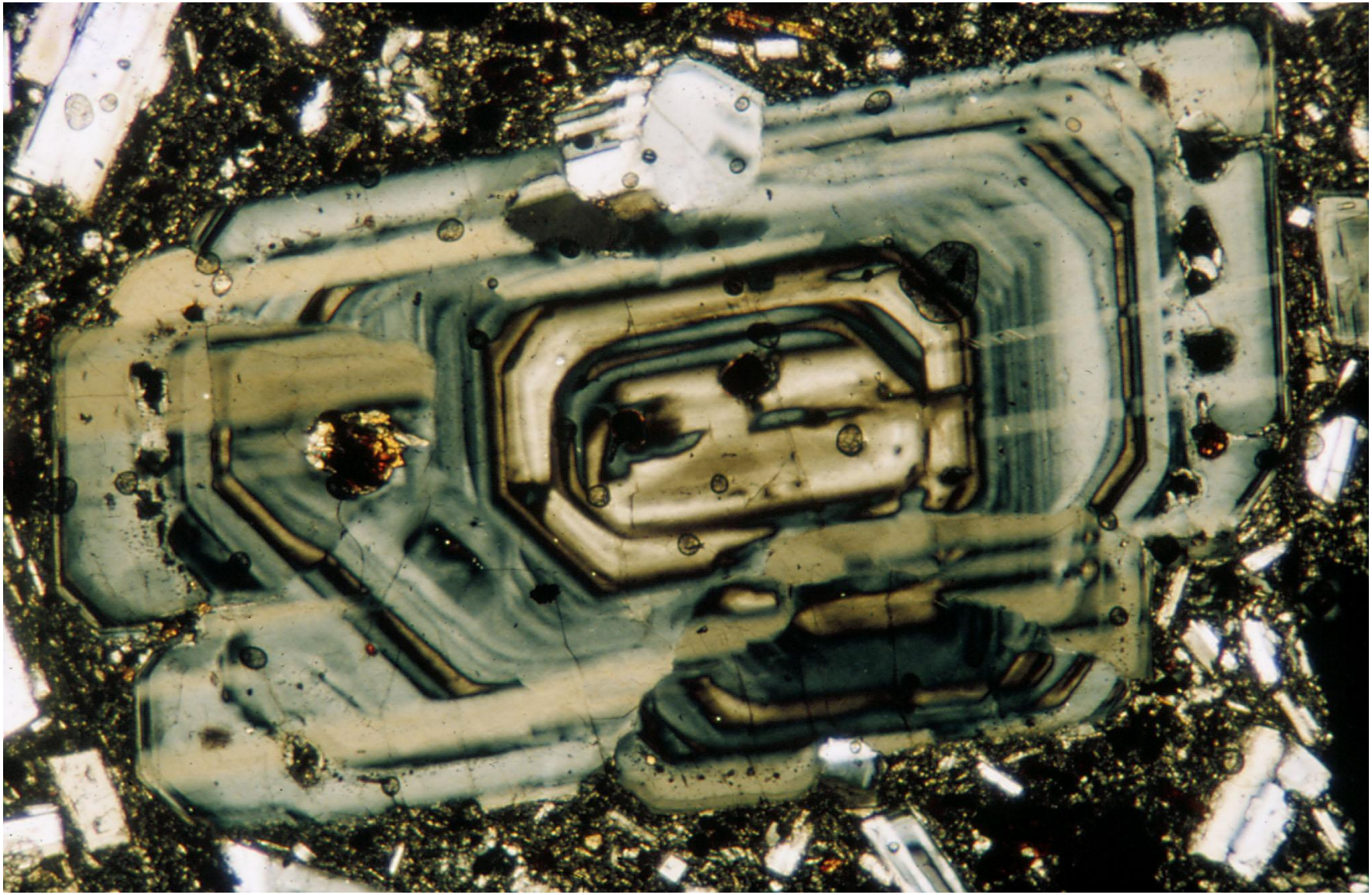

KAlSi3O8
orthoclase
alkali feldspars
miscibility gap
50
miscibility gap
PH2O=
1kbar
5kbar
1100°C
1000°C
900°C
750°C
650°C
NaAlSi3O8
CaAl2Si2O8
10
30
50
70
90
albite
oligoclase
andesine
Labradorit
bytownite
anorthite
plagioclase

Influence of the magma composition in the sequence of crystallization

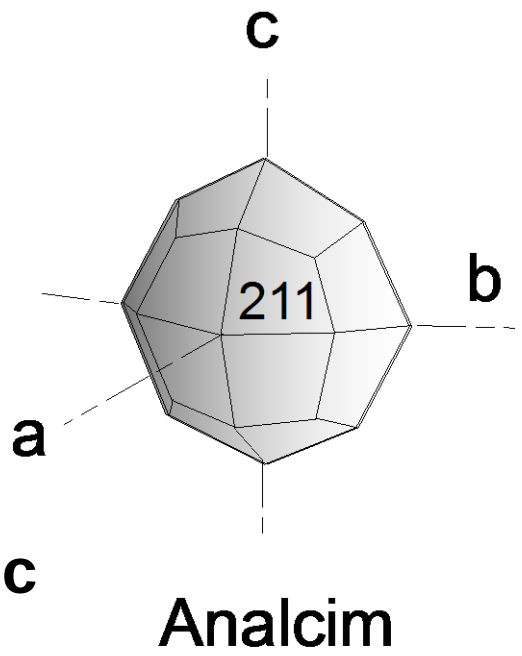


Chemical zoned plagioclase

The growth zone reflects changes in Ca/Na-ratio (often expressed in anorthite content) and occurs by fractional crystallization



Feldspathoids (foids)



Analcim

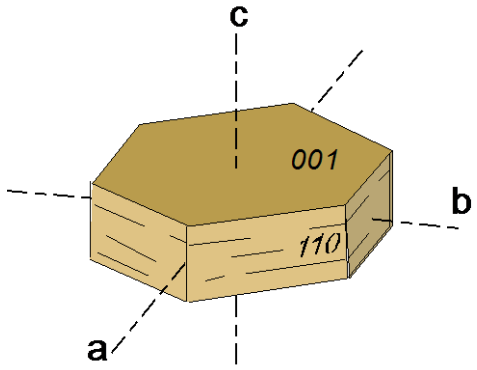
- **leucite (cubic)**
- **nepheline (hexagonal)**
- **sodalite-series (hauyne, sodalite): cubic**

- (K, Ca,Na) [$AlSiO_4$ · *x* (Cl, SO_4)]
  cations basic module

- are formed in magmas instead feldspars if it is not sufficient SiO_2 in the melt. Since K, Ca and Na are required, they are usually formed in alkali rich melts.

- usually in siliceous-arm magmas of continental rift areas basanites, nephelinites, tephrites, phonolithes.

Biotite



•$K(Mg,Fe^{2+},Fe^{3+},Al,Ti)_{2.5\text{-}3.0}[(Al,Fe^{3+})Si_3O_{10}(OH)_2]$

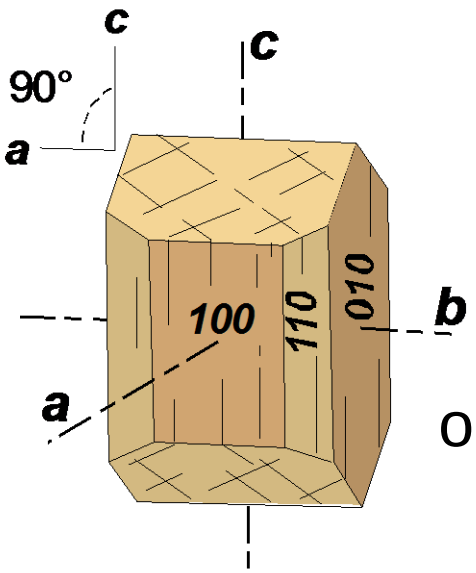
- As **mafic phase** in diorites, tonalites, granodiorites, granites and Rhyolites, if sufficient H_2O and potassium in the melt. In biotite are approx. 8 wt.% K_2O!

Pyroxenes (mafic mineral phase)

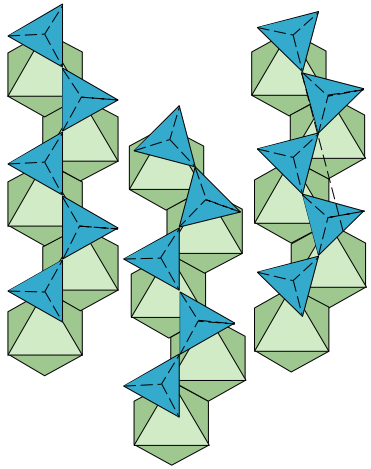
general formula: $A_2B_2[(Si,Al)_2O_6]$

with A = Na, **Ca**, Mg, Fe^{2+}, Mn

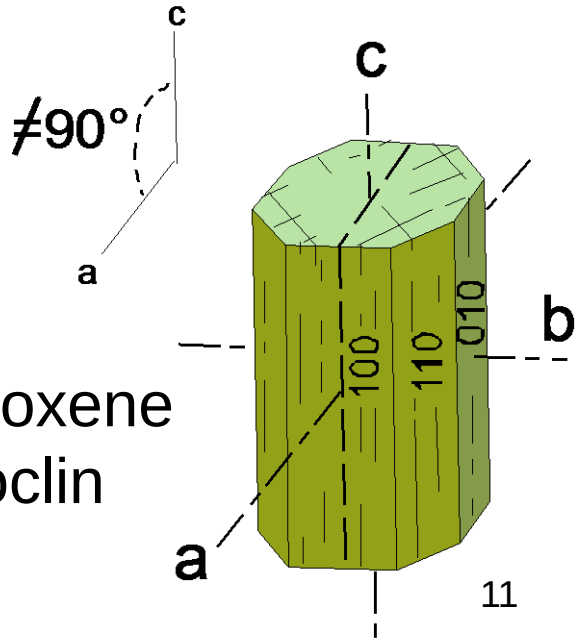
B = **Mg**, **Fe^{2+}**, Mn, Fe^{3+}, Al, Ti, Cr



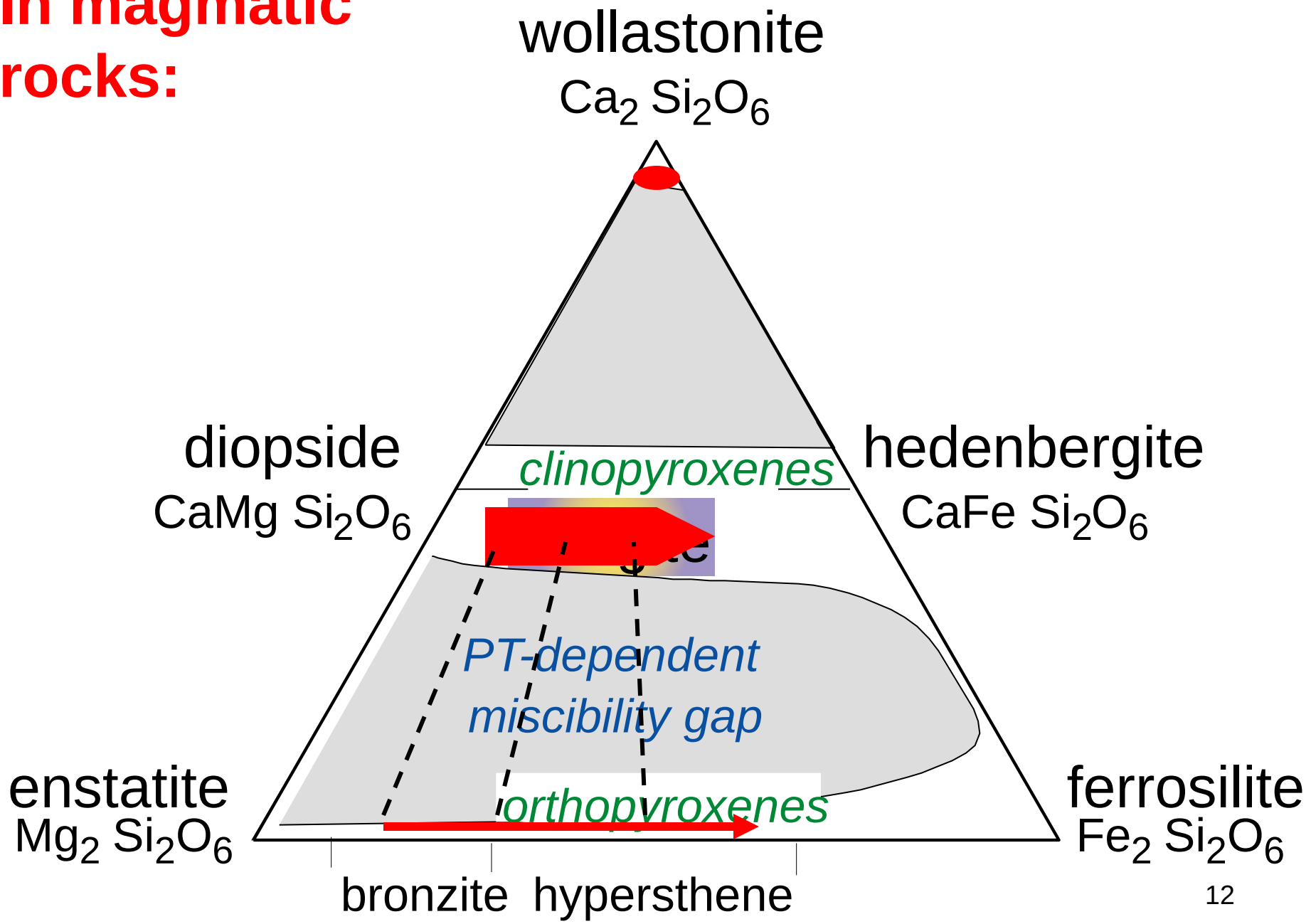
orthopyroxene
rhombic



clinopyroxene
monoclin



In magmatic rocks:



Amphibole group (mafic phase)

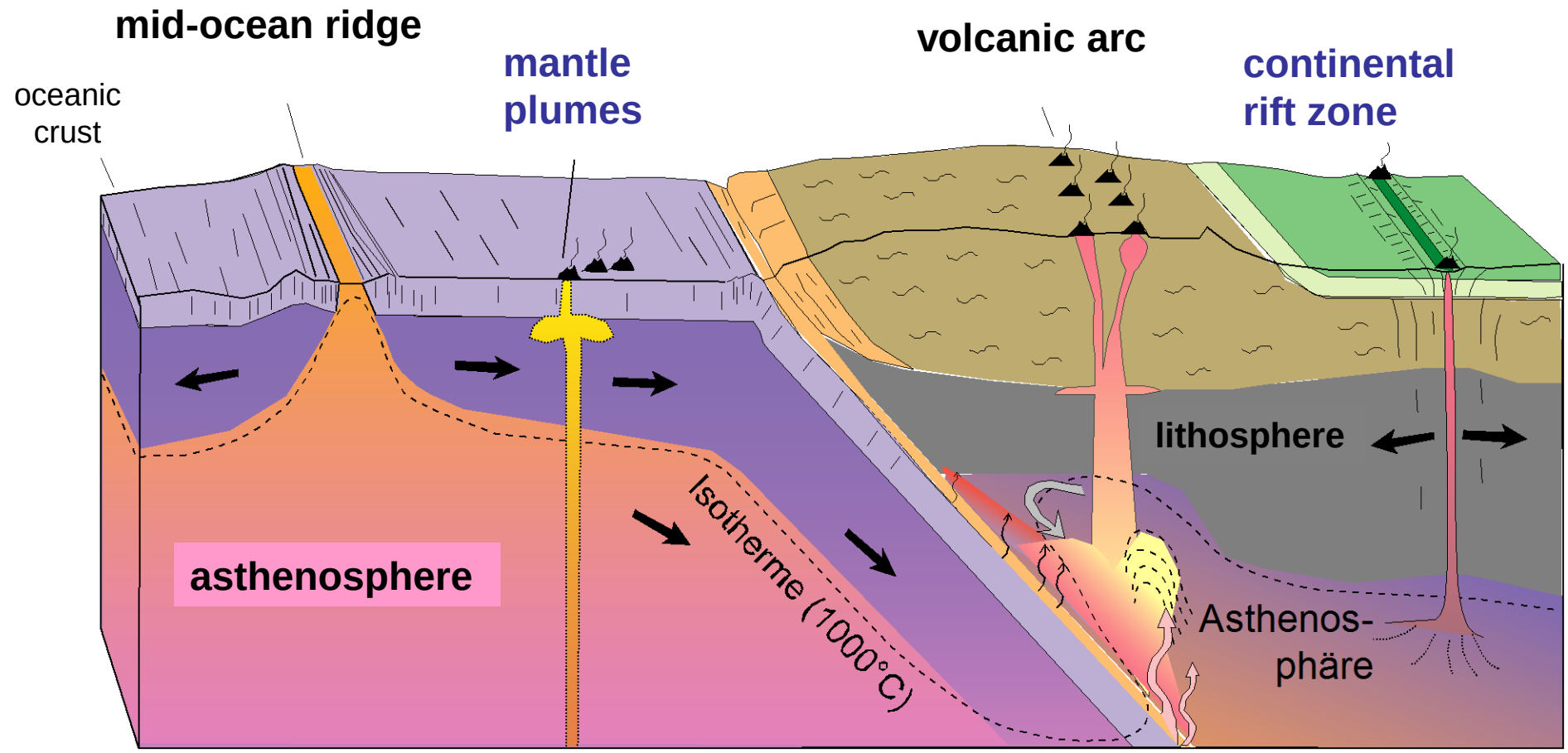
- general formula:

$$A_{0\text{-}1}X_2Y_5[(Si,Al)_8O_{22}(OH,F,Cl)_2]$$

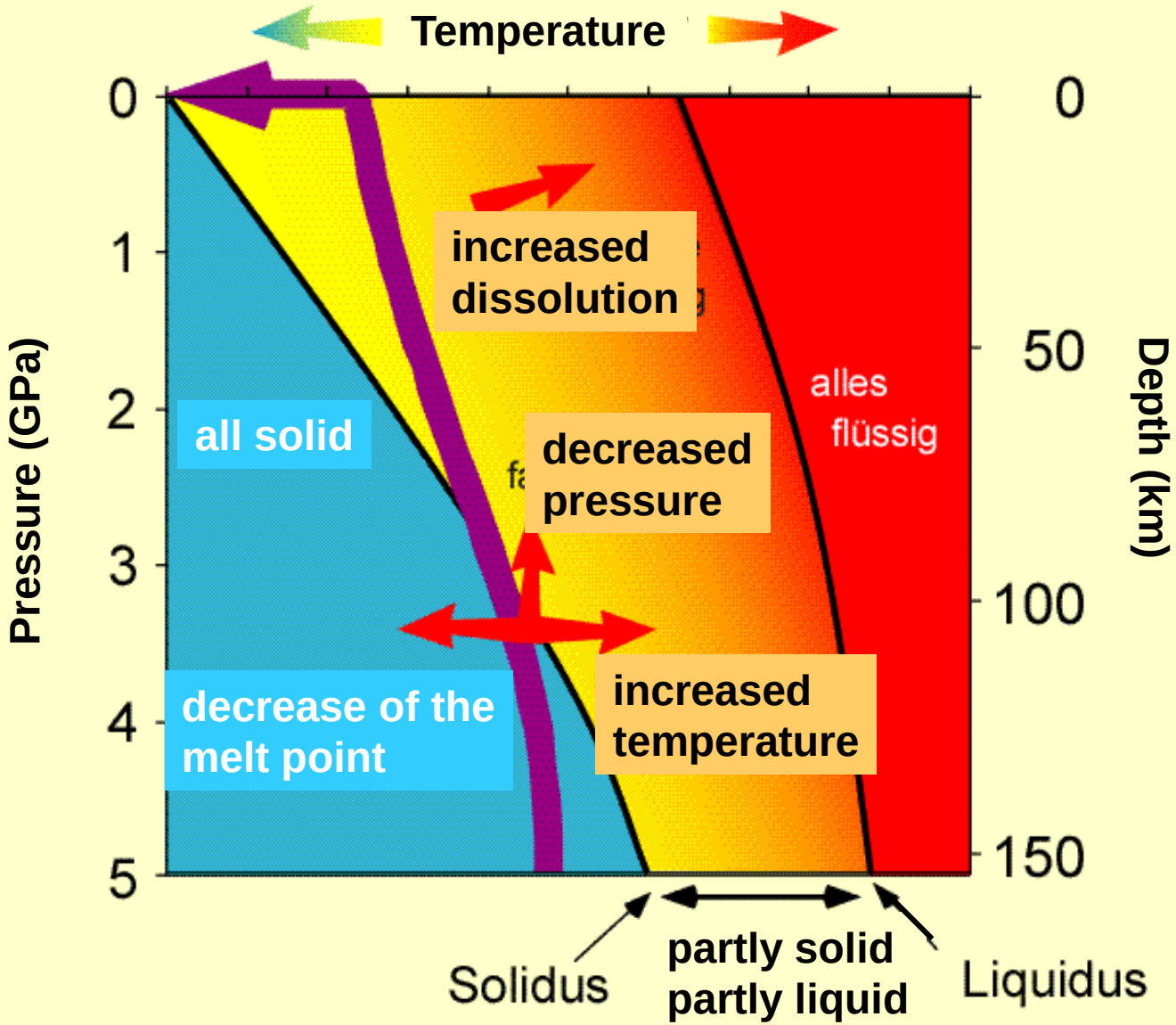
- with A = K, Na
- X = Na, Ca, Mg, Fe^{2+}, Mn
- Y = Mg,Fe^{2+}, Mn, Fe^{3+}, Al, Ti, Cr

- They are formed in basic and intermediate melts, when sufficient Ca, Fe, Mg and H_2O (>2 wt.% in the melt) are available.

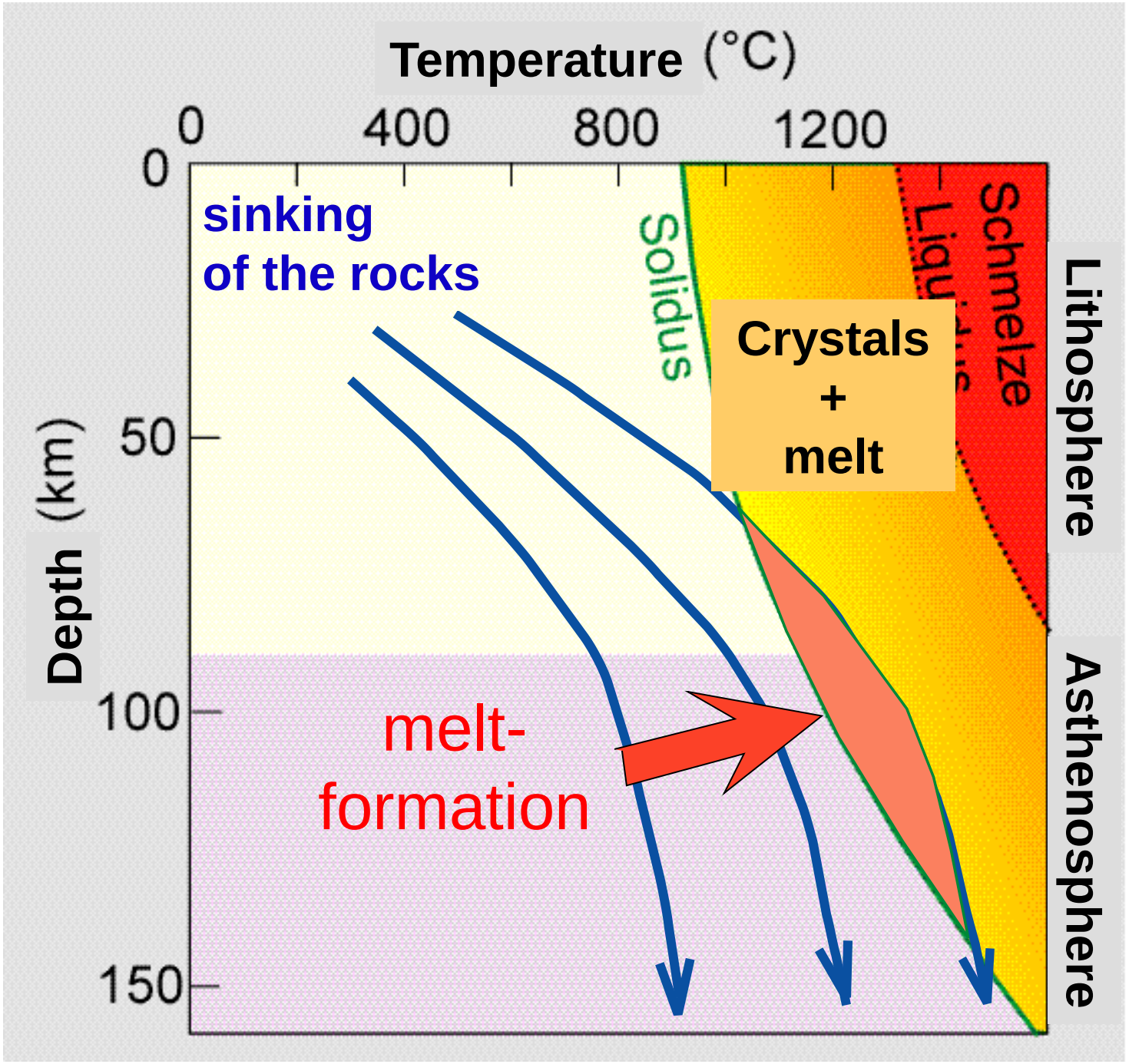
Areas, in which occur melt formation and volcanoes in plate tectonic concept.



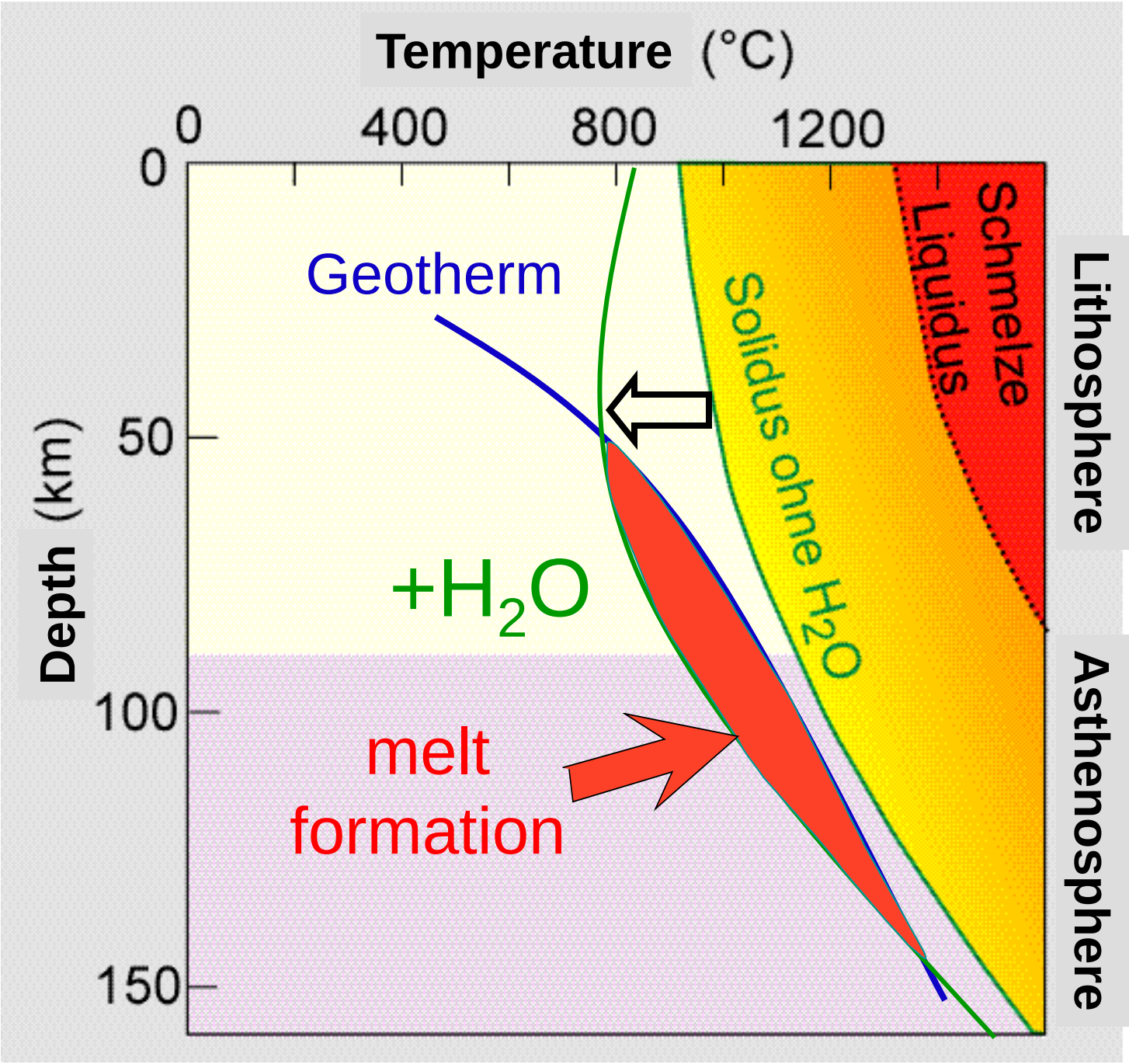
Pressure-Temperature-(PT)-Diagram



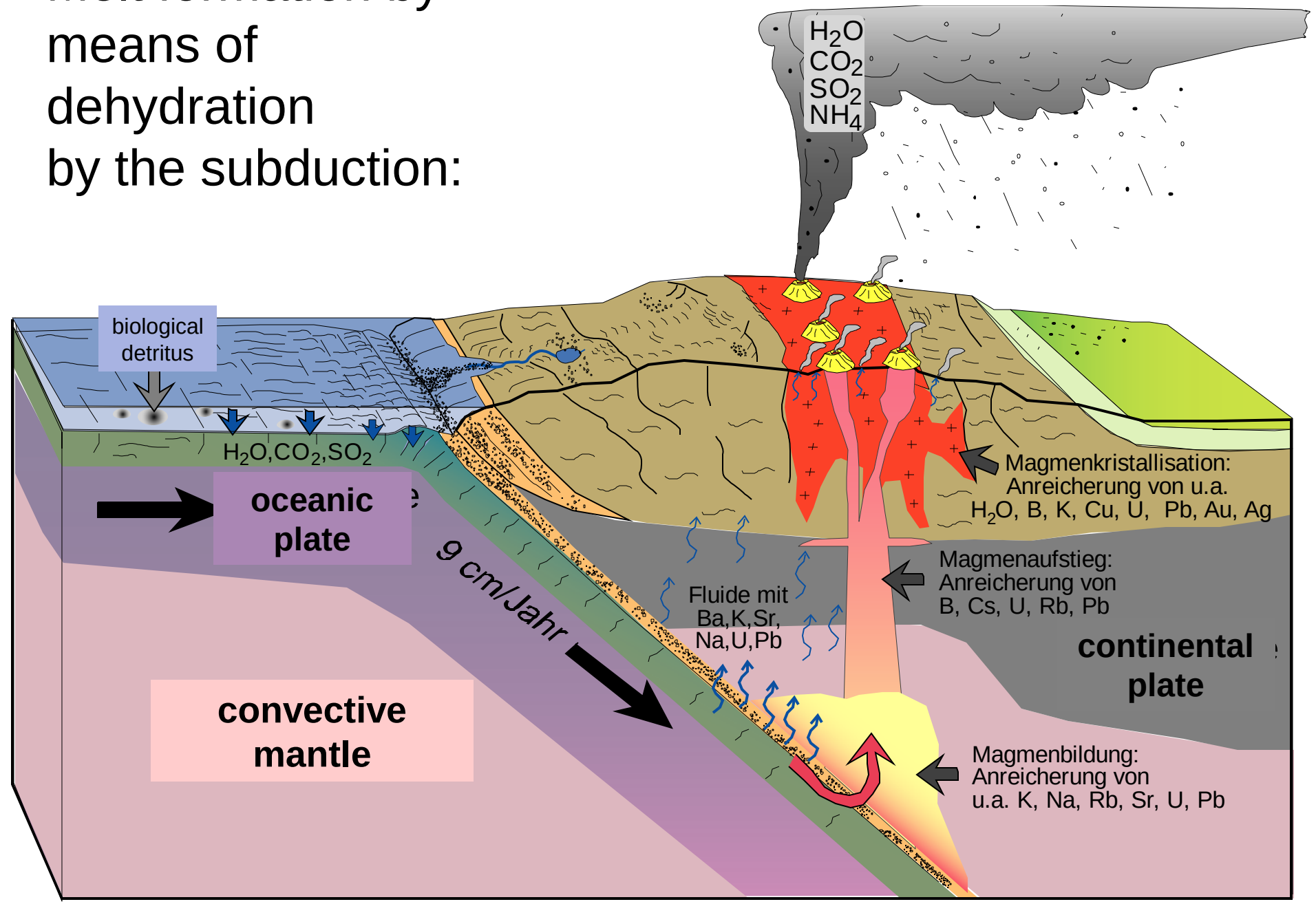
Why a rock melts?



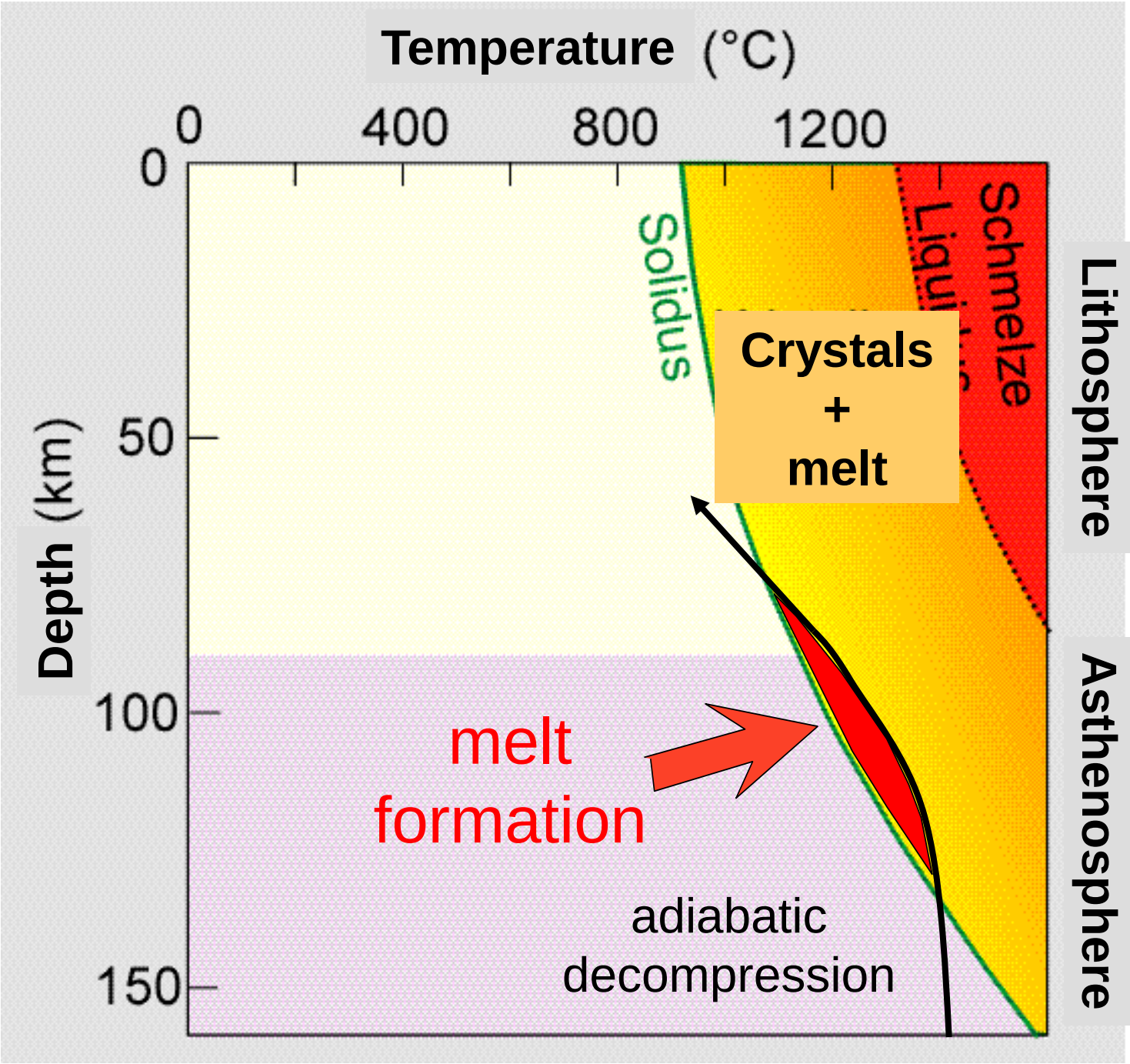
Melt by means of dehydration of minerals
➔ + H_2O



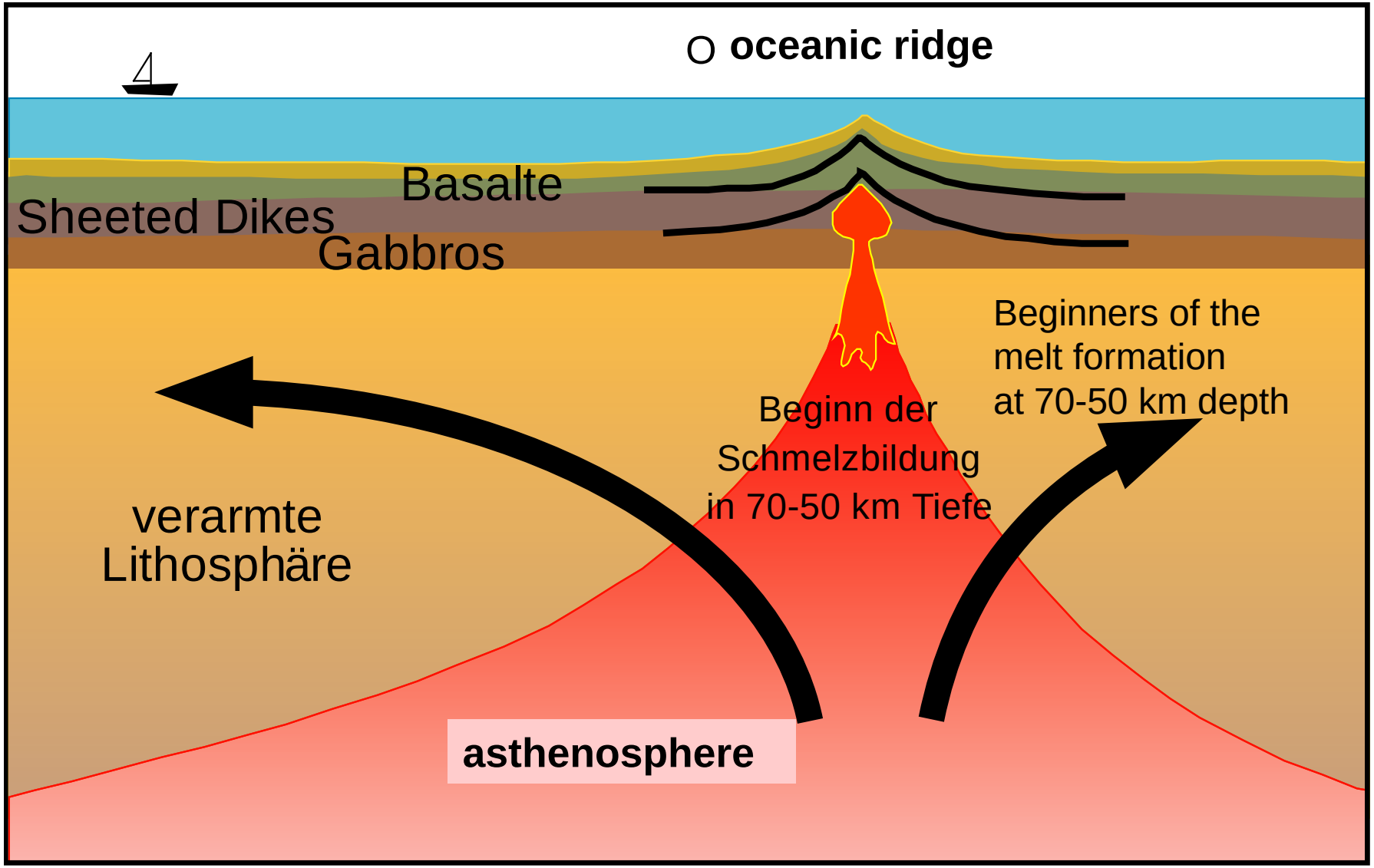
Melt formation by means of dehydration by the subduction:



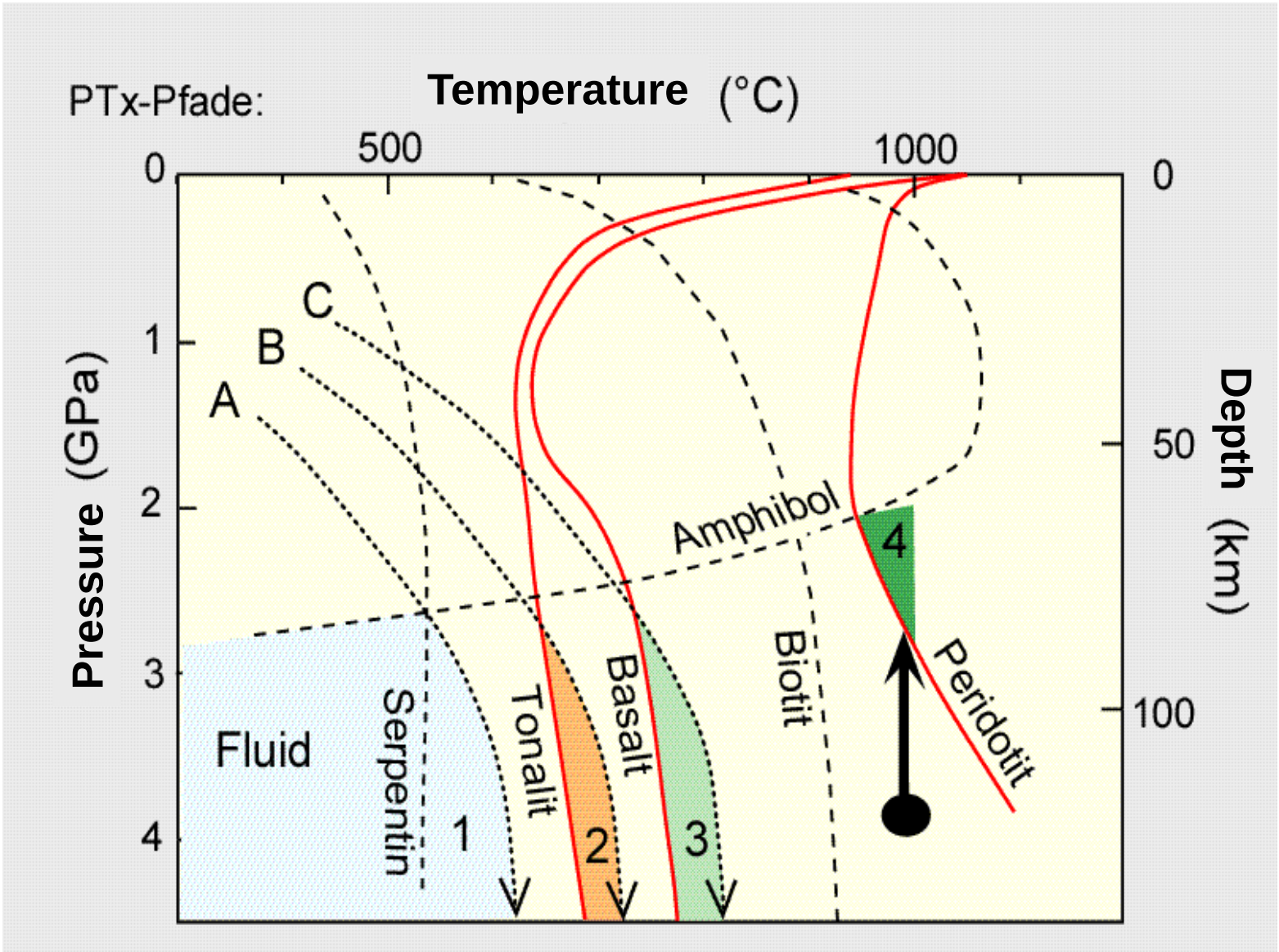
Melt formation by means of adiabatic decom-pression:
plastic mantle material ascends in area of mid-ocean ridge or in mantle plumes, this occurs nearly adiabatic. This means that not heat exchange with the colder surrounding takes a place.
By means of such nearly isothermal decompression is the Solidus exceeded and it is shifted with the increasing pressure (depth) up to higher temperature.



Structure of oceanic spreading centers

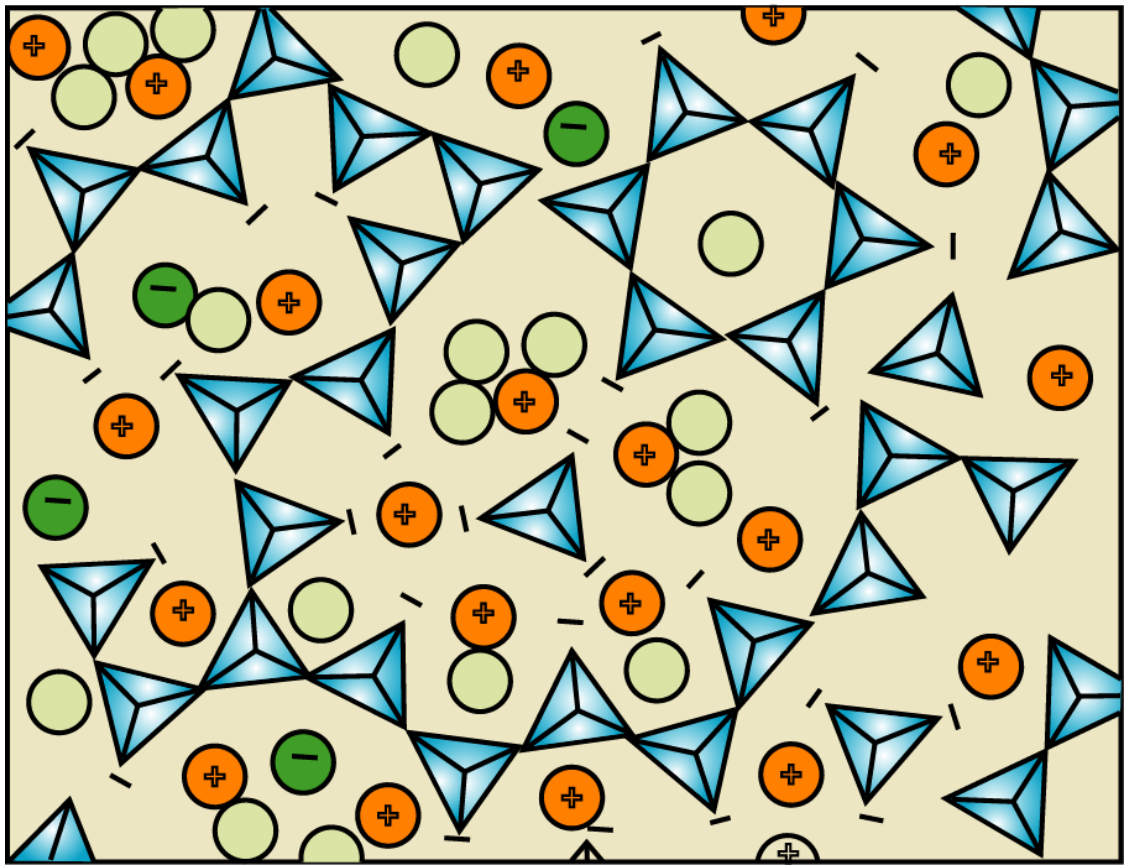


Influence of material systems (peridotite, basalt and tonalite) on the solidus (red curves) and stability limits for hydrous minerals (amphibole, biotite, serpentine)

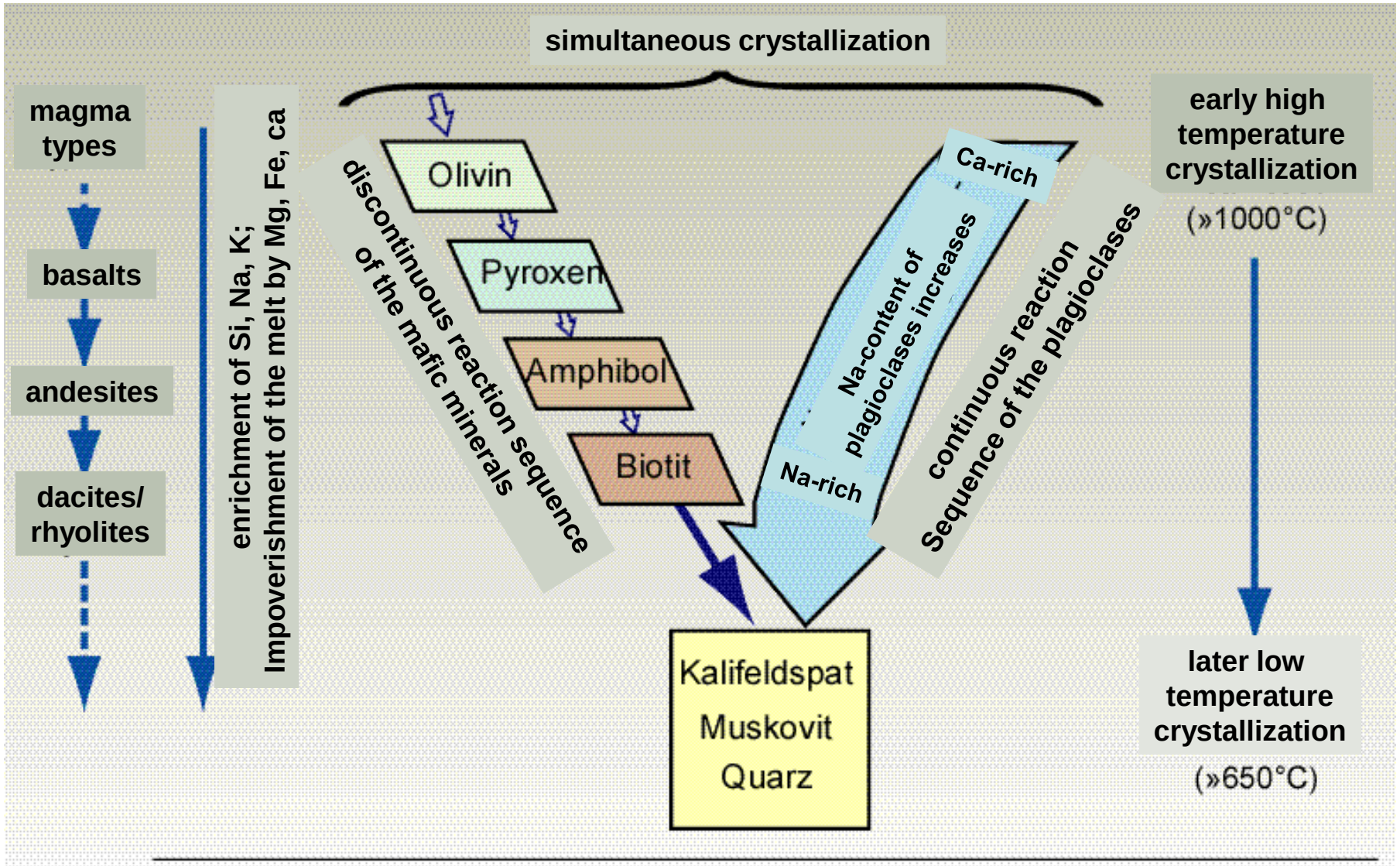


Viscosity and diffusion in rock melt

Melt with interlaced SiO_4-tetrahedron:
more SiO_2 ➔ higher interlacing
and viscosity
increase an H_2O ➔ depolimerized
➔ low viscosity

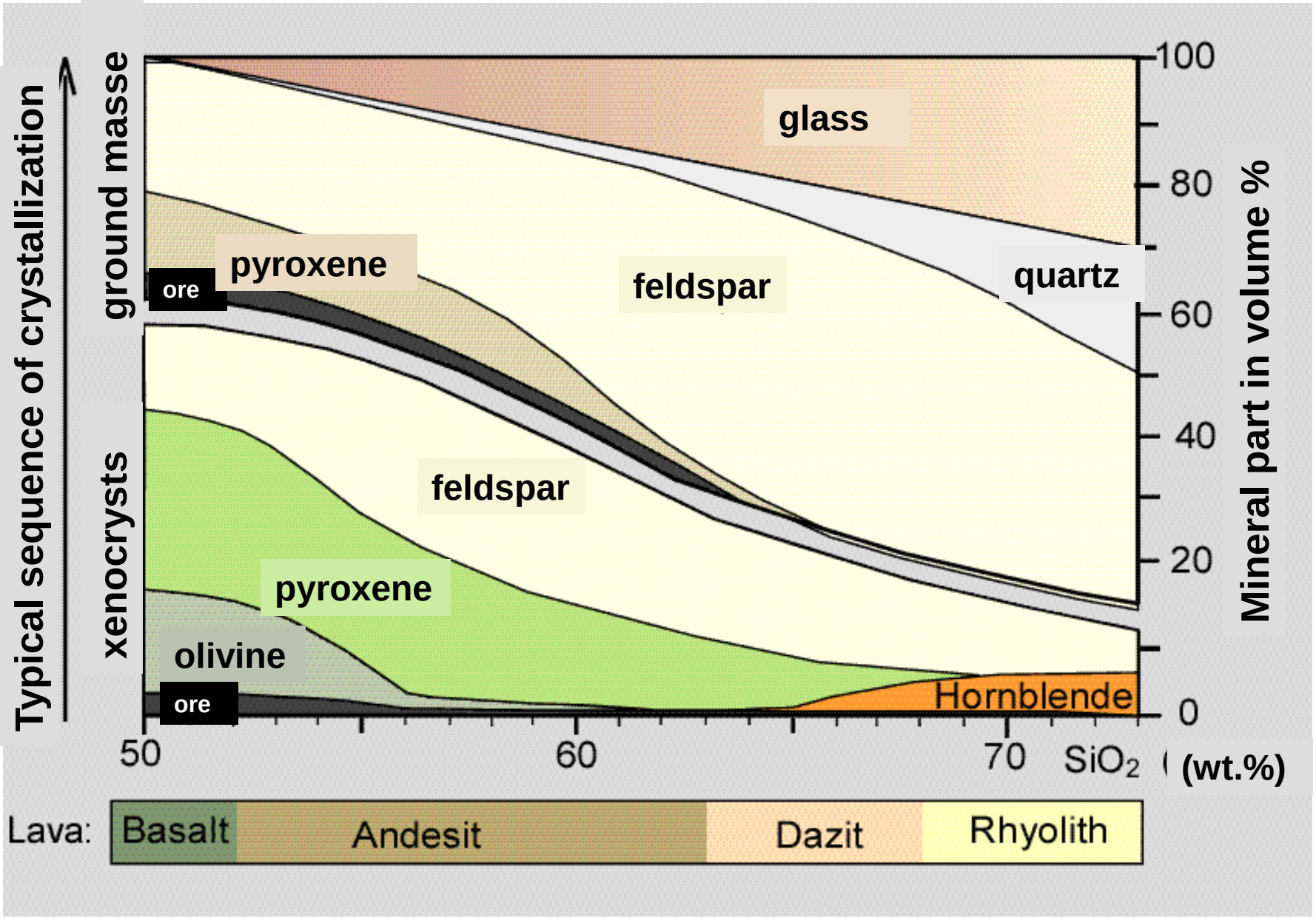


Crystallization sequence and differentiation of magmas

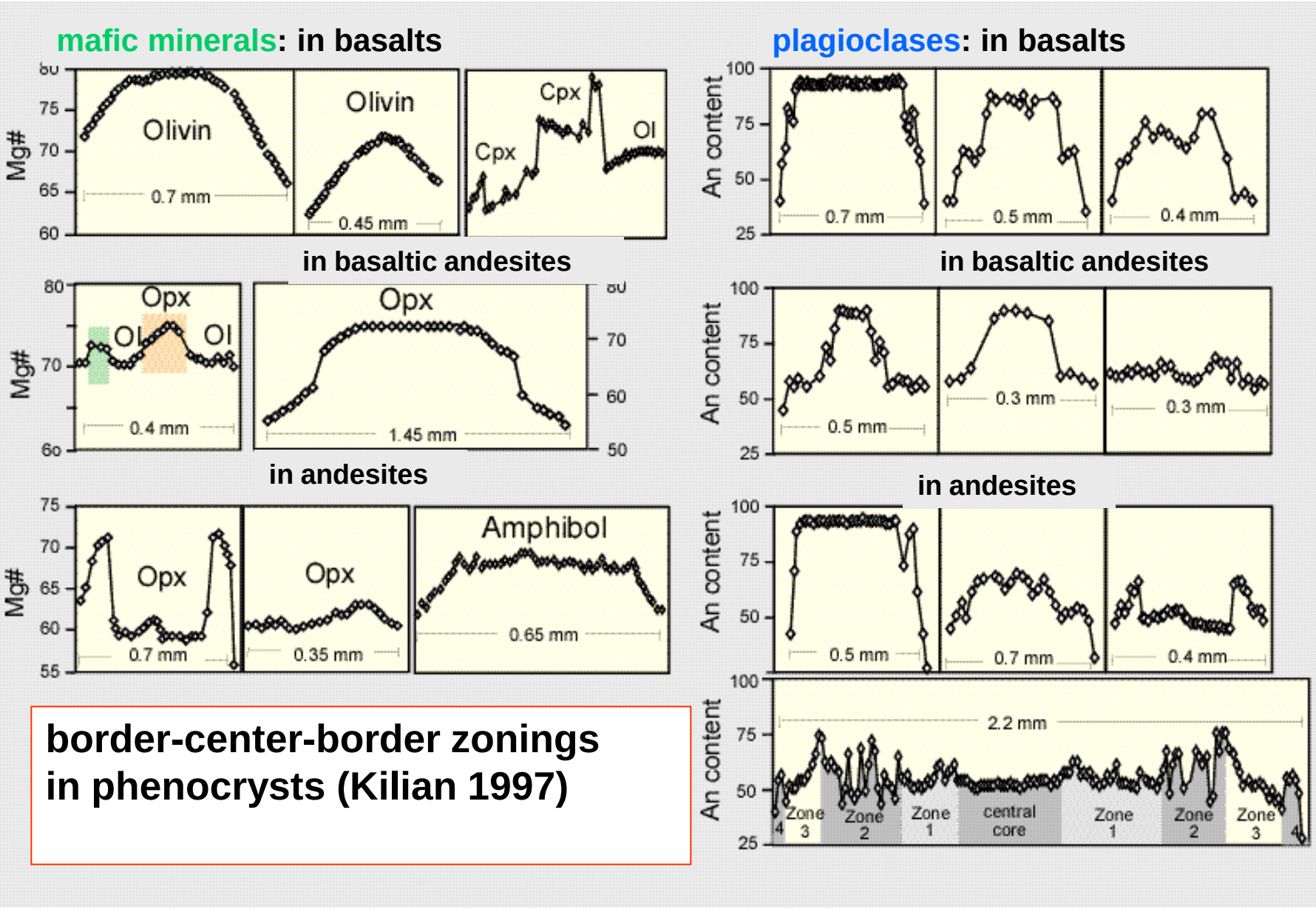


BOWEN's explication of discontinuous and continuous reaction sequences for the differentiation of magmas

Typical crystallization sequences

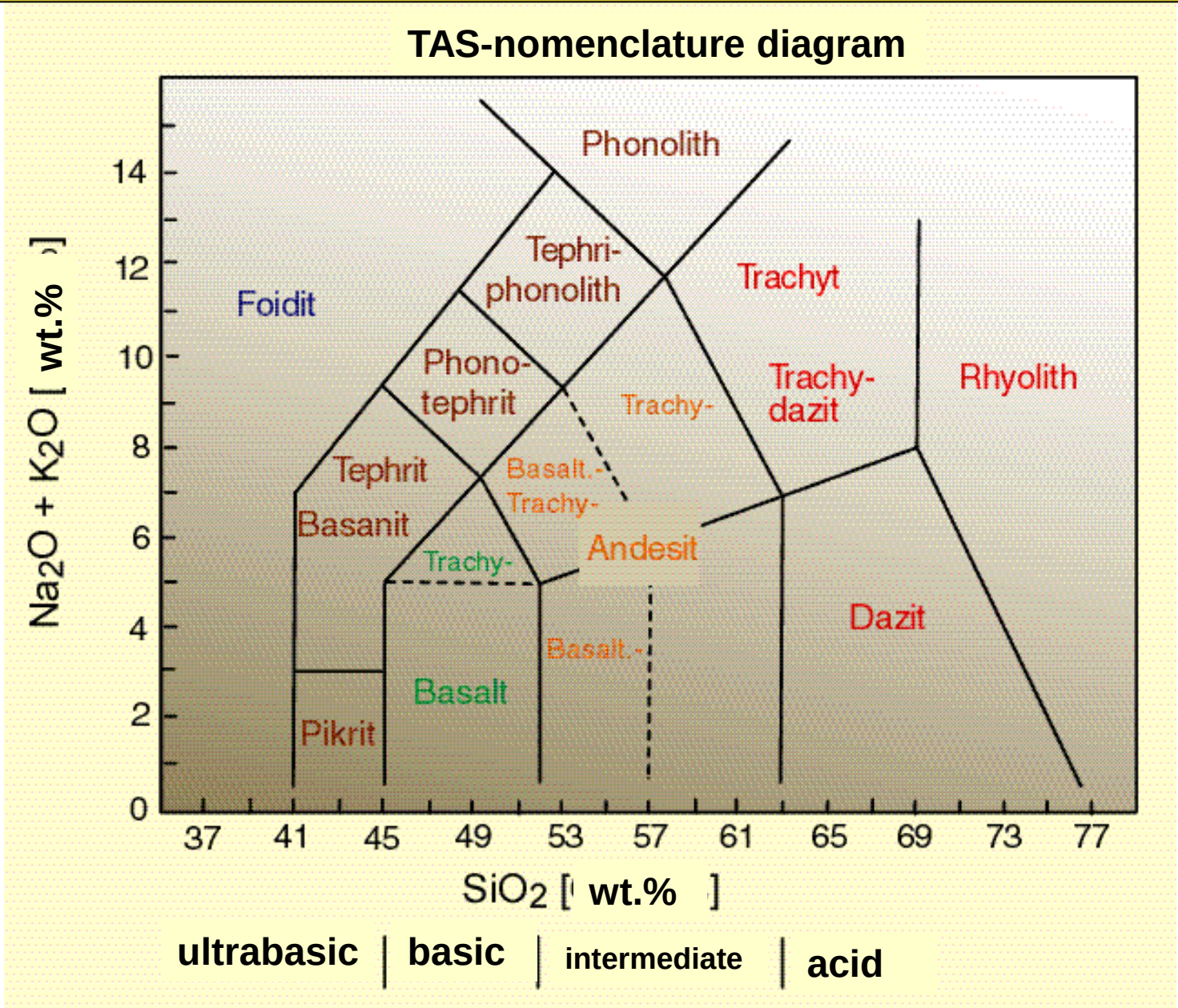


Example of chemical zonings in mafic phenocrysts (border-center-border-profile) and plagioclases.

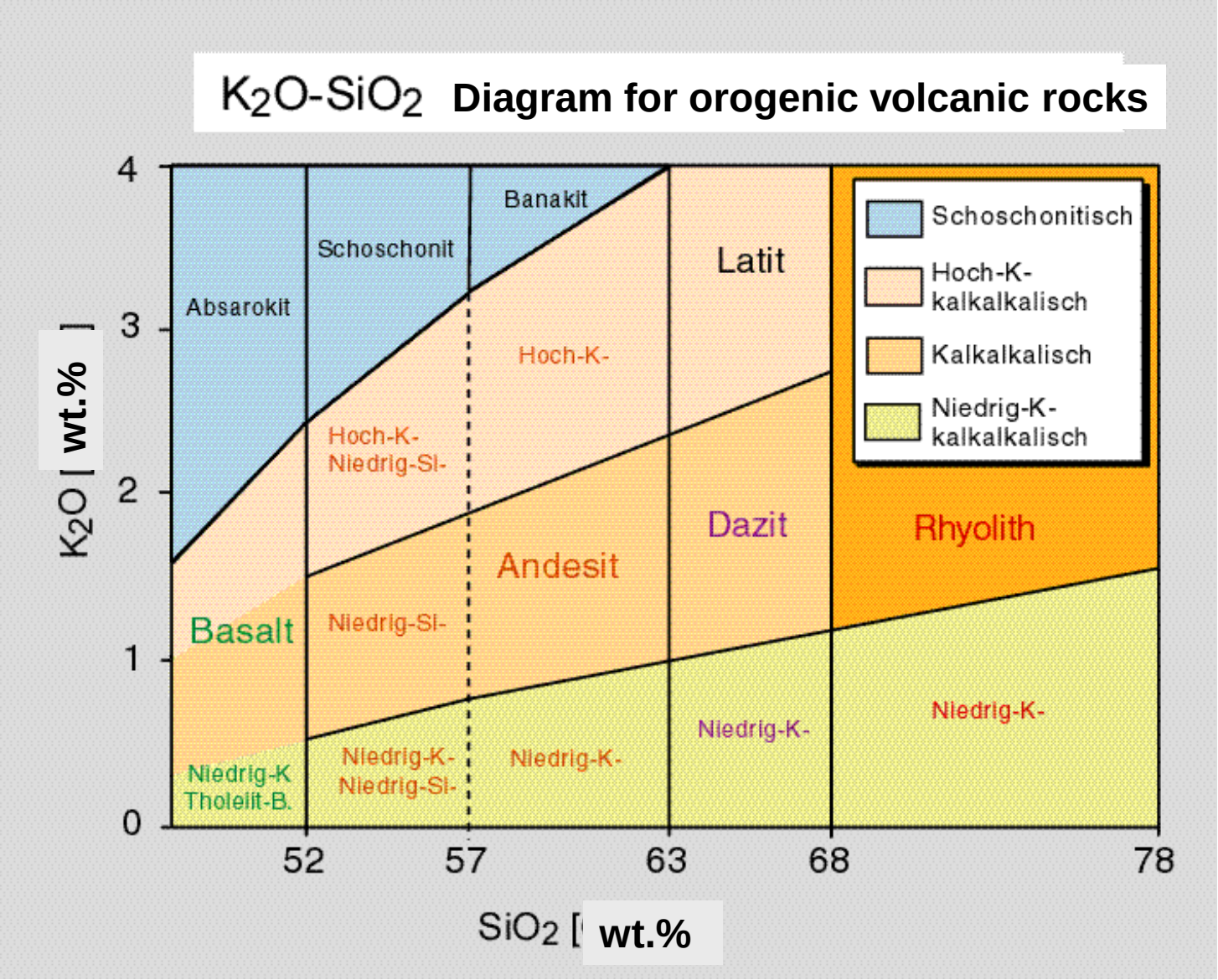


border-center-border zonings in phenocrysts (Kilian 1997)

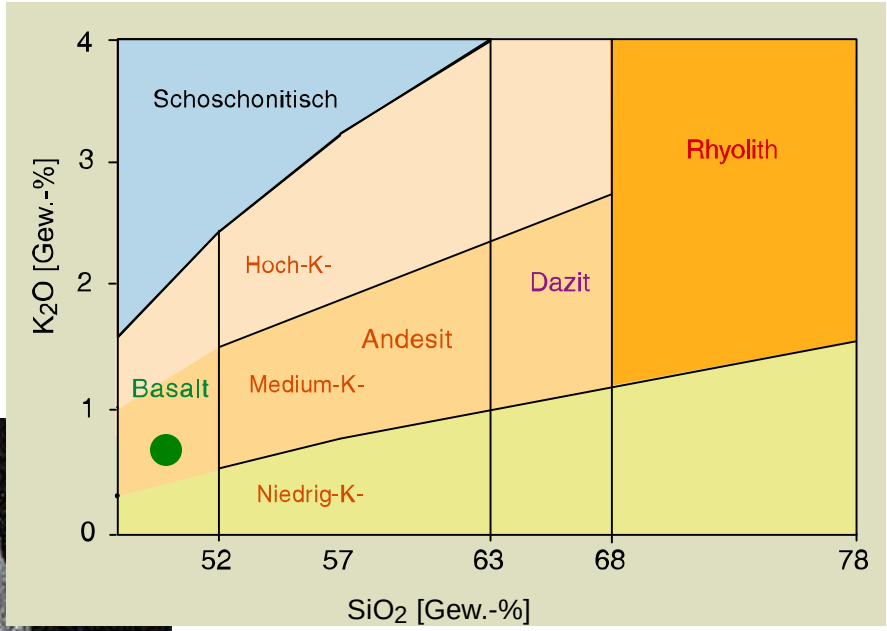
Commonly used chemical classification of von volcanic rocks according the „Total alkali versus Silica“ (TAS) contents.

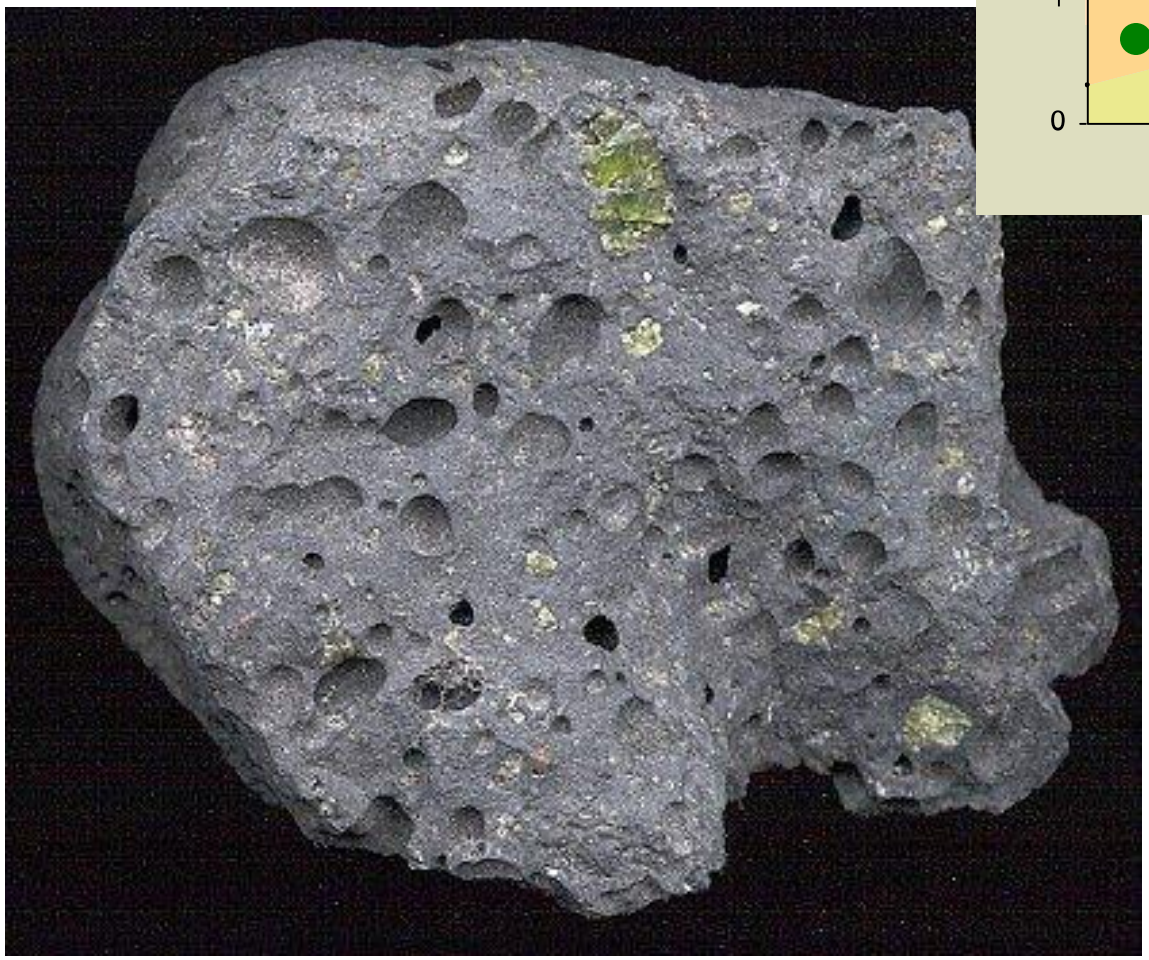


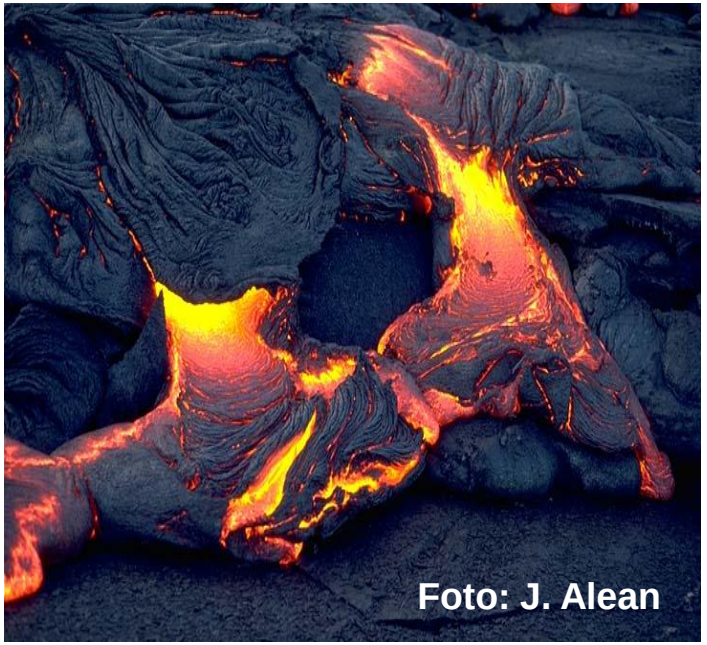
Volcanic rocks from volcanic arcs above subduction zones are often chemical classified according to the SiO_2 and K_2O-contents



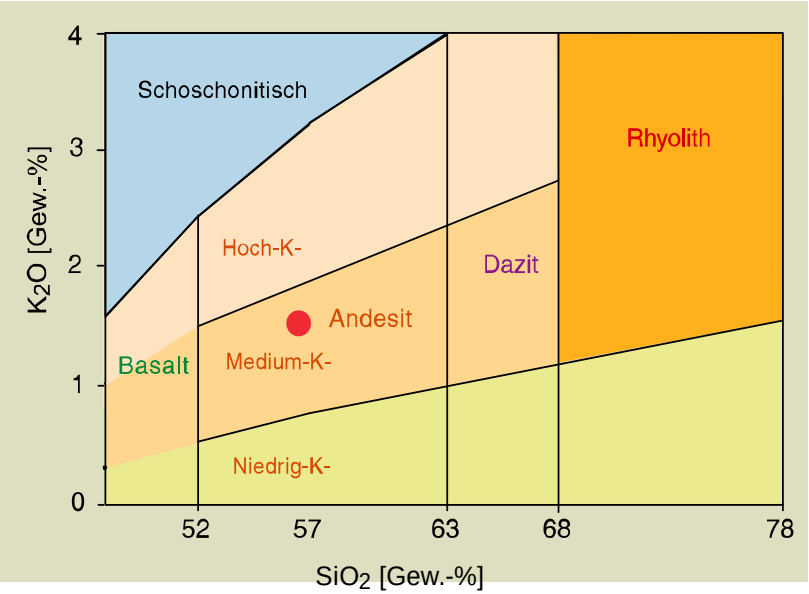
vesicular basalt with olivine and plagioclase



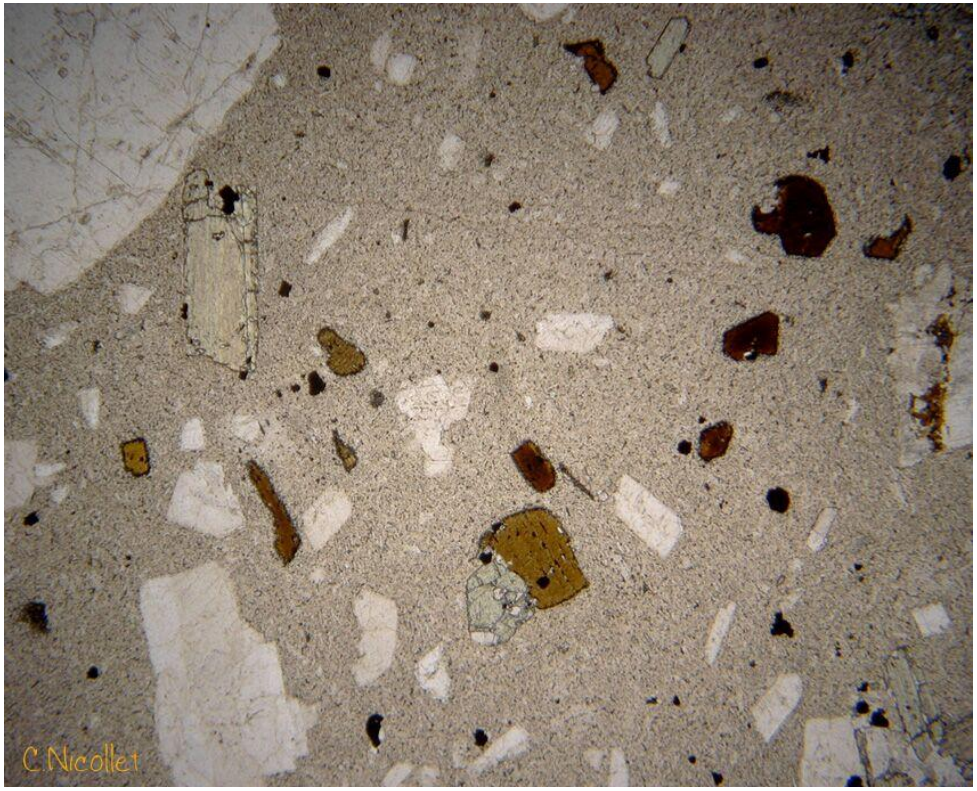


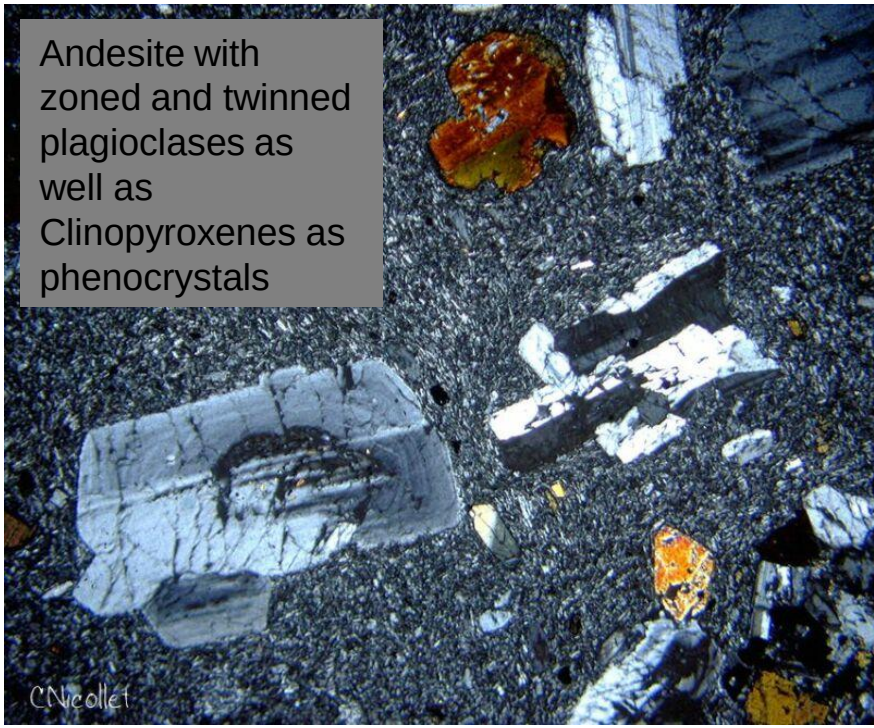


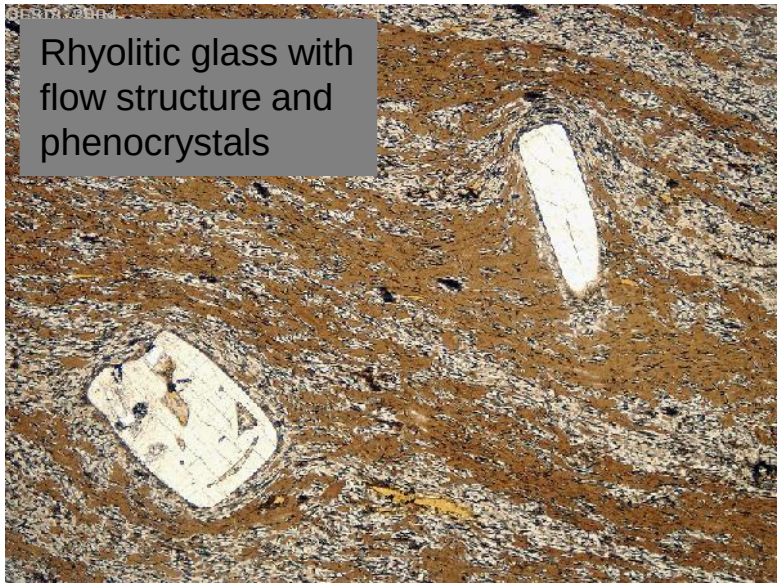
Andesite, the most common volcanic rocks above subduction zones

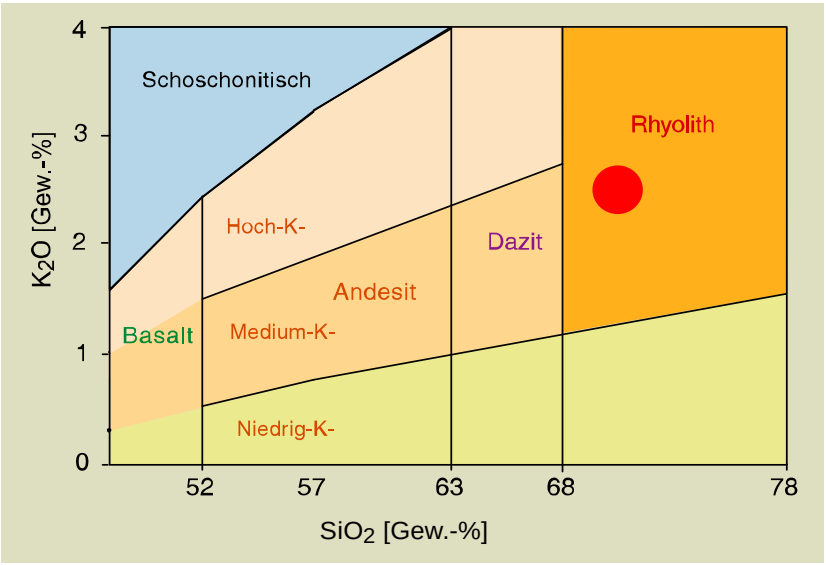


Andesite with fine-crystalline matrix in the “swim” phenocrysts of plagioclase (light), pyroxenes (grey) and hornblendes (brown).

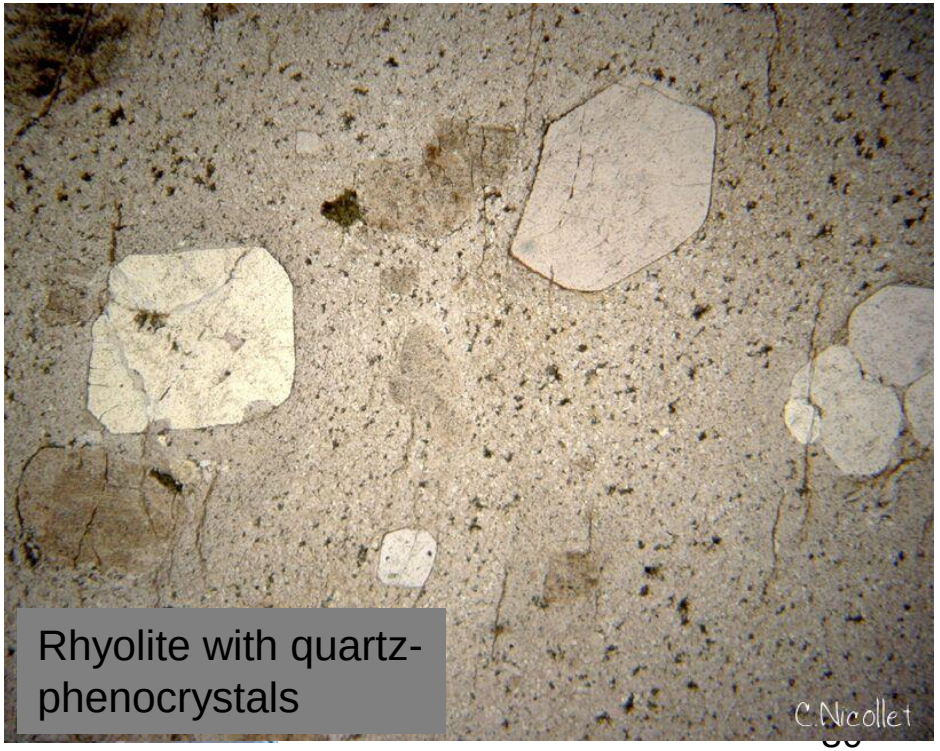


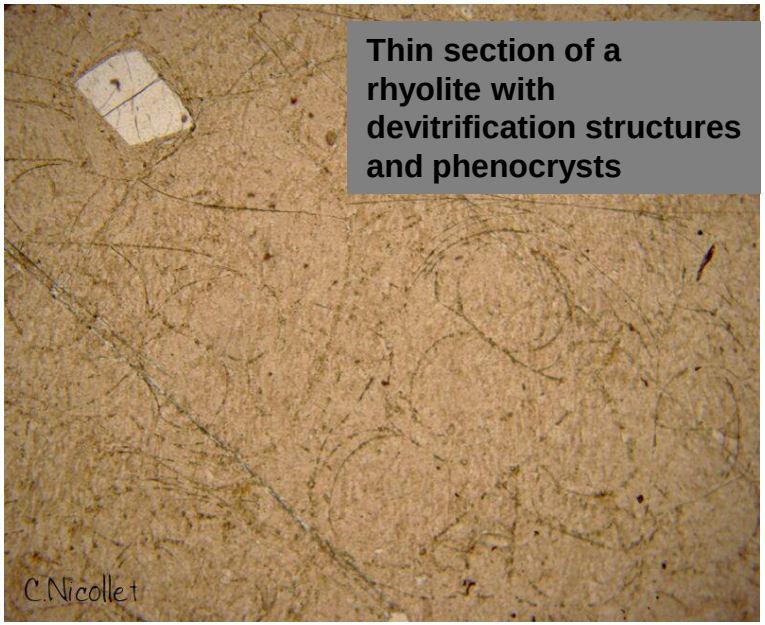


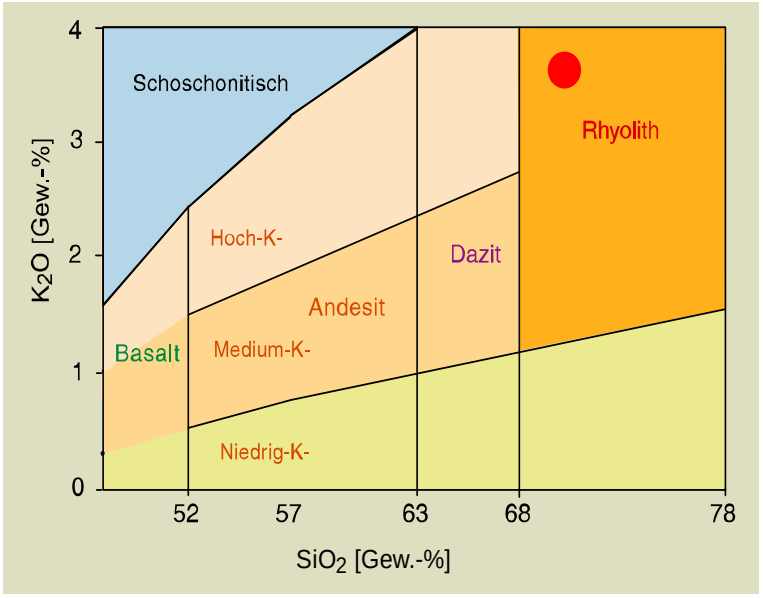

Rhyolitic glass with flow structure and phenocrystals


Schoschonitisch
Rhyolith
Hoch-K-
Dazit
Andesit
Basalt
Medium-K-
Niedrig-K-
K_2O [Gew.-%]
SiO_2 [Gew.-%]
0
1
2
3
4
52
57
63
68
78


Rhyolite from Bad-Kreuznach


Rhyolite with quartz-phenocrystals
C.Nicollet

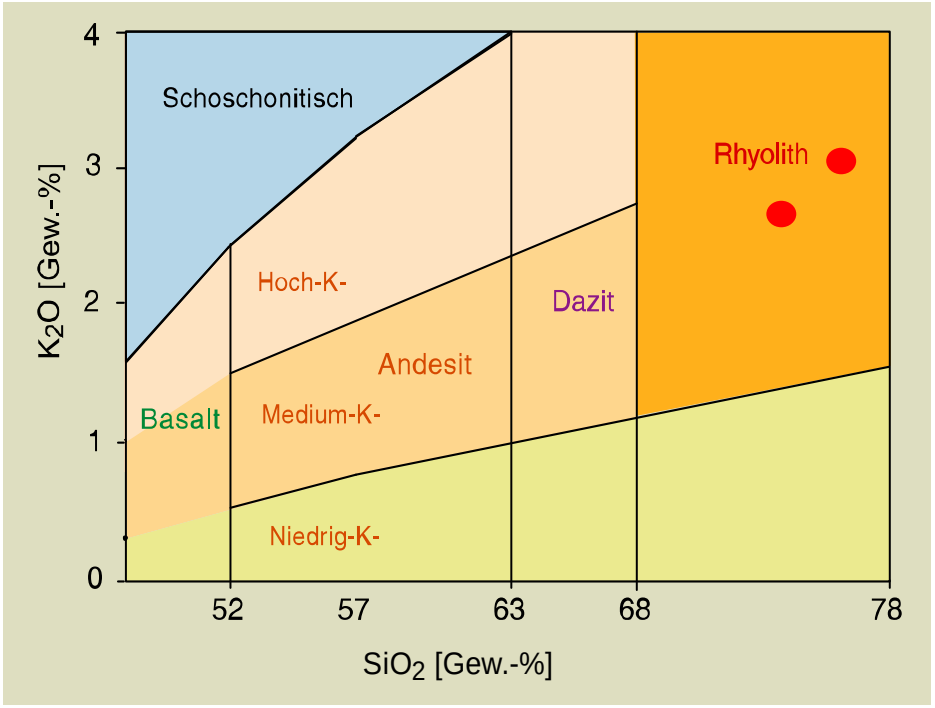


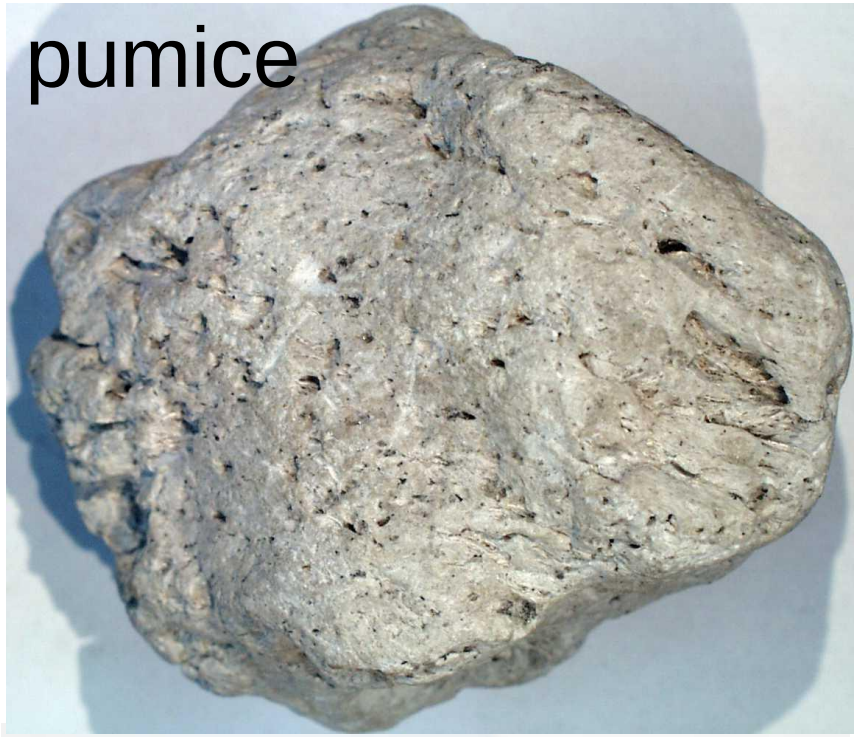


vesicular rhyolite from Hesseneck at Schwarzwald:

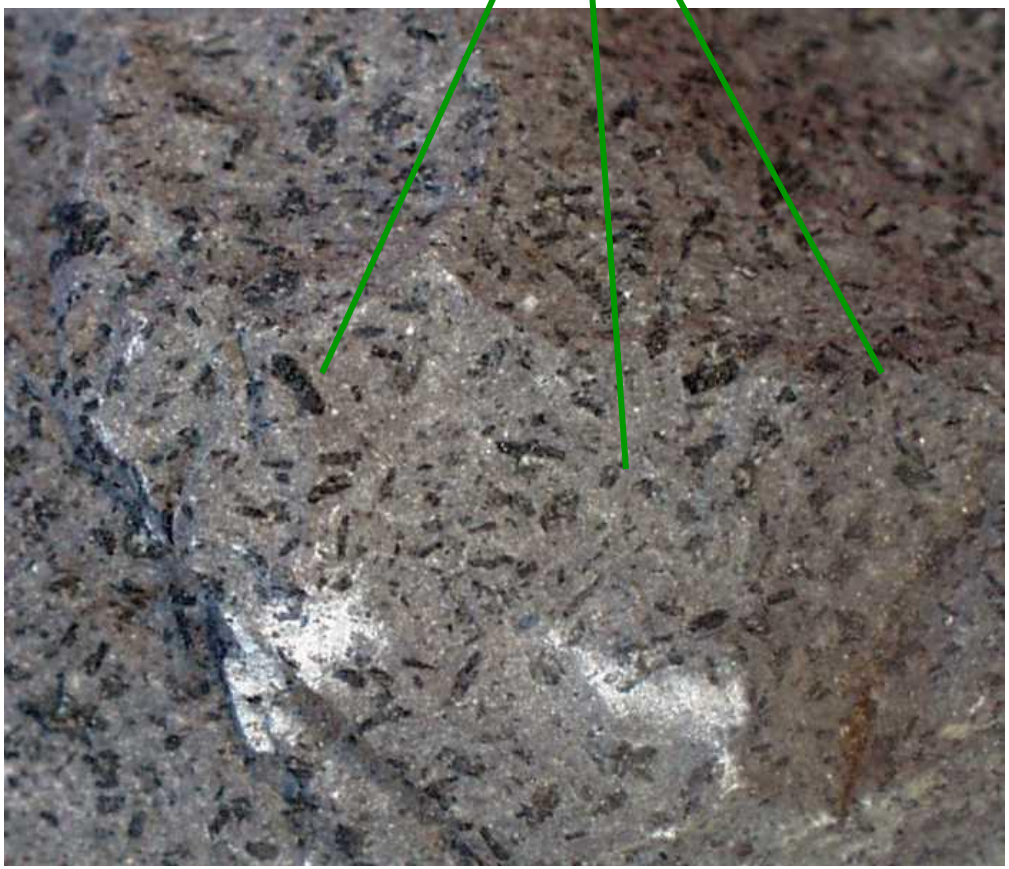
Rhyolite from Lipari as:

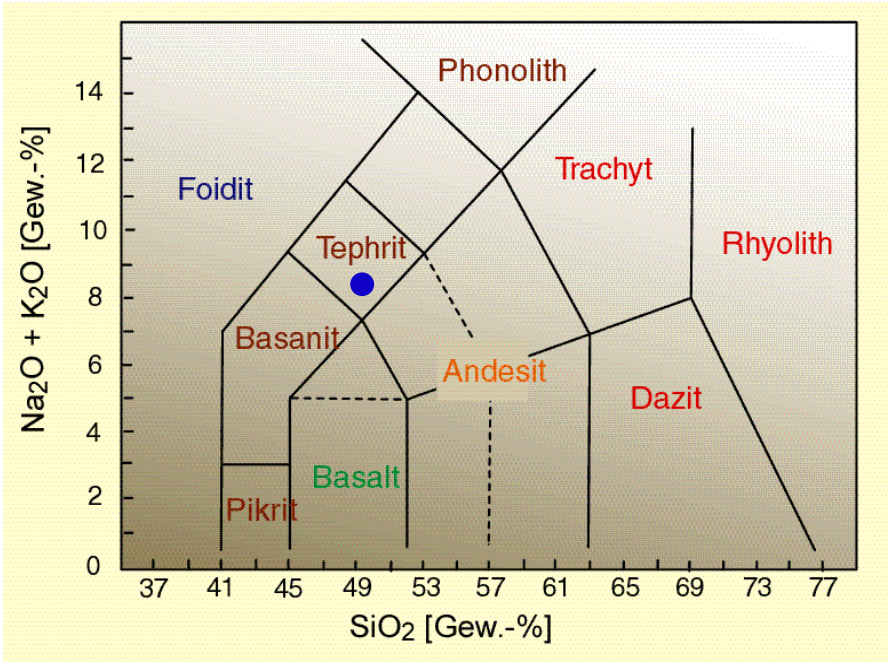
obsidian with phenocrysts and flow structure

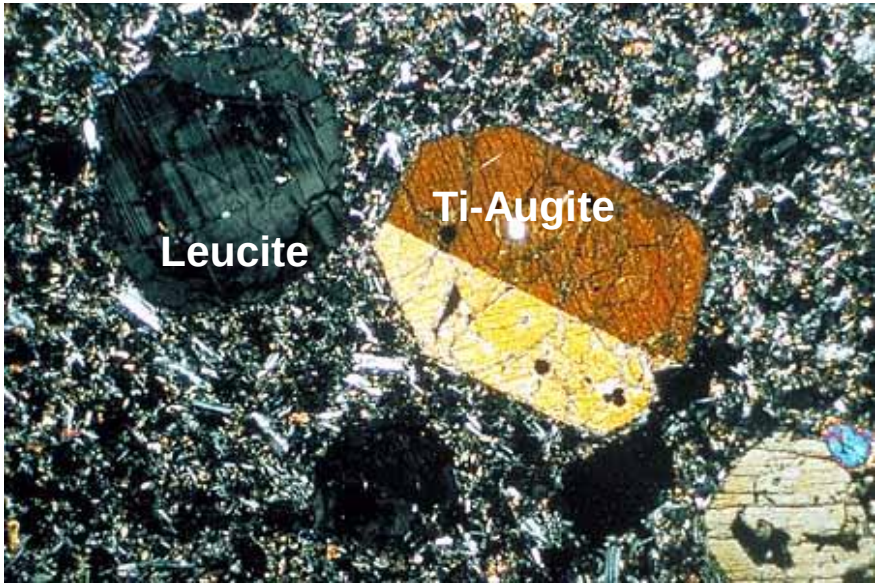




Tephrite from Kaiserstuhl

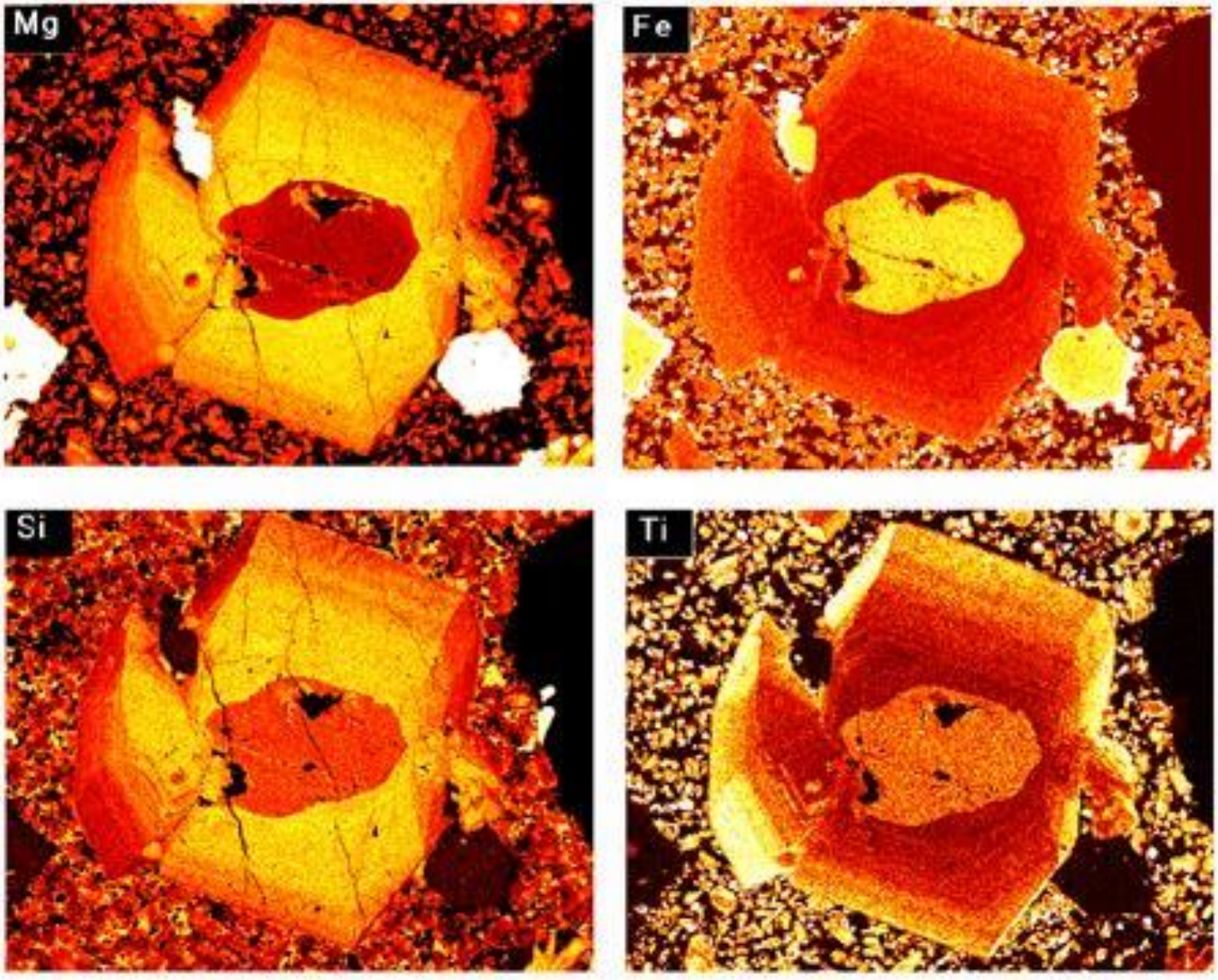






Geomuseum Claustal

Chemical zoning of clinopyroxenes (from H.-P. Meyer)



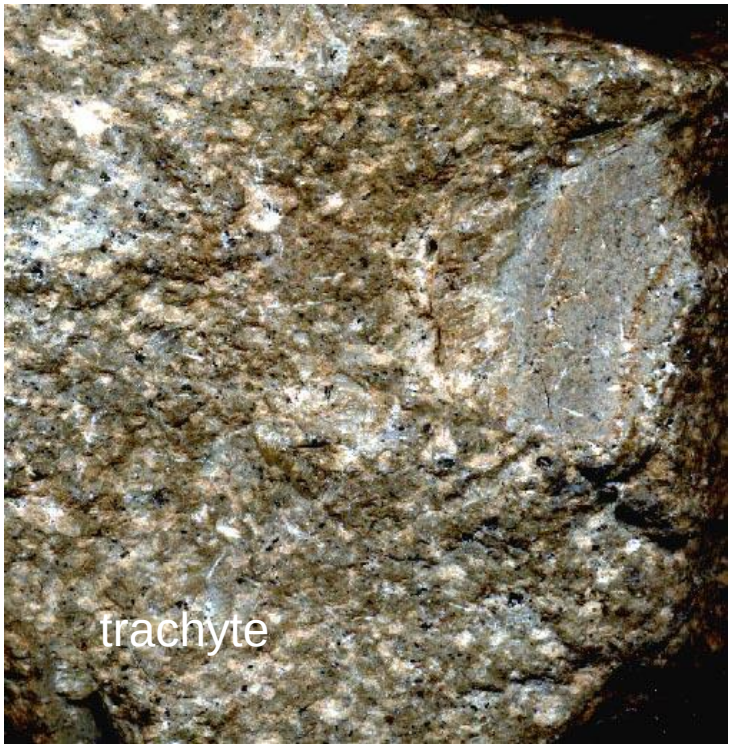
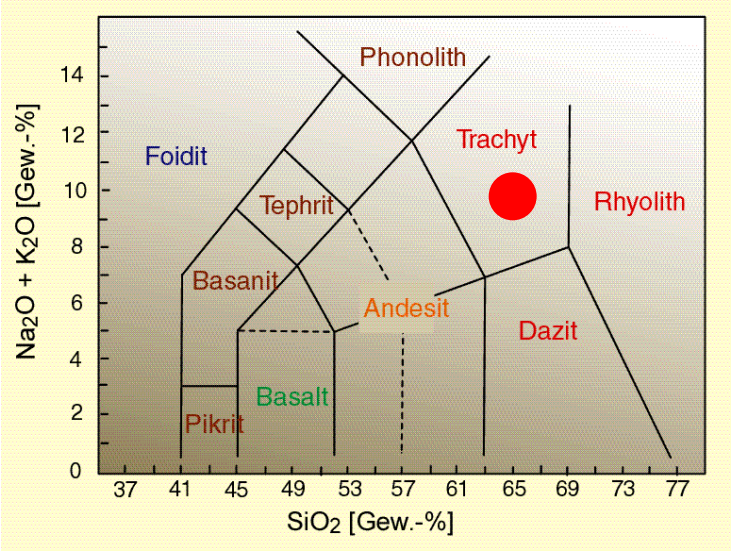
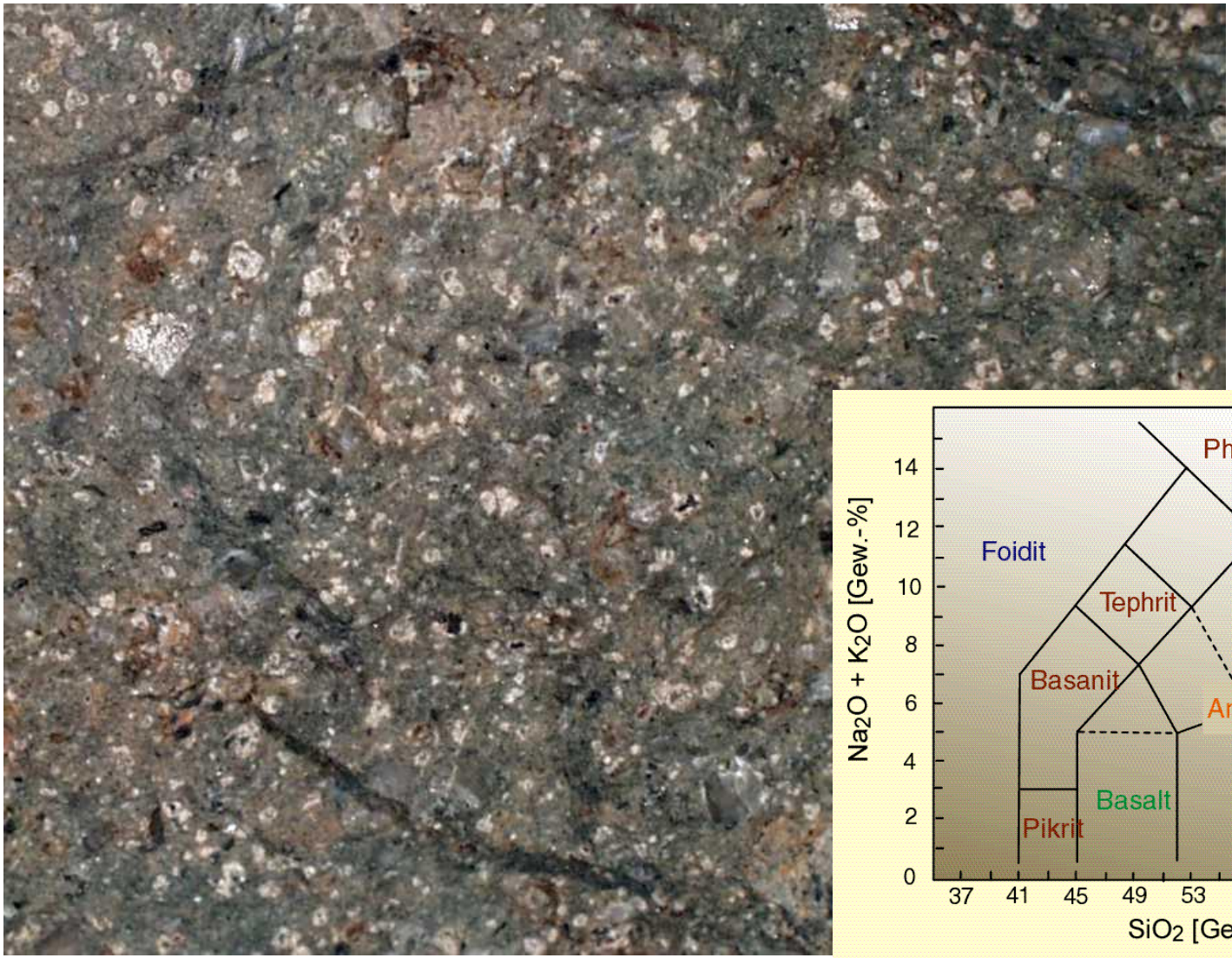


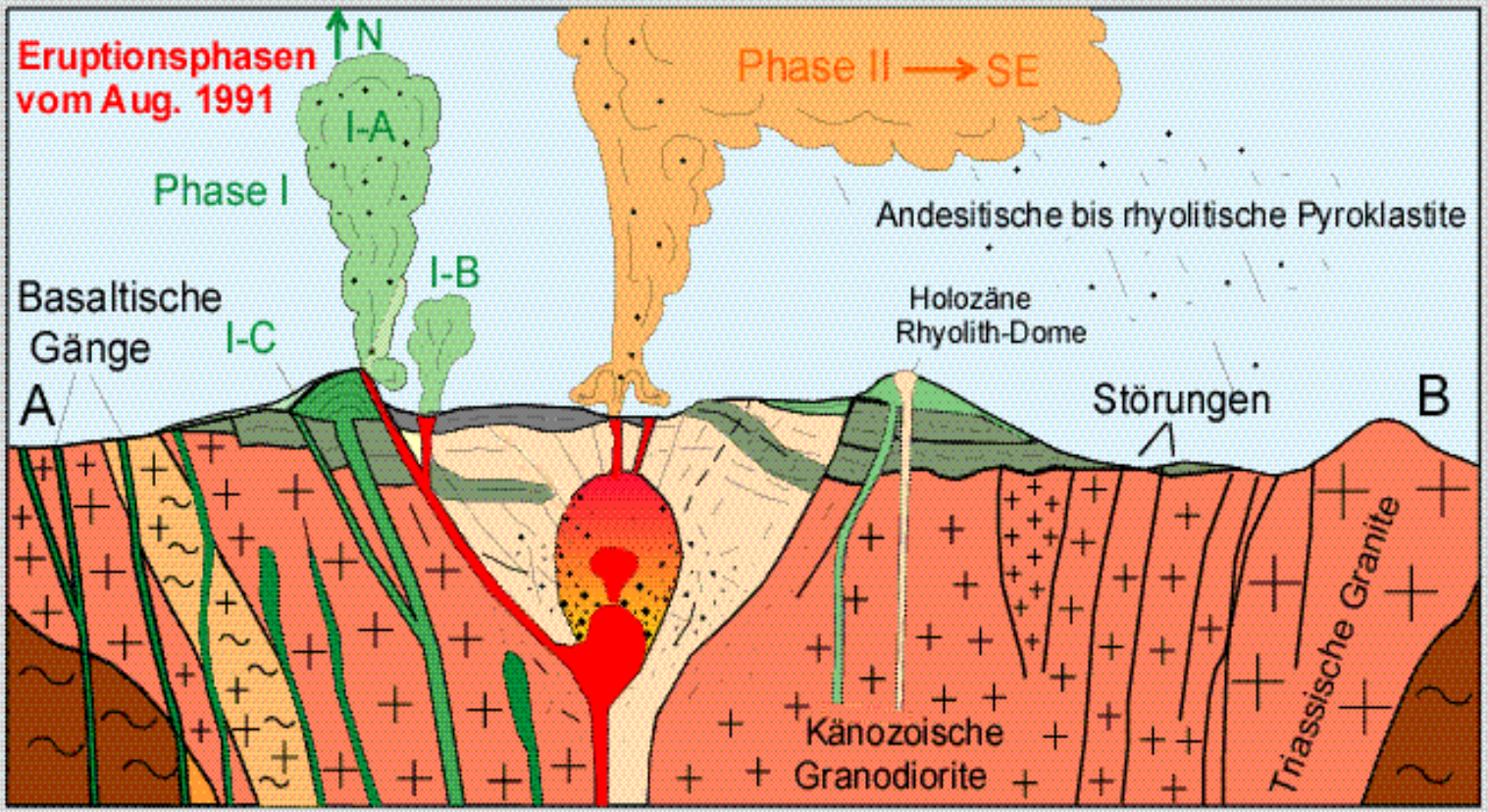
Foto: Ralph Dezepich



Phonolite from the Hohenkrähen, Hegau

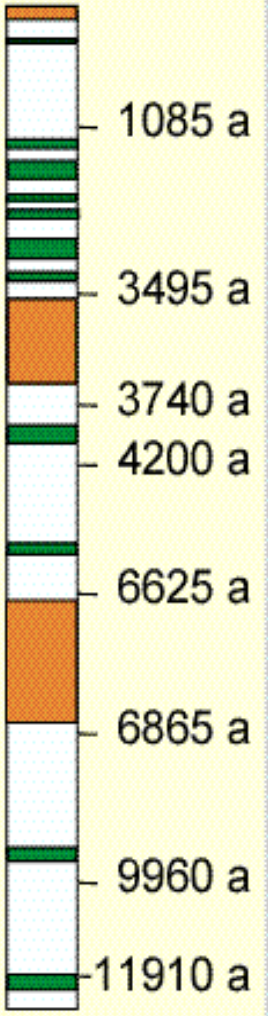


Complexes intrusion and eruption events



Kilian (1997)

Holocene tephra profile



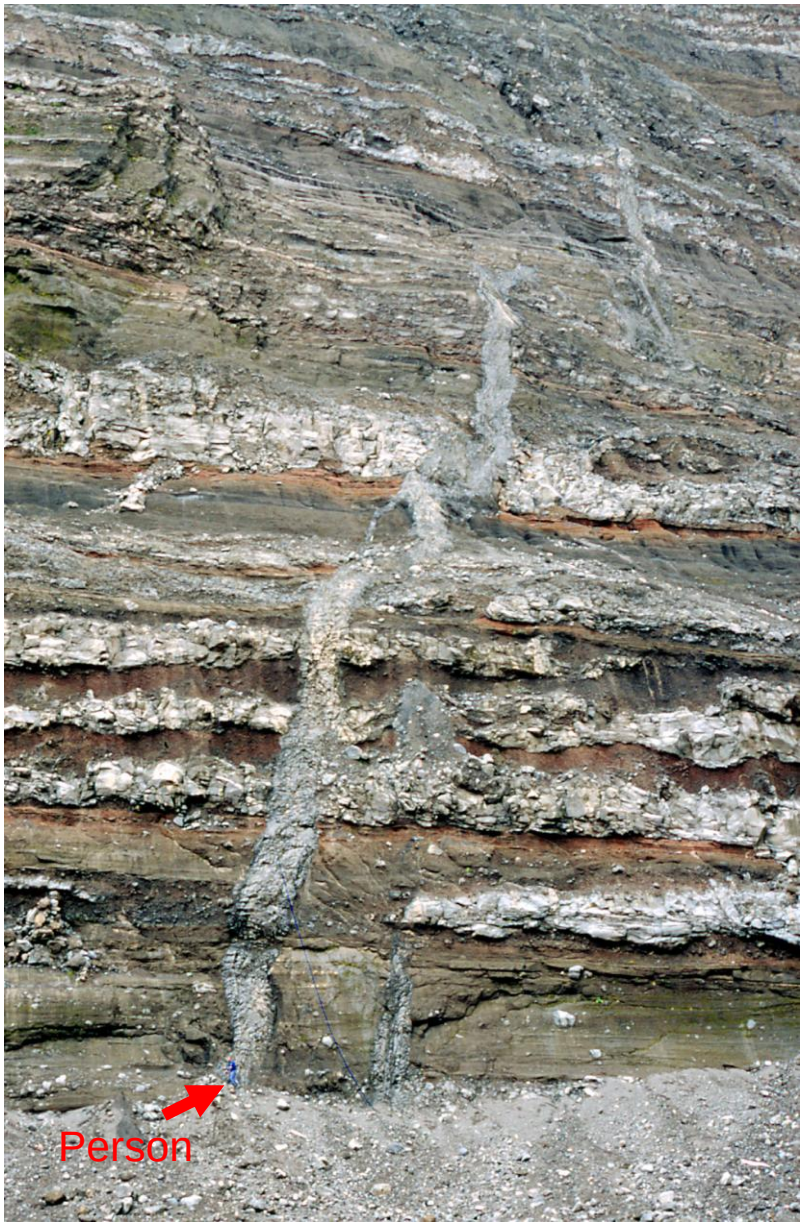
Stern & Naranjo (1991)

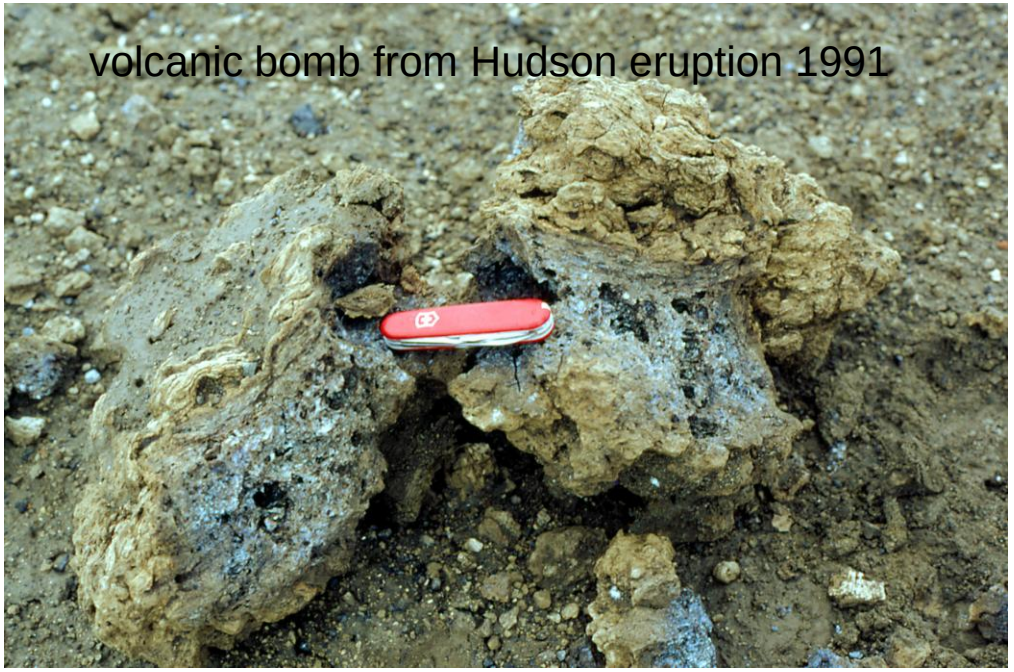
Dacitic-rhyolitic plinian eruptions

Basaltic-andesitic lavas and eruptive

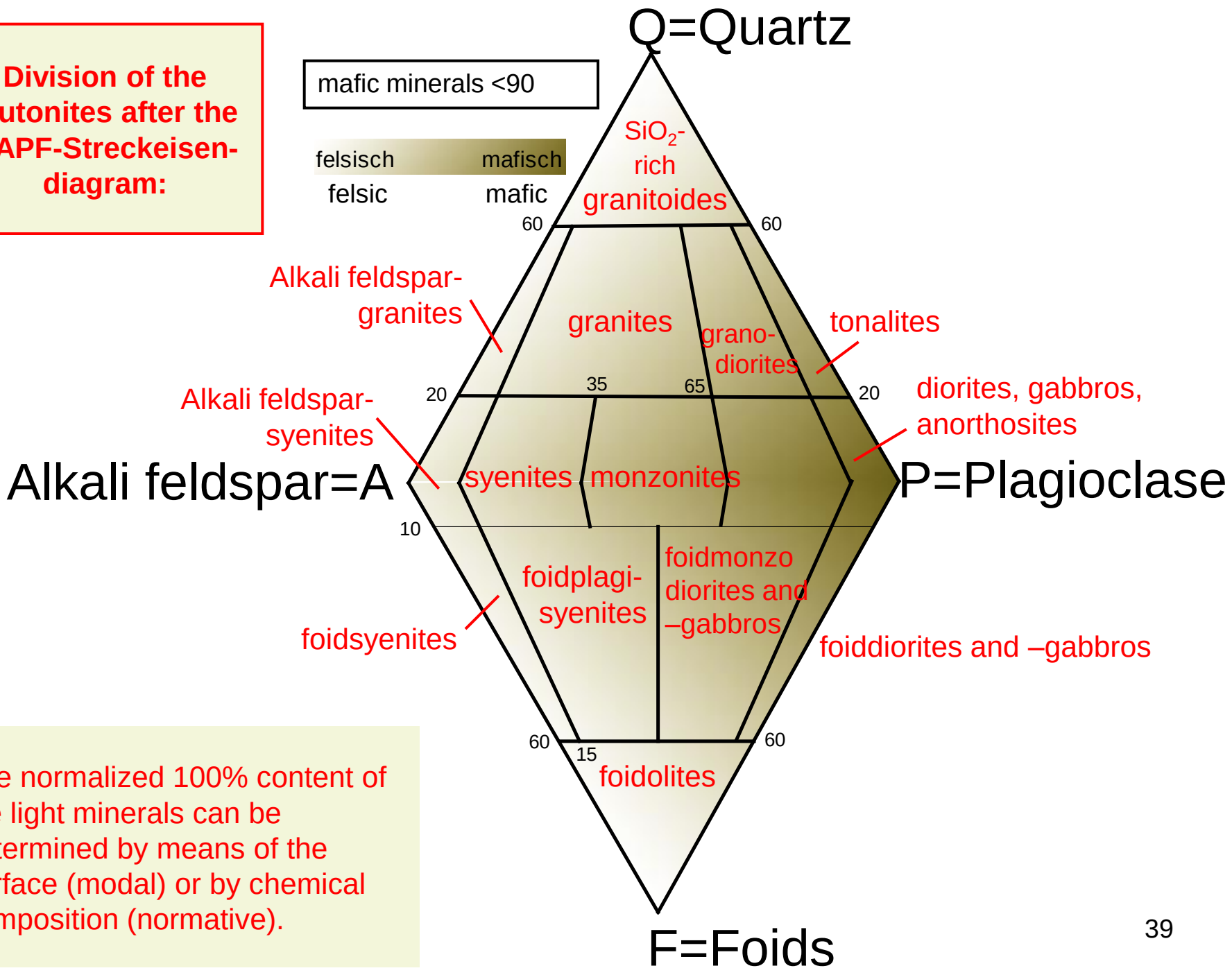
Tertiary-mesozoic plutonites

Lava and mud flows, which are penetrated by a subsequent magmatic gang . (Michinmahuida volcano, South Chile)

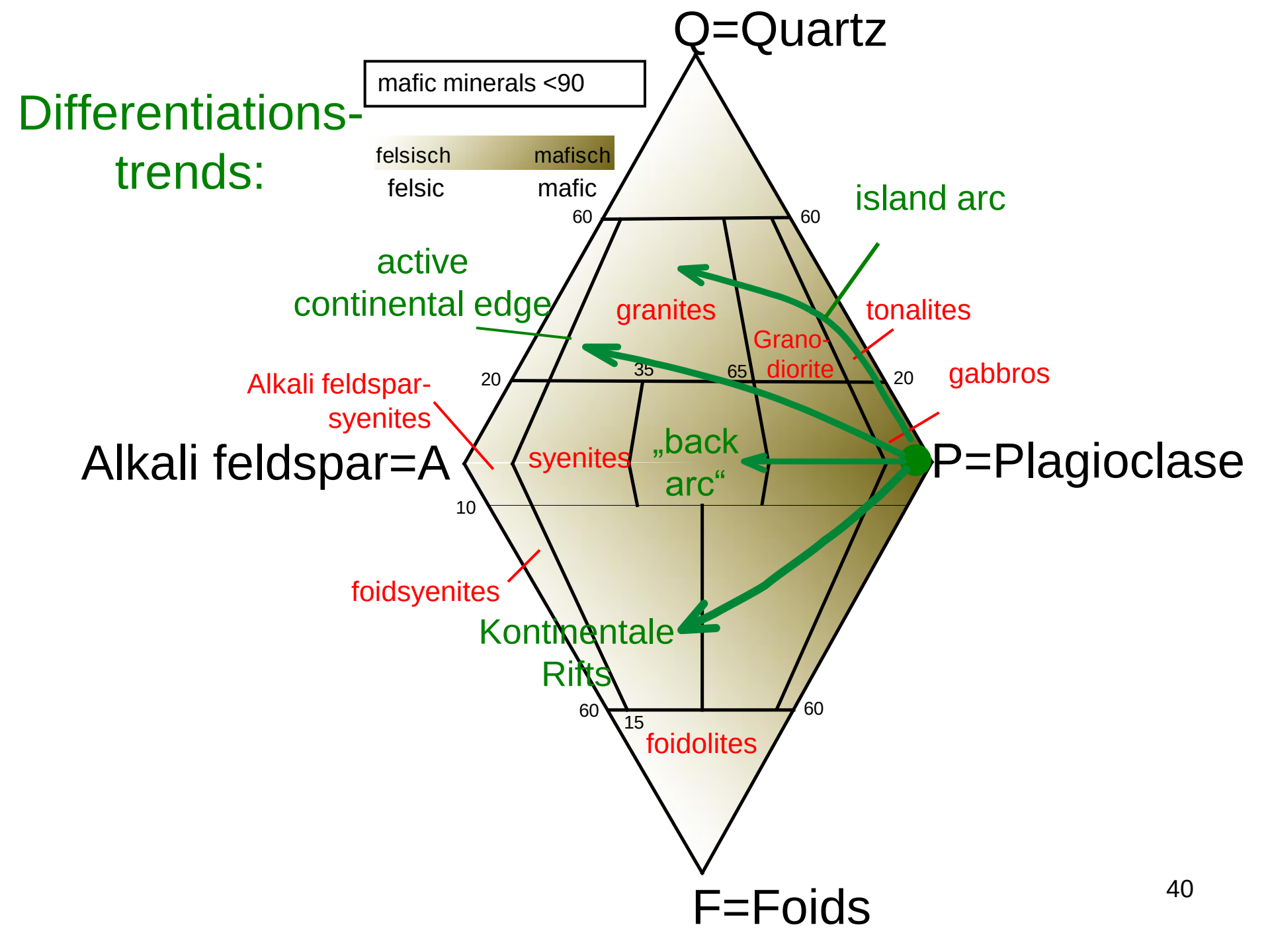




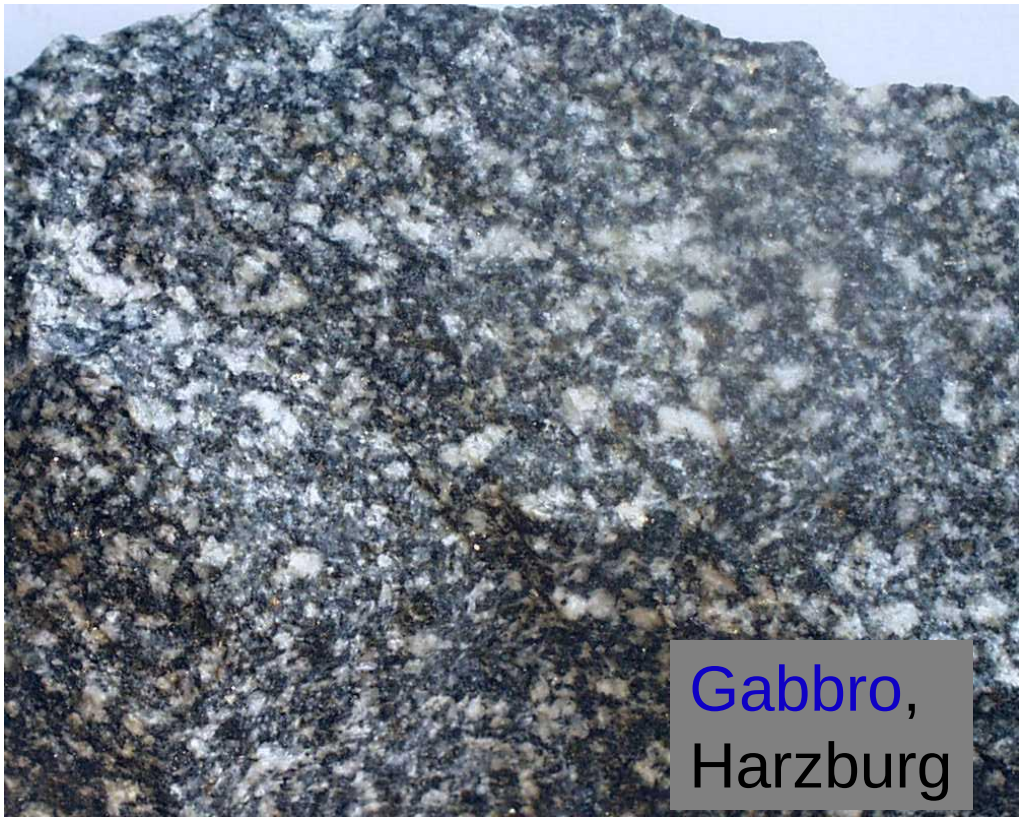
Division of the plutonites after the QAPF-Streckeisen-diagram:

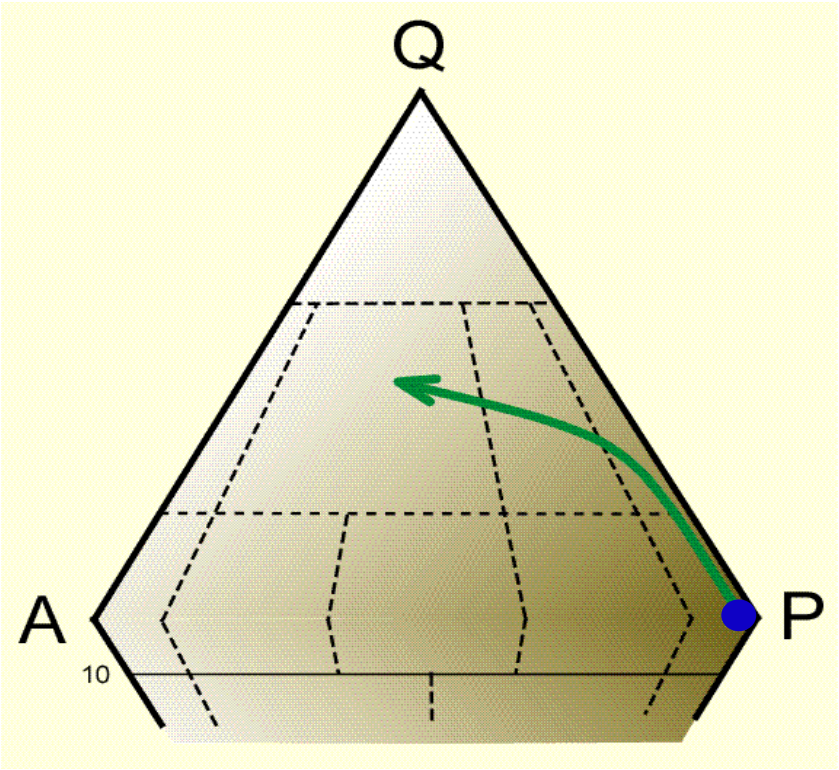


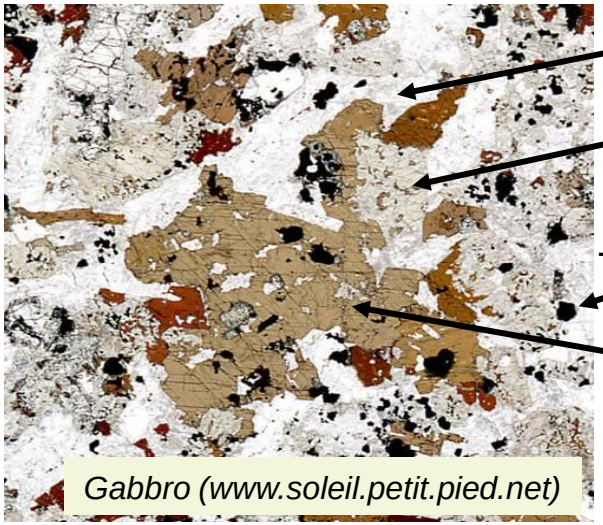
The normalized 100% content of the light minerals can be determined by means of the surface (modal) or by chemical composition (normative).


Differentiations-trends:
Q=Quartz
mafic minerals <90
felsisch
mafisch
felsic
mafic
island arc
active continental edge
granites
tonalites
Grano-diorite
gabbros
Alkali feldspar-syenites
Alkali feldspar=A
syenites
„back arc“
P=Plagioclase
foidsyenites
Kontinentale Rifts
foidolites
F=Foids
60
60
20
35
65
20
10
60
15
60

Gabbros represent the rock depth equivalent of basalts and they have almost only plagioclase as light mineral constituent.

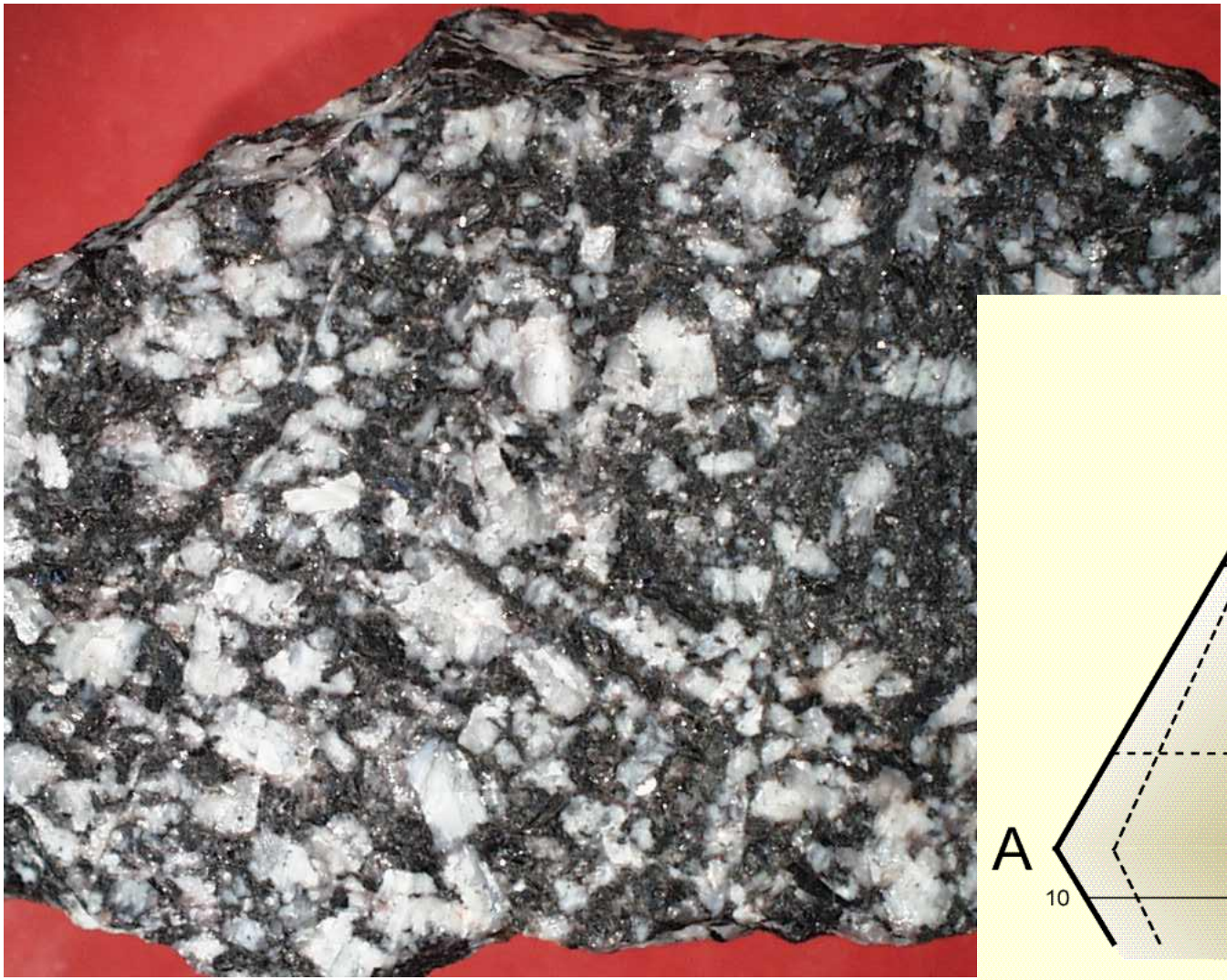


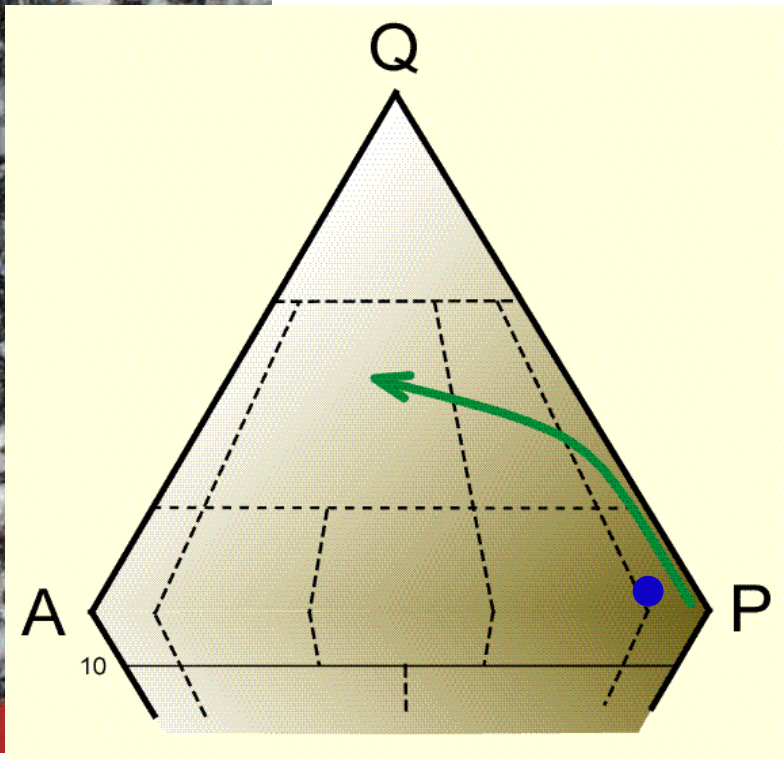




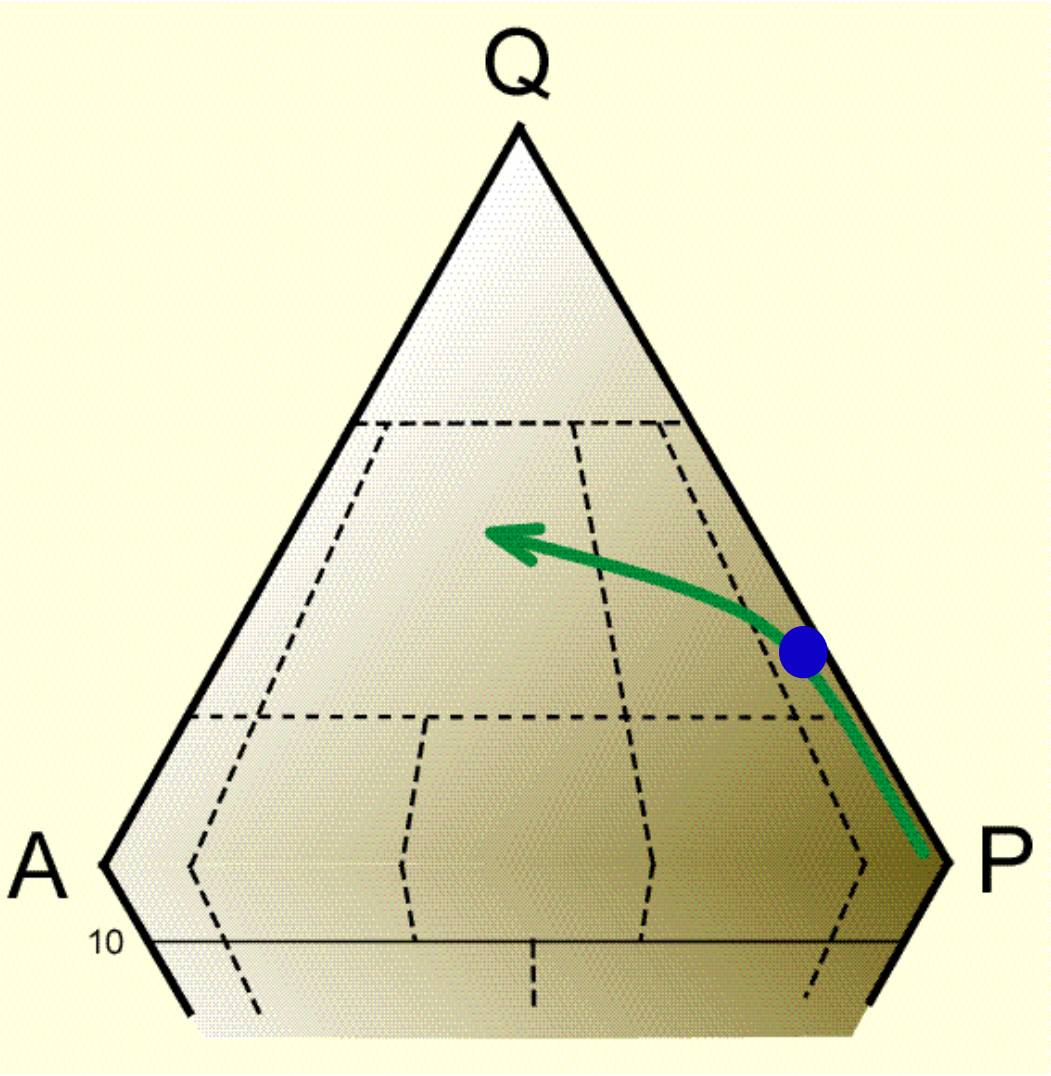
Gabbro (www.soleil.petit.pied.net)

Diorite from Lindefels, Odenwald

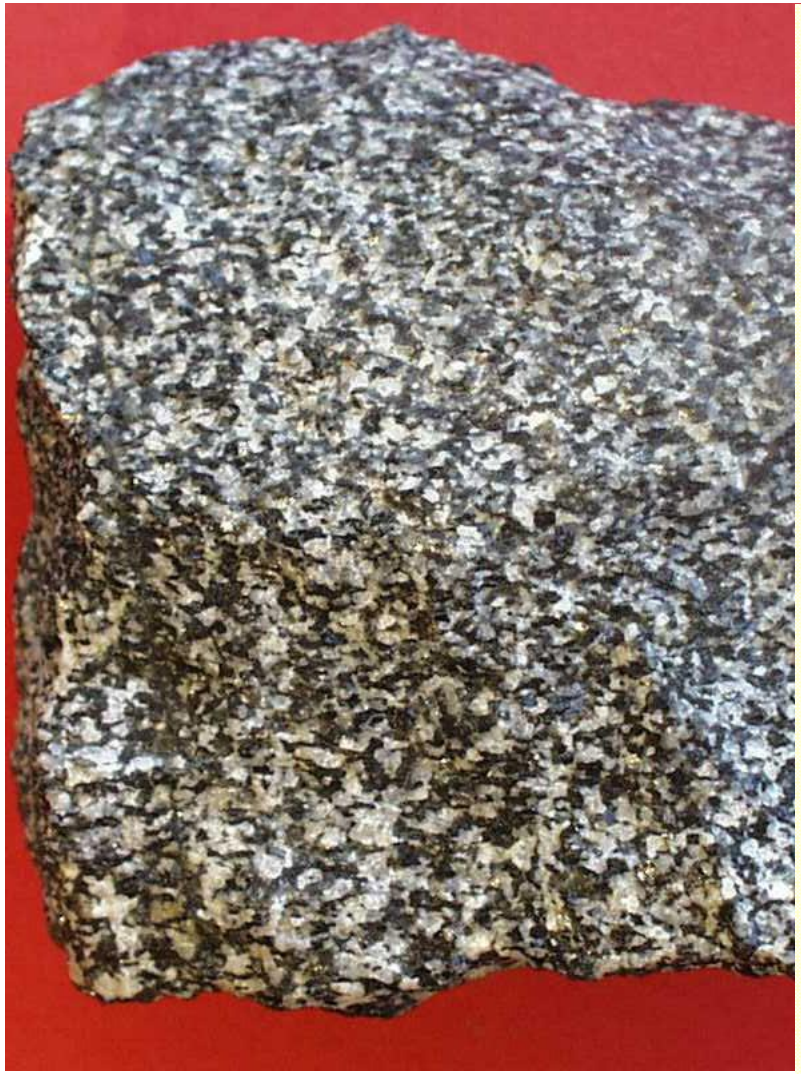


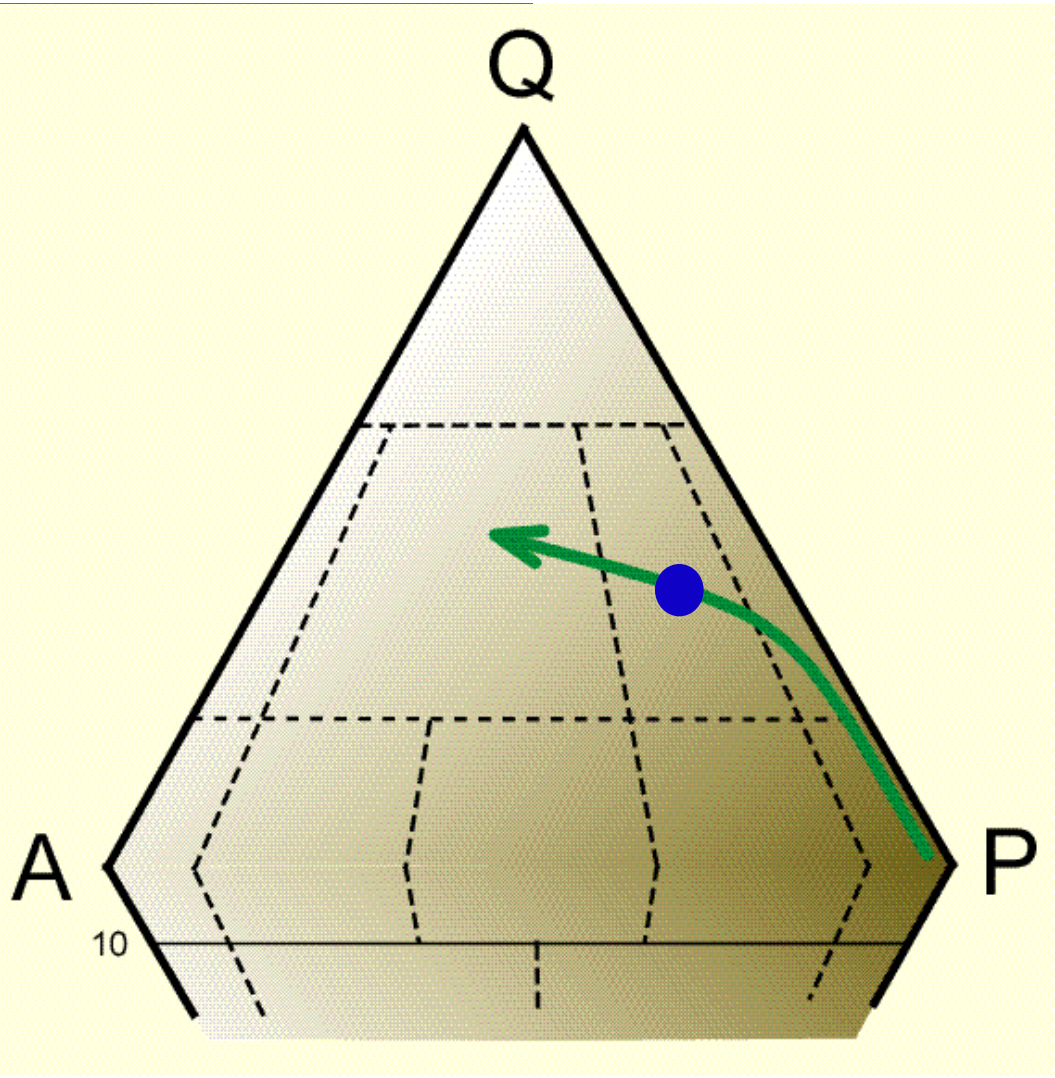


Tonalite

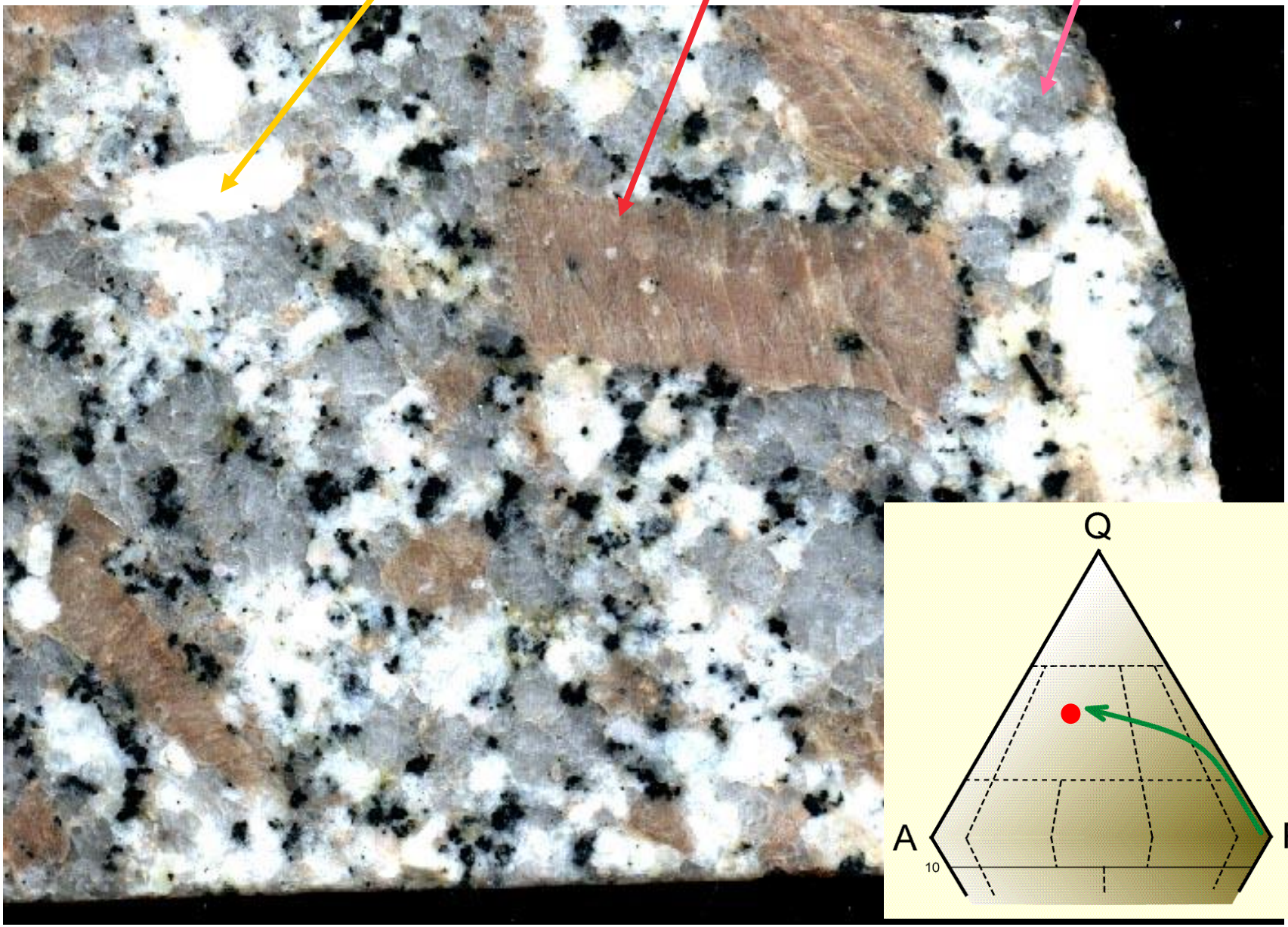


Granodiorite from Wiesental, Schwarzwald (Variszisch)

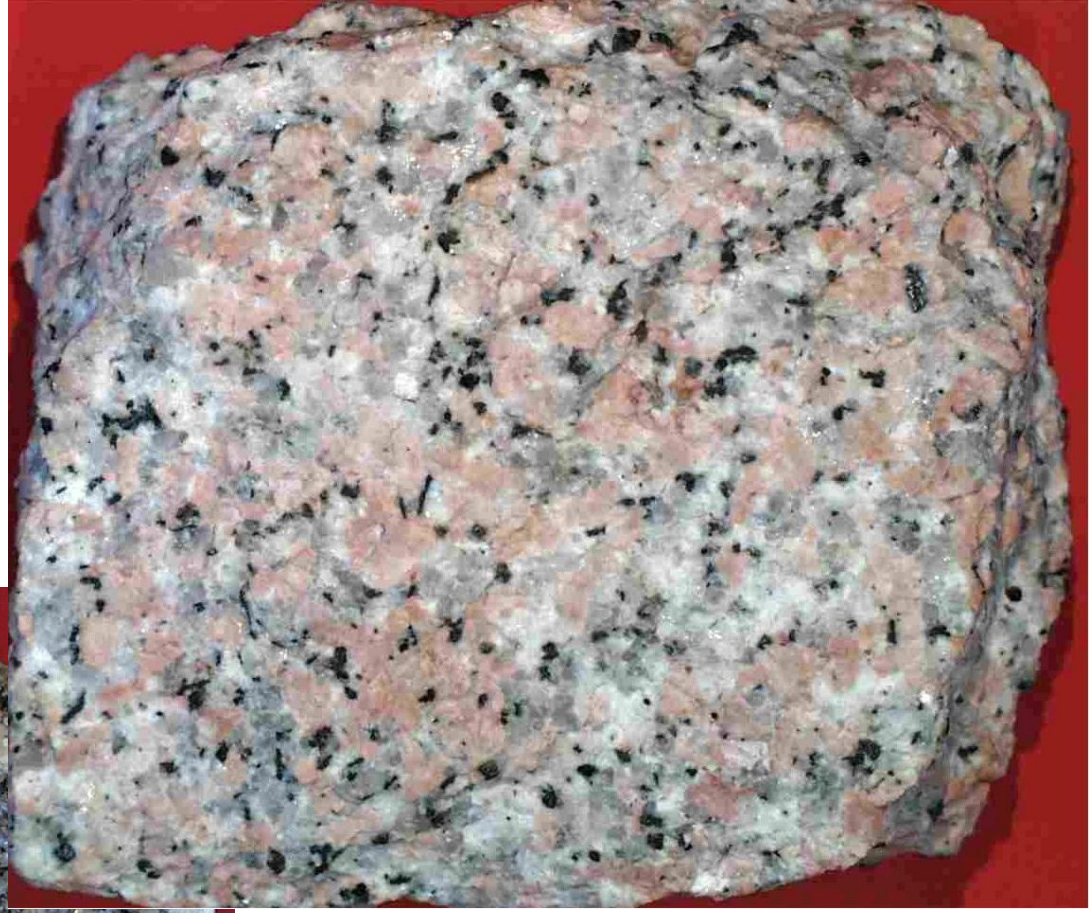




Granite with: plagioclase alkali feldspar quartz



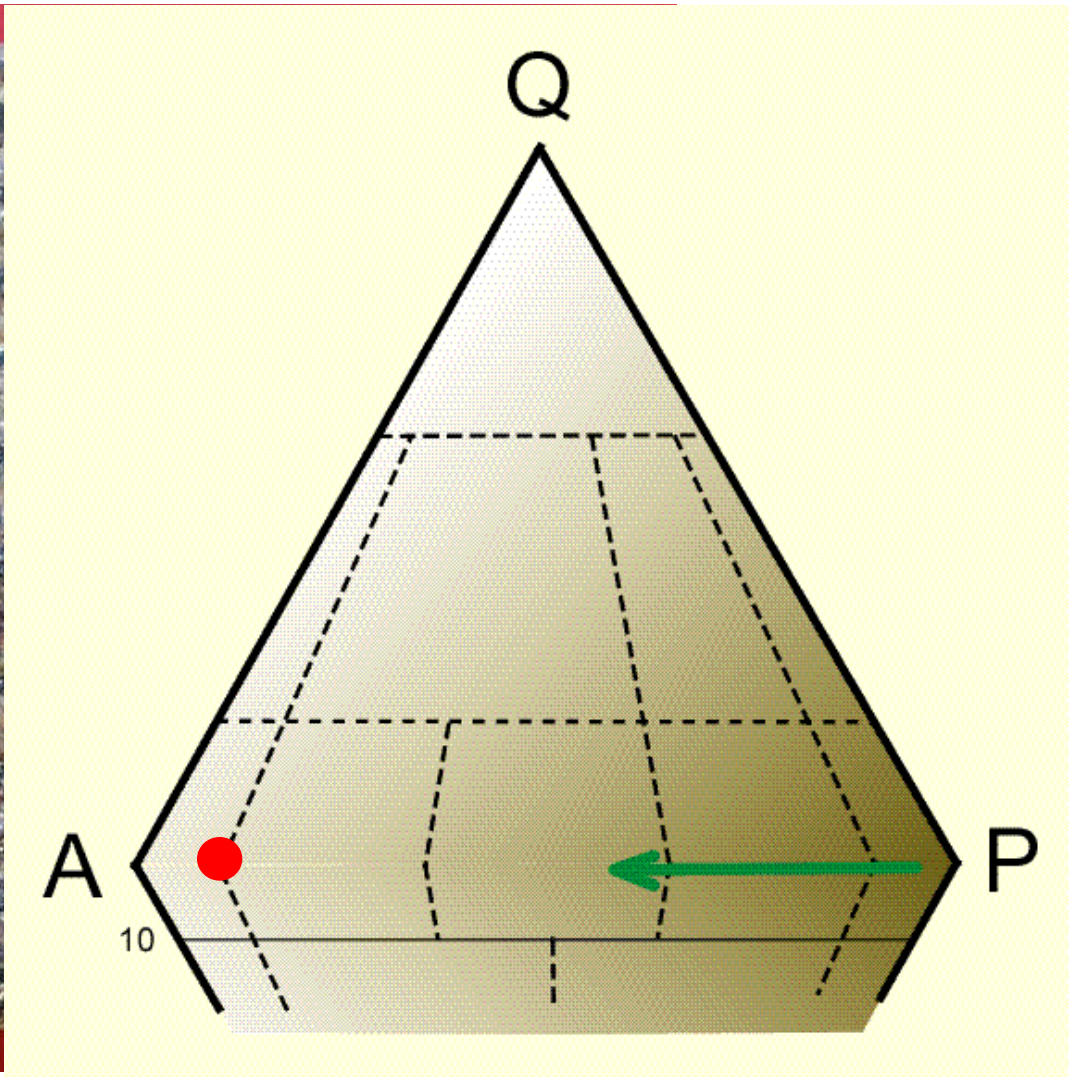
Granites:



Graphic granite: graphic intergrowth of quartz and alkali feldspar by simultaneous crystallization (eutectic composition)

Paine granite-intrusion in South Chile (12 million years old)

Syenite from Plauschener Grund, Dresden



Carbonatites represent magmatic rocks, which result mainly from carbonatic melt formed in the earth mantle. They occur almost without exception at continental rift areas (Rhine graben and African rift system). In the past it was considered as marble.

Carbonatic intrusions in Kaiserstuhl

Cooling stages and vapor pressure development by the crystallization of a magma.