Lecture 6: Metamorphic facies concept

Metamorphic rock names include parts from all three effects that metamorphism can have on a rock: mineralogy, composition and fabric

composition terms: meta-pelite; meta-granite; meta-basalt

add mineralogy: garnet-staurolite meta-pelite; hornblende-plagioclase meta-basalt

add fabric name: slate; gneiss; granofels

final name includes all three (if known):

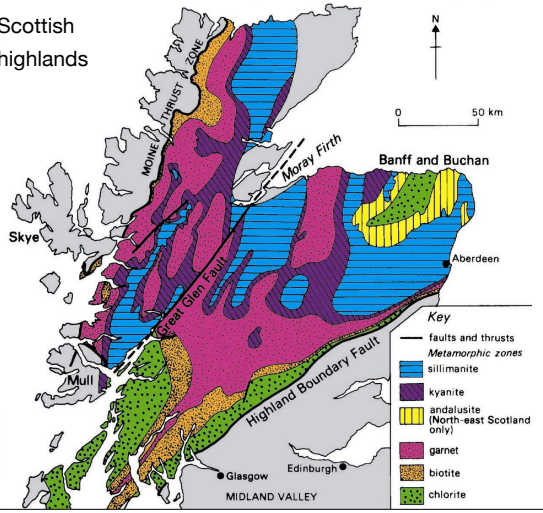
- garnet-staurolite meta-pelite schist
- hornblende-plagioclase meta-basaltic gneiss
- garnet-pyroxene migmatite
- plagioclase augen mylonite

Now need a final component: metamorphic grade

Ideally the name of a metamorphic rock gives a (rough) indication of its overall grade, and these grade-related names can be established in the field

Barrovian and Buchan style metamorphism

Scottish highlands



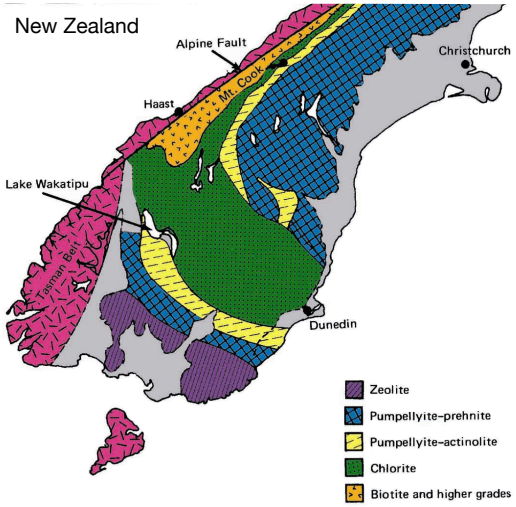
Barrow zones:

- sillimanite zone
- kyanite zone
- garnet zone
- biotite zone
- chlorite zone

Buchan zones:

- andalusite zone

Low-grade metamorphism



Barrow zones:

- sillimanite zone
- kyanite zone
- garnet zone
- biotite zone
- chlorite zone

Coombs zones:

- pumpellyite-actinolite zone
- pumpellyite-prehnite zone
- zeolite zone

Estimators of grade: mineral zones

Because minerals have a limited stability in pressure and temperature, their presence or absence can be used as an indicator of the general P-T conditions in a rock

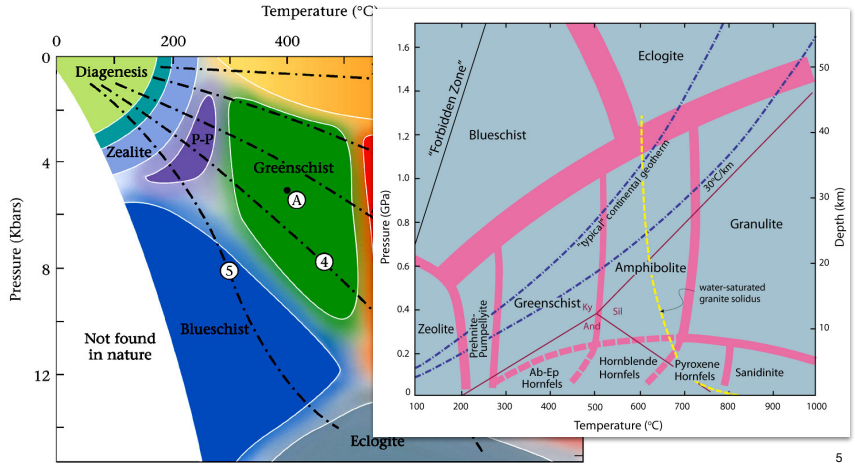
Mineral zoning	Chlorite zone	Biotite zone	Almandine zone	Staurolite zone	Kyanite zone	Sillimanite zone
Chlorite						
Muscovite						
Biotite						
Almandine						
Staurolite		← zone boundary of biotite zone				
Kyanite						
Sillimanite		→ increasing metamorphic grade				
Sodic plagioclase						
Quartz						

from Bucher and Frey 2002

However, this doesn't only depend on P and T - bulk composition also pays a role: you cannot make a garnet in a pure quartzite or marble

Metamorphic facies (after Eskola 1915)

Characteristic paragenesis of minerals that give a first-order indication of *P-T*



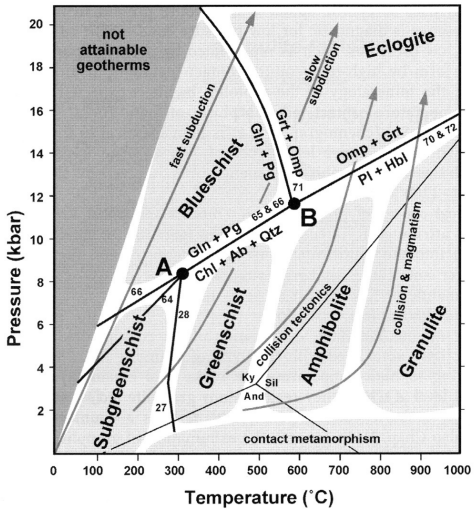
Metamorphic facies: minerals depend on compo

Metamorphic facies	Greenschist		Amphibolite		
Mineral zoning	Chlorite	Biotite	Garnet	Staurolite	Sillimanite
Metamafites					
Albite					
Albite-oligoclase					
Oligoclase-andesine					
Andesine					
Epidote					
Actinolite		blue-green		green	green and brown
Hornblende					
Chlorite					
Calcite					
Biotite		green-brown		brown	
Muscovite					
Quartz					
Metapelites					
Chlorite					
Muscovite					
Biotite					
Garnet					
Staurolite					
Alumosilicate				andalusite	sillimanite
Chloritoid					
Plagioclase	clastic		oligoclase		
Quartz					

The characteristic set of minerals in a meta-pelitic greenschist is going to be different from that in an equivalent-grade meta-basalt.

from Bucher and Frey 2002

Metamorphic facies: boundaries are gradational



Boundaries between the facies are gradational, because the positions of mineral reactions in P-T space, and hence changes in mineralogy, depend on the bulk rock composition.

from Bucher and Frey 2002

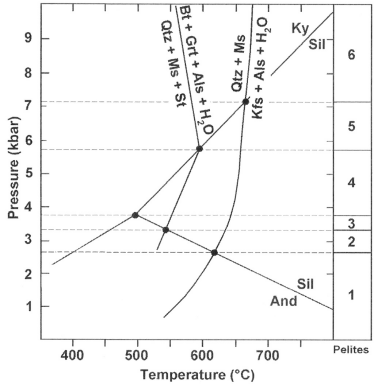
Metamorphic facies: minerals for different protoliths

	Ultramafic rocks	Marbles	Metapelites	Metamarls	Metabasalts	Metagranitoids	Fluids
Protolith	Ol+Opx±Cpx±Spl	Cal+Dol+Qtz+ Kfs±Chl, ±Ab,±"clay"	"clay"+Qtz±Ab±Kfs	Cal+"clay"	Pl+Cpx±Opx±Qtz	Pl+Kfs+Qtz±Hbl± Bt ±Ol±Cpx±Opx	
Subgreenschist	Ol+Opx±Cpx±Grt chrysotil+Brc+Act chrysotil+Tlc+Act± Chl	Cal+Dol+Qtz+ Kfs+Chl+Ms	Kln(Prl)+Chl+ Illite+Qtz	Cal+Kln(Prl)+ Chl+Illite+Qtz	Pl+Cpx±Opx±Ol Zeolites	"clay", illite, zeolites Prh, Stilp, Chl+Kfs	H_2O-CH_4
Greenschist	Atg+Brc+Di+Chl	Cal+Dol+Qtz+Chl	Prl(Als)+Chl+Ms± Pg±Cld, ±Bt, ±Grt	Cal+Qtz+Mrg+ Chl+Ms±Ep	Pmp+Prh+Chl+ Ab±Ep Ab+Chl+Ep+Act± Phe, ±Bt, ±Stp	Ab+Kfs+Chl+Qtz± Bt±Act±Ep	H_2O
	Atg+Tlc+Di+Chl	Cal+Dol+Qtz+ Kfs+Ab					
Amphibolite	Atg+Fo+Di+Chl Atg+Fo+Tr+Chl	Cal+Dol+Qtz+Tlc	St+Chl+Grt+Ms	Cal+Qtz+Pl± Hbl±Grt±Bt	Pl+Hbl+Ep	Pl+Kfs+Qtz±Bt± Ms±Hbl	H_2O-CO_2
	Tlc+Fo+Tr+Chl Ath+Fo+Tr+Chl En+Fo+Tr+Chl	Cal+Dol+Tr+Phl Cal+Dol+Di+Phl Cal+Qtz+Tr+Di+ Phl	St+Bt+Als+Ms St+Bt+Grt+Ms Crd+Bt+Grt+Ms		Pl+Hbl+Grt Pl+Hbl+Cpx±Bt		
Granulite	En+Fo+Hbl+Spl En+Fo+Di+Spl	Cal+Qtz+Di+Phl Cal+Dol+Di+Spl	Bt+Als+Kfs+Grt Opx+Qtz	Cal+Qtz+Pl+Cpx± Grt	Pl+Cpx+Grt	Opx+Qtz+Fsp± Ol±Cpx Mesoperthite	No fluid or CO_2
		Cal+Dol+Fo+Spl	Opx+Crd+Bt+Qtz		Pl+Cpx+Opx± Hbl±Bt		
		Cal+Qtz+Di+Spl	Opx+Als+Qtz±Spr± Spl				
Blueschist	Atg+Fo+Di+Chl	$CaCO_3$+Dol+Qtz+ Phe	Carpholite	Cal+Gln+Ep+ Phe+Pg	Gln+Lws+Chl±Pg		CO_2
			Phe+Tlc+Grt		Gln+Ep±Grt±Pg± Cld±Tlc±Chl		
			Phe+carpholite Tlc+Ky				
Eclogite	Atg+Fo+Di+Chl En+Fo+Di+Grt		Jd+Qtz(Coe)+Tlc+ Ky		Omp+Grt±Ky Omp+Grt±Zo±Phe	Jd+Qtz±Phe±Ky	H_2O-N_2
					Omp+Grt±Zo± Tlc±Cld		

from Bucher and Frey 2002

Bathozones and bathograds (Carmichael 1978)

For a *given bulk rock composition*, the appearance of an indicator mineral can be a good indicator of P and/or T. Carmichael proposed six *P*-zones for the meta-pelites, allowing for a quick estimate of pressure from thin section mineral parageneses:



Bathograds:

5 → 6: qtz + ab + ms + sil → Kfs + ky + liq

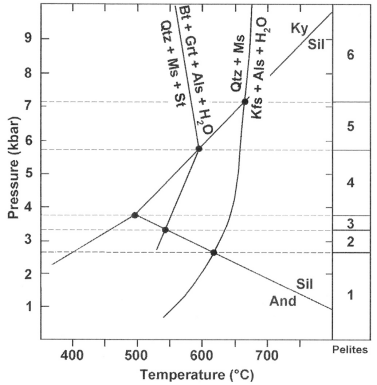
4 → 5: qtz + ms + st + sil → bt + gt + ky + fl

3 → 4: and → ky or sil
2 → 3: bt + gt + and + fl → qtz + ms + st + sil
1 → 2: Kfs + and + fl → qtz + ms + sil

Note that these zones are essentially all within the amphibolite facies

Bathozones and bathograds (Carmichael 1978)

From these bathograd reactions we can now define bathozones with a characteristic mineral paragenesis. Essentially this is a subdivision of the amphibolite facies valid for meta-pelitic protoliths



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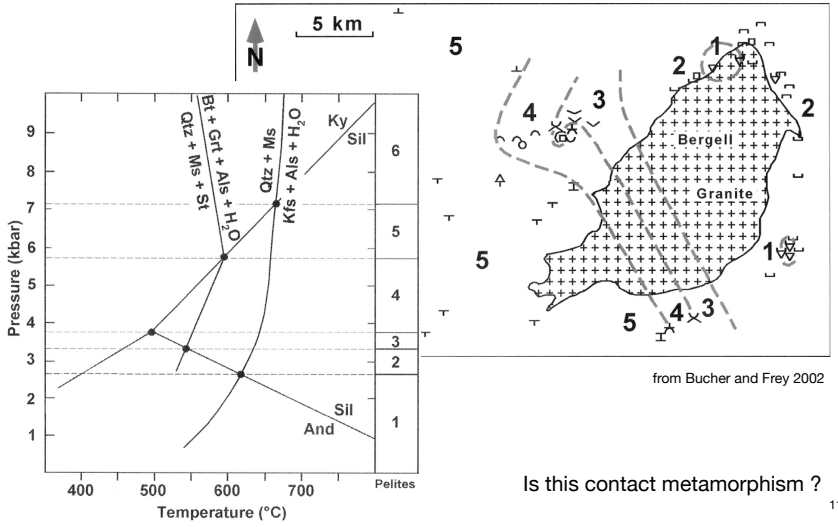
Bathozones and bathograds (Carmichael 1978)

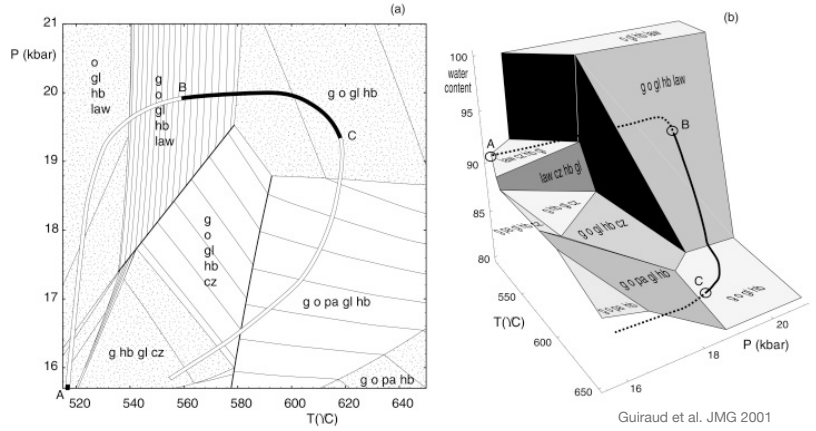


from Bucher and Frey 2002

Is this contact metamorphism ?

Metamorphic pseudosections

Can extent this by calculating the positions of these reactions for the exact bulk-rock composition of the sample we are looking at. This is called a pseudosection. It is a section through the positions of mineral reactions in *P-T-X* space at fixed *X*.



Guiraud et al. JMG 2001

Metamorphic pseudosections

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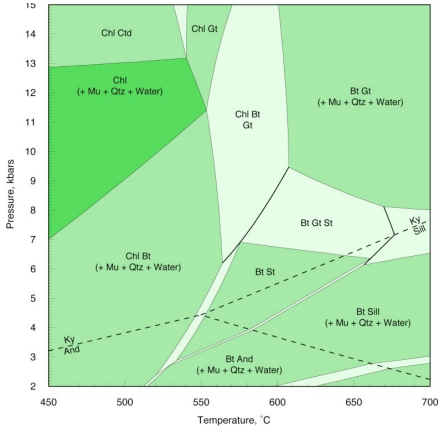


Calculated for:

K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O

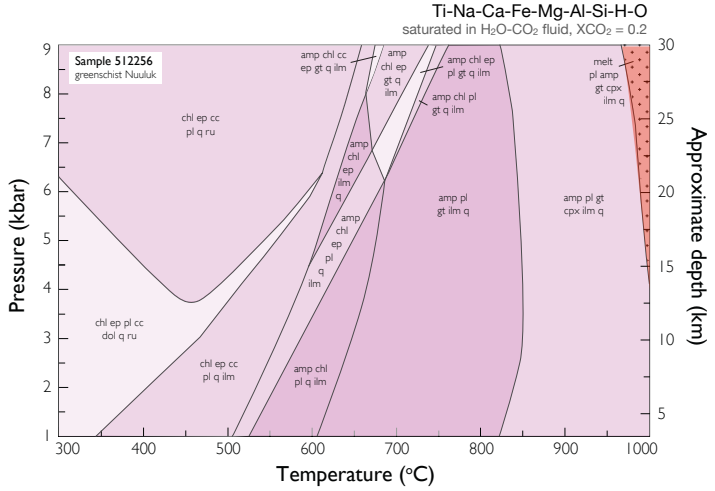
Considering: Chl, Bt, Gt, St, Al-Sil, Ctld, Crd

Not considering: Opx, Cpx, Pl, melt

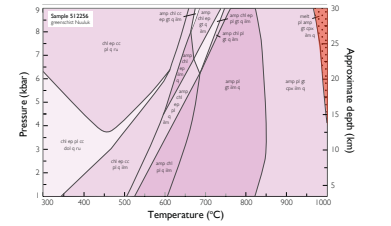
In excess: H_2O, Qtz, Ms

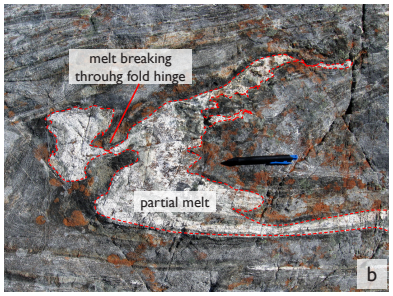
http://serc.carleton.edu/research_education/equilibria/pseudosections.html

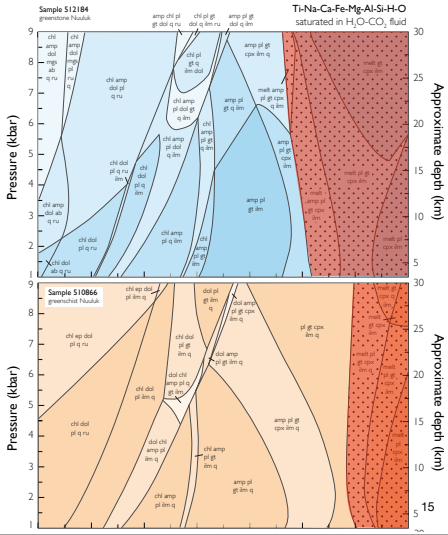
Pseudosections: dependence on bulk composition



Pseudosections: dependence on bulk composition







Overlapping pseudosection fields