ARE REACTION TEXTURES RELIABLE GUIDES TO TRACE PTt PATHS ?

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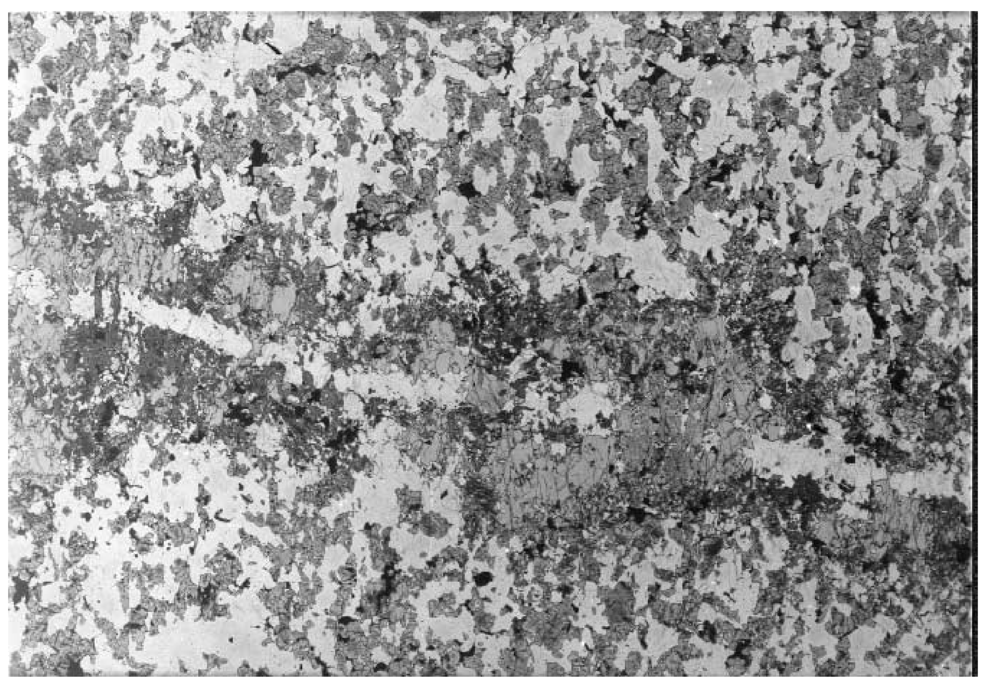
Assemblages in coronitic and reactional textures are commonly used to characterize a portion of PT(t) path. However, caution must be used in their interpretation in terms of PT path and tectonic mechanisms. Three examples are used to point out that metamorphic reactions are likely produced by a great variety of PT paths.

Cpx-Grt VEINS IN THE MAFIC GRANULITES FROM BEFORONA (MADAGASCAR) :

The timing of mineral reactions depend on when fluid becomes available at reaction sites



Cm-size veins consisting of cpx-grt +/-hbl, bt and Mg-Fe carbonates occur in an anhydrous garnet-free granulite (opx-cpx-pl-q).

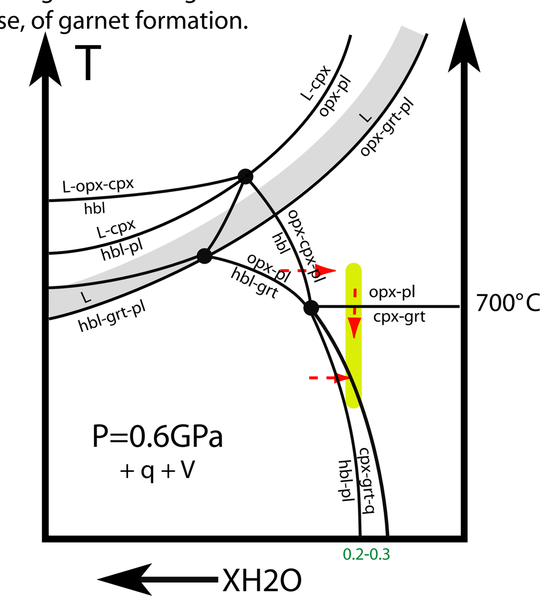
The formation of Beforona-Aloatra is characterized by the abundance of basic solid masses metamorphized under the conditions of the facies granulite of IP (granulite with 2 pyroxenes ± coronitic Hb and metatroctolites). Garnet and Hornblende do not have a homogeneous distribution in these rocks, but are located in veins with a thickness of millimetric to centimetric size. The geometry of the veins suggests that they are related to cracks.

In the anhydrous 2 pyroxenes-bearing granulites, the veins consist of Grt Cpx Q ± Opx and Pl, suggesting the transition from IP Granulite to HP granulite conditions through the reaction : (I) Opx Pl = Cpx Grt Q.

Granulites with Hbl (Opx Cpx Pl Q Hbl) are characterized by coronitc textures of pyroxenes and Pl around Hbl. This coronitc textures might suggest the following dehydration reactions : (2) Hbl Pl = Cpx Grt Q V et (3) Hbl = Opx Cpx Pl V.

Metamorphic PT conditions were estimated at about 0.5-0.6 GPa et 700-750°C. In the veins, the lack of partial melting and the occurrence of hydrous and carbonated minerals, like hornblende, biotite and calcite have been used to estimated a fluid XH20 (H20/H20+CO2) of 0.2-0.25 assuming Pf = Pt.

Veins are characterized by a compositional change (mainly a loss of sodium), suggesting mass transfer during fluid percolation. We suggest that formation of the Grt bearing veins is related to the infiltration of CO2 rich fluids at constant P et T (see figure below) in fractures, under the High Pressure granulitic conditions. The mass transfer observed in the veins is probably a consequence rather than a cause, of garnet formation.

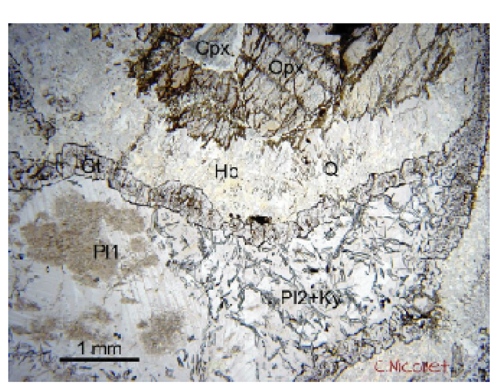


NO REACTION WITHOUT FLUIDS !

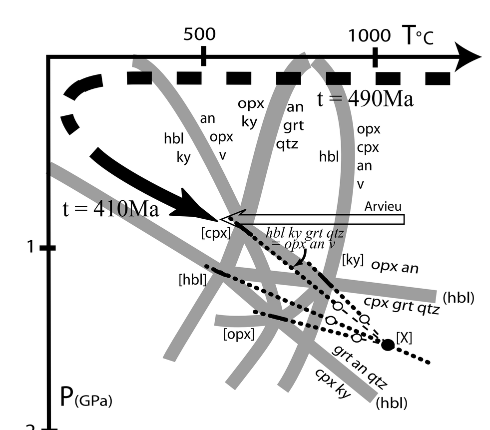
The host rock IP assemblages (Opx-Cpx-Pl-Q-Ilm-Mag) with or without Hbl) were metastable with respect to HP garnet granulite. On the other way, the garnet forming reactions were triggered by infiltration of (carbonic) fluids in the veins. The lack of reactions in the host rock reflects extremely sluggish kinetics in the complete absence of an intergranular fluid medium. This is also true for solid-solid reaction as Opx+Pl=Cpx+Grt+Q in the Hbl free granulites.

AN UNUSUAL Hb-Ky-Gt CORONITIC ASSEMBLAGE OF THE METANORITE FROM ARVIEU (French Massif Central):

A reaction boundary could never be crossed



A - Coronitic assemblages in the metanorite of Arvieu consisting of hornblende, garnet, quartz and kyanite between the magmatic minerals orthopyroxene and plagioclase 1 (altered in the core). The needles of kyanite are located at the grains boundaries of the zoned plagioclase 2. Plane polarized light.

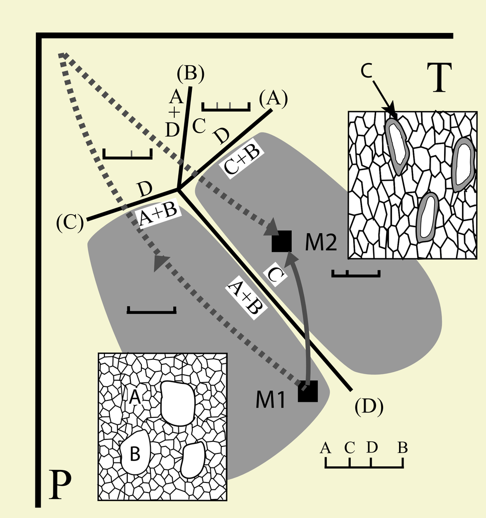


B -Semi-quantitative petrogenetic grids in CFMAS(H) system for a fixed XMg ratio. The univariant reactions in the CFMASH system (dashed lines) linked the Fe and Mg end-member invariant points (open circles) ; filled circle : CFMASH invariant point. For a fixed bulk XMg, only a restricted portion of the CFMASH univariant reactions is stable (heavy black lines: we call them "pseudo-invariant points"). Around these stable CFMASH pseudo-invariant points, all the possible divariant Fe-Mg reactions are represented by thick grey lines (the thickness of the line qualitatively schematizes the divariant field of these reactions).
The first potion of the PTt path (black dashed line) represent the emplacement of the gabbroic complex in an oceanic crust at low P, at 490 Ma.
The black arrow shows the end, at 410 Myr, of the P-T-t paths of the metanorite of Arvieu. The open arrow illustrates the apparent isobaric cooling path at P~1 GPa of the metanorite of Arvieu.

A near isobaric cooling at high pressure, illustrated by the open arrows in Fig. B, is the simplest solution to explain the mineralogy of the metanorite. These P-T evolutions have crucial geodynamic implications, because they suggest that the HP-HT metamorphism follows "immediately" the emplacement of the gabbro during its cooling, such that, magmatism and metamorphism are related to the same geodynamic event. These P-T paths are inferred only by petrographical observations and do not take into account geochronological and thermodynamics constraints. In this particular case, the ages of 490-480 Ma for the mafic magmatism and 410 Ma for the HP metamorphism, means that the gabbro cooling at high pressures required at least 70-80 Ma, suggesting unrealistically slow cooling! For comparison, a straightforward thermal modeling predicts that a 2 kilometre thick sill will cool by conduction to a temperature of 700°C in about 3 Myr. Therefore, these isobaric cooling paths have no geological meaning and cannot be interpreted as the real P-T-t paths.
The two stage P-T-t path proposed in Fig. B (black arrow) is consistent with the geodynamic constraints from the hercynian belt of the French Massif Central. Indeed, the retrograde stage is related to the emplacement of the gabbroic complex in an oceanic crust at 490 Ma, followed by 'rapid' isobaric cooling at low pressure to greenschist facies conditions. The anhydrous character of the gabbroic rocks favors preservation of magmatic textures and assemblages (Opx-Cpx-An), whereas the hydrous surrounding rocks are transformed to low grade actinolite, chlorite, epidote, albite bearing rocks. This complex is then involved in the eo-Hercynian subduction and collision at about 410 Ma. We suggest that, during the subduction, the surrounding rocks are dehydrated, as proposed by Heinrich (1982), providing a source of fluids for the partial hydration of the gabbro and its HP metamorphism. The extent of the arrested reactions may have been controlled by the limited deviation of fluid present conditions (Rubie, 1986).

THE REACTION BOUNDARY IS NOT CROSSED

The metanorites of the French Massif Central illustrate very well what Rubie emphasized in 1990: "the timing of mineral reactions will not necessarily depend on when equilibrium boundaries are crossed in P-T space, but rather on when fluid becomes available at reaction sites". In the same way, the triggering of a reaction does not occur exactly when the conditions of equilibrium (TE and PE) are reached. It requires a significant overstep of the P-T conditions (TE + T and PE + P), which can be reached by different ways. In our case, the equilibrium boundary of the reaction has never been crossed .



Coronitic textures and the two different possible P-T-t paths for a rock A+B affected by one thermal (metamorphic) event (plain arrow) or two distinct thermal events M1 and M2 (dashed arrows). For kinetic reasons, the assemblage A+B could be temporarily metastably preserved out of its stability field, at low P/T, between M1 and M2; during the M2 event, the coronic assemblage is formed without crossing the equilibrium boundary of the reaction A+B=C in the stability field of the produced phases C+A/B. The binary composition diagrams show the compositions of the phases used in the invariant point and the divariant stable assemblages.

EVOLUTION OF UHT GRANULITES FROM ANDRIAMENA (MADAGASCAR) :

A portion of PTt path completely fictive

UHT metamorphism (>900°C, 7-13kbar) have been recognized in several terranes of the futur East Gondwana (India, Sri Lanka, Antartica). In Madagascar, it have been firstly identified by Nicollet et al. (1991). High Mg-Al granulites preserve numerous complex coronitic and symplectite textures providing plenty information to reconstruct an almost continuous petrographical PT path, near the peak temperature. PT evolution can be deduced from a FMAS petrogenetic grid (figure 5).

Sapphirine-bearing granulites occur in two localities (figure 2) and compose an infinitesimal volume with respect to the Andriamena complex. Due to the tropical weathering, they form several boulders, wich certainly come from a very near locality.

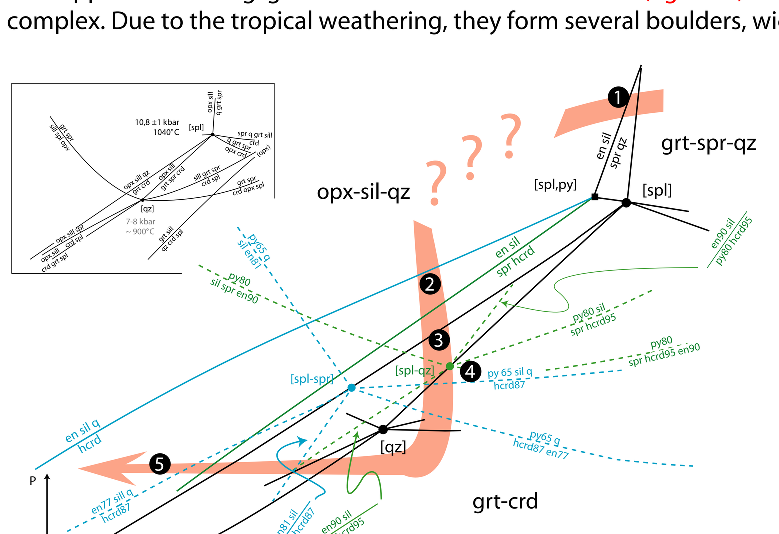
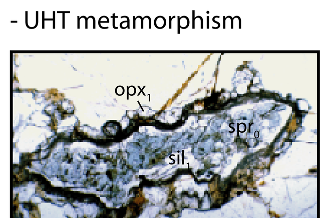


figure 5 : petrographical PT path deduced from the Al-Mg granulites in a FMAS system (black lines = univariante reactions and dashed lines = isopleths for divariante

- UHT metamorphism

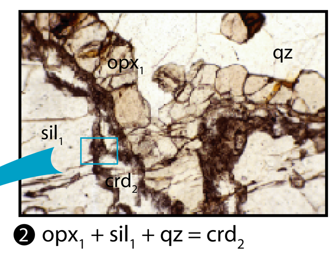


Earliest assemblage (spr_0-grt_0-qz) implies peak PT conditions of ~11kbar, >1050°C

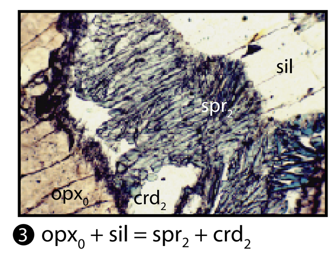
❶ $spr_0 + qz = opx_1 + sil_1$

⟶ cooling above the $P_{[spl]}$

- near Isothermal Decompression (ITD)

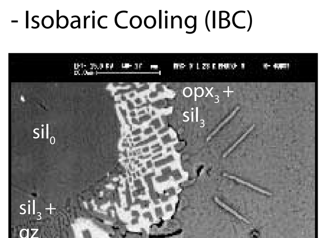


❷ $opx_1 + sil_1 + qz = crd_2$



❸ $opx_0 + sil = spr_2 + crd_2$

- Isobaric Cooling (IBC)

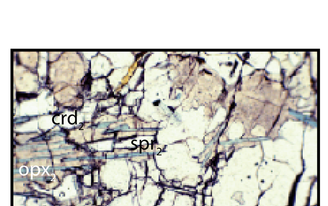


❺ $crd_2 = opx_3 + sil_3 + qz$

backscattered electron image

late development of opx_3-sil_3-qz at the expense of crd_2 suggesting a come back into the opx-sil-qz stability field probably through an IBC at ~7 kbar.

This very fine symplectite is visible on the photo 1-2-3.



❹ $grt_0 = opx_2 + spr_2 + crd_2$

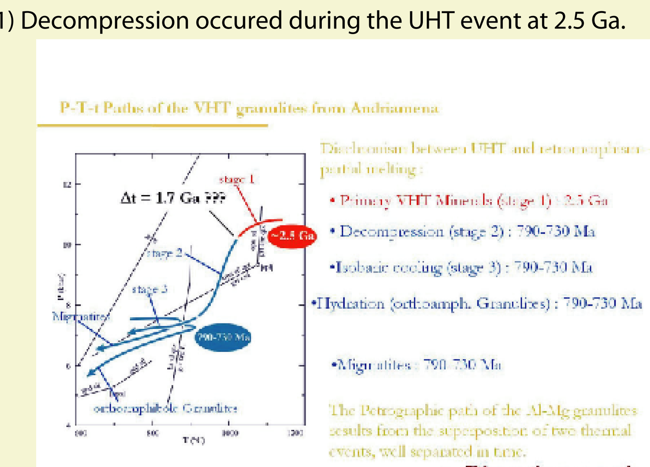
A sequence of symplectite assemblages developed at the expense of grt, opx and sil indicate a near-ITD of the order of 3-4 kbar, at about 900-1000°C : [spl]>T>[qz]

others ITD observed reactions :
opx + sil = grt + spr + crd
grt + sil = spr + crd
grt + qz = opx + crd
grt = opx + spl + crd

APPARENT PETROGRAPHICAL PATH VS REAL PT PATH

What is the signification of the ITD portion of the PTt path recorded by the Al-Mg granulites ?

1) Decompression occured during the UHT event at 2.5 Ga.

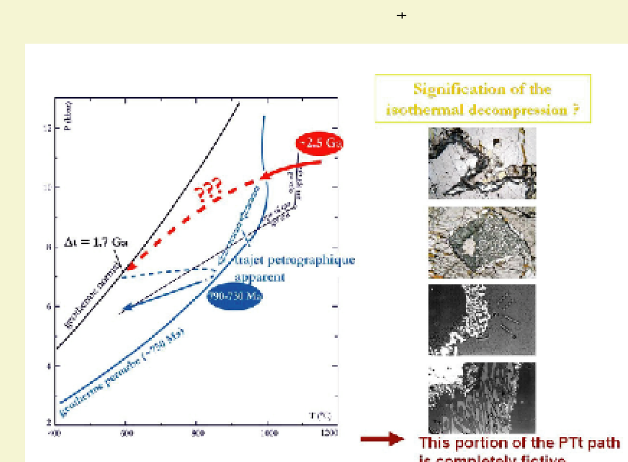


The P–T diagram summarizes the distinct petrographic P–T paths inferred from the Mg-granulites (sapphirine-bearing and orthoamphibole-bearing rocks) and the pelitic migmatite from the Andriamena unit (north–central Madagascar).

But this Pt path is obtained during two quite separate stages in time.(Mais ce trajet PT est obtenu en deux étapes bien séparées dans le temps.) The extreme thermal event is responsable of the first portion (red) of the PT path and is dated at 2.5 Ga.

All the continuation of the PT path is related to a second thermal event, at 770 Ma, which generate partial melting and partial hydration of the Mg-granulites.

But it is not realistic to consider that the rocks resided under conditions of very high T during near 1.7Ga !



Interpretative P–T path constructed in view of petrological, geochronological and geodynamic constraints.
Continuous red arrow indicates 2. 5Ga P–T evolution inferred from petrographical observations. Dashed red line indicates hypothetical 2 .5Ga P–T evolution not recorded by mineral changes.
The blue arrow indicates 750Ma P–Tevolution : the thermal perturbation at 750 Ma brought back the sample to high temperature (~850°C, 7kbar). The primary UHT assemblages were reequilibrated in this new conditions : but, the metamorphic reactions occurred without the sample having been subjected to the equilibrium P–T conditions of the observed reactions : the isothermal decompression of about 3-4 kbar (open blue arrow) - deduces from these reactions - draws a fictive PT path joining the 2.5 Ga "high pressure" stability field and the lower pressure stability field associated with the 750 Ma event.