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Two ultra high temperature (UHT) metamorphic events in the Gruf complex (Central Alps) ? Constraints by in situ dating of zircon and monazite

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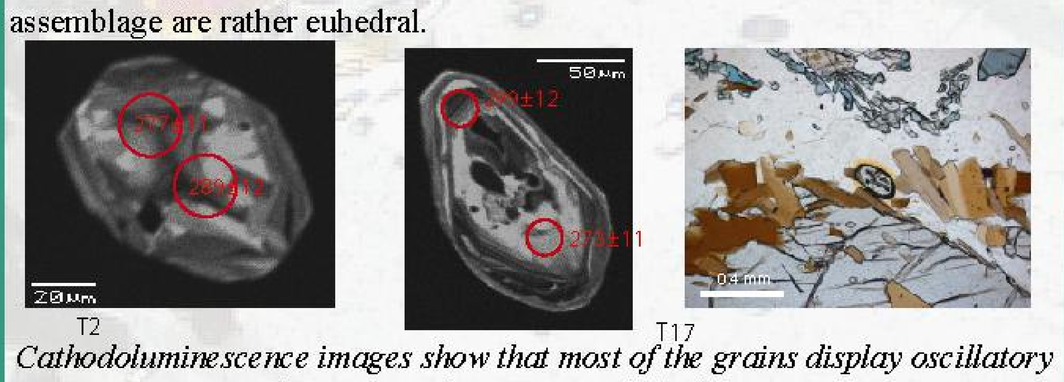
Introduction

The Gruf complex in the Lepontine Alps is one of the two occurrences of Phanerozoic UHT metamorphism in the world, discovered by Cornelius (1916), Cornelius & Dittler (1929), Baker (1964). Because of its "young " age, this area is of major interest to understand the geodynamic signification of such extreme metamorphic conditions. Unfortunately, the age of the UHT metamorphism is currently a matter of debate. Based on zircon U/Pb dating, Galli et al. (2013 and ref herein) have proposed a Permian age: in their samples, minerals of the charnockitic paragenesis are included within the zircon cores. Rims of these zircon grains yield 34-29 Ma ages interpreted as dating the Alpine amphibolite facies migmatisation. A distinct interpretation is proposed by Liati and Gebauer (2003) (as previously suggested by Droop and Bucher,1984), who consider that the zircon Alpine rims grew during the UHT metamorphic event. Based on monazite dating, Schmitz et al. (2009) follow this interpretation, whereas Galli et al. (2013) suggest that the Alpine age is the result of monazite resetting processes during Alpine migmatisation. To contribute to this discussion, here we present monazite and zircon LA-ICPMS in situ dating (in thin section) in a UHT granulite.

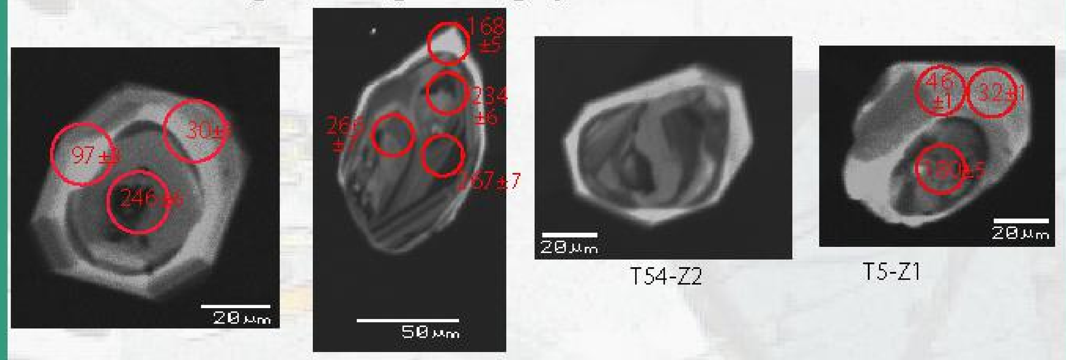
Zircons

Zircons are subhedral elongated and/or resorbed rounded crystals 30-100 µm long. They contain very tiny inclusions among which biotite, white micas and apatite were only unequivocally identified. Sillimanite is not observed in the zircon, whereas it is present in the monazite.

Zircons included in the primary minerals are resorbed grains and seem to be relics in the phenocrysts whereas zircons included in the Crd - Bt matrix assemblage are rather euhedral.



Cathodoluminescence images show that most of the grains display oscillatory or sometimes complex zoning. These grey to dark domains are sometimes ...



surrounded by highly luminescent rims (<5 µm to 15 µm) with euhedral faces.

Petrography of the residual granulites

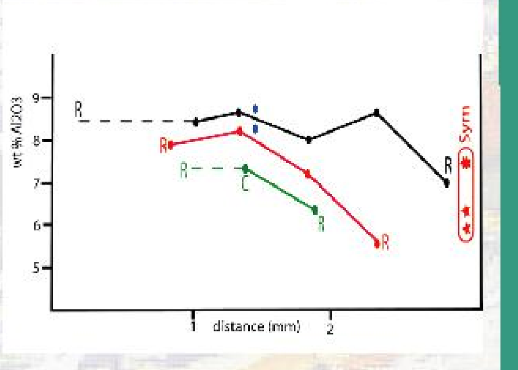
The residual granulites are well described by Droop and Bucher (1984), Galli et al. (2011), Guevara and Caddick (2016). Galli et al. (2011) have found them in-situ for the first time: they described them as enclaves of schlieren / restites within orthogneisses and charnockites.

The mineral associations of the residual granulites are complex with (at least) 2 generations of Al-rich orthopyroxene, sillimanite, cordierite, sapphirine and garnet (with rare inclusions of quartz) ± spinel ± biotite. Parts of the rocks show a charnockitic paragenesis with Opx, Bt, Kf, Pl, Qtz. The primary crystals of the residual granulites are millimetric to plurimillimetric. Opx is Al_2O_3-rich (core :7.5-8.6% and rim: 5.5 to 7 %). The peak UHT paragenesis of the schlieren granulites probably was : Al-rich Opx - Sil - Spr - Bt - Grt - Crd - Rt - apatite.

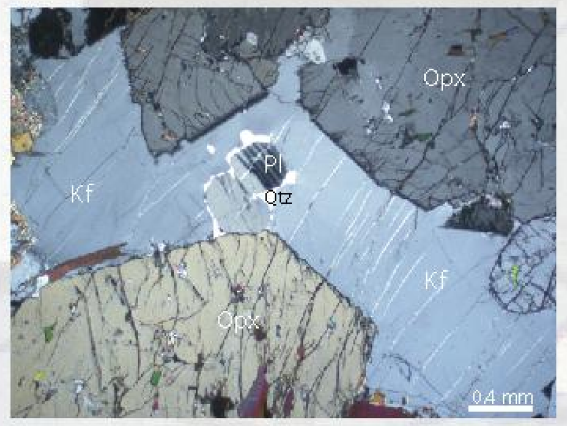
The secondary symplectites are abundant and complex, with Spr, Sil, Crd, Opx ± Sp; Sil 1 phenocrysts are surrounded by Spr2 + Crd2 in contact with Opx ± Bt ; the garnet is destabilized into symplectites of Opx2+Crd2. These 2 reactions indicate a pressure decrease. Al_2O_3 content in Opx 2 is between 7.4 to 5.9% similar to the rims of the primary phenocrysts. Primary Opx probably continues to grow at the beginning of the retrograde evolution, by decompression, while garnet is destabilized: this suggests that the primary paragenesis and retrograde symplectites are the product of a single metamorphic event.

Both zircons and monazites are included in the large crystals from the UHT assemblage as well as in the late symplectites.

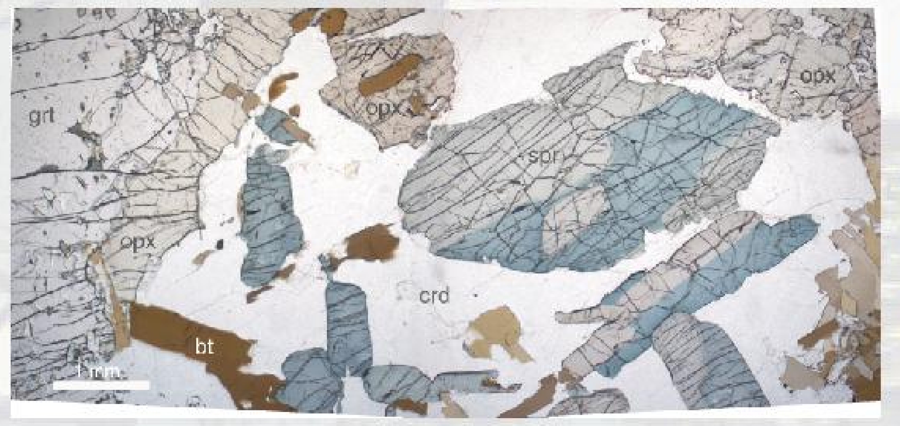
Al_2O_3 profiles in primary Al-rich Opx versus Opx in symplectites around the garnet.



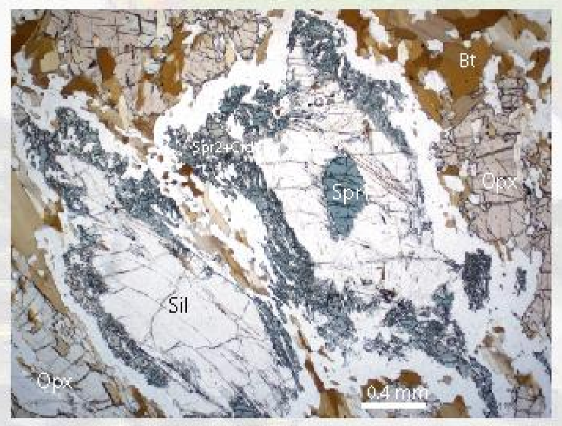
Compositions of the rims in the primary Opx and those of the symplectites overlap. This suggests that the growth of the Opx I rim and the Grt destabilization are contemporaneous with the beginning of the retrograde evolution.



The charnockitic paragenesis



The UHT granulite paragenesis



The retrograde reaction Opx + Sil = Spr + Crd

Complex retrograde symplectites. Opx + Crd symplectite replaces Grt

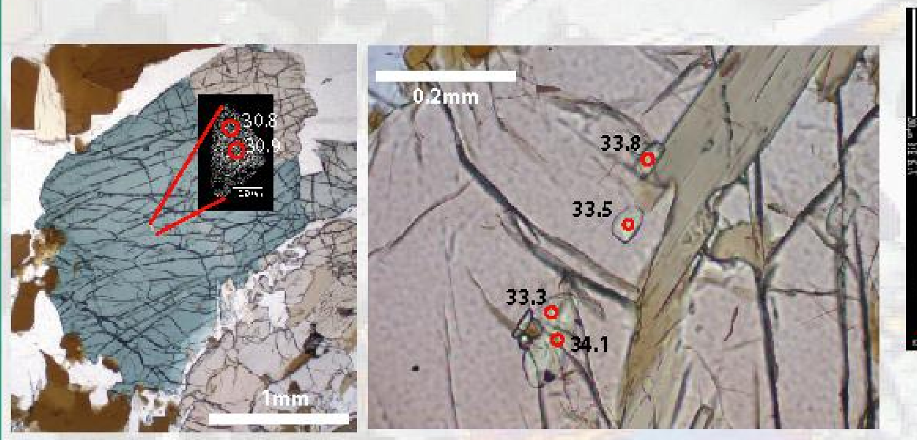
These two reactions reflect decompression

Discussion

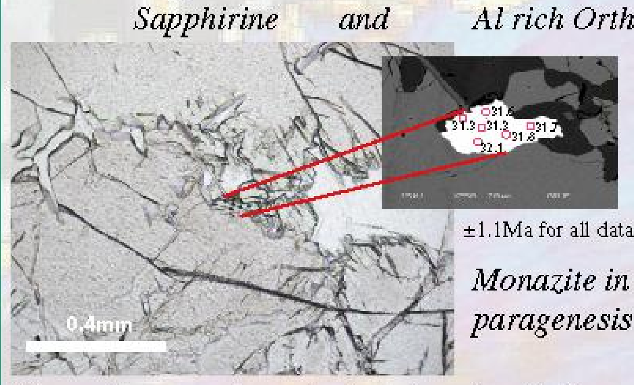
- Ages obtained in zircon cores between 236 and 304 Ma are in agreement with the results of Liati and Gebauer (2003) and Galli et al. (2013). Following these authors these Permo-Triassic ages are interpreted as the age of the charnockitisation. This charnockitisation can be linked to the post Hercynian event responsible of the widespread formation of granulites in the Southern Alps : Ivrea, Sesia, Malenco zones... The scattering of the ages between 236 to 304 Ma in a single sample is rather surprising. Indeed, it can not be only attributed to mixing ages between the cores and the very thin rims.
- The monazite ages, similar to the ages measured in the thin euhedral rims of some zircons demonstrate that the Spr-Opx-Sil UHT paragenesis of the restite in the charnockite equilibrated at 31 Ma, in agreement with Liati and Gebauer (2003), Schmitz et al. (2009), Droop and Bucher (1984). Galli et al. (2011, 2012, 2013) disagree with this interpretation arguing that the intense Alpine migmatisation (in upper amphibolite facies conditions) was responsible of the complete resetting of hypothetical Permian monazites. To solve this ambiguity, we chose to date in situ the granulite restites in the charnockites: if such restitic refractory rocks result from a Permian UHT metamorphism, partial melting as well as significant fluid interaction during Alpine metamorphism are unlikely. This precludes a fluid/melting mediated resetting of monazite. The 31 Ma age obtained in the monazites as well in the zircon rims is definitely the age of the UHT metamorphism.
- We propose that this typical UHT paragenesis crystallised at Alpine time during a short-lived event (less than 5Ma, between 33 to 30 Ma) from refractory lithologies such as restites or schlieren in the Permian charnockites/granites. The refractory character was acquired during the Permian (U?)HT metamorphic event. Unfortunately, the few minerals in tiny inclusions in zircon grains do not allow to precise what were the mineral assemblages in these rocks during the Permian event.
- As proposed by Oalman et al. (2016), the short-lived Alpine UHT metamorphism could have been driven by lithospheric thinning associated with slab breakoff and asthenospheric upwelling coeval with crystallization of the Bergell tonalite-granodiorite. A similar hypothesis is proposed for the only other example of Phanerozoic UHT metamorphism of the island of Seram (Indonesia): the UHT conditions were produced by slab rollback-driven lithospheric extension and the exhumation of hot subcontinental lithospheric mantle (Pownall et al, 2014).
- Using numerical models to explain ultra-hot orogeny, Perchuk et al. (2017) show that UHT conditions at the bottom of the crust might be produced by lateral propagation of the hot asthenospheric front during plate convergence associated with lithospheric delamination. In this model, a close relationship of HT-UHT metamorphism with tonalitic magmatism is proposed.

Monazites

Monazites are present in the core of large Spr, Opx, Crd crystals or form clusters of small grains in the late symplectites. All the grains are strongly zoned in Th, U and Y, but all yield a homogeneous age of 31.8 ± 0.3 Ma.



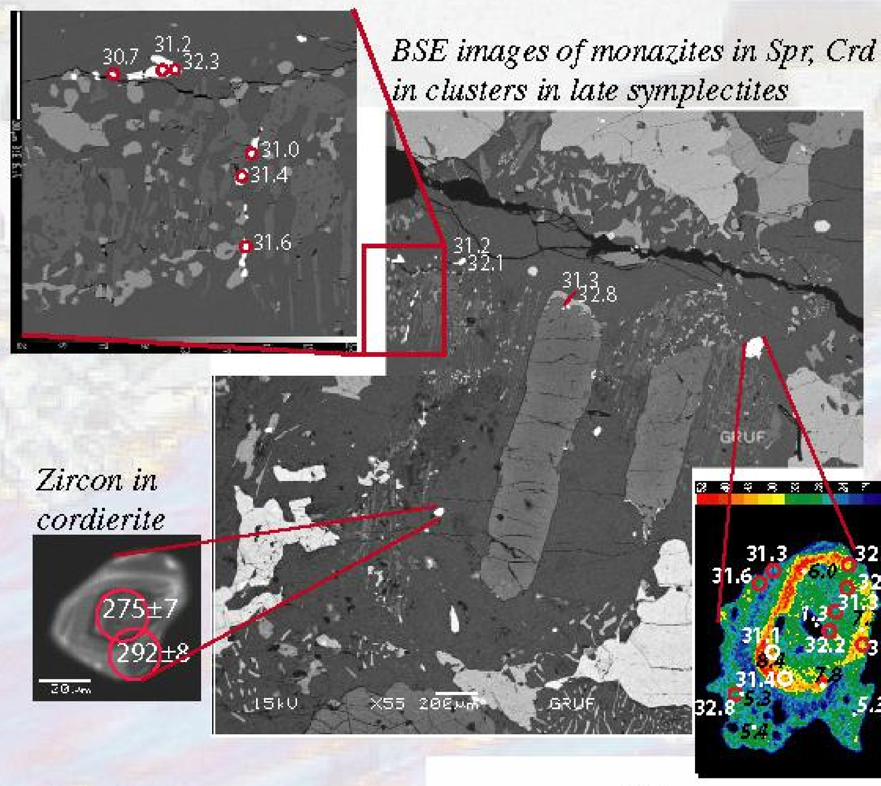
Monazite inclusions in the UHT minerals :
Sapphirine and Al rich Orthopyroxene



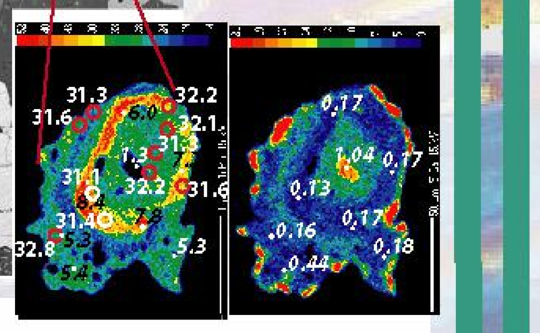
±1.1Ma for all datas

Monazite in the charnockitic paragenesis

BSE images of monazites in Spr, Crd and in clusters in late symplectites

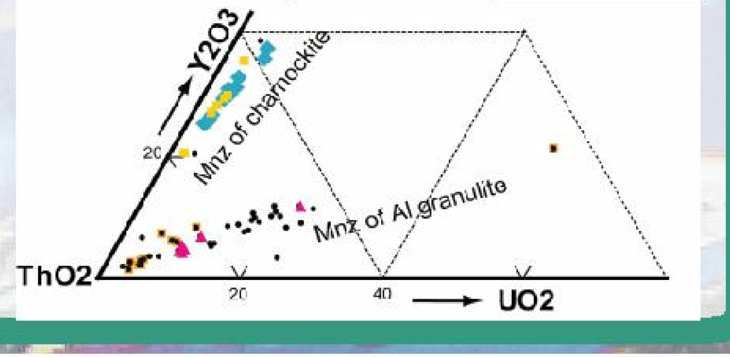


Zircon in cordierite

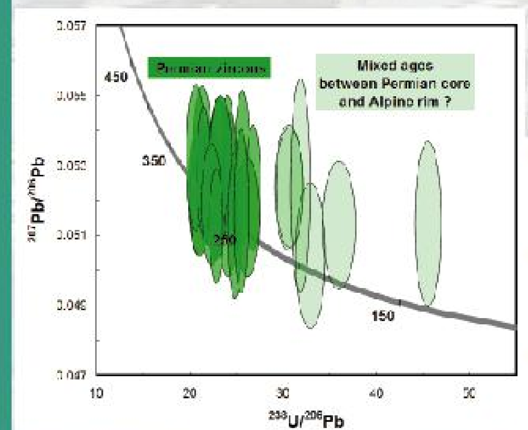


ThO_2 and Y_2O_3 X-ray maps (spots; in wt%) and $^{208}Pb/^{232}Th$ ages (circles)

Monazites are characterized by chemical variations of the LREE-, Th- and Ca-contents that broadly follow the brabantite substitution ($2REE^{3+} = Th^{4+} + Ca^{2+}$). Y_2O_3 is variable (from 0.1 to 5.5 wt%): it increases with the ThO_2 content (1.3 to 10.8 wt%) and is inversely correlated with the UO_2 content (which varies from 0.2 to 3.5 wt%). The monazites in the charnockitic assemblage are Y- and U-rich, and Th-poor compared to those in the residual granulites

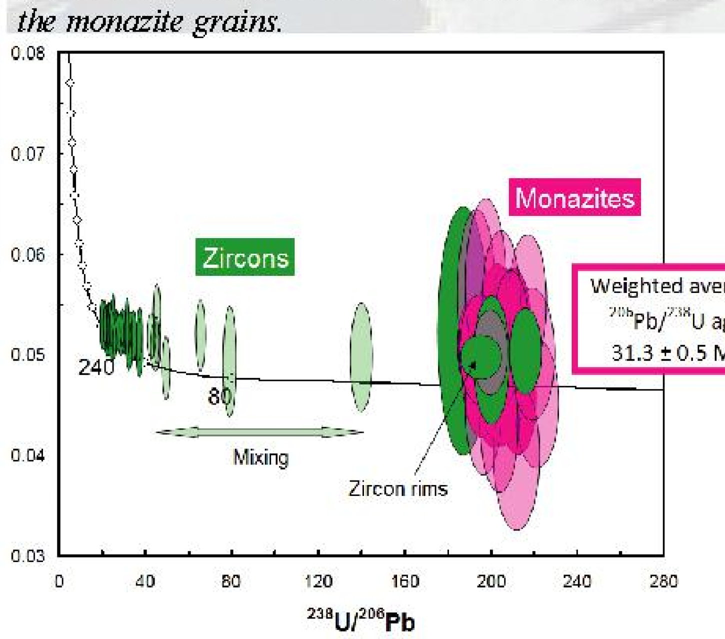


In situ dating of zircon and monazite

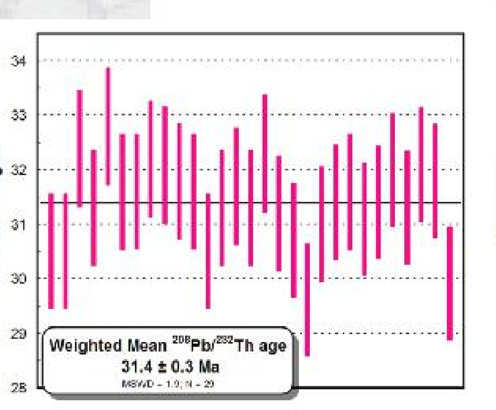


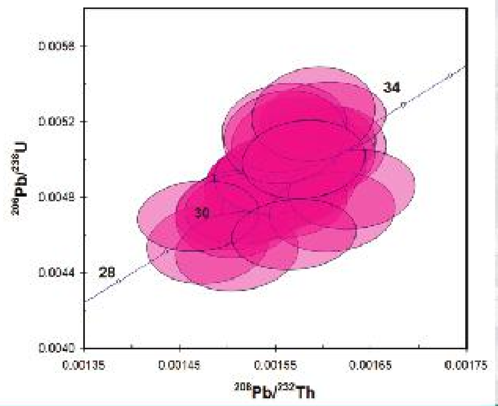
Tera Wasserburg diagram for zircon grains that apparently do not have an Alpine border. Young ages are interpreted as intermediate ages.

Tera Wasserburg diagram showing the zircon and monazite age results : zircon rims yield the same ages as in the monazite grains.



$^{208}Pb/^{232}Th$ weighted mean ages and $^{206}Pb/^{238}U$ versus $^{208}Pb/^{232}Th$ diagram in monazites. All ages at the 2 σ level.





U/Pb ages in zircon and Th/U/Pb ages in monazite measured in the same sample confirm the ages previously measured. Zircon cores yield Permian ages 236 ± 6 Ma to 304 ± 6 Ma, which are in some grains surrounded by a narrow rim at 33.2 ± 1.2 Ma. Intermediate ages reflect mixing between the core and the very thin rim. Monazite grains yield a weighted mean $^{208}Pb/^{232}Th$ age of 31.4 ± 0.3 Ma (MSWD=1.9, N=29) similar to the weighted mean $^{206}Pb/^{238}U$ age of 31.3 ± 0.5 Ma. No correlation is observed between ages and textural positions, nor between ages and chemical compositions of the monazites. The age of 31.4 ± 0.3 Ma is interpreted as the time of complete (re-)crystallisation of the monazite in equilibrium with the UHT paragenesis.

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