Geodynamic significance of the Variscan eclogites in the External Crystalline Massifs (Western Alps): marker of a subduction or crustal thickening?

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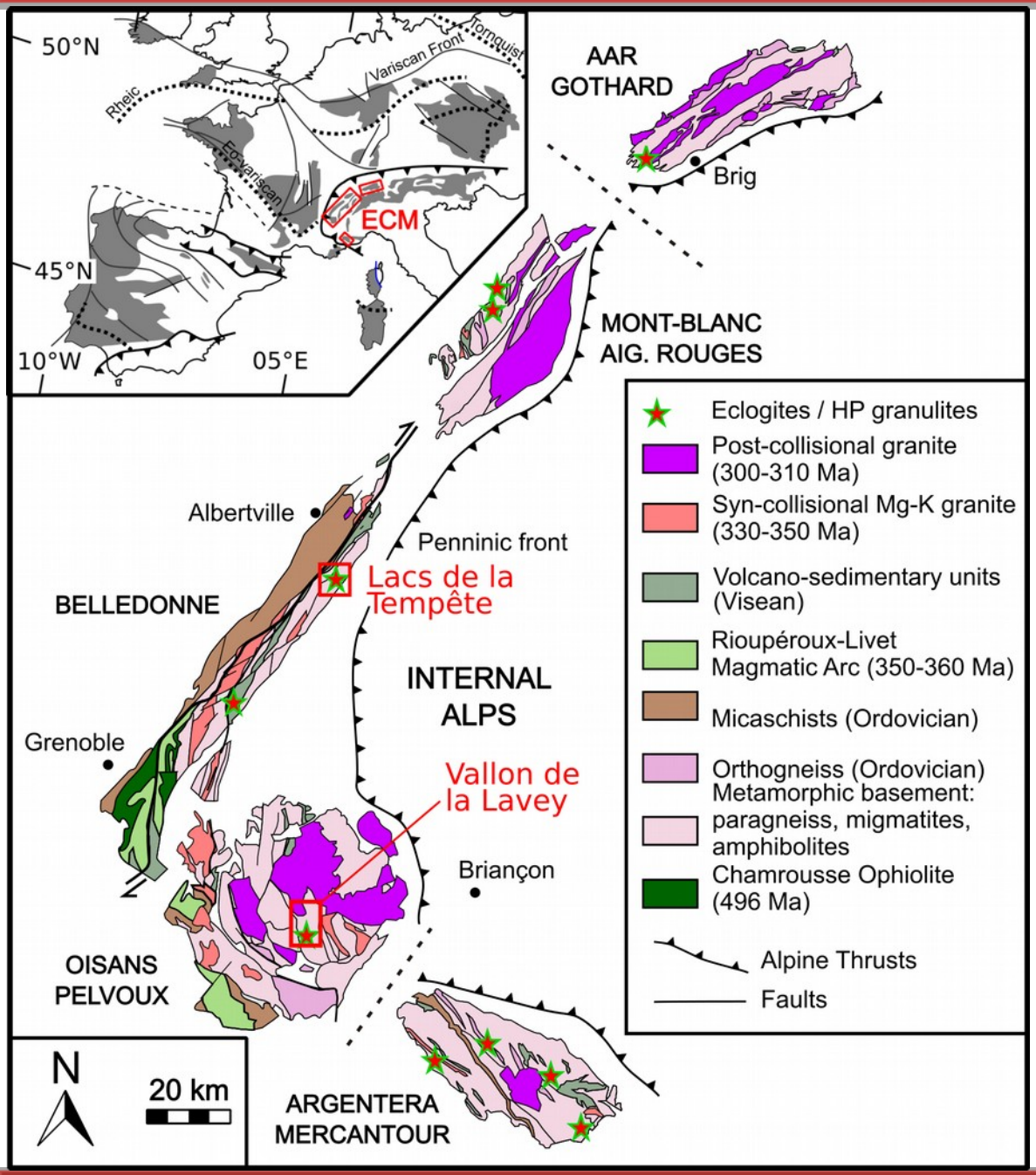
Geological Setting



<u>The External Crystalline Massifs (ECM)</u>

- Exposed portions of Paleozoic basement in the External Alps

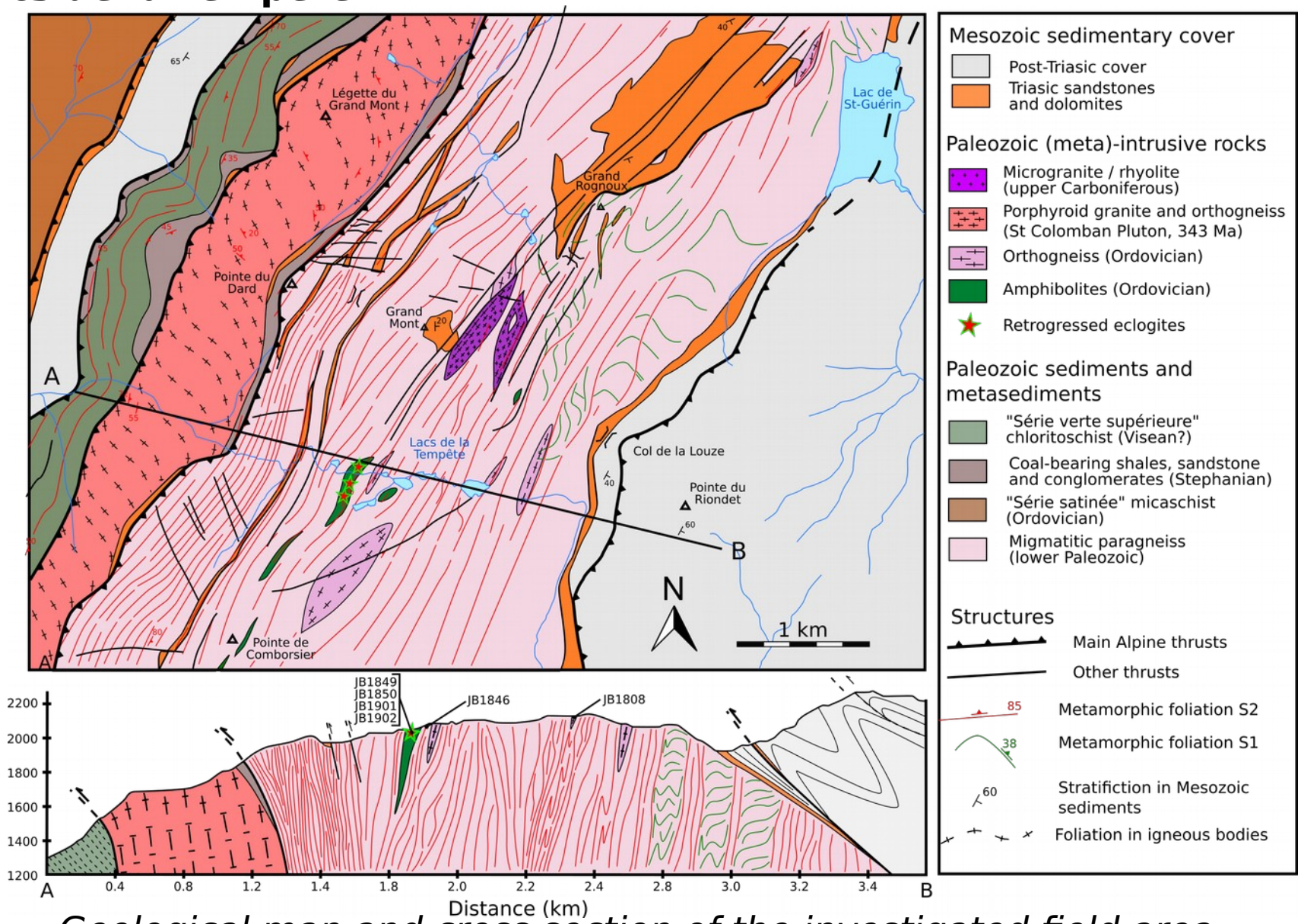
- Strong Variscan overprint, with amphibolite / granulite facies metamorphism

- Relics of HP rocks (Eclogites and HP granulites) preserved in high grade metamorphic domains

Focus the Lacs de la Tempête retrogressed eclogites (NE Belledonne)
+ one sample of HP mafic granulite (JB-19-56) from La Lavey Valley (Oisans)

Field description and structures

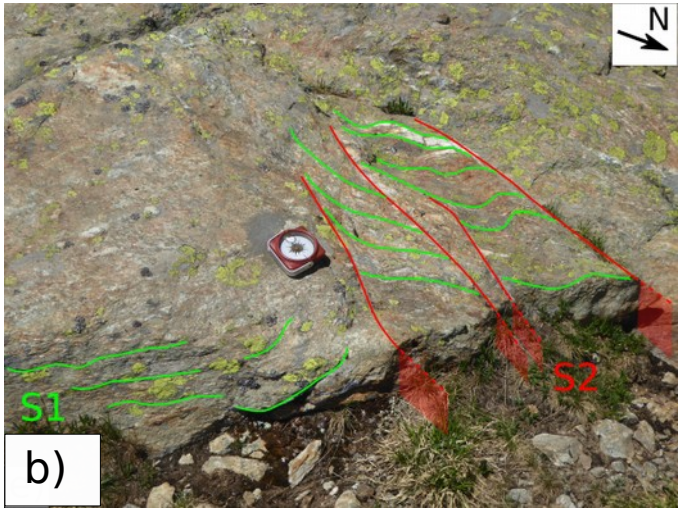
Lacs de la Tempête

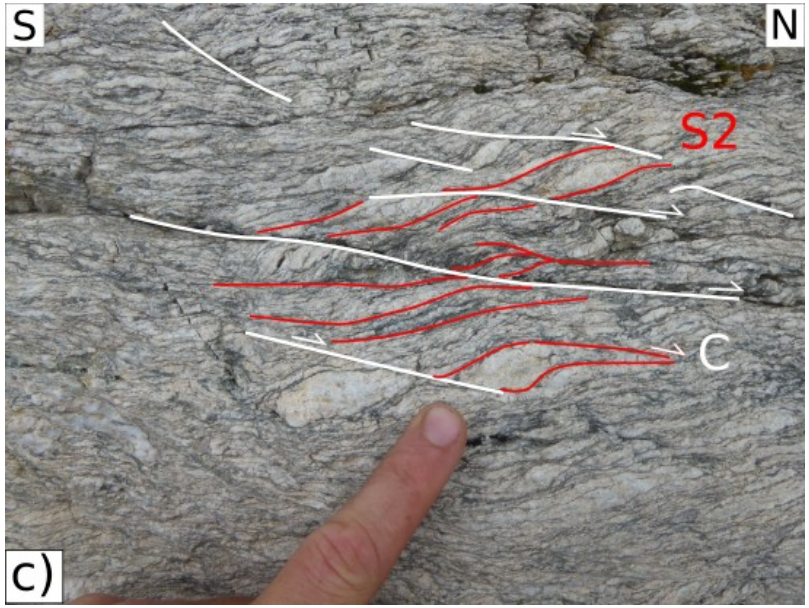


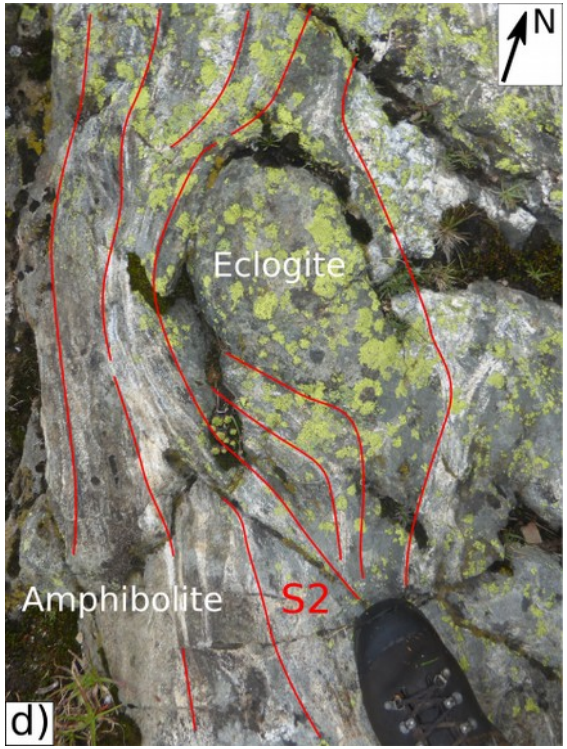
Geological map and cross section of the investigated field area

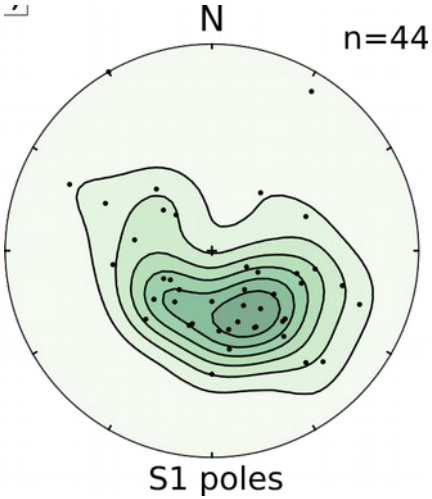
Field description and structures

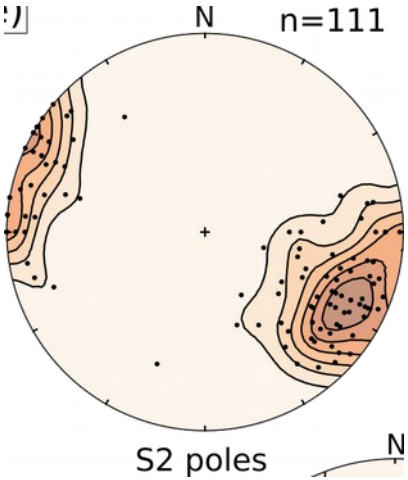
Lacs de la Tempête











Field description and structures

Lacs de la Tempête

Lacs de la Tempête gneiss series:

- High grade metasedimentary sequence with local migmatization
- Intercalation of mafic and felsic igneous protoliths (orthogneiss and amphibolite) forming decameter to hectometer-size lenses in the metasediments

Structures:

- S1: flat-lying foliation preserved in low-strain domains
- S2: steeply-dipping foliation formed by ductile dextral shearing in a transpressive setting, that obliterates the former structures. Probably associated with the crustal-scale East-Variscan Shear Zone (e.g. Guillot et al. 2009), a strike-slip shear zone active from late-Carboniferous to early Permian, that runs through the ECM from the Aar-Gothard to the Maures-Esterel massif.

Petrographic description

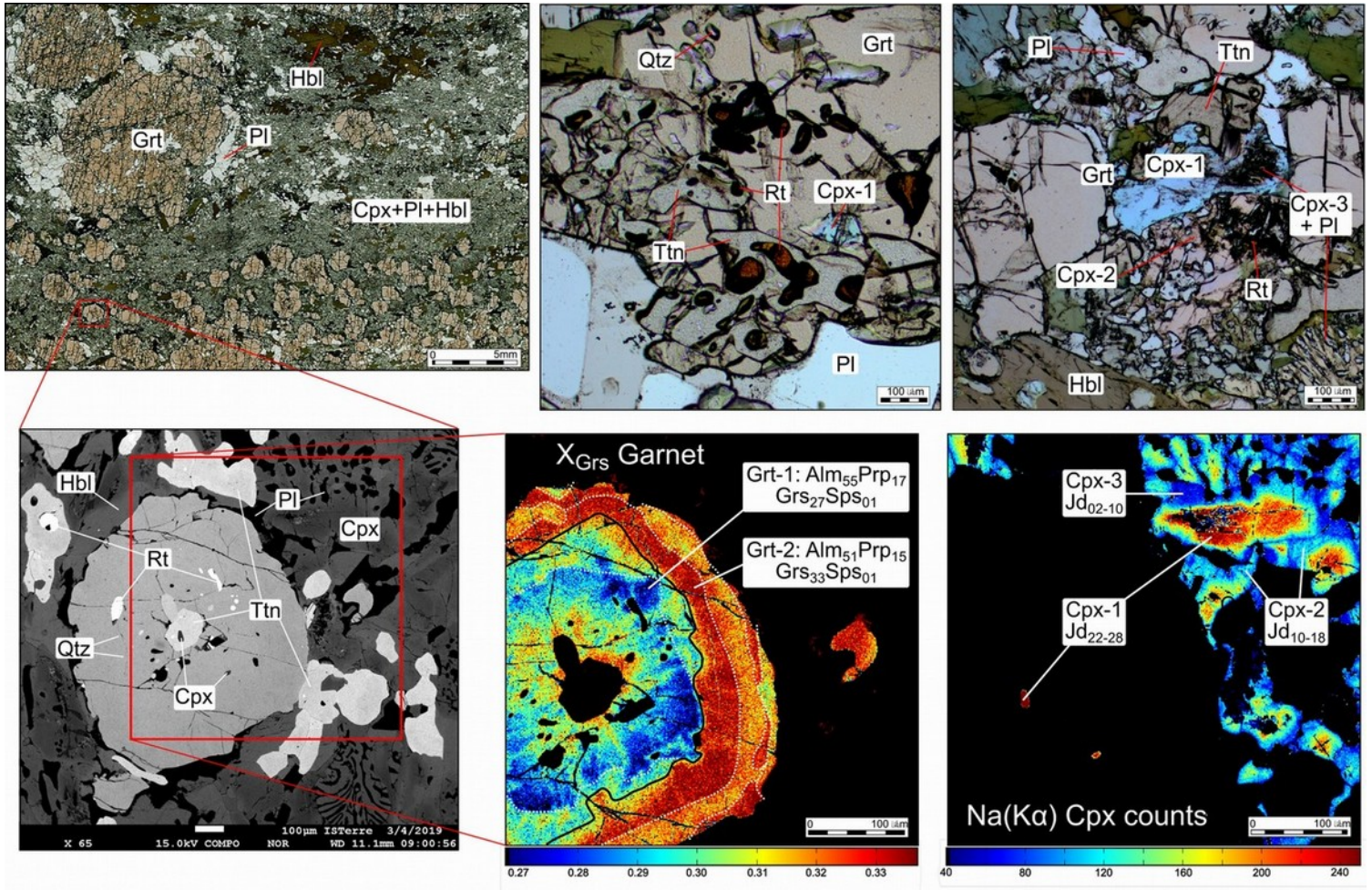
Sample N°	Description	Mineralogy	U-Pb Zrc	U-Pb Rt	PT estimates
		Lacs de la Tempête (NE Belledonne Massif)			
JB-18-03B	retrogressed eclogite	Grt-Cpx-Pl-Hbl-Rt-Ttn±Qtz±Ilm±Ep±Chl (Cpx+Pl+Hbl) symplectites (former Omp) Accessory Zrc-Ap	x	x	
JB-18-49	retrogressed eclogite		x		
JB-19-01	retrogressed eclogite		x		
JB-19-02	retrogressed eclogite		x		
JB-18-50	retrogressed eclogite	as other retrogressed eclogites + preserved coarse grains Omp	x		x
JB-18-08	Orthogneiss	Qtz-Pl-Kfs-Chl-Ms-Bt, Accessory Zrc	x		
JB-18-46	Migmatitic Metasediment	Qtz-Pl-Kfs-Bt-Grt-Chl Accessory Rt-Ilm-Ap-Mnz-Zrc	x		
		La Lavey Valley (Oisans-Pelvoux Massif)			
JB-19-56	mafic HP granulite	Hbl-Pl-Cpx-Grt-Ilm±Bt±Opx±Rt±Qtz Accessory Zrc	x	x	

- 5 retrogressed eclogites + 1 metasediment + 1 orthogneiss from the Lacs de la Tempête area selected for U-Pb dating of zircon and rutile on separated grains
- 1 additional sample of mafic HP granulite from Oisans

- P-T estimation by thermodynamic modelling with PerpleX on JB-18-50 (retrogressed eclogite)

Petrographic description

The retrogressed eclogites

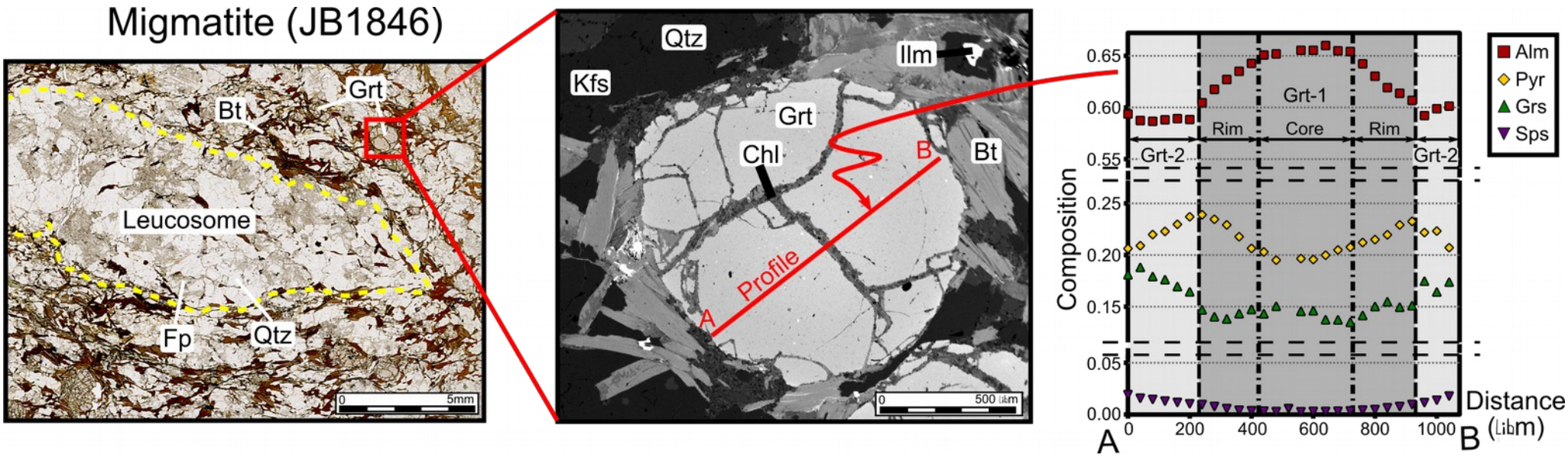


3 paragenesis

- HP (Eclogitic) : Grt1+Omp+Rt+Qtz (Qtz only in Garnet)
- HT (Amphibolite/Granulite) : Grt2+Hbl+Cpx2-3+Pl+Ttn/Ilm
- BT (Greenschist) : Ep+Act+Chl+Ab+Ttn (generally restrained to small cracks, but more pervasive in the most retrogressed samples)

Petrographic description

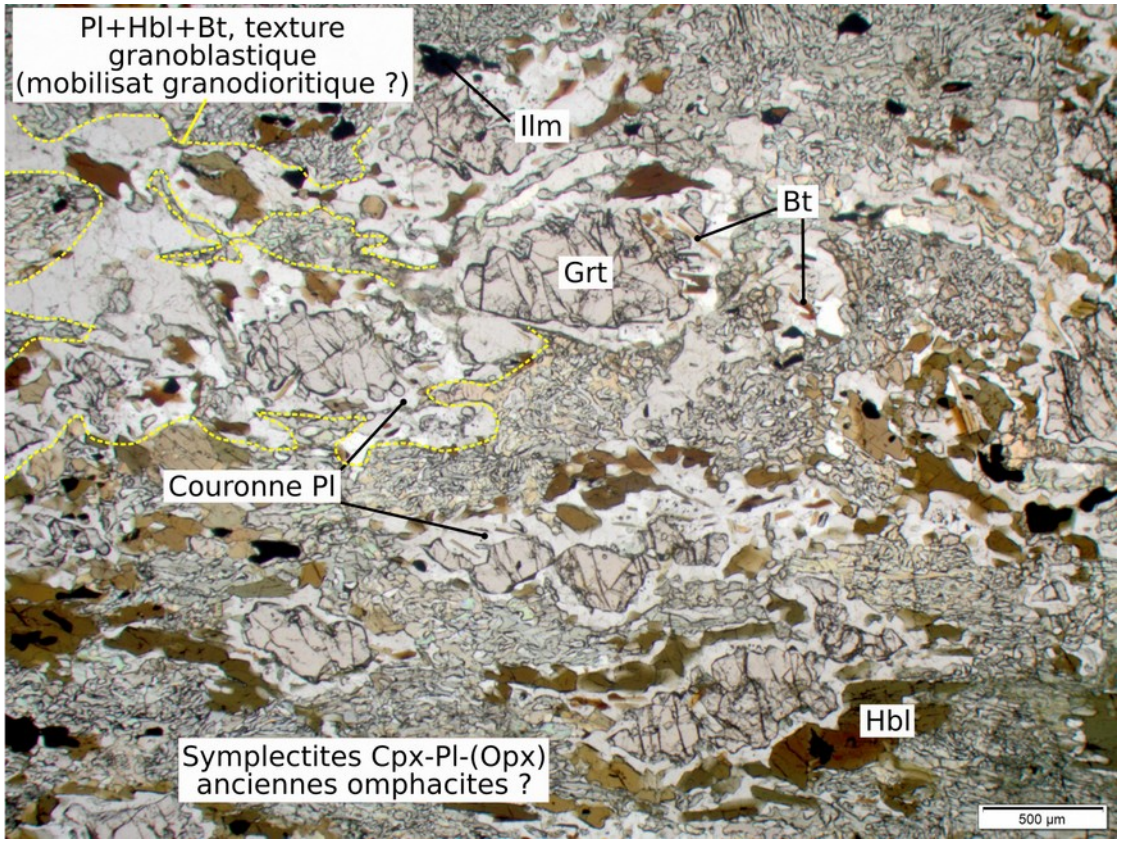
The migmatitic metasediments

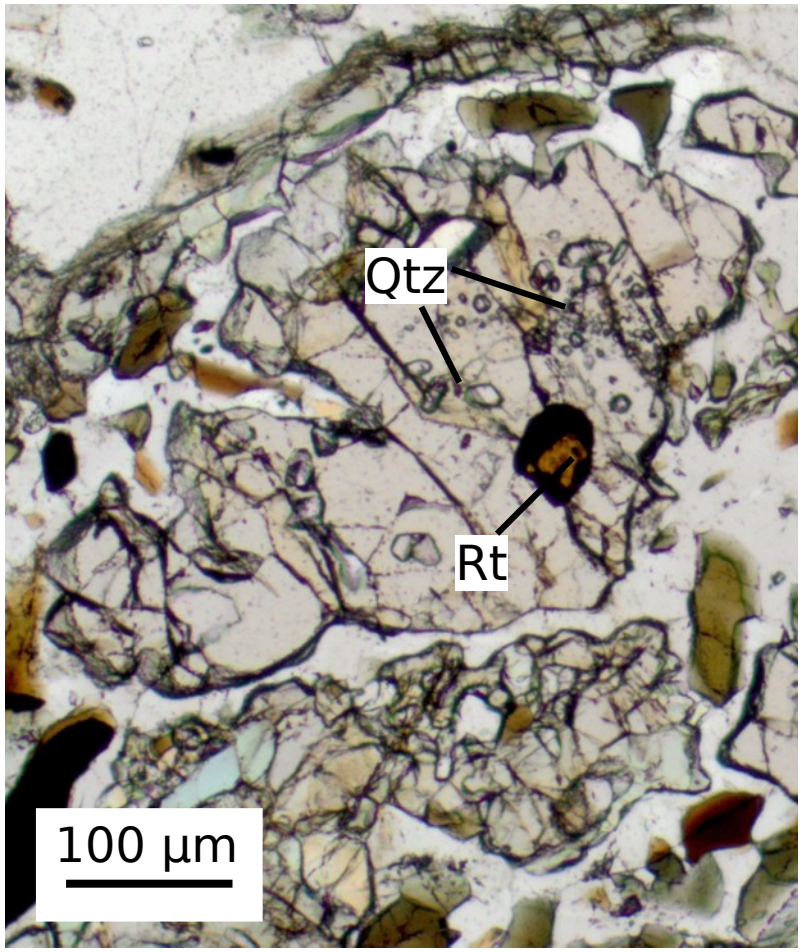


- Qtz-Fp rich augens (<1cm), interpreted as leucosomes
- Other domains (Mesosome) with Qtz-Pl-Bt-Grt-Rt-Ilm
- Garnet contains inclusions of Qtz and Rt and presents complex zoning, interpreted as the result of two episodes of garnet growth (Grt-1 and Grt-2)

Petrographic description

Mafic HP Granulite (La Lavey)

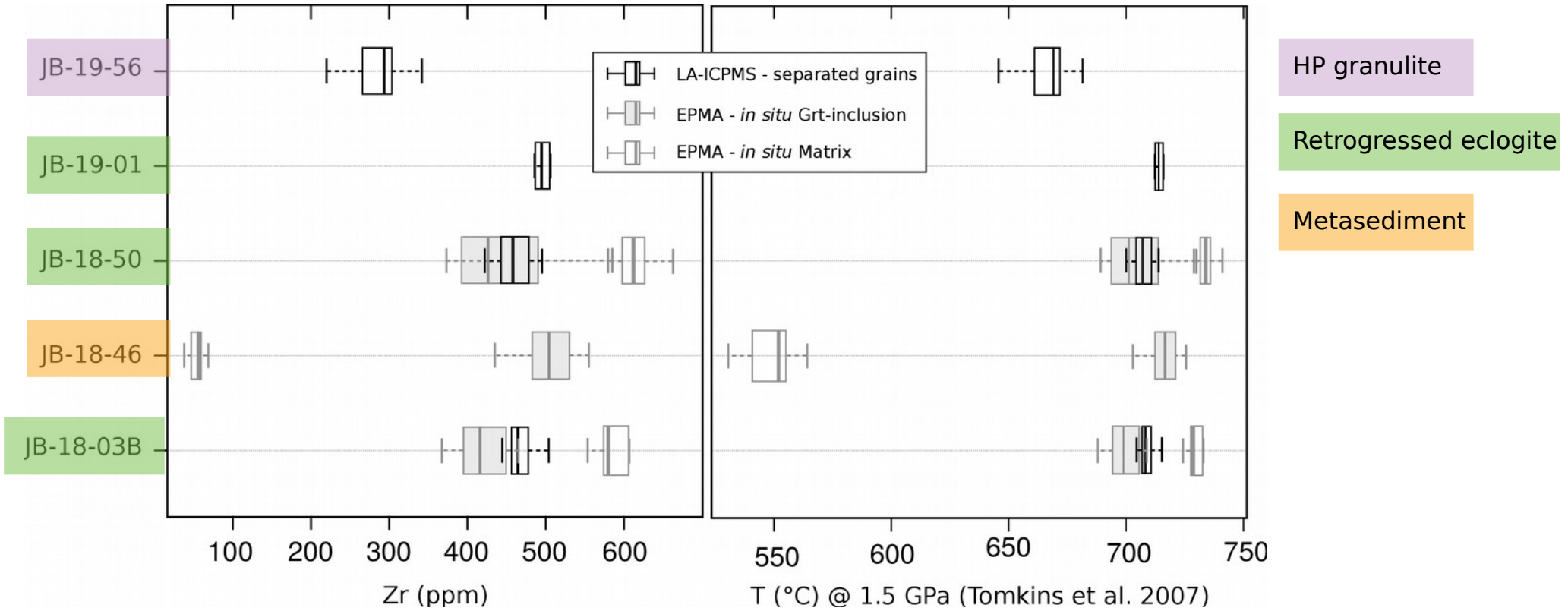




HP assemblage: Grt-Qtz-Cpx-Rt. Rt+Qtz only preserved as inclusions in garnet
Cpx+Pl+Opx symplectites: former omphacite grains?

Resorption of Garnet and symplectites, development of a Pl+Hbl+Bt+Ilm assemblage with a granoblastic texture that grows preferentially around garnet
-> Either subsolidus HT recrystallization or crystallized granodioritic liquid

Zr in rutile thermometry



T ~ 690-740 °C for the samples from the Lacs de la Tempête, T ~ 650-680 °C for the sample from La Lavey (JB-19-56).

Slight difference between Grt-inclusions and matrix rutile for the retrogressed eclogites, either due to lower P, higher T or SiO2 undersaturated conditions during crystallization of rutile in the matrix.

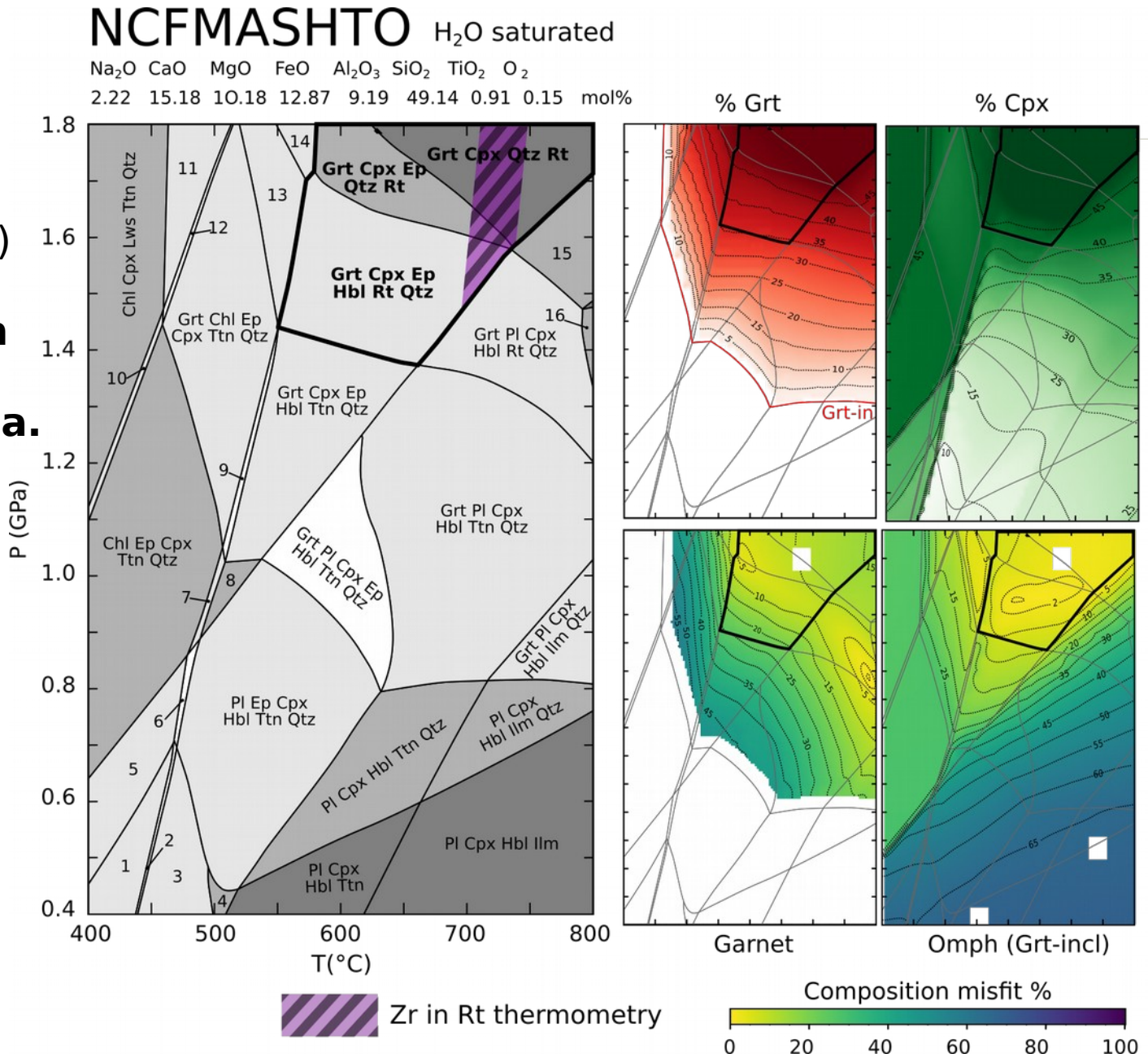
Matrix rutile in metasediments crystallized during retrogression at lower P-T conditions

Thermodynamic modelling (PerpleX)

Eclogite – prograde (JB-18-50)

Peak-P assemblage in the field Grt-Cpx-Qtz-Rt-(Hbl-Ep)

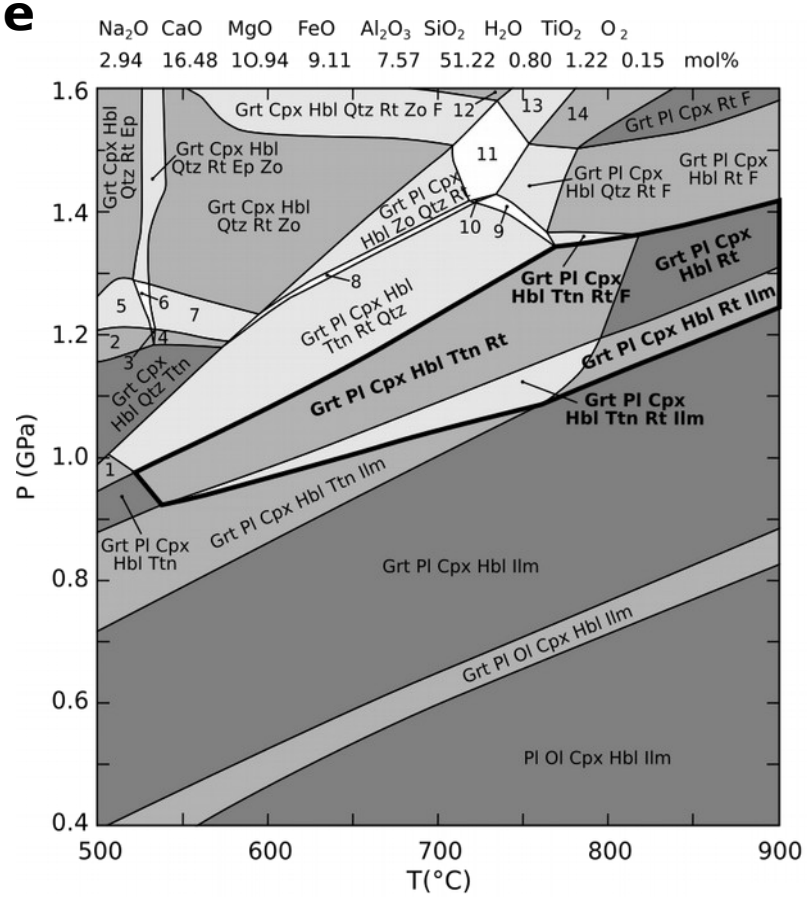
Grt-Omph composition + Zr in Rt
-> peak P conditions at ca. 1.6 GPa and 720 °C

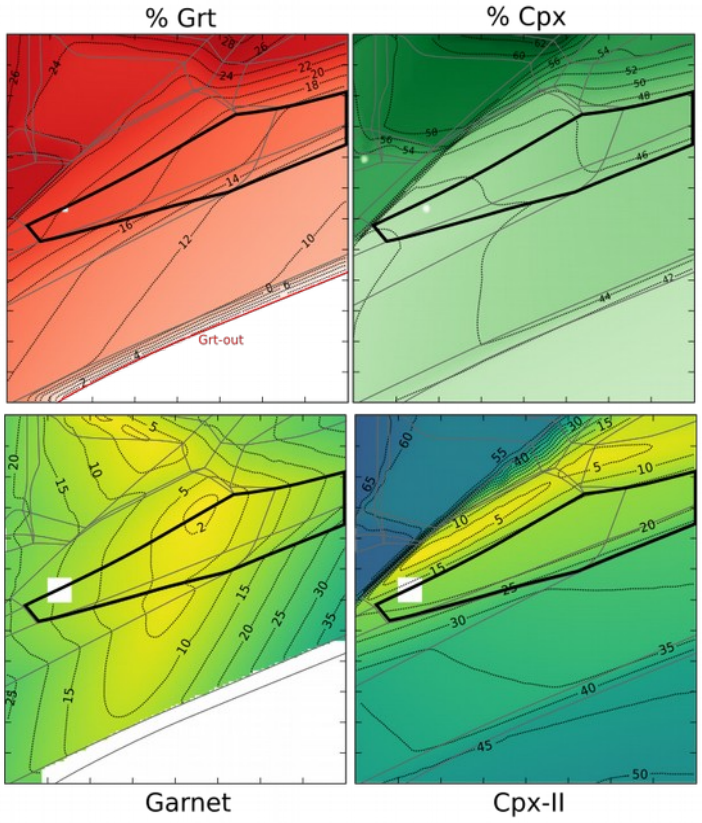


Thermodynamic modelling (PerpleX)

Eclogite – retrograde (JB-18-50)

constrained amount of H2O
Grt-1 excluded from the reactive composition

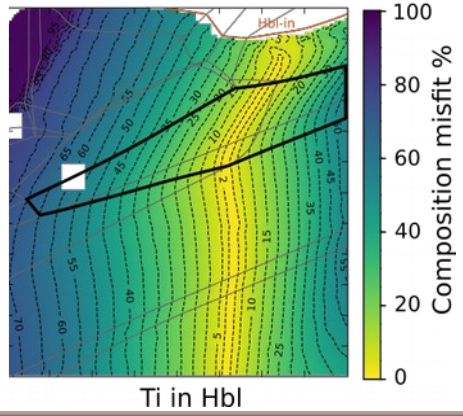




Retrograde assemblage in the field Grt-Pl-Cpx-Hbl-Rt-Ilm/Ttn

Grt-Cpx composition + Ti in Hbl used for thermobarometry

-> retrogression at ca. 1.2 GPa and 750 °C



U-Pb dating - Zircon

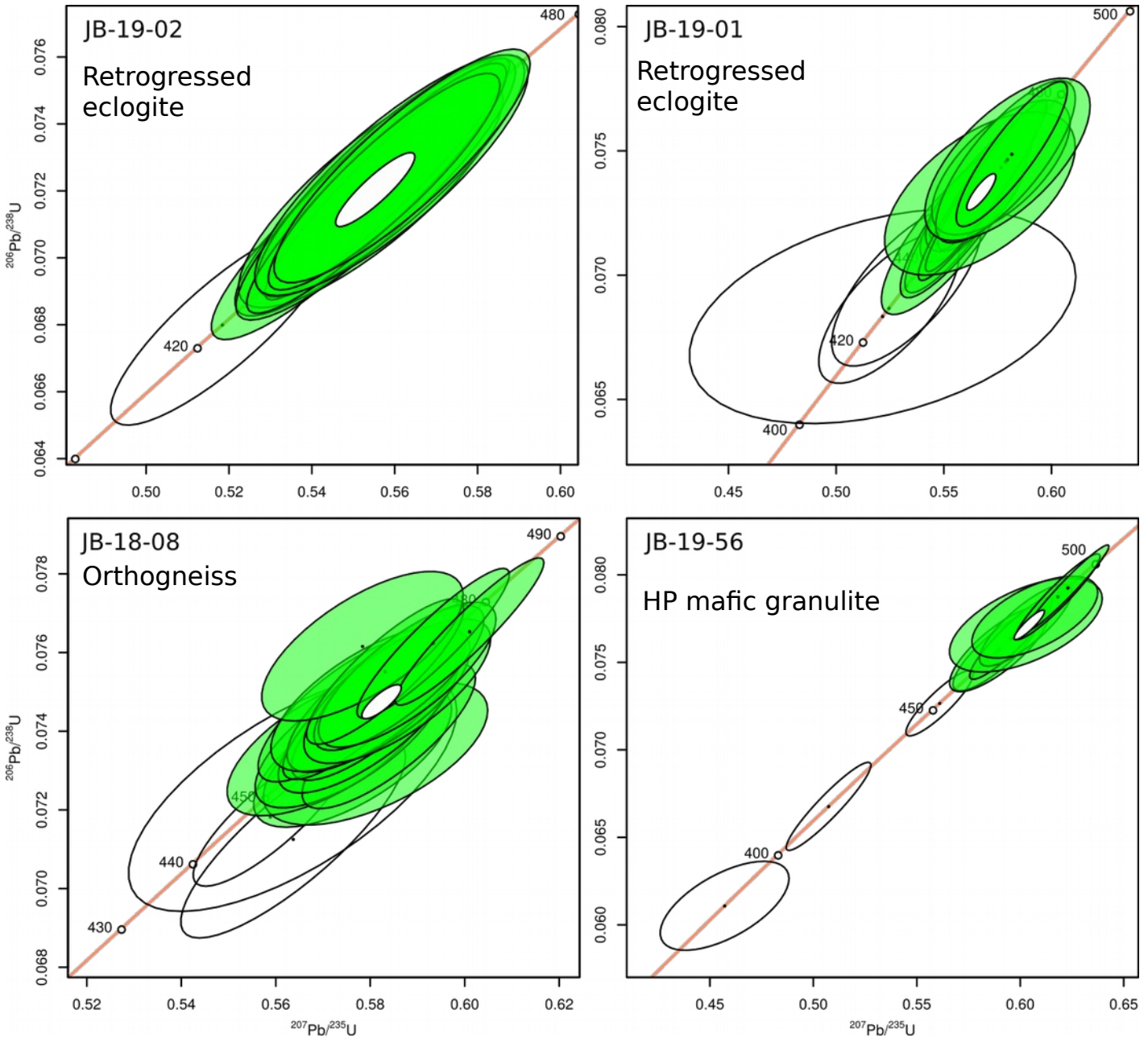
Zircon Cores

Ordovician age for zircon cores

Retrogressed eclogites (Lacs de la Tempête): ca. 450 Ma

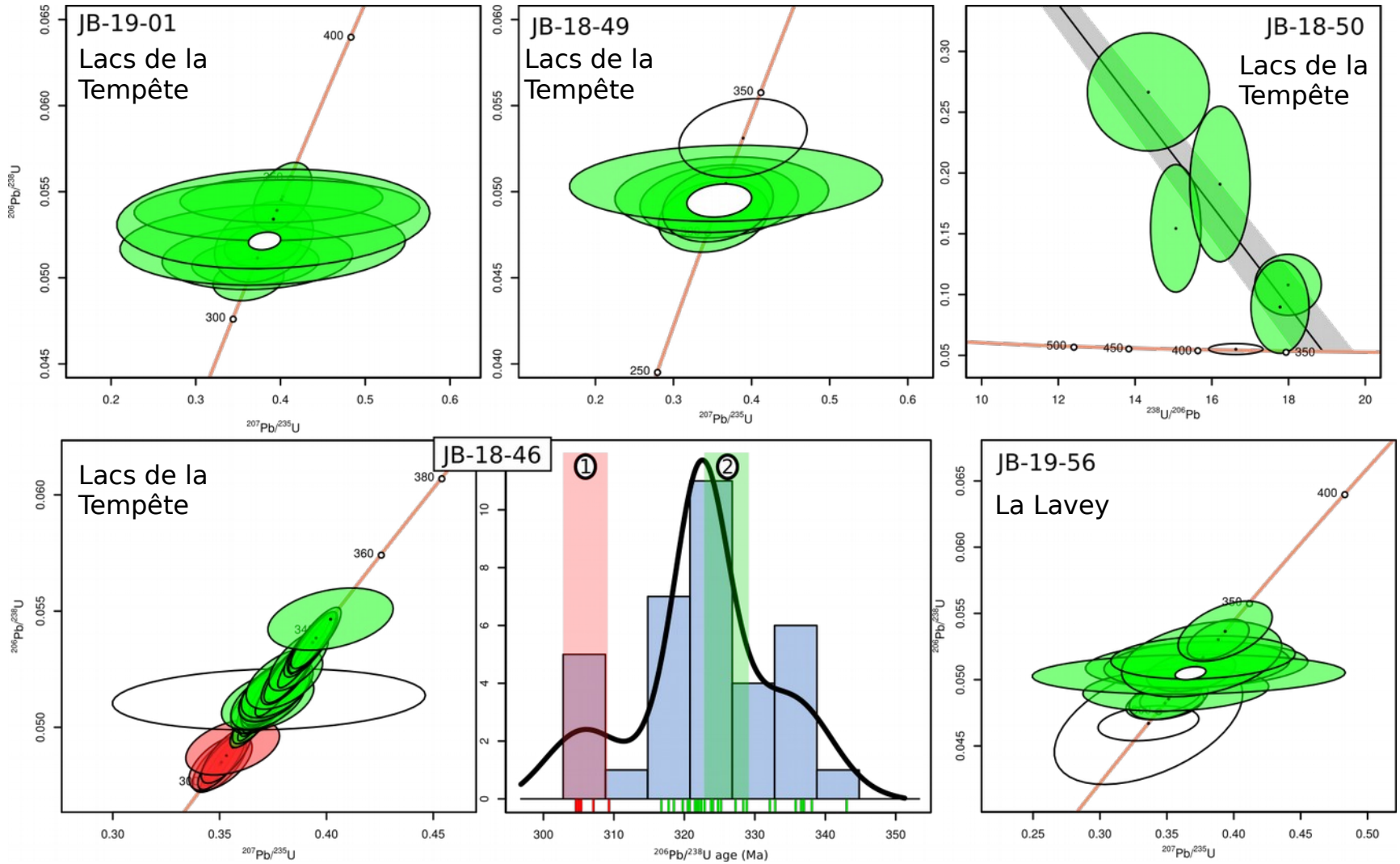
Orthogneiss (Lacs de la Tempête): ca. 465 Ma

HP Mafic granulite (La Lavey): ca. 480 Ma



U-Pb dating - Zircon

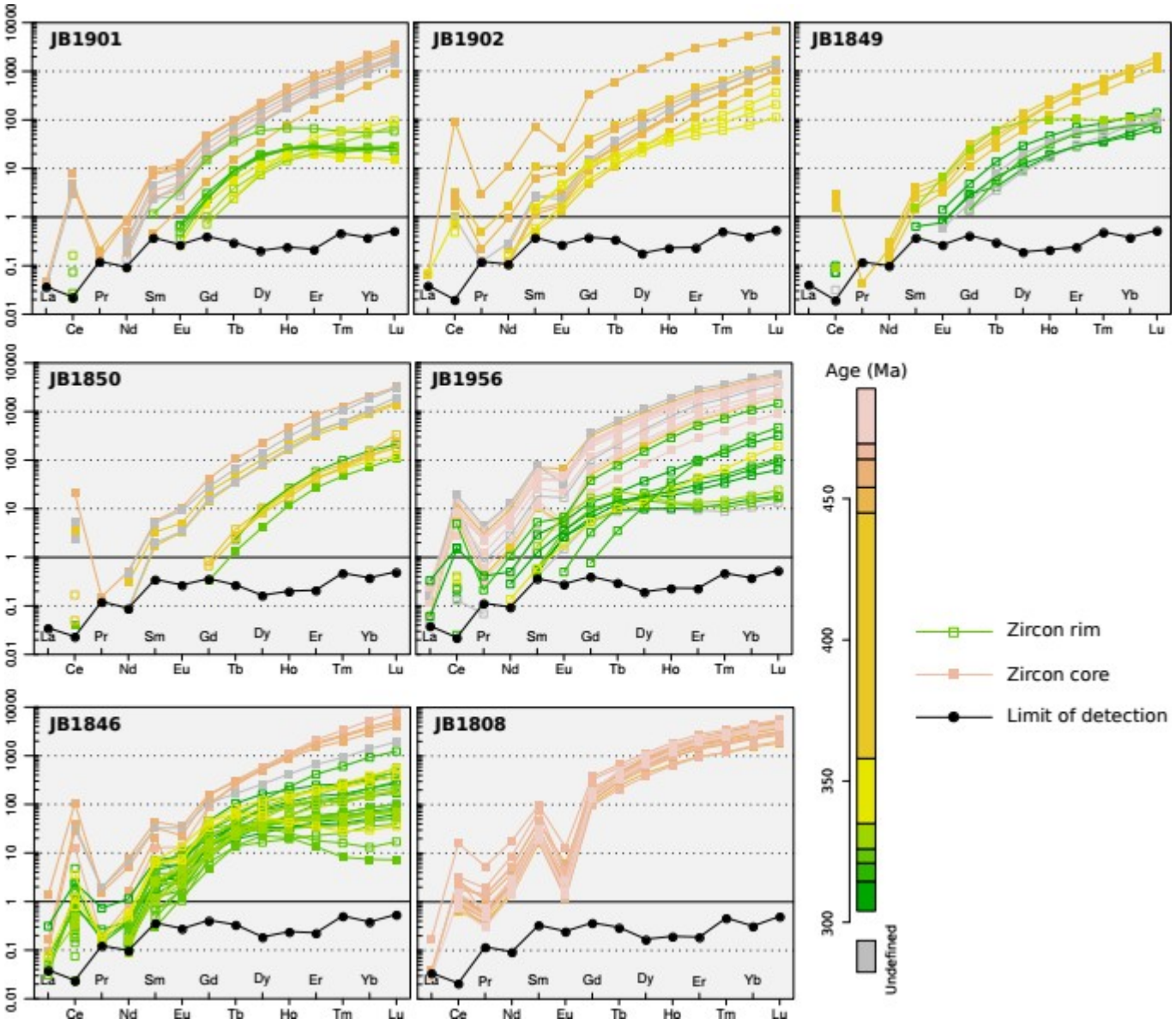
Zircon Rims

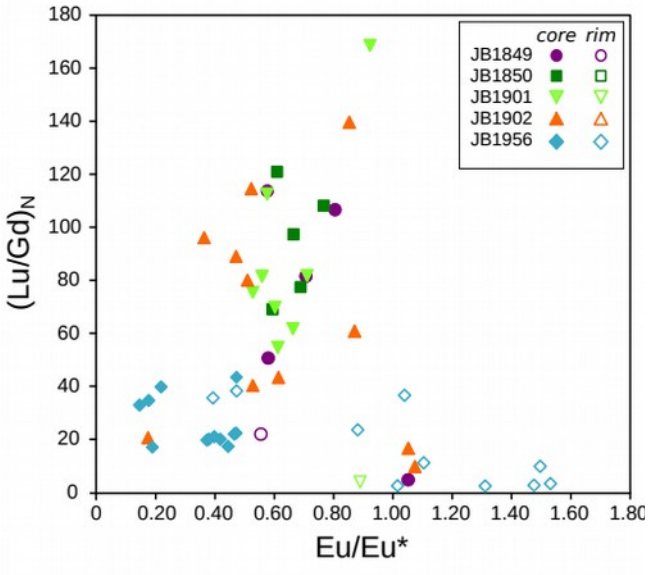


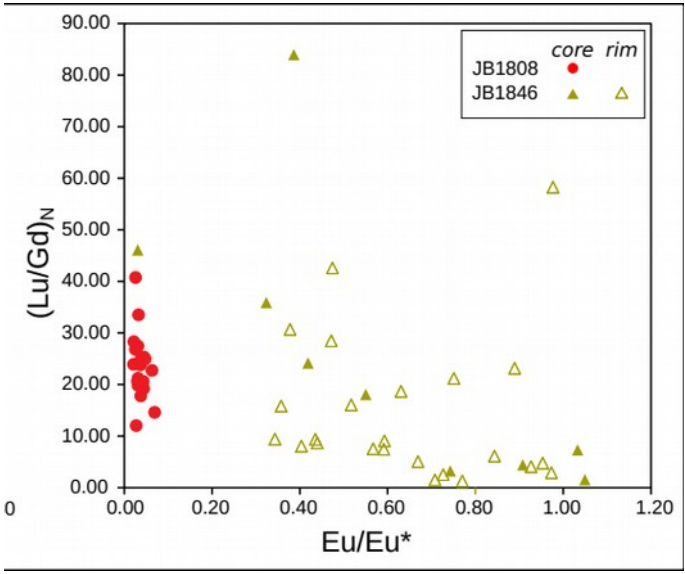
Major zircon growth event between ca. 315-330 Ma + second event at ca. 305 Ma, only recorded in the metasediments. No significant age difference between localities

U-Pb dating - Zircon

Zircon REE composition







U-Pb dating - Zircon

Zircon REE composition

Zircon cores (>400 Ma)
Magmatic signature, with high HREE and a negative Eu anomaly (esp. For the orthogneiss JB-18-08 and the mafic granulite JB-19-56)

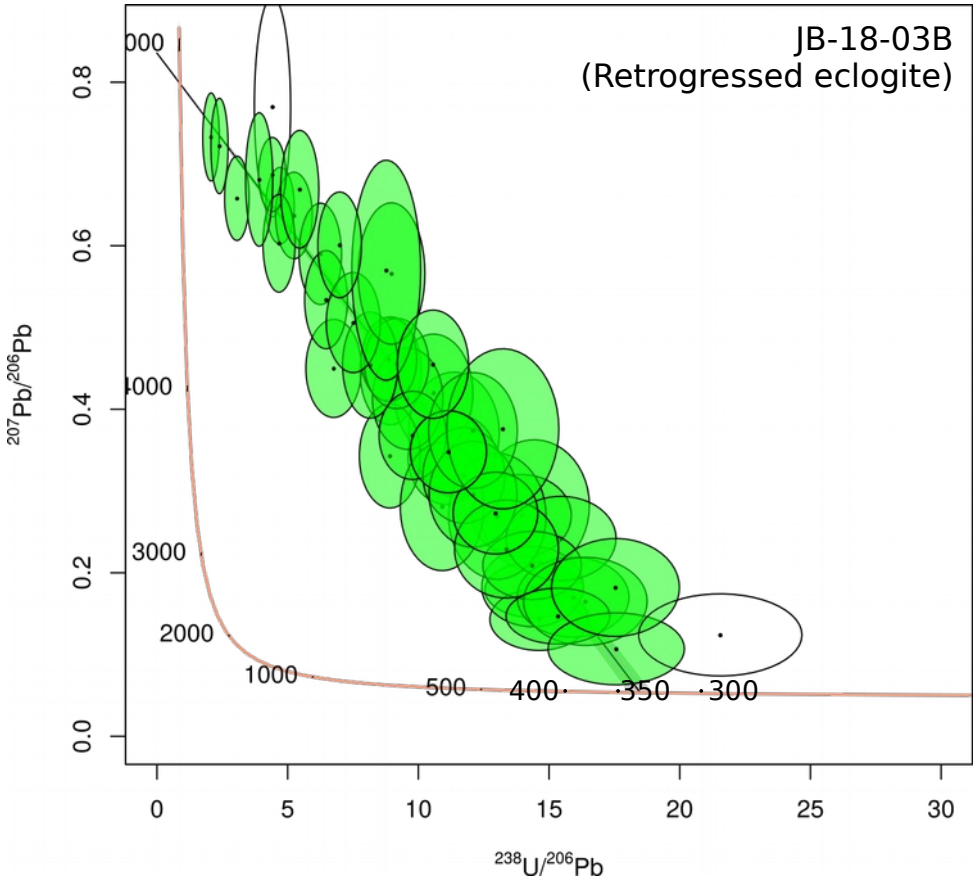
Very small Eu anomaly for the retrogressed eclogites, maybe due to early growth of zircon in a non-differentiated basaltic liquid, where Eu has not been fractionnated yet by Pl crystallization, or to absence of Eu anomaly in the bulk rock

Zircon rims (300-350 Ma)
1-2 log unit less REE than in the cores

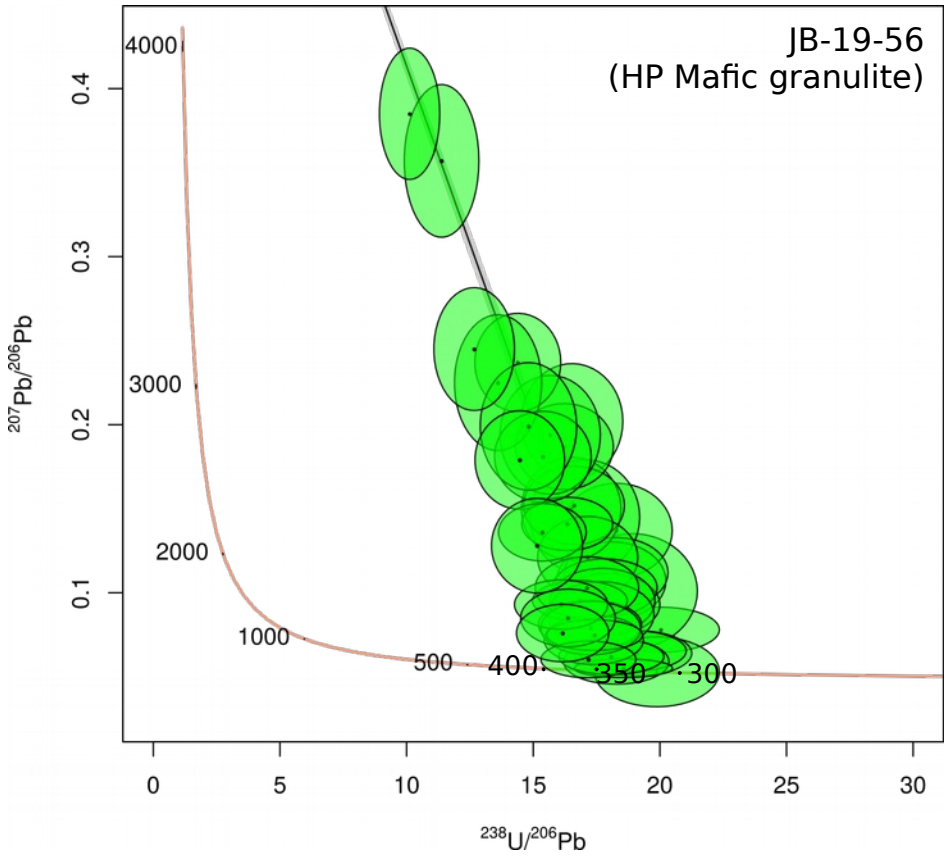
Variety of REE profiles:
- Flat HREE profiles -> growth of zircon in presence of garnet that scavenges HREE
- Steeper slope in HREE -> growth of zircon during garnet breakdown
- Eu anomaly usually small to non-existent (when it could be measured) in the retrogressed eclogites, more variation in the metasediments and the mafic granulites -> Suggests zircon grew in a Pl-poor or Pl-free assemblage in the retrogressed eclogites, either at eclogitic conditions or during decompression in a metastable eclogitic assemblage

U-Pb dating - Rutile

U-Pb Rutile



Lacs de la Tempête



La Lavey

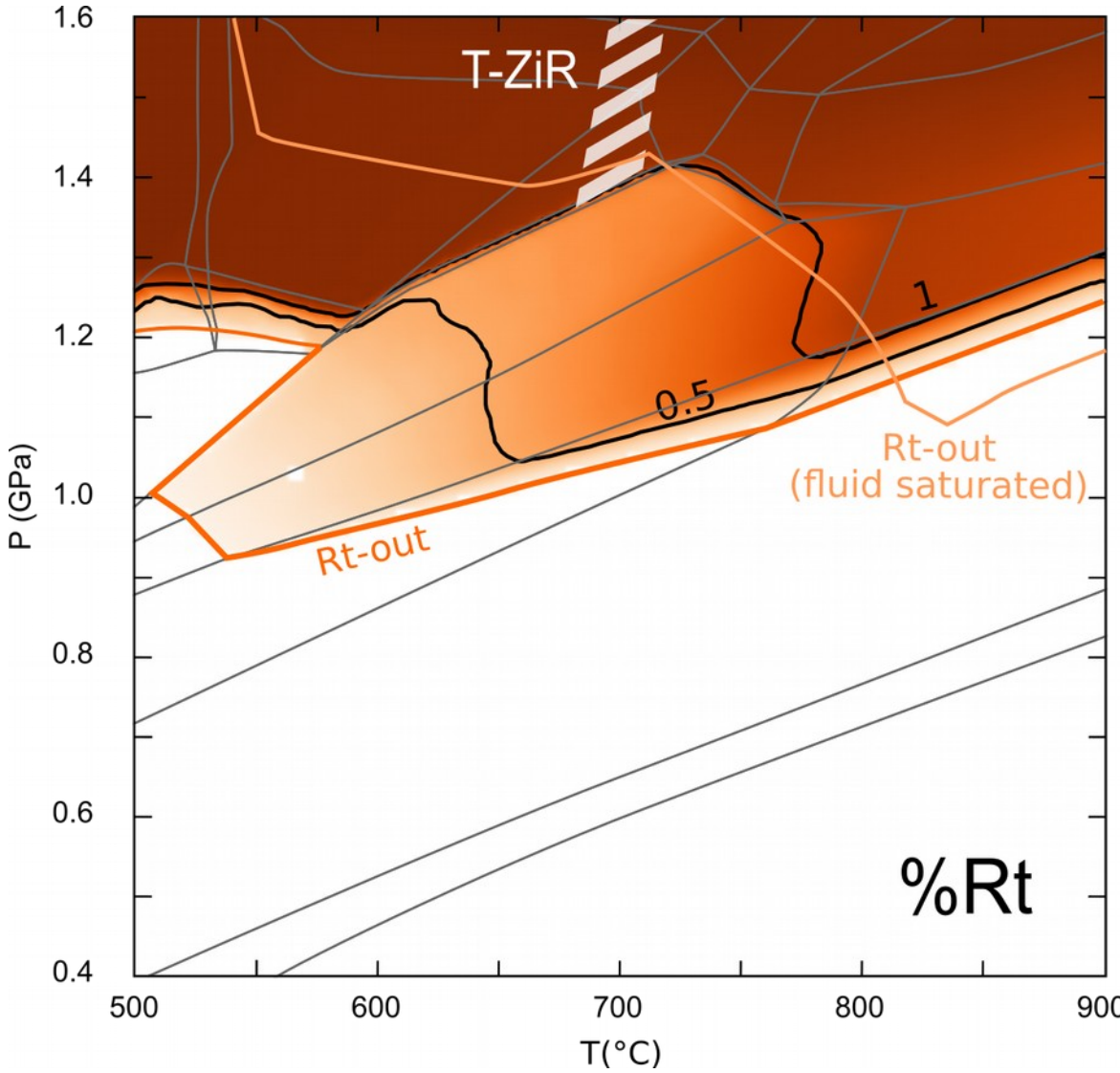
Rutile U-Pb ages at ca. 340 Ma. No significant difference between the two localities.

Correlation U-Pb ages / P-T evolution

When does rutile grows ?

In the retrogressed eclogites, rutile is only stable at P > 1.0 GPa (at 700 °C) if fluid is undersaturated and at P> 1.4 GPa under fluid-saturated conditions. Decompression below 1.3-1.4 GPa is associated with the resorption of rutile and the development of titanite/ilmenite

-> Rutile probably grows at P > 1.4 GPa in the eclogitic facies and record the HP stage



Rutile vol% (JB-18-50)

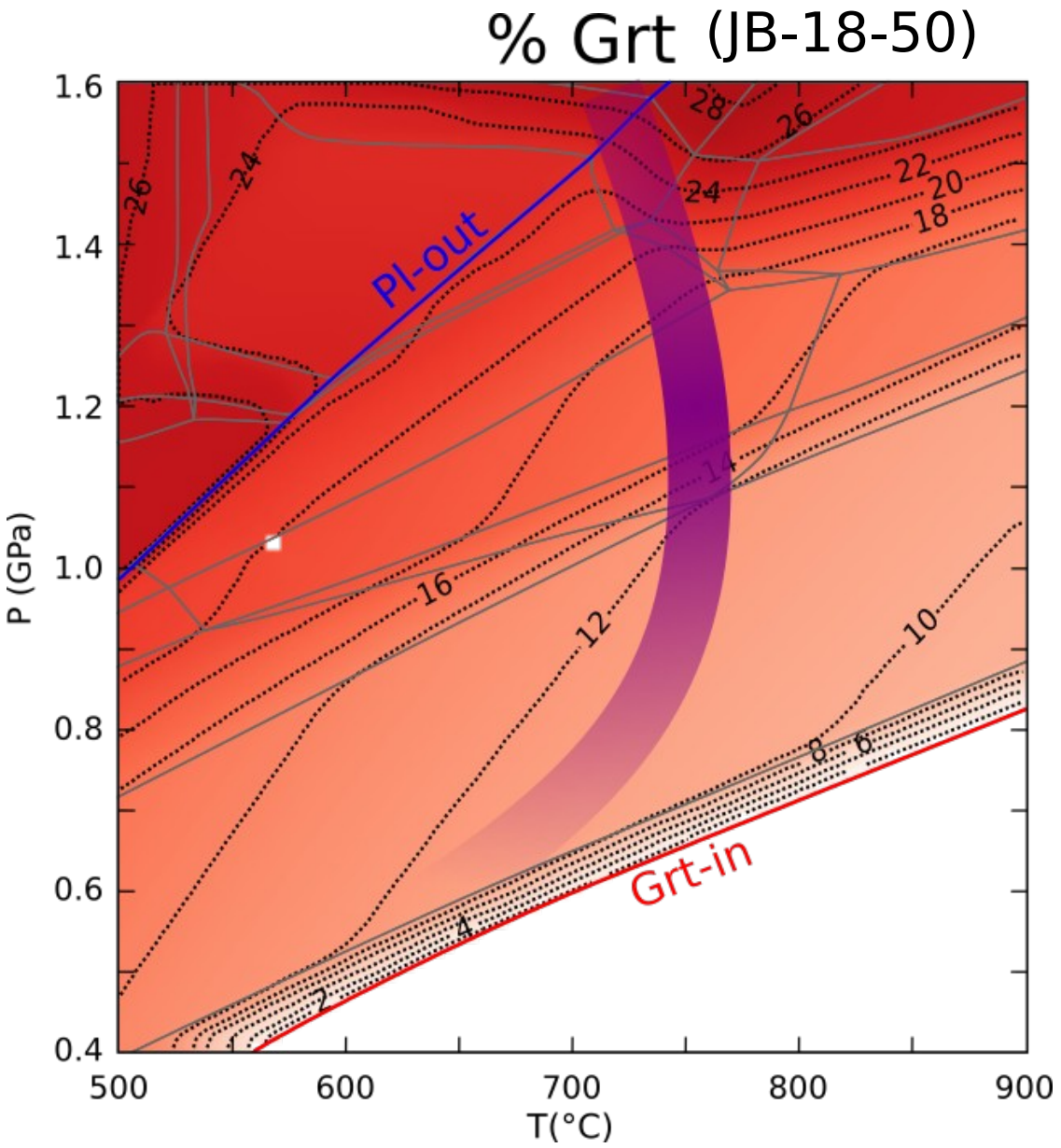
Correlation U-Pb ages / P-T evolution

When does zircon grows ?

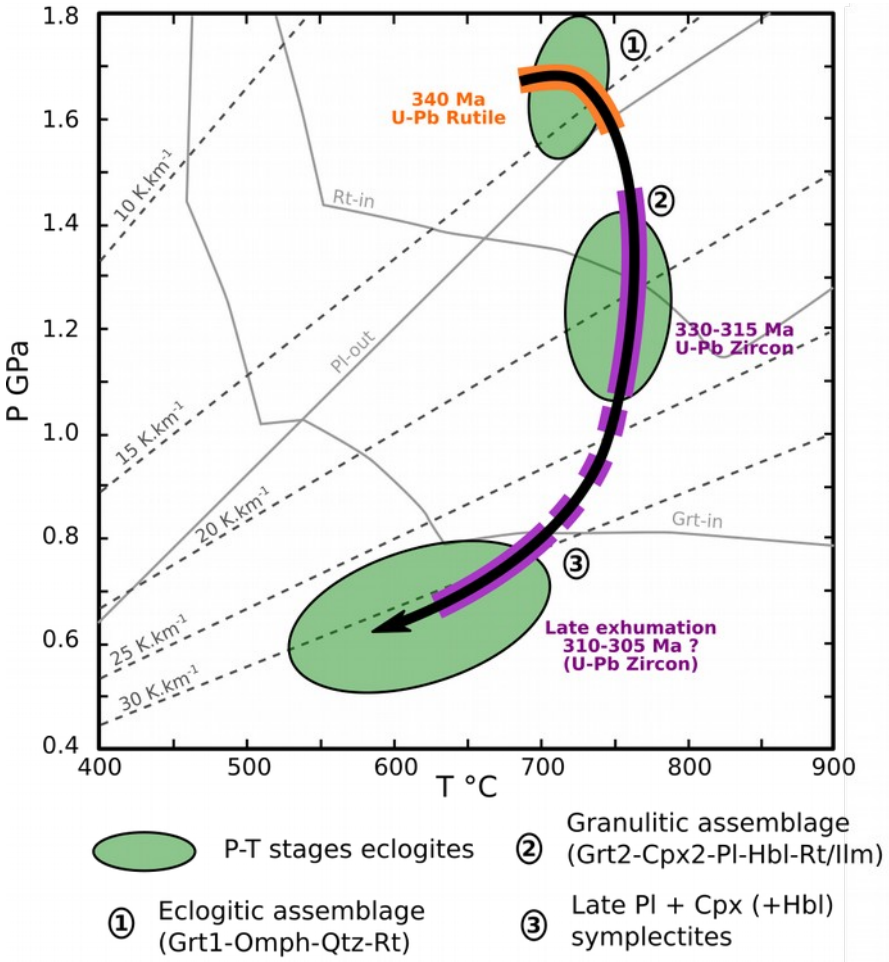
-Large spread of zircon ages, younger than rutile
-> post-dates the HP stage

REE in zircon:
- zircon growth starts in presence of garnet and absence of plagioclase, and then continues during garnet-breakdown

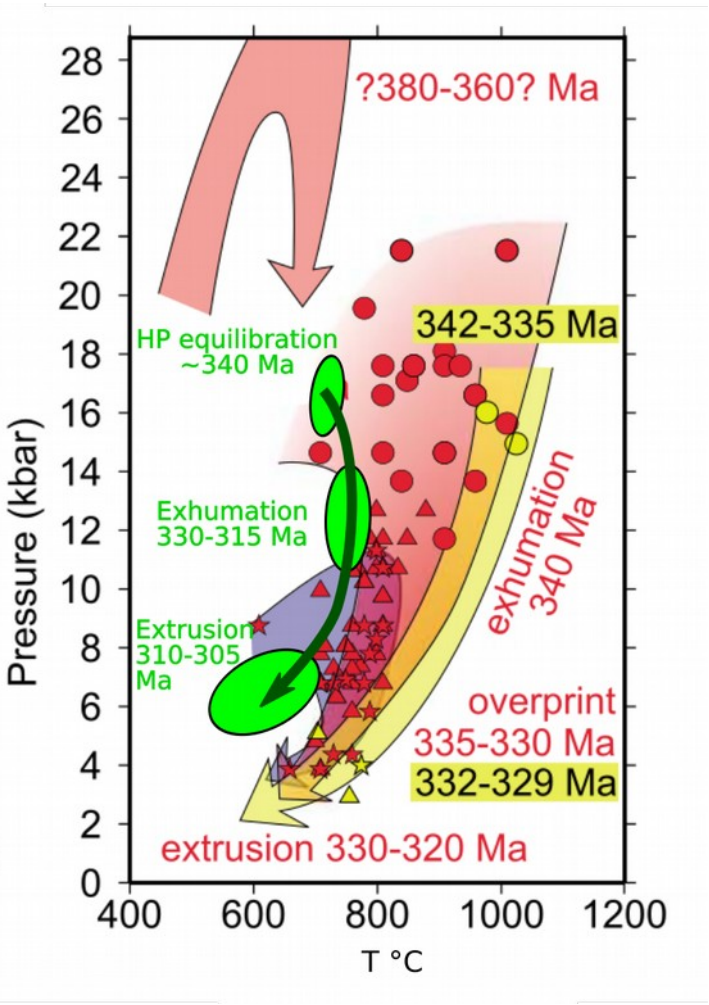
-> **Zircon growth during decompression**, with probably a peak at ca. 1.0-1.2 GPa corresponding to the crystallization of the HT assemblage



P-T-t evolution



P-T-t path for the ECM eclogites



Comparison with eclogites and HP granulites from the central and eastern Variscan Belt (Maierova et al. 2016)

P-T-t evolution

Main results

- Mid-Carboniferous age for the HP stage (340 Ma), with an equilibration along a HP-MT gradient (ca. 12-15°C/km), followed by decompression between ca. 330-315 Ma

- P-T-t evolution similar to the HP rocks from Argentera (Rubatto et al. 2010, Ferrando et al. 2008)

- No evidence of a former equilibration along a low-T gradient (<10°/km)

- Main exposures of HP rocks in the high-strain domains of the East-Variscan Shear Zone

Geodynamical interpretations

- No evidence for a Devonian subduction in the ECM

- HP metamorphic assemblage probably equilibrated in the orogenic lower crust during the main Visean nappe-stacking phases

- Localized exhumation of lower crustal domains possibly related to transpressive shearing in the EVSZ

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