Coupling tectonic and metamorphic processes: the Monte Rosa nappe (Western Alps)

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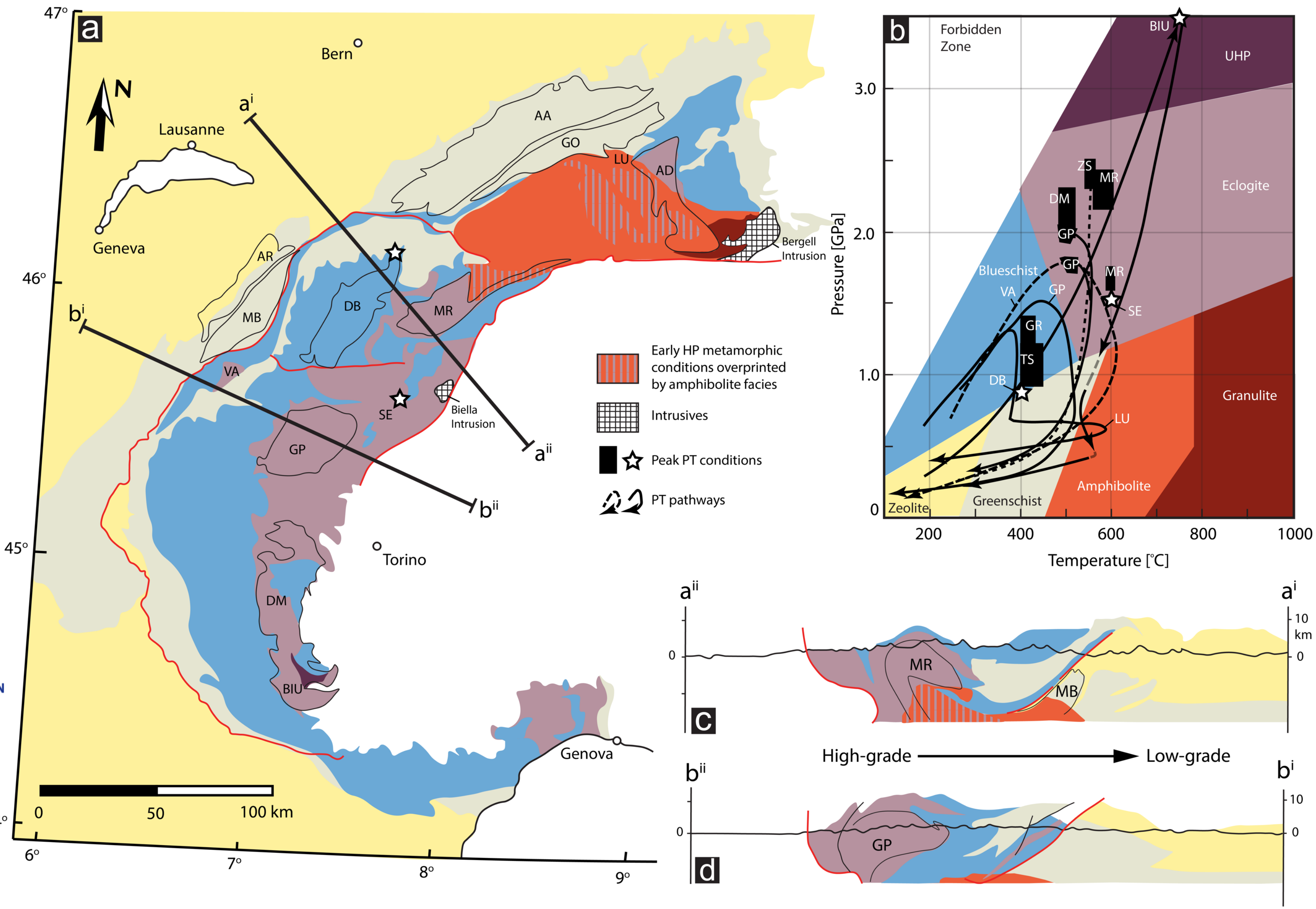
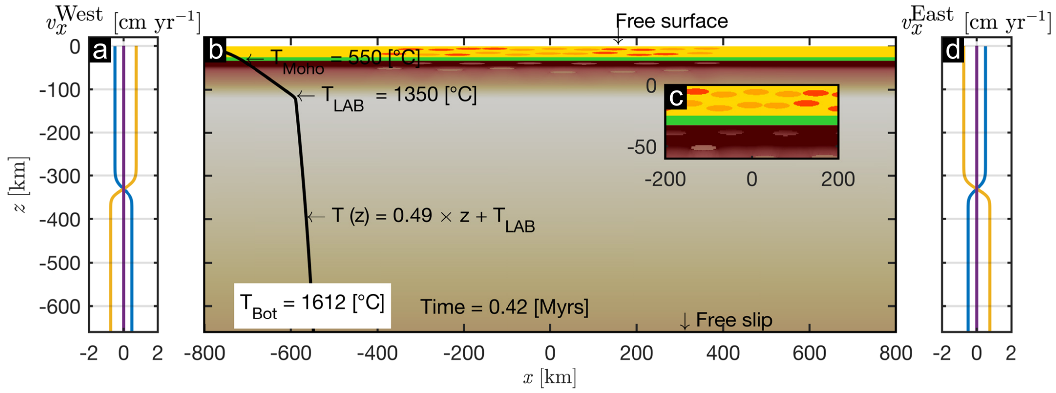
Metamorphic architecture of the western European Alps (modified after Bousquet et al., (2008))



Numerical modelling metamorphic architecture:

Coupling tectonics and metamorphism
J D Vaughan Hammon et al.,

Initial model configuration:

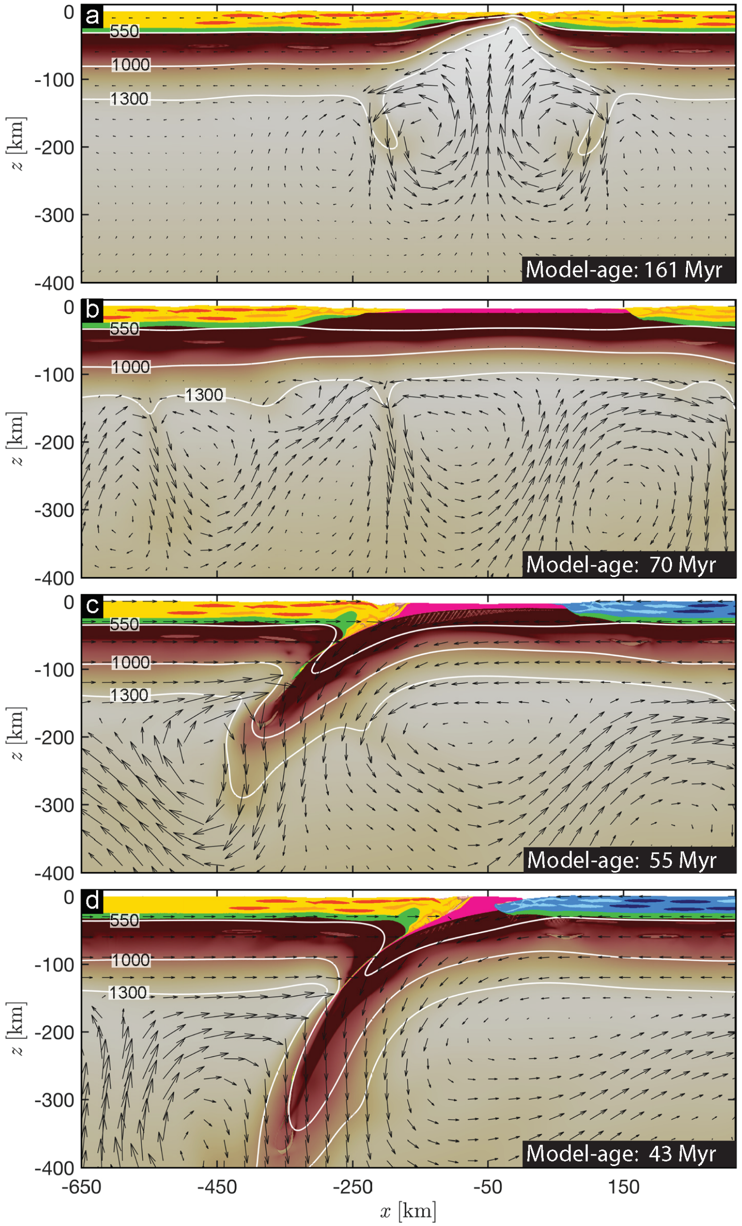


Legend

- Temperature [°C]
- Velocity field
- Weak inclusion
- Strong inclusion
- Upper crustal matrix
- Lower crust
- Mica | calcite sediments
- Serpentinite
- η_{eff} [Pa s] (10^{18}, 10^{20}, 10^{22}, 10^{24})
- Extension
- Cooling
- Convergence

In order to be applicable to the tectono-metamorphic evolution of the Western Alps, the model is divided into 4 distinct periods of activity, analogous to the Wilson Cycle involving embryonic oceans.

Model evolution:



(1) Extension (50 Myr, applying 1.0 cm yr^{-1} absolute boundary velocity) of a rheologically heterogeneous lithosphere which leads to the formation of magma-poor continental margins bounding a marine basin floored by exhumed mantle.

(2) A 60 Myr period without far-field extension or convergence (0 cm yr^{-1} applied boundary velocity) allowing for thermal equilibration of the evolved basin margin system. At the end of this period, we parameterize a serpentinization front propagating through the upper portions of the exhumed mantle (3 and 6 km).

(3) Convergence is applied with 1.5 cm yr^{-1} absolute boundary velocity for 30 Myr to model subduction initiation and basin closure.

(4) The applied boundary velocity is reduced to 1.0 cm yr^{-1} for the rest of the simulation during which we model subduction and exhumation of continental crust and serpentinites.

Let's explore continental collision further...

Paleogeography at a convergent plate boundary:

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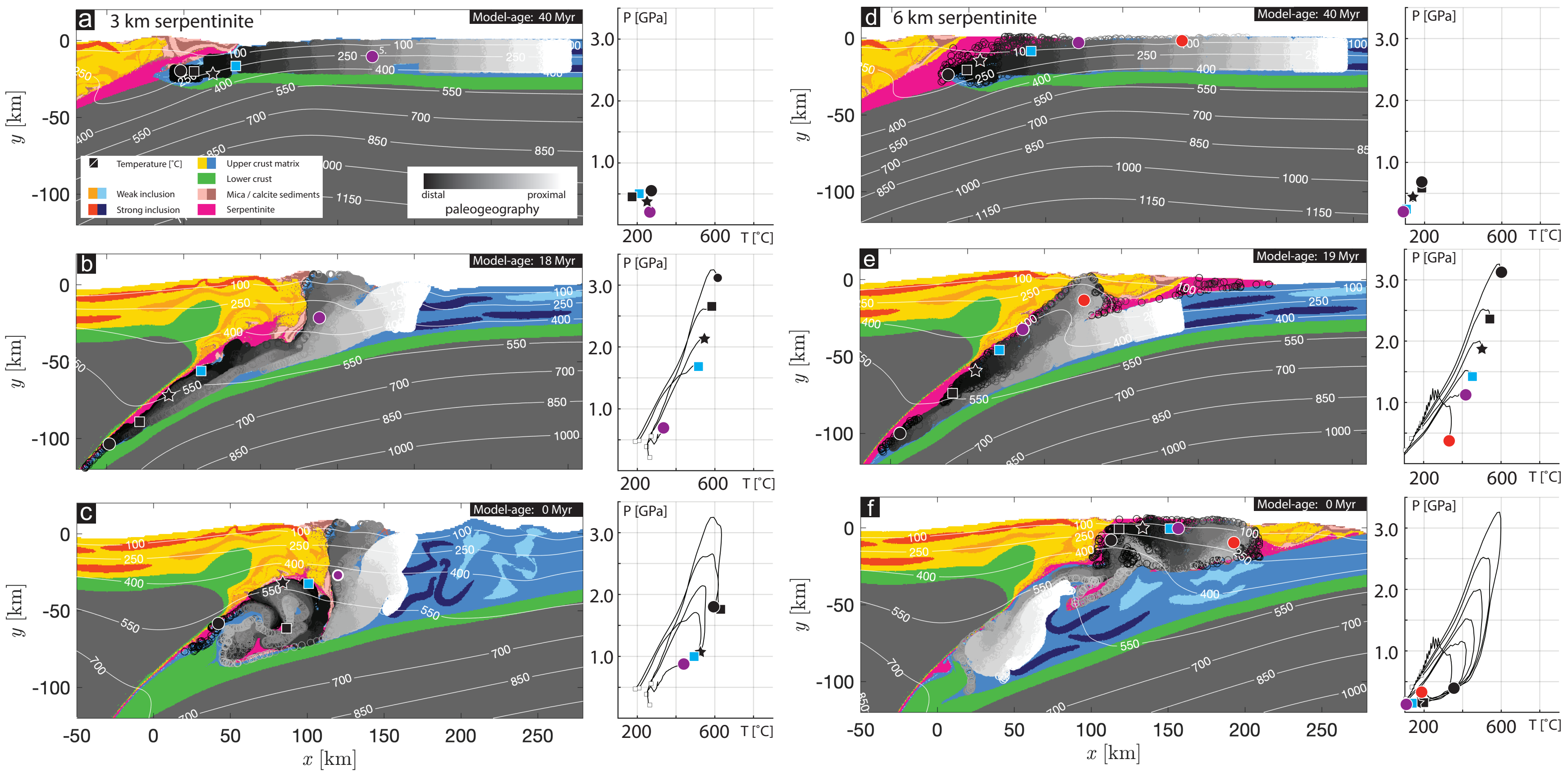
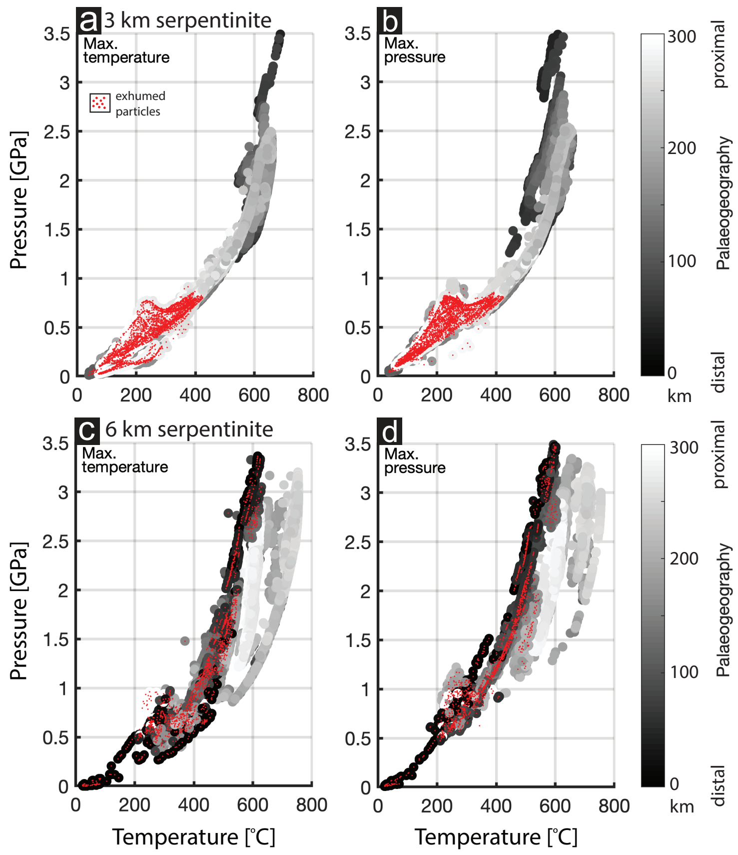
Marker-in-cell method enables physical quantities to be traced throughout the model evolution, including initial paleogeography at the passive margin prior to subduction and exhumation.



Peak P-T conditions and paleogeography



Numerical modelling metamorphic architecture:

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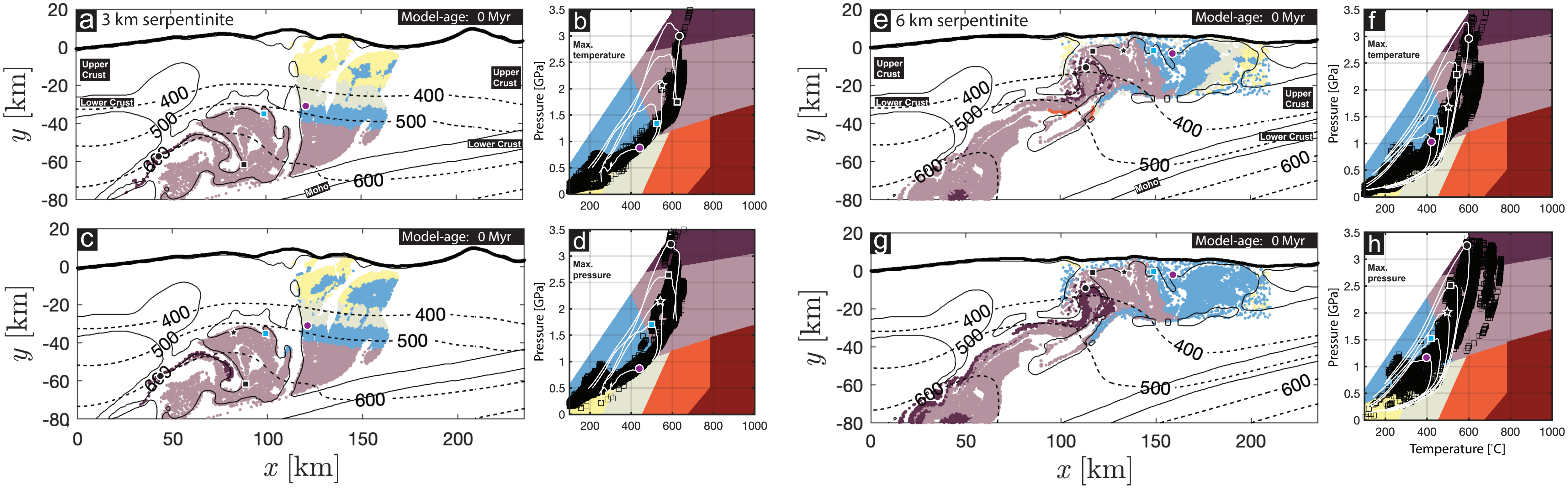
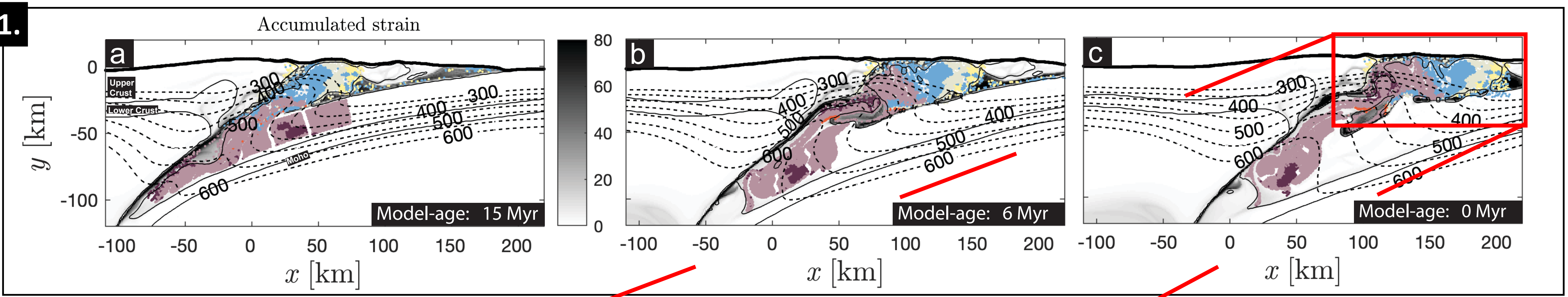
Marker-in-cell method enables physical quantities to be traced throughout the model evolution, including peak metamorphic conditions. Peak conditions (max. P or max. T) are used to define a metamorphic facies based on a simplified metamorphic grid (modified after Philpotts & Ague, 2009).



3 km serpentinite model shows a vertical gradient in metamorphic facies

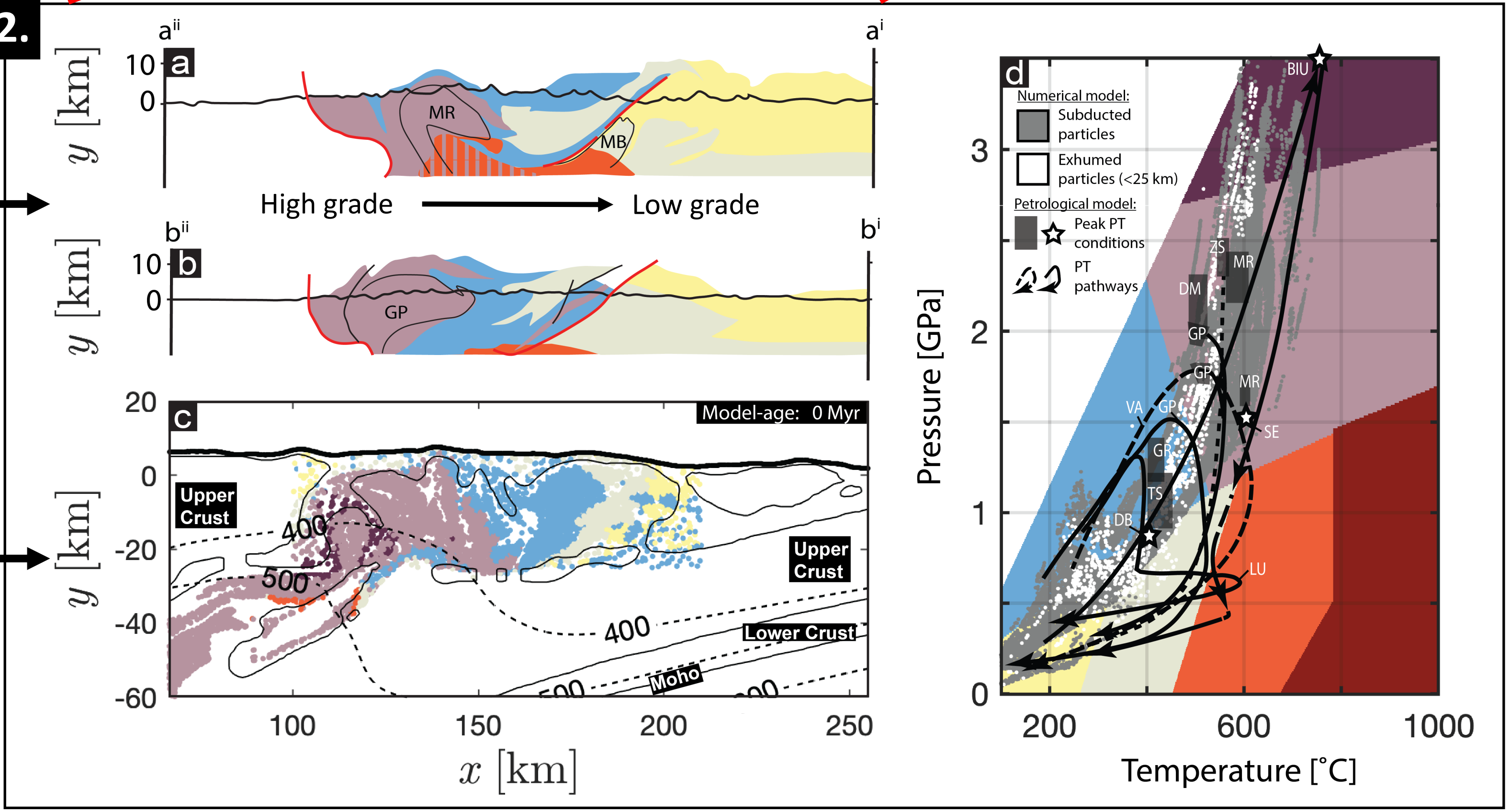
6 km serpentinite model shows a laterally varying metamorphic gradient

Numerical modelling metamorphic architecture:



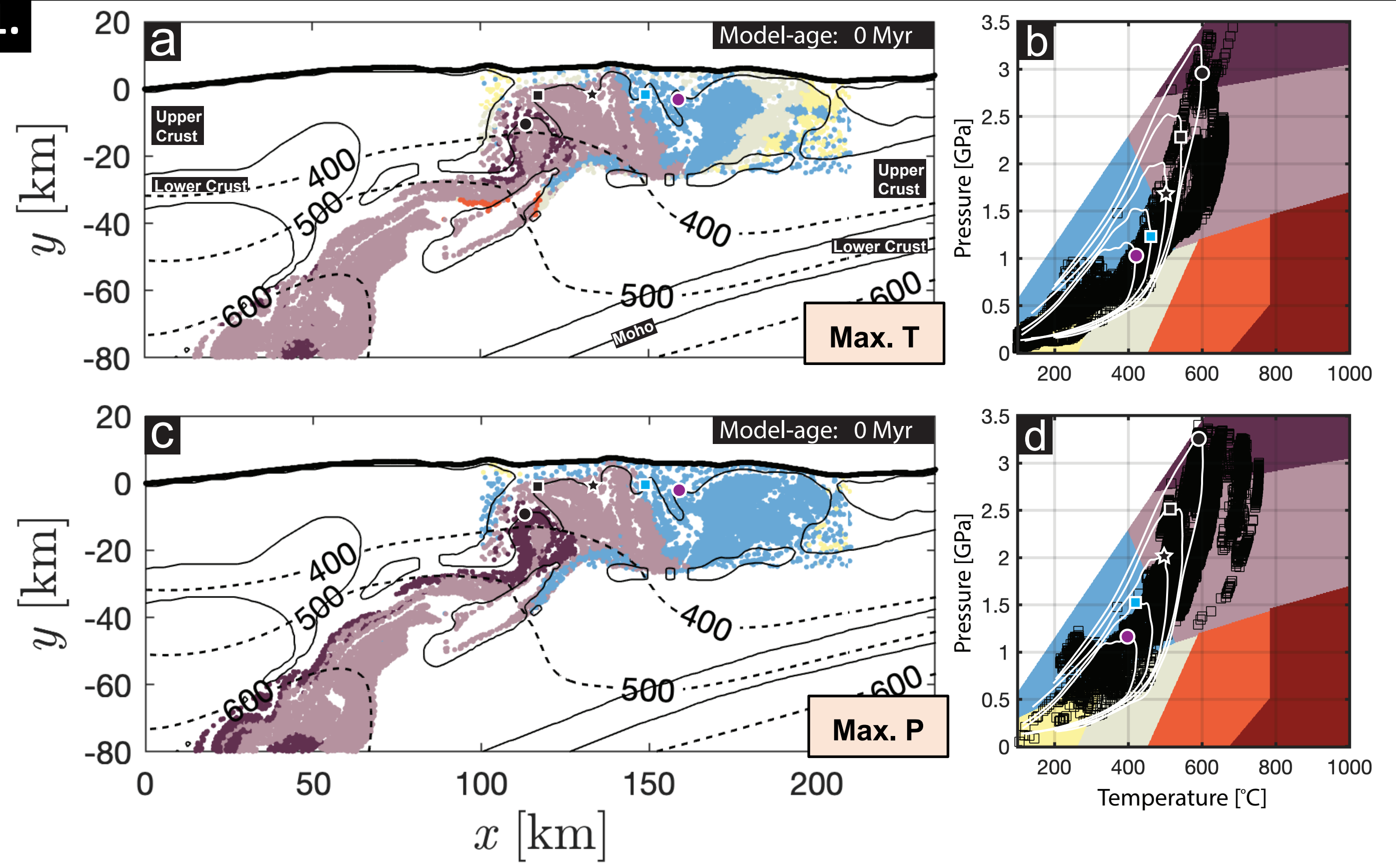
Metamorphic section in the western European Alps (modified after Bousquet et al., (2008))

Results of numerical model

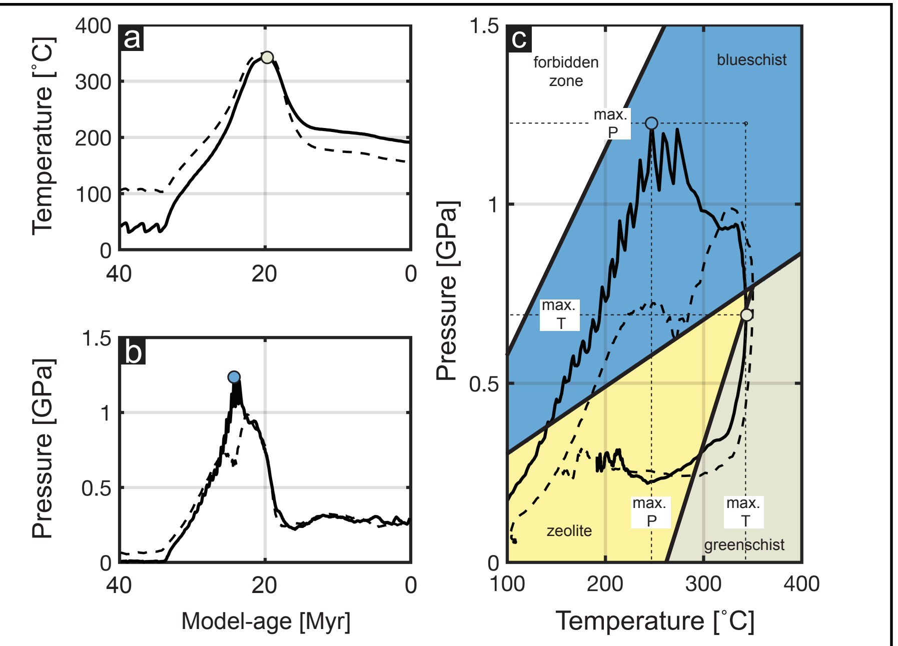


Temperature- or pressure-dominated metamorphism?

1.



2.

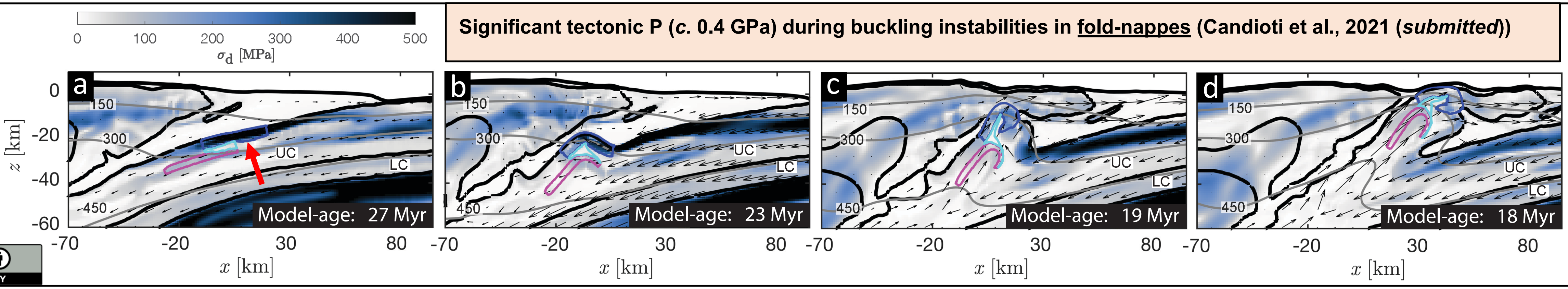


Disparity between max. P and max. T metamorphic facies:

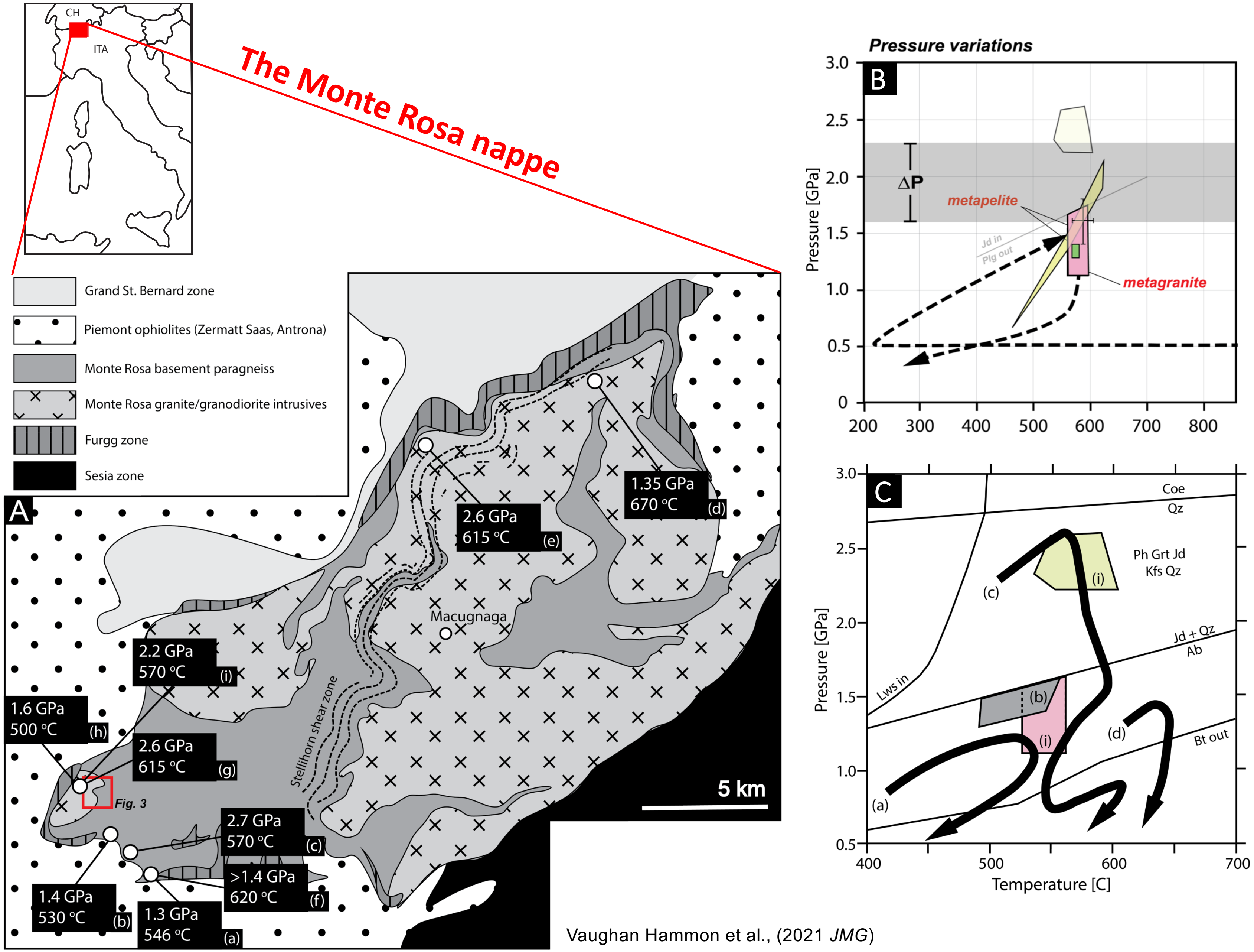
- **Max. P => blueschist**
- **Max. T => greenschist**

3.

Significant tectonic P (*c.* 0.4 GPa) during buckling instabilities in <u>fold-nappes</u> (Candioti et al., 2021 (*submitted*))



Nappe-scale pressure variations:



Vaughan Hammon et al., (2021 *JMG*)

Why pressure difference? Possible explanations:

1) Mechanical P variations

2) Tectonic mélange

3) Granite did not record peak-P
(a) sluggish kinetics
(b) retrogression

(Not supported: Luisier et al., 2019)

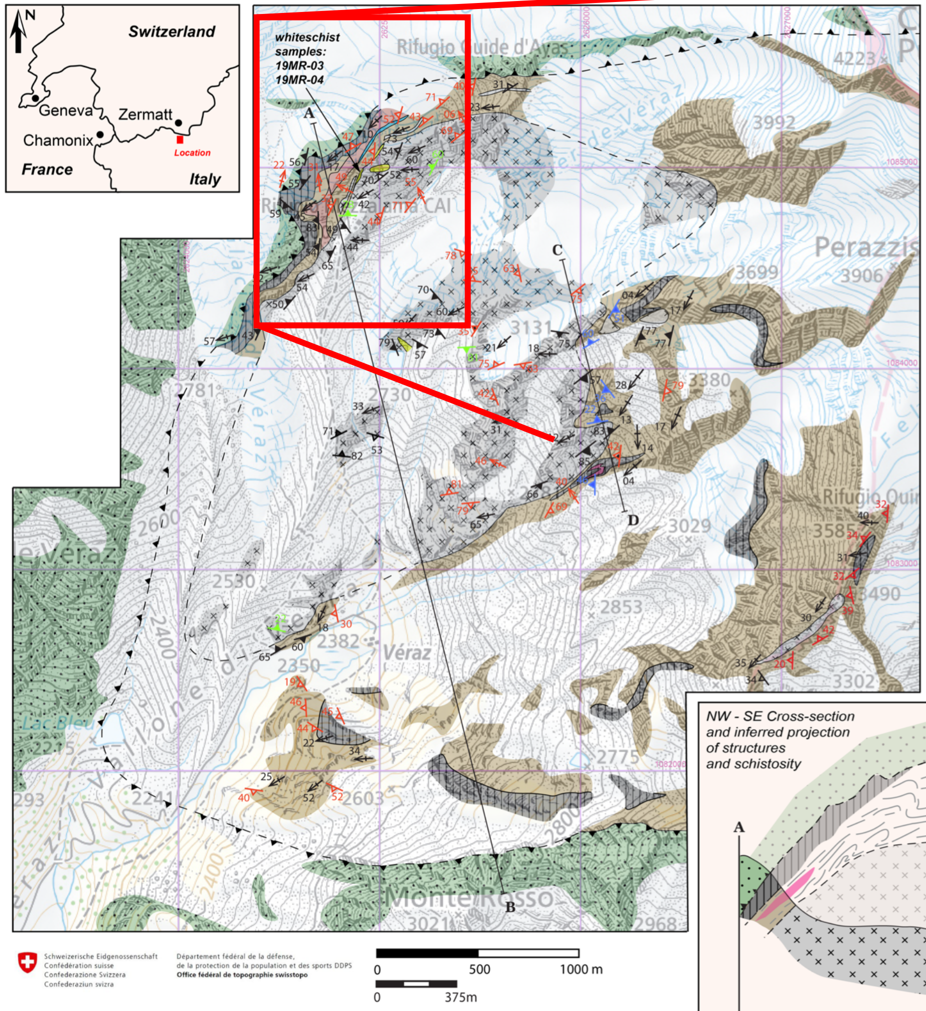
4) Thermodynamic database

(Not supported: Luisier et al., (2019), Vaughan Hammon et al., (2021))

(a) Borghi et al., 2004
(b) Dal Piaz and Lombardo 1986
(c) Gasco et al., 2011
(d) Keller et al., 2004
(e) Le Bayon et al., 2006
(f) Lapen et al., 2007
(g) Le Bayon et al., 2006
(h) Chopin and Monie 1984
(i) Luisier et al., 2019

The Monte Rosa nappe at val d’Ayas, Italy:

Coupling tectonics and metamorphism
J D Vaughan Hammon et al.,



Zermatt-Saas Ophiolite suite:

Exposure of lower portions of ophiolite units of the Zermatt-Saas derived from Mesozoic oceanic domains. A diverse suite of lithologies have been grouped together due to a differing palaeo-geographic origin compared to the underlying Monte Rosa nappe. A large structural discontinuity lies at the base of this sequence, interpreted to be a tectonic contact.

Serpentanite, meta-basalts, meta-gabbros, meta-rodingite.

Monte Rosa Basement suite:

Exposure of the far western extent of the Monte Rosa nappe. A diverse group of lithologies are highlighted within the structurally highest portions of the continental inner Penninic nappe. Metamorphic assemblages are preserved in areas, ranging from Late-Palaeozoic Variscan orogenesis, Permian magmatism through to Eocene Alpine Orogenesis.

- *Metapelites*
- *Diopside bearing metacarbonates*
- *Metavolcano-sedimentary with mafic boudins (Furgg Zone)*
- *Garnet bearing micaschists with mafic boudins (Furgg Zone)*

Monte Rosa Intrusive suite:

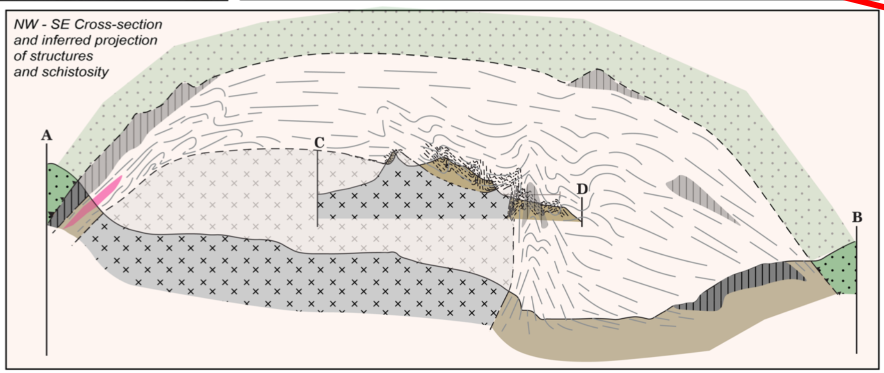
- *Metagranite, granodiorite, pegmatites, aplites*
- *White mica, talc, chloritoid + quartz bearing ‘whiteschists’*

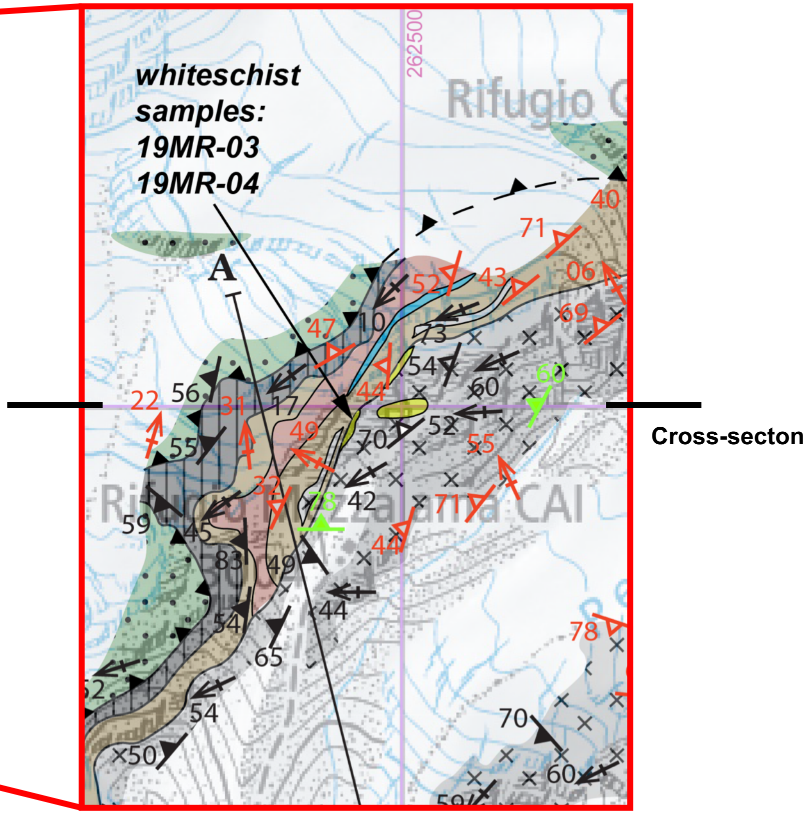
Symbols:

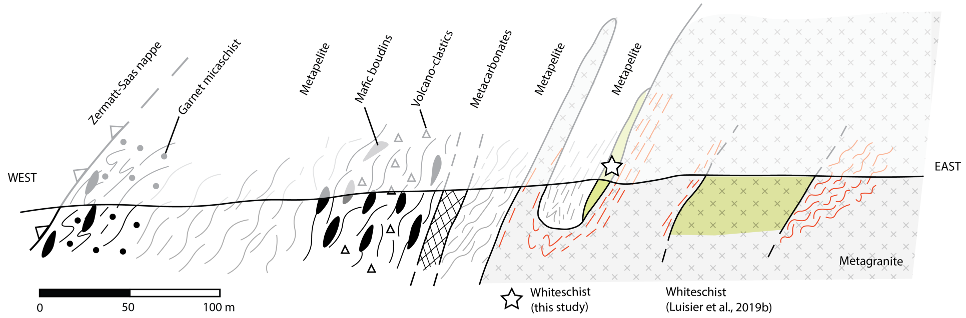
- *Geological contact (observed)*
- *Geological contact (inferred)*
- *Tectonic contact*
- *Trace of cross-section* (A–B)
- *Trace of schistosity*

Interpretted structural delineations:

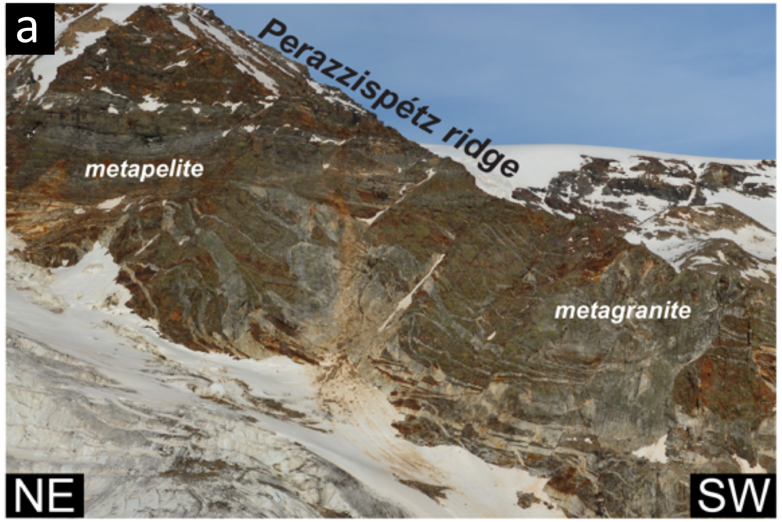
- *(S1) pre-Intrusive schistosity*
- *(S2) early Alpine schistosity*
- *(D2) early Alpine lineation*
- *(S3) late Alpine schistosity*
- *(D3) late Alpine folding axial plunge*
- *(S4) late Alpine brittle fault*





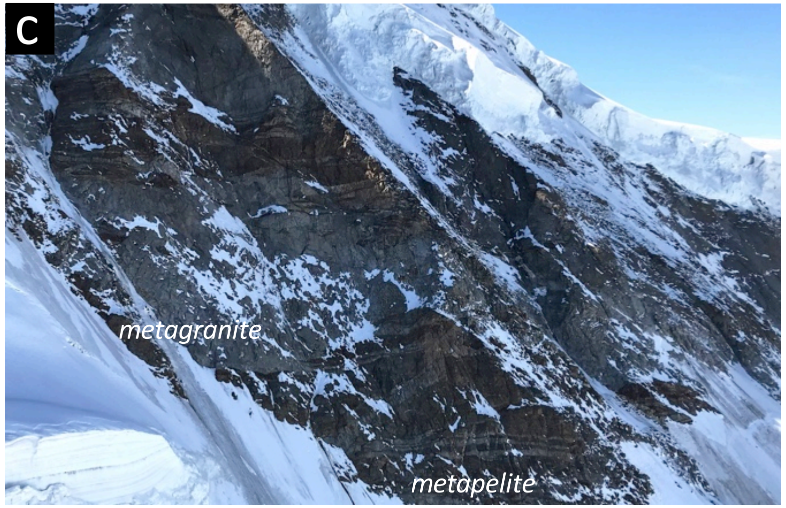


Coherency in the Monte Rosa nappe:

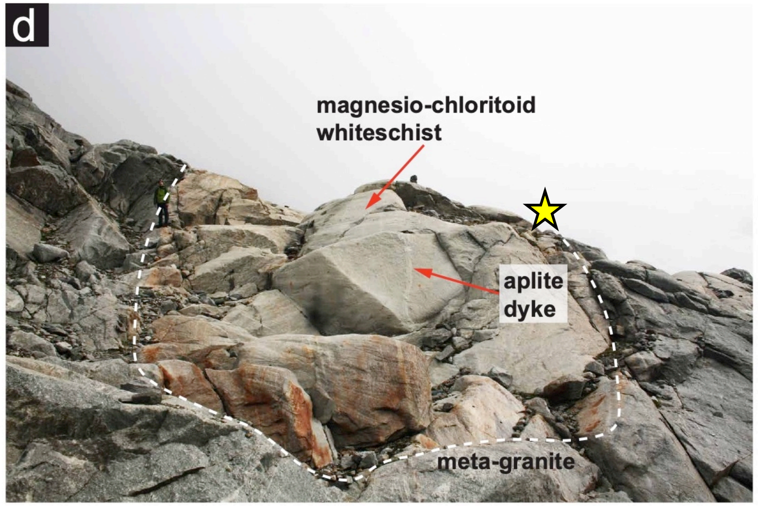


Large-scale pre-Alpine igneous structures observable (val d'Ayas, IT)

Contact within the basement (val d'Ayas, IT)

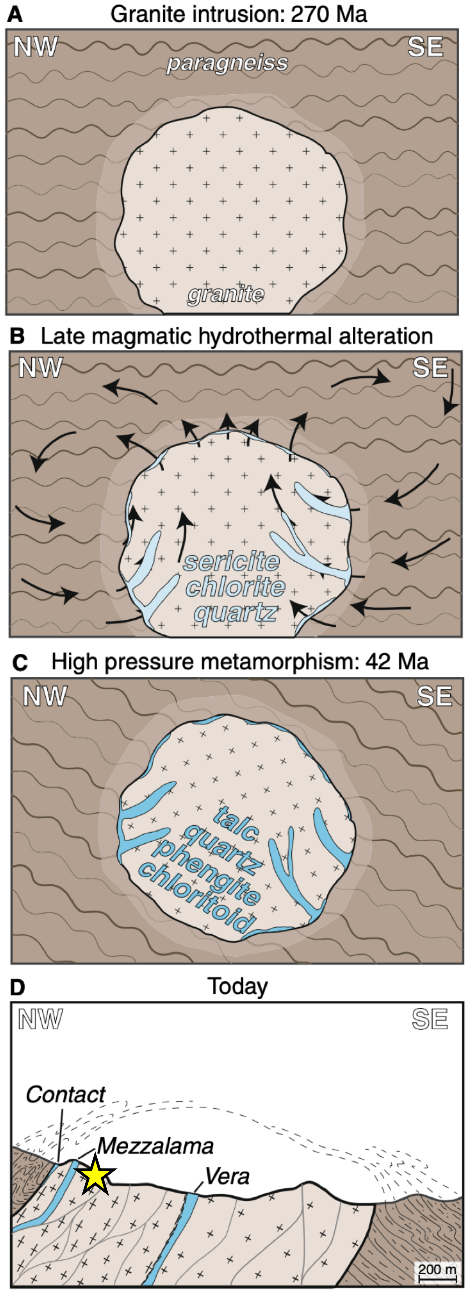


Large-scale pre-Alpine igneous structures observable (Jägerhorn summit, CH)



Igneous structures observed within whiteschist (val d'Ayas, IT)

Luisier et al., (2021)



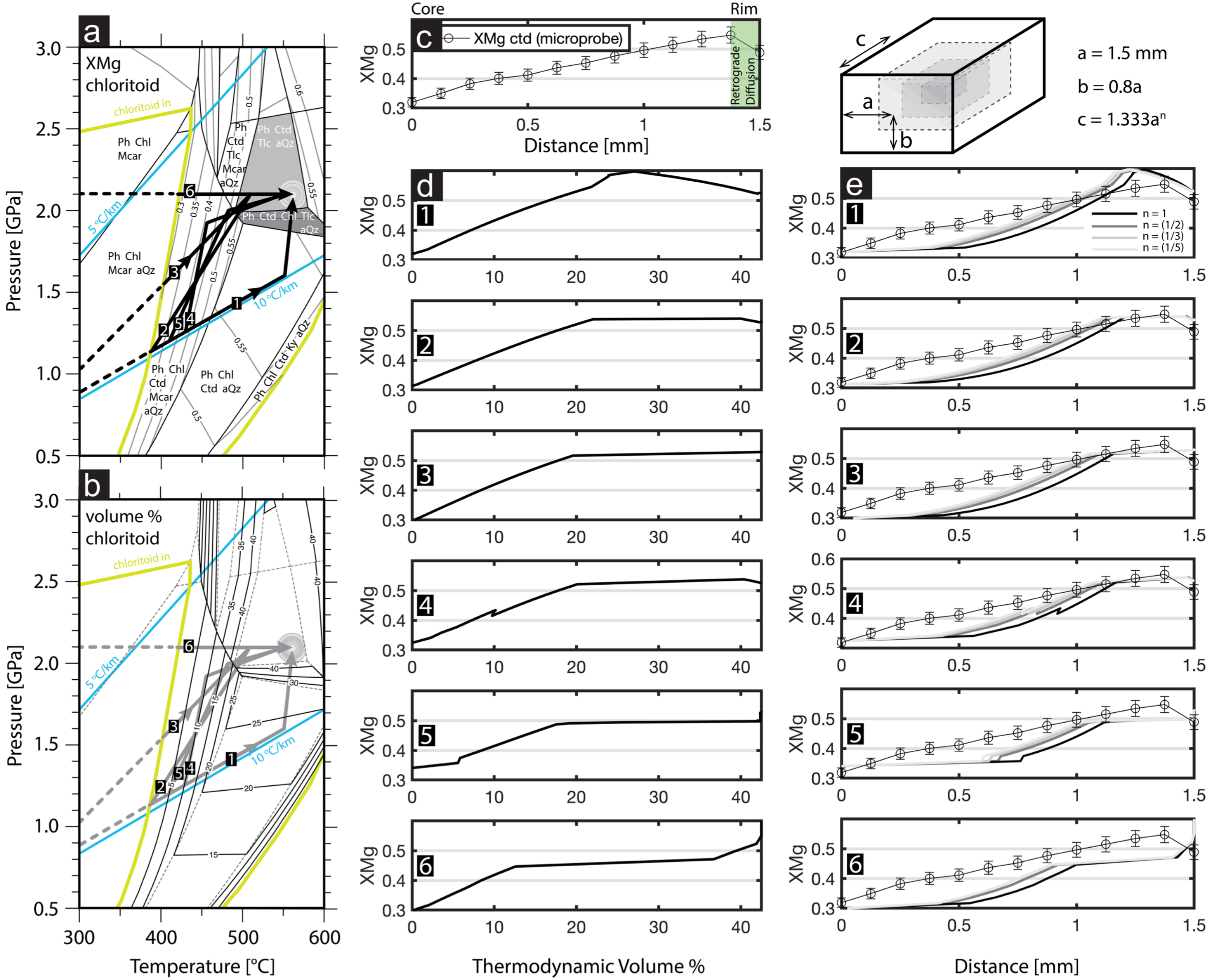
New whiteschist results:

Whiteschist at contact (val d'Ayas, IT)

2.2 ± 0.1 GPa

560 ± 20°C

To better constrain the prograde pressure-temperature history of the Monte Rosa nappe during Alpine orogenesis, we compare Mg zoning in chloritoid from natural samples of whiteschist lithologies with several pressure-temperature pathways and the corresponding Mg zoning predicted by pseudo-section modelling. Our results indicate that pseudo-section modelling predicts well the observed zoning in chloritoid, suggesting that the whiteschist paragenesis grew under conditions close to equilibrium. Our results also reveal that the whiteschist likely deviated from the prograde burial pathway recorded in other lithologies in order to have a ca. 0.6 GPa higher pressure. However, the exact conditions at which the whiteschist deviated are still contentious due to the strong temperature dependency of Mg partitioning in whiteschist assemblages. Our pseudo-section results suggest that there was no dramatic isothermal dynamic pressure increase recorded in the whiteschist.



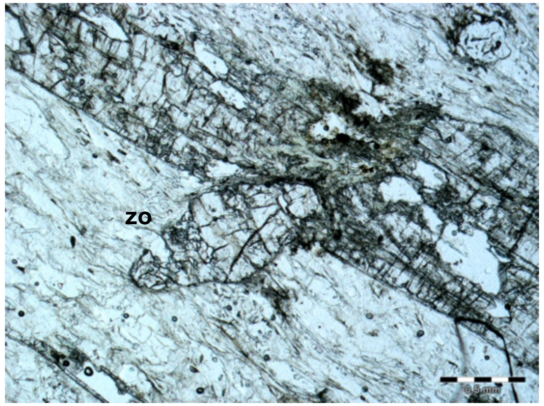
New whiteschist results:

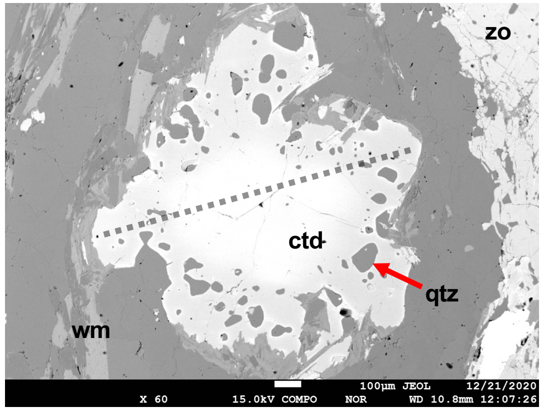
Whiteschist?? (Jägerhorn, Macugnaga, IT)

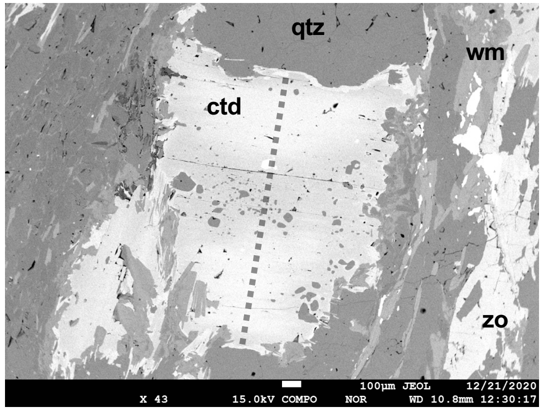
Unique assemblage:

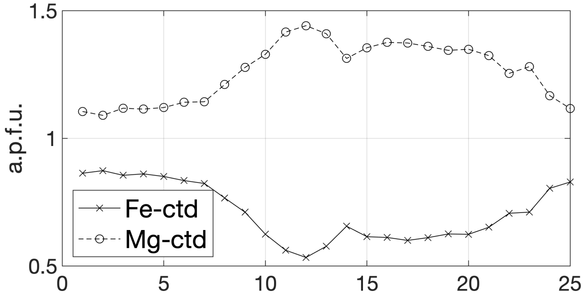
white mica, chloritod, zoisite, quartz

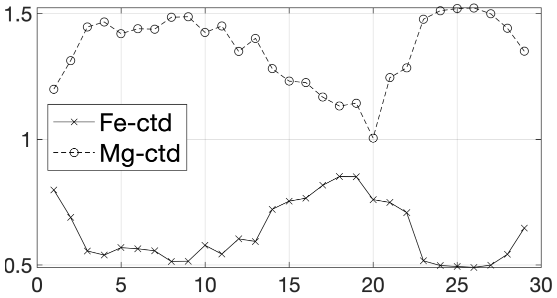
(no talc)

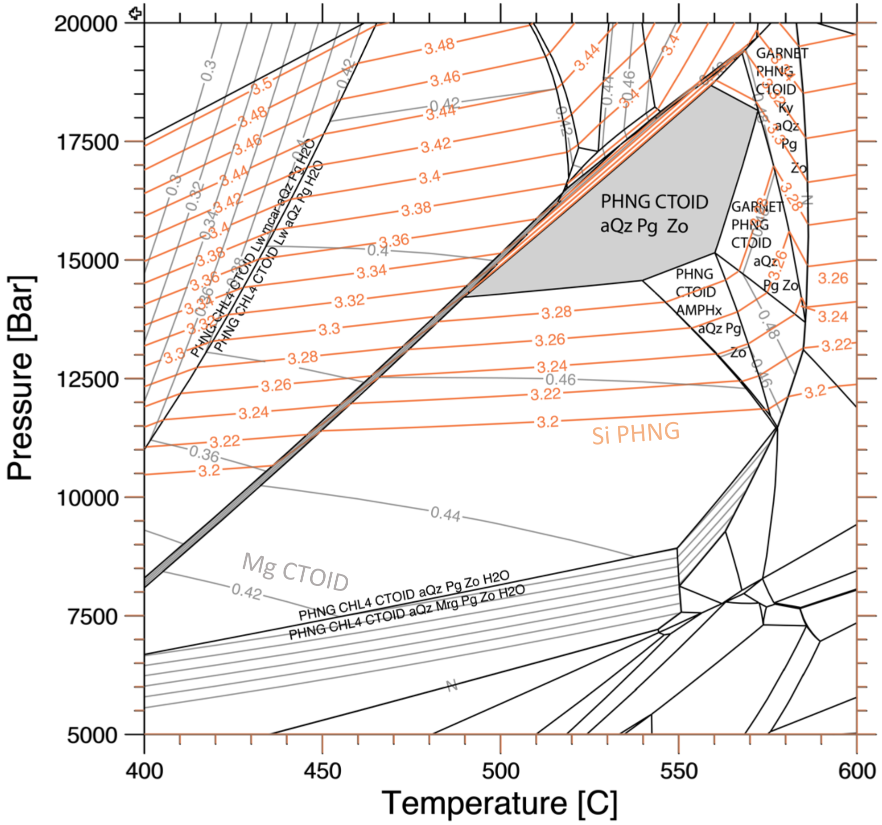












Preliminary:

1.65 ± 0.2 GPa

530 ± 40°C

More details on route:

https://www.camptocamp.org/outings/1250102/fr/traversee-du-jagerhorn-arete-est-descente-gorner-gletscher

Main conclusions:

1) Numerical modelling predicts subduction related metamorphic evolution/distribution within the Western Alps

2) No evidence for tectonic mélange in the upper Monte Rosa nappe

3) Most lithologies in the Monte Rosa record *c.* 1.6 GPa, whiteschist records higher *c.* 2.2 GPa

4) Peak temperatures are consistent between 550-600°C