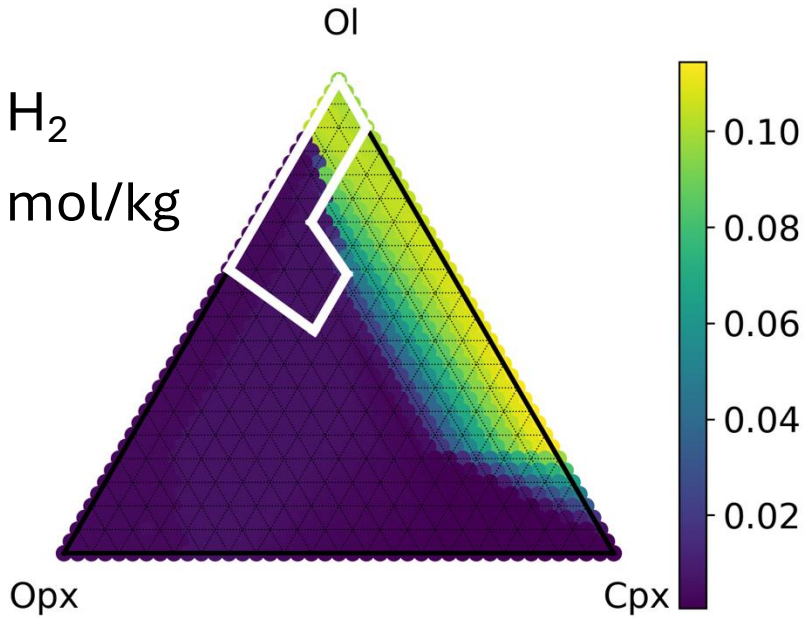
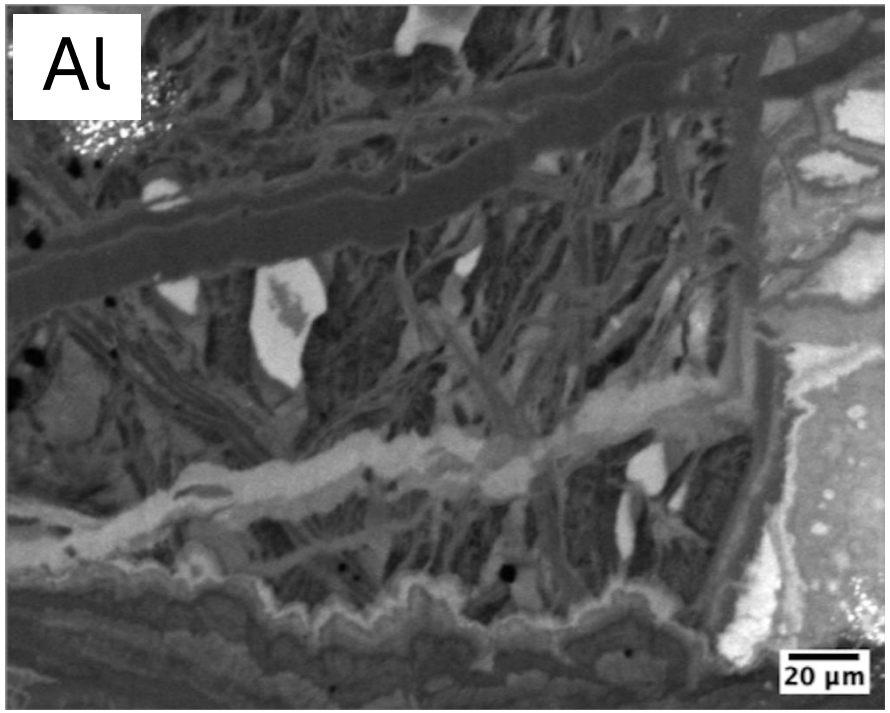




UNIVERSITÉ DE FRANCHE-COMTÉ

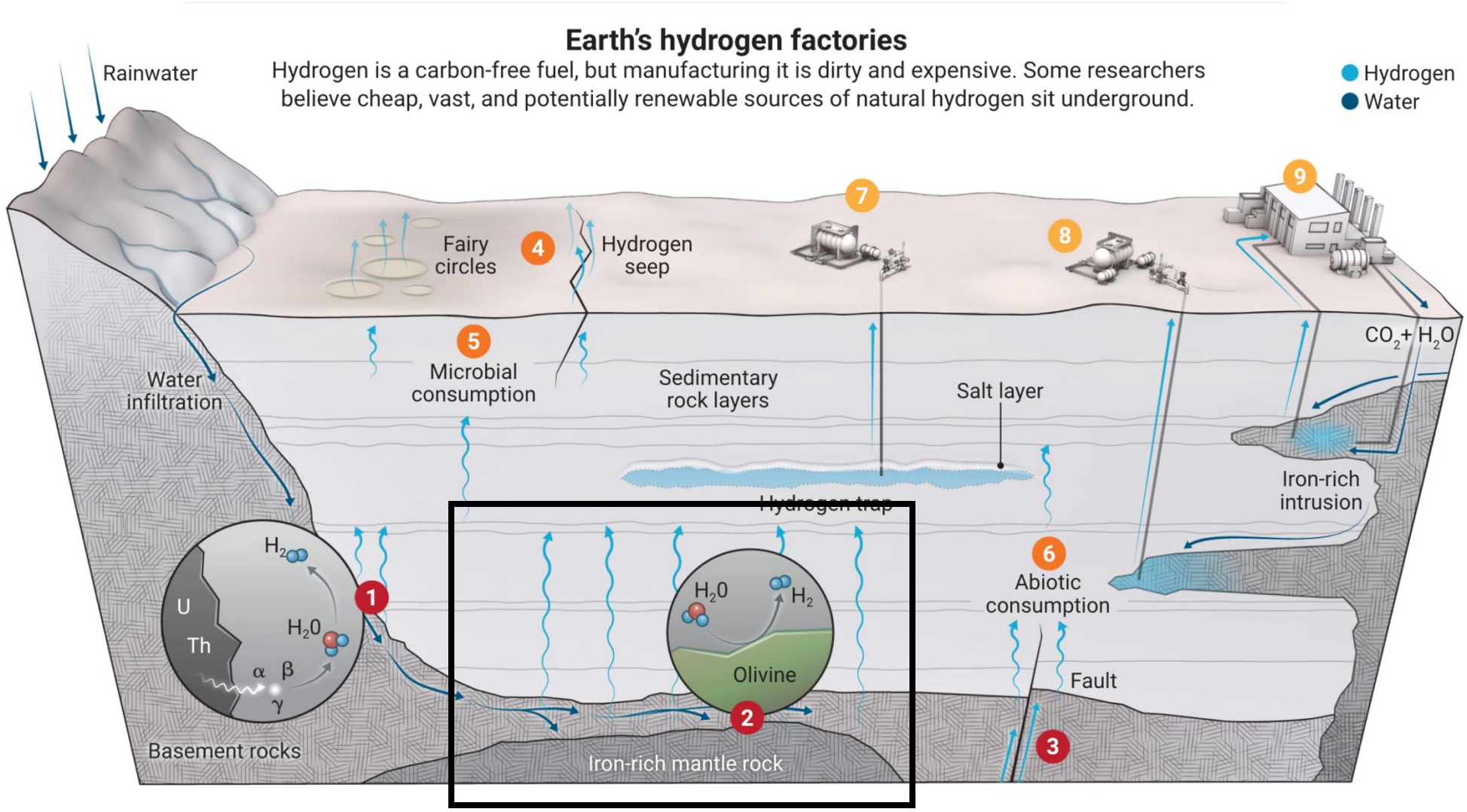
CHRONO ENVIRONNEMENT

La variable oubliée, l'impact de la salinité sur la production naturelle de H_2 lors de la serpentinisation

Guillaume Siron

Colloque annuel GDR HydroGeMM, 4-6 novembre 2024

H_2 cycle



Sciences, doi: 10.1126/science.adh1460

Serpentinization

Olivine

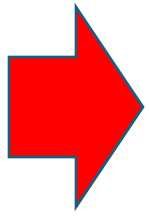
$(Mg\mathbf{Fe})_2SiO_4$

Fe^{2+}

+

Water

H_2O



Serpentine

$Mg_3Si_2O_5(OH)_4$

+

Magnetite

Fe_3O_4

Fe^{2+} et Fe^{3+}

+

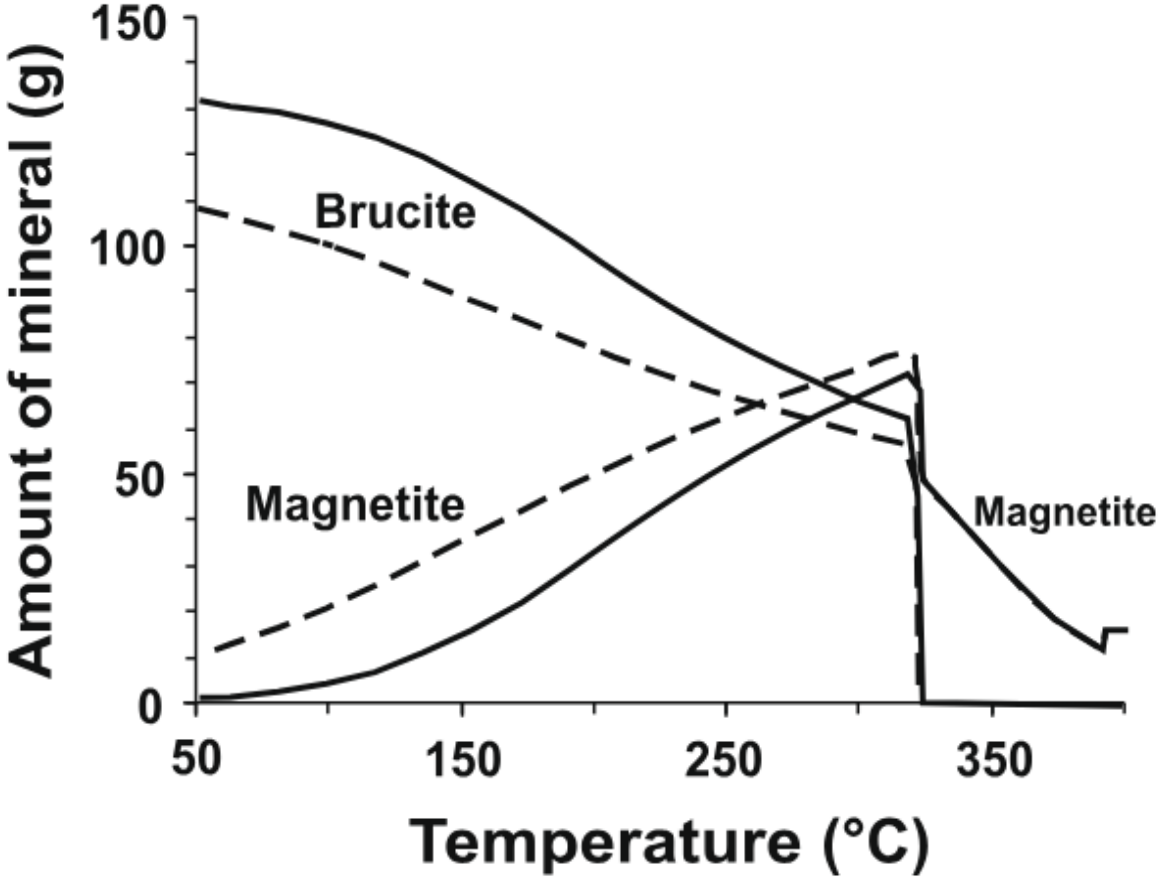
Hydrogen

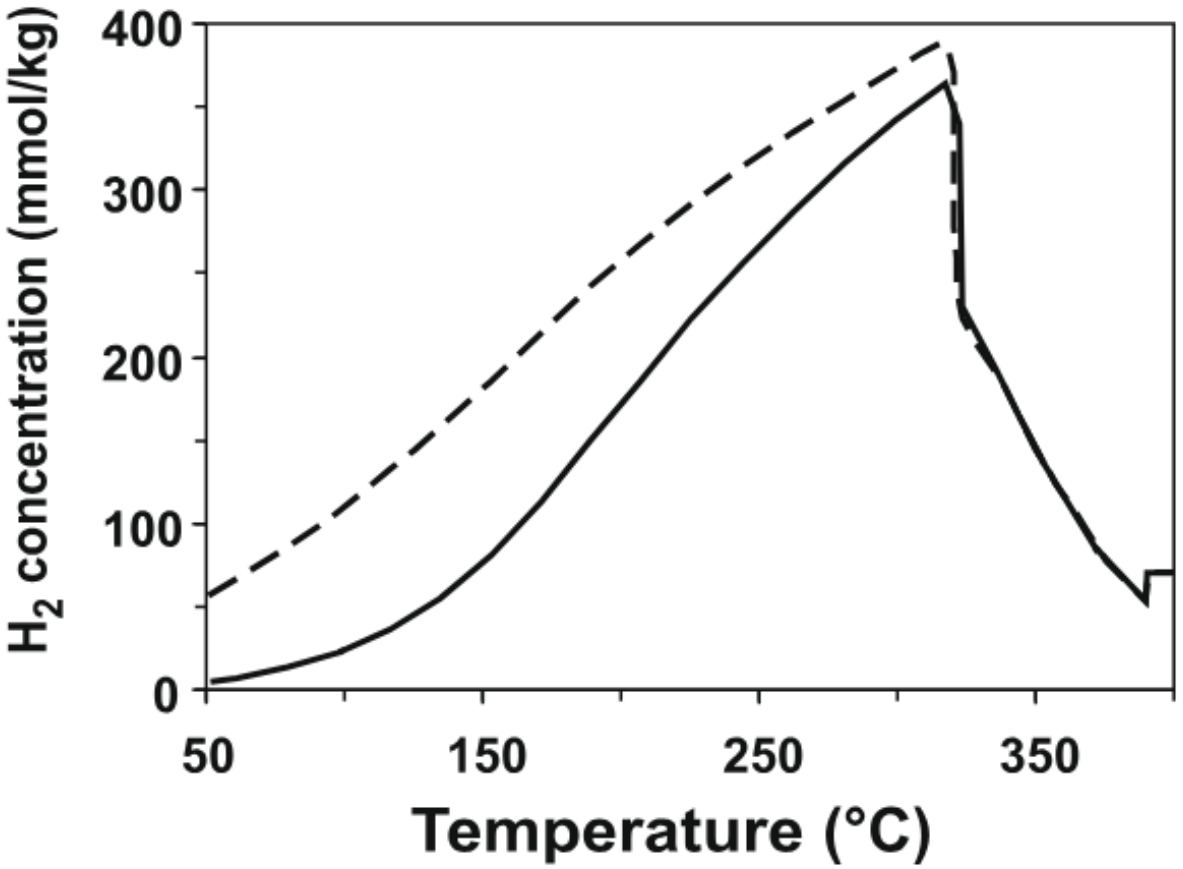
H_2

Serpentinization ⇒ important source of hydrogen

Oxidation of Fe in minerals

Serpentinization



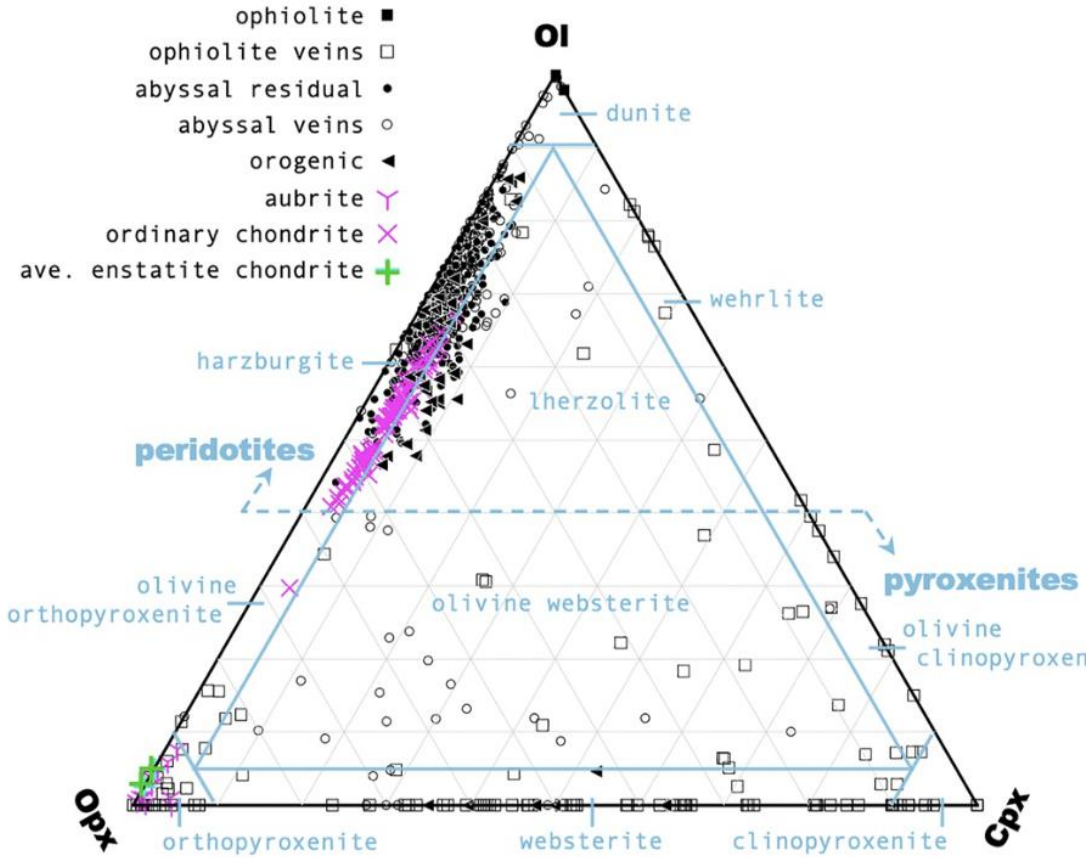


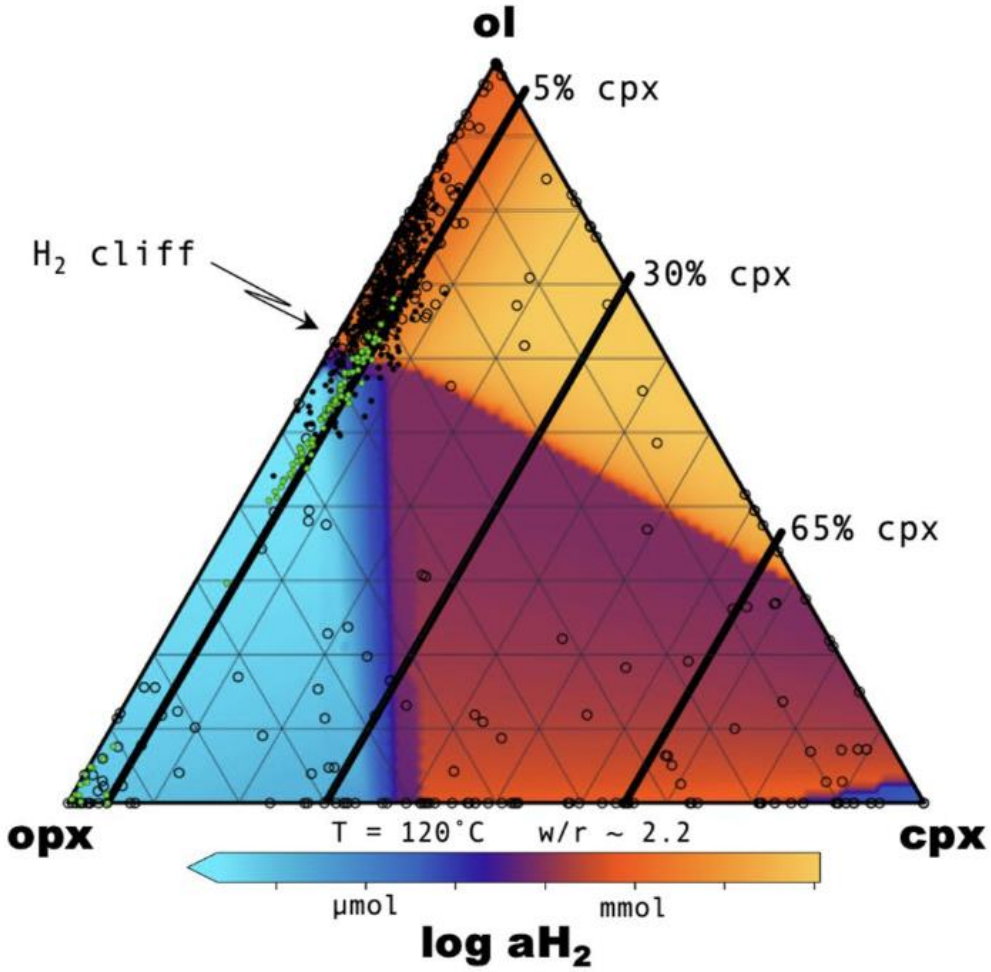
McCollum & Bach (2009)

Serpentinization and H_2 production are well known at seafloor

Maximum at about 300 °C, competition with Fe phases (Br, Ol)

Serpentinization





Ely et al. (2023)

Peridotite: variations in compositions

⇒ important and sharp variations in H_2 production

One (important) missing variable

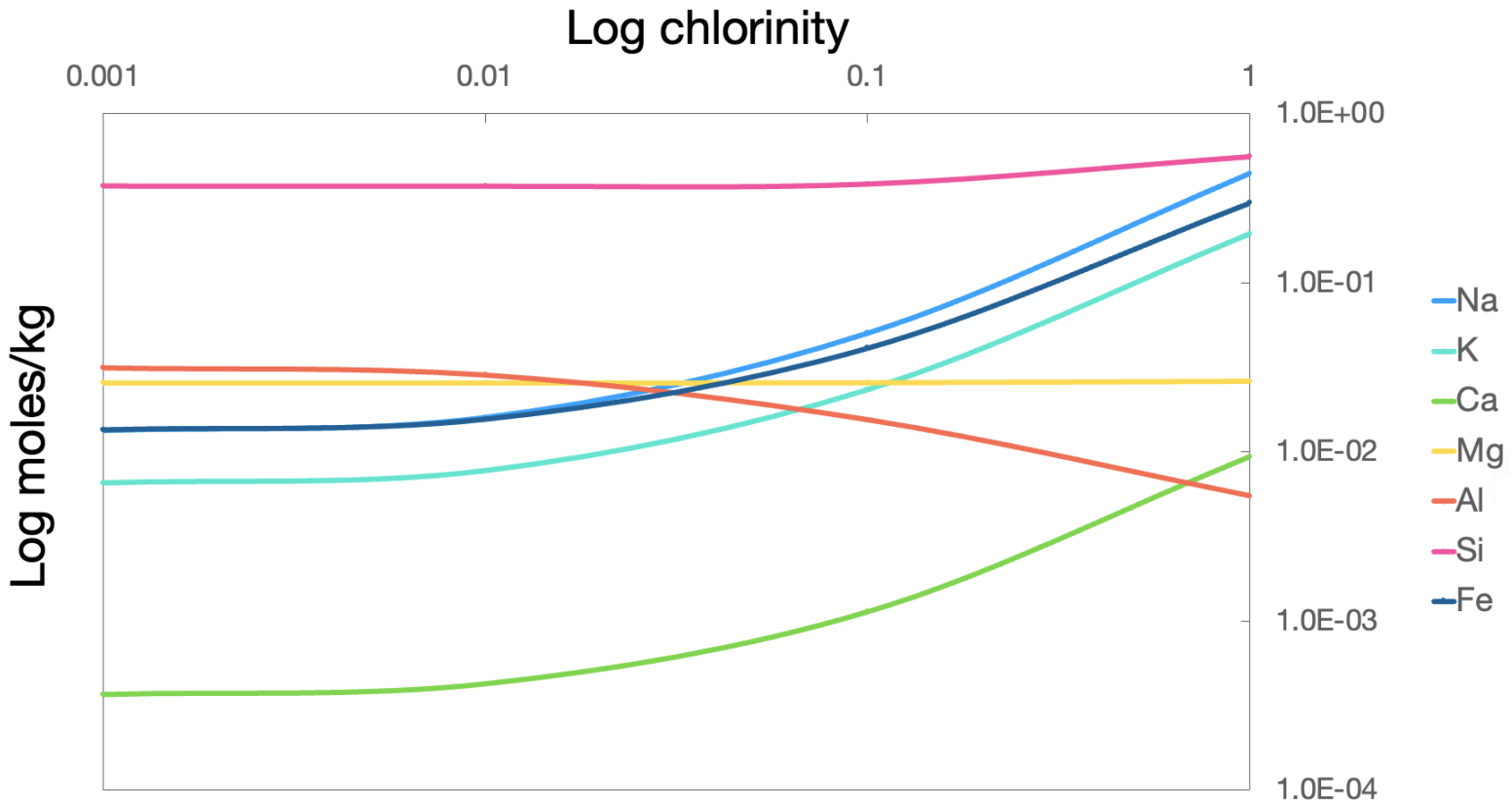
Cations complex with Cl:

HCl, NaCl, KCl, $MgCl_2$, $FeCl_2$, $CaCl_2$

→ Impact on solubilities

→ Impact on kinetics

Ms-Bt schist at 600 °C and 0.5 GPa



One (important) missing variable

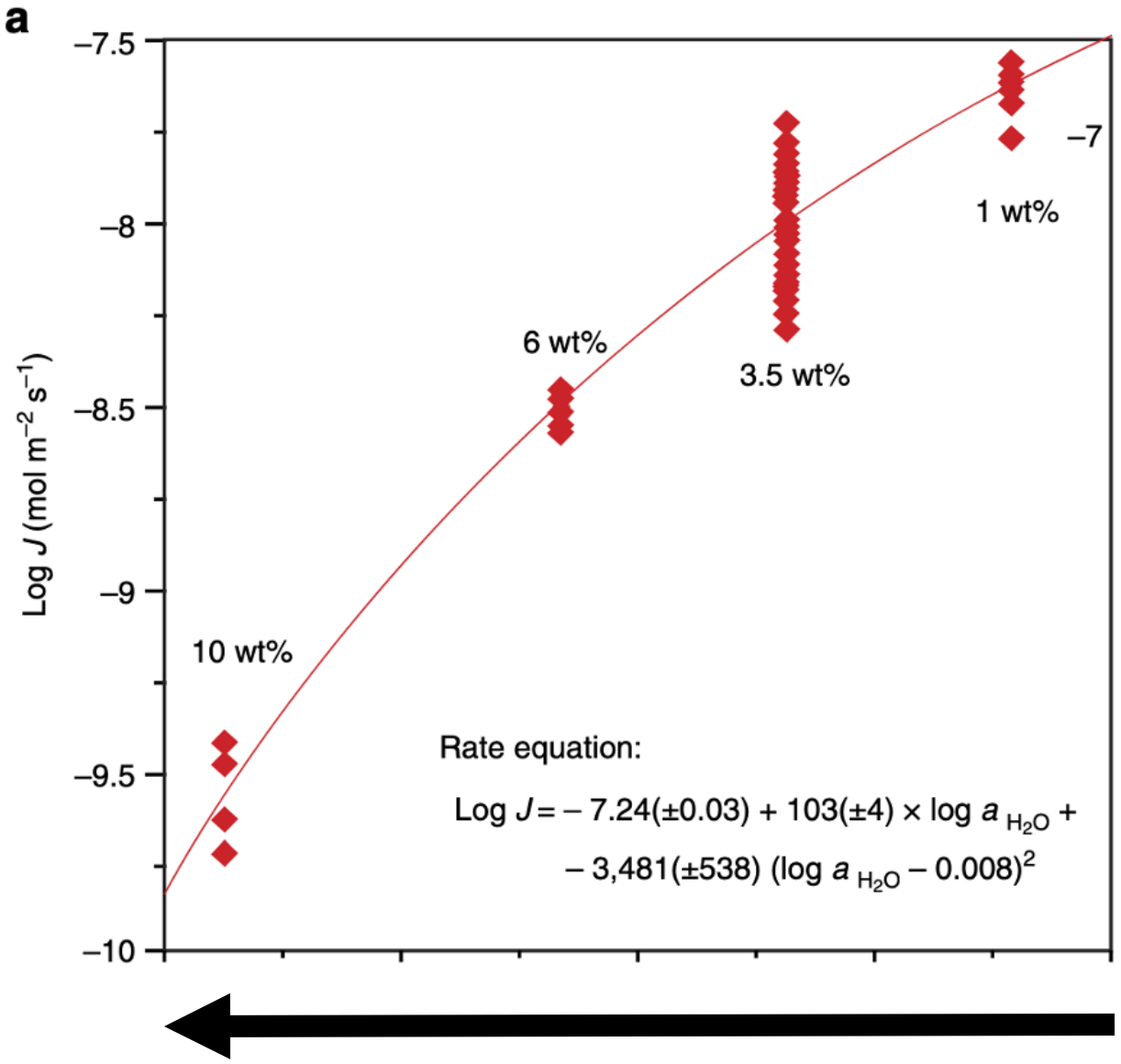
Cations complex with Cl:

HCl, NaCl, KCl, $MgCl_2$, $FeCl_2$, $CaCl_2$

→ Impact on solubilities

→ Impact on kinetics

Lamadrid et al. (2017)



One (important) missing variable

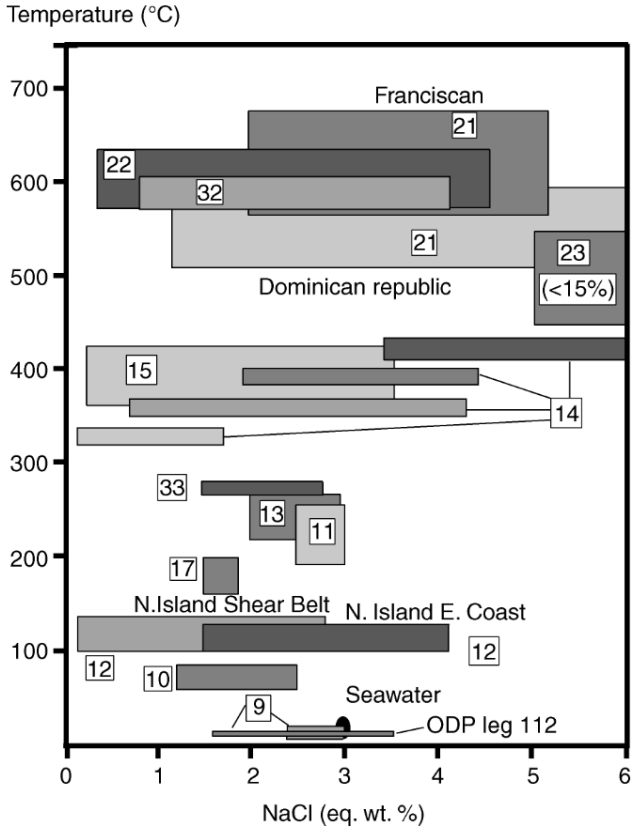
Cations complex with Cl:

HCl, NaCl, KCl, $MgCl_2$, $FeCl_2$, $CaCl_2$

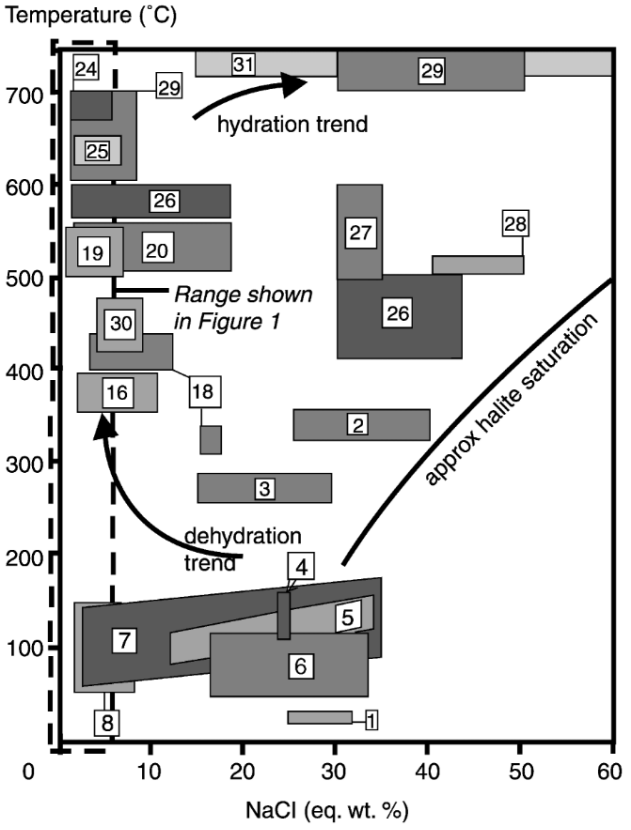
→ Impact on solubilities

→ Impact on kinetics

No evaporites



Evaporites



Yardley & Graham (2002)

Thermodynamic modeling setup

0.5 GPa, 300 ºC

Surface fluid

Low solute load

Interact with

Rock A:

Granite

Quartzite

Carbonate

Interact with

Fluid B

Rock B:

Peridotite

EQ6

Reaction between

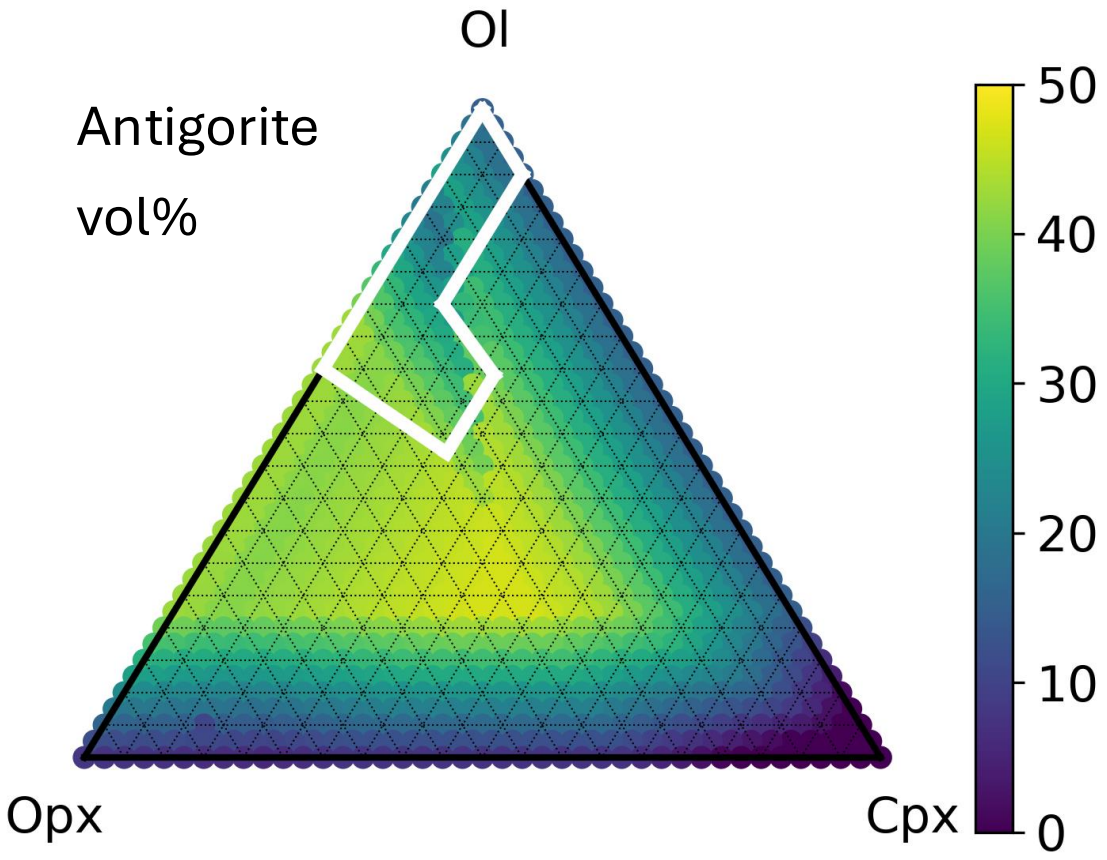
fluid and rock

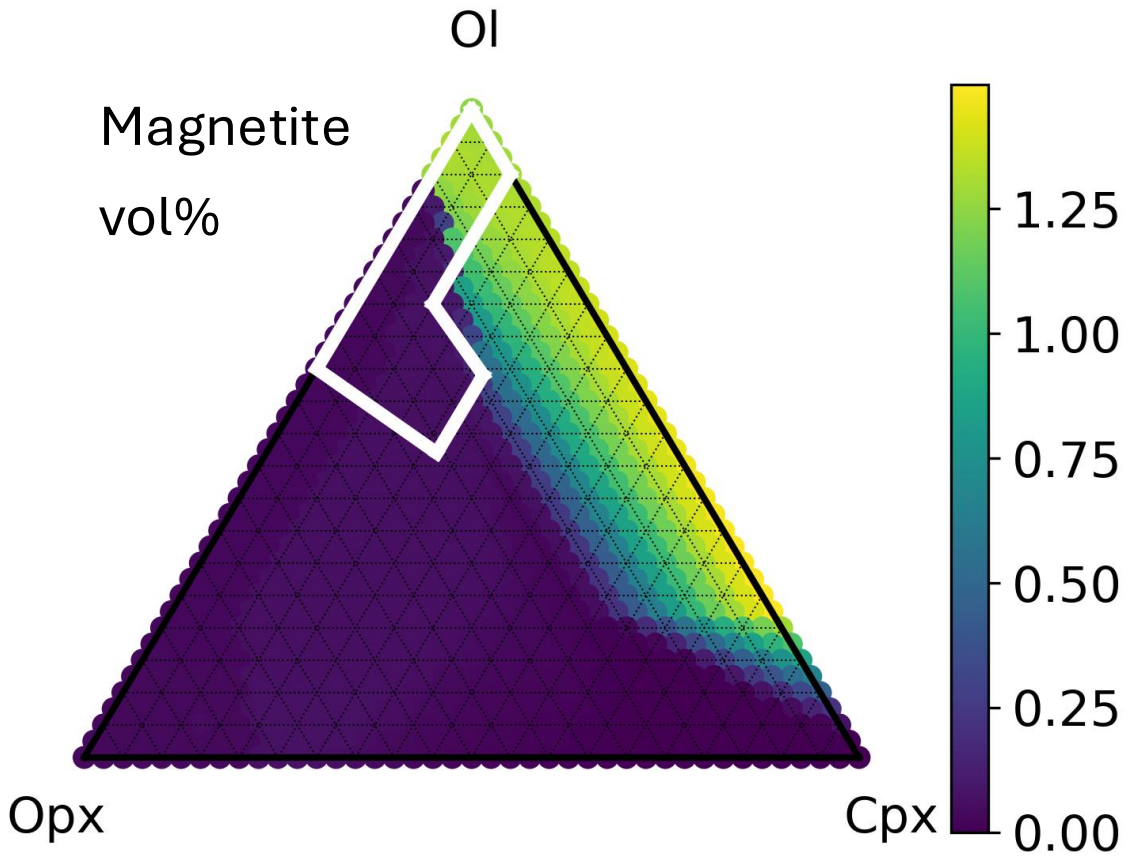
Variable salinities:

0.01 – 10 mol/kg

Granitic upper crust

fluid after interaction with granite, F/R=1, Cl=0.1 mol/kg

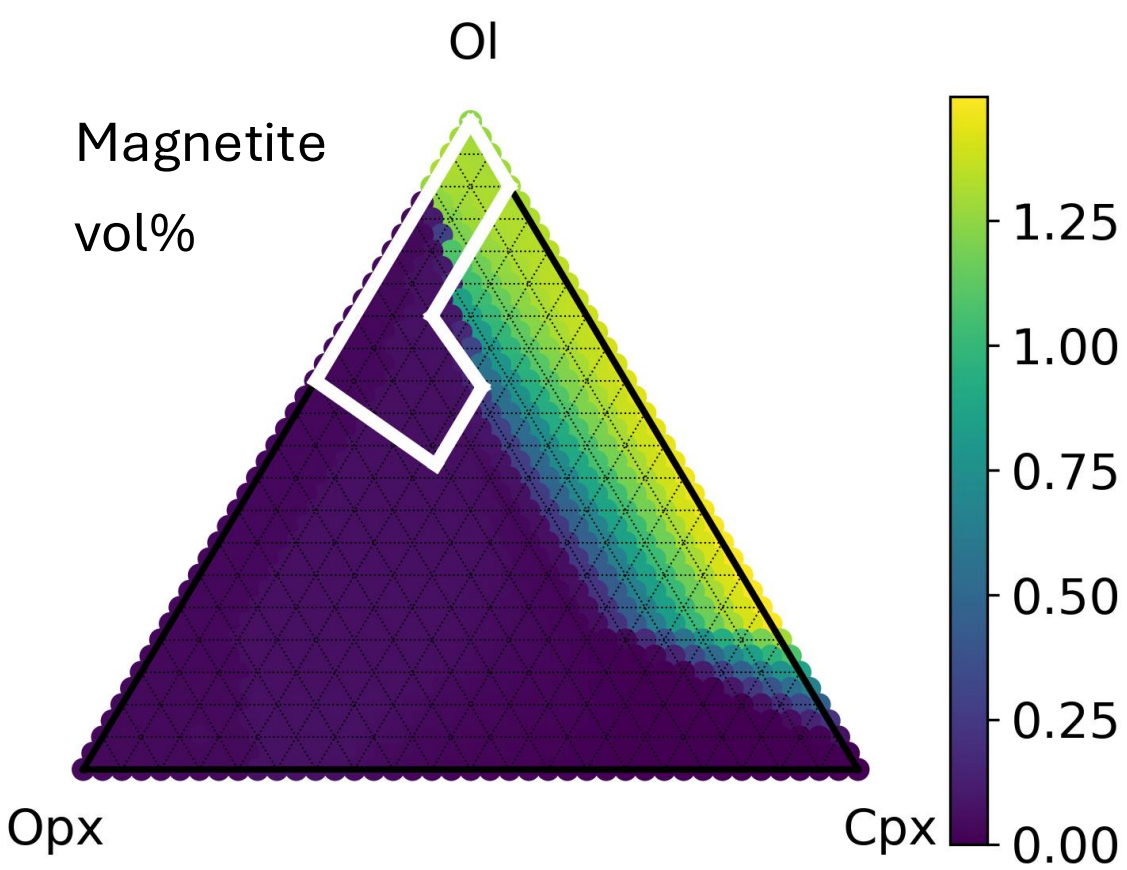


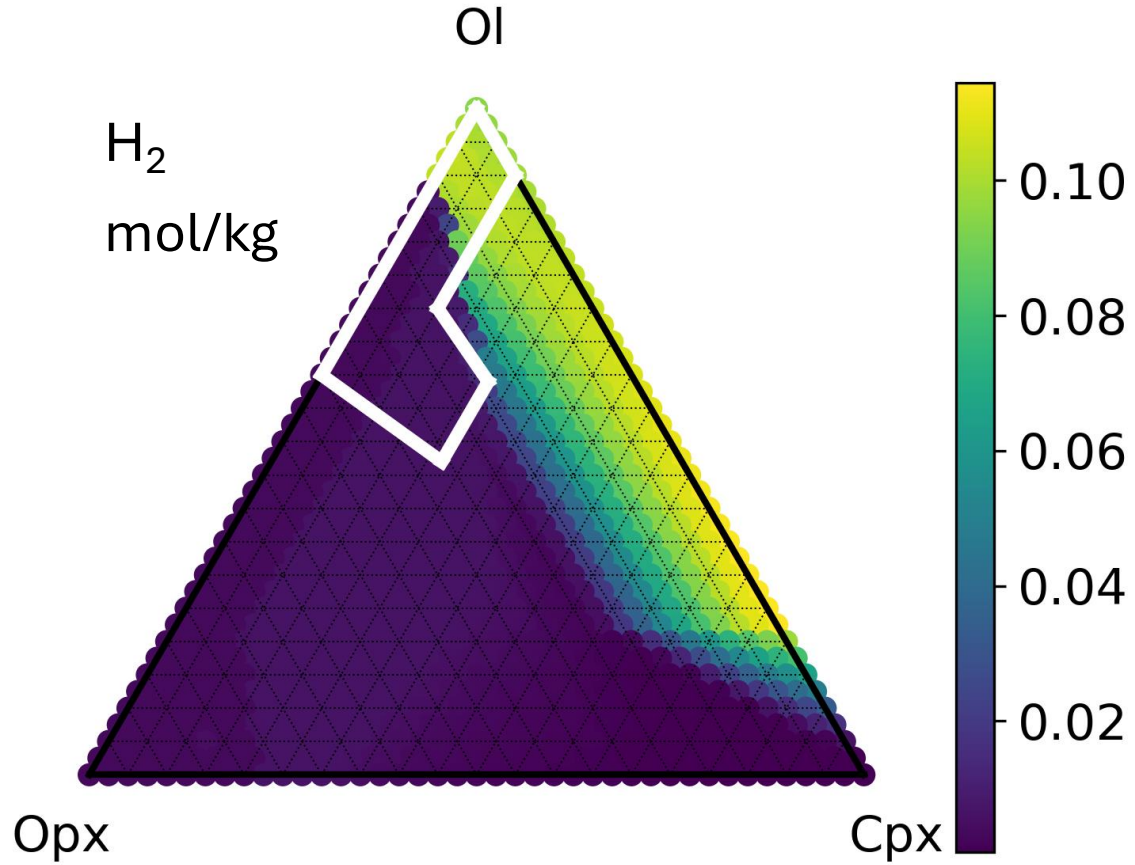


Decoupling serpentinization ≠ magnetite

Granitic upper crust

fluid after interaction with granite, F/R=1, Cl=0.1 mol/kg





Coupling Magnetite = H_2 content

Granitic upper crust

fluid after interaction with granite, F/R=1

Cl = 0.01 M

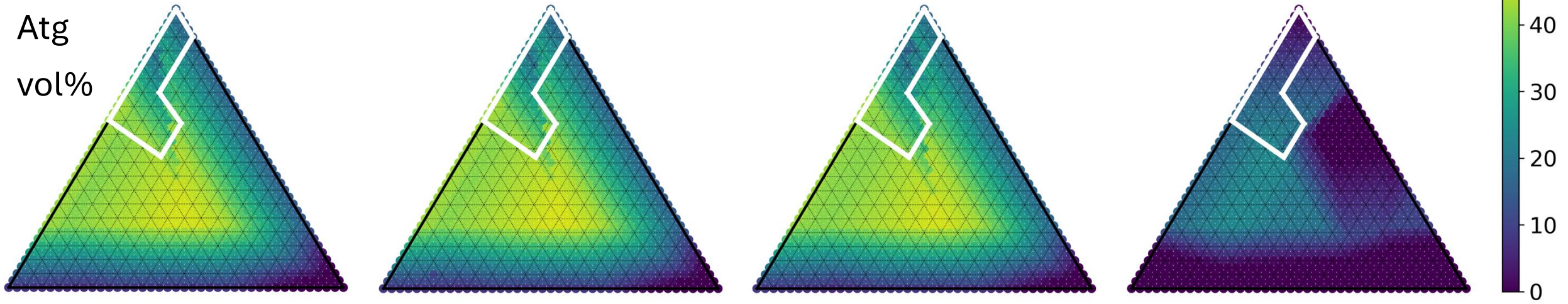
Cl = 0.1 M

Cl = 1 M

Cl = 5 M

Atg

vol%



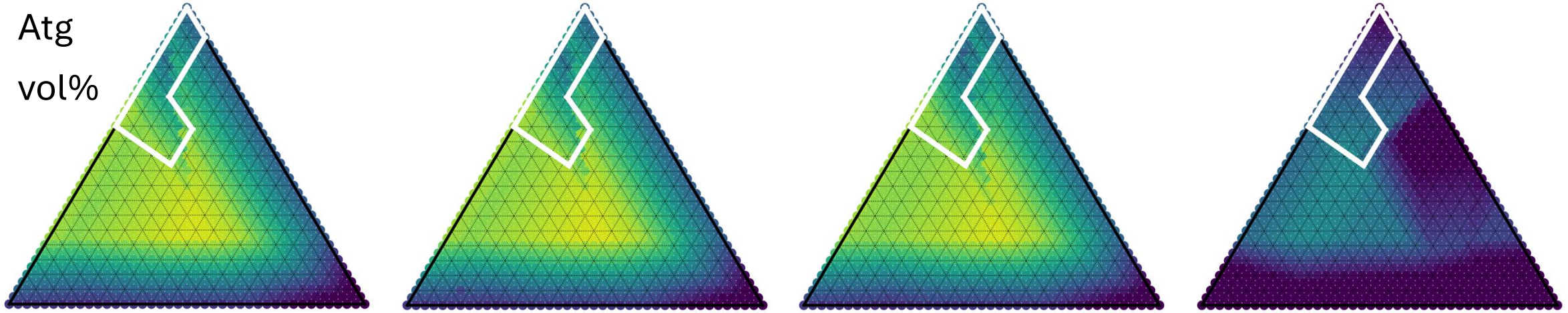
Higher salinity ⇒ lower serpentinization degree

Granitic upper crust

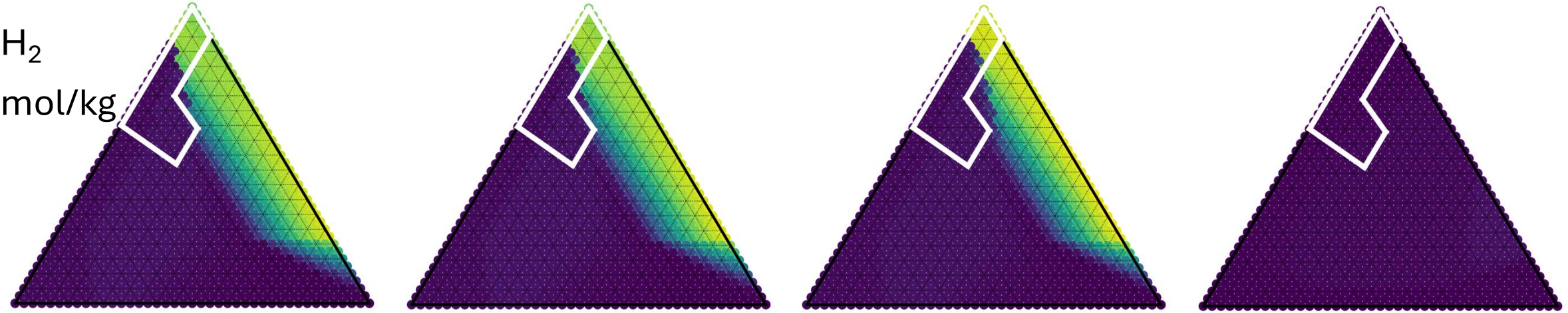
fluid after interaction with granite, F/R=1

Cl = 0.01 M | Cl = 0.1 M | Cl = 1 M | Cl = 5 M

Atg vol%



H_2 mol/kg



Higher salinity ⇒ lower H_2 production

Quartzite upper crust

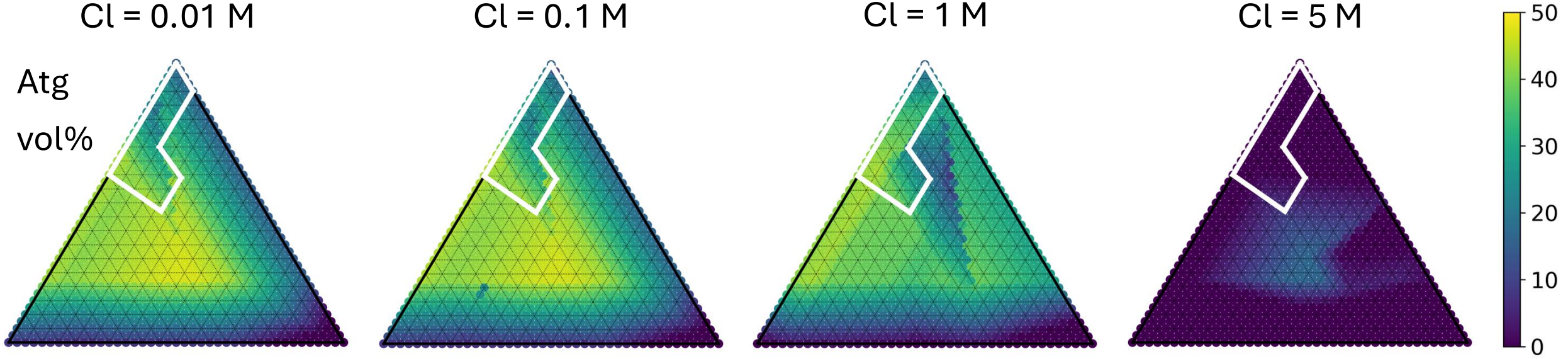
fluid after interaction with quartzite, F/R=1

Cl = 0.01 M

Cl = 0.1 M

Cl = 1 M

Cl = 5 M

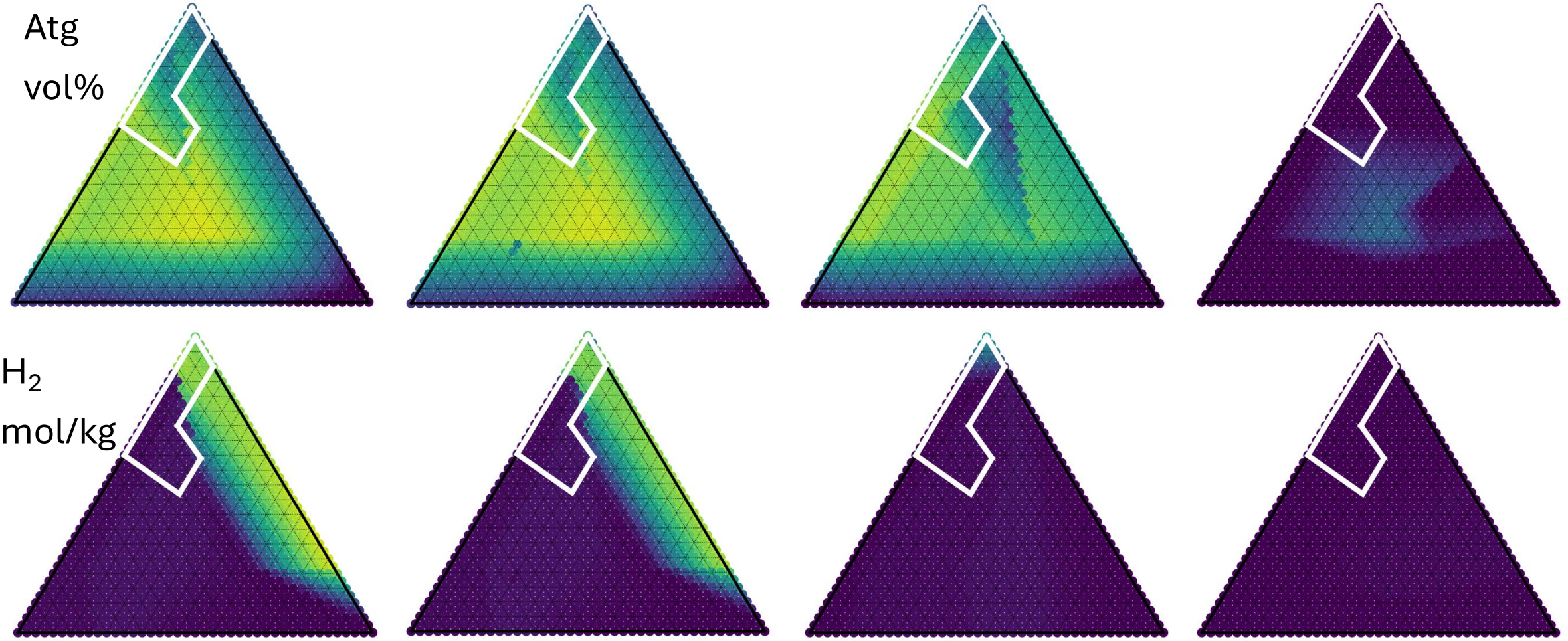


Similar to granite: higher salinity ⇒ lower serpentinization degree

Quartzite upper crust

fluid after interaction with quartzite, F/R=1

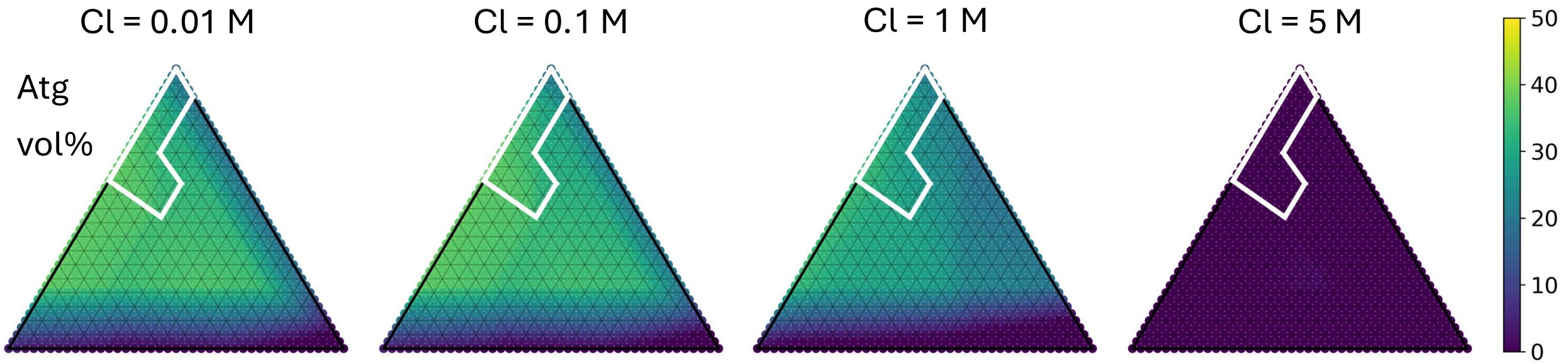
Cl = 0.01 M | Cl = 0.1 M | Cl = 1 M | Cl = 5 M



Higher salinity ⇒ lower H_2 production

Carbonate upper crust

fluid after interaction with carbonate, F/R=1



Lower serpentinization degree than granite/quartzite

Infiltrating fluid more oxidized

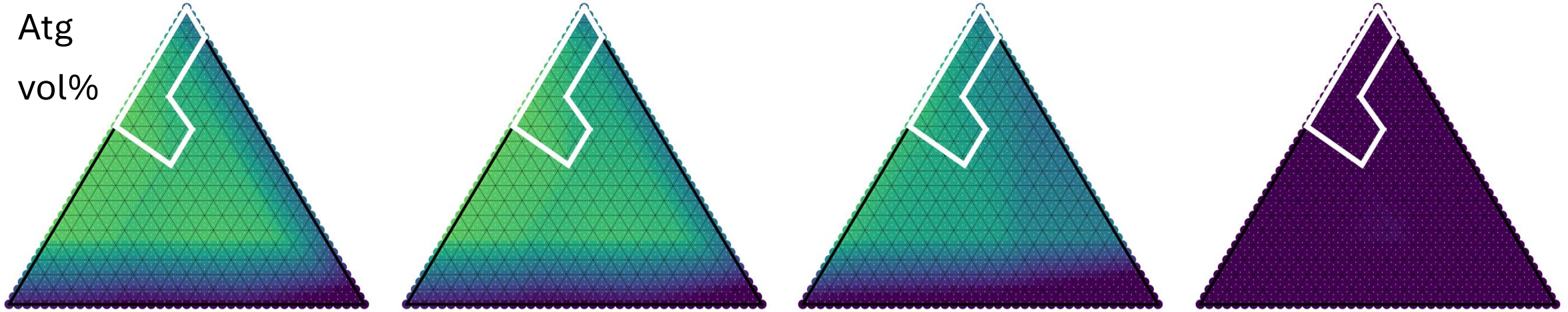
Lower serpentinization at high salinities

Carbonate upper crust

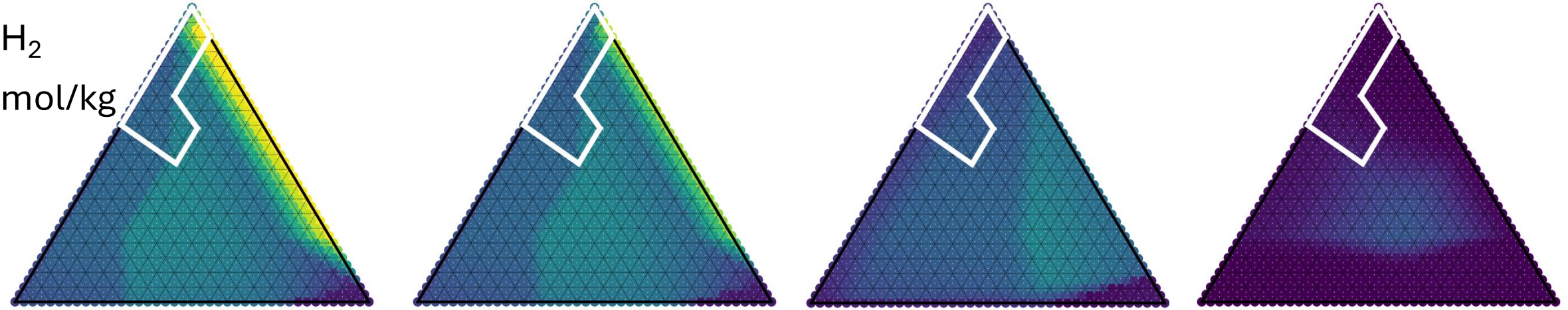
fluid after interaction with carbonate, F/R=1

Cl = 0.01 M | Cl = 0.1 M | Cl = 1 M | Cl = 5 M

Atg vol%



H_2 mol/kg



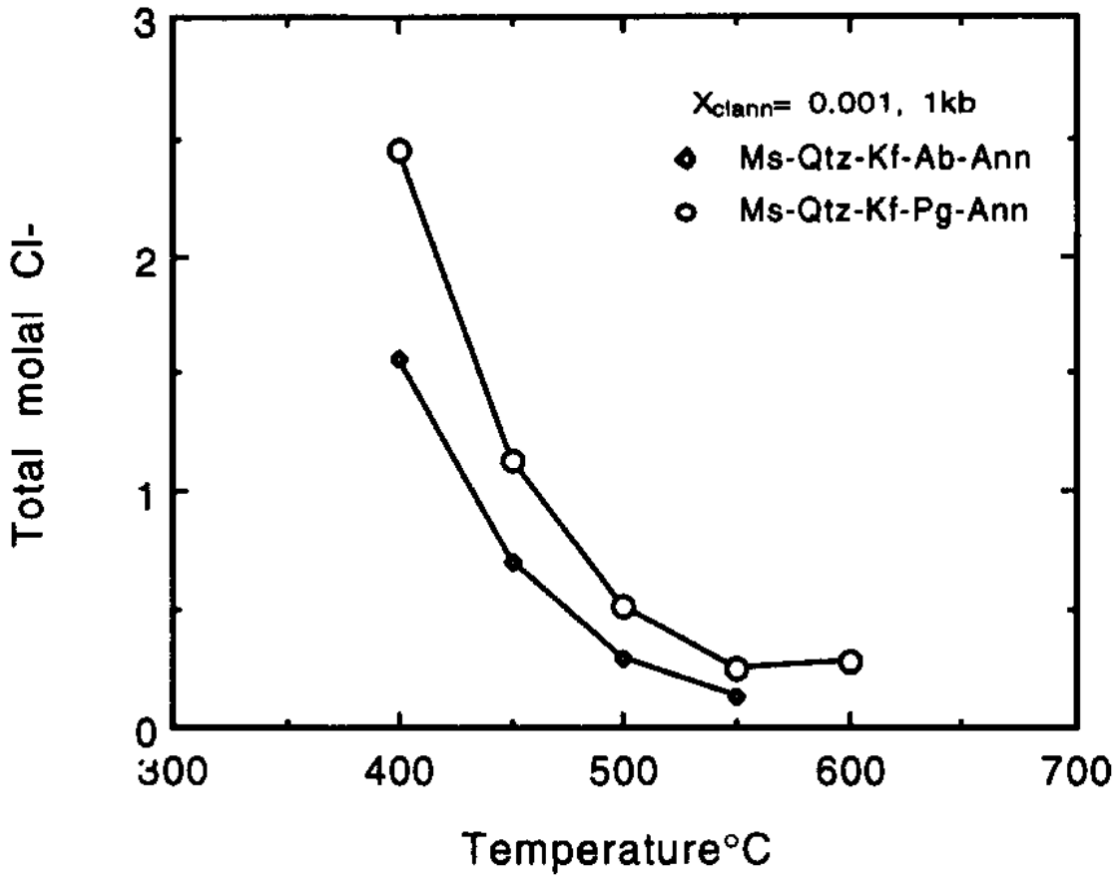
Lower H_2 production ⇒ 100 times less than granite/quartzite

Summary

- Initial composition plays a major role in both serpentinization and H_2 production
- Serpentinization and H_2 production are (partly) decoupled
- Fluid: not just H_2O ⇒ importance of the upper crust on the amount of H_2 produced at depth
- High salinities will reduce the production of H_2
- Evaporites and carbonated upper crust might impact the H_2 production at depth

What is the behavior of Cl during serpentinization?

Cl in hydrous minerals



Zhu & Sverjensky (1991)

Equilibrium hydrous mineral-fluid:

Ann + 2**HCl** = Cl-Ann + $2H_2O$

In serpentine:

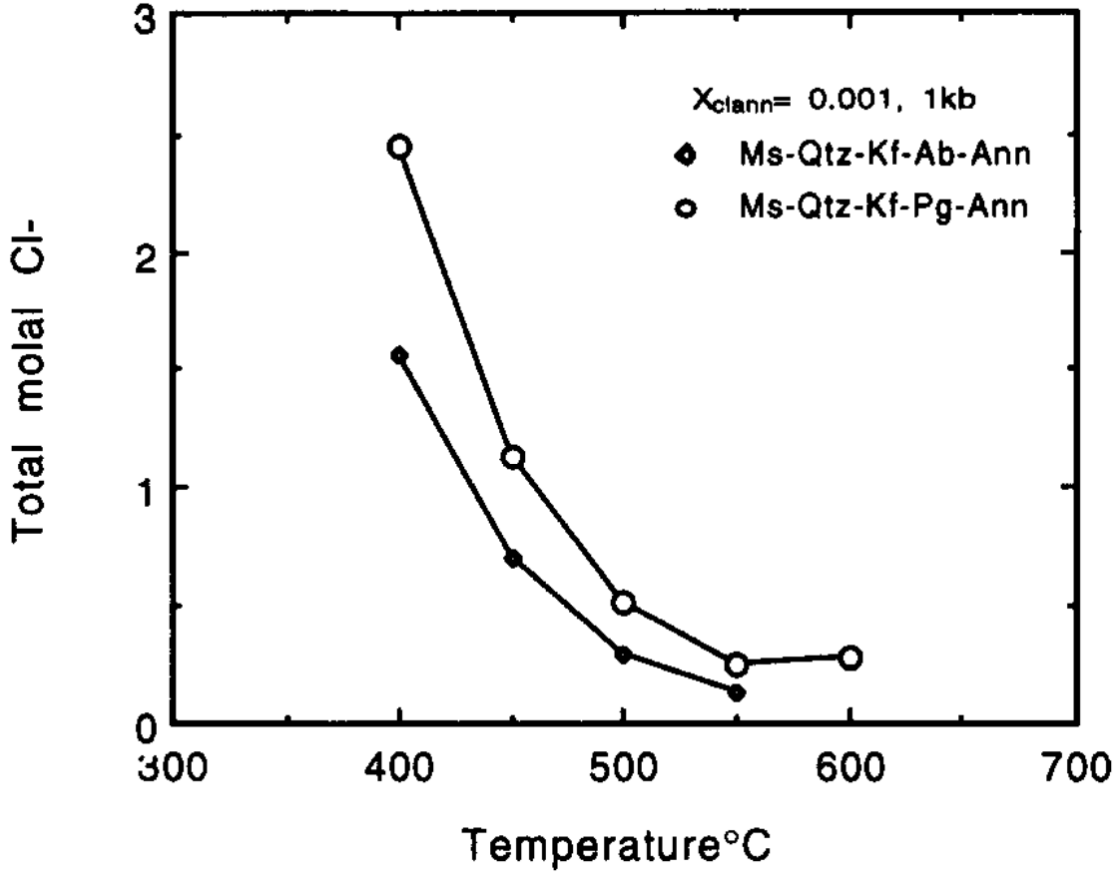
$Mg_3Si_2O_5(OH,\mathbf{Cl})_4$

Strongly dependent on pH

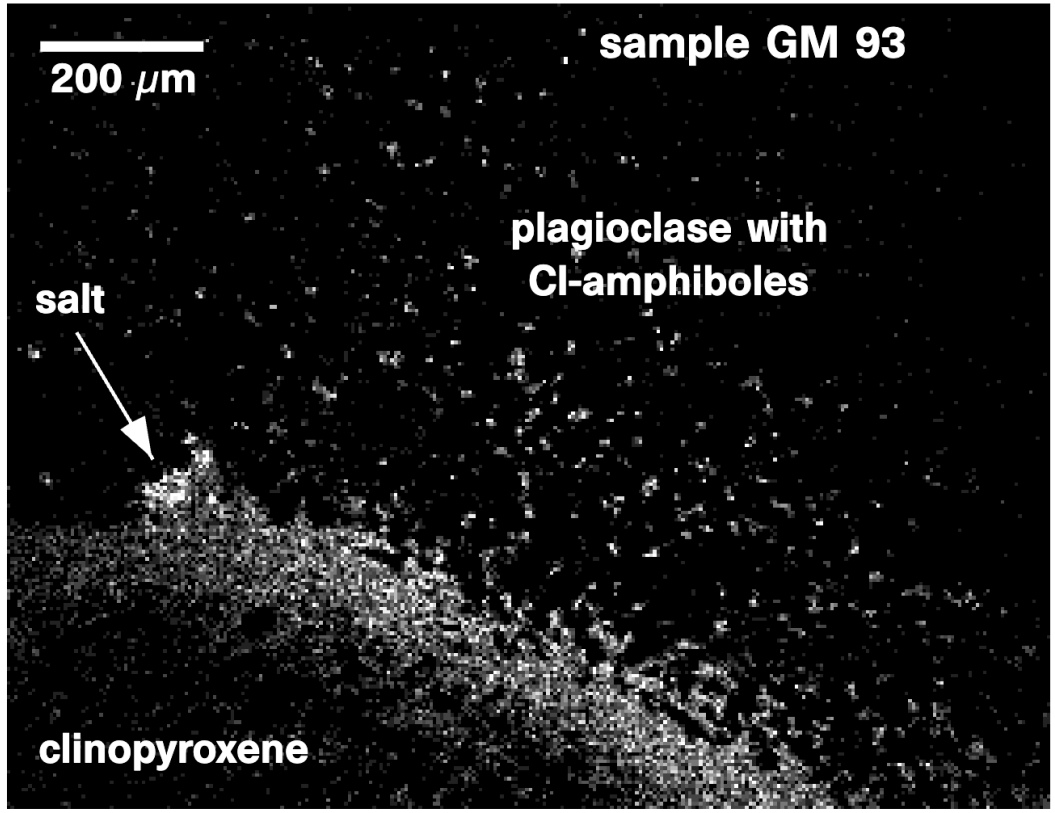
Incompatible in most hydrous minerals

No data on serpentine

Cl in hydrous minerals



Zhu & Sverjensky (1991)



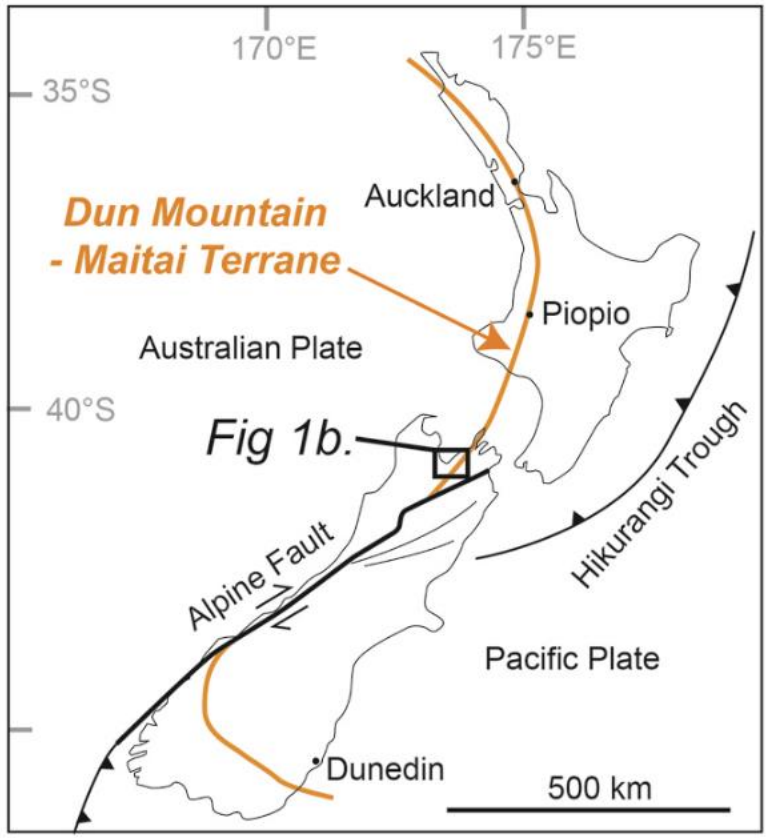
Markl & Bucher (1998)

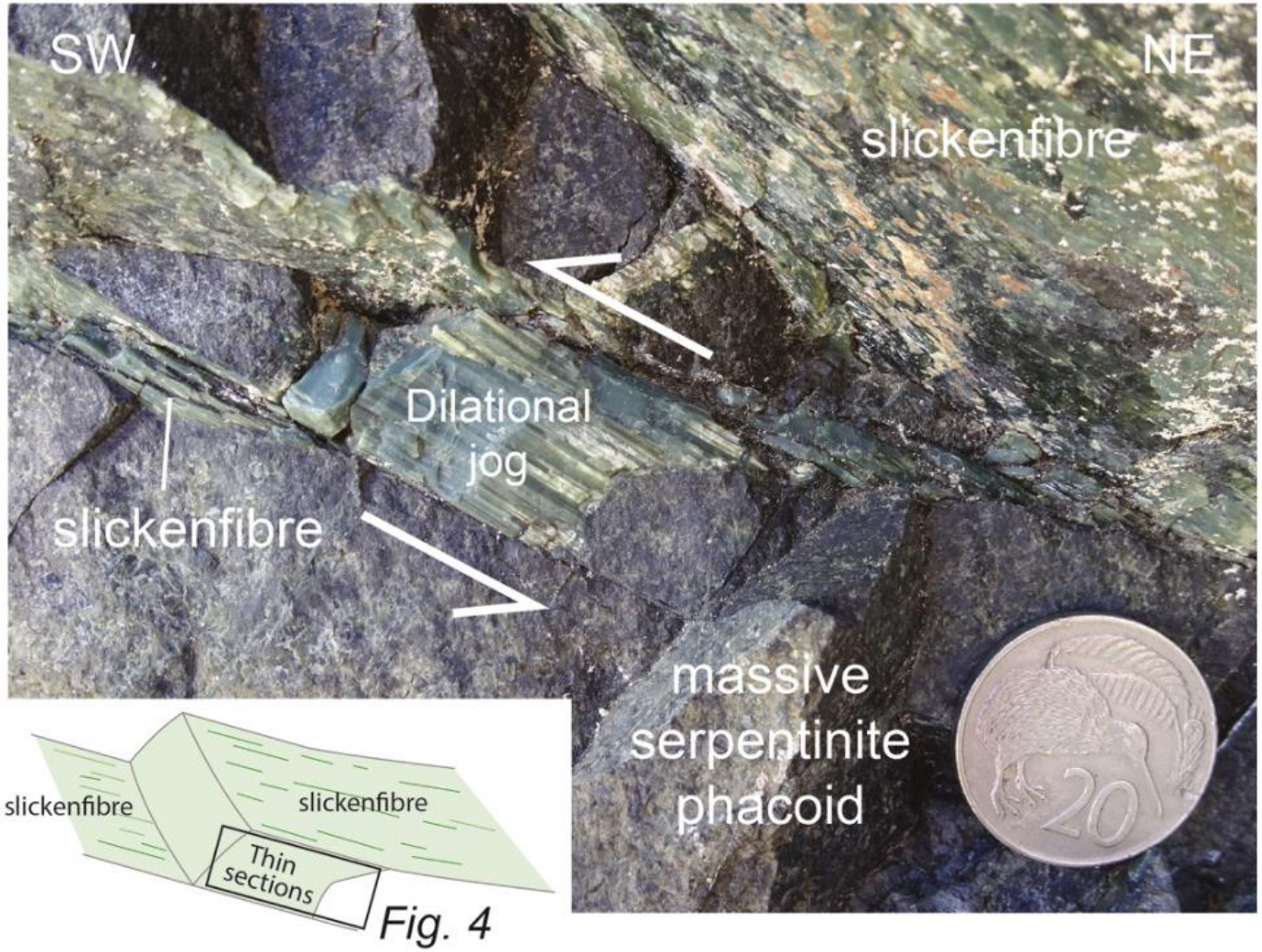
Strongly dependent on pH

Incompatible in most hydrous minerals

No data on serpentine

Geological setting



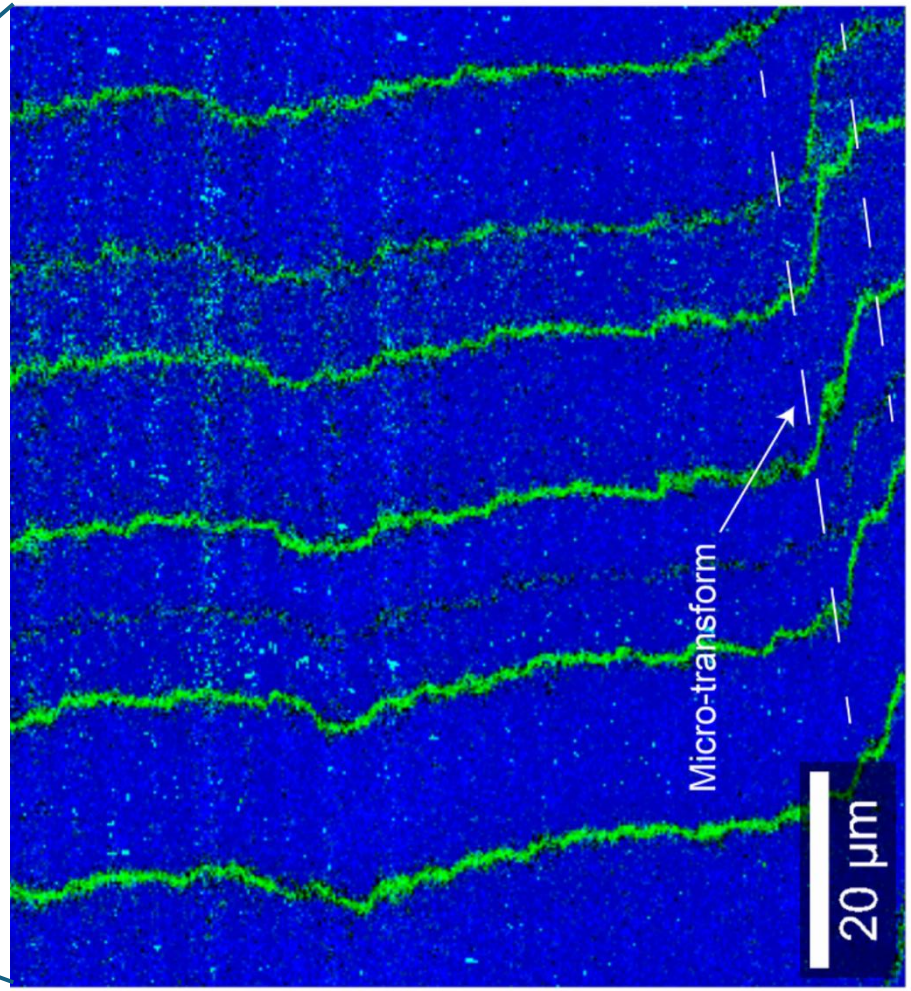


Smith et al. (2023)

Coupled dissolution/precipitation hard to study

Easier to look at precipitation only first

Serpentine jog



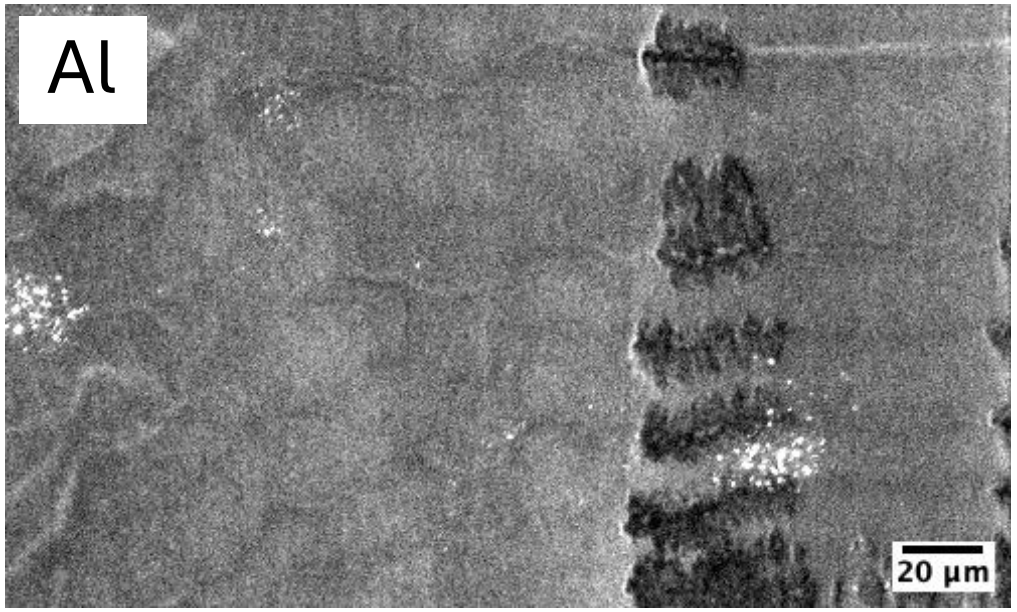
Smith et al. (2023)

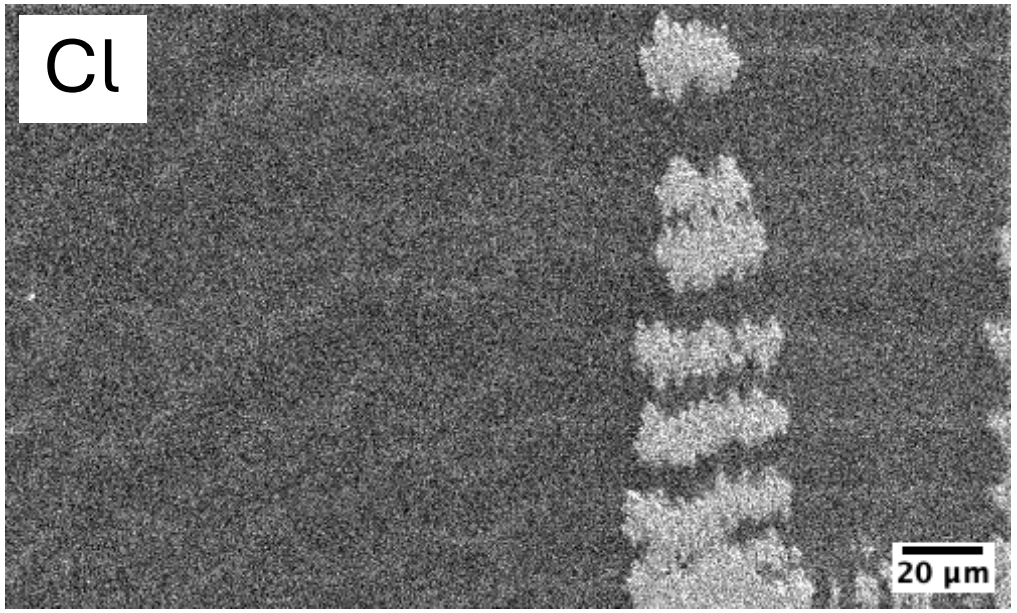
Step 1: opening and fast cristalization of chrysotile (green)

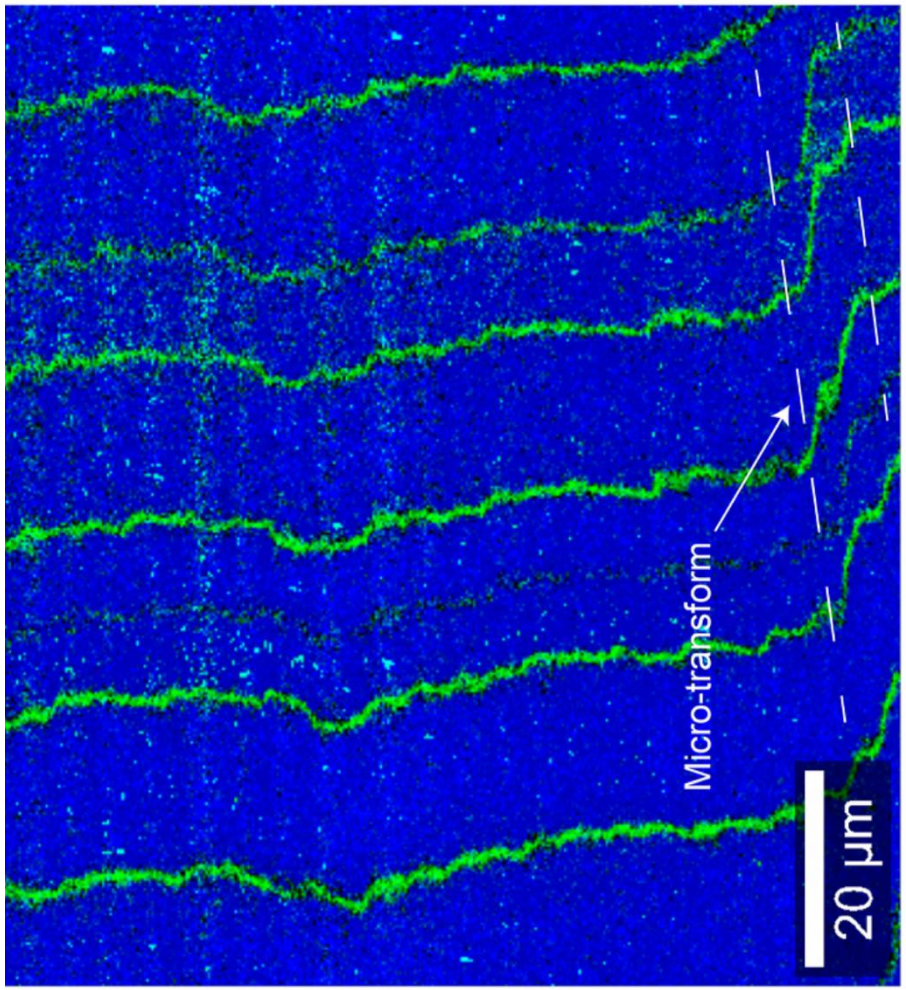
Step 2: slow precipitation of lizardite (blue)

Repeat

Serpentine jog







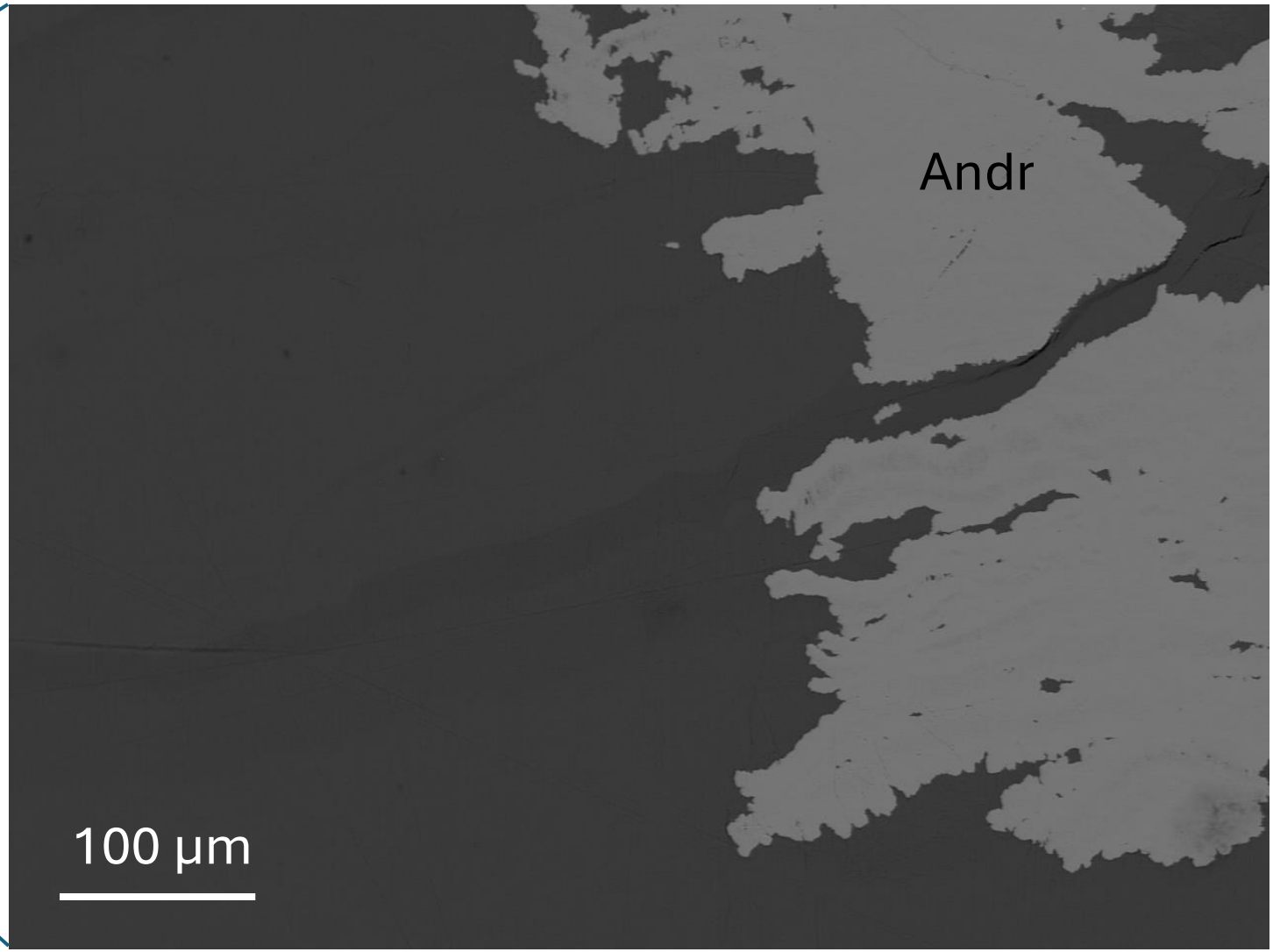
Smith et al. (2023)

Chrysotile: high Cl

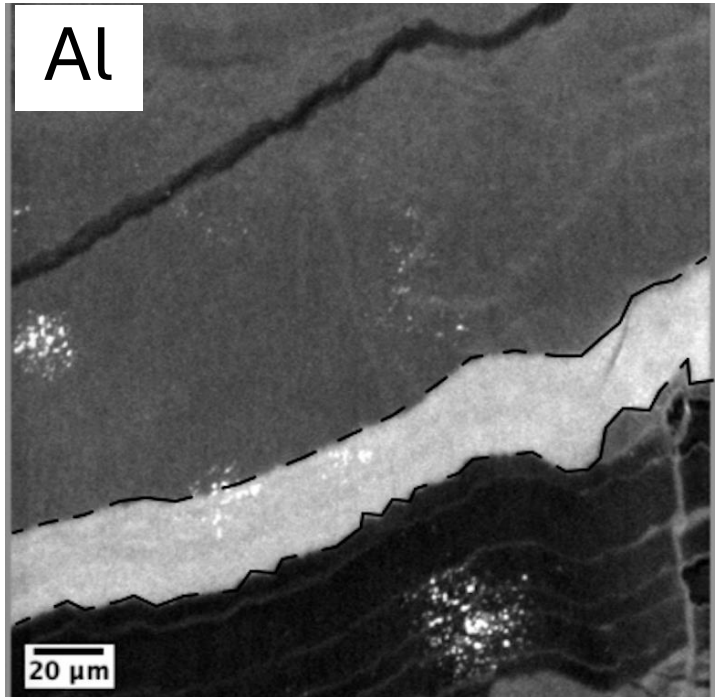
Lizardite: no enrichment in Cl

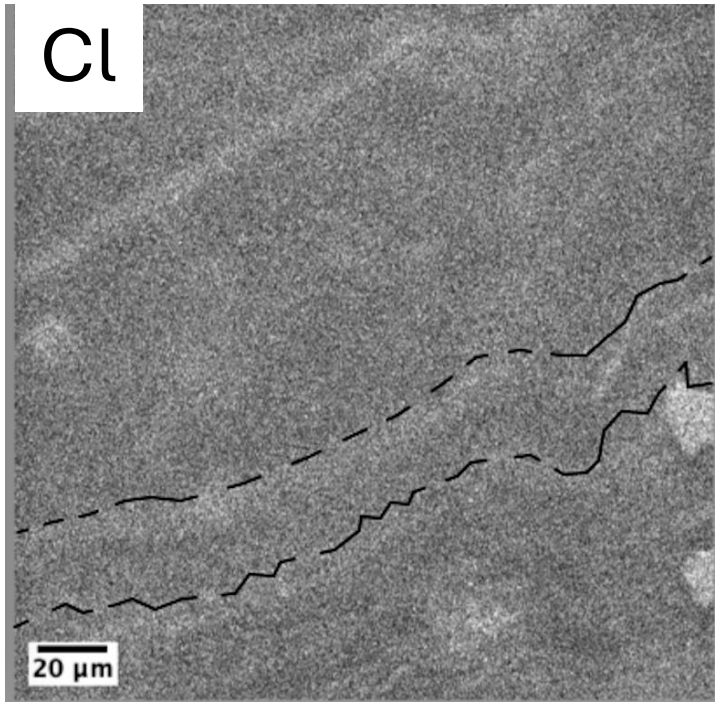
⇒ no desiccation process

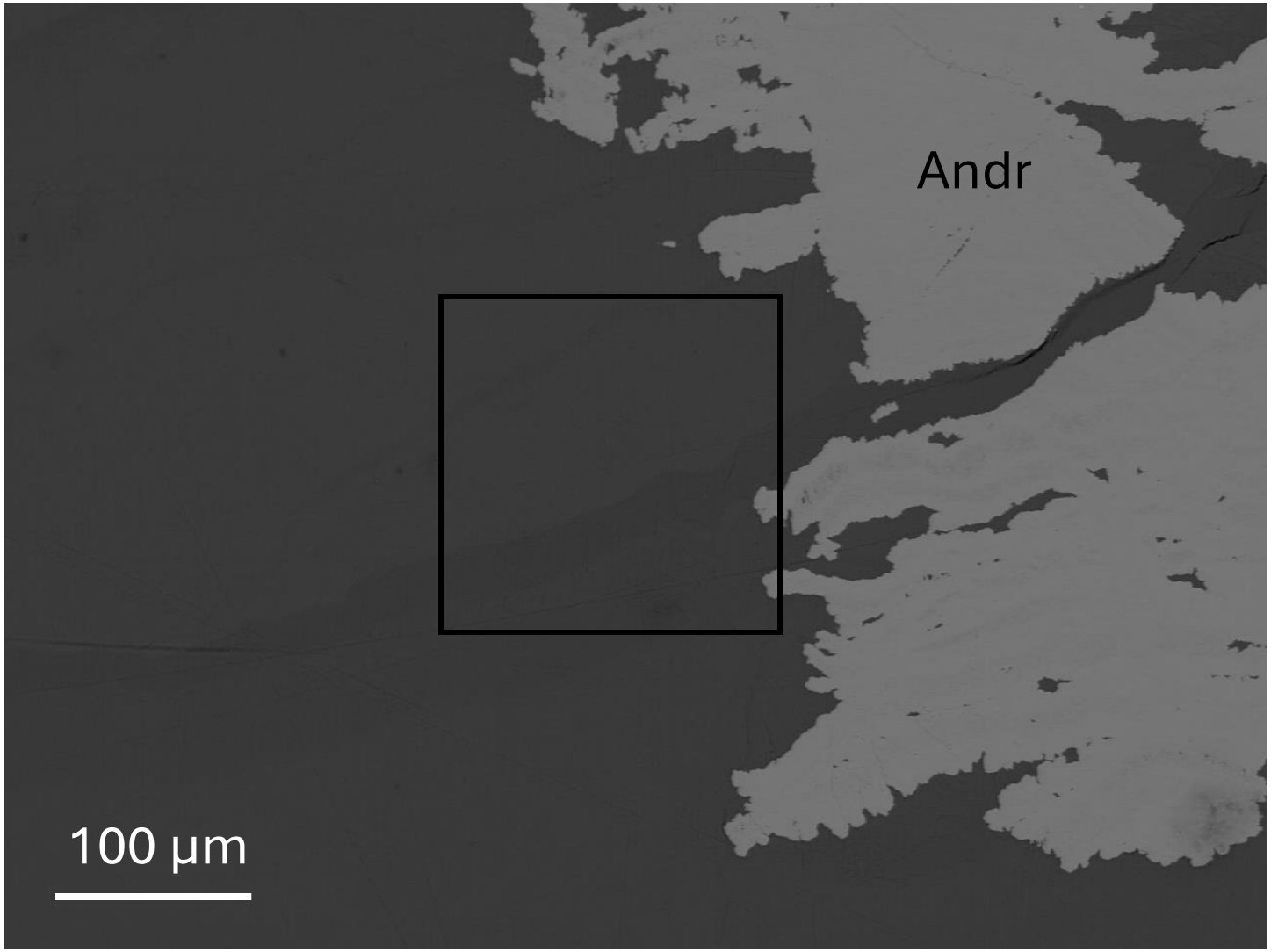
Last opening



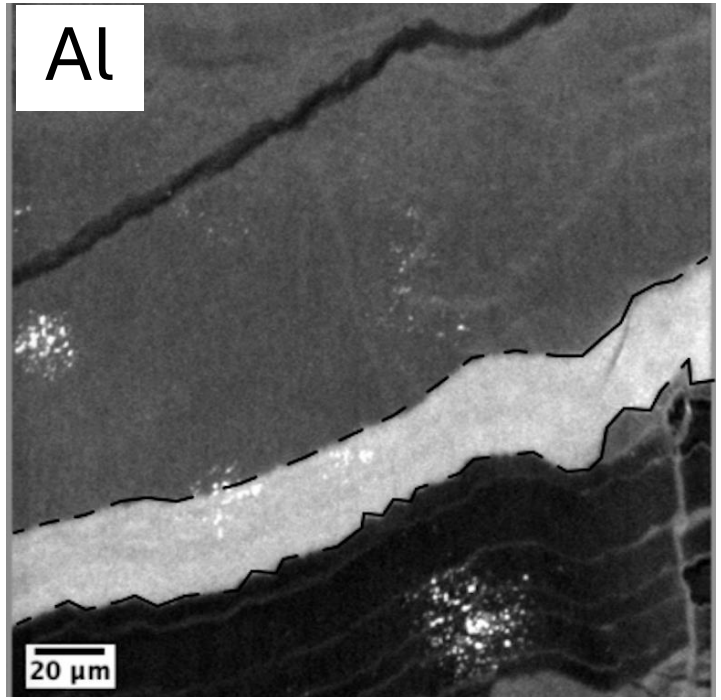
How does the alternance begins?

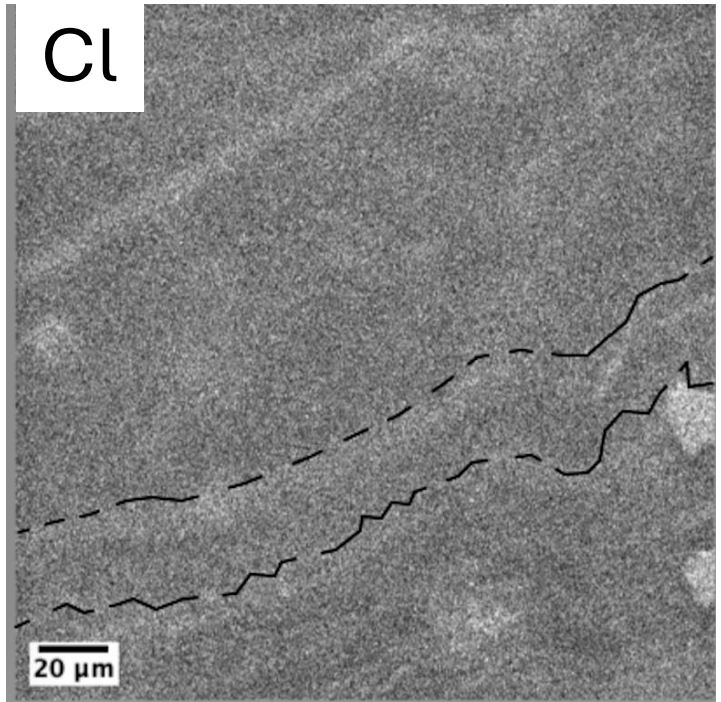


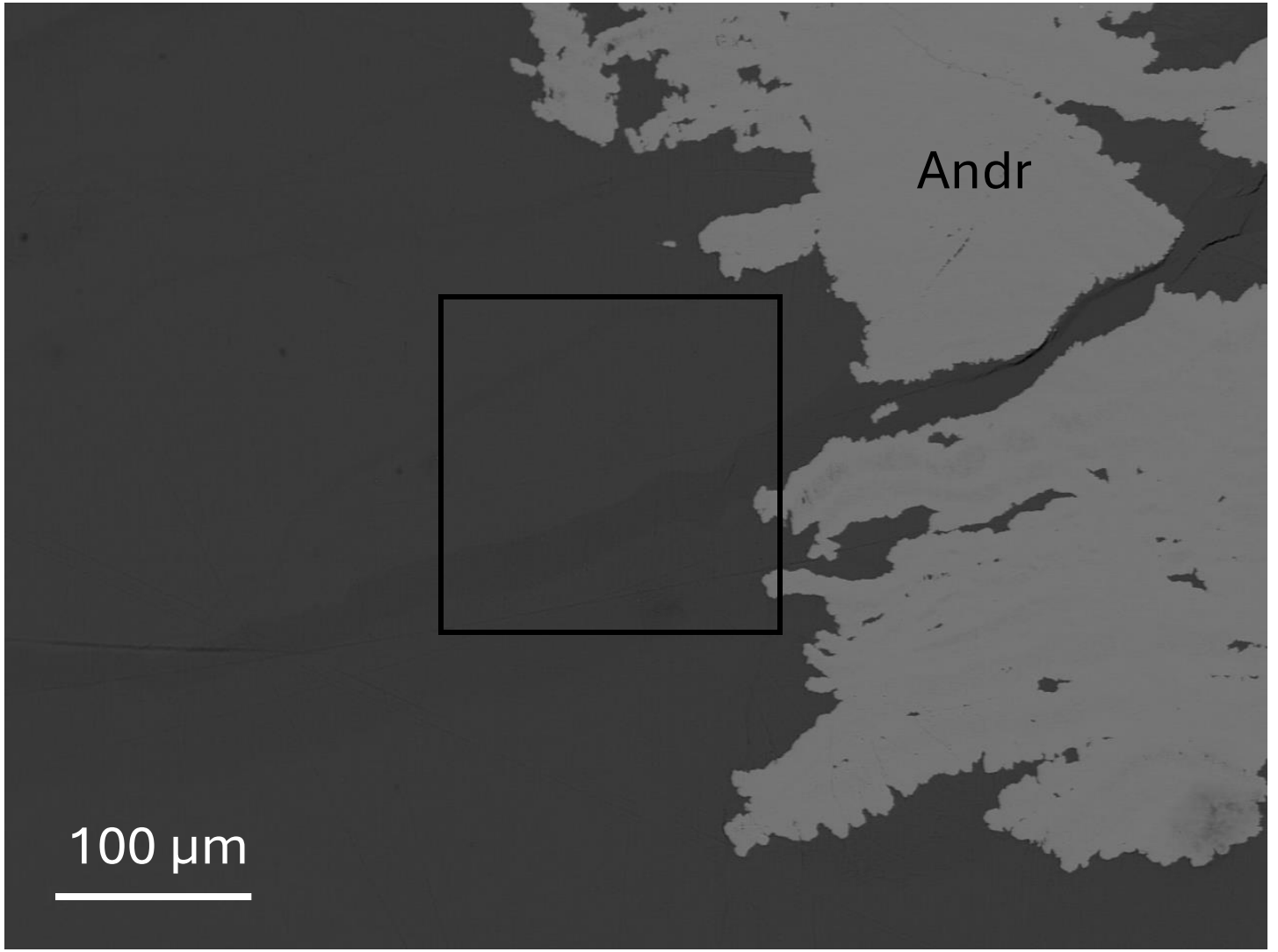




Large variations in trace elements between generations



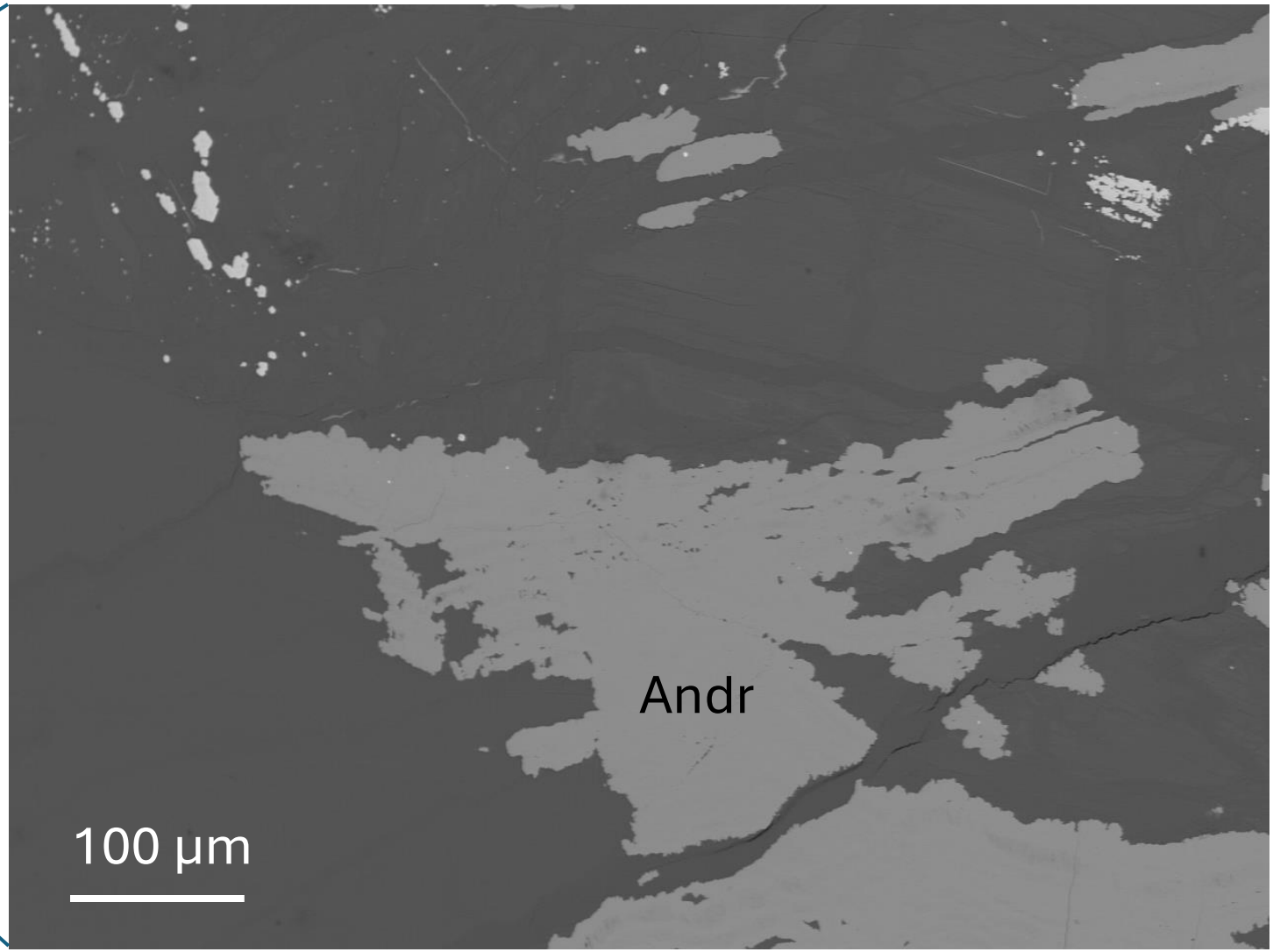




Large variations in trace elements between generations

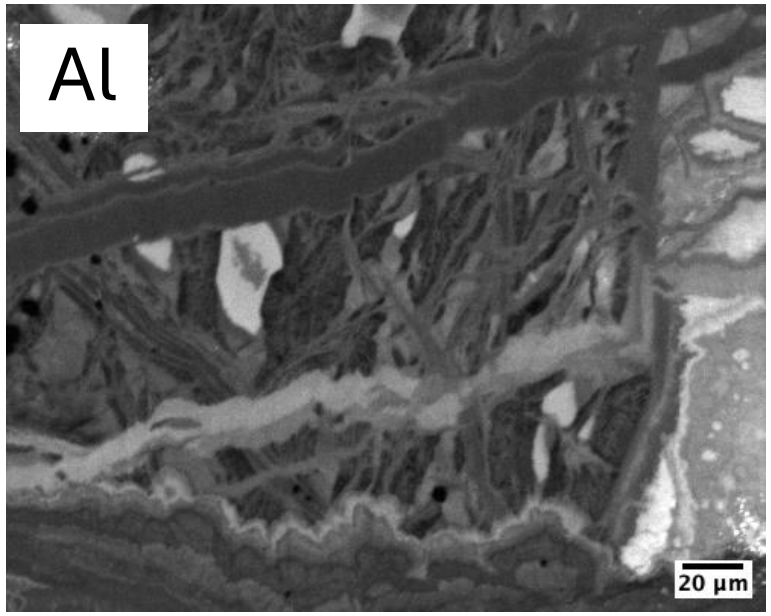
Cl seems higher close to the bulk rock

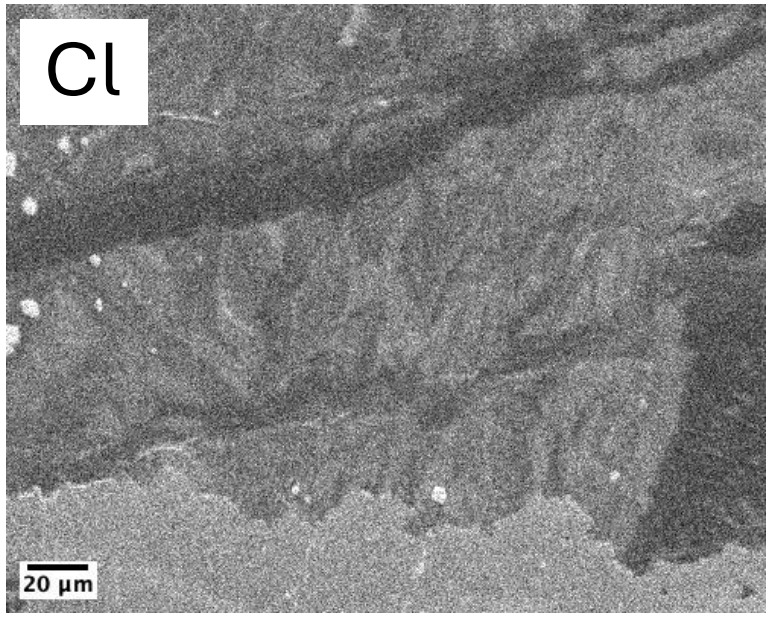
Mesh serpentine

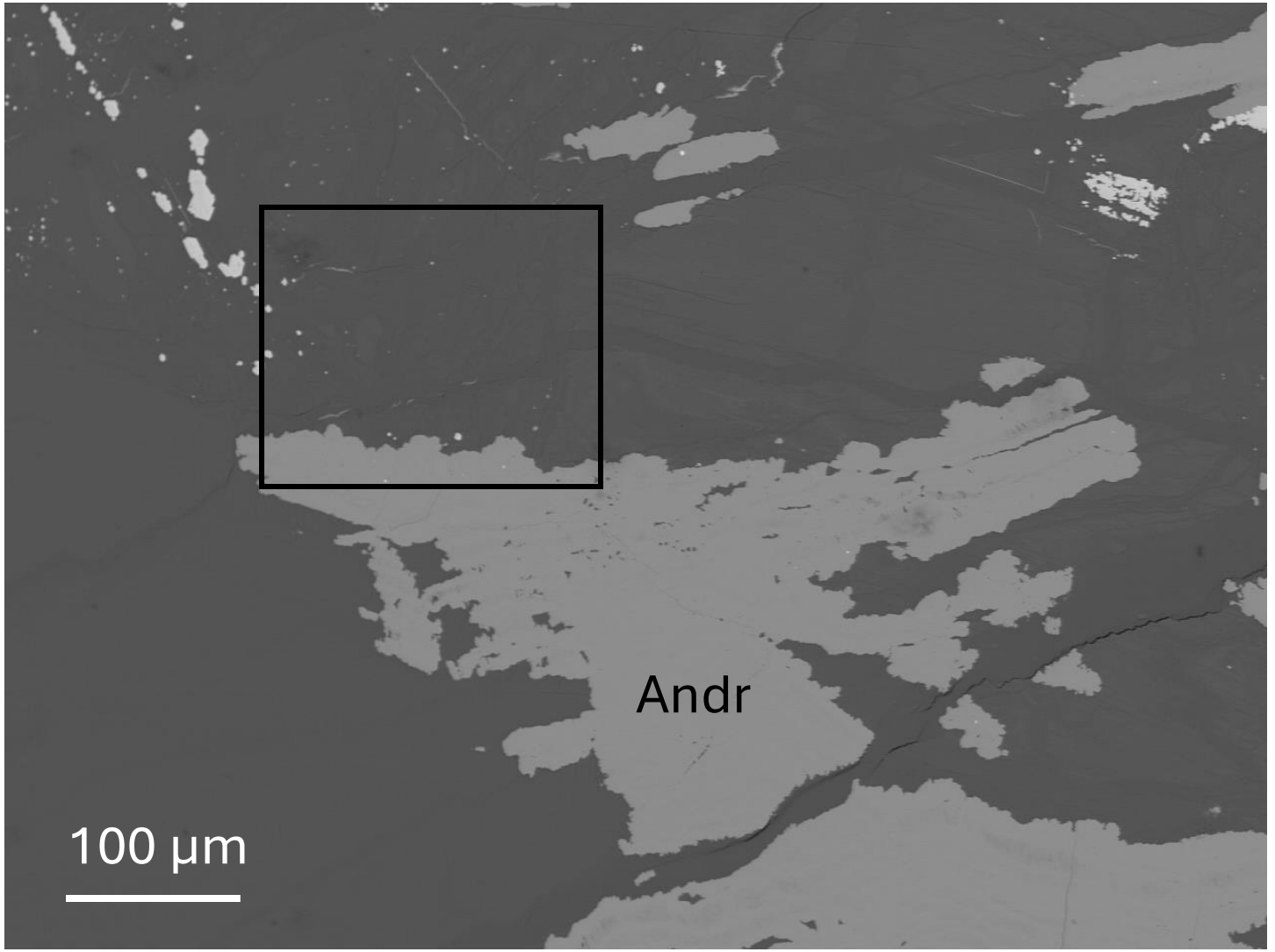


Can we see evolution in the mesh serpentine where several micro-fractures are filled?

Mesh serpentine







All micro-fractures filled with serpentine have different Cl contents

No clear trend, even for pseudomorphs

Take home message

- Initial peridotite composition is important
- The composition of the upper crust is likely going to affect the amount of H_2 produced at depth
- High Cl, carbonate rocks, such as evaporites, will significantly reduce the amount of H_2 produced
- The evolution of of Cl incorporation in hydrous minerals, particularly serpentines, is largely unknown

Requires:

- numerical models with accurate interactions of downgoing fluids with superficial rocks

- experiments to constrain the compatibility of Cl


Thank you!