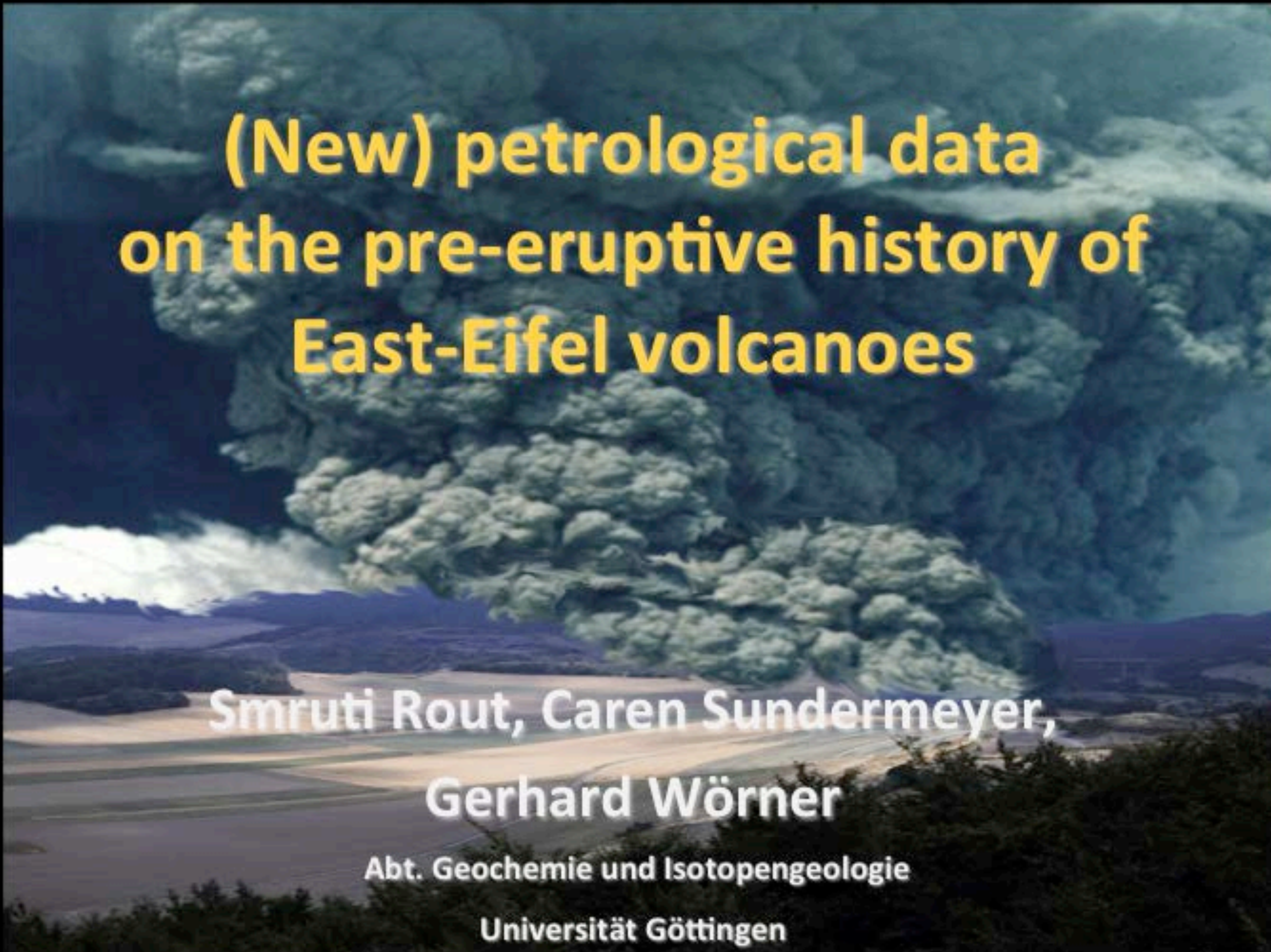
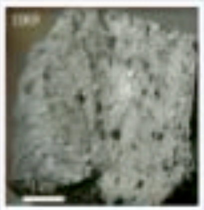


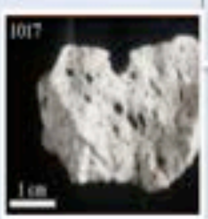
(New) petrological data on the pre-eruptive history of East-Eifel volcanoes

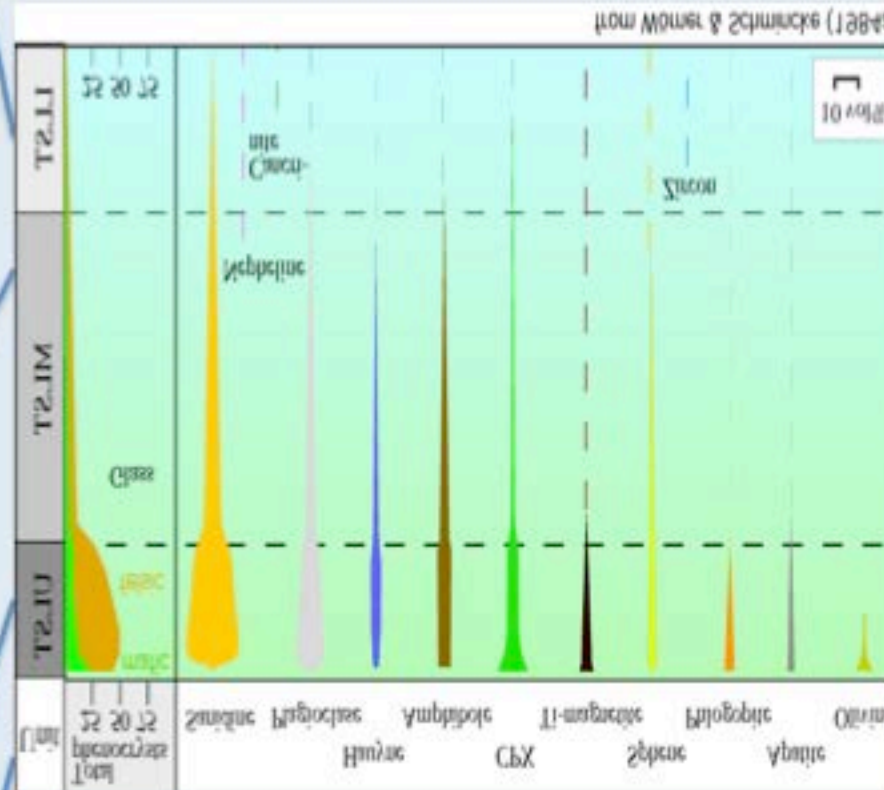
Smruti Rout, Caren Sundermeyer,
Gerhard Wörner
Abt. Geochemie und Isotopengeologie
Universität Göttingen


The eruption of the Laacher See Volcano
13.000 ky ago
Two craters
© Walter Müller

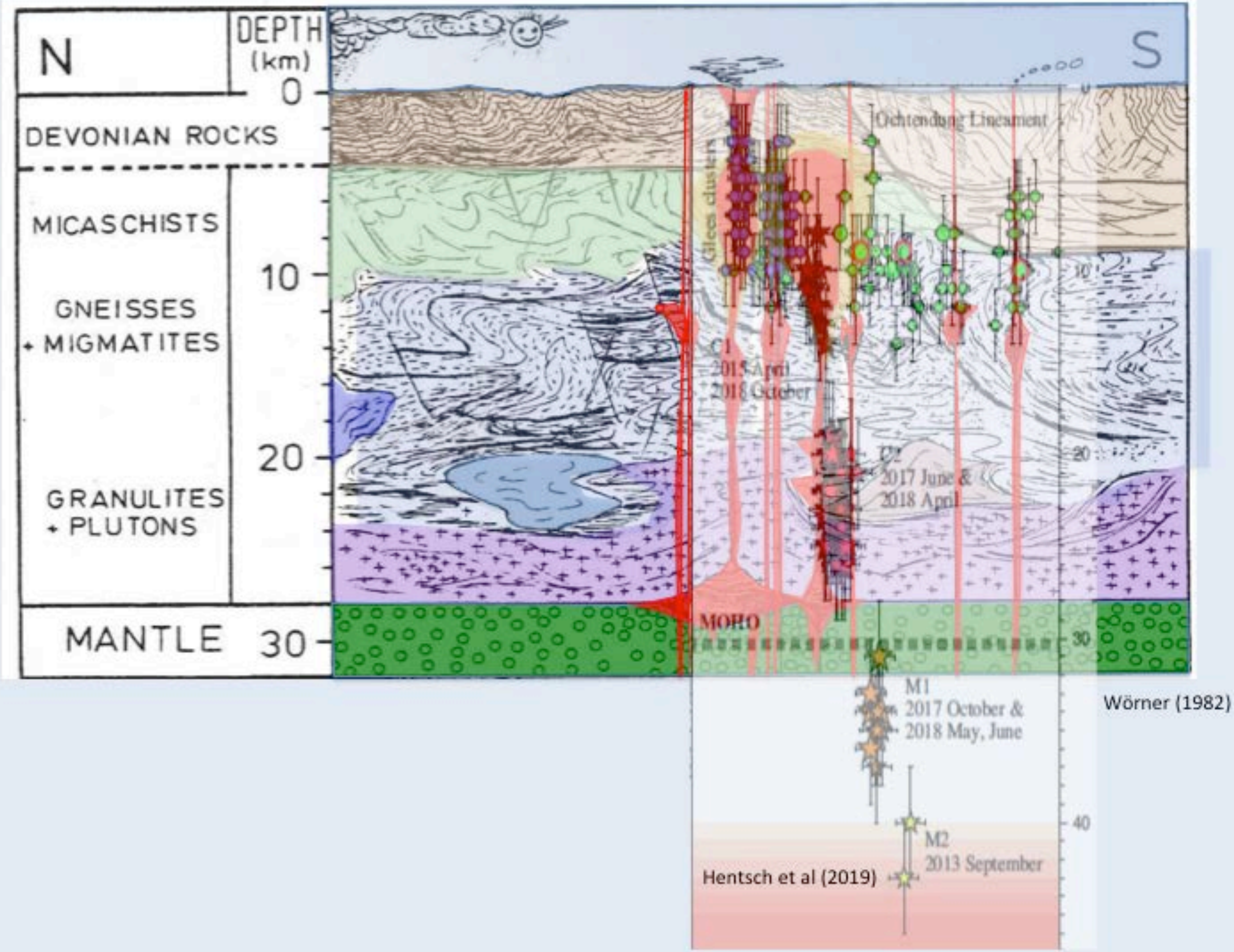
Laacher See tephra from base to top: strong petrographic and compositional variations







Schmincke and Wörner (1984b)


N
DEPTH (km)
S
0
10
20
30
40
DEVONIAN ROCKS
MICASCHISTS
GNEISSES + MIGMATITES
GRANULITES + PLUTONS
MANTLE
Ochtendung Lineament
Glees cluster
C1
2015 April
2018 October
D2
2017 June &
2018 April
MOHO
M1
2017 October &
2018 May, June
M2
2013 September
Wörner (1982)
Hentsch et al (2019)

Our research questions:

- **Q1.** How "old" was the phonolite magma at the time of eruption ?

  Method : Direct dating of magmatic crystals in the phonolite magma

- **Q2.** What is the timing of recharge and mixing in the Laacher See magma reservoir prior to eruption ?

  Method : Diffusion modelling across compositional unconformities generated by magma mixing

- **Q3.** What magma compositions are involved ?

  Method : In-situ EMP and laser ablation ICPMS trace element analysis of zoned phenocrysts

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Previous results:

Bourdon et al (1994):
crystal ages 30.0±1.9, cumulate age 28.9±1.9
-> max ca. 29 ka prior to eruption

Schmitt (2006) crystal age 17.1±1.3
Schmitt et al (2010) max crystal age 32.7+4.2+4.2-4.1 ka
carbonatite unmixing age: 19.5 ± 1.8 ka
Higly evolved magmas existed **-> max. 32.7+4.2-4.1 ka** prior to eruption

Schmitt et al (unpublished):
detrital zircons max 45.1 +7.4-6.9 ka **-> max ca. 39.5 ka** prior to eruption

Ehrentraud, Münker et al (unpublished):
cumulate crystal age **25.2±5.3**

Our research questions:

- **Q1.** How "old" was the phonolite magma at the time of eruption ?

Method : Direct dating of magmatic crystals in the phonolite magma

"Houston, we have a problem !"

These ages only indicate the maximum age for the existence of a highly evolved (and potentially explosive) phonolite magma reservoir.

We have only little information on the timing of magmatic differentiation between a basanite parent and evolved phonolite magma, except from Bourdon et al (1994):

Apparent ages of crystallization inferred from internal isochrons in the pumices from the main part of the magma chamber are about 13 ± 3 kyr, indistinguishable from the eruption age. This implies that the residence time of these phenocrysts did not exceed 1–2 kyr. Older, less precise, ages for the upper part of the magma chamber (~ 30 kyr) suggest mixing of older crystals from cumulates and/or longer residence times. Mineral isochrons for cumulate nodules are not well defined, with 'ages' ranging from 10 to 30 kyr, suggesting in-situ cumulate formation 10–20 kyr prior to the eruption. The time required to explain the $^{230}Th/^{232}Th$ difference between potential basanite and Laacher See phonolite is inferred to be about 100 kyr. Together, these observations favor a cooling model where differentiation of potential basanite takes place in a deep magma body over about 100 kyr, followed by emplacement of the resulting mafic phonolite into an upper crustal chamber and continued differentiation toward evolved phonolite. The time-scale for the development of zonation in the Laacher See magma chamber is estimated to be 10–20 kyr at most.

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"What's the problem ?"

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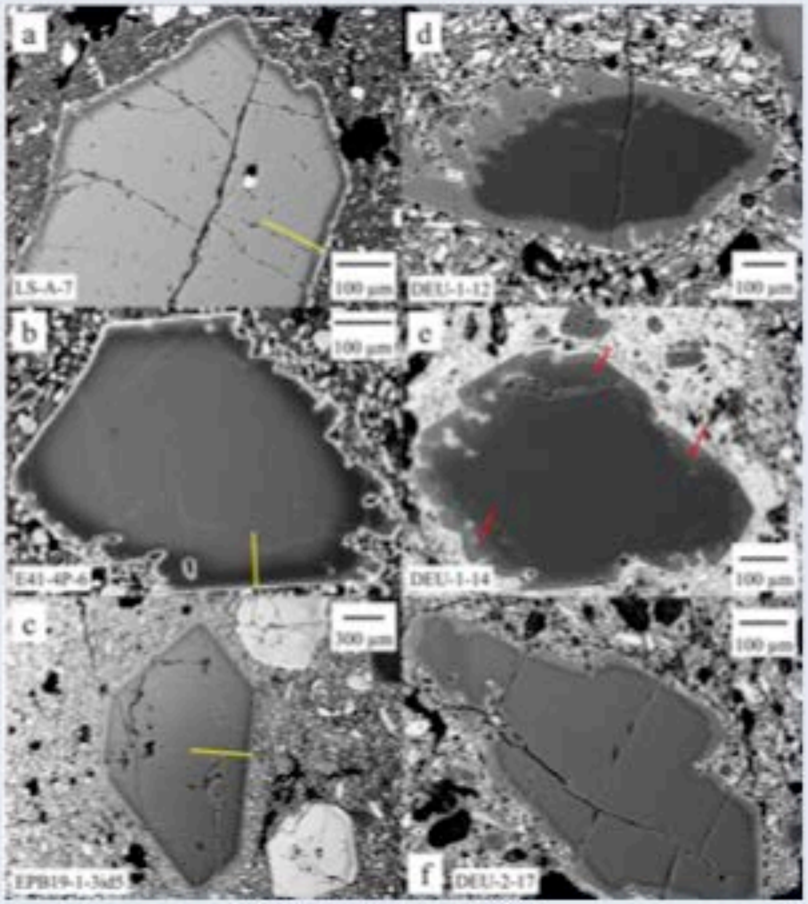
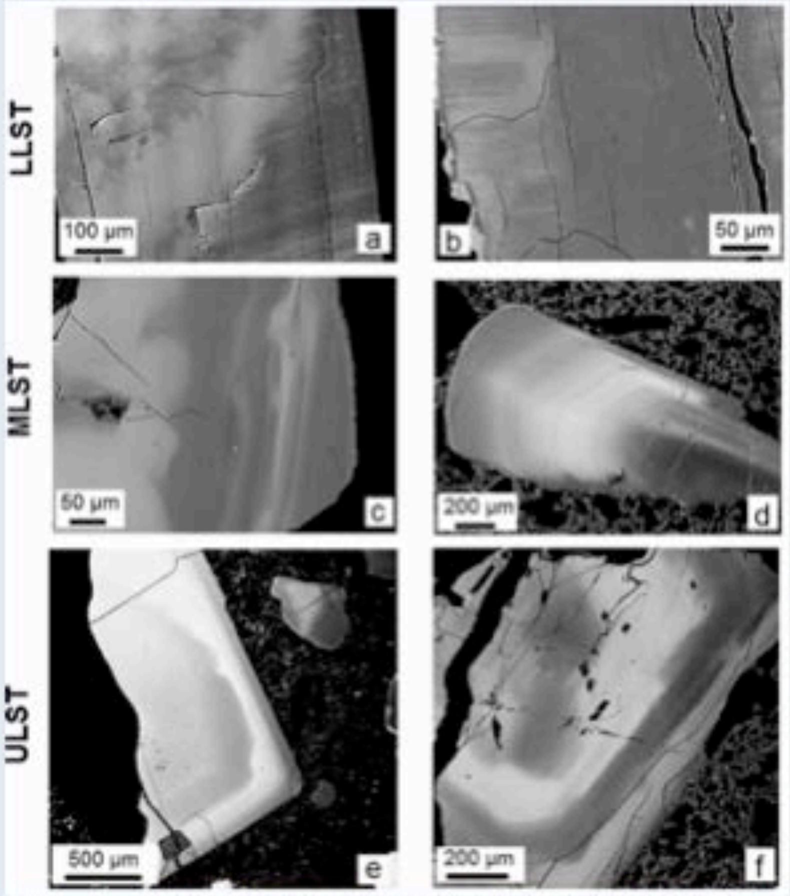
Zoned olivine in basanite and basanite-phonolite hybrid magmas



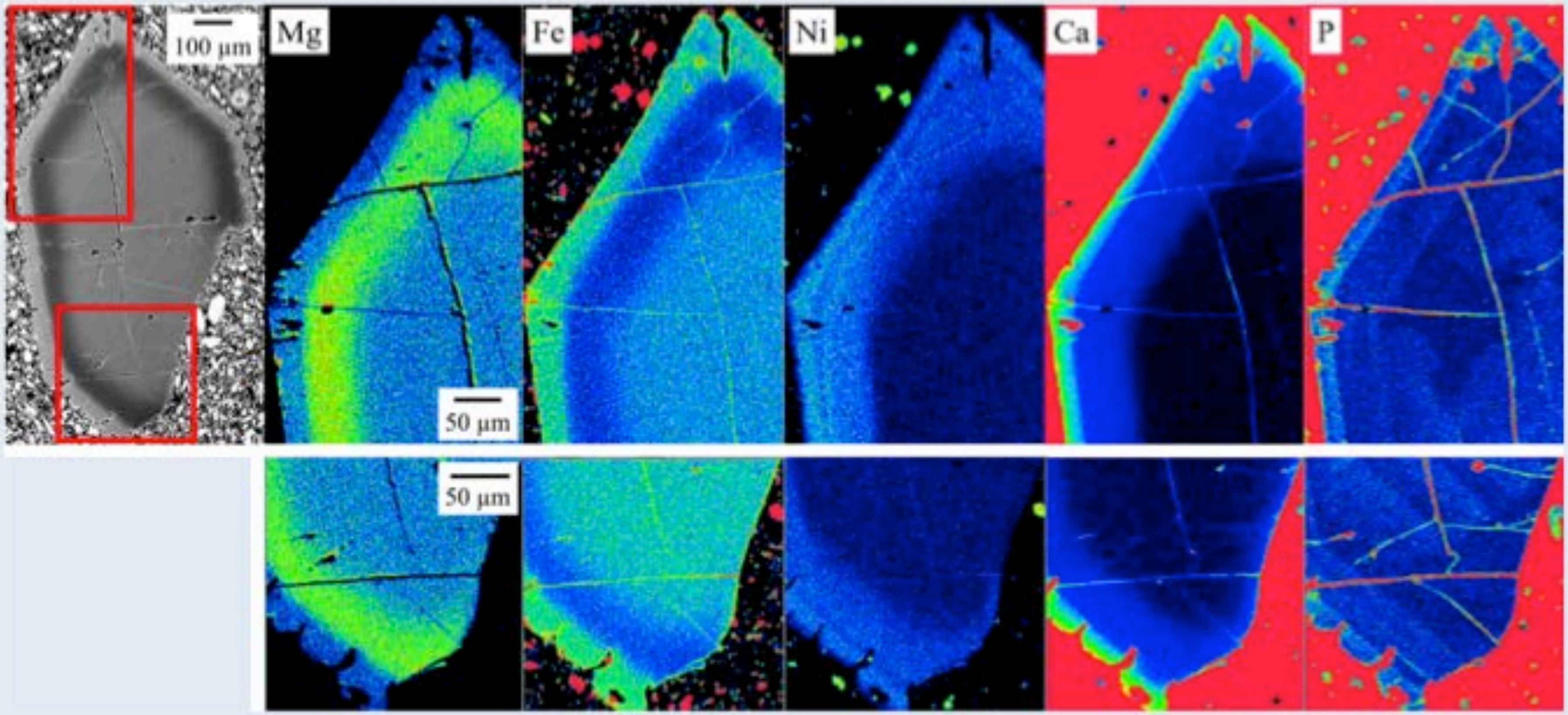
Sundermeyer et al (2020)

Zoned sanidine in phonolite and basanite-phonolite hybrid magmas



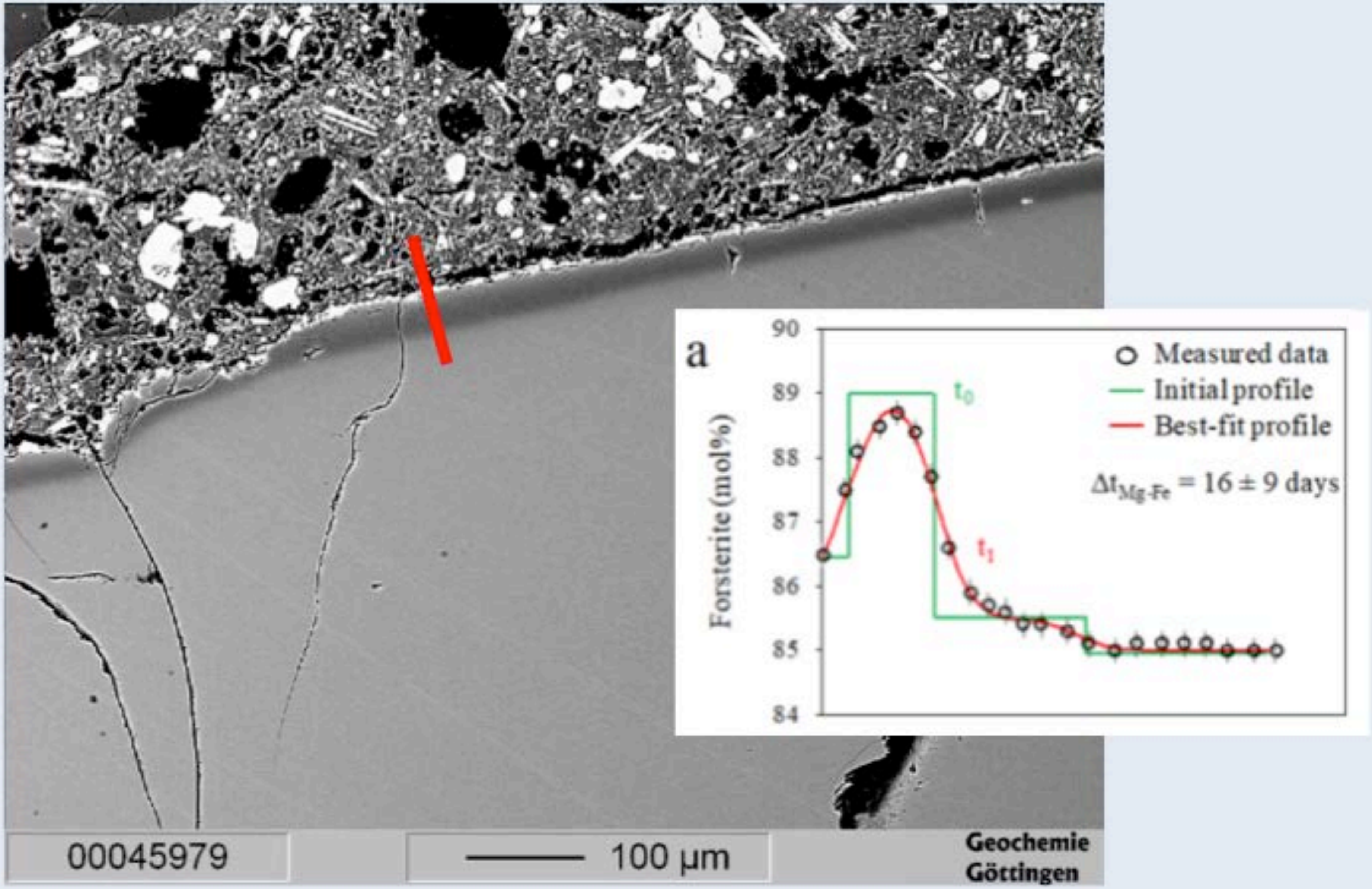
Rout and Wörner (2018) Rout and Wörner (2020)

Diffusion modelling across compositional unconformities in olivine crystals generated by magma mixing

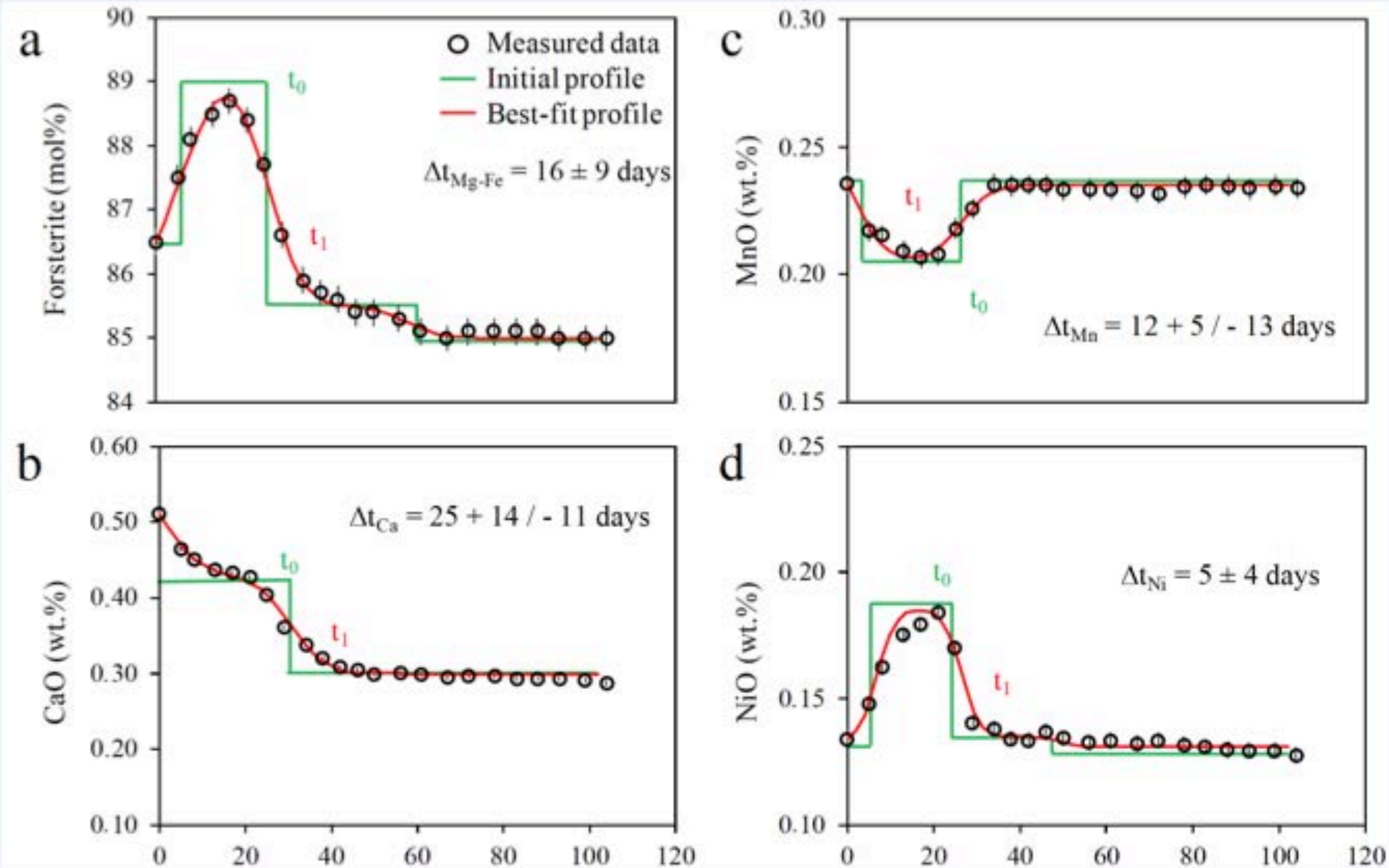


Sundermeyer et al (2020)

Diffusion modelling Olivine

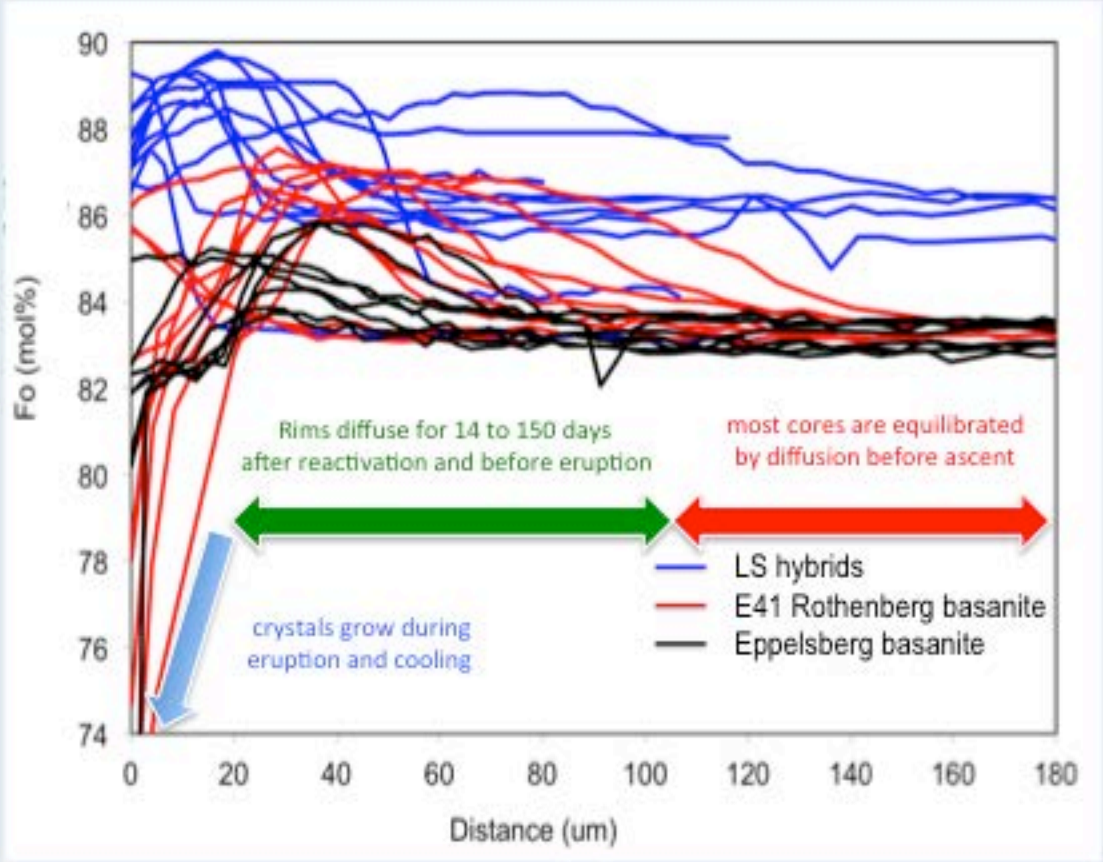


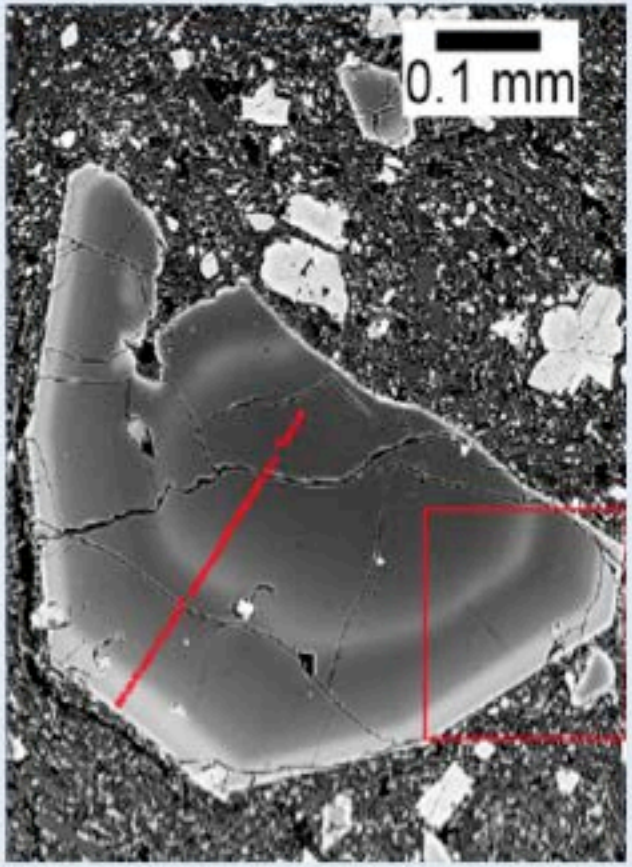
Diffusion modelling Olivine



Sundermeyer et al (2020)

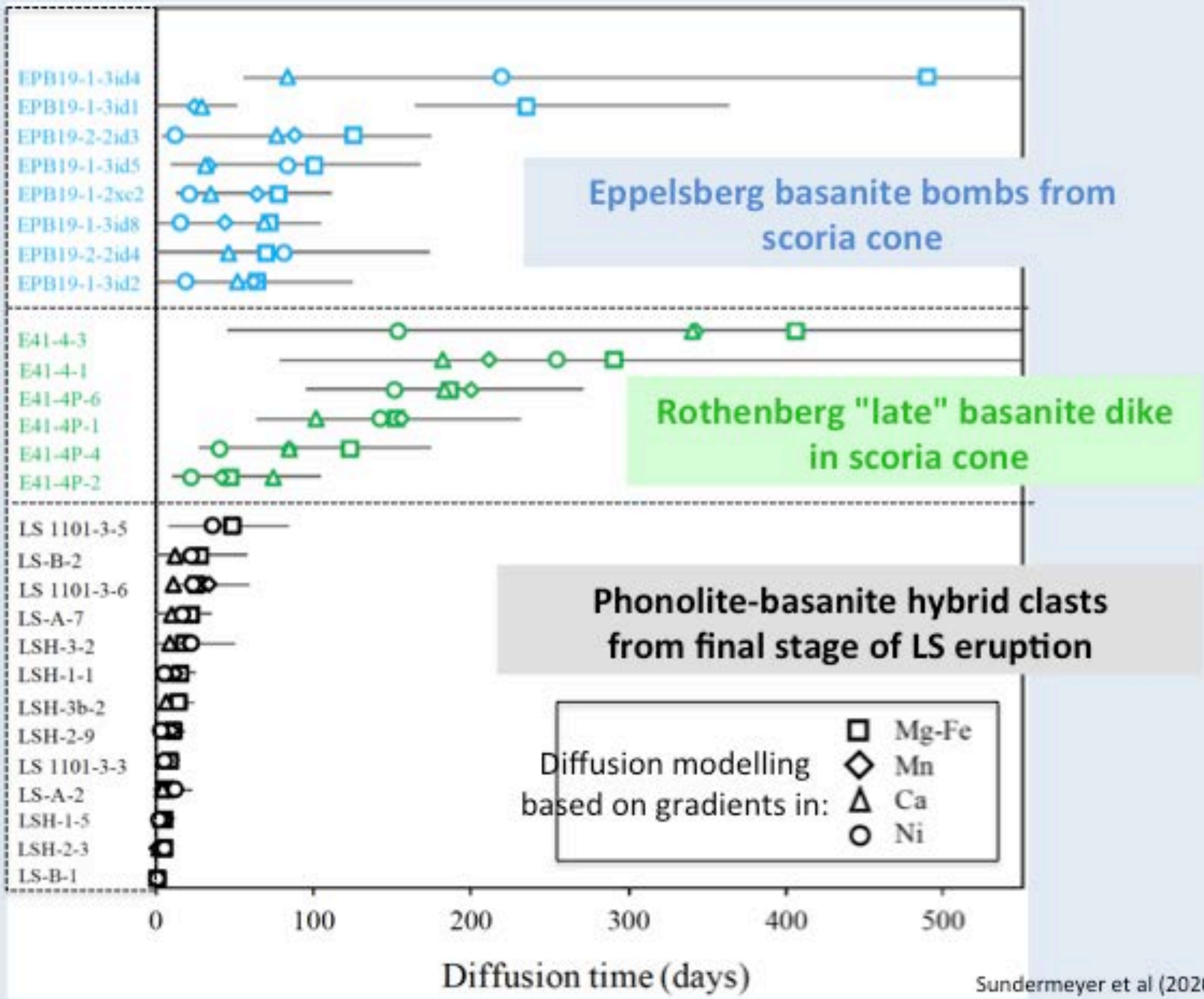
Diffusion modelling Olivine





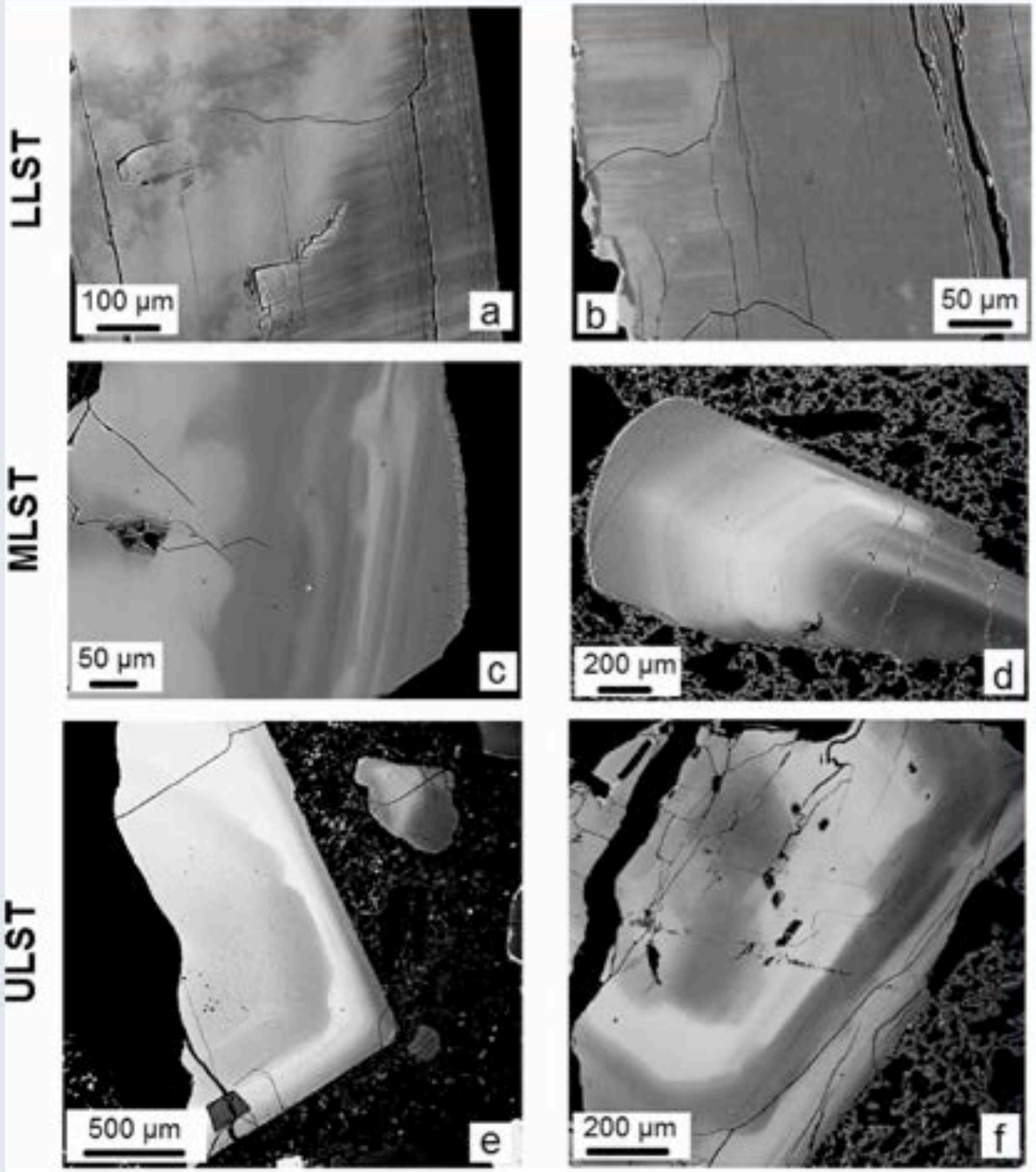
Sundermeyer et al (2020)

Olivine in LS hybrids vs. olivine in basanites



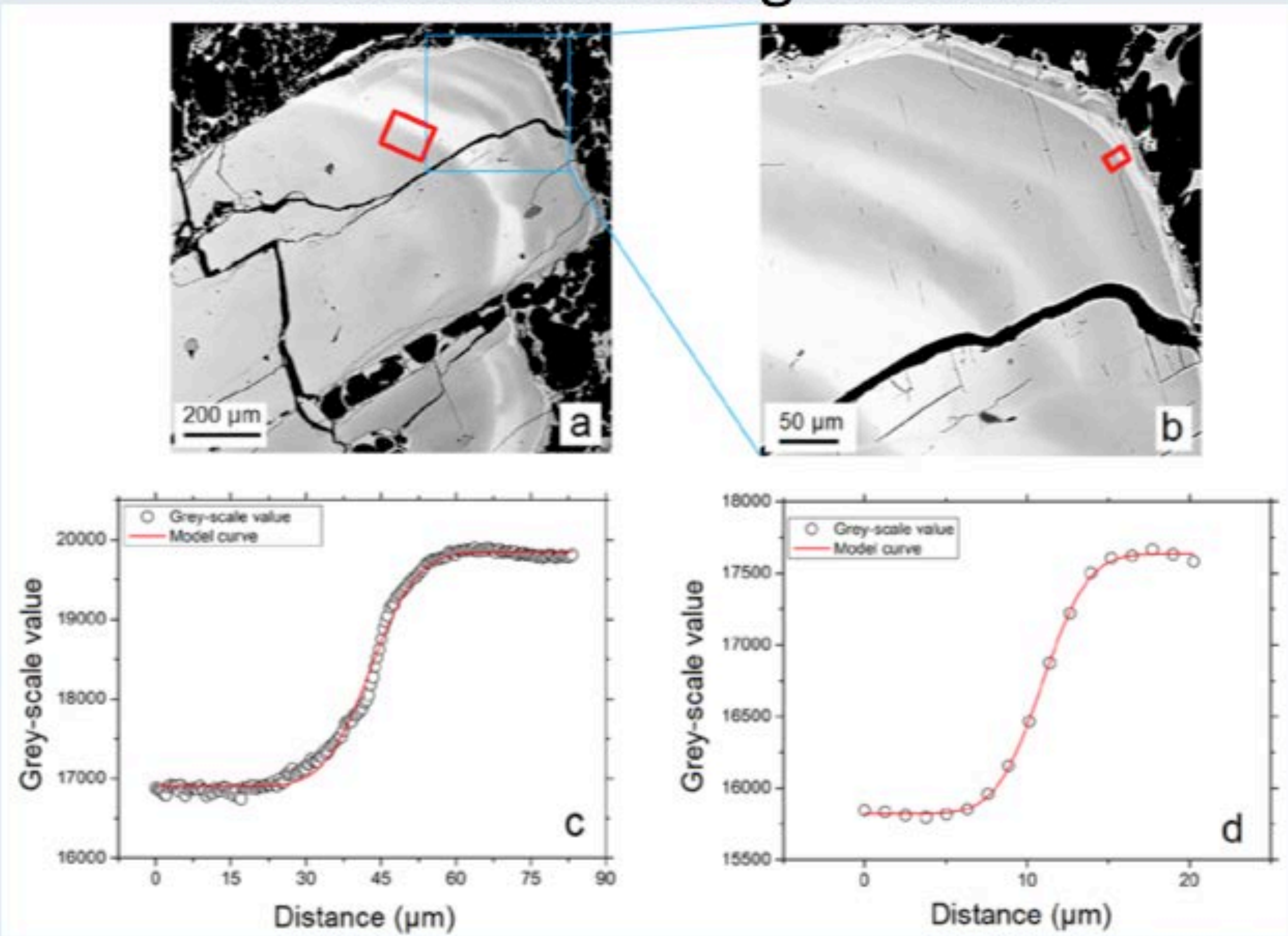
Sundermeyer et al (2020)

Diffusion modelling Sanidine



Rout and Wörner (2018)
Rout and Wörner (2020)

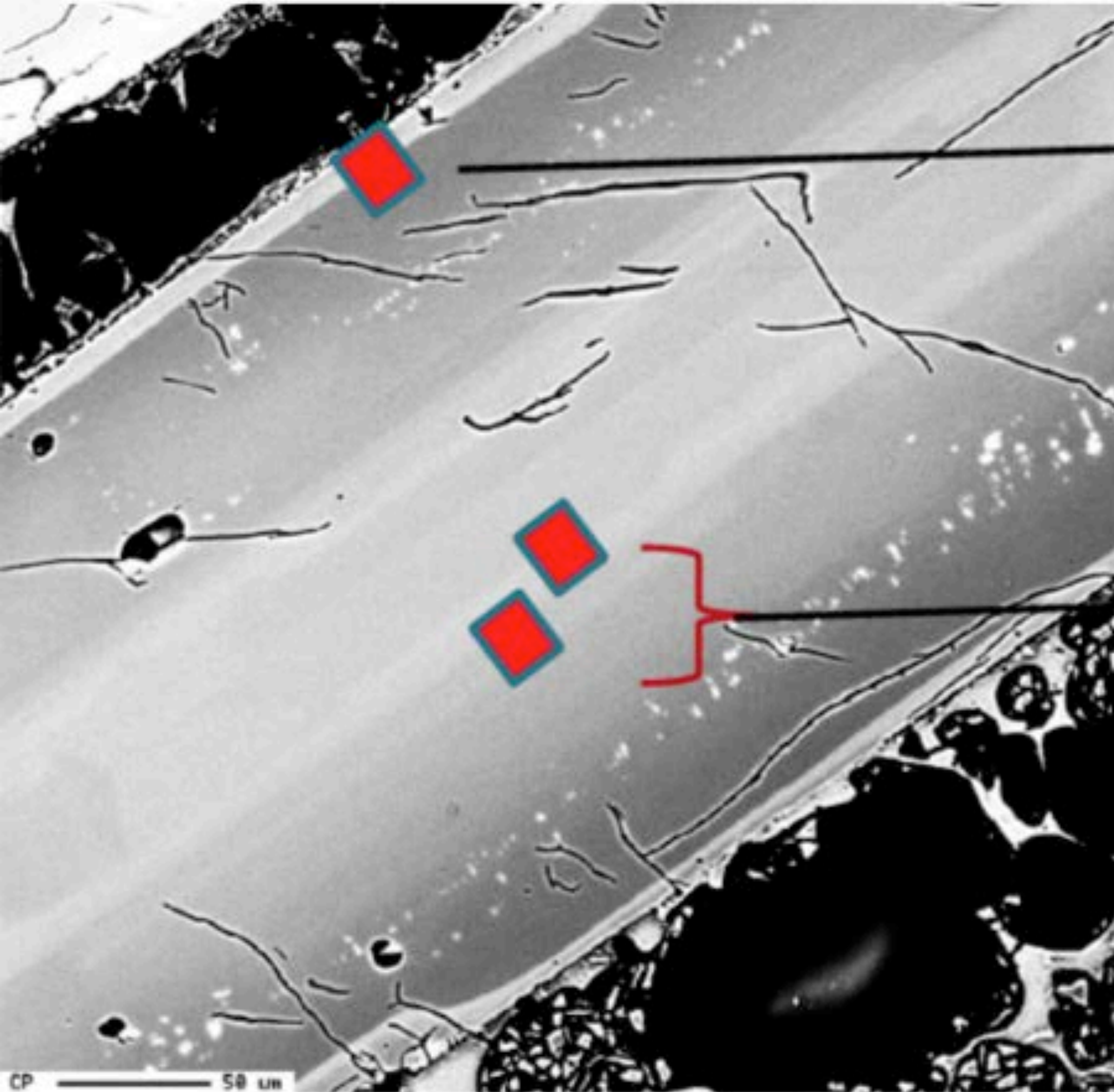
Diffusion modelling Sanidine



Rout and Wörner (2018)
Rout and Wörner (2020)

zoned sanidine in ULST Hybrid

(mingled phonolite + basanite lava)



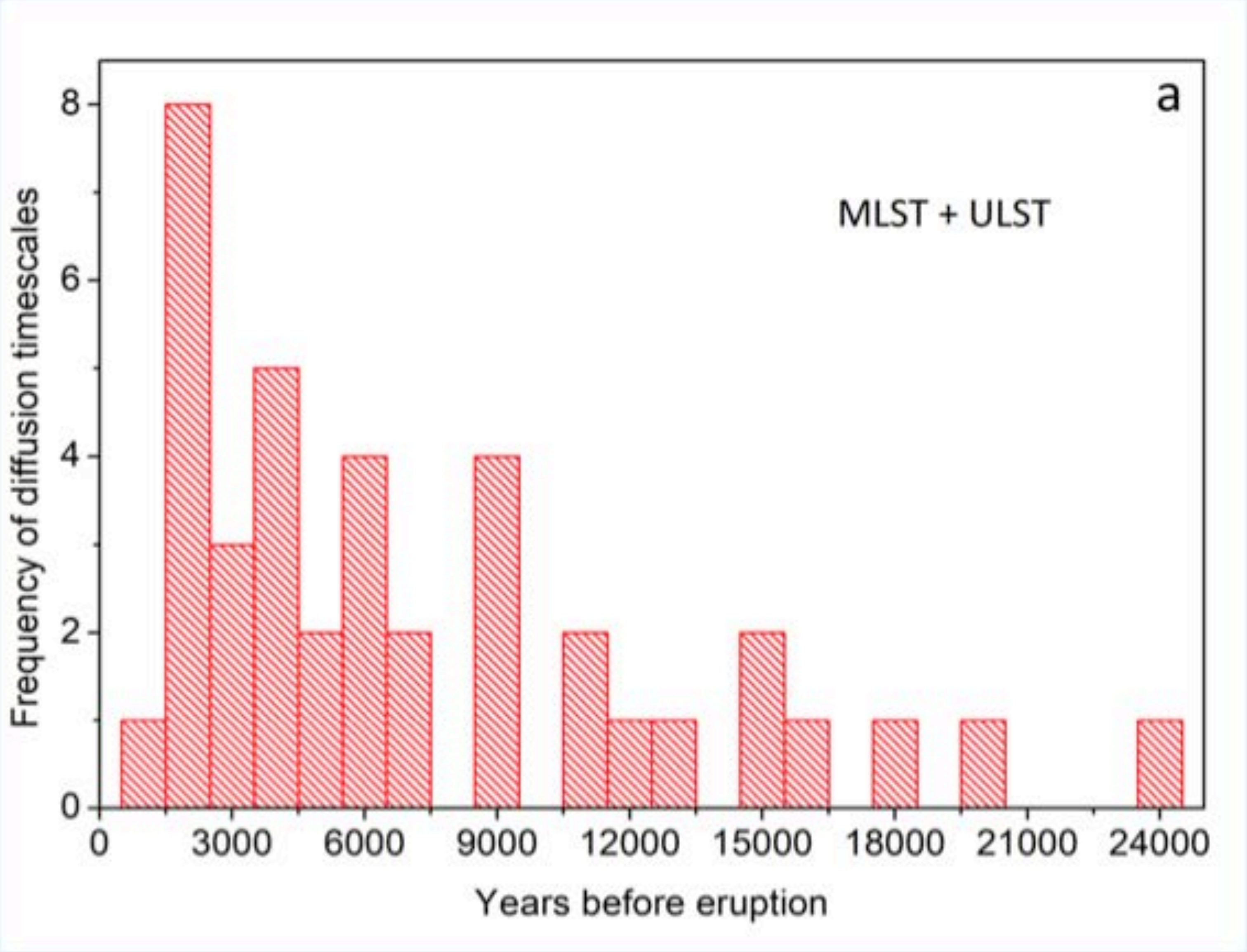
Diffusion times:

4 to 7 years in outermost boundary

1500 to 3000 years in core zonations

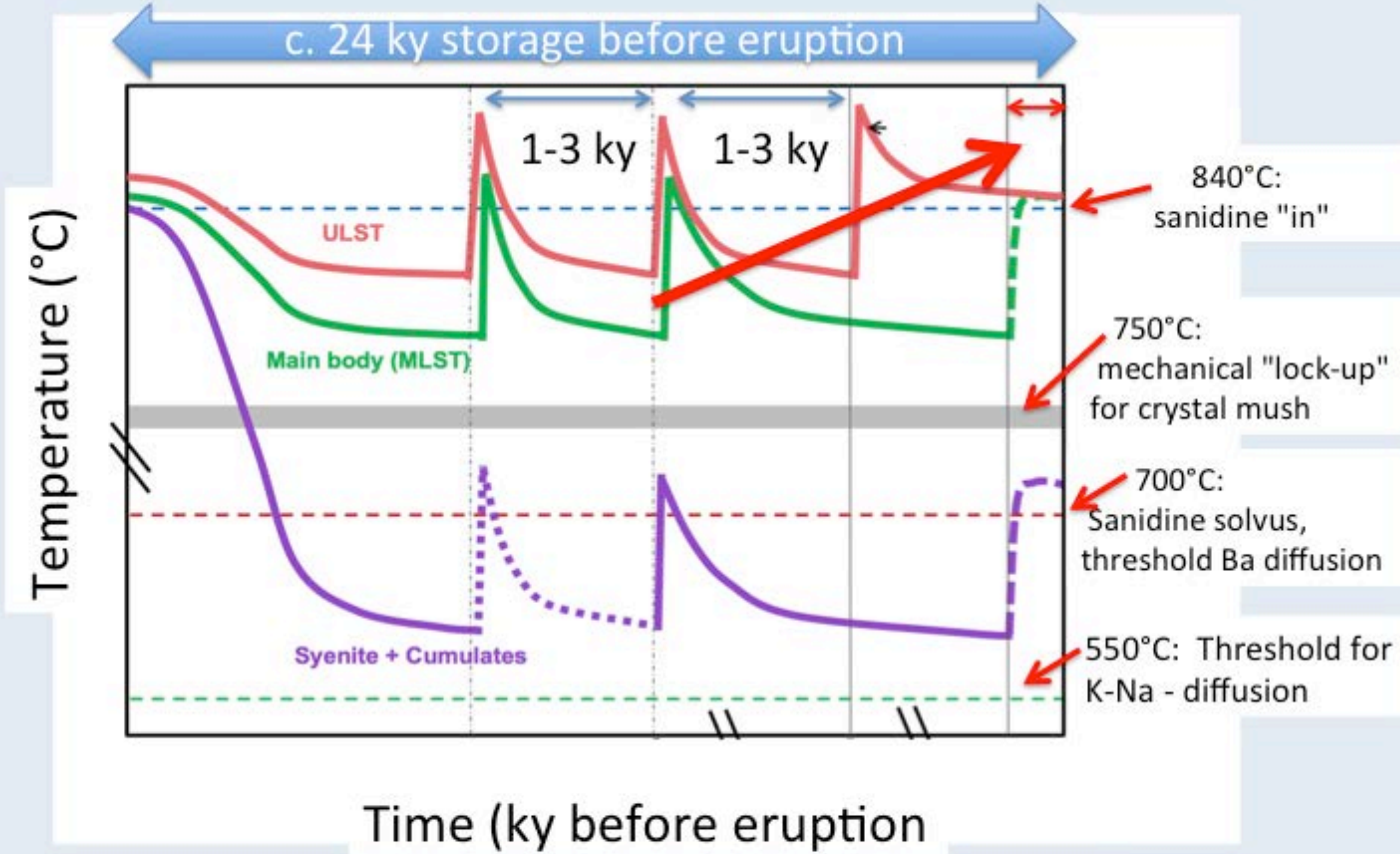
Rout and Wörner (2018) Rout and Wörner (2020)

Diffusion modelling Sanidine



Rout and Wörner (2018)
Rout and Wörner (2020)

Age and temperature fluctuation
in the phonolitic magma reservoir



Rout and Wörner (2018)
Rout and Wörner (2020)

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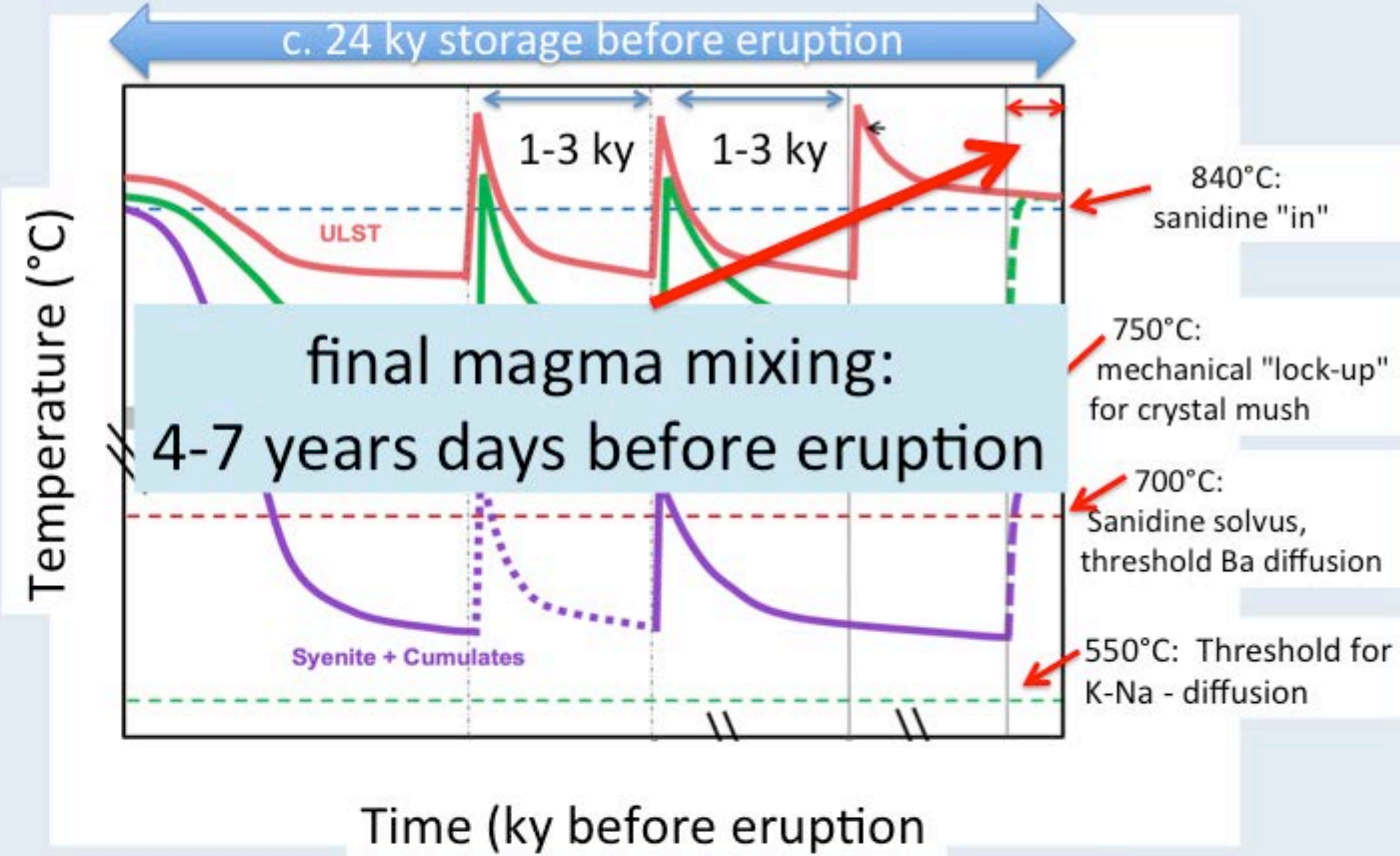
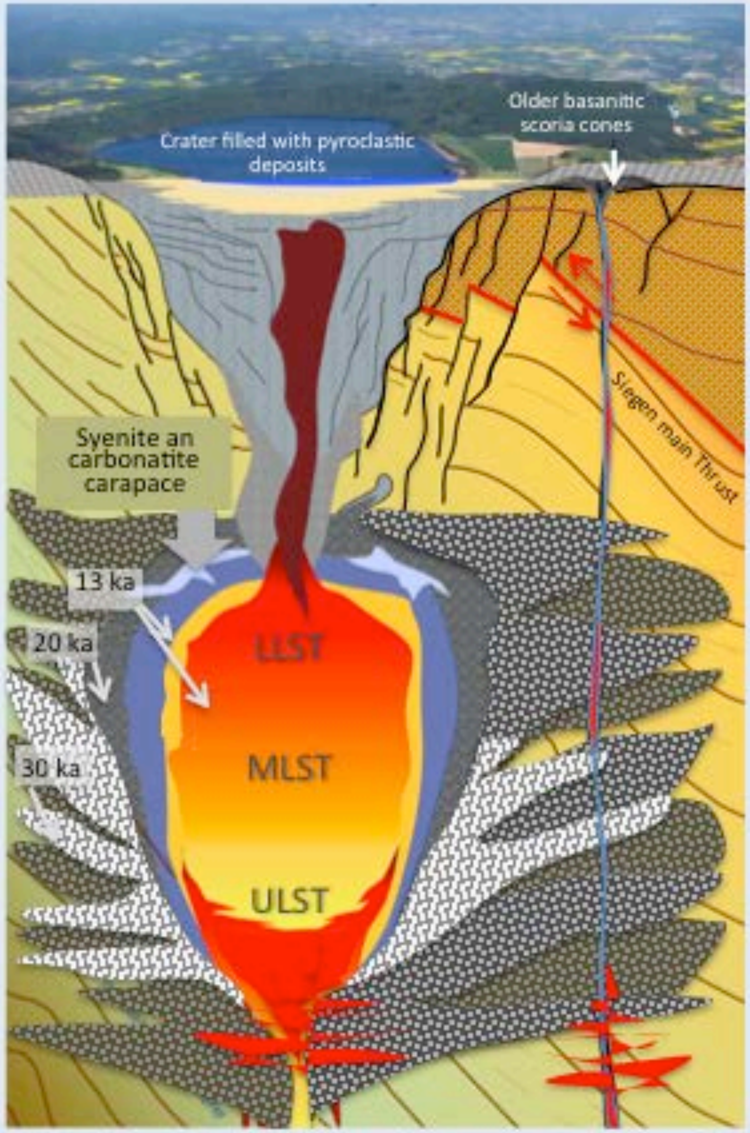


Rout and Wörner (2018)
Rout and Wörner (2020)

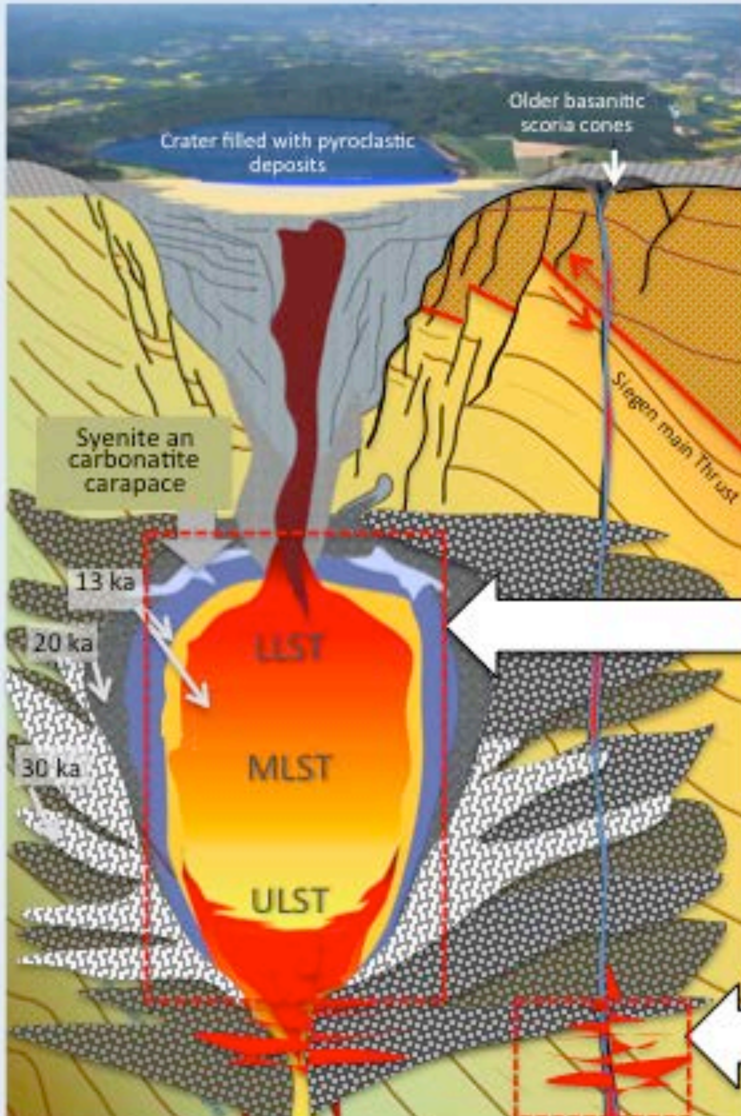
Physical model of LS magma reservoir constrained by...

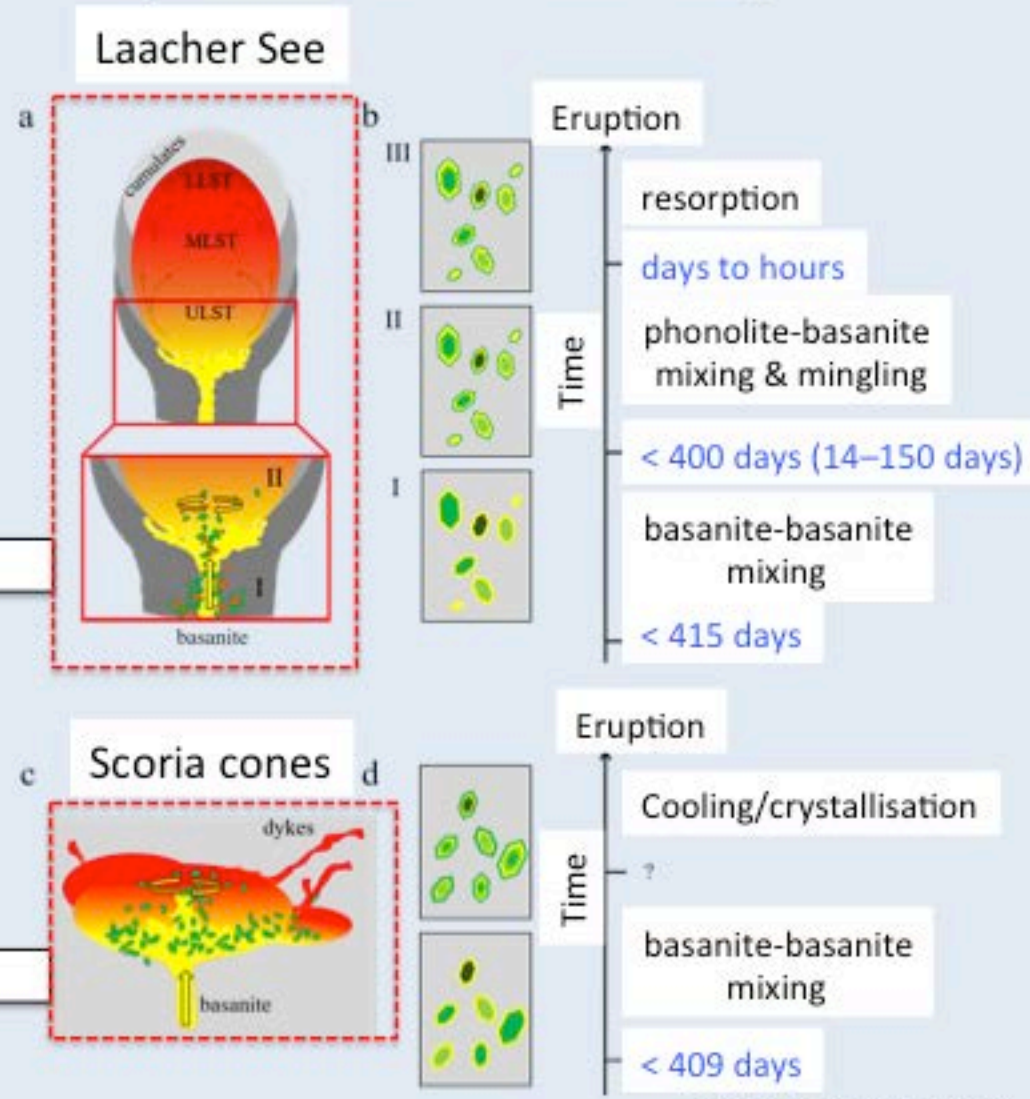


- pressure (depth) estimates from xenoliths and phonolite petrology,
- erupted volumes and compositions
- cognate cumulates and syenite/ carbonate and cruystal lithics
- dating of zircons
- analogy to Alnö alkaline syenite/ carbonatite intrusive ring complex

Sundermeyer et al (2020)

Temporal evolution of the LS magma reservoir constrained by diffusion modelling





Sundermeyer et al (2020)

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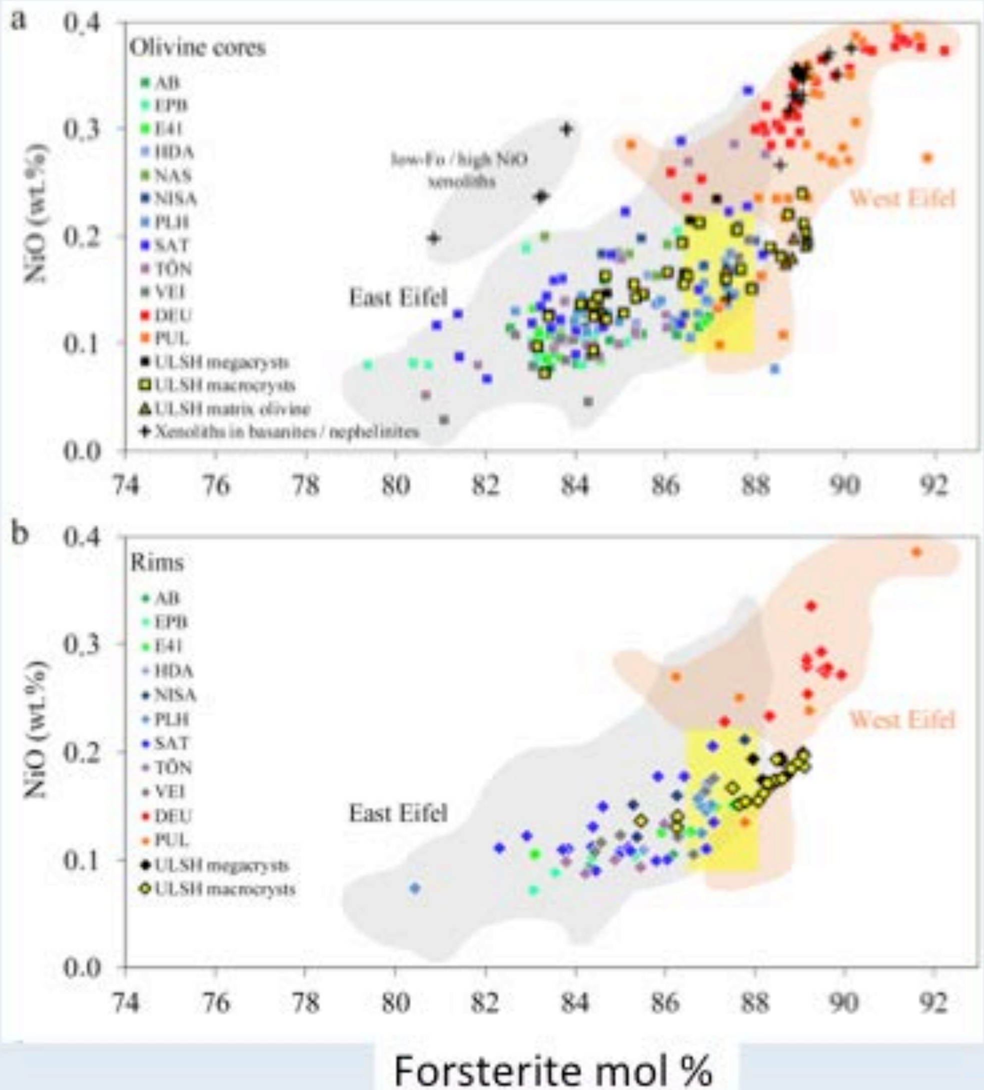
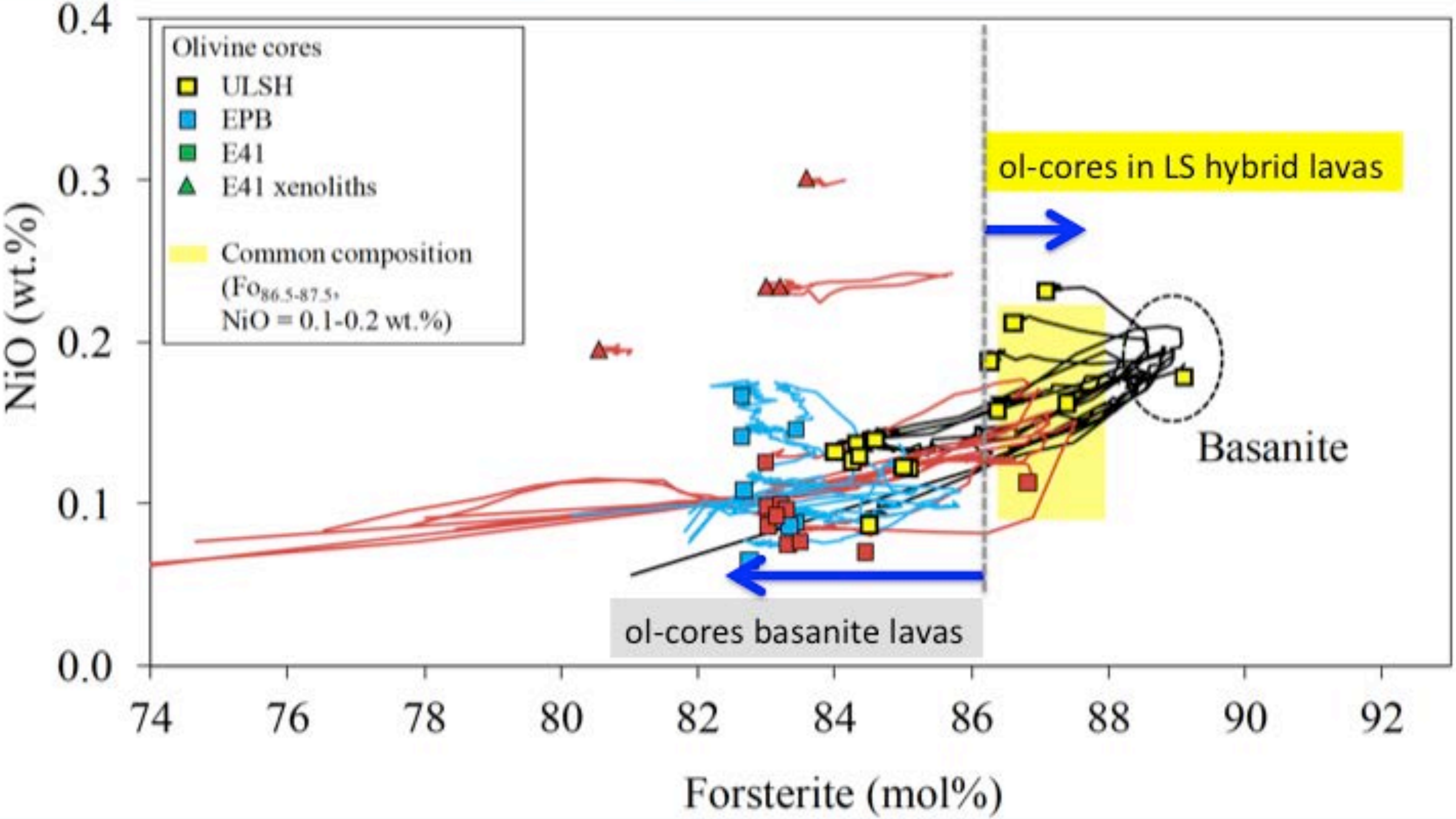
Recharge magma composition

constrained by olivine core compositions

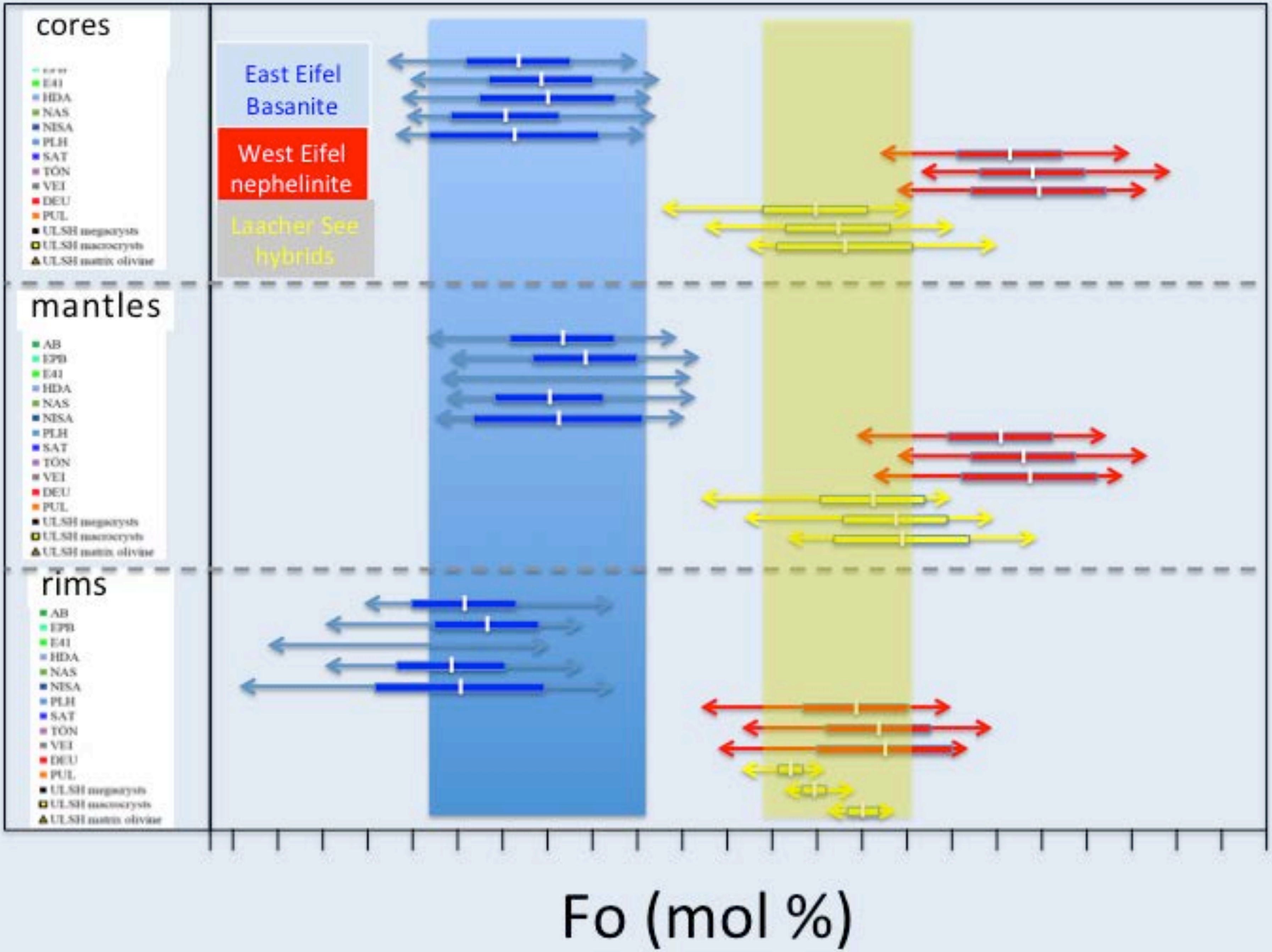


Sundermeyer et al (2020)

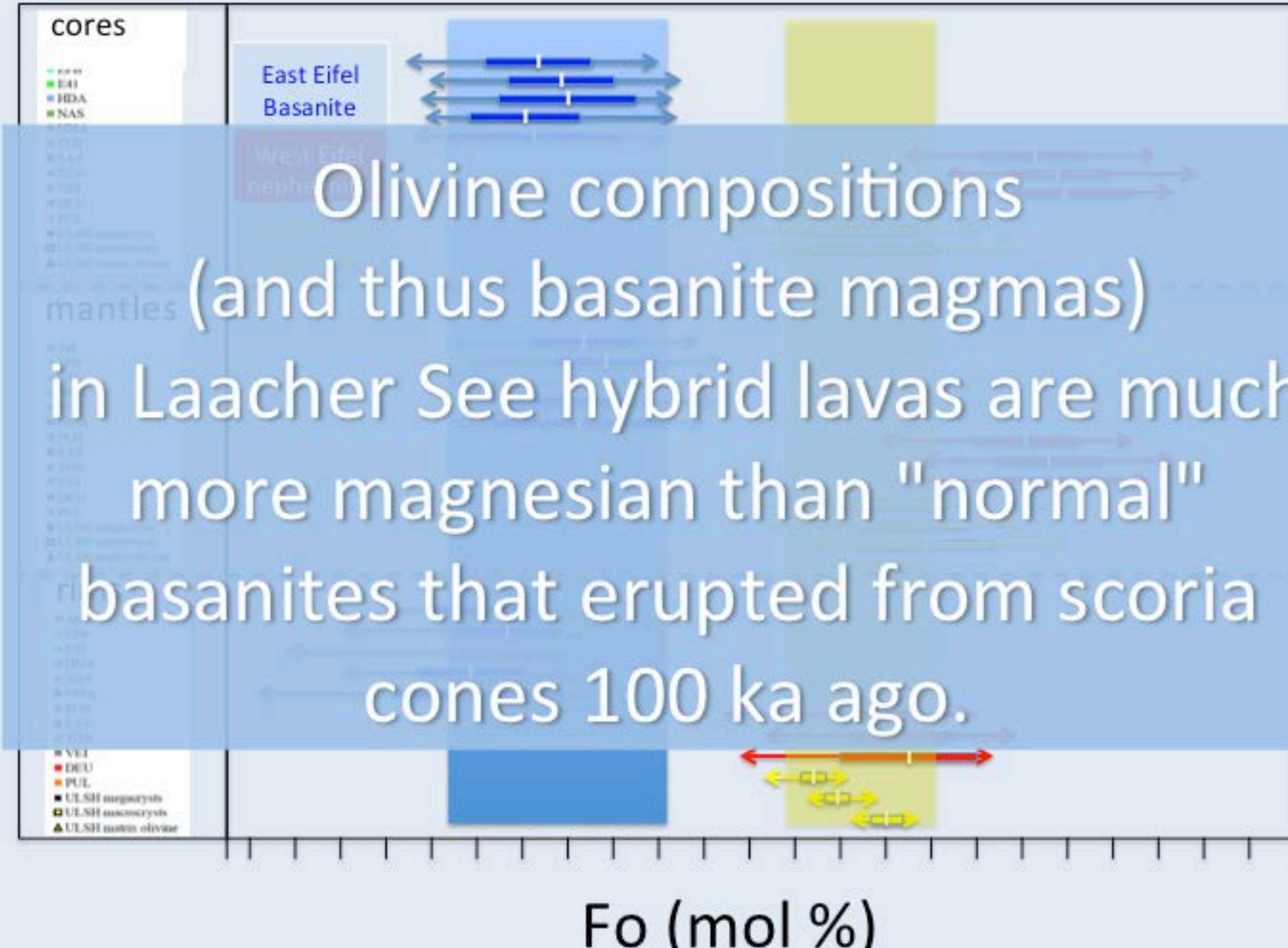
Recharge magma composition



Sundermeyer et al (2020)



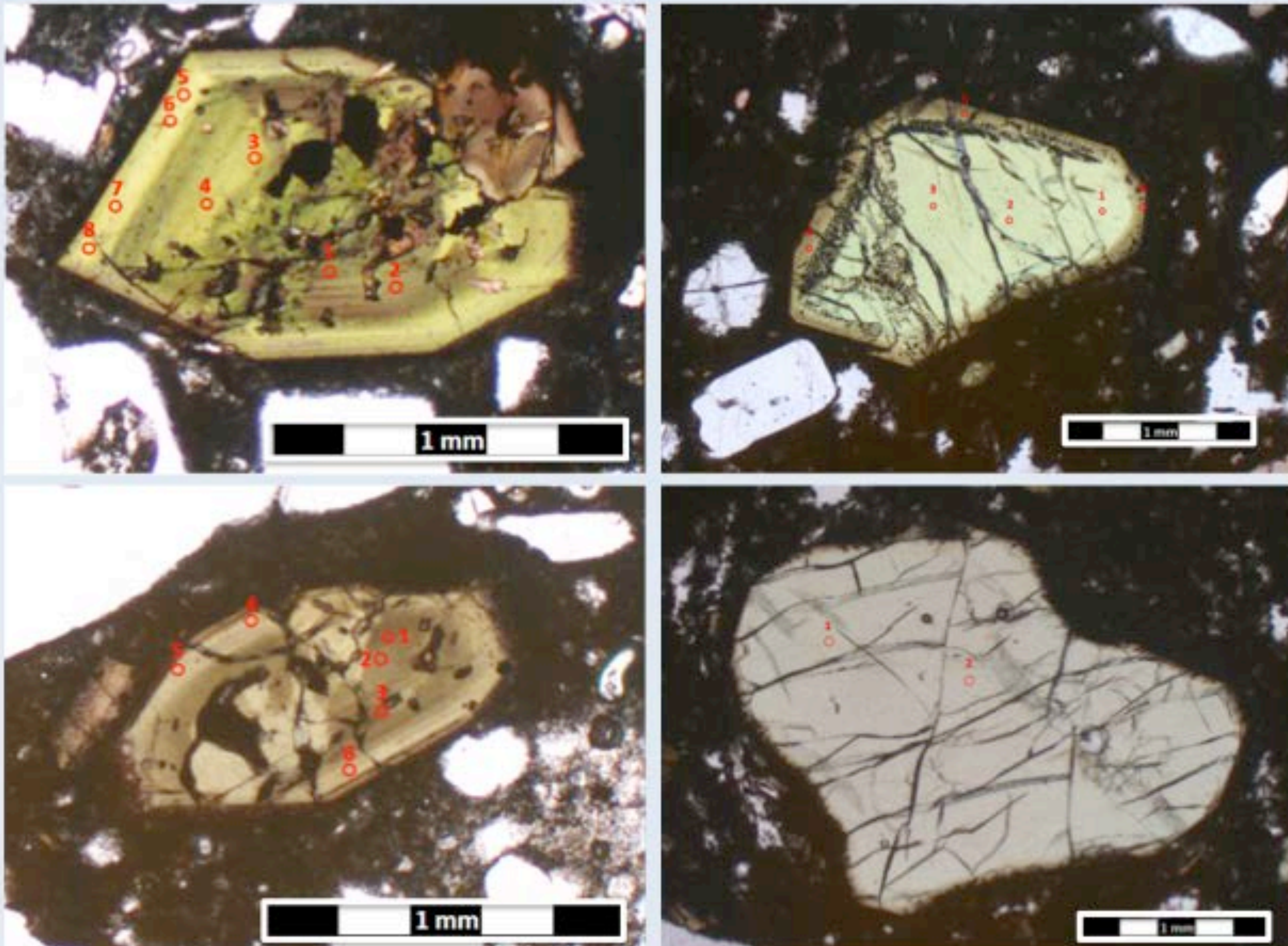
cores
mantles
rims
East Eifel Basanite
West Eifel nephelinite
Laacher See hybrids
AB
EPB
E41
HDA
NAS
NISA
PLH
SAT
TON
VEI
DEU
PUL
ULSH megacrysts
ULSH macrocrysts
ULSH matrix olivine
Fo (mol %)



Olivine compositions (and thus basanite magmas) in Laacher See hybrid lavas are much more magnesian than "normal" basanites that erupted from scoria cones 100 ka ago.

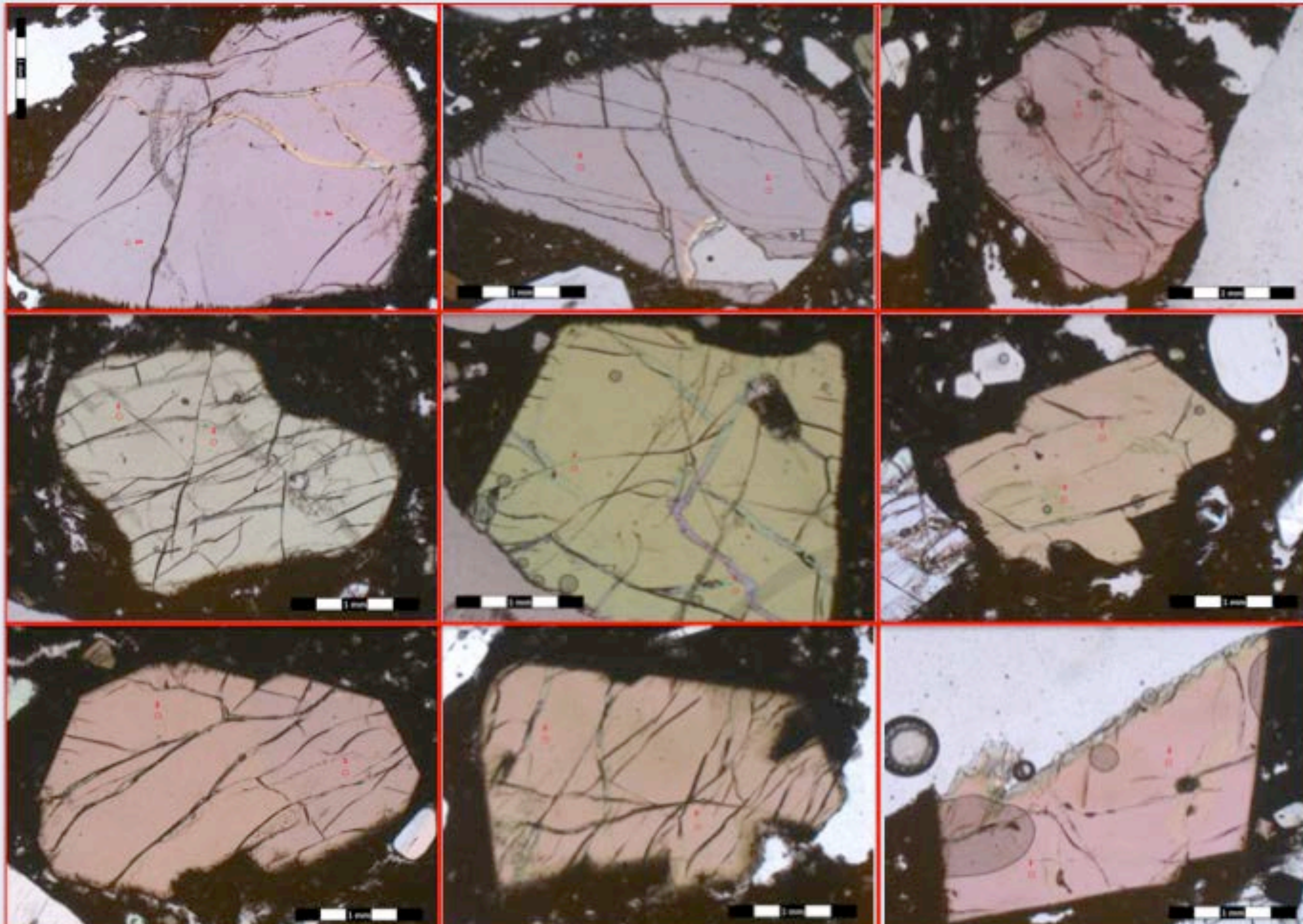
Recharge magma composition

What about Cpx compositions ?

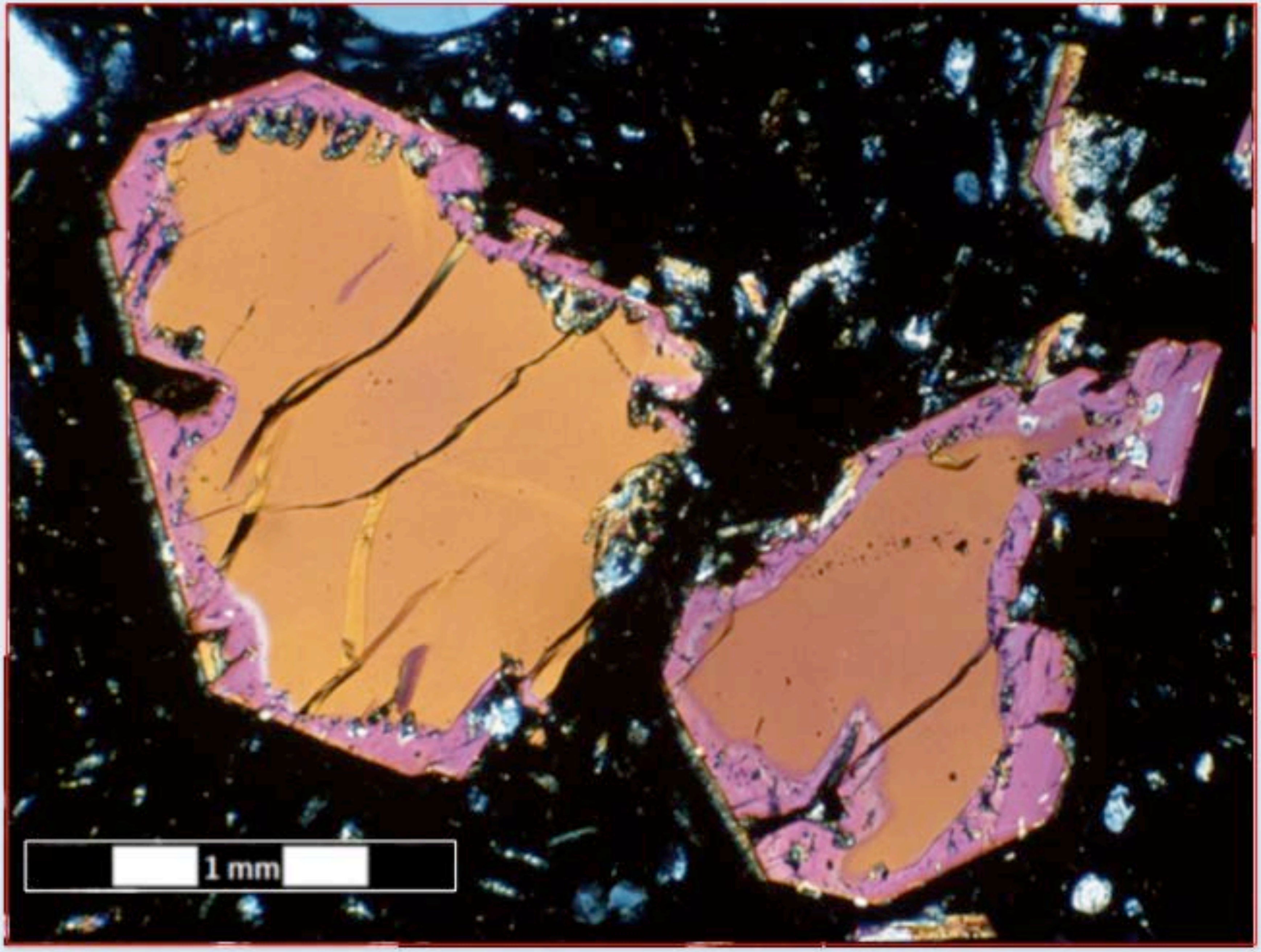


Wörner et al (unpublished)

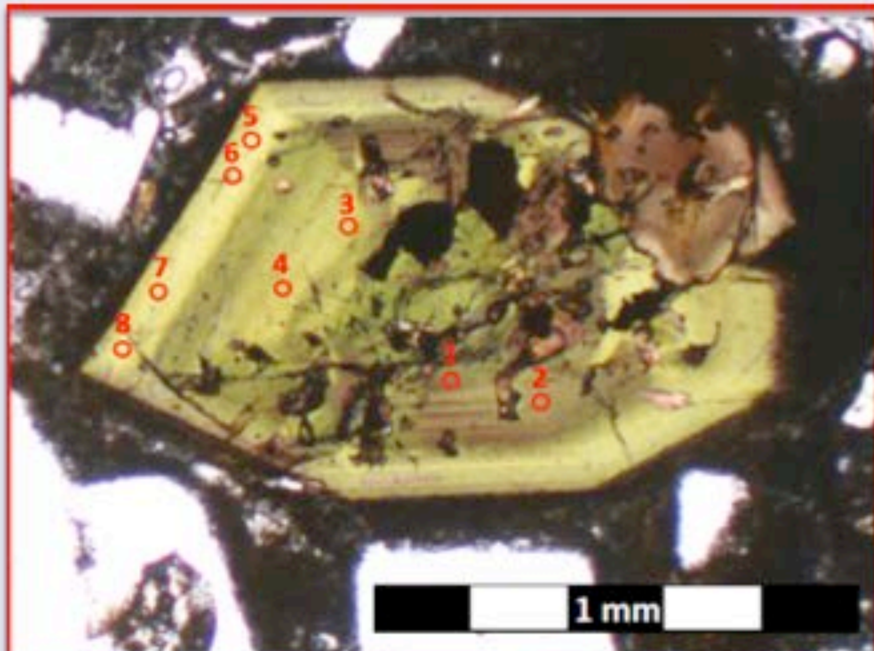
Serie 2: Homogeneous CPX megacrysts, resorbed/euhedral

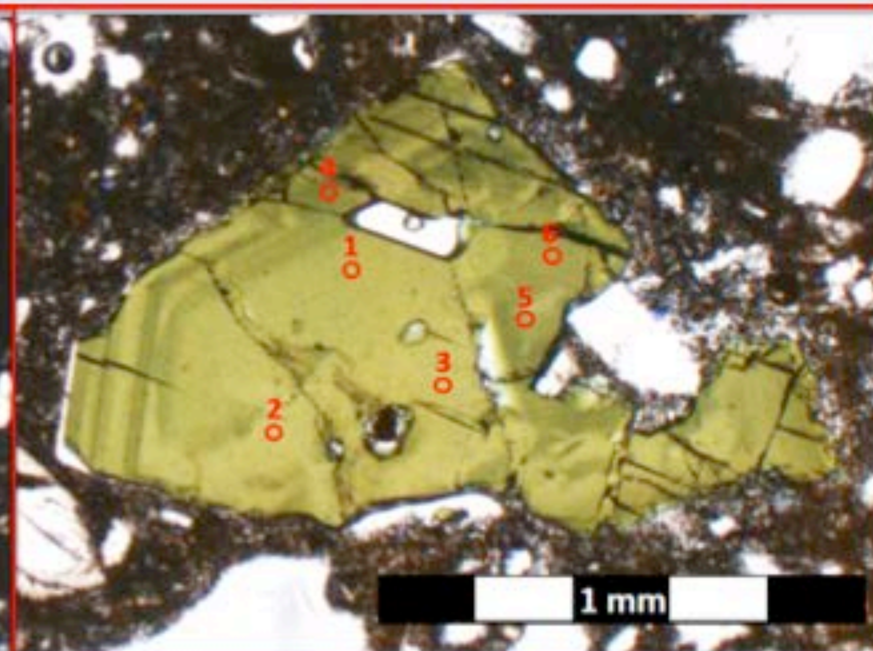


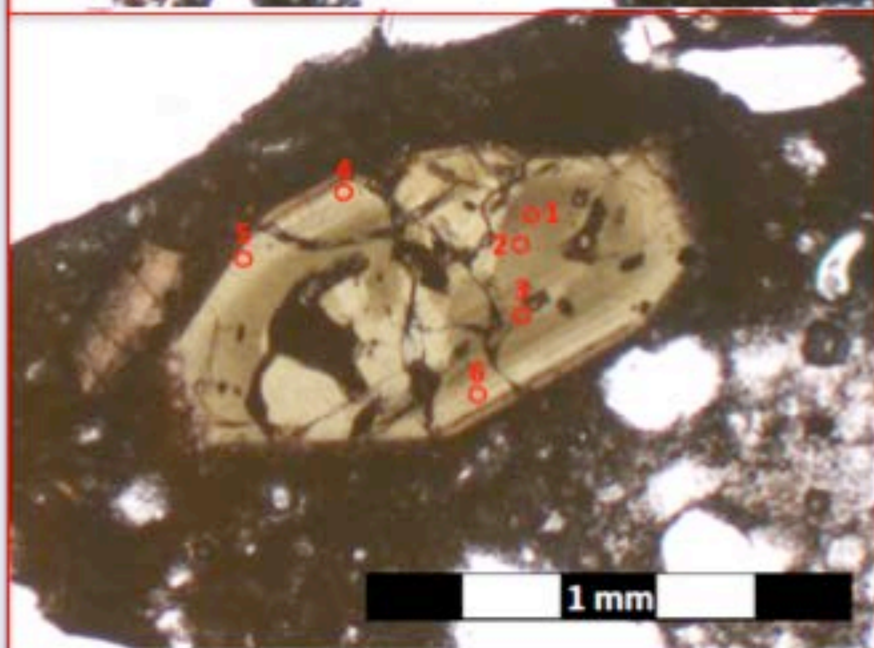
Serie 1: Homogeneous resorbed CPX megacrysts +Mg-rich overgrowth



Serie 3a: Small green CPX with oszillatory zoning (Fe-rich)



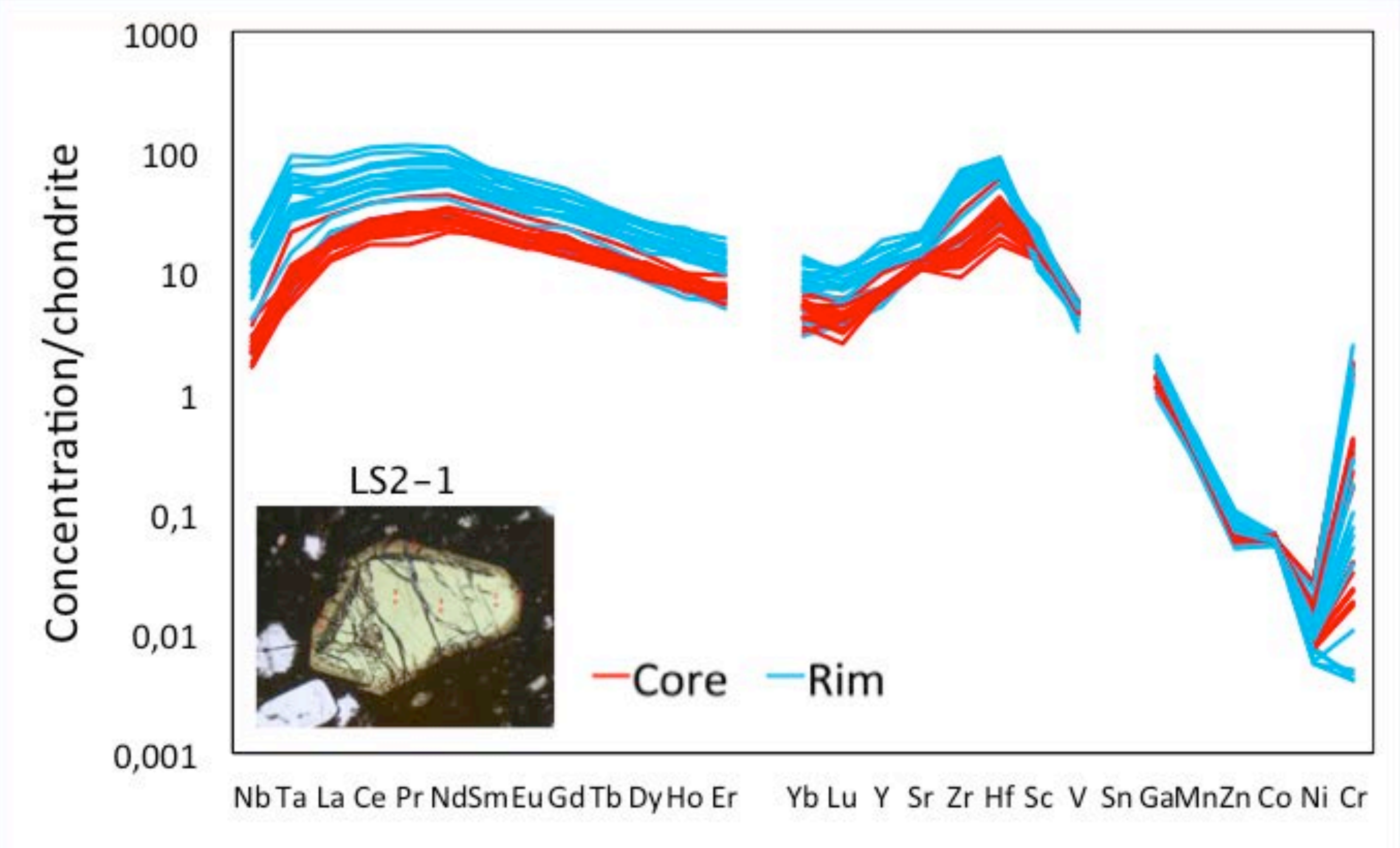




Serie 3b: Small brown CPX with oszillatory zoning (Mg-rich)

Wörner et al (unpublished)

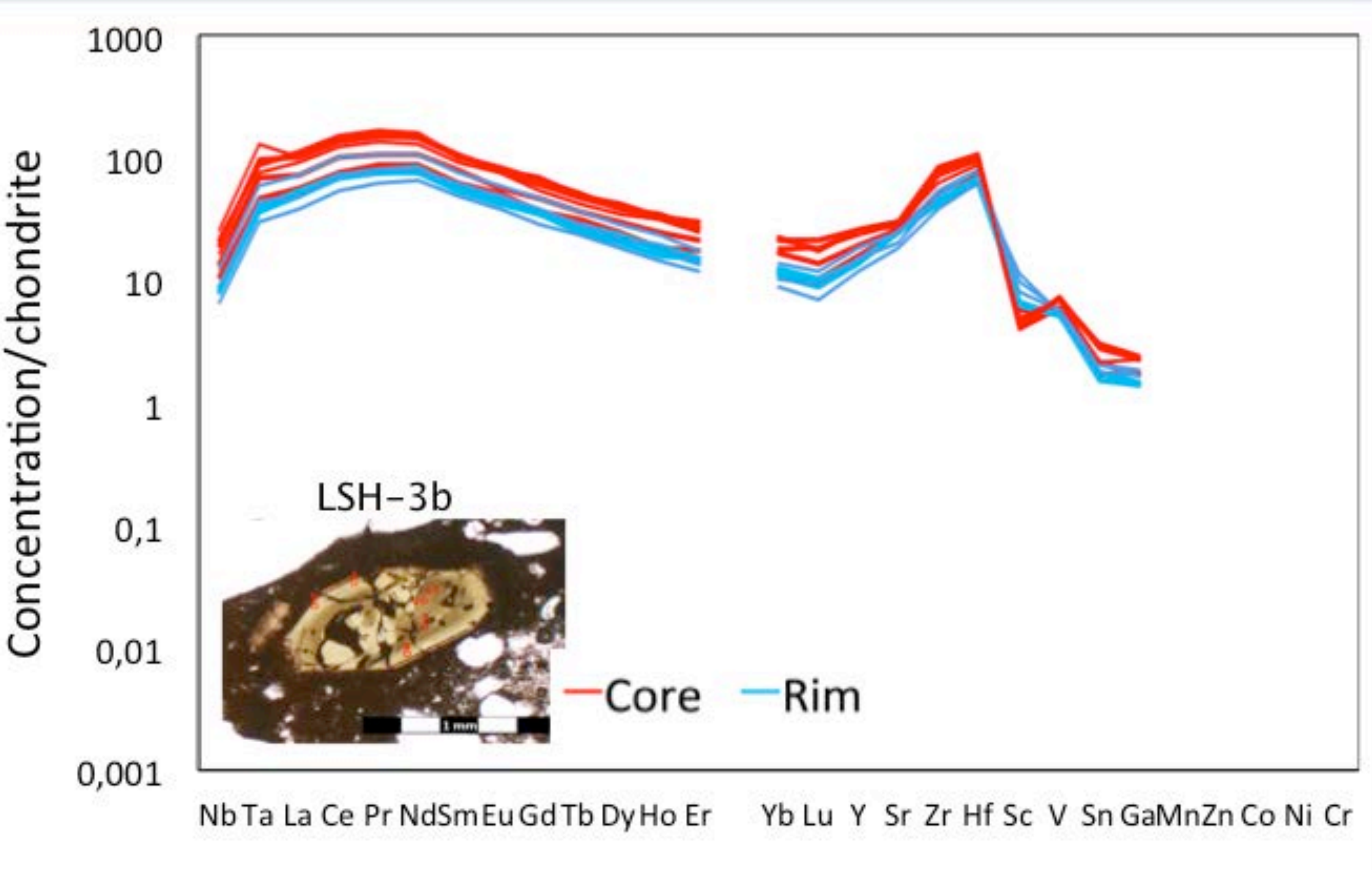
Serie 2: Homogeneous mega-CPX with resorption and overgrowth



Daten: L. Kallas, D. Hoffmann

Wörner et al (unpublished)

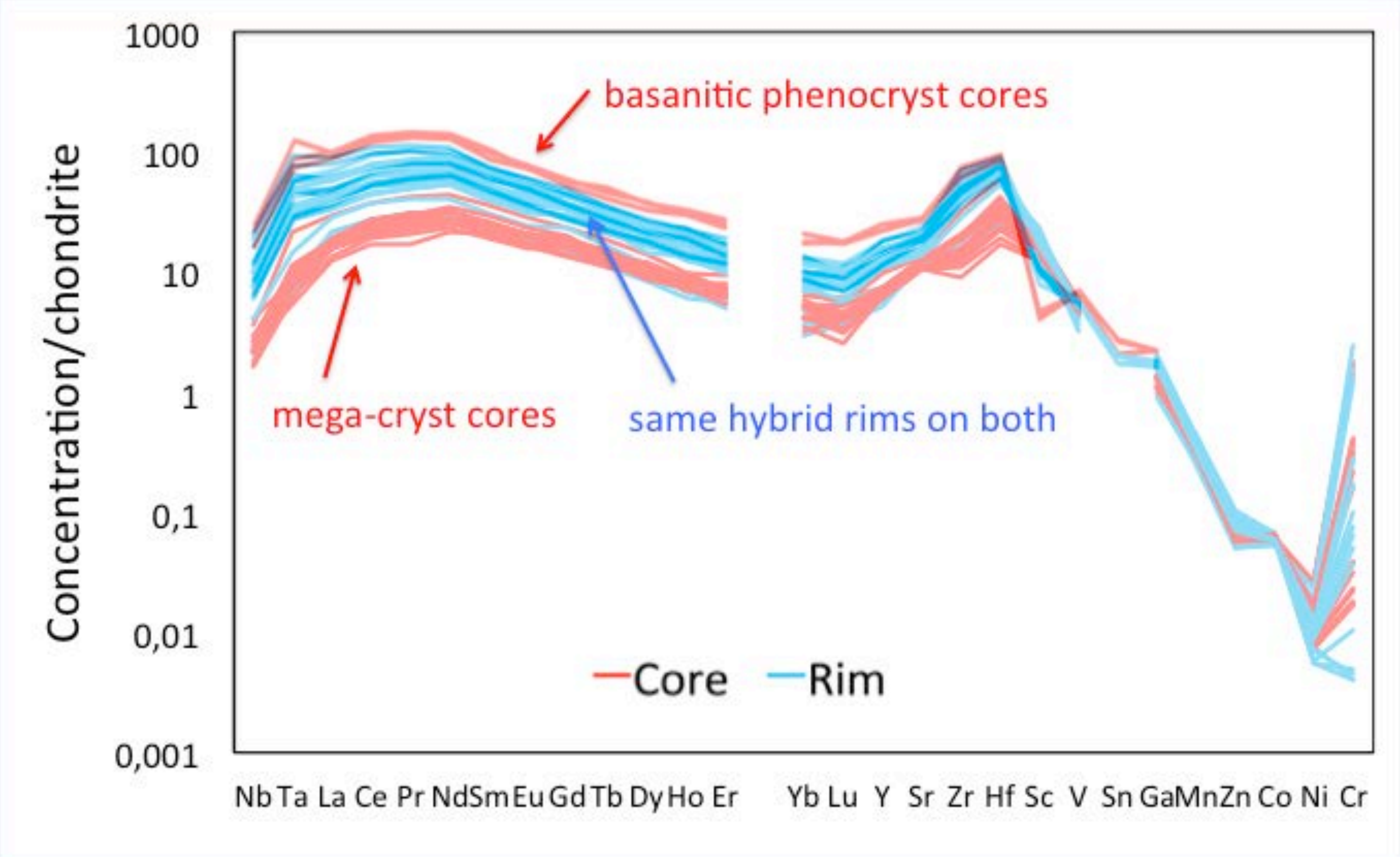
Serie 3b: brown, small CPX phenocrysts with oszillatory zonation



Daten: L. Kallas, D. Hoffmann

Wörner et al (unpublished)

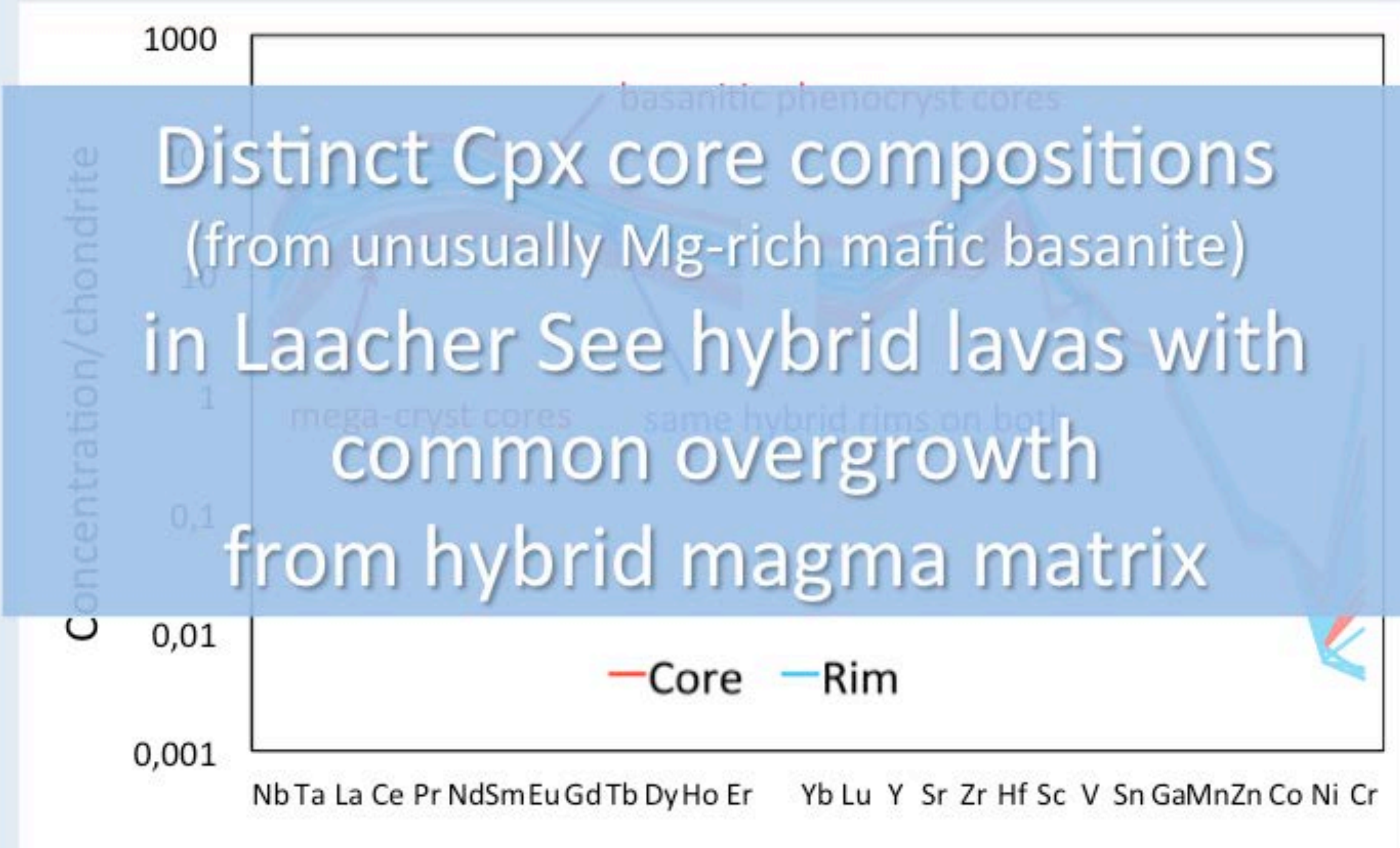
Serie 3b and megacrysts



Daten: L. Kallas, D. Hoffmann

Wörner et al (unpublished)

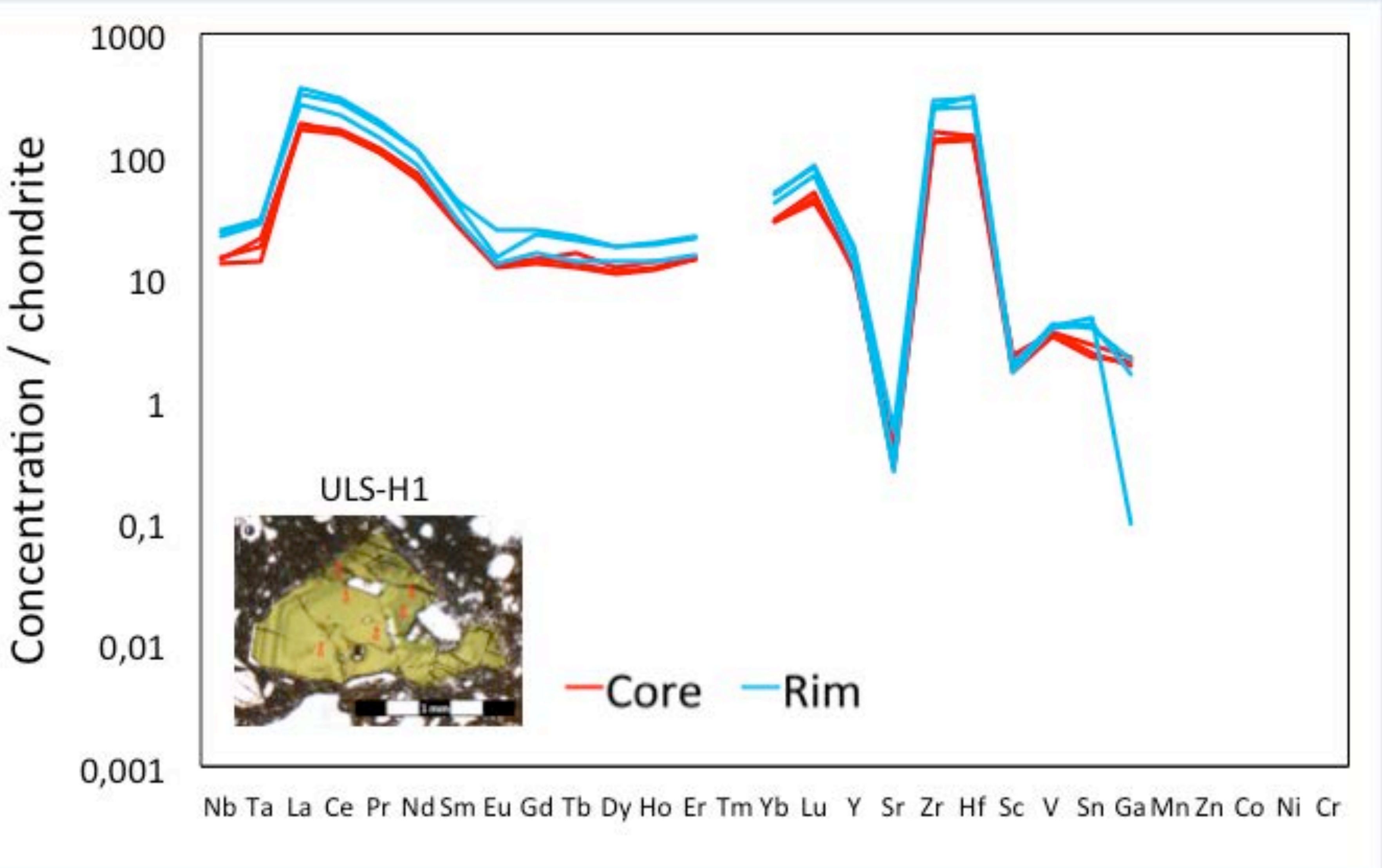
Serie 3b and megacrysts



Distinct Cpx core compositions
(from unusually Mg-rich mafic basanite)
in Laacher See hybrid lavas with common overgrowth from hybrid magma matrix

Wörner et al (unpublished)

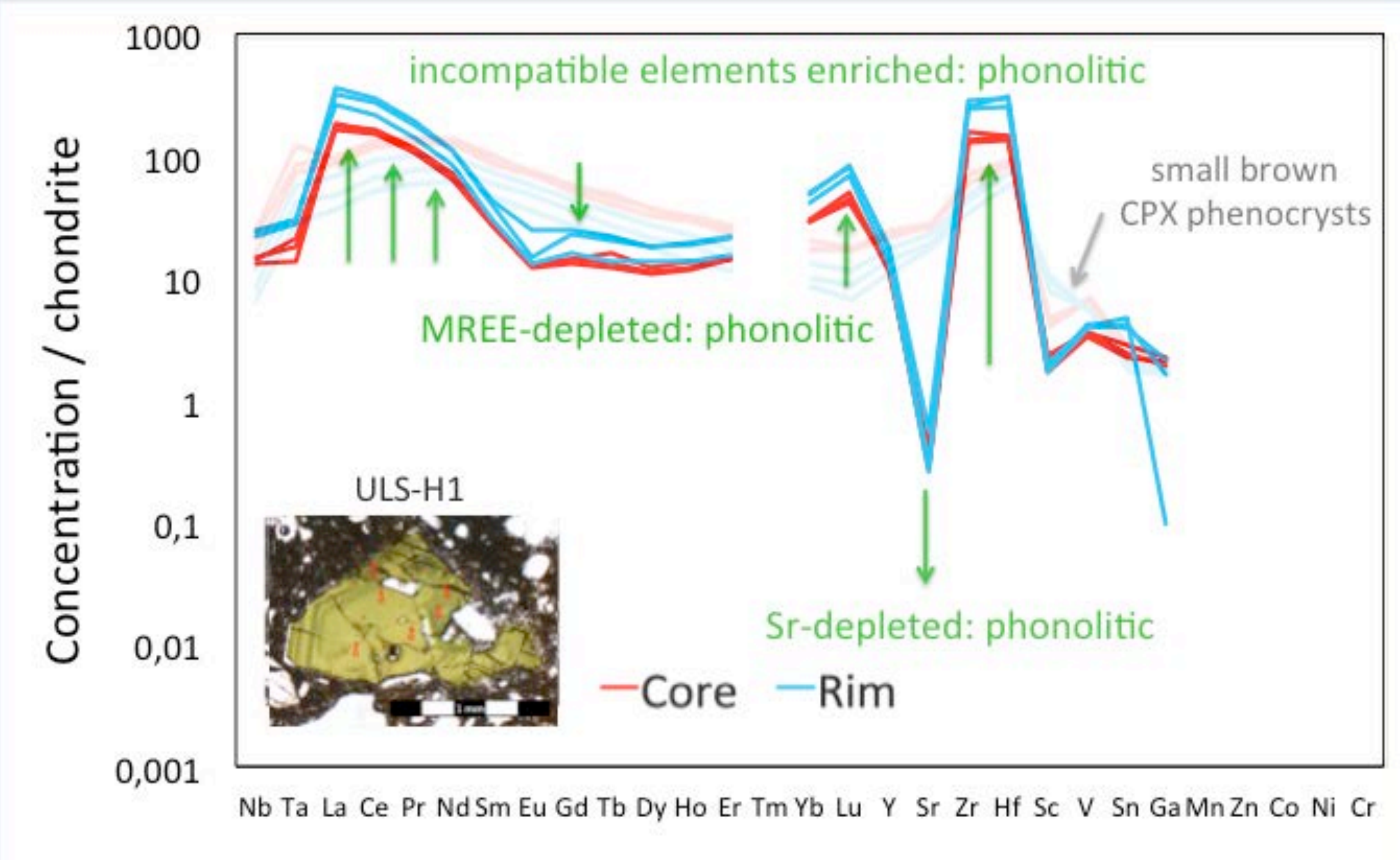
Serie 3a: Small green CPX with oszillatory zoning (Fe-rich)



Daten: L. Kallas, D. Hoffmann

Wörner et al (unpublished)

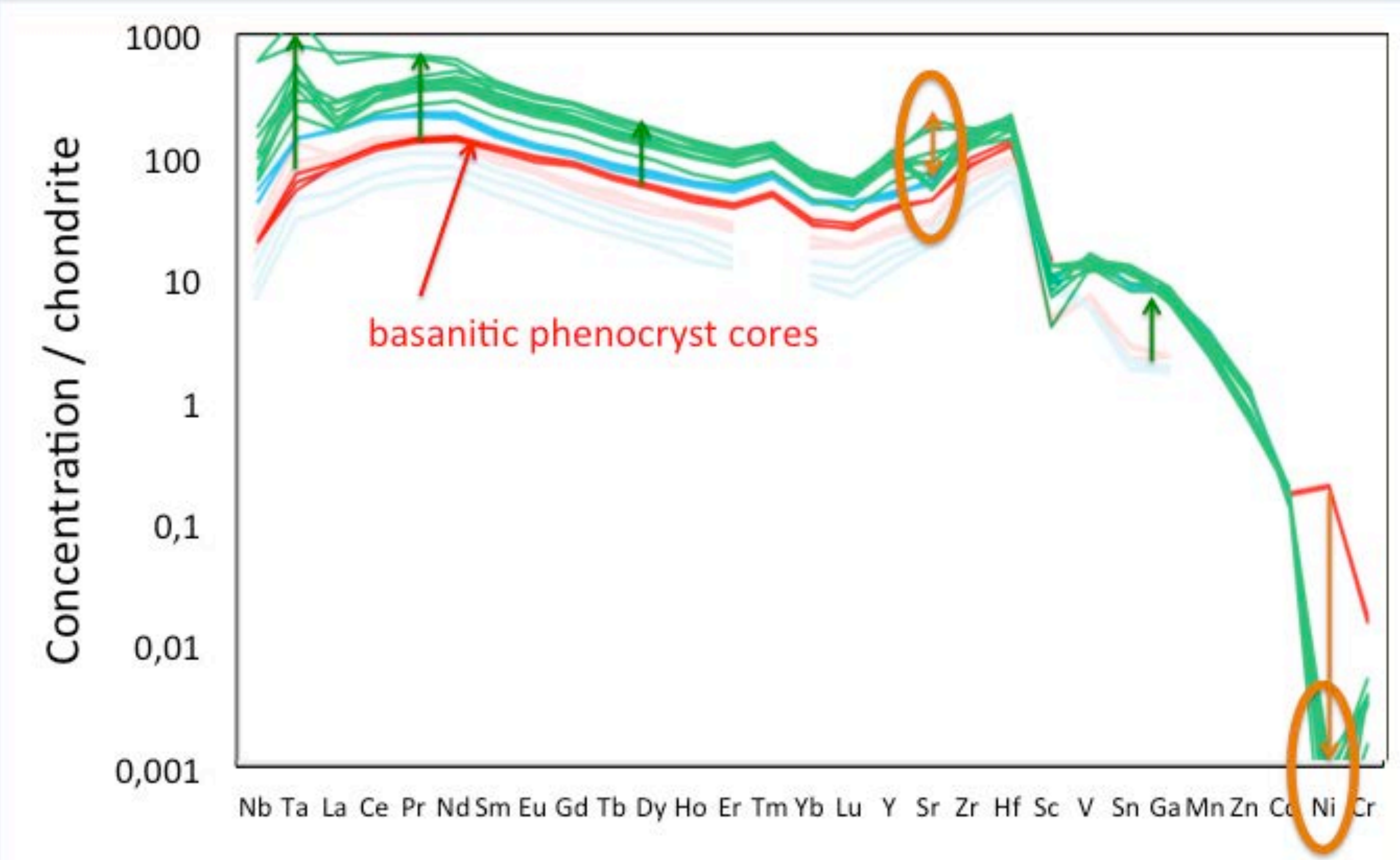
Serie 3a: Small green CPX with oszillatory zoning (Fe-rich)



Wörner et al (unpublished)

Daten: L. Kallas, D. Hoffmann

Serie 4: CPX from three mafic cumulates from phonolite (Mg-rich)



Daten: L. Kallas, D. Hoffmann

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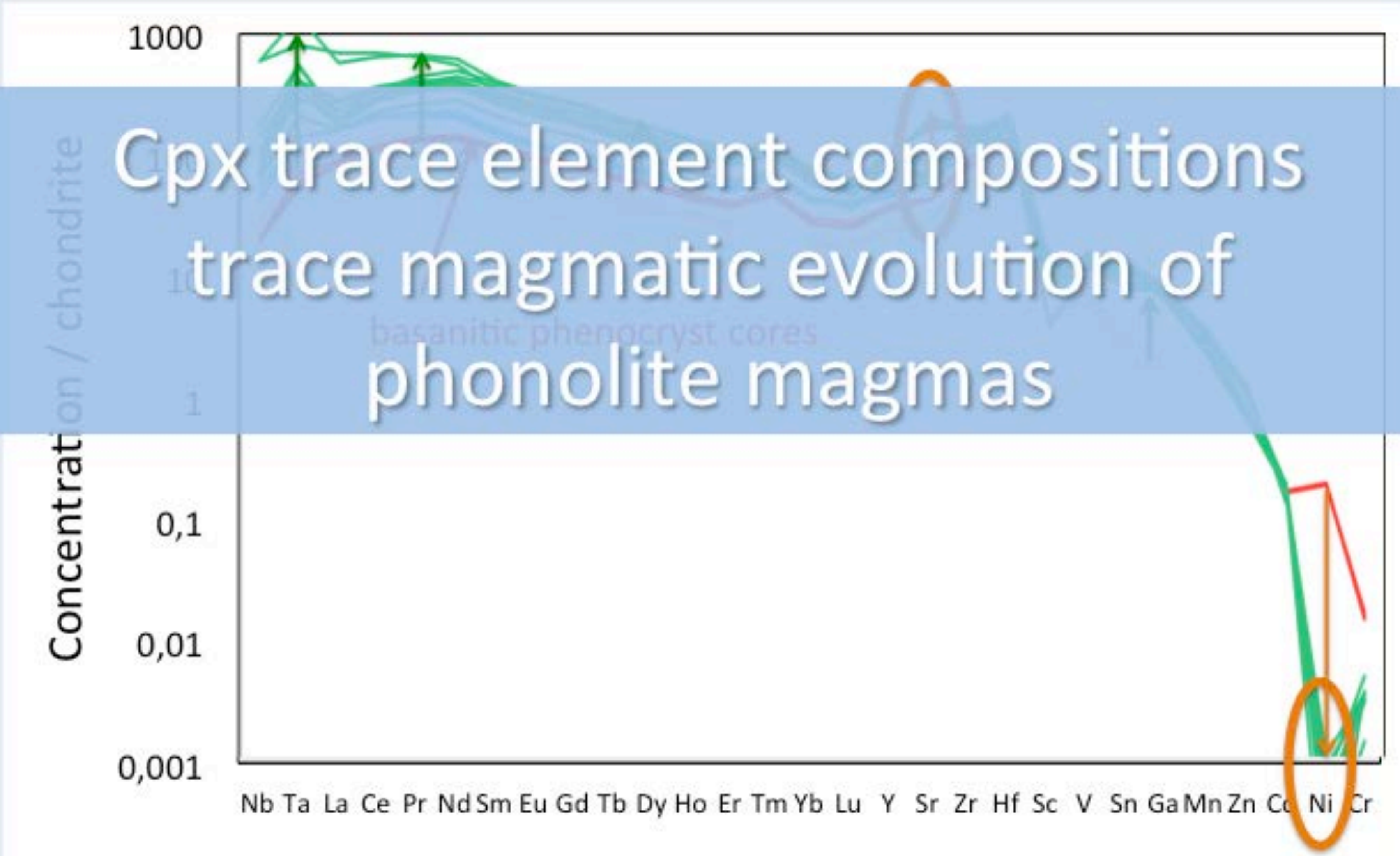
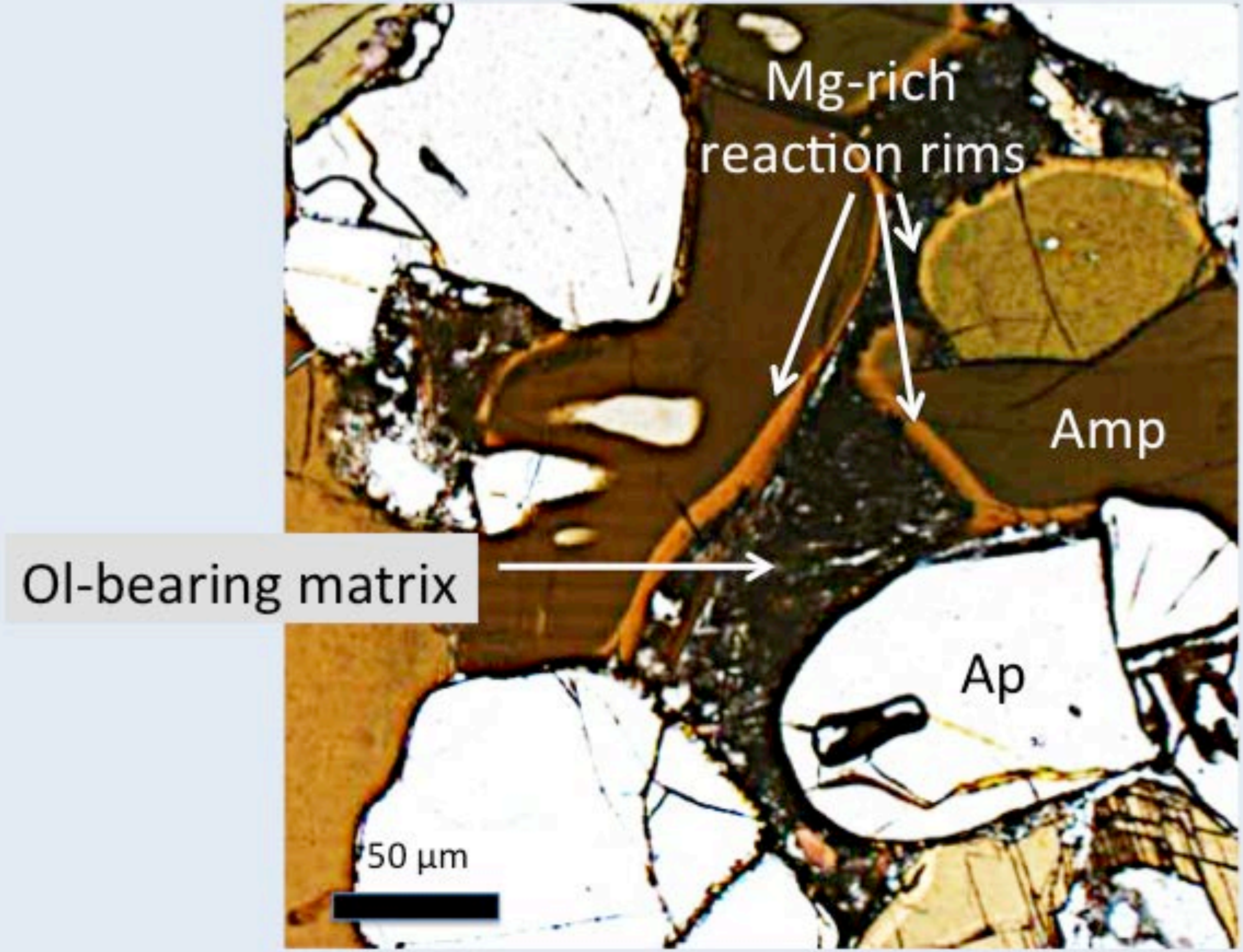


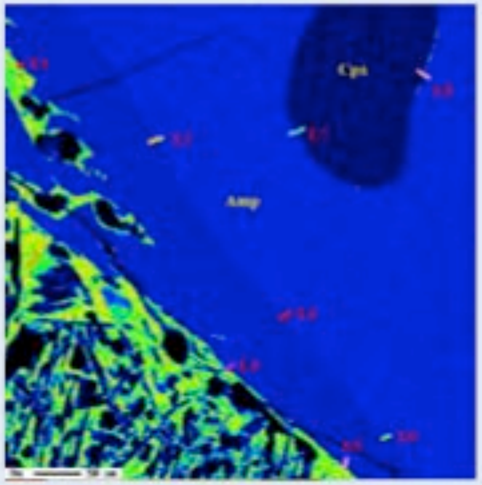
Cpx trace element compositions trace magmatic evolution of phonolite magmas

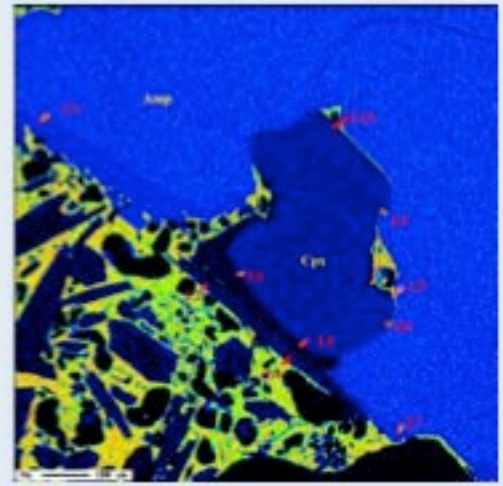
Amphibole and cpx from a phonolitic cumulate

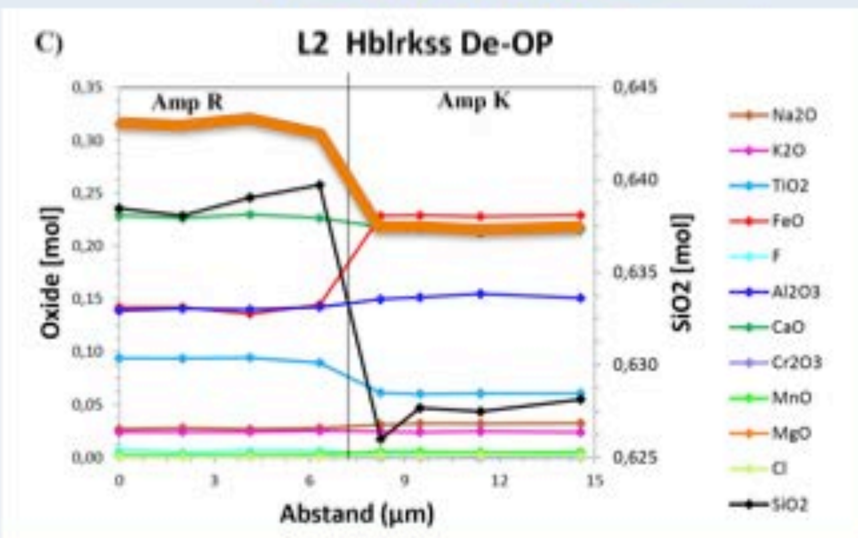


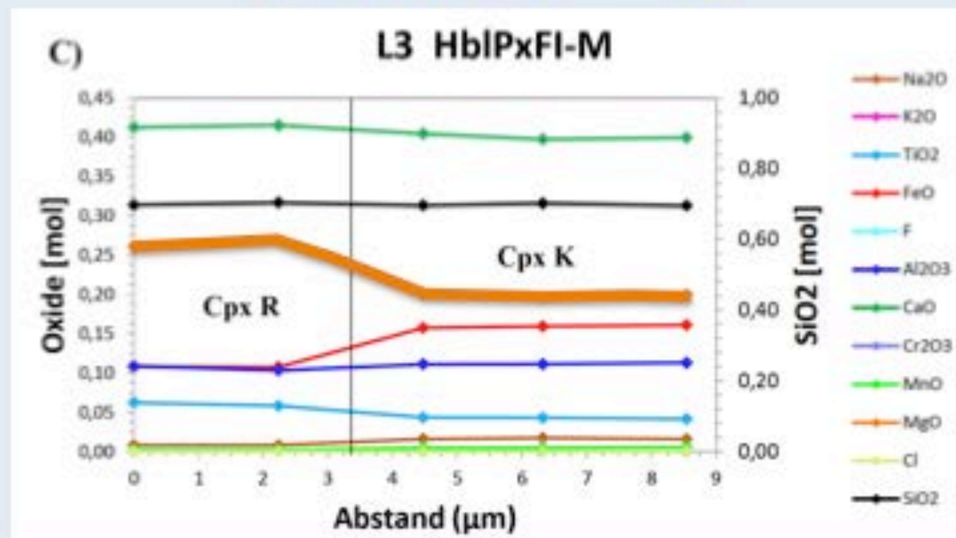
Wörner et al (unpublished)

Serie 5: Amphibole from a mafic phonolitic cumulate









Rim Core

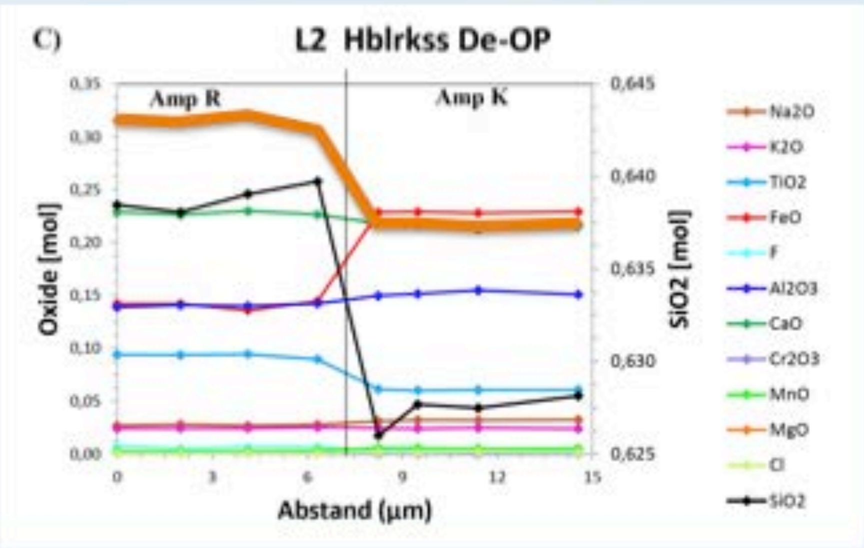
Rim Core

Daten: D.C. Binda

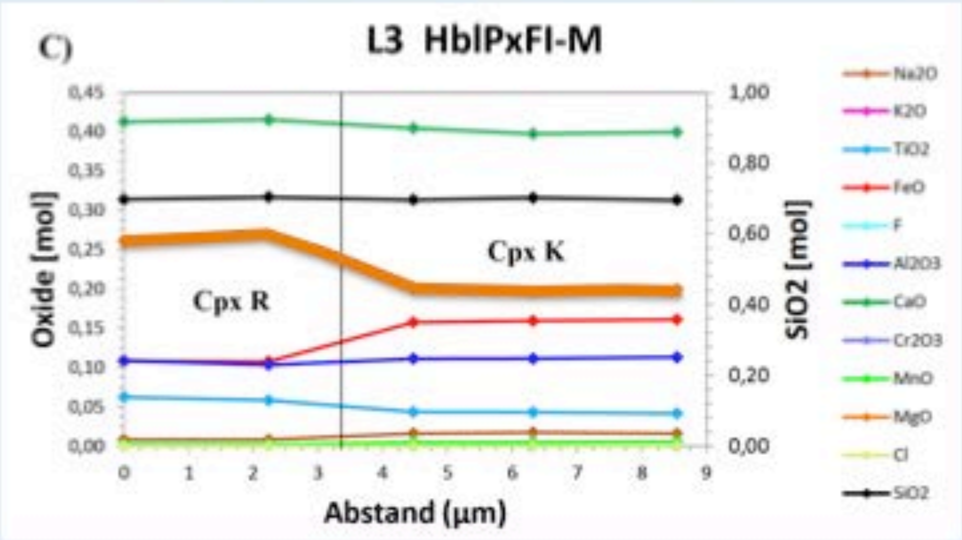
Wörner et al (unpublished)

Serie 5: Amphibole from a mafic phonolitic cumulate

same observation: Mg-rich basanitic magma intrudes phonolitic cumulates days before (and even during ?) eruption



Rim Core



Rim Core

Wörner et al (unpublished)

Conclusions:

- Evolved phonolite magma and associated syenites and carbonatites existed be low the Laacher See Volcano for at least 30.000 years prior to the eruption.
- The core of the magma reservoir never cooled below 630-670°C and was theremally held active by recharge events at 1.5 to 3. ky frequency
- The liquid core remained above solidus temperatures.
- Differentiation from basanite to phonolite may have taken 100.000 years
- A batch of mafic magma intruded and resided for hundreds of years (homogenization of olivine cores)
- Basanite interacted with the phonolite reservoir and its cumulates 4-7 years before eruption
- An unusually mafic,Mg-rich new batch of basanite ascended and mixed with less mafic basanite and phonlite magma(<400 days (15 to 150) days prior to eruption.
- Resorption and final growth within days to hours of eruption
- The new basanite magma that may have triggered the LS eruption is distingly more mafic and ascended much more rapidly compared to "normal" basanite magmas that erupted at scoria cones c. 100 kyr before.