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How much energy for life (H_2) is generated by serpentinization at passive continental margins?

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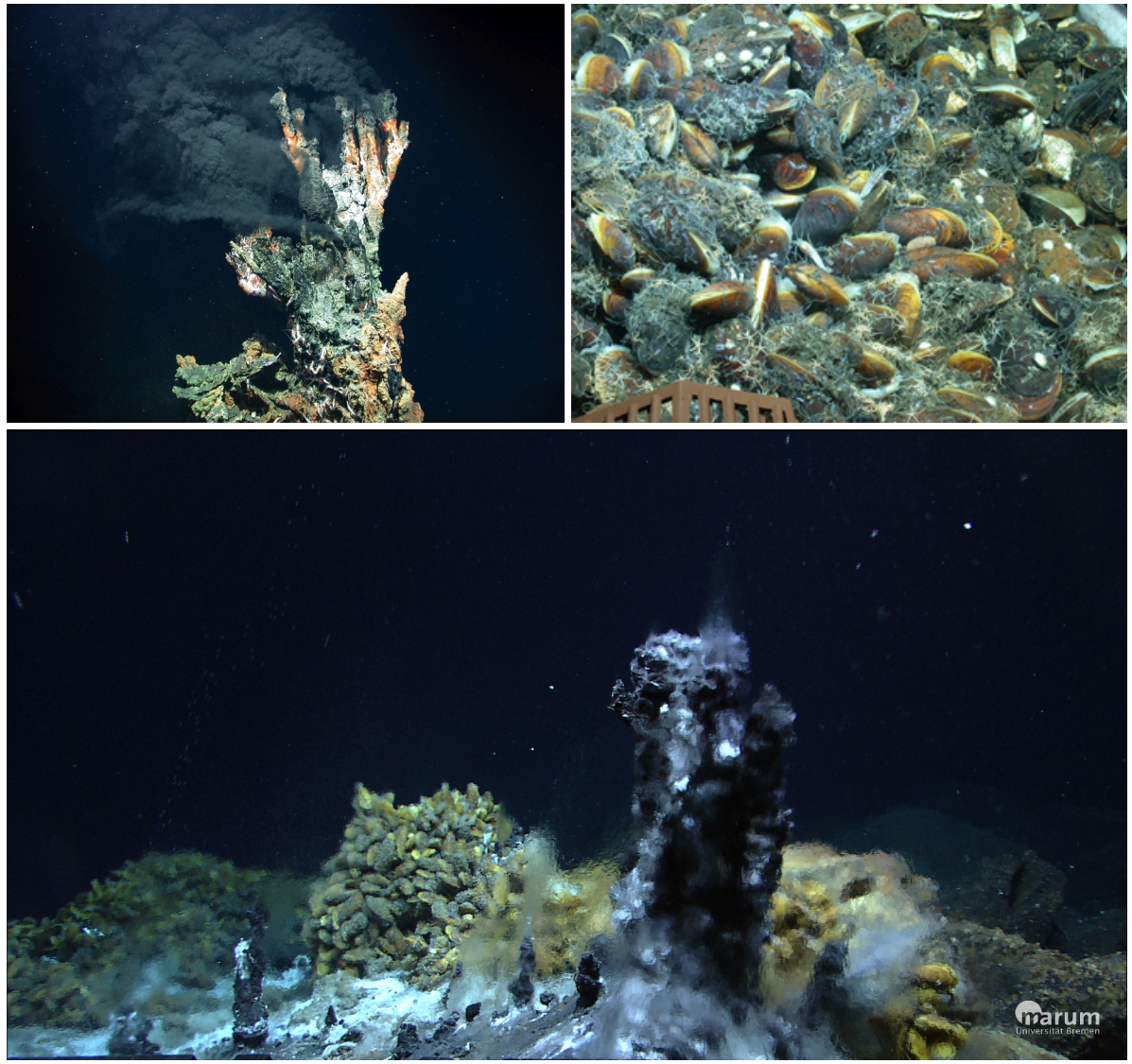
Review: Serpentinization & life

Logatchev (serpentinite-hosted hydrothermal system @ MAR)



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Serpentinization = hydration of mantle rocks by seawater

☞ includes the oxidation of ferrous Fe to ferric Fe

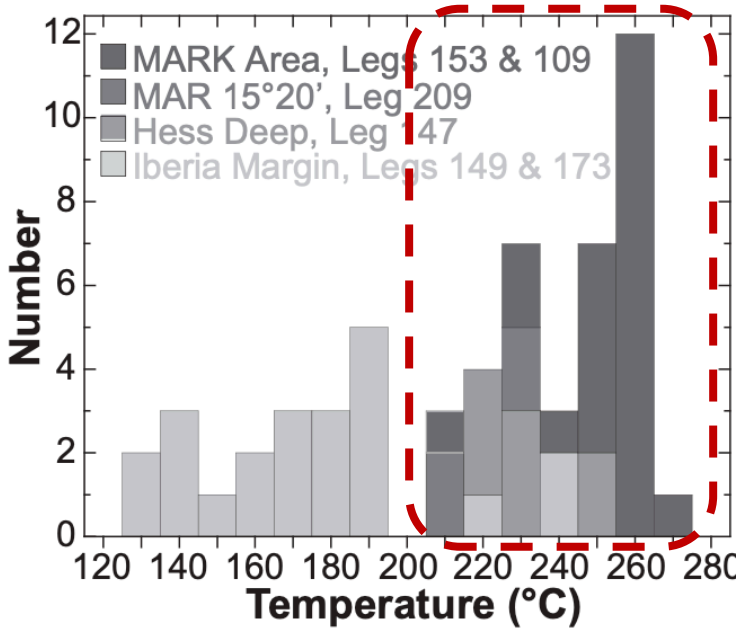
☞ oxidation of Fe releases molecular hydrogen (H_2)

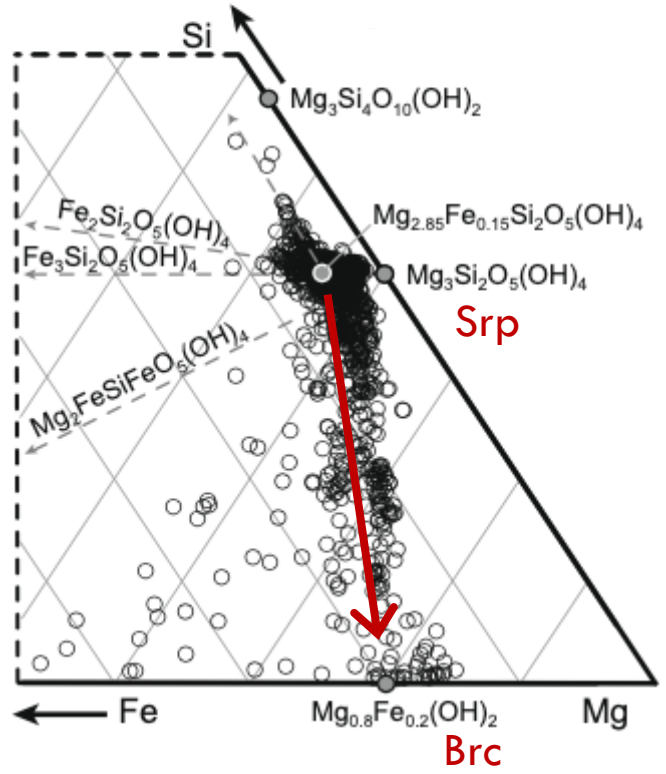
☞ H_2 supports chemosynthetic-based life at/below the seafloor

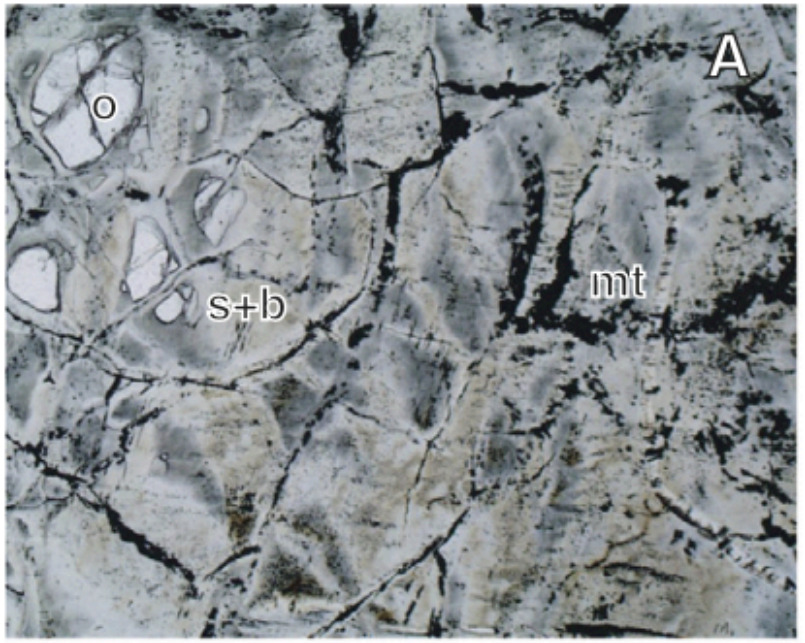
☞ main serpentinization sites on Earth include slow-/ultraslow-spreading MORs and passive continental margins

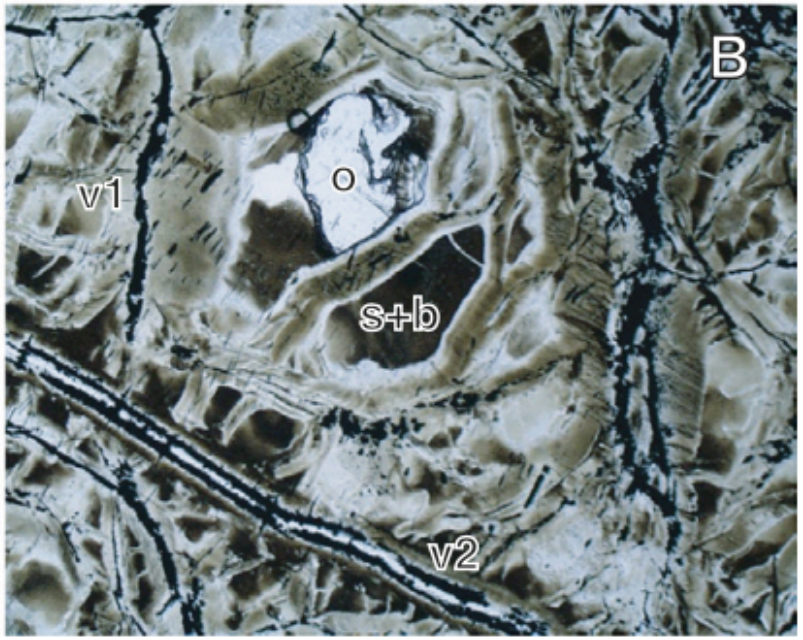
Review: Serpentinization at slow-spreading MORs

- ☞ includes the serpentinization of depleted mantle rocks (harzburgites & dunites)
- ☞ typical mineral assemblages include Mg-rich serpentine, Fe-rich brucite, and magnetite (Bach et al., 2006; Klein et al., 2009)
- ☞ serpentinization temperatures commonly range from 200–280°C (Klein et al., 2014)





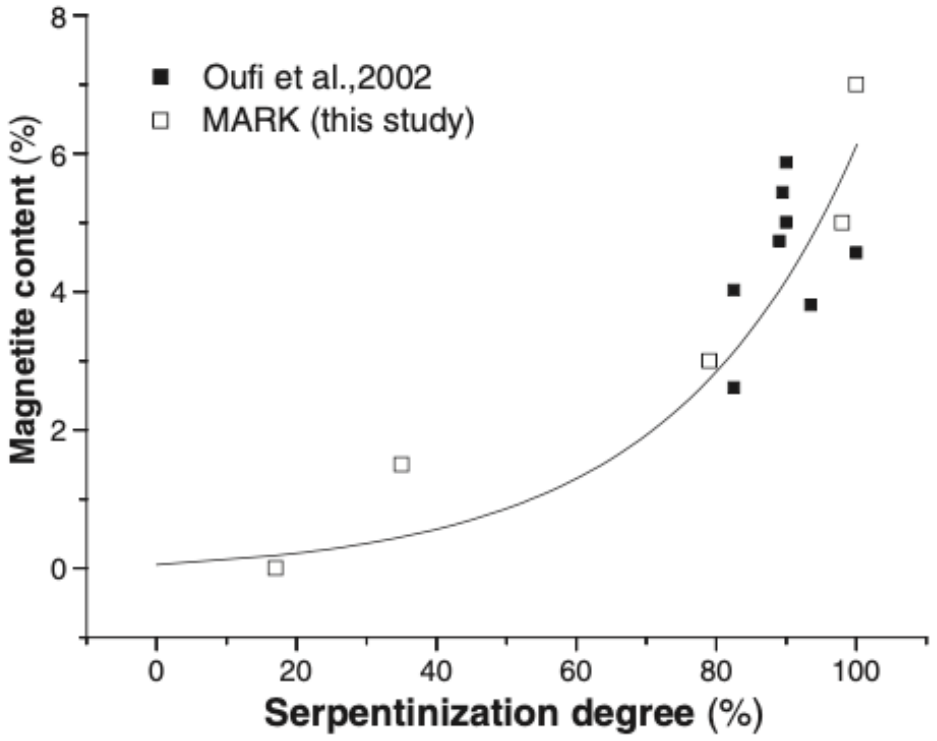


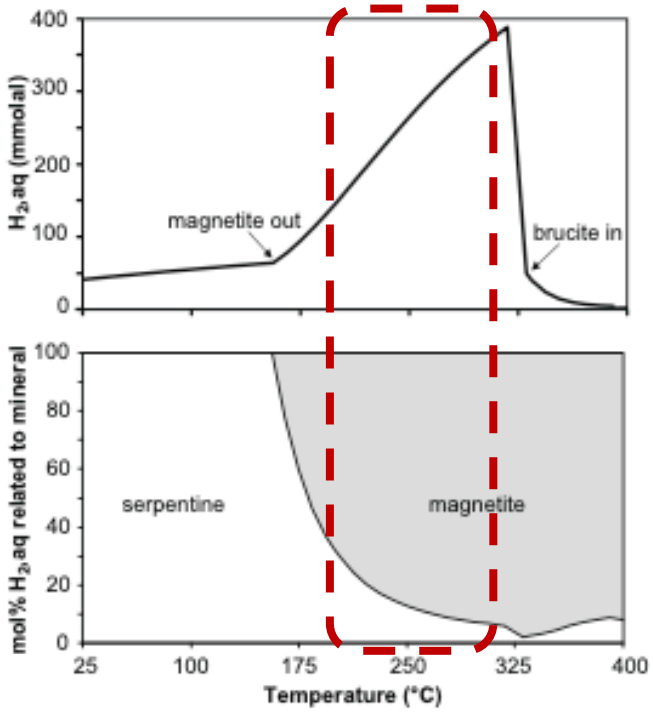


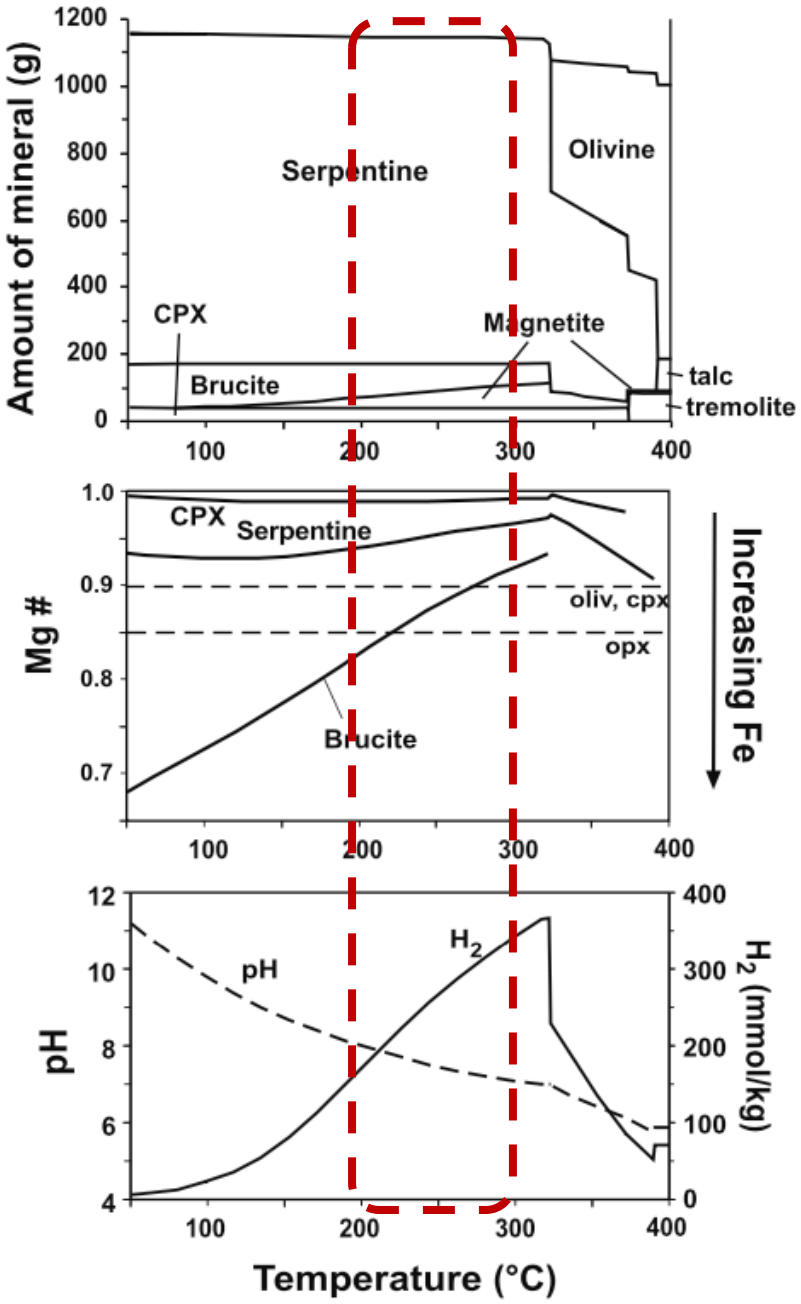
Review: H_2 production @ MORs

- ☞ large quantities of magnetite host the bulk of the Fe(III) at 200–280°C
- ☞ about 200–350 mmol H_2 are produced per kg rock

(McCollom & Bach, 2009; Klein et al., 2009; Andreani et al., 2013)

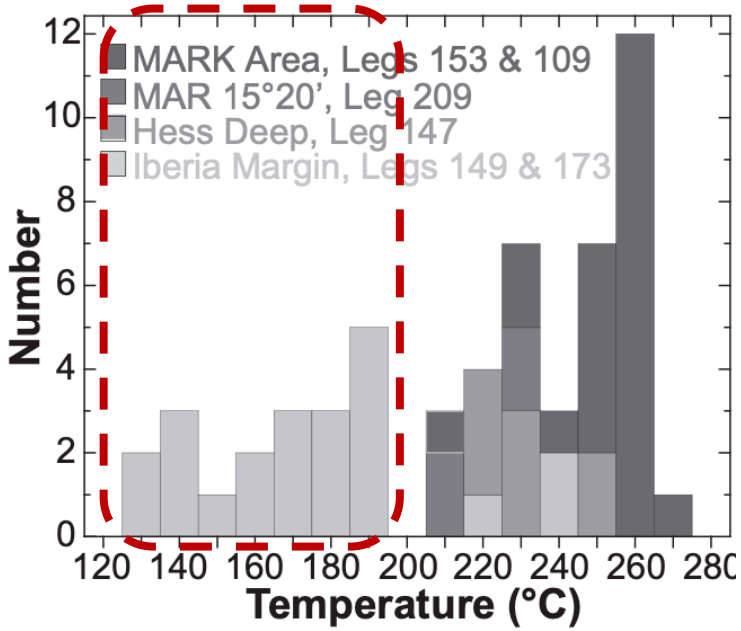


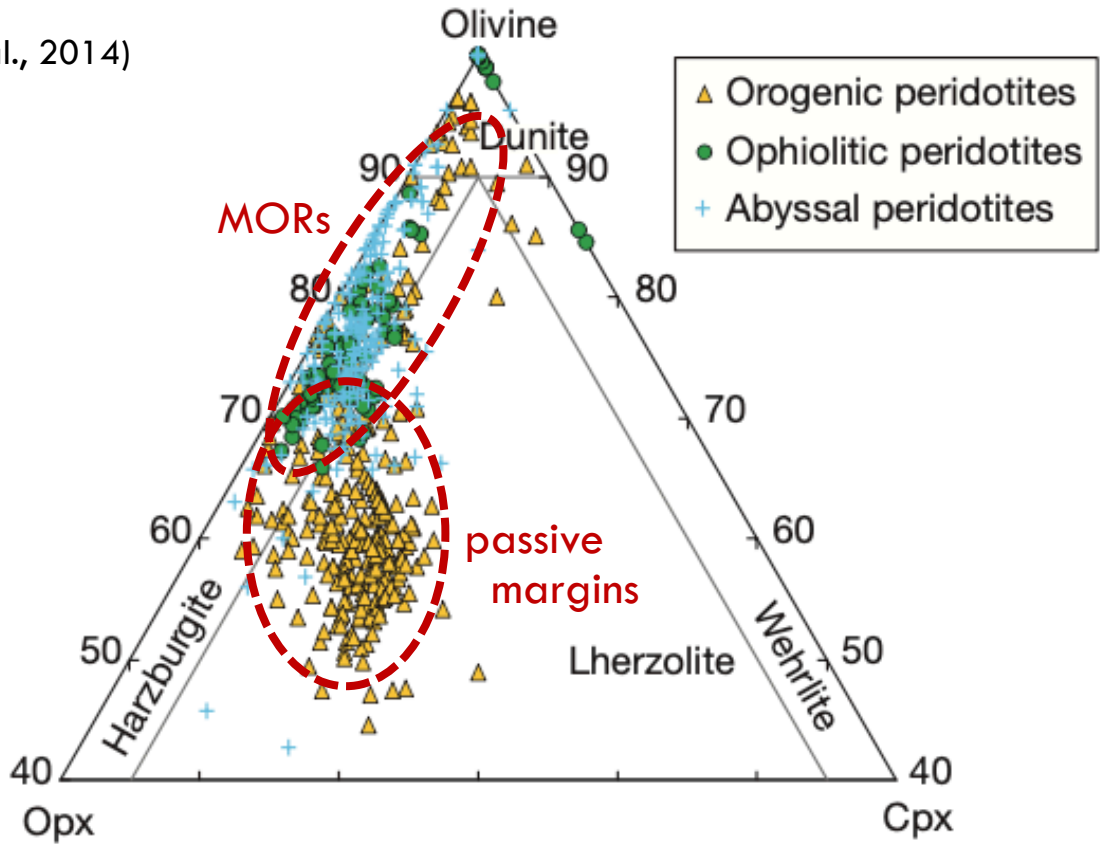




Serpentinization @ passive margins?

- ☞ rocks are less depleted (lherzolitic) (Bodinier & Godard, 2014)
- ☞ serpentinization temperatures are lower (<200°C) (Klein et al., 2014)



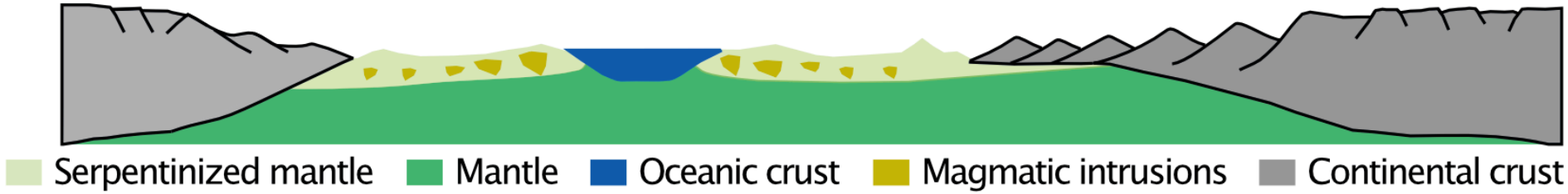


☞ How much H_2 is produced during serpentinization at passive continental margins?

Research question

	MID–OCEAN RIDGE	OCEAN–CONTINENT TRANSITION	CONTINENT
dominant lithology:	‘oceanic‘ mantle harzburgites to dunites increasing Mg, Fe	← increasing depletion	sub–continental lithospheric mantle lherzolites increasing Si, Al, Ca, Na
	slow–spreading		
depth of 400°C isotherm:	8–9 km		
serpentinization T:	200–280°C		
main Fe(III)–hosting phase:	magnetite		
H_2 per kg rock:	200–350 mmol		

?



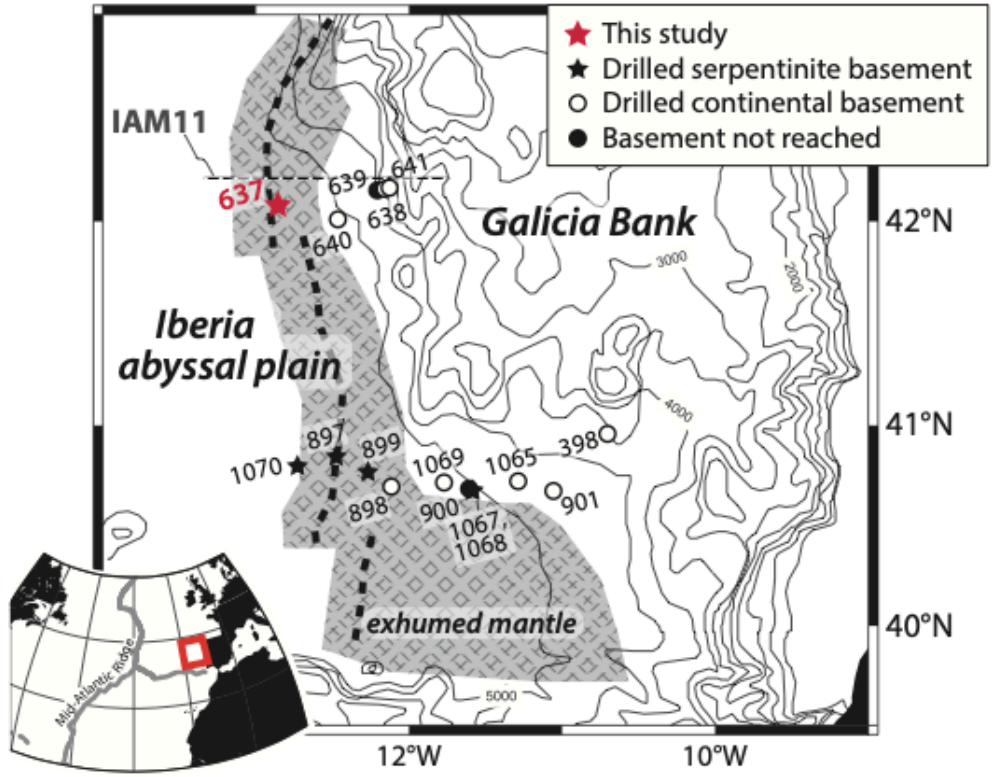
☞ How much H_2 is produced during serpentinization at passive continental margins?

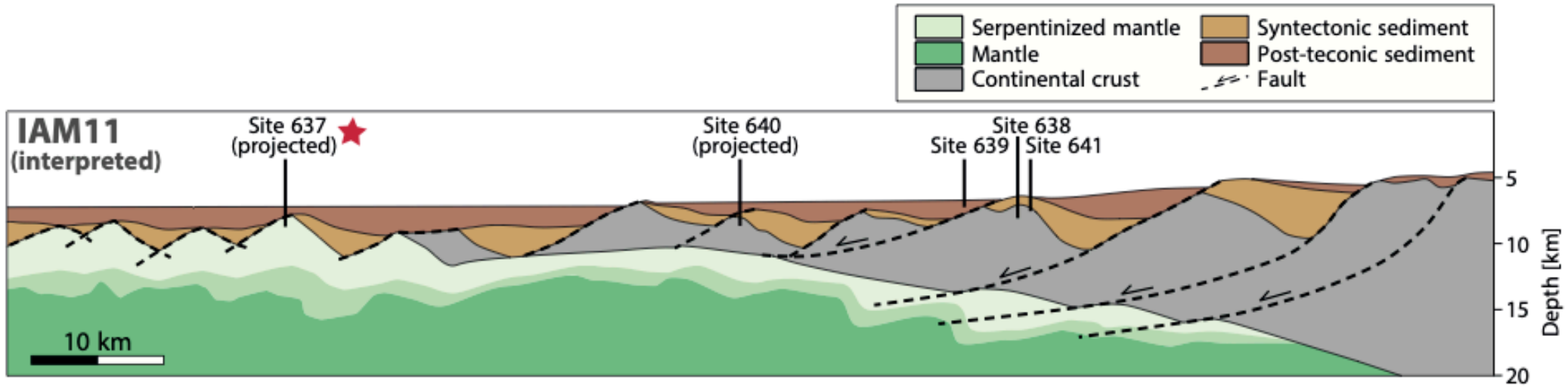
Sample origin

☞ ocean–continent transition zone of the West Iberia margin

☞ most continent-ward samples recovered from this setting

= least affected by melt-depletion?





Petrography

Relict primary phases:

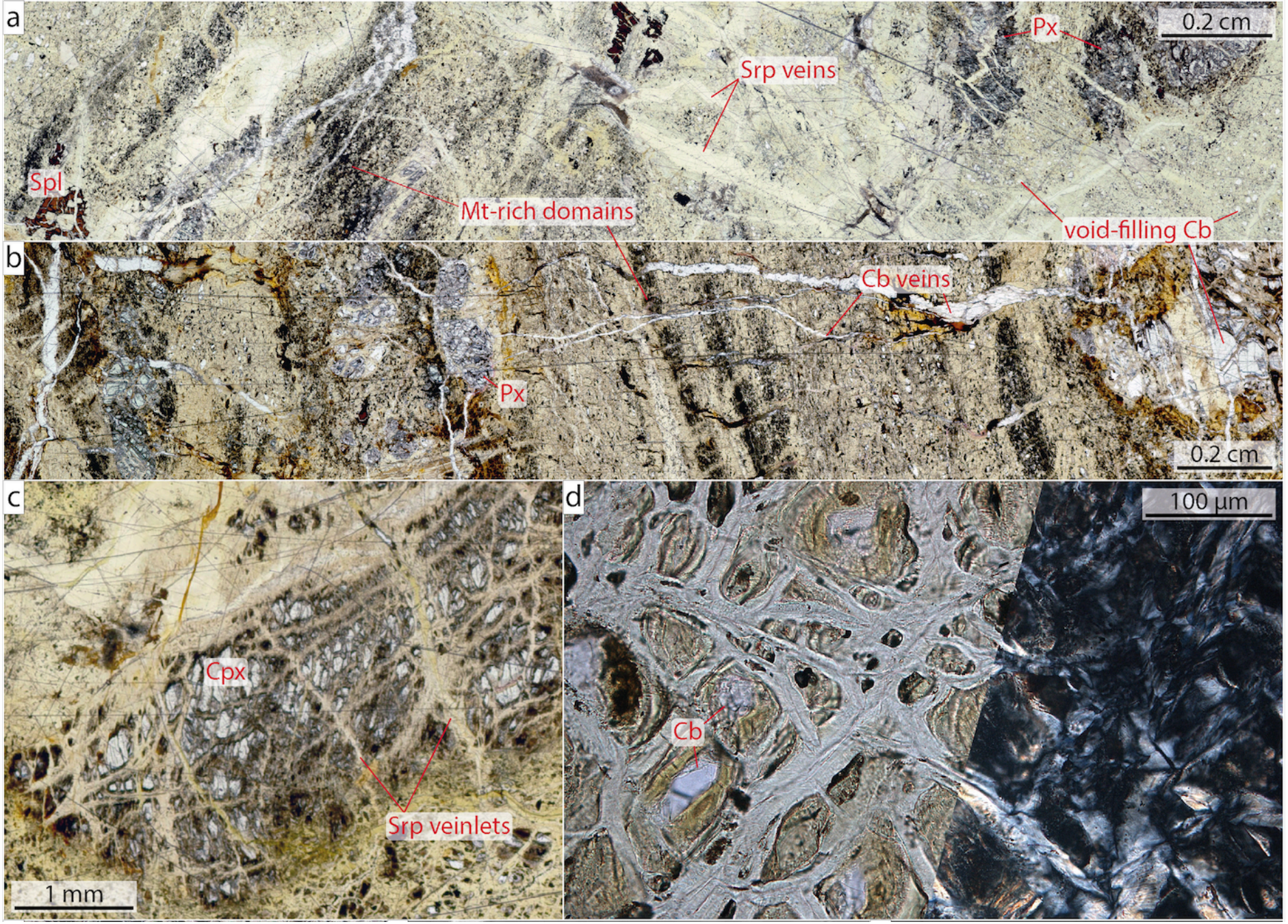
- ☞ Cpx
- ☞ Spl

Secondary phases of main serpentinization event:

- ☞ Srp
- ☞ some Mt

Phases related to late (cold) seafloor–seawater reactions:

- ☞ Srp–stevensite–talc mix
- ☞ Fe-oxides
- ☞ Cb



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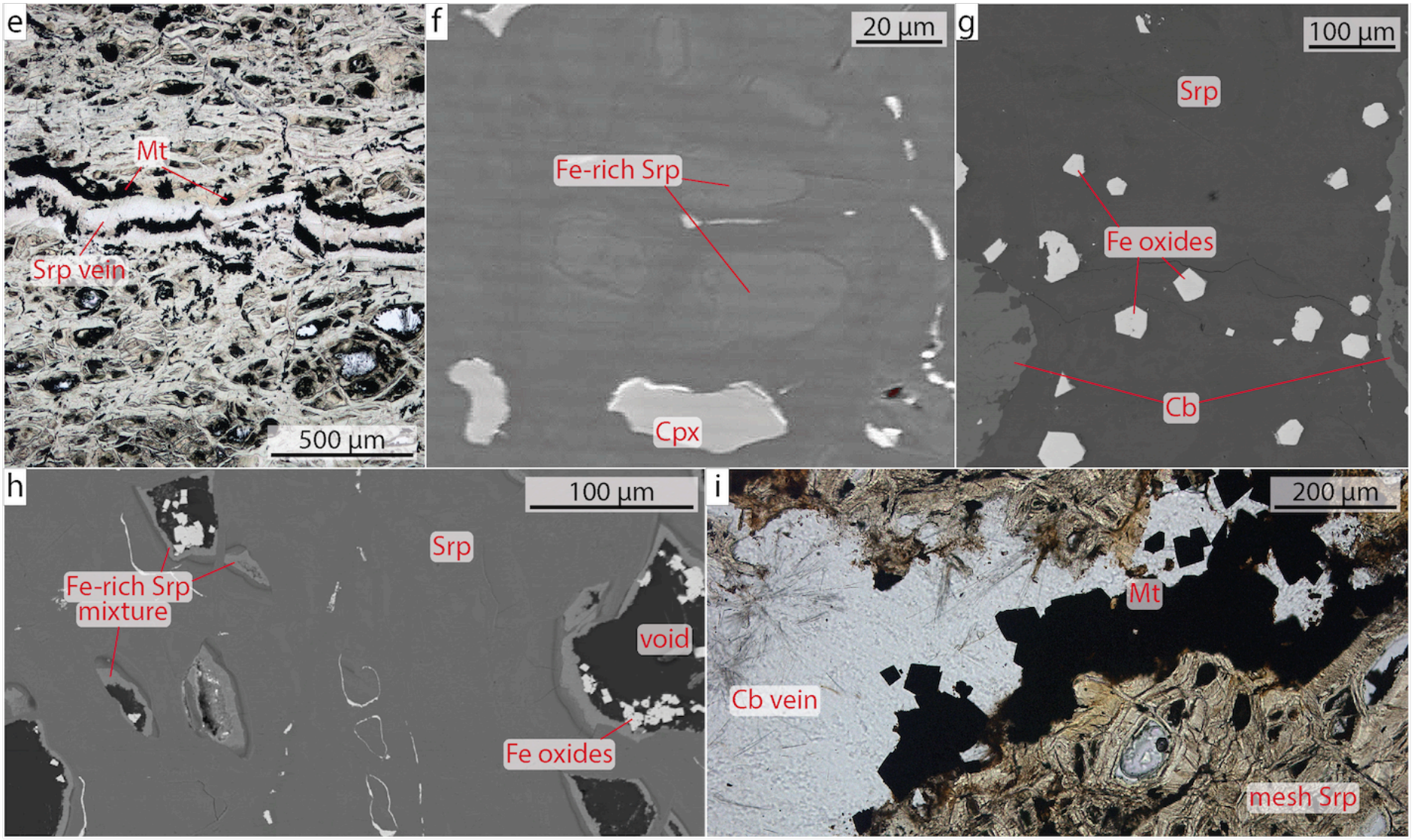
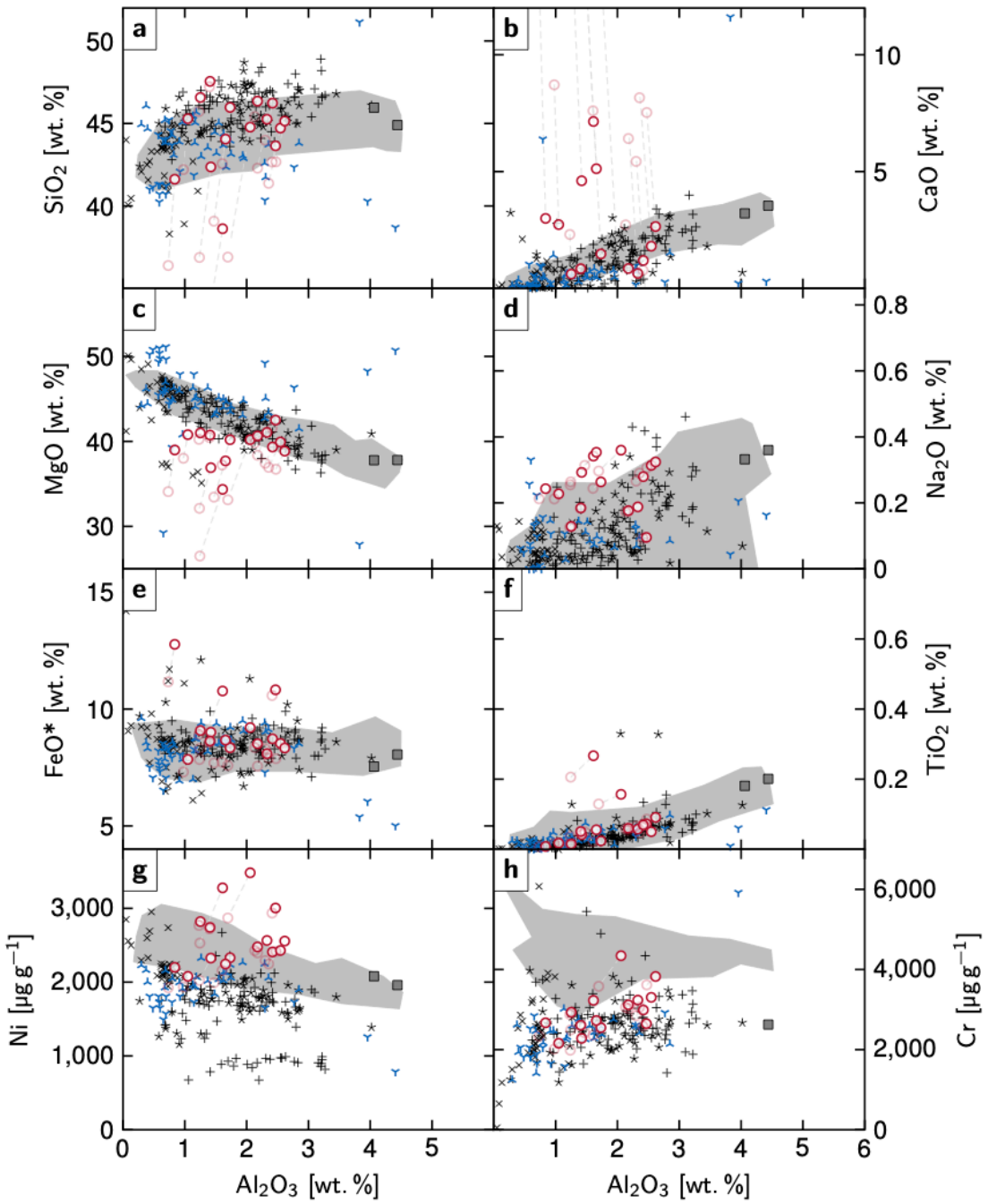


☞ record of serpentinization events affecting the seafloor during & after the break-up of Pangea

Degree of depletion

- ☞ heterogeneous bulk rock compositions
- ☞ likely metasomatised (e.g., addition of $CaCO_3$)



Degree of depletion

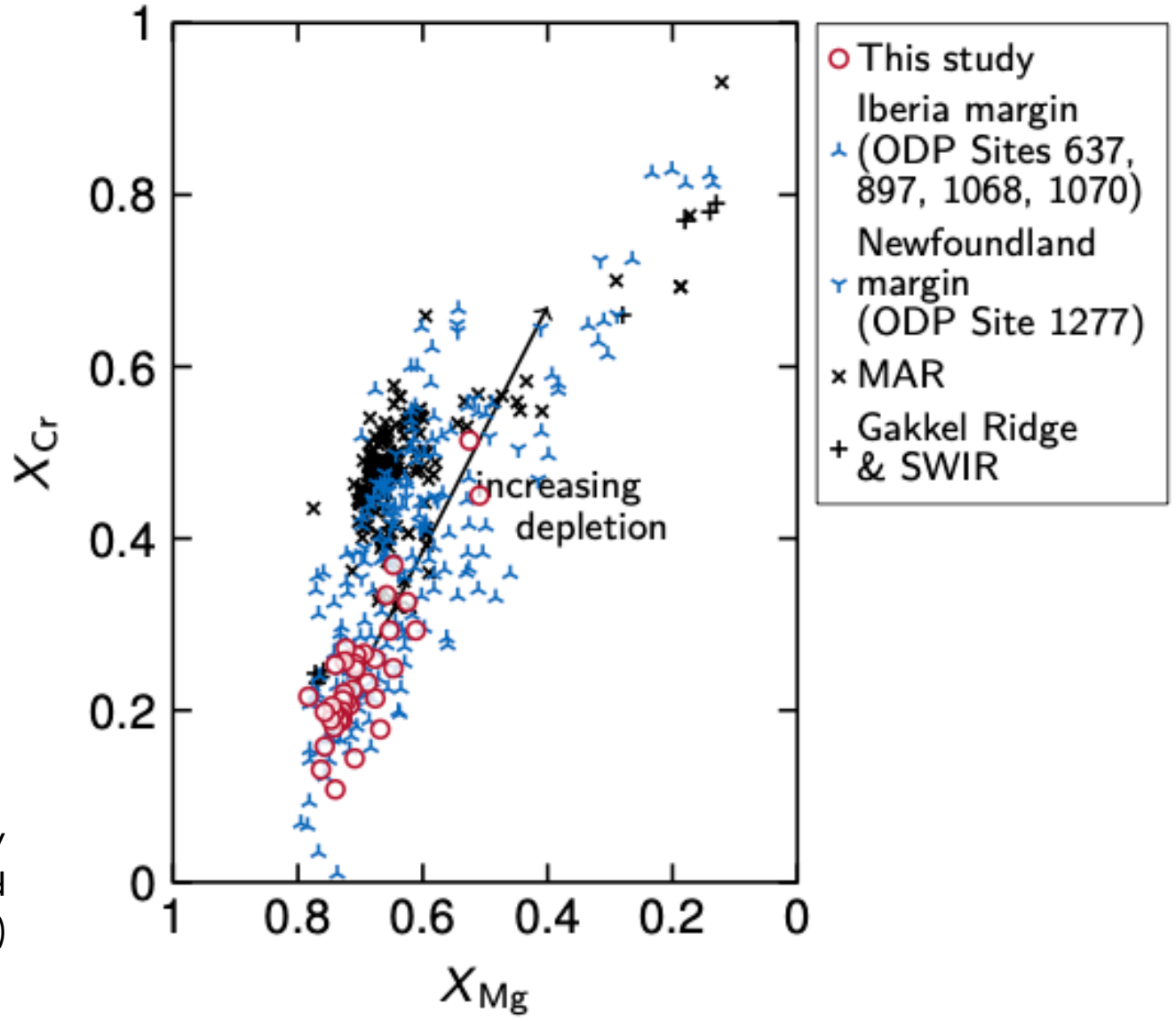
- ☞ heterogeneous bulk rock compositions
- ☞ likely metasomatised (e.g., addition of $CaCO_3$)

- ☞ spinels are very rich in Mg & Al
- ☞ compositions suggest very little depletion

- ☞ the samples are/once were compositionally close

  to sub-continental lithospheric mantle

  (or, at least, they are as close as we can get as they are among the least-depleted rocks recovered during ocean drilling)

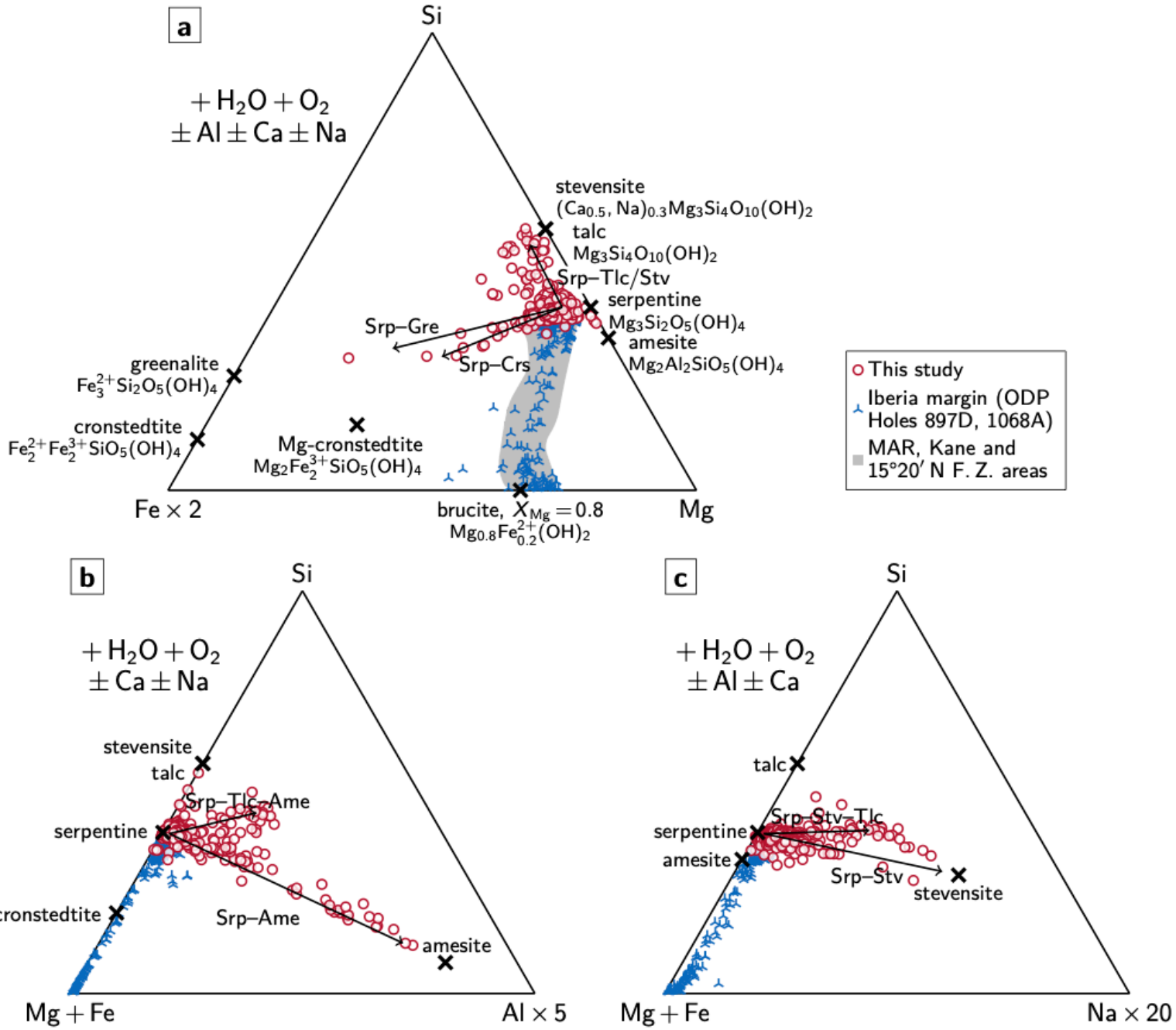


Secondary mineral chemistry

- ☞ mostly Srp w/ X_{Mg} ~0.95
- ☞ intergrowth of Srp w/ cronstedtite and amesite/talc/stevensite
- ☞ NO brucite !

cronstedtite = host of Fe(III)

stevensite = smectite-group mineral



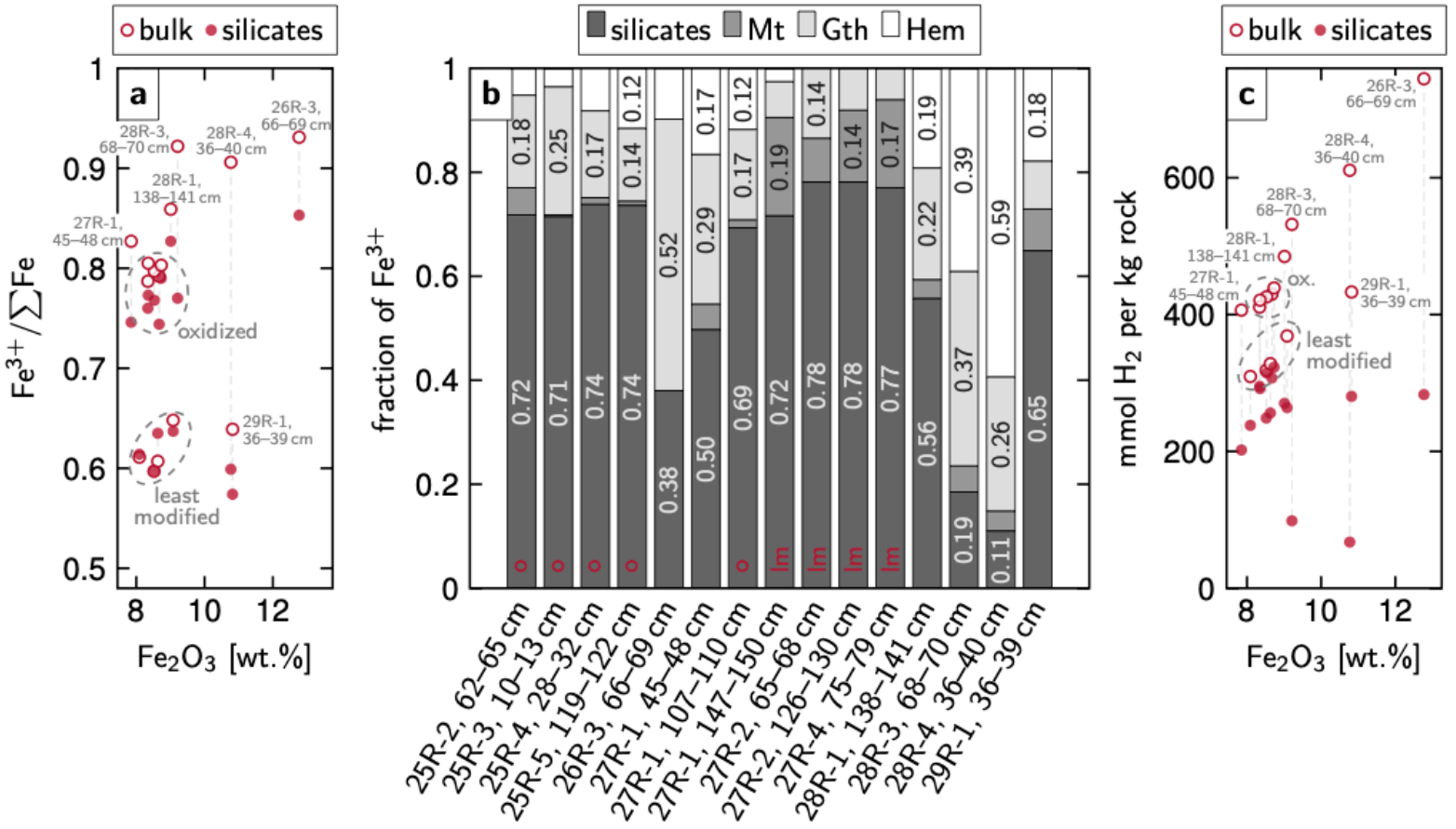
Fe(III) distribution & H_2 production

	sample type		
	least modified	oxidized	meta-somat.
mean $Fe_2O_3^{tot}$ (wt%)	8.58	8.57	9.71
mean Fe(III)/Fe^{tot}	0.62	0.79	0.84
mean Mt (wt%)	0.87	1.01	0.58

- ☞ Fe(III)/Fe^{tot} varies between least-modified/oxidized/metasomatized samples
- ☞ most Fe(III) is contained in Srp
- ☞ magnetite hosts only minor amounts of Fe(III)

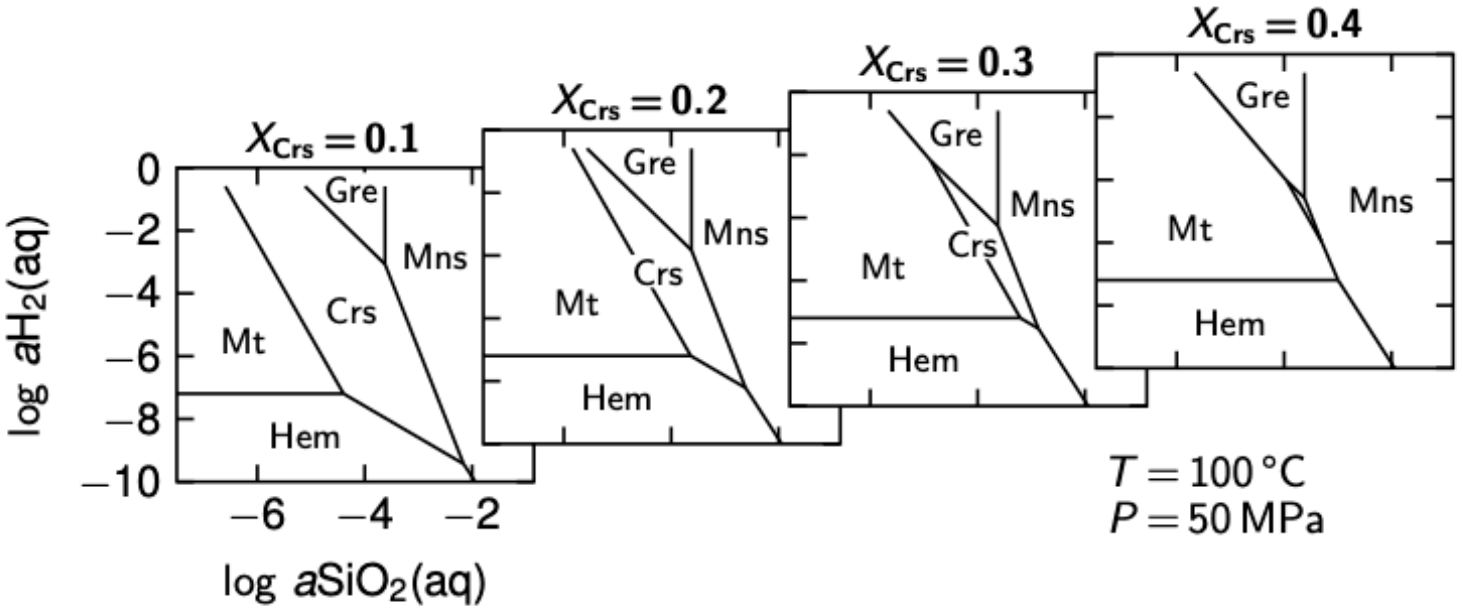
- ☞ least-modified samples (i.e., initial serpentinization) produced up to 300 mmol H_2 per kg rock

  (assuming that all Fe was initially ferrous and H_2O was the only oxidant)



Stability of cronstedtite

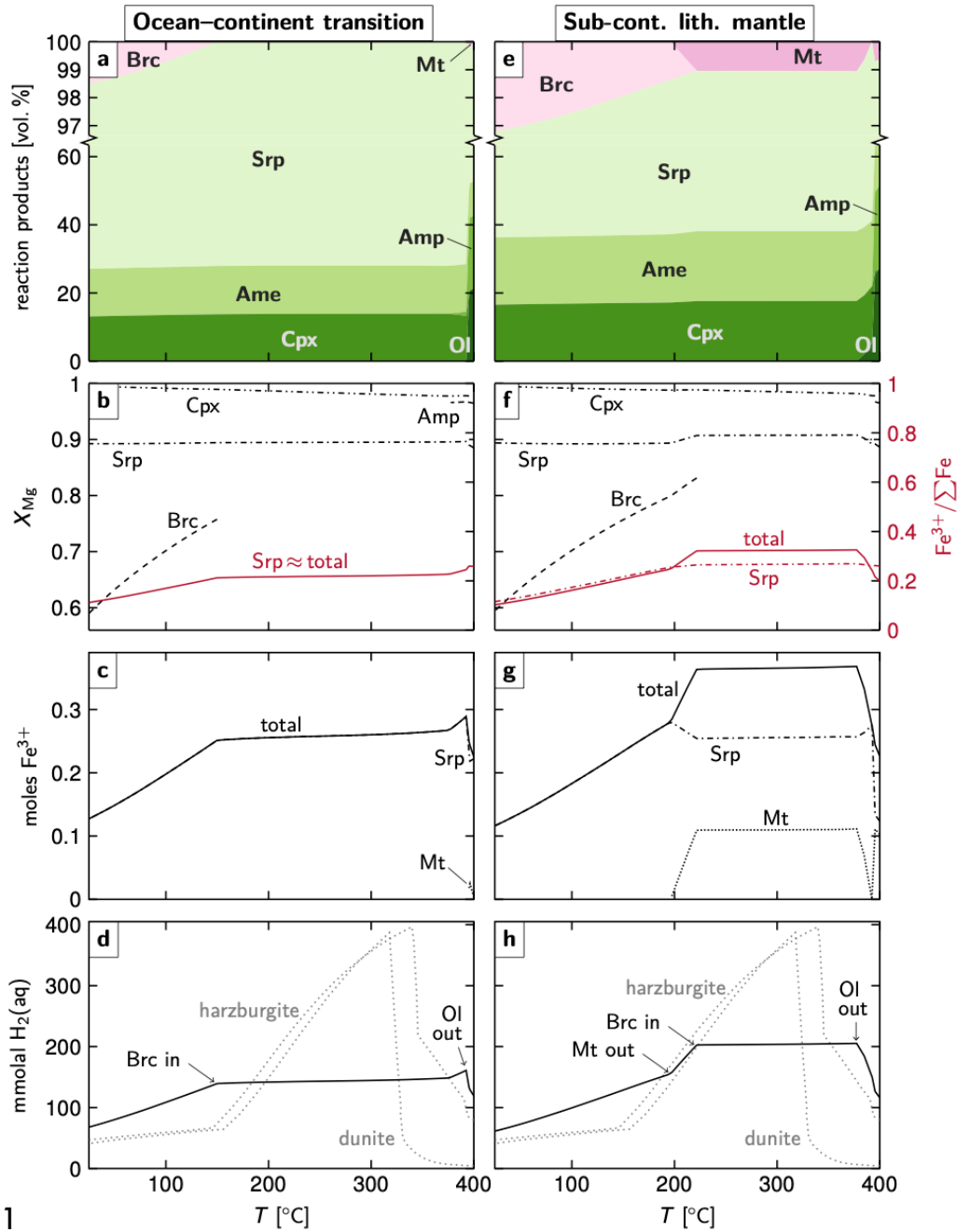
- ☞ cronstedtite-rich Srp is stable at elevated $aSiO_2$
- ☞ high-$aSiO_2$ conditions particularly feasible during serpentinization of lherzolitic mantle rocks
- ☞ formation of Srp w/ high Crs components more likely at passive margins relative to MORs (where depleted harzburgites/dunites are serpentinized)



Reaction path modeling

- ☞ during hydration, lherzolitic rocks form little brucite and/or magnetite
- ☞ Fe is distributed into serpentine ($X_{Mg} < 0.9$)
- ☞ lherzolites produce up to 150 mmol H_2 per kg at $T < 200°C$

- ☞ in comparison to depleted rock types, lherzolites produce much more H_2 at low T



P = 50 MPa
w/r mass ratio = 1

H_2 production from rift to ridge

- reduced magmatism at passive margins leads to low geothermal gradients, inducing low serpentinization *T*
- Fe(III)-rich serpentine produces high rates of H_2
- at ultraslow-spreading MORs, much less H_2 is generated by the serpentinization of depleted rocks at similarly low alteration *T*
- at slow-spreading MORs, higher thermal gradients lead to the formation of magnetite and high H_2 fluxes
- **much serpentinization & H_2 production takes place within the habitable zone at passive margins**