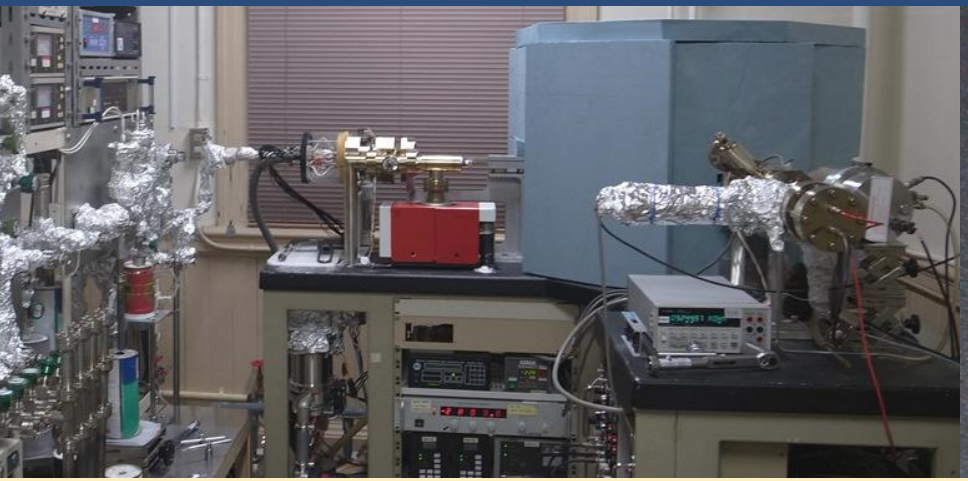
Mantle metasomatism inferred from halogens and noble gases within mantle-derived materials



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Acknowledgement

Satoko ISHIMARU *(Kumamoto University)* Shoji ARAI *(Kanazawa University)*

Masako YOSHIKAWA Tatsuhiko KAWAMOTO Yoshitaka KUMAGAI *(Kyoto University)*

Tetsuo KOBAYASHI *(Kagoshima University)* Keisuke NAGAO *(KOPRI)*

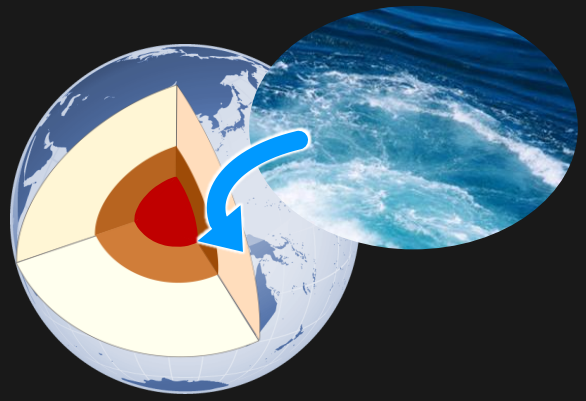
Halogens & noble gases

Powerful tracers of water

Strongly partitioned into water

Distinct compositions in each reservoir

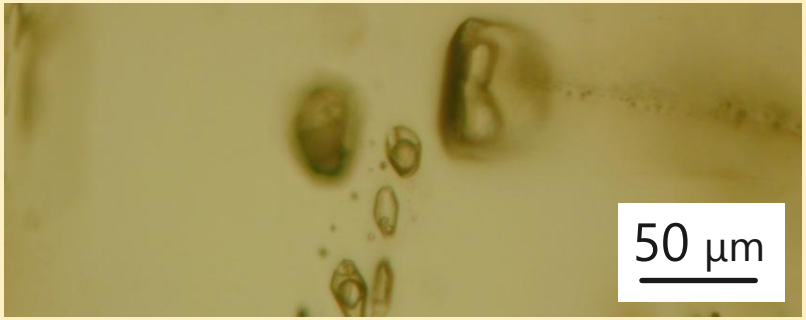
Scarce in the mantle



Mantle xenoliths

○ Primary information on slab-derived fluids

Fluid inclusions in olivine



Kawamoto et al. (2013)

✖ Low halogen concentration

Halogen concentrations in DMM*

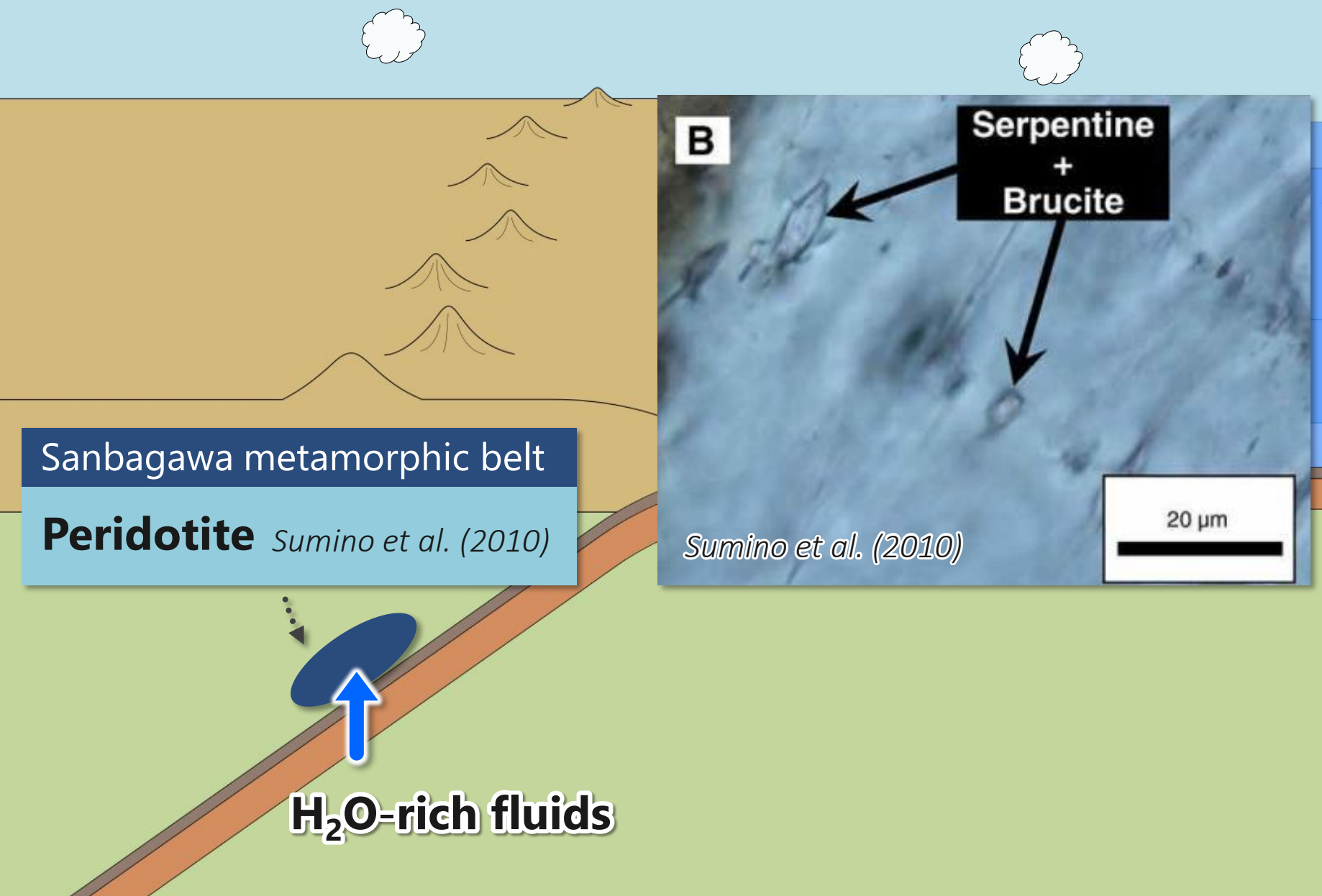
Cl [ppm]	Br [ppb]	I [ppb]
0.5–6	2–8	0.04–0.8

Saal et al. (2002); John et al. (2011); Kendrick et al. (2012)

*Depleted MORB Mantle

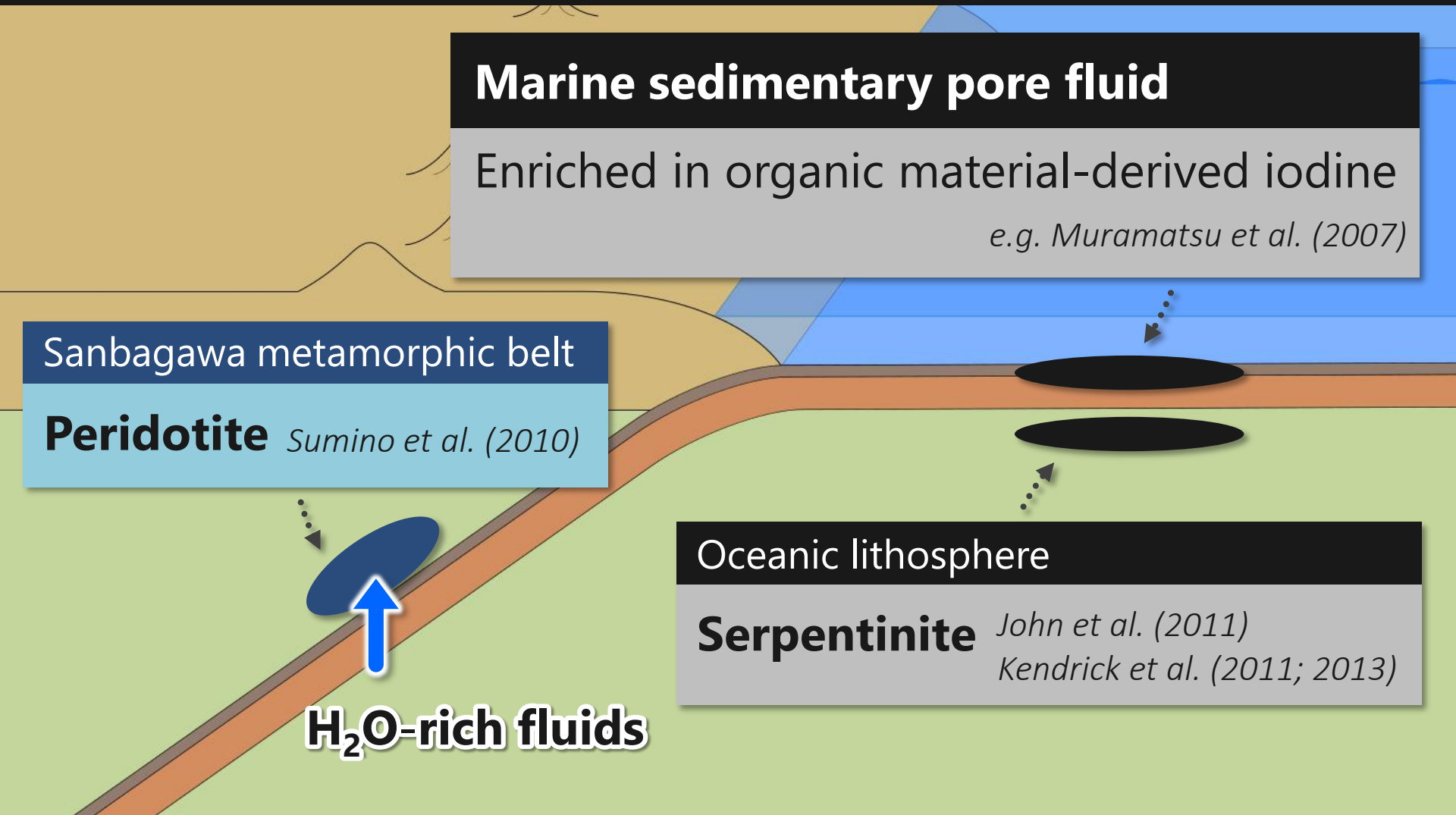
Difficult to analyze **Few published studies**

Halogens & noble gases subducted into the mantle



Halogens & noble gases subducted into the mantle

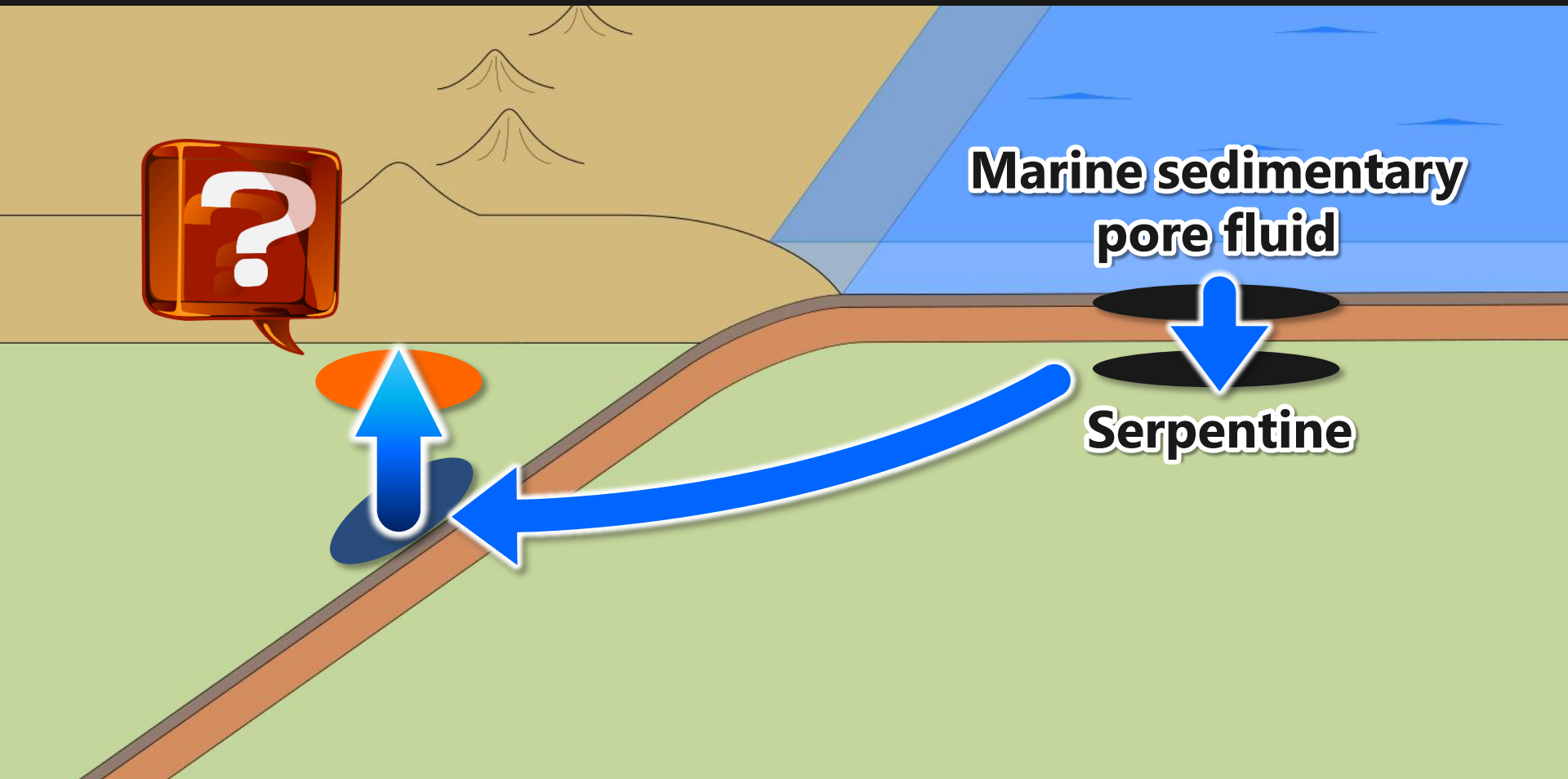
Similar halogen & noble gas signatures



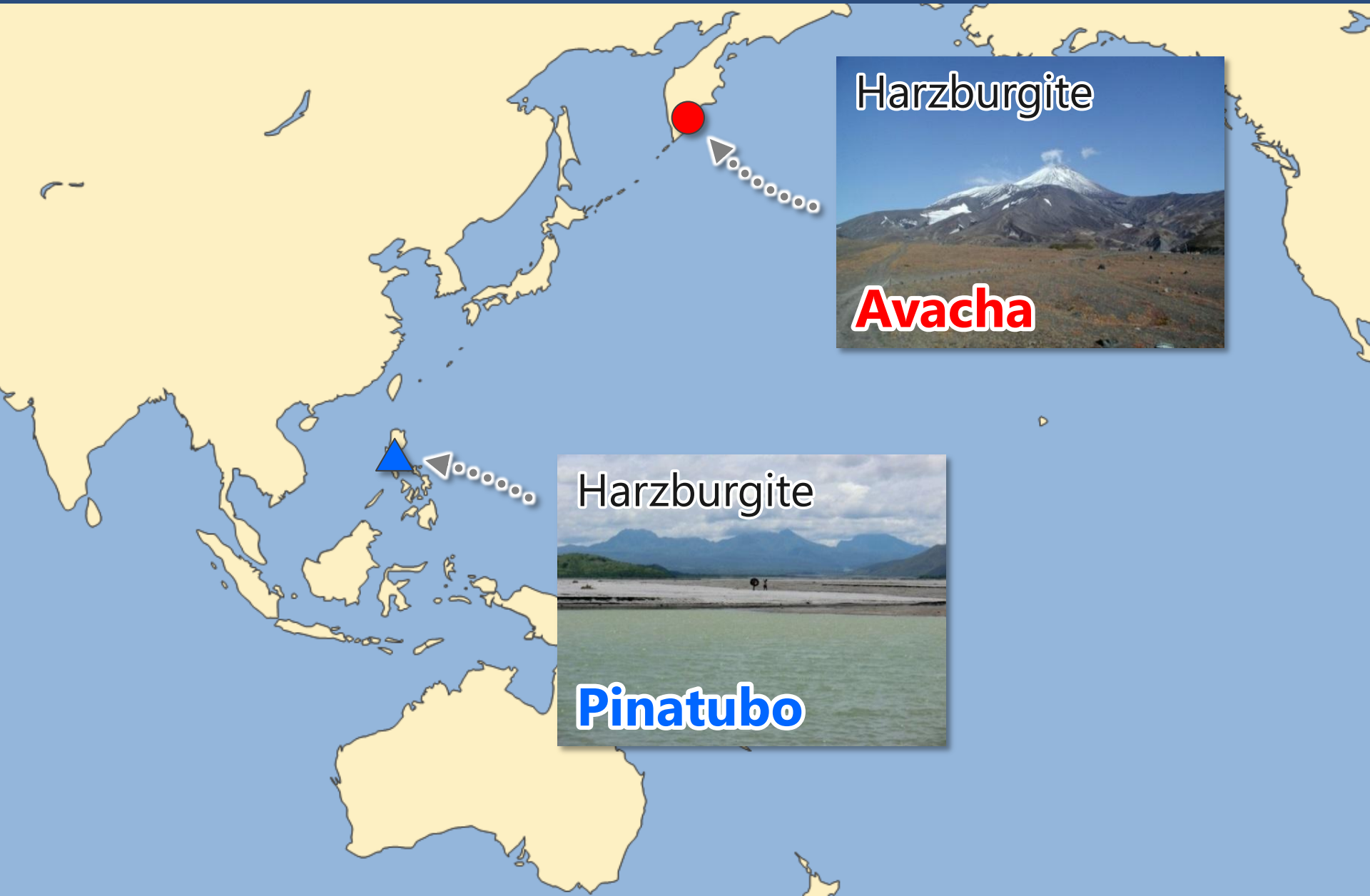
Halogens & noble gases subducted into the mantle

Sedimentary pore fluid → Serpentine → Mantle ?

Do they extend into the mantle ?

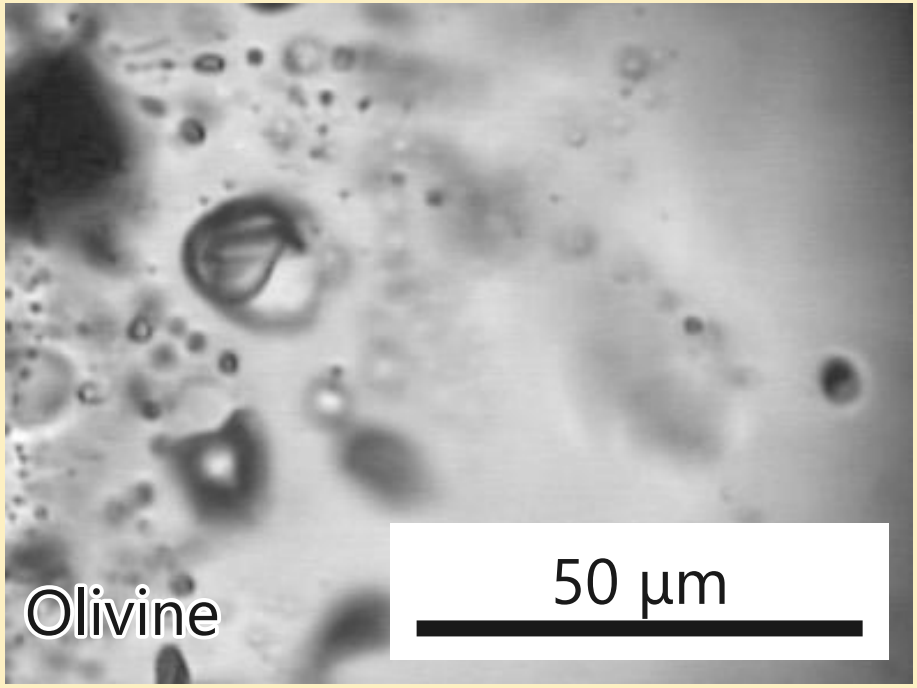


Mantle xenoliths from volcanic fronts



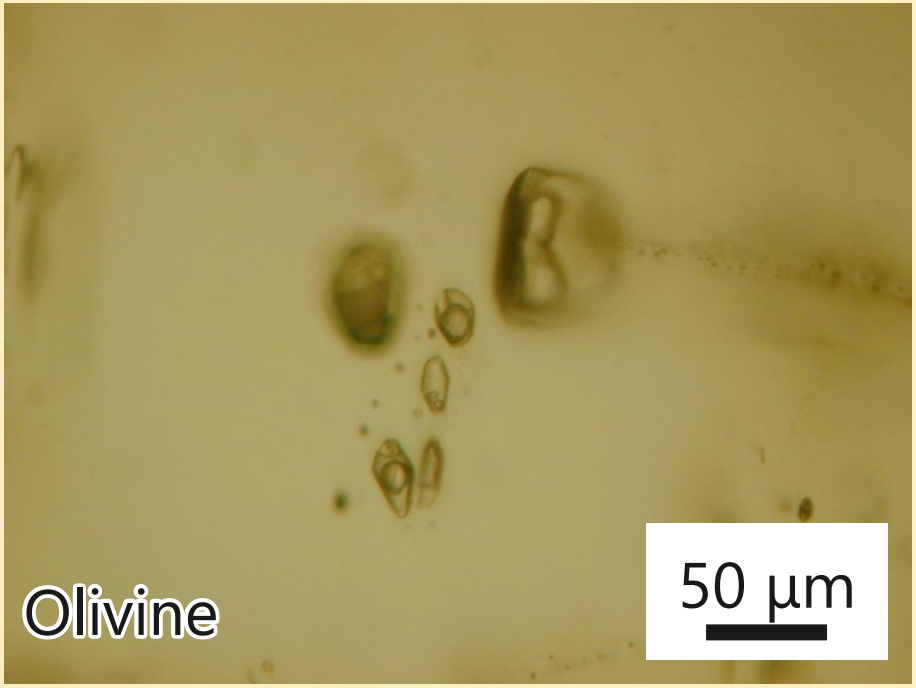
H_2O-rich fluid inclusions

Avacha



Ishimaru et al. (2007; personal comm.)

Pinatubo



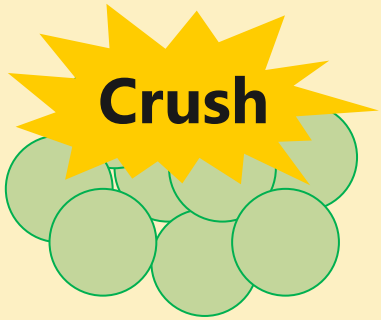
Kawamoto et al. (2013)

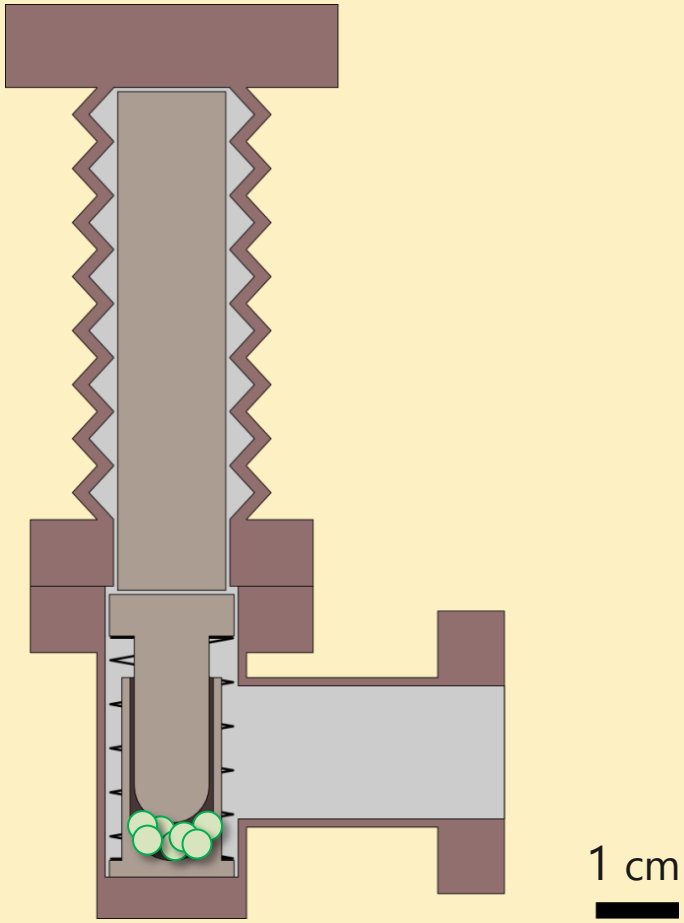
Pristine information on subducted water

Noble gas mass spectrometry

Static operation ▶ High sensitivity, high precision

Noble gas extraction | *in vacuo* crushing



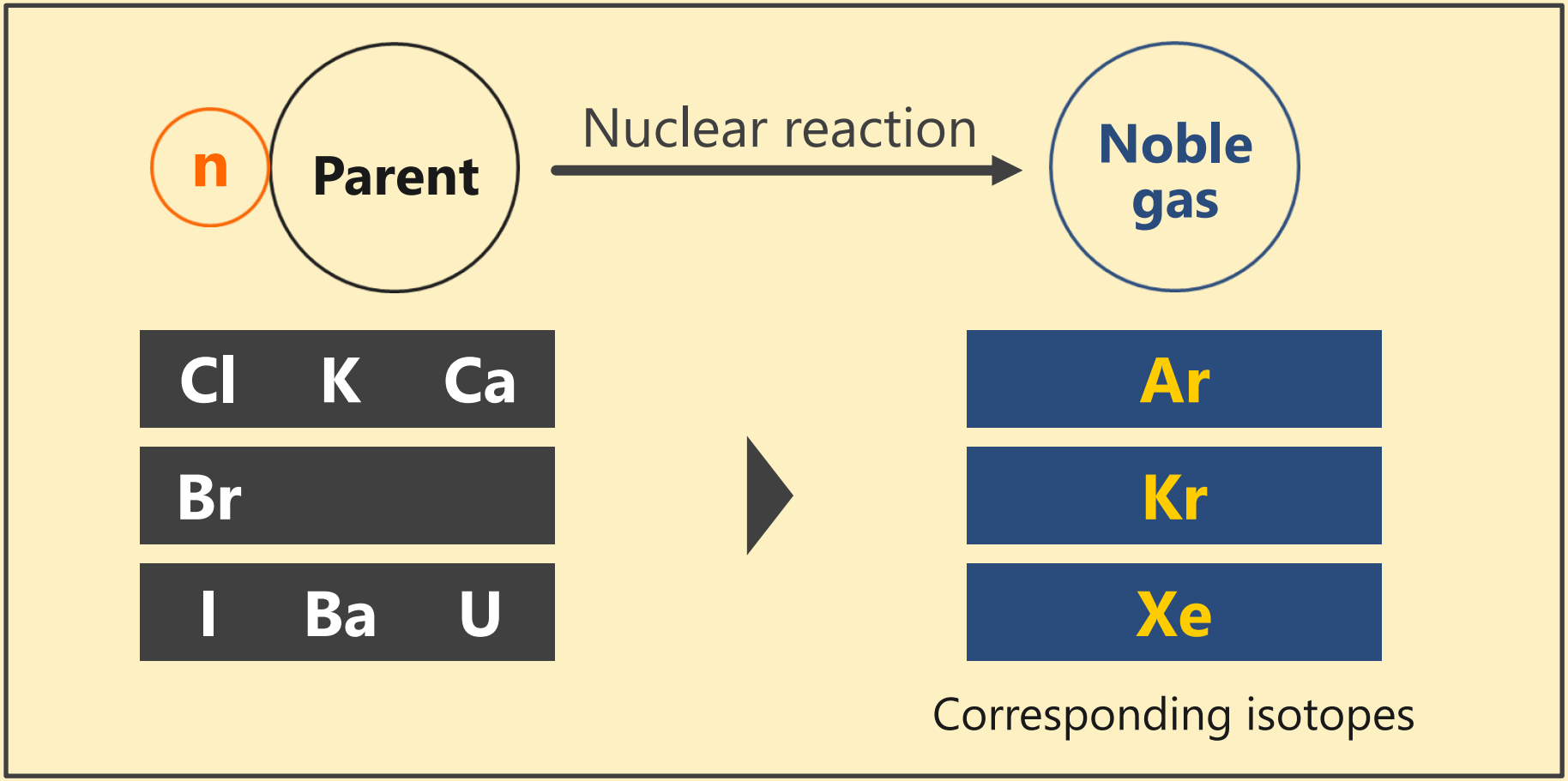


Selectively extract from fluid inclusions

Halogen analysis by using noble gas MS

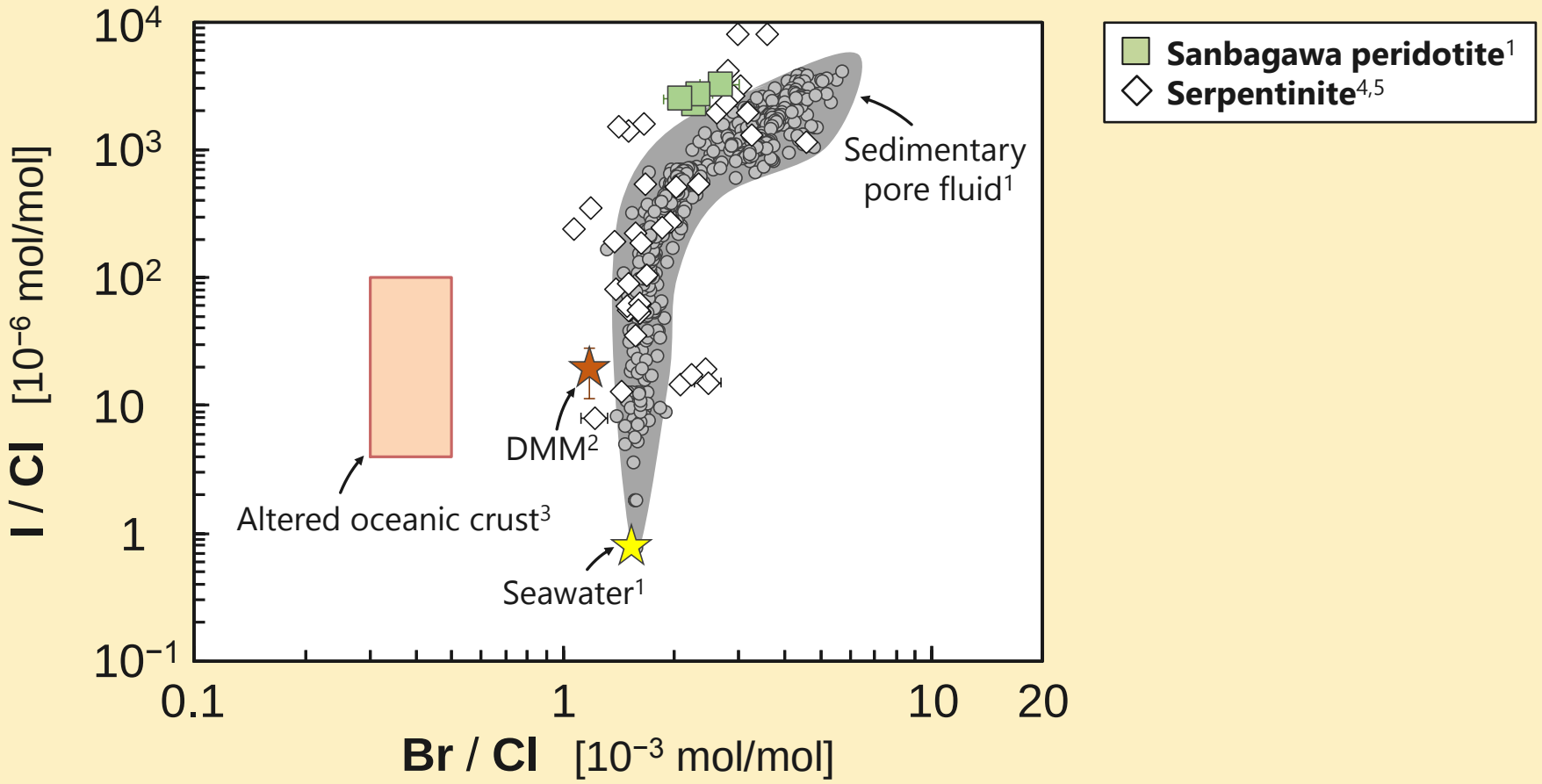
An extension of the Ar-Ar and I-Xe dating methods

Neutron irradiation ⟶ Noble gas mass spectrometry



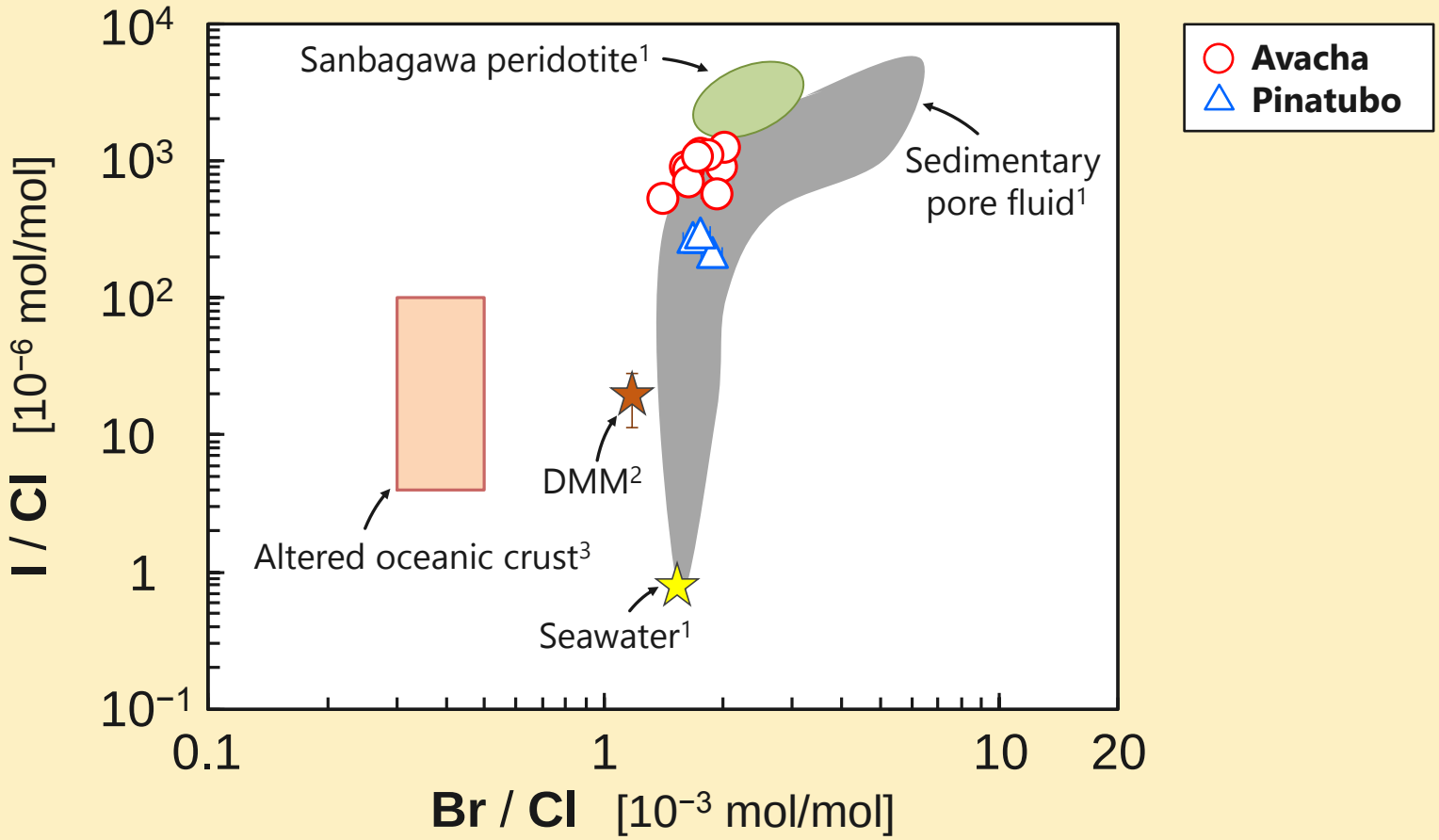
e.g. Johnson et al. (2000)

Halogen elemental ratios | Cl / Br / I



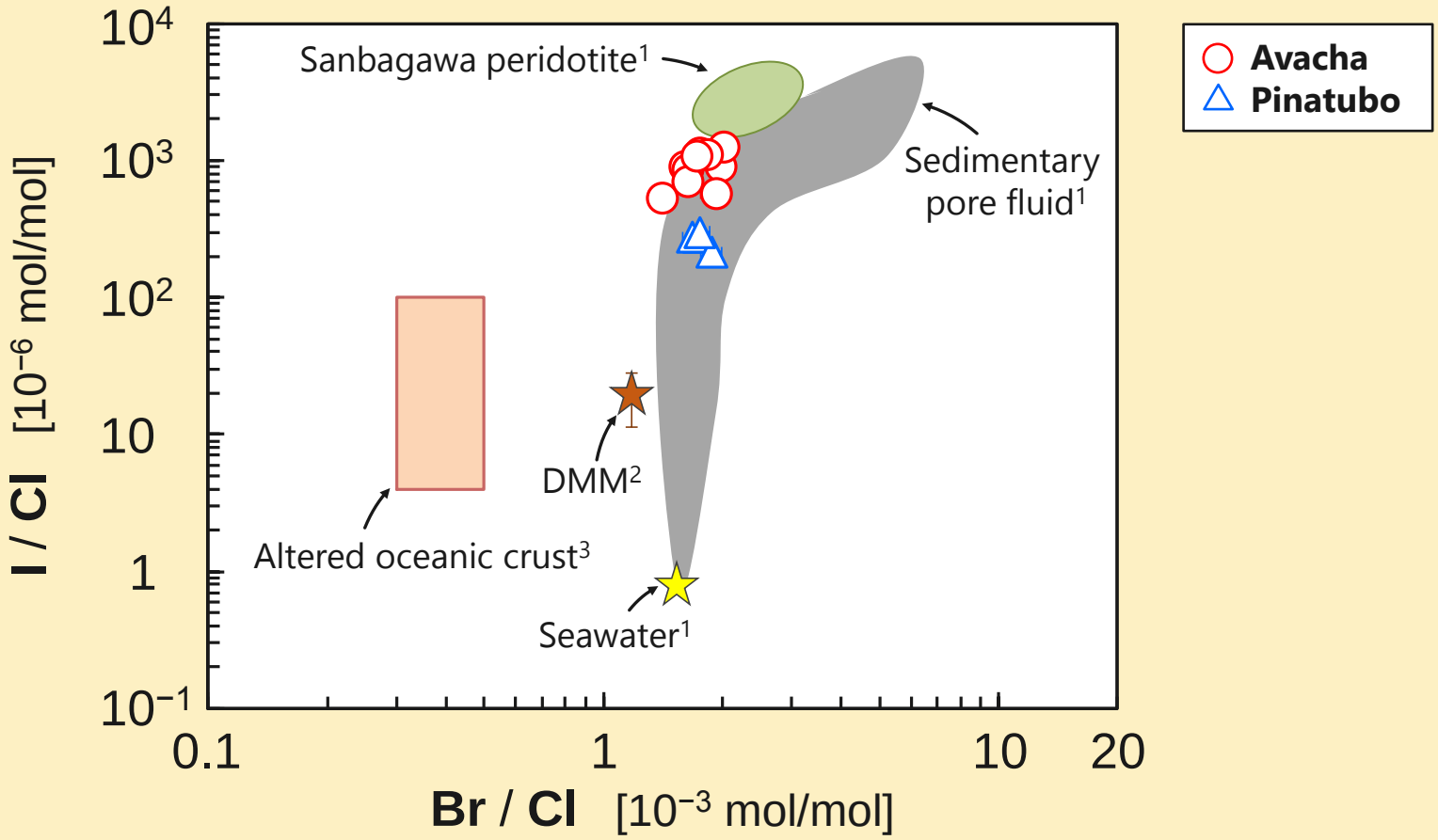
[1]Sumino et al. (2010) & references therein; [2]Kendrick et al. (2012); [3]Chavrit et al. (2012)
[4]John et al. (2011); [5]Kendrick et al. (2011; 2013)

Halogen elemental ratios | Cl / Br / I



[1]Sumino et al. (2010) & references therein; [2]Kendrick et al. (2012); [3]Chavrit et al. (2012)

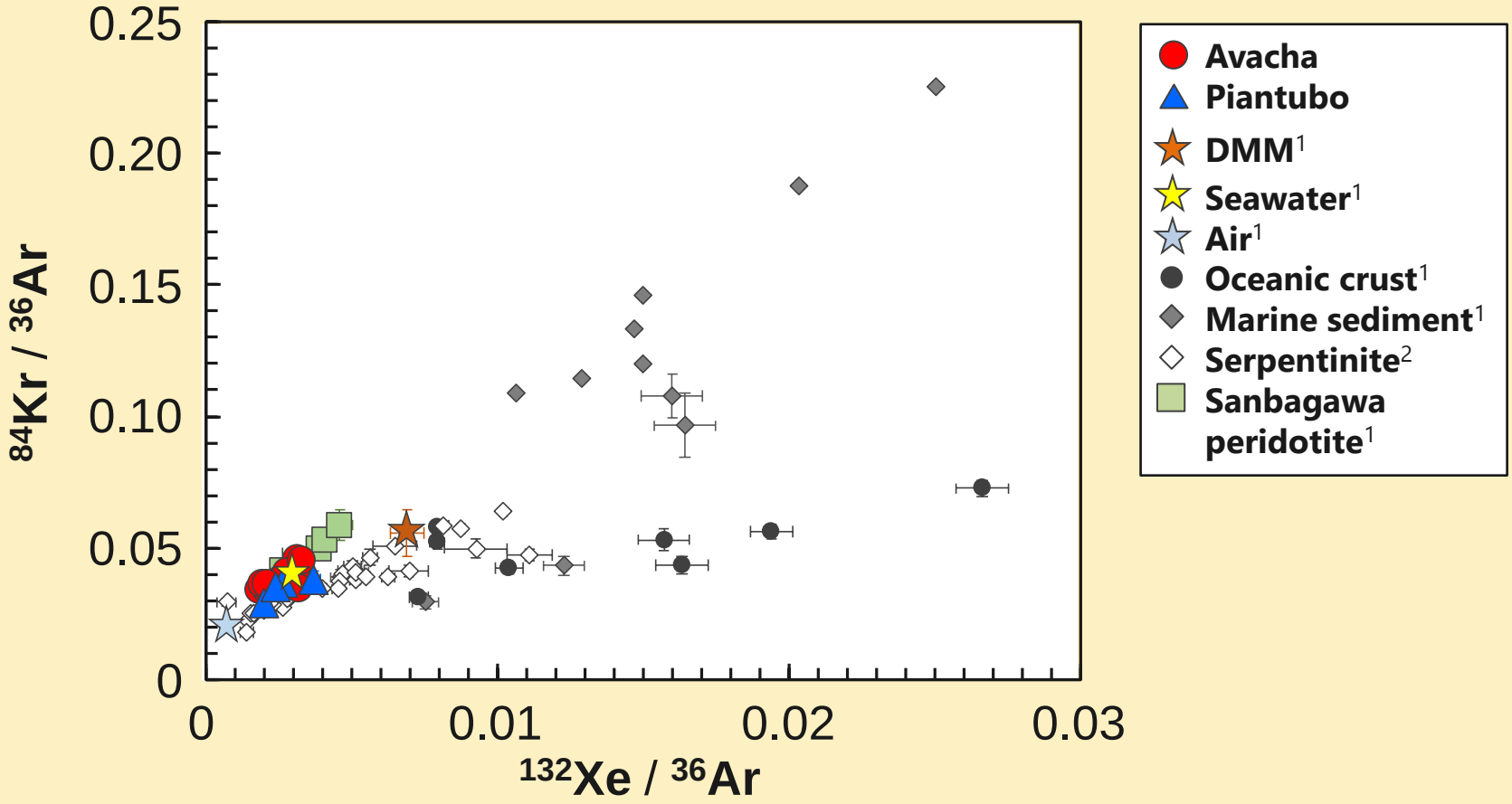
Halogen elemental ratios | Cl / Br / I



Overlap with marine sedimentary pore fluid & serpentinite

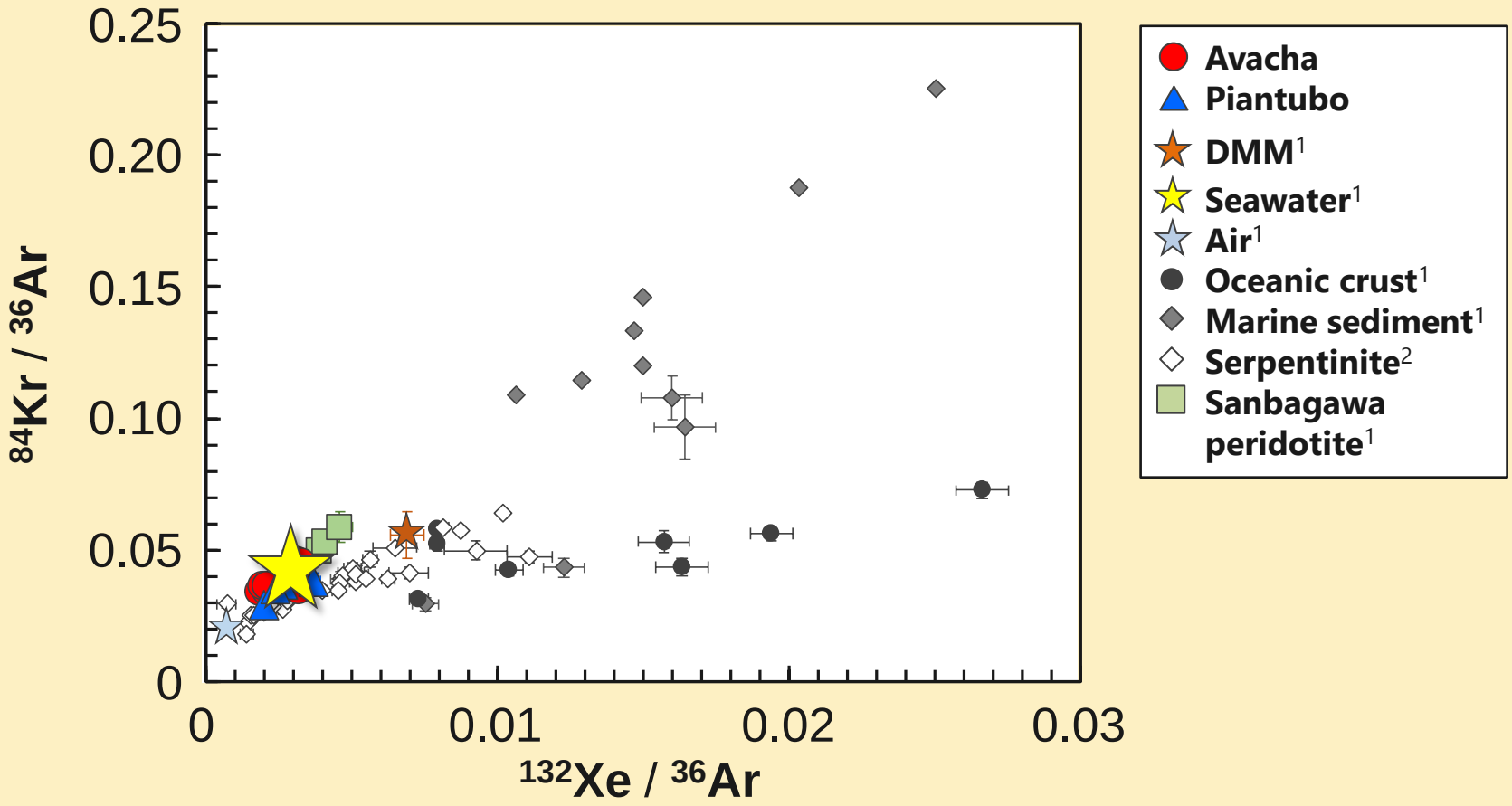
- **Subducted from sedimentary pore fluid**

Noble gas elemental ratios | ^{36}Ar / ^{84}Kr / ^{132}Xe



[1]Sumino et al. (2010) & references therein; [2]Kendrick et al. (2011; 2013)

Noble gas elemental ratios | ^{36}Ar / ^{84}Kr / ^{132}Xe



Seawater-like ^{36}Ar / ^{84}Kr / ^{132}Xe signatures

Equivalent to marine sedimentary pore fluid

▶ **Subducted from sedimentary pore fluid**

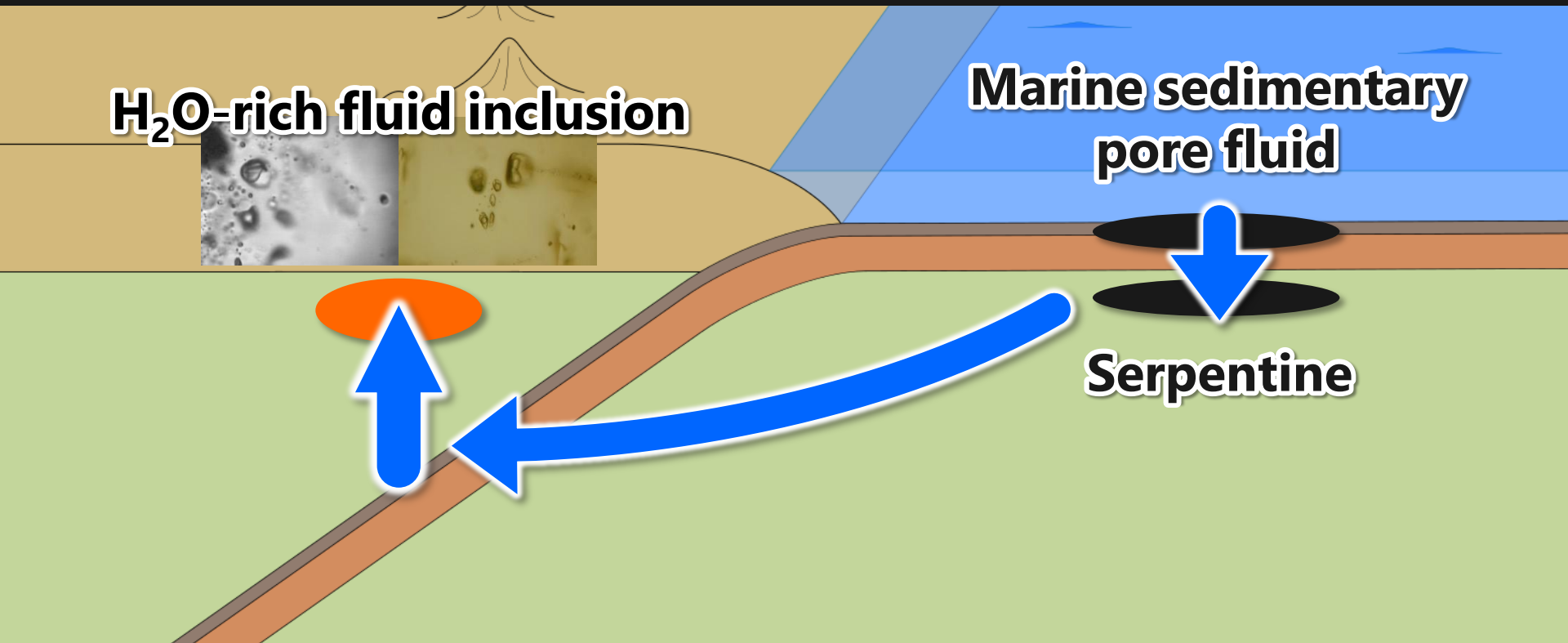
Halogens & noble gases subducted into the mantle

Sedimentary pore fluid-like signatures in H_2O

▼

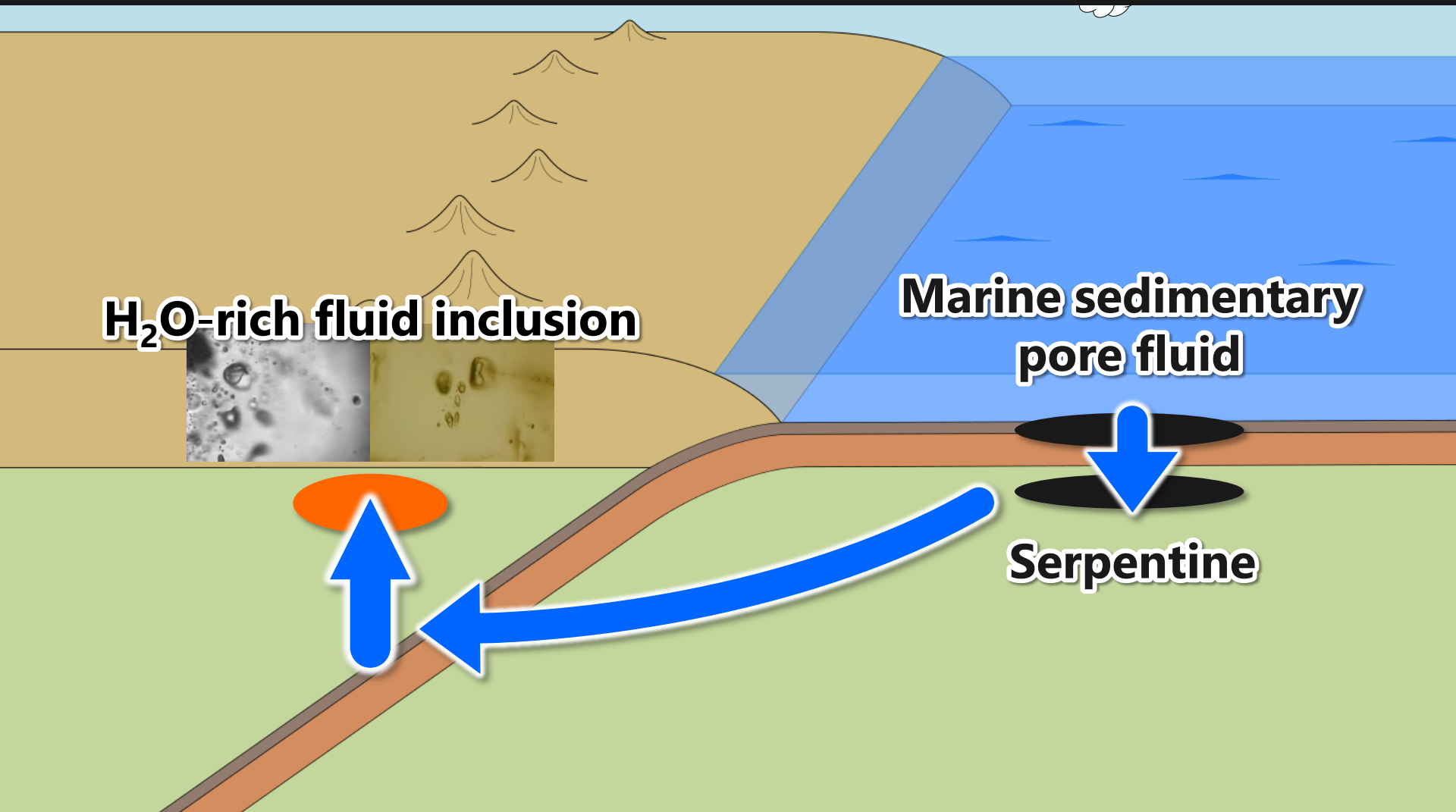
Sedimentary pore fluid-derived water is subducted.

Probably carried by serpentine



Serpentine-derived water beneath volcanic front

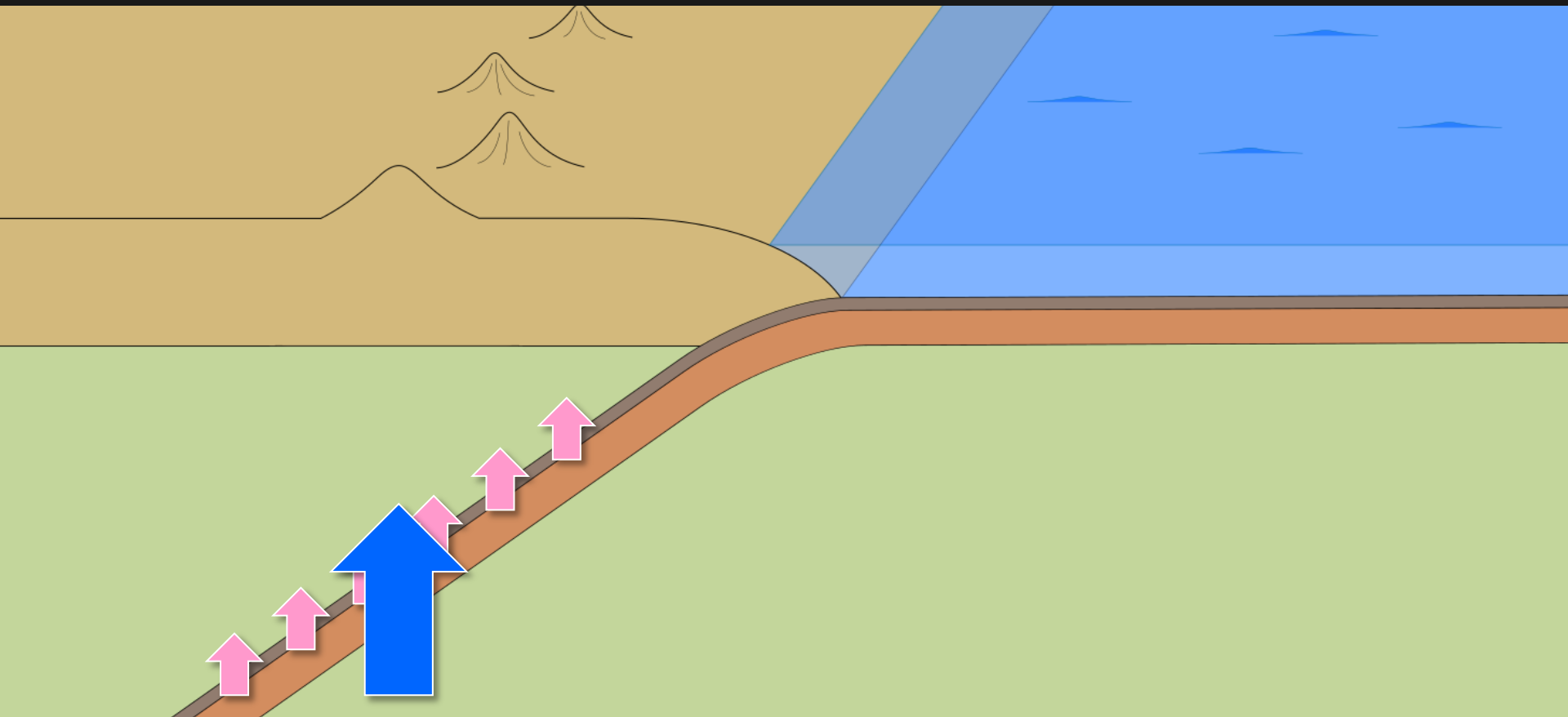
Oceanic crust ? Sediment ?



Serpentine-derived water beneath volcanic front

Oceanic crust ?　Sediment ?

Overwhelmed by serpentine-derived water



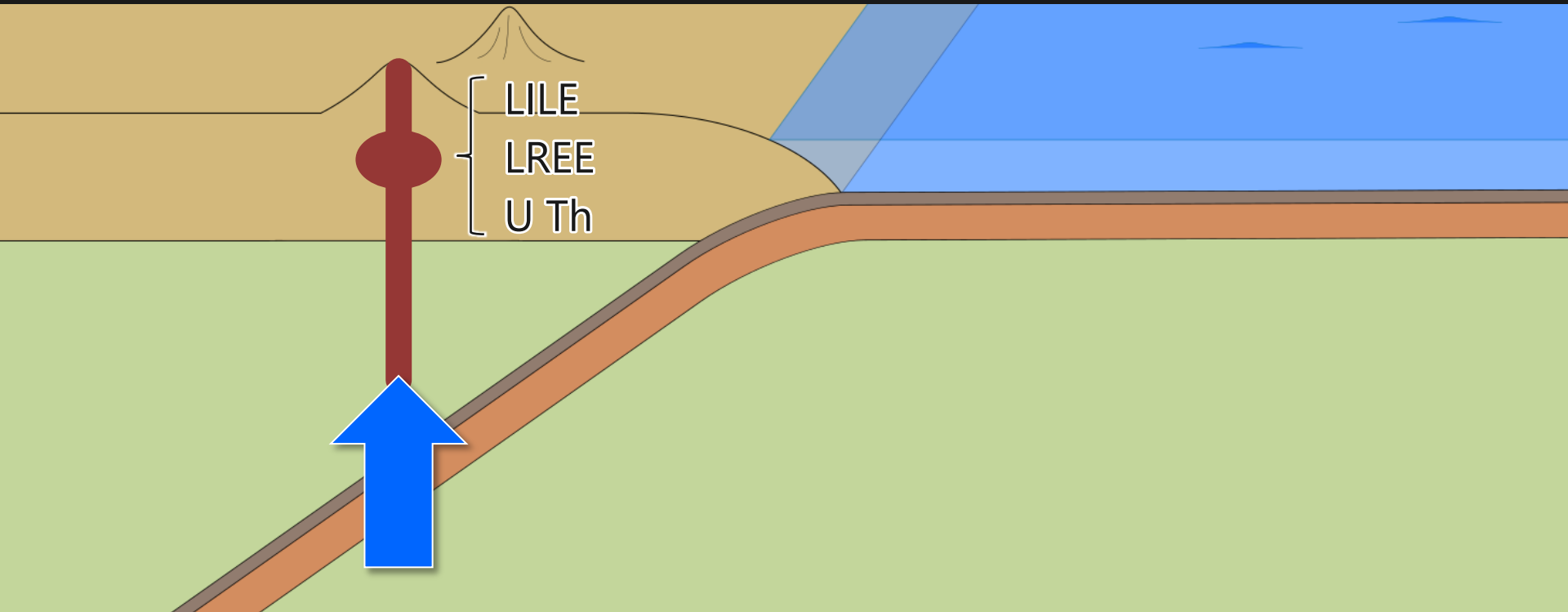
Serpentine-derived water beneath volcanic front

Trace elements in arc magmas

Major source of water beneath volcanic front is serpentine.

e.g. Herman & Green (2001); Skora & Blundy (2010)

This study | Major source of water is serpentine.



Bilateral program between RFBR & JSPS

*Deep mantle cycling of crustal components and formation of **diamond**iferous lithology in the sublithospheric mantle*

1/4/2015 – 31/3/2017

Russia

(Titles omitted)

D.A. Zedgenizov A. Ragozin V. Kalinina M. Kolesnichenko A. Bobrov

E. Sirotkina A. Tamarova

Japan

H. Kagi T. Irifune H. Sumino H. Ohfuji K. Komatsu Y. Orihashi A. Shinozaki

M. Nishi T. Kunimoto T. Arimoto M. Kobayashi

Previous studies | Halogens in diamonds

Johnson *et al.* (2000) *GCA*, **64**, 717-732

Noble gas and halogen geochemistry of mantle fluids: Comparison of African and Canadian diamonds

L. H. JOHNSON,[1] R. BURGESS,[1,*] G. TURNER,[1] H. J. MILLEDGE,[2] and J. W. HARRIS[3]

Burgess *et al.* (2002) *EPSL*, **197**, 193-203

Constraints on the age and halogen composition of mantle fluids in Siberian coated diamonds

R. Burgess [a,*], E. Layzelle [a], G. Turner [a], J.W. Harris [b]

Burgess *et al.* (2009) *GCA*, **73**, 1779--1794

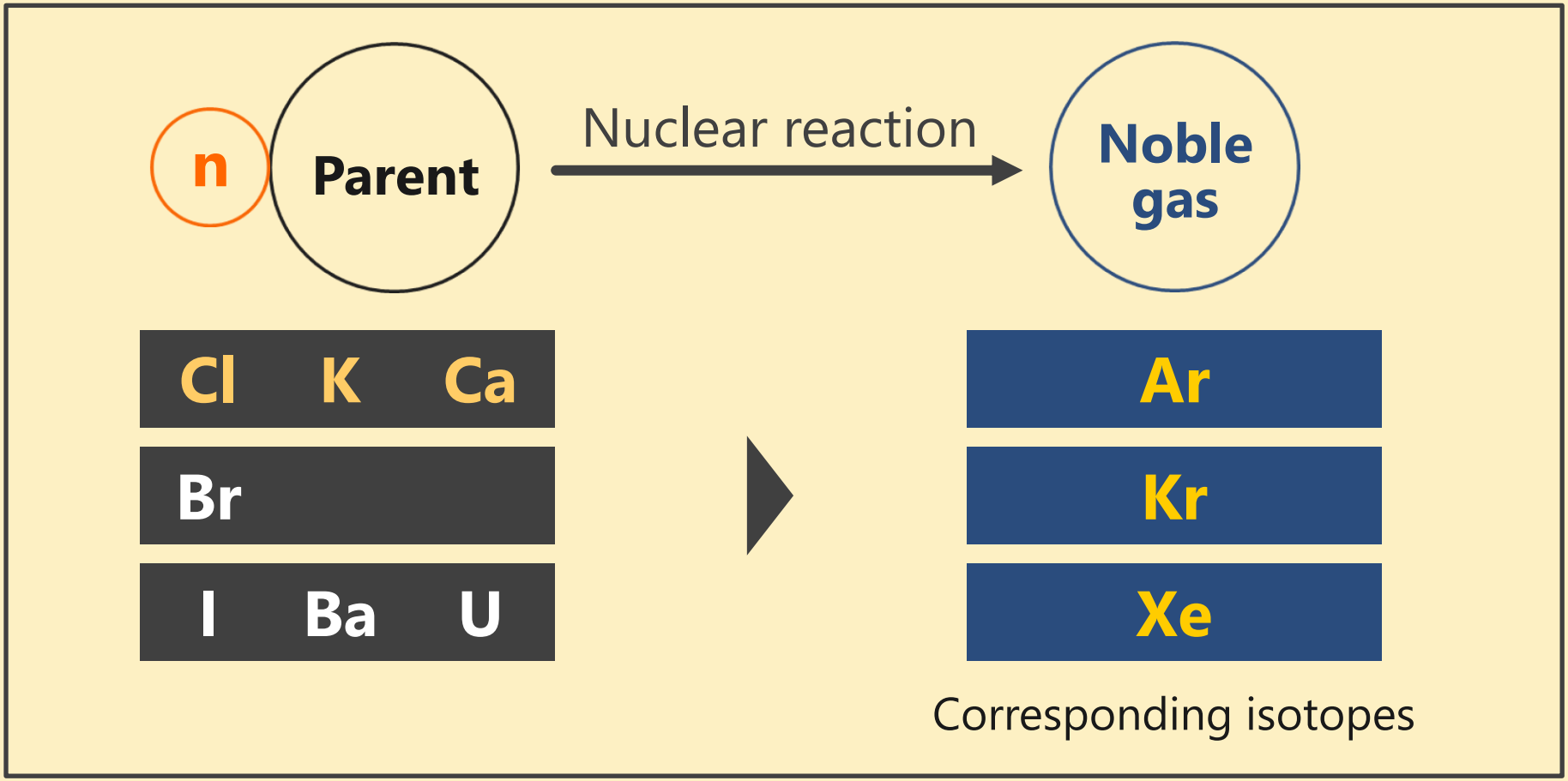
Volatile composition of microinclusions in diamonds from the Panda kimberlite, Canada: Implications for chemical and isotopic heterogeneity in the mantle

Ray Burgess [a,*], Pierre Cartigny [b], Darrell Harrison [a], Emily Hobson [a], Jeff Harris [c]

Previous studies | Halogens in diamonds

An extension of the Ar-Ar and I-Xe dating methods

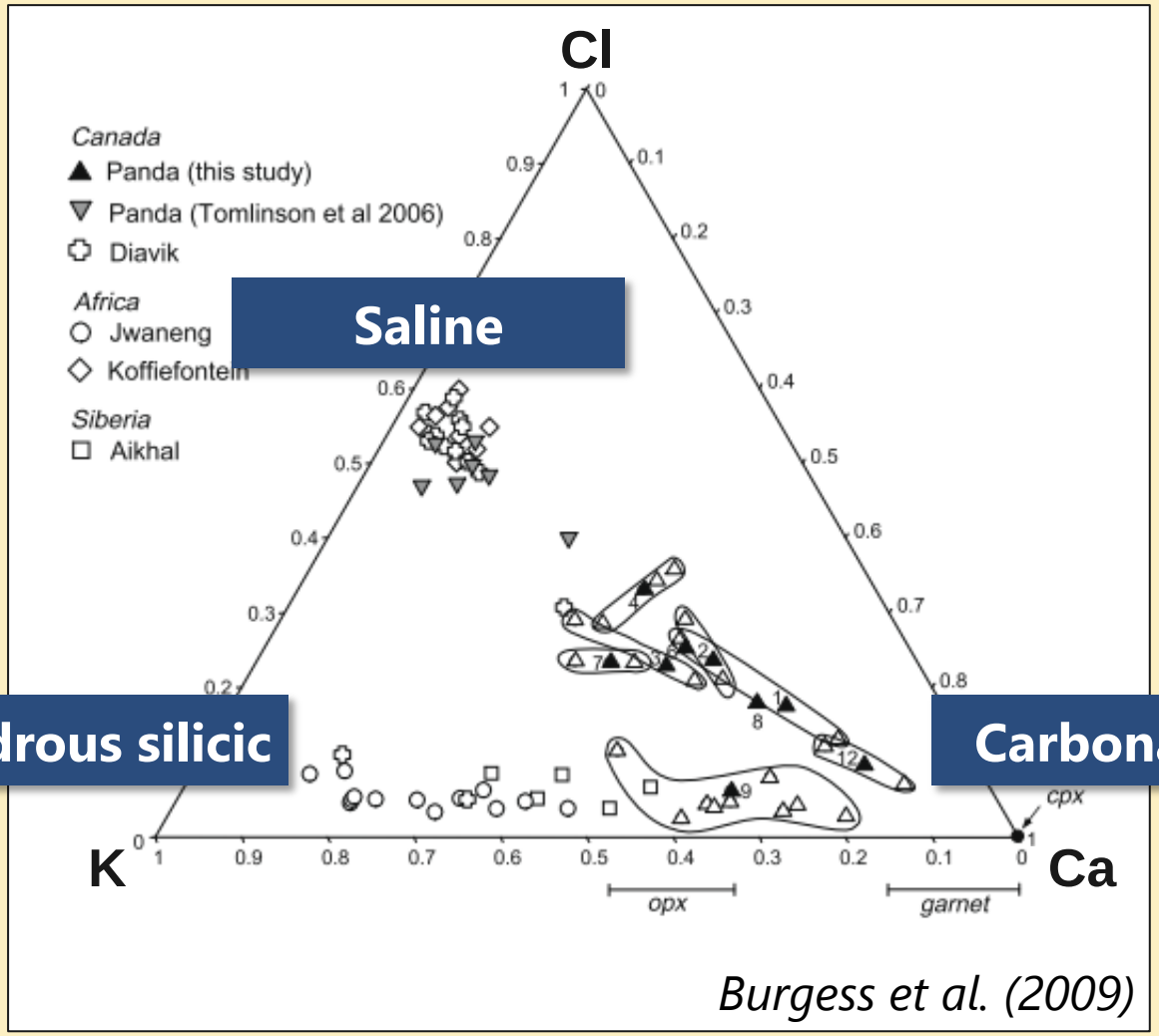
Neutron irradiation ⟶ Noble gas mass spectrometry



e.g. Johnson et al. (2000)

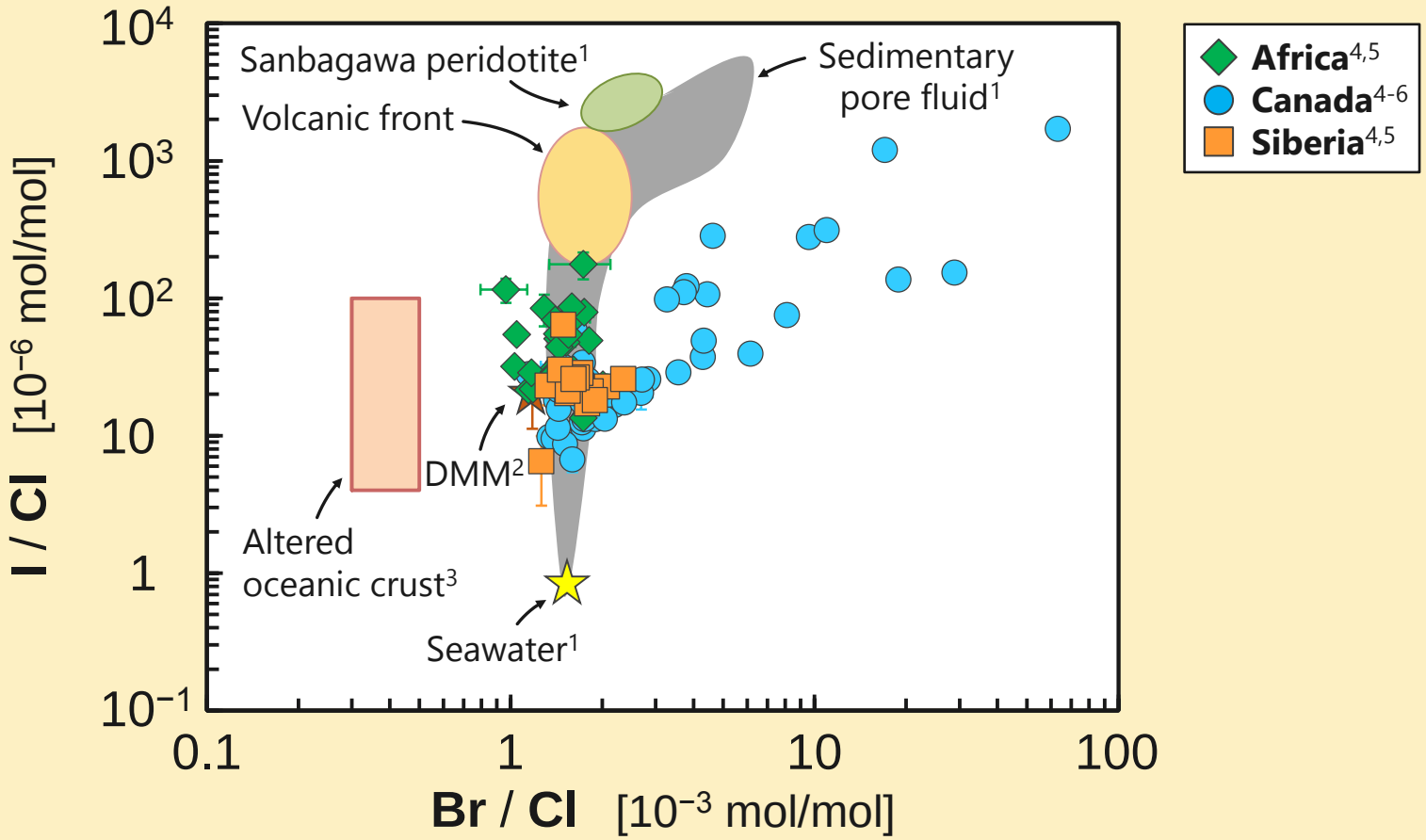
Previous studies | Halogens in diamonds

Compositions and origins of diamond-forming fluids



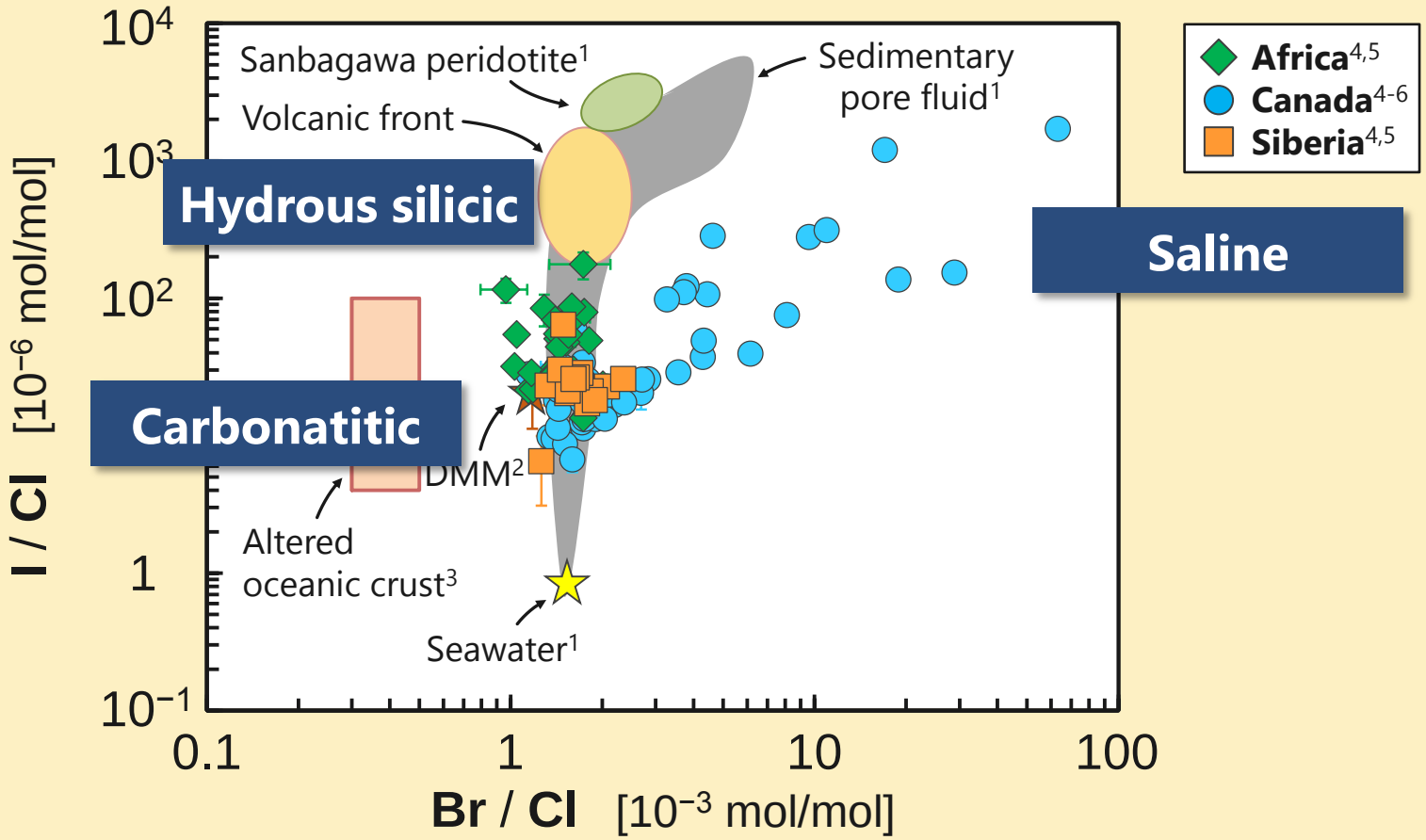
Burgess et al. (2009)

Previous studies | Halogens in diamonds



[1]Sumino et al. (2010) & references therein; [2]Kendrick et al. (2012); [3]Chavrit et al. (2012)
[4]Johnson et al. (2000); [5]Burgess et al. (2002); [6]Burgess et al. (2009)

Previous studies | Halogens in diamonds



- **Carbonatitic** ▶ DMM-like
- **Hydrous silicic** ▶ High I / Cl
- **Saline** ▶ High I / Cl & Br / Cl

Future studies on diamonds

Halogen & noble gas compositions along depth

Constrain depth information ← (From residual pressure?)

Halogen & noble gas analysis

Homogeneous?

Heterogeneous?

Relationship between depth?

Subduction related?

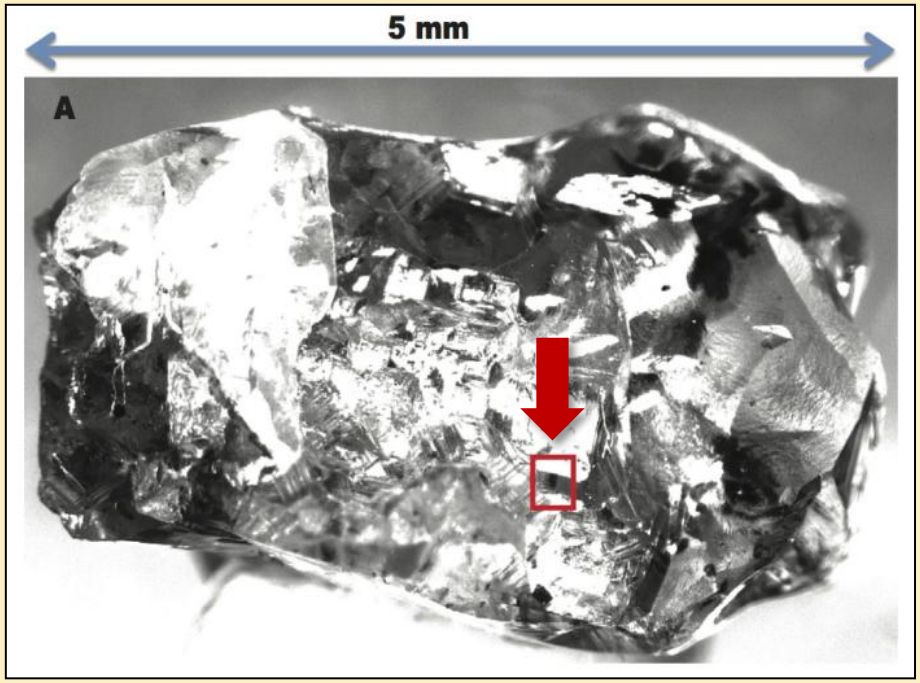
Information on fluid distribution in the mantle

Future studies on diamonds

Deep diamonds

Lower mantle

Transition zone



Ringwoodite inclusion

1 wt.% H_2O in transition zone

Subduction origin?

Juvenile water?

⋮

Pearson et al. (2014)

Halogens & Noble gases

(The most ?) powerful tracers of subducted water in the mantle

H_2O-rich fluid inclusions within mantle xenoliths

The best medium to investigate slab-derived fluids

Sedimentary pore fluid-like halogens & noble gases

- Sedimentary pore fluid-derived water is subducted.
- This subducted water is carried by serpentine.
- Serpentine is major source of water beneath volcanic front.

Halogens & noble gases in diamonds should be investigated.

Unknown samples

Isotope ratios

Concentrations

↓

Neutron-derived isotopes

Standard samples

Conversion factors

- Ar-Ar standards

  e.g. Hb3Gr GA1550

- I-Xe standards

  e.g. Shallowater Bjurböle

▼

Compositions of unknown samples

e.g. Johnson et al. (2000)

$$[^{36}Ar]_m = [^{36}Ar]_t + [^{36}Ar]_{Ca} + [^{36}Ar]_{Cl}$$

$$[^{37}Ar]_m \exp(\lambda_{37Ar} t) = [^{37}Ar]_{Ca}$$

$$[^{38}Ar]_m = [^{38}Ar]_t + [^{38}Ar]_K + [^{38}Ar]_{Ca} + [^{38}Ar]_{Cl}$$

$$[^{39}Ar]_m \exp(\lambda_{39Ar} t) = [^{39}Ar]_K + [^{39}Ar]_{Ca}$$

$$[^{40}Ar]_m = [^{40}Ar]_{t+r} + [^{40}Ar]_K$$

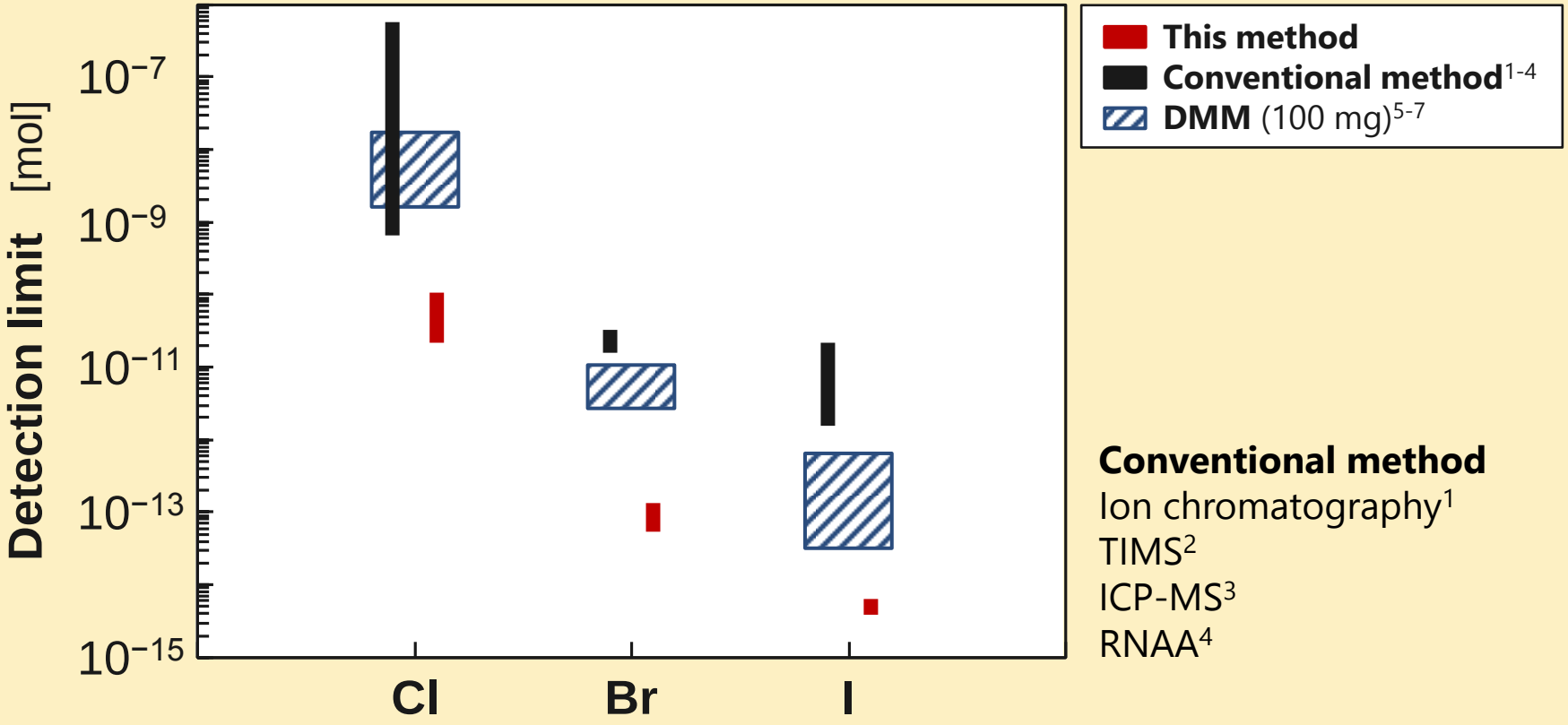
$$[^{36}Ar]_m = [^{36}Ar]_t + [^{36}Ar]_{Ca} + [^{36}Ar]_{Cl}$$

$$[^{37}Ar]_m \exp(\lambda_{37Ar} t) = [^{37}Ar]_{Ca}$$

$$[^{38}Ar]_m = [^{38}Ar]_t + [^{38}Ar]_K + [^{38}Ar]_{Ca} + [^{38}Ar]_{Cl}$$

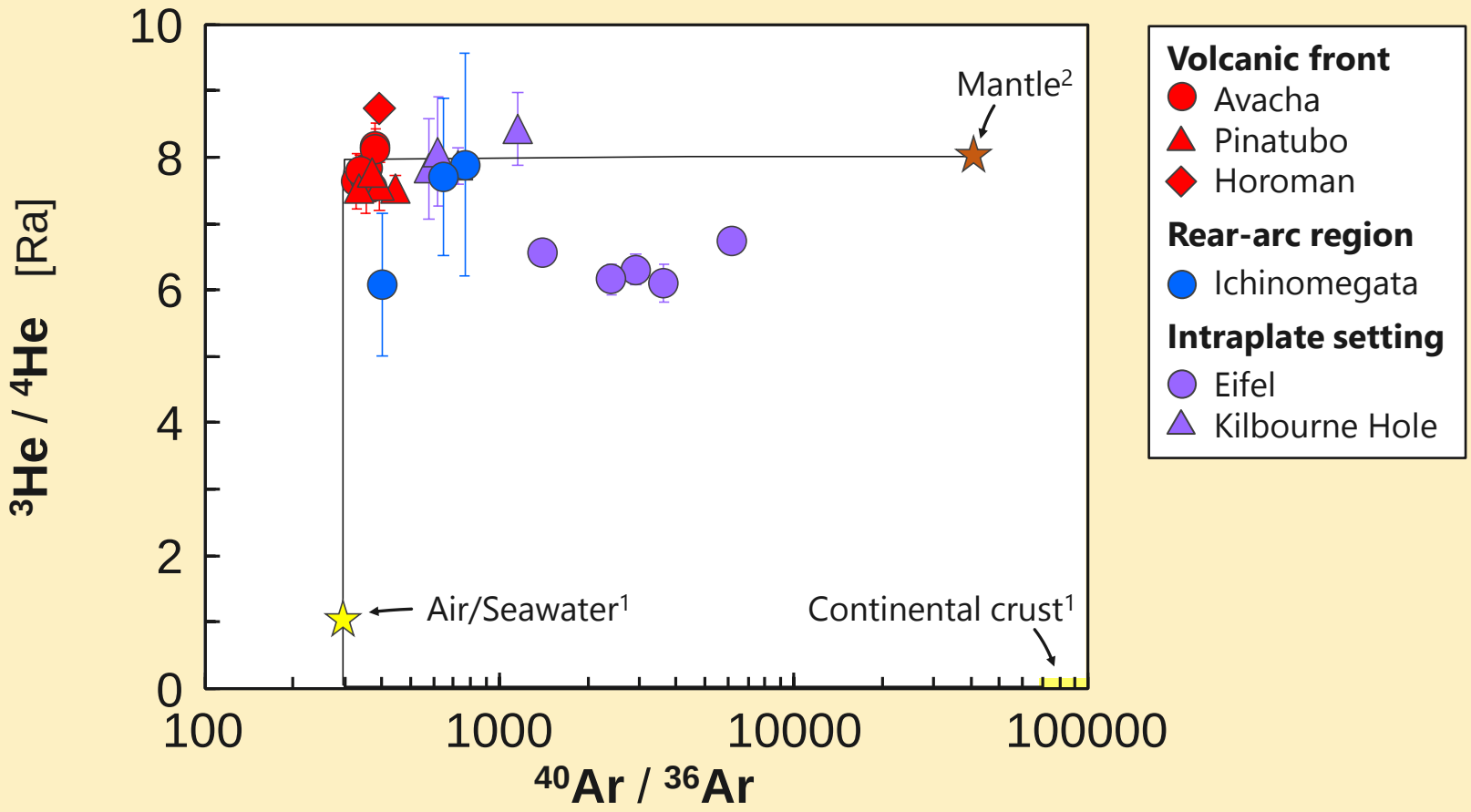
$$[^{39}Ar]_m \exp(\lambda_{39Ar} t) = [^{39}Ar]_K + [^{39}Ar]_{Ca}$$

$$[^{40}Ar]_m = [^{40}Ar]_{t+r} + [^{40}Ar]_K$$

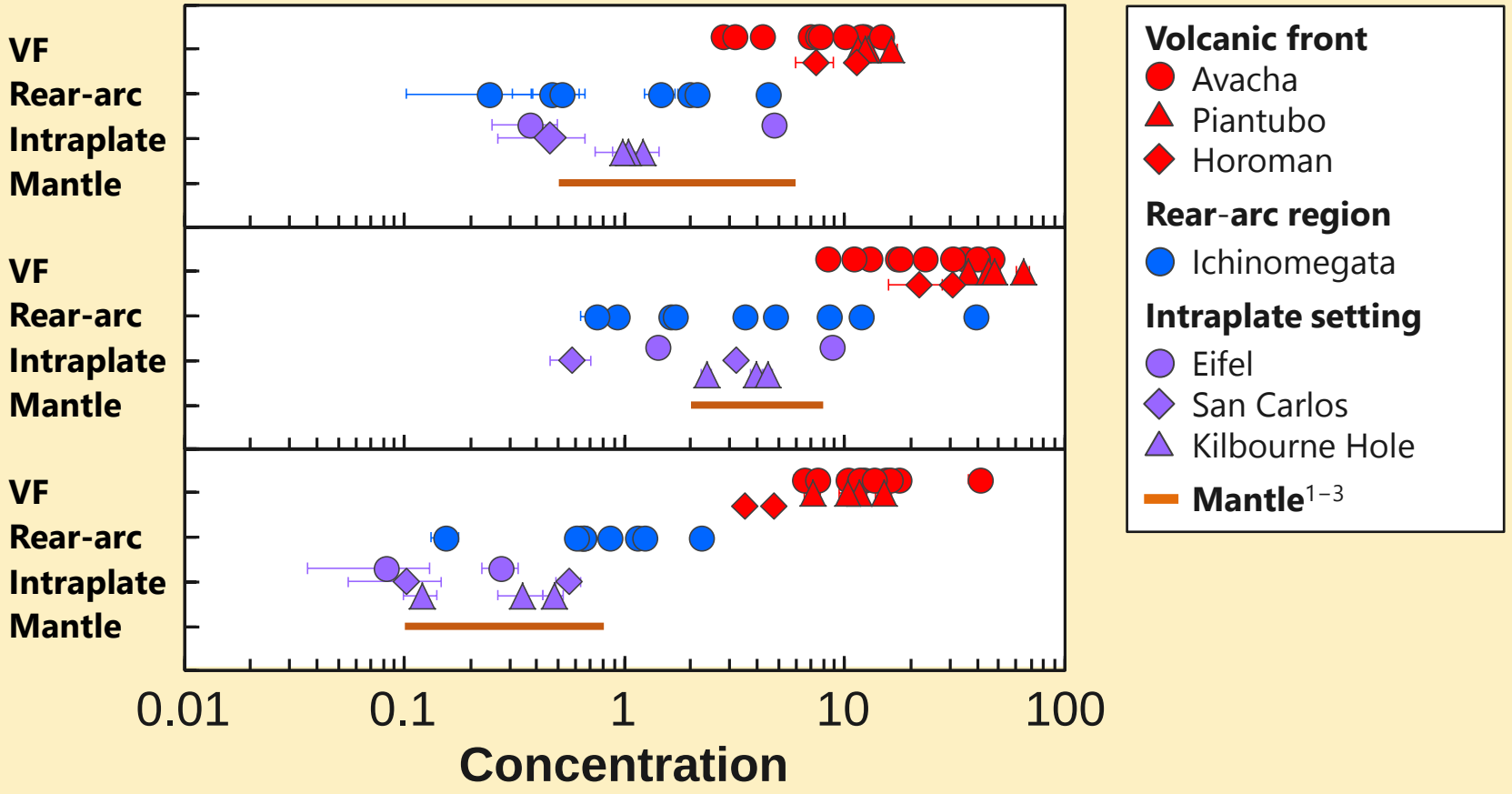


Conventional method
Ion chromatography[1]
TIMS[2]
ICP-MS[3]
RNAA[4]

[1]Michel & Villemant (2003); [2]Fujitani & Nakamura (2006); [3]Chai & Muramatsu (2007)
[4]Ozaki & Ebihara (2007); [5]Saal et al. (2002); [6]John et al. (2011); [7]Kendrick et al. (2012)



[1]Ozima & Podosek (2002); [2]Holland & Ballentine (2006)



[1]Saal et al. (2002); [2]John et al. (2011); [3]Kendrick et al. (2012)

Serpentine-derived water beneath volcanic front

Partition coefficients of trace elements *D* $^{\text{fluid/melt}}_{\text{LILE}}$

H_2O + NaCl > H_2O *Kepler (1996); Kawamoto et al. (2014)*

This study | Slab-derived fluids contain halogens.