Les verres naturels d'origine magmatique:

des outils pour mieux comprendre l'évolution de la Terre interne

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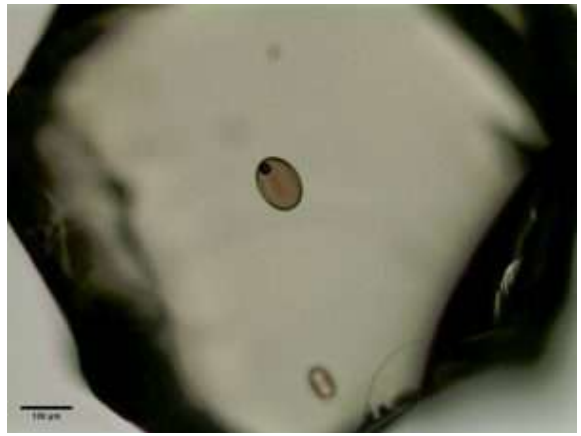
UNIL | Université de Lausanne
Institut des sciences de la Terre

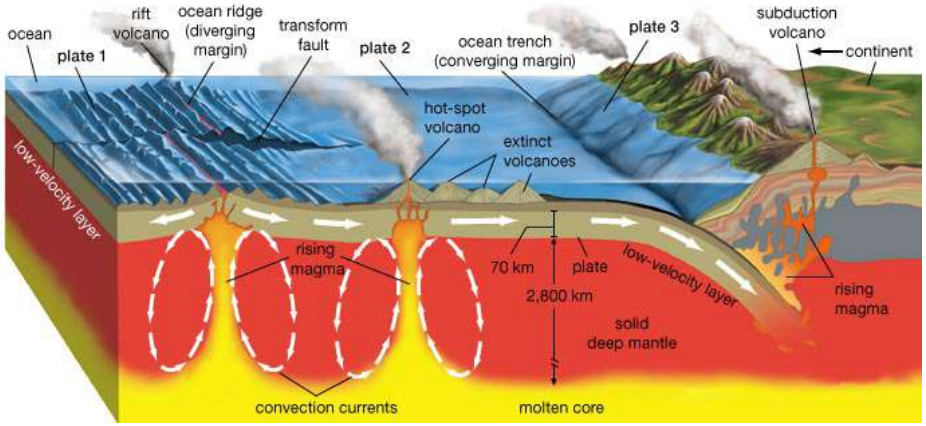


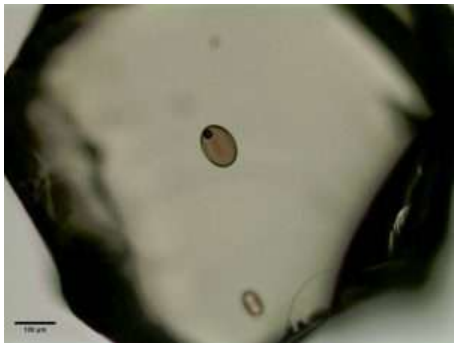
Journée scientifique 'Verres naturels', Institut de physique du globe de Paris, 30 Mai 2022

Verres et inclusions vitreuses: pourquoi?

30 Mai 2022

Problématiques et utilité en Sciences de la Terre





Verres océaniques et inclusions vitreuses **= liquide figé**

Roches holocristallines (pas de verre)

Basalte microcristallin

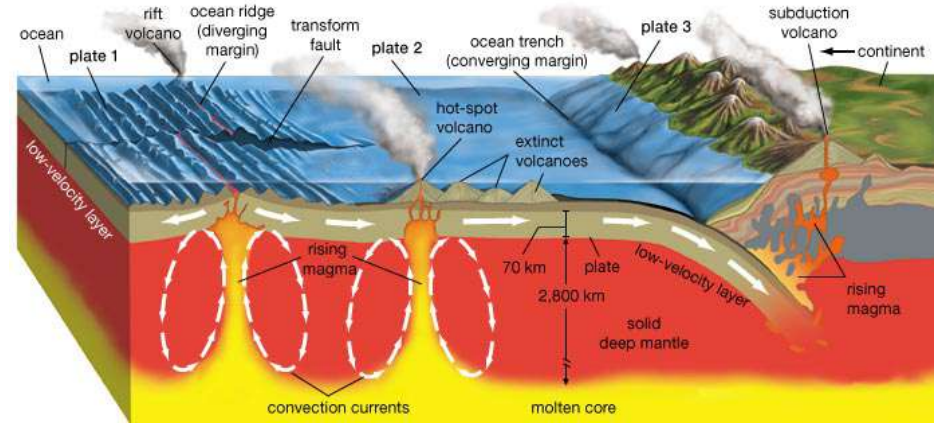
Andésite sériée

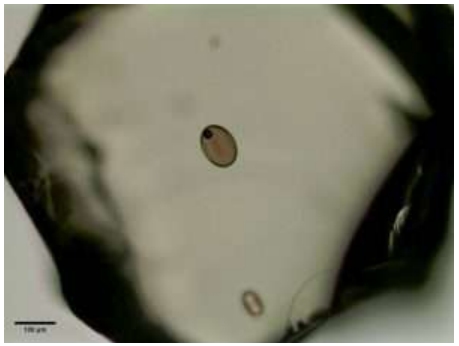
Roche volcaniques (surface) **= liquide? magma? cumulat?**

Verres et inclusions vitreuses: pourquoi?

30 Mai 2022

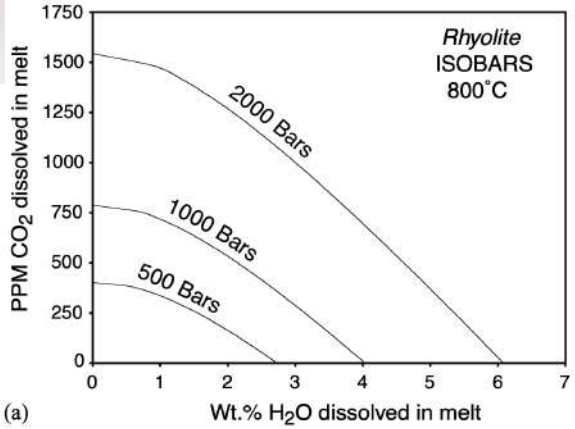
Problématiques et utilité en Sciences de la Terre





Inclusion vitreuse **=> préservation d'espèces solubles à HP**

Basalte vacuolaire (poreux)



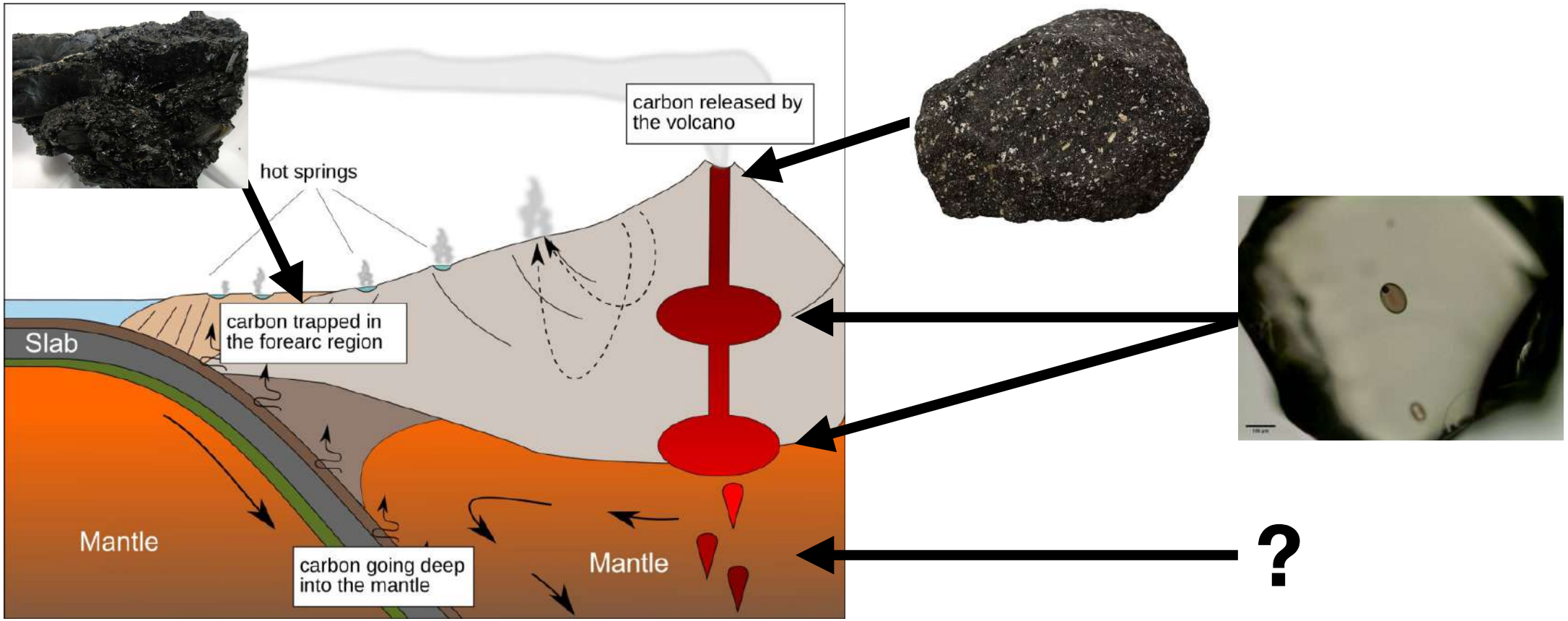
Newmann and Lowenstern (2002)

Espèces solubles à HP **= éléments volatils**

Verres et inclusions vitreuses: pourquoi?

30 Mai 2022

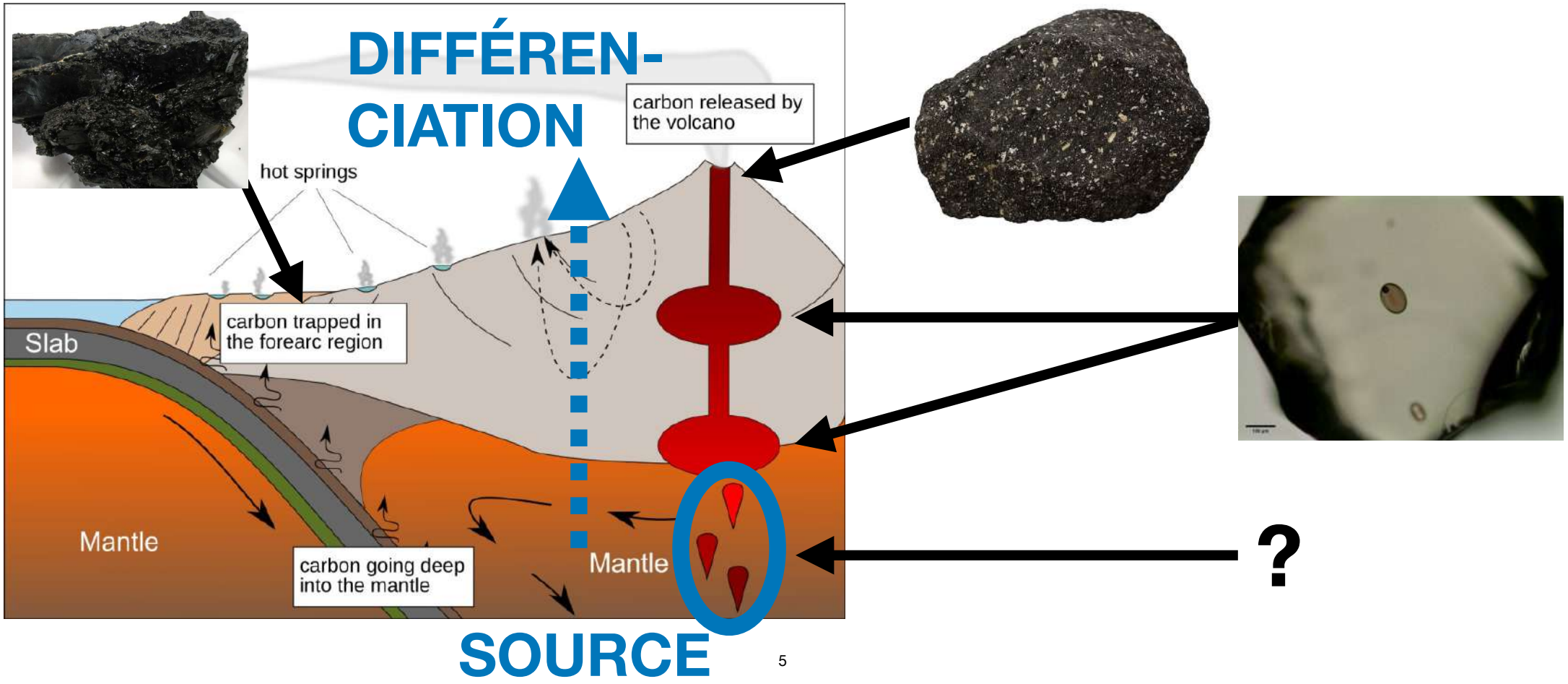
Problématiques et utilité en Sciences de la Terre



Verres et inclusions vitreuses: pourquoi?

30 Mai 2022

Problématiques et utilité en Sciences de la Terre



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Partie 2: Verres ‘mantelliques’ (dont les inclusions vitreuses)

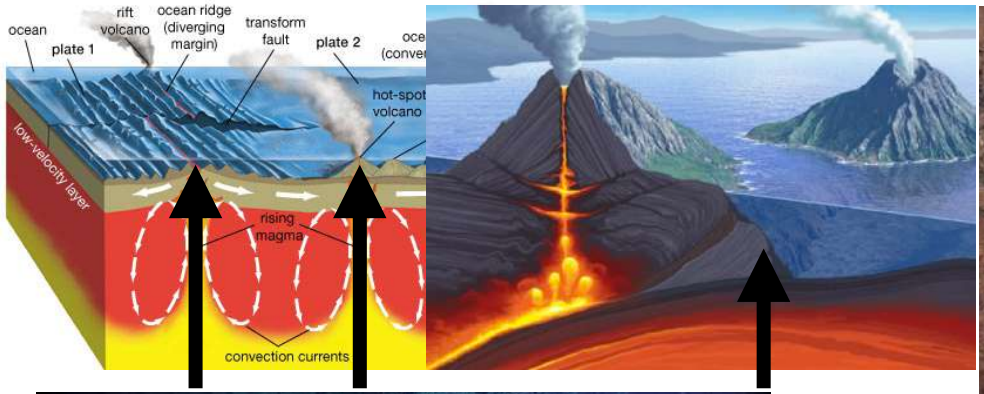
Partie 1:

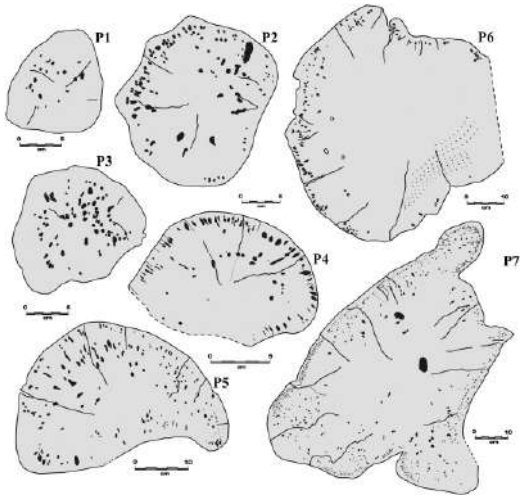
Verres océaniques (dont les inclusions vitreuses)

Verres océaniques

30 Mai 2022

Rides intra-océaniques, points chauds et zones de subduction





Duraiswami et al. (2013)

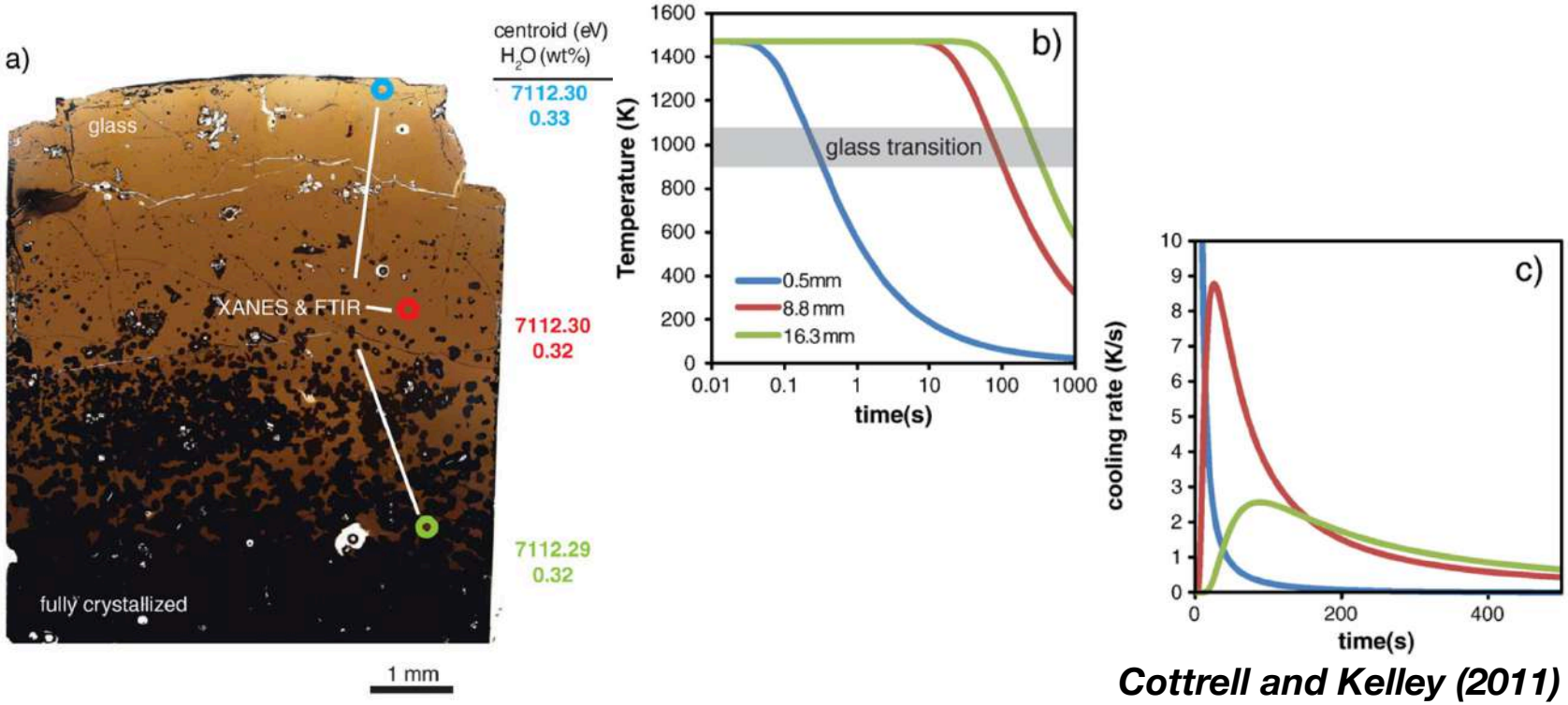
Pillow lava **=> bordure vitreuse figée**

Vésicularité = ***f*(X$_{volatils}$, profondeur…)**

Verres océaniques

30 Mai 2022

Rides intra-océaniques, points chauds et zones de subduction



Cottrell and Kelley (2011)

Pillow lava **=> importance de la cinétique de refroidissement**

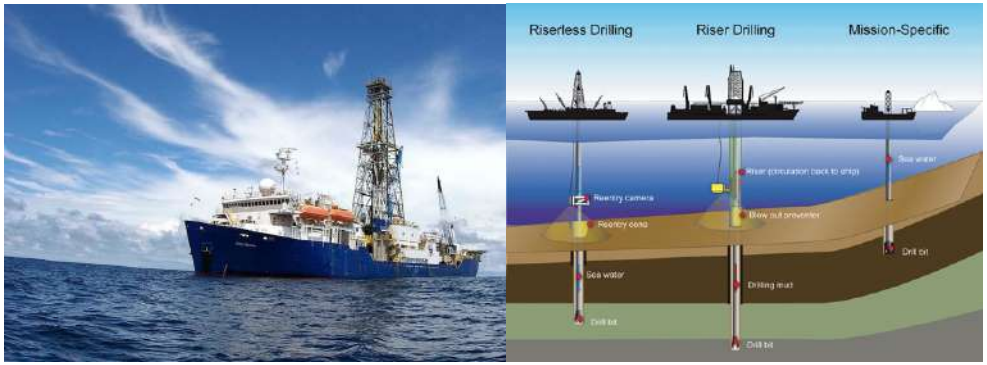
Verres océaniques

30 Mai 2022

Campagnes océanographiques

IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM

ECORD
EUROPEAN CONSORTIUM FOR OCEAN RESEARCH DRILLING



International (JOIDES Resolution)

National (Pourquoi pas?)

Ifremer

30 Mai 2022

Verres océaniques: éléments volatils

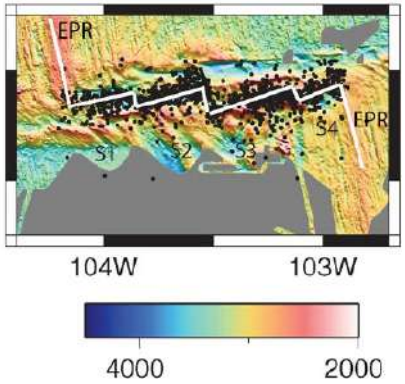
Rides intra-océaniques

articles

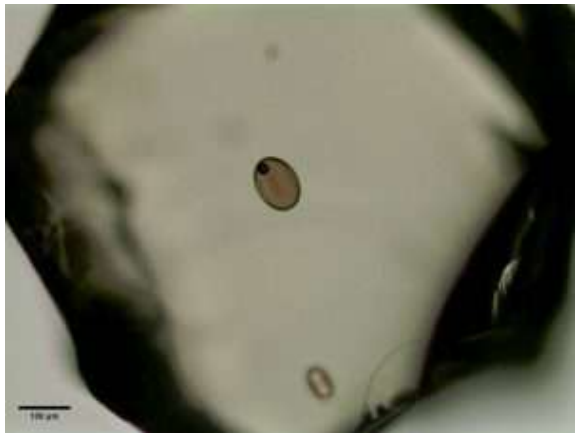
Vapour undersaturation in primitive mid-ocean-ridge basalt and the volatile content of Earth's upper mantle

Alberto E. Saal*, Erik H. Hauri†, Charles H. Langmuir* & Michael R. Perfit‡

Saal et al. (2002)



Institute of Geophysics and Planetology (Hawaii)

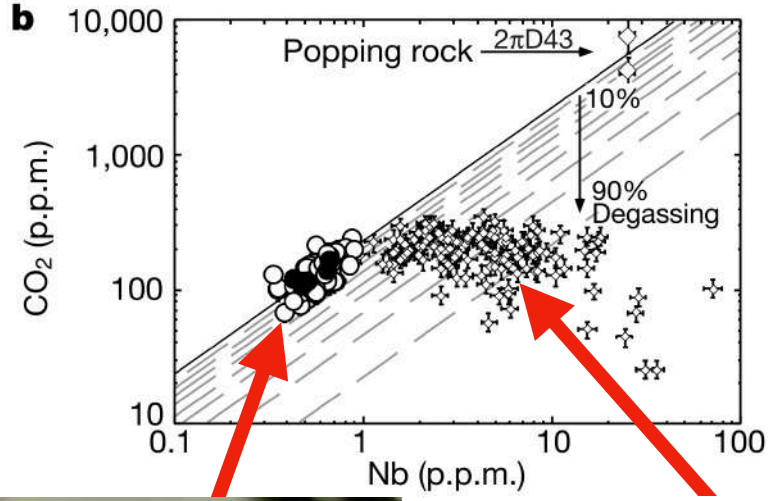


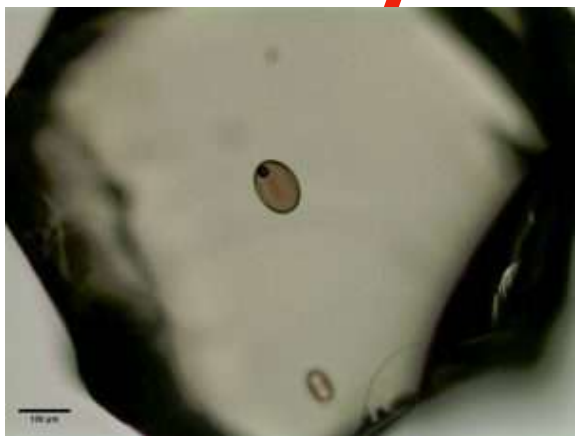
Objectif **= mesures des teneurs en (H_2O, CO_2, F, S, Cl) dans des verres et inclusions vitreuses sous-saturées**

Verres océaniques: éléments volatils

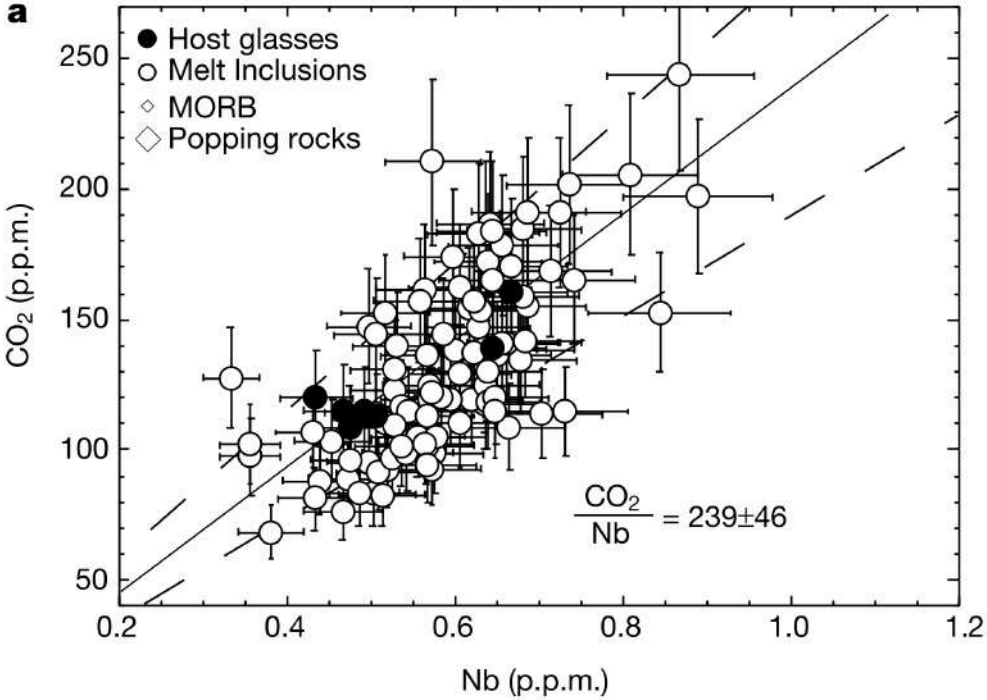
30 Mai 2022

Rides intra-océaniques





Saal et al. (2002)

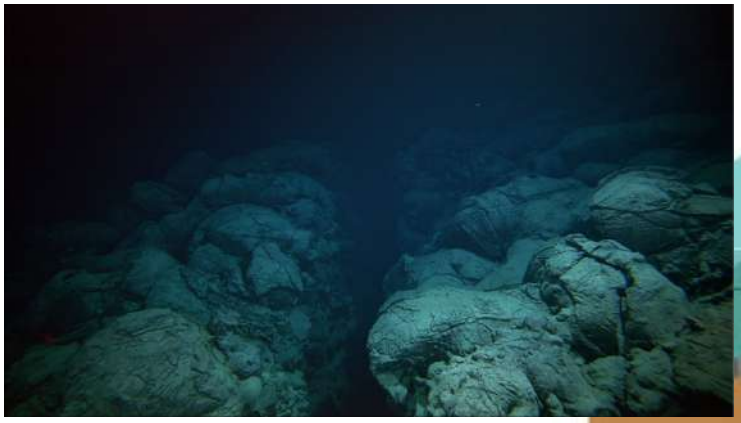


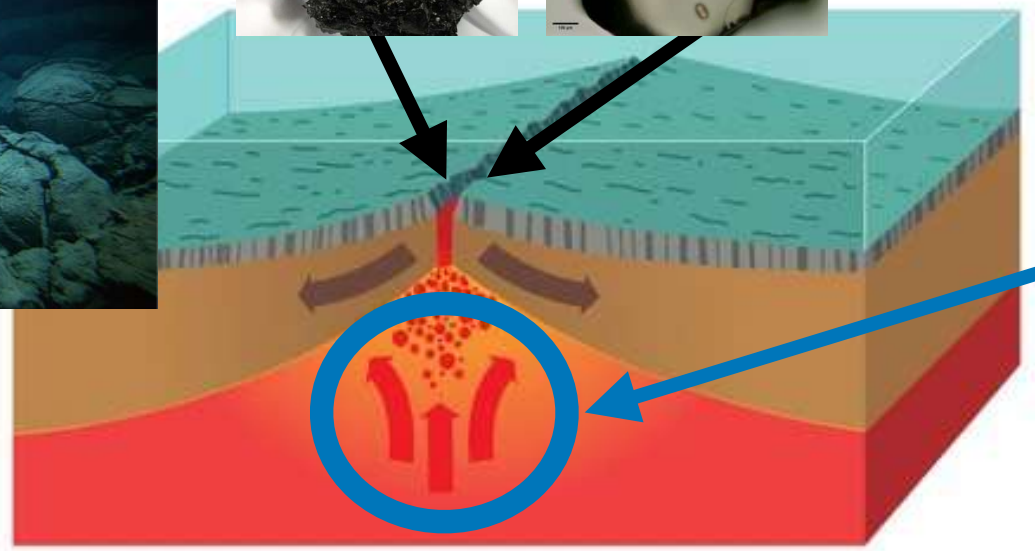
Résultat **= corrélations inter-éléments => comportements géochimiques des volatils**

Verres océaniques: éléments volatils

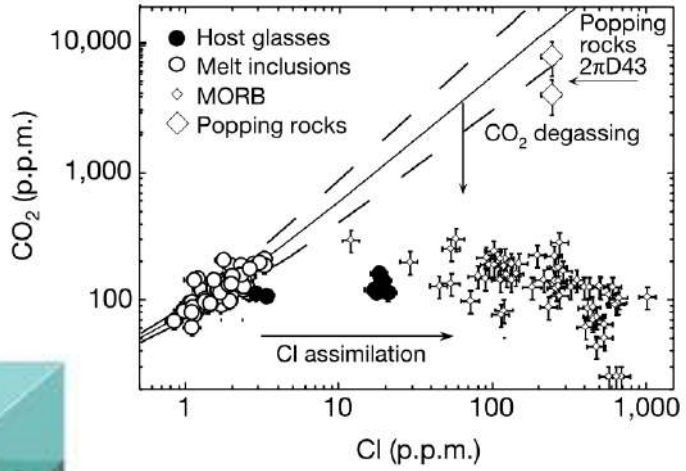
30 Mai 2022

Rides intra-océaniques





Saal et al. (2002)



SOURCE

72 ppm CO_2
142 ppm H_2O
16 ppm F
1 ppm Cl
146 ppm S

Implications **= verres océaniques et inclusions vitreuses sous-saturées => premières estimations directes de la composition du manteau asthénosphérique 'appauvri'**

Verres océaniques: éléments volatils

30 Mai 2022

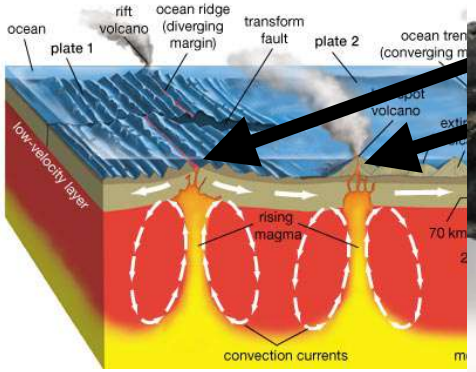
Rides intra-océaniques et points chauds

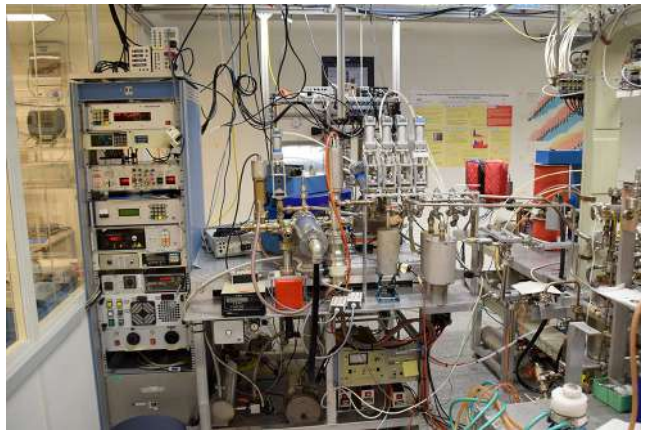
ARTICLES
PUBLISHED ONLINE: 27 FEBRUARY 2017 | DOI: 10.1038/NGEO2902
nature geoscience

Seawater cycled throughout Earth's mantle in partially serpentinized lithosphere

M. A. Kendrick[1]*, C. Hémond[2], V. S. Kamenetsky[3], L. Danyushevsky[3], C. W. Devey[4], T. Rodemann[5], M. G. Jackson[6] and M. R. Perfit[7]

Kendrick et al. (2017)





ETH (Suisse)

Objectif **= mesures des teneurs en éléments volatils halogènes (F, Cl, Br, I) dans des verres océaniques sous-saturés**

Verres océaniques: éléments volatils

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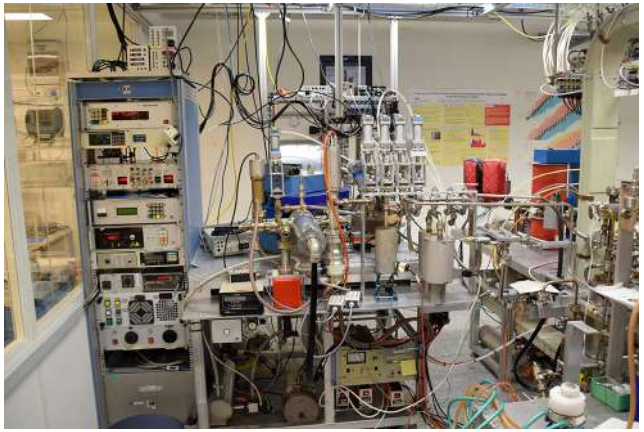

ETH (Suisse)

Résultat **= large gamme de compositions isotopiques des sources mantelliques**

Verres océaniques: éléments volatils

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Rides intra-océaniques et points chauds

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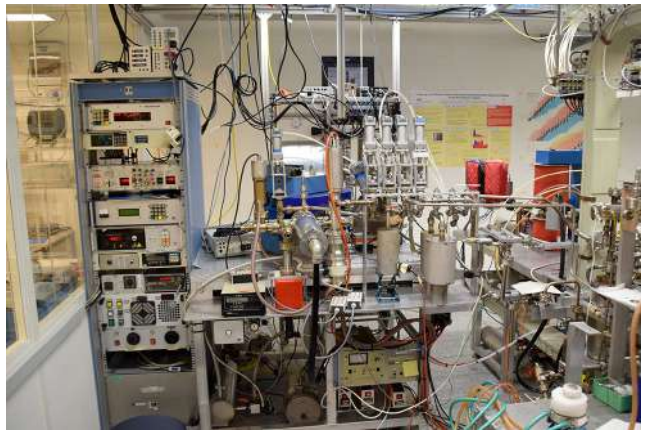
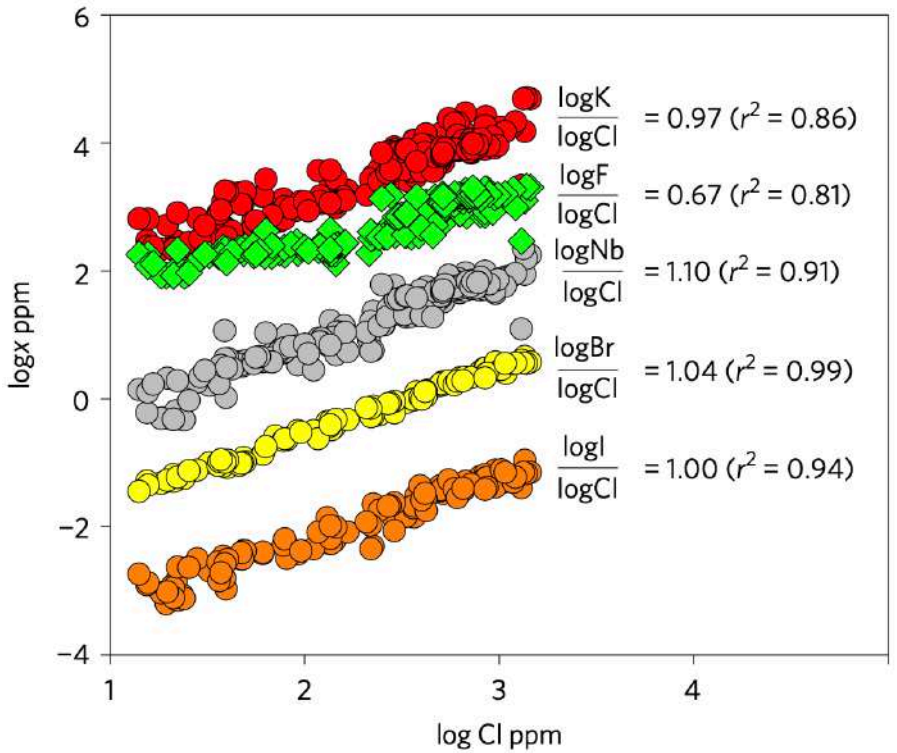


ETH (Suisse)

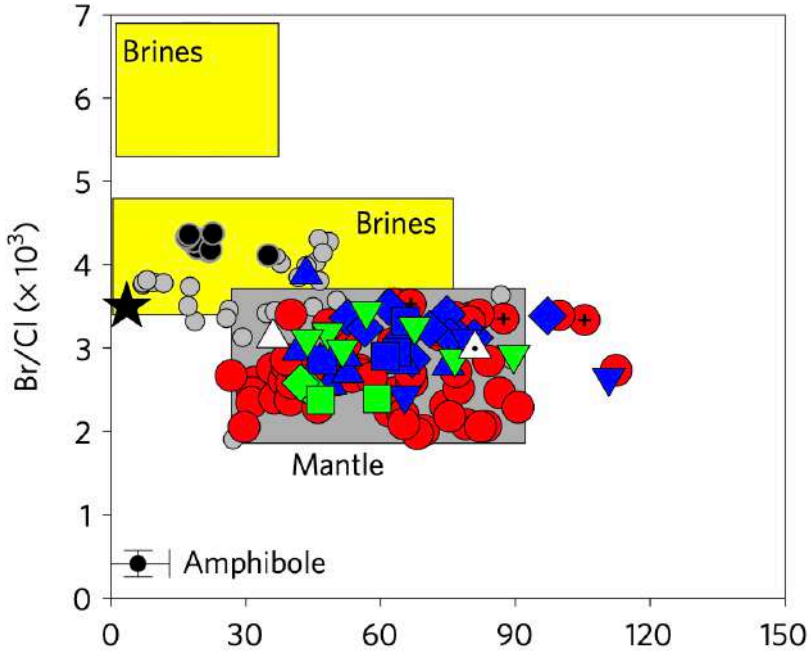


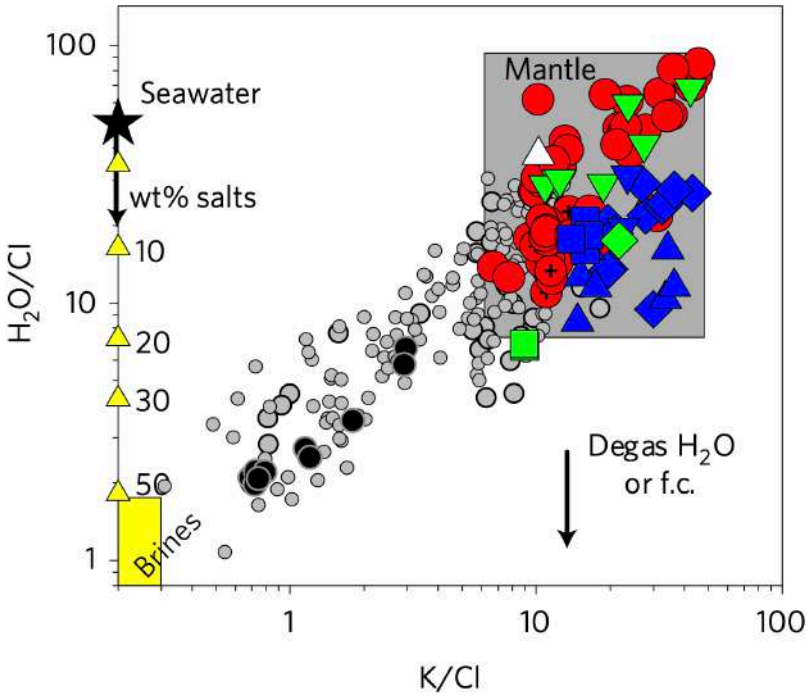
Résultat **= corrélations inter-éléments dans les verres => comportements géochimiques des éléments halogènes**

30 Mai 2022

Verres océaniques: éléments volatils

Rides intra-océaniques et points chauds





Kendrick et al. (2017)

EM
- Pitcairn
- Society
- Samoa
- Reunion

HIMU
- St Helena
- Foundation
- Tuvalu

Hi $^3He/^4He$
- Baffin
- Lau

MORB
- MORB
- Mac. Is.

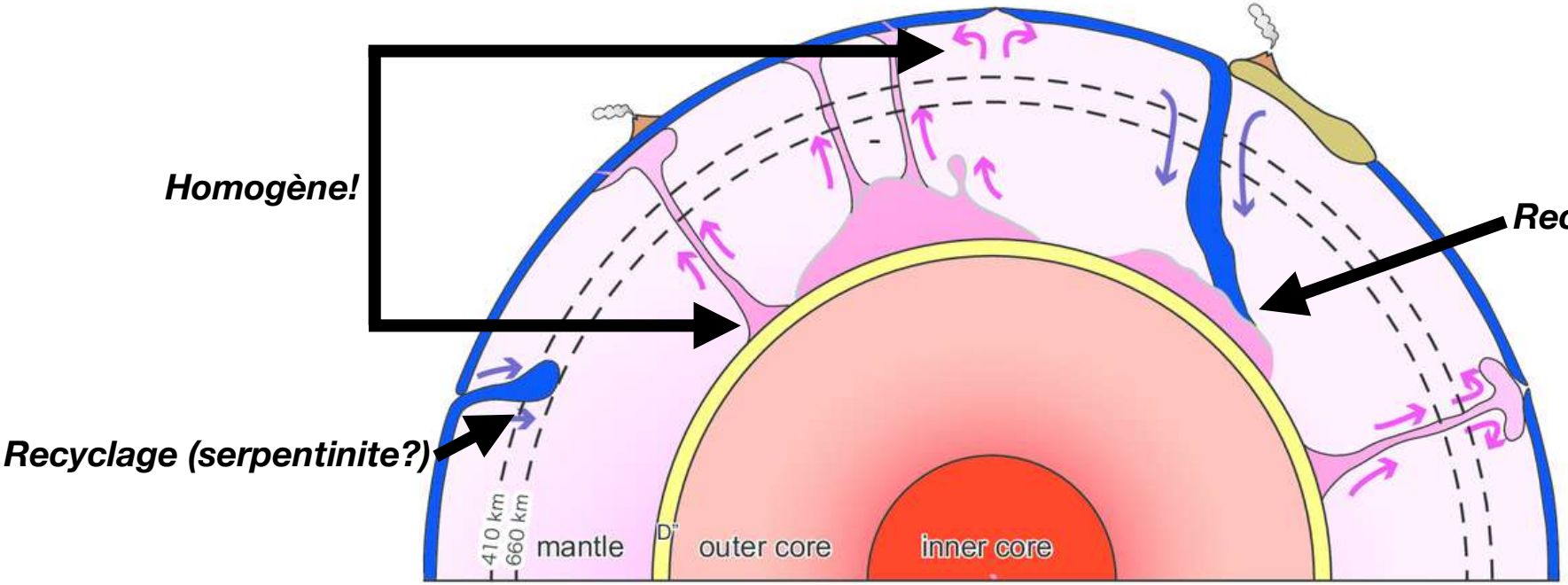
Assimilated SW
- This study + lit.
- Ontong Java
- Seawater-derived brines

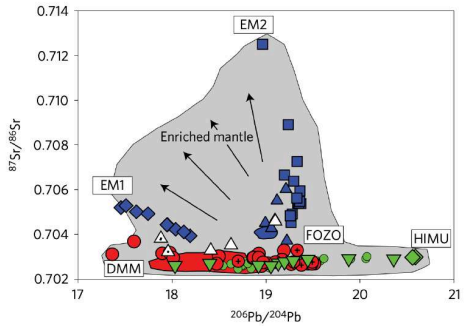
Résultat **= composition homogène du manteau en éléments halogènes => recyclage**

Verres océaniques: éléments volatils

30 Mai 2022

Rides intra-océaniques et points chauds





Implications **= verres océaniques => premières estimations directes de la composition du manteau terrestre en éléments halogènes 'lourds' (Br et I), recyclage profond…**

Verres océaniques: liens redox-volatils

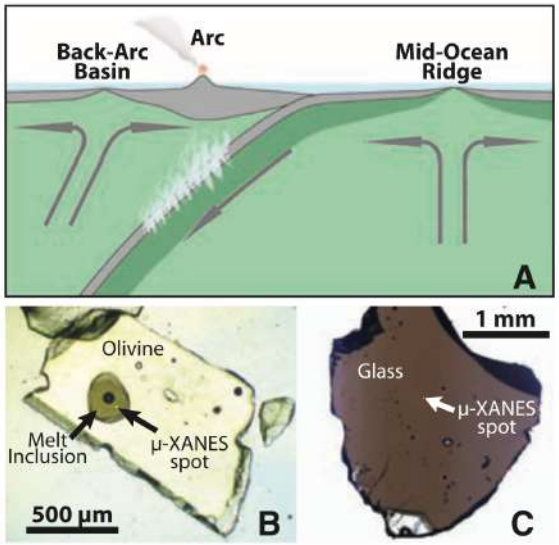
30 Mai 2022

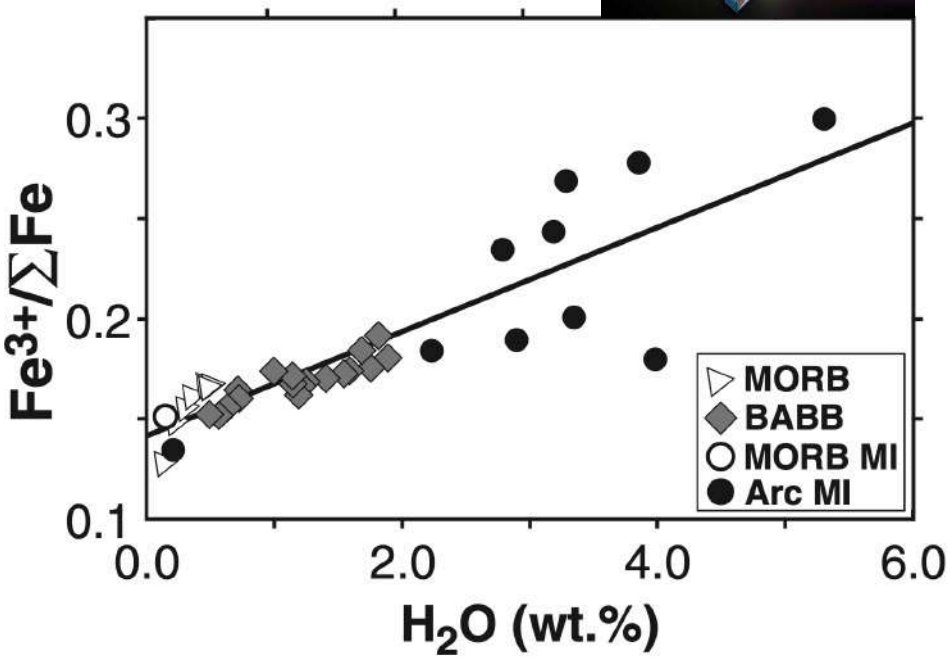
Zones de subduction

Water and the Oxidation State of Subduction Zone Magmas

Katherine A. Kelley[1]*† and Elizabeth Cottrell[2]*

Kelley and Cottrell (2009)





Résultat **= lien redox-processus de fusion aux zones de subduction**

Verres océaniques: liens volatils-redox

30 Mai 2022

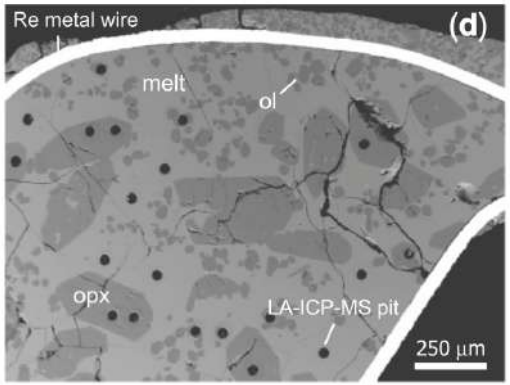
Zones de subduction

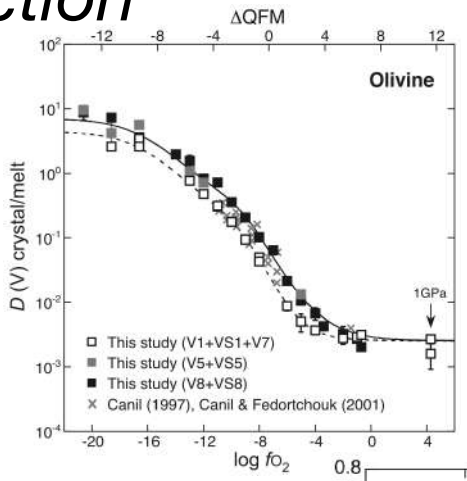
JOURNAL OF PETROLOGY | VOLUME 50 | NUMBER 9 | PAGES 1765–1794 | 2009 | doi:10.1093/petrology/egp053

The Crystal/Melt Partitioning of V during Mantle Melting as a Function of Oxygen Fugacity Compared with some other Elements (Al, P, Ca, Sc, Ti, Cr, Fe, Ga, Y, Zr and Nb)

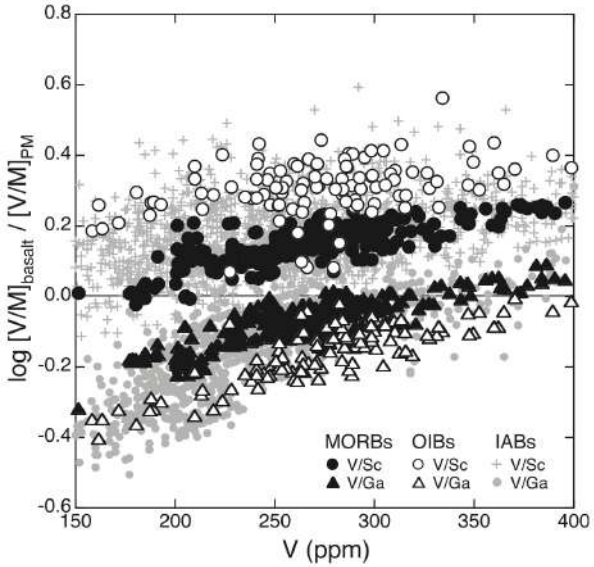
GUILHERME MALLMANN* AND HUGH St. C. O'NEILL

Mallmann and O'Neill (2009)





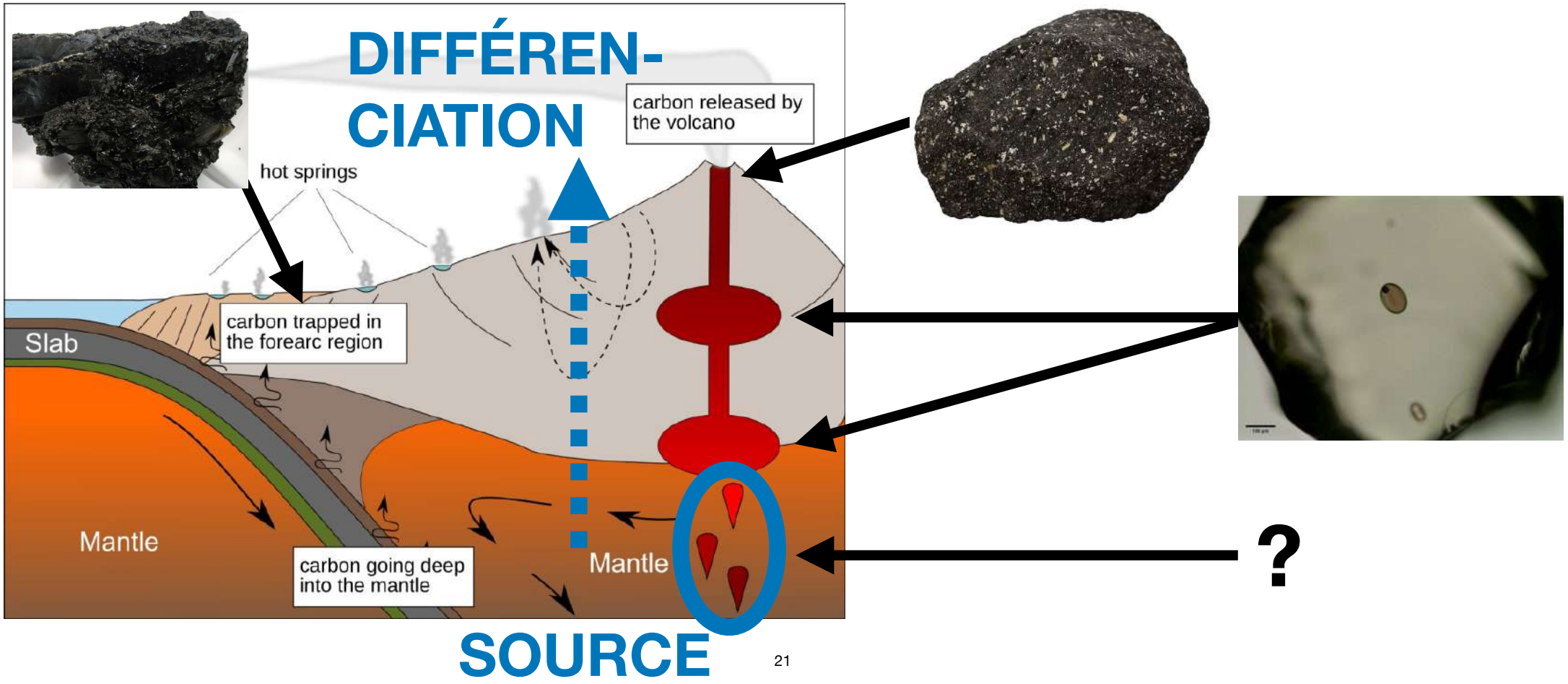
Résultat expérimentaux = **partage des éléments multivalents (ex. V) lors de la fusion/cristallisation => redox MORB = redox ZS**



Verres océaniques: liens volatils-redox

30 Mai 2022

Zones de subduction: toujours la même problématique…

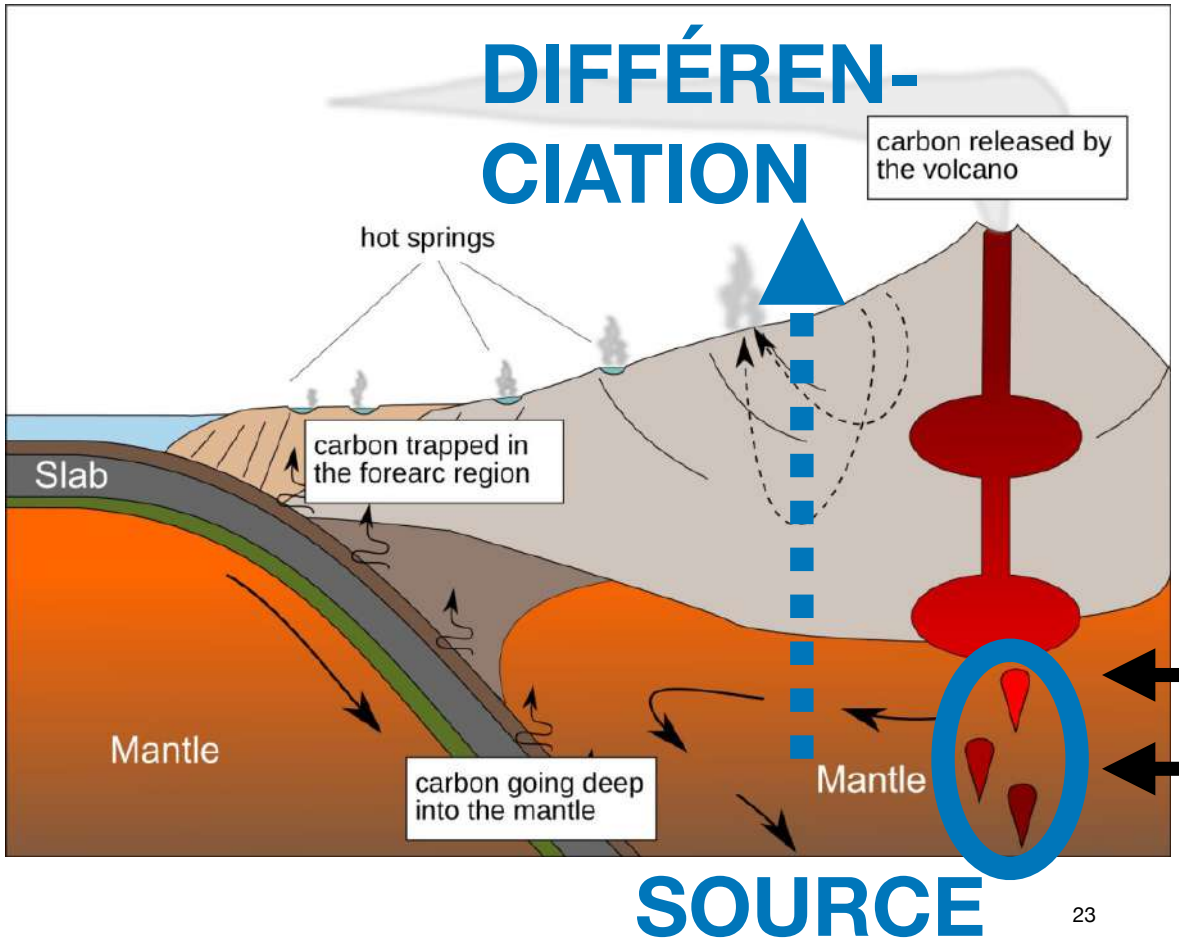


Partie 2:

Verres ‘mantelliques’ (dont les inclusions vitreuses)

Verres ‘mantelliques’

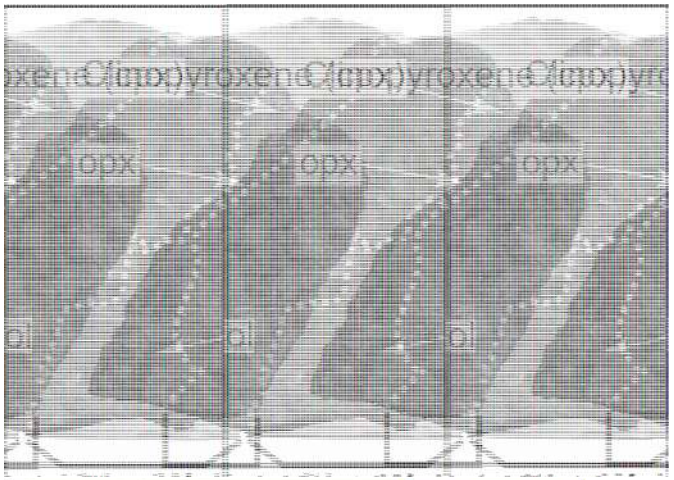
Zones de subduction: un accès à la source?



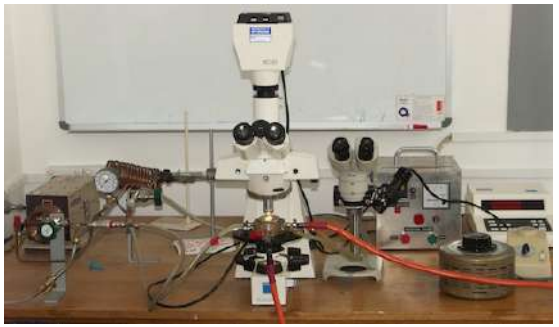
Xénolithe du manteau lithosphérique (roche grenue, holocristalline?)

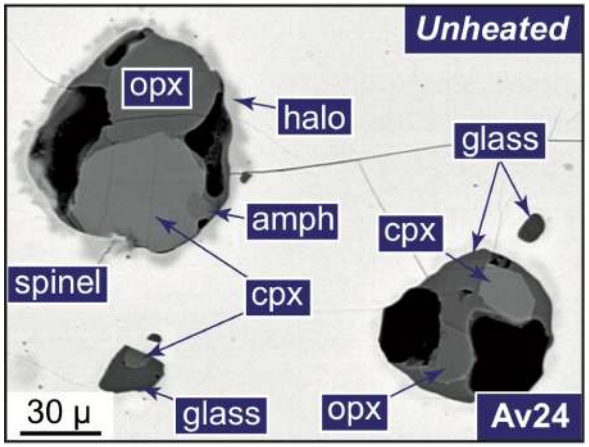
Verres ‘mantelliques’: nature des liquides

30 Mai 2022



Manteau ZS ‘percolé’





Bénard et al. (2016)

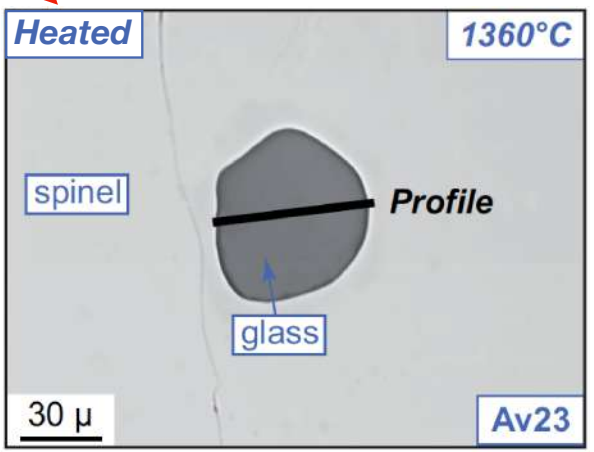
JOURNAL OF PETROLOGY

Journal of Petrology, 2016, Vol. 57, No. 10, 1955–1982
doi: 10.1093/petrology/egw066
Original Article

OXFORD

Primary Silica-rich Picrite and High-Ca Boninite Melt Inclusions in Pyroxenite Veins from the Kamchatka Sub-arc Mantle

A. Bénard[1,2]*, O. Nebel[1,2], D. A. Ionov[3], R. J. Arculus[1], N. Shimizu[4] and N. Métrich[5]



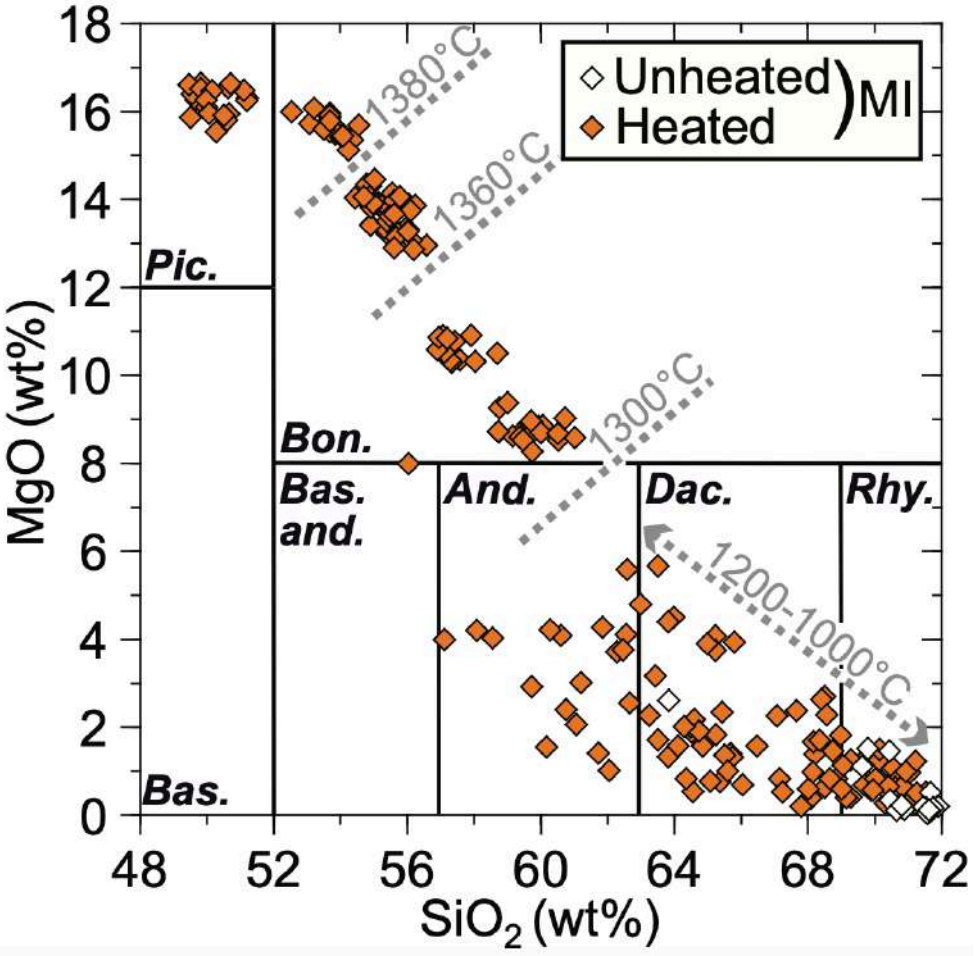
Objet = **inclusions vitreuses à 2 pyroxènes +/- amphibole**

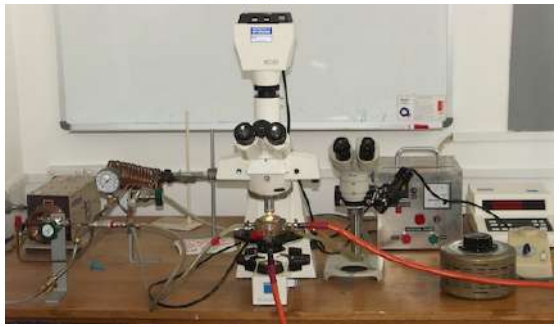
Résultat = **verre homogène**

Verres ‘mantelliques’: nature des liquides

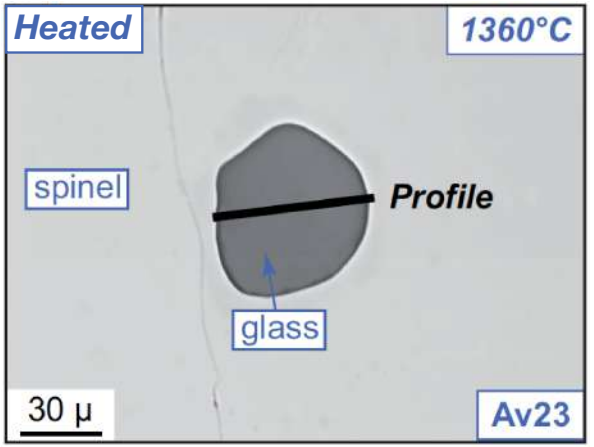
30 Mai 2022

Manteau ZS ‘percolé’





Résultat **= une large gamme de composition au sein d’une même série d’échantillons (différenciation) => magmas primitifs identifiés**



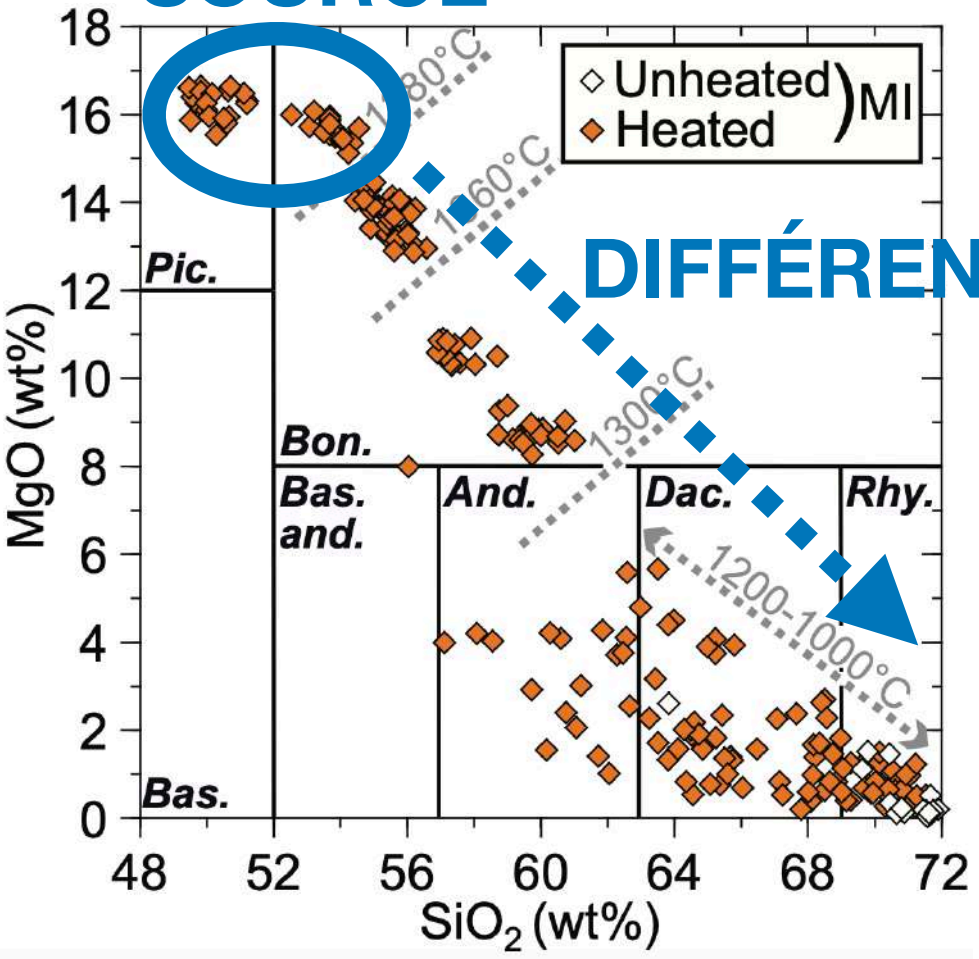
Bénard et al. (2016)

Verres ‘mantelliques’: nature des liquides

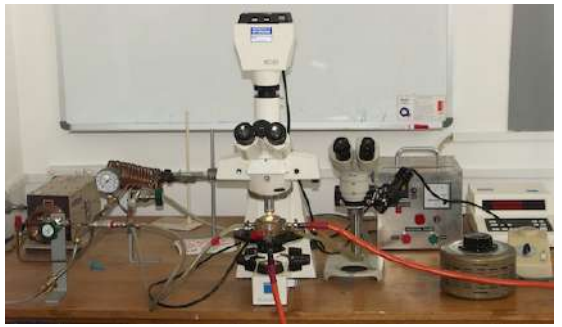
30 Mai 2022

Manteau ZS ‘percolé’

SOURCE



DIFFÉRENCIATION



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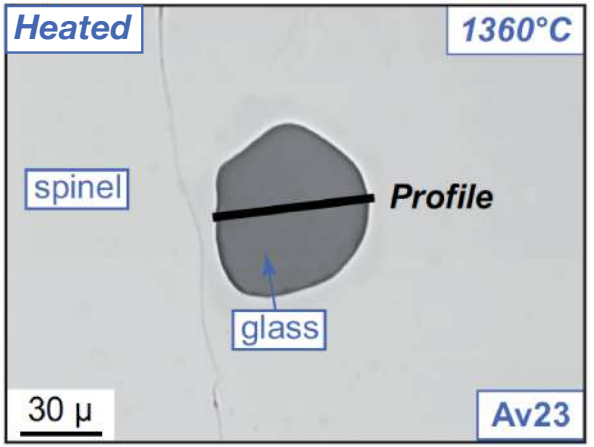
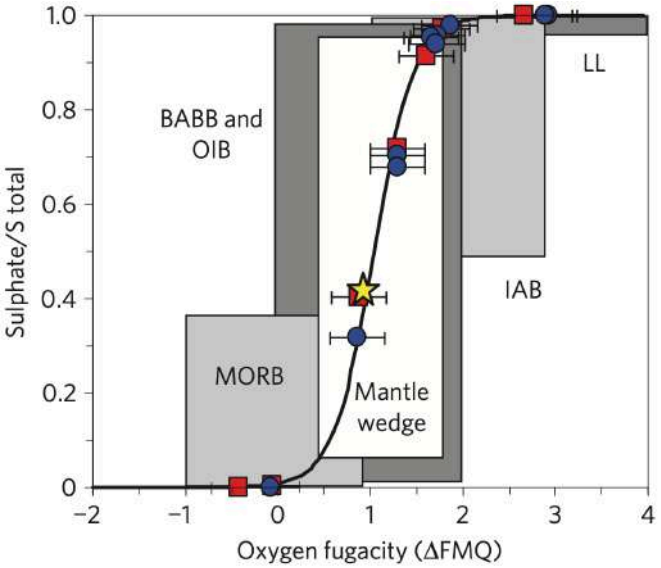


Bénard et al. (2016)

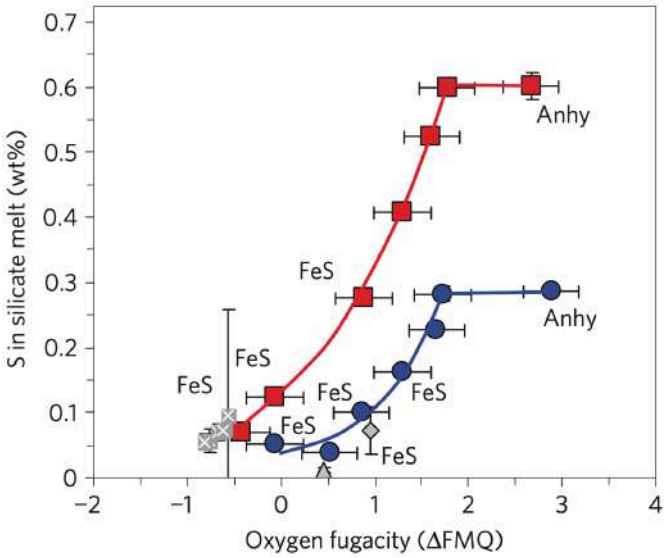
Verres ‘mantelliques’: liens volatils-redox

30 Mai 2022

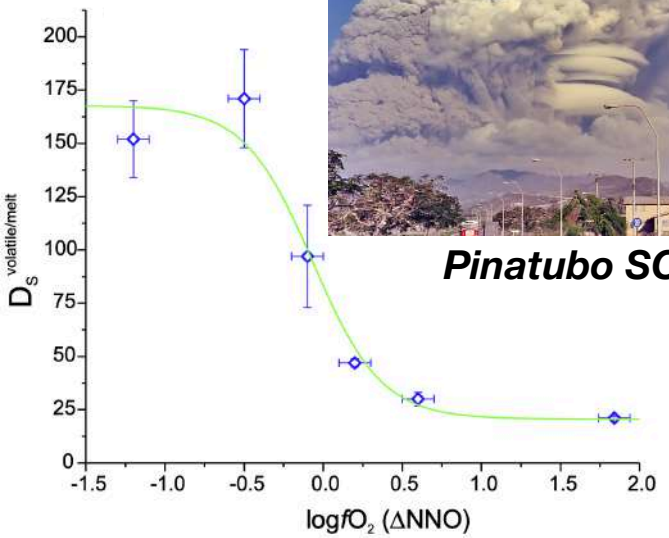
Manteau ZS ‘percolé’



Botcharnikov et al. (2011)



Pinatubo SO_2 (1991)



Zajacz et al. (2012)

Enjeu = **les conditions redox contrôlent la spéciation du soufre et donc sa solubilité dans les liquides silicatés saturés ou son partage fluide/liquide => impact sur le transport, le dégazage…**

Verres ‘mantelliques’: liens volatils-redox

30 Mai 2022

Manteau ZS ‘percolé’

nature COMMUNICATIONS

ARTICLE

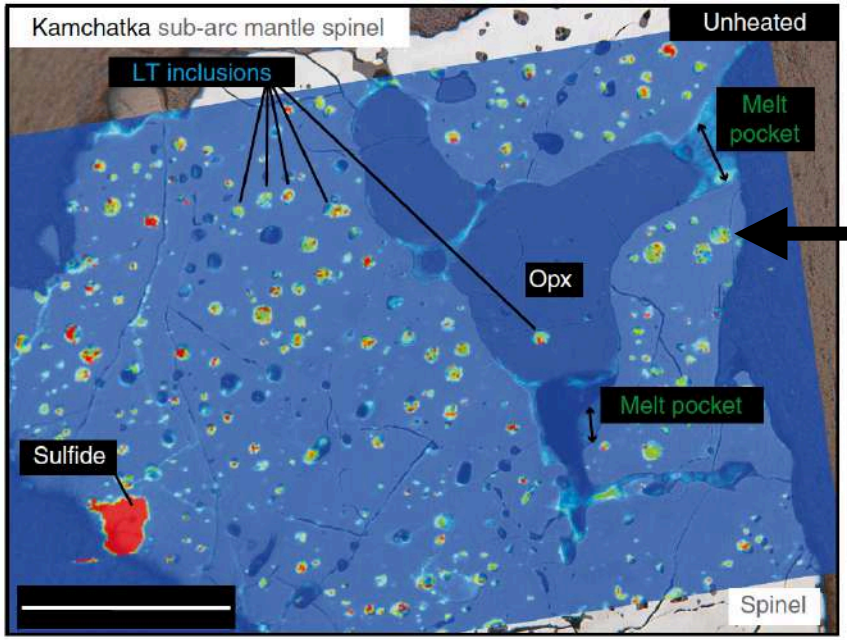
DOI: 10.1038/s41467-018-05804-2 OPEN

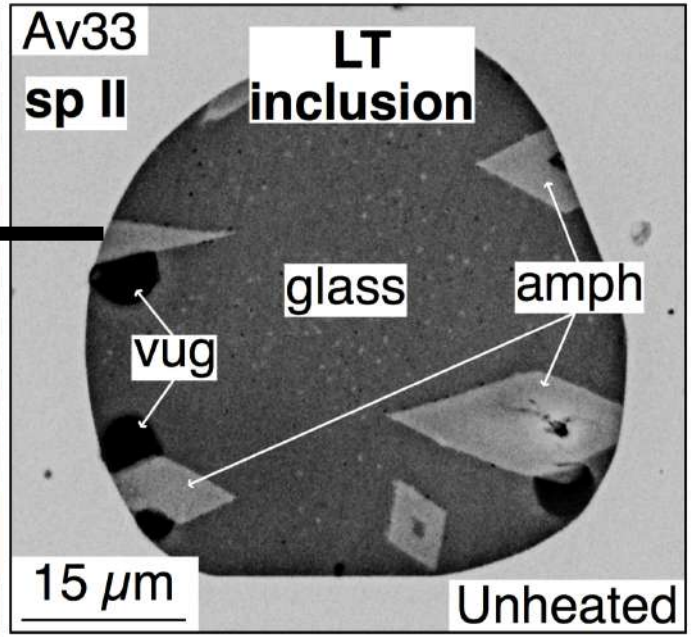
Oxidising agents in sub-arc mantle melts link slab devolatilisation and arc magmas

Antoine Bénard[1,2,10], Kevin Klimm[3], Alan B. Woodland[3], Richard J. Arculus[1], Max Wilke[4], Roman E. Botcharnikov[5,6], Nobumichi Shimizu[7], Oliver Nebel[2], Camille Rivard[8] & Dmitri A. Ionov[9]

Bénard et al. (2018)

Objet = **inclusions vitreuses à amphibole**





Verres ‘mantelliques’: liens volatils-redox

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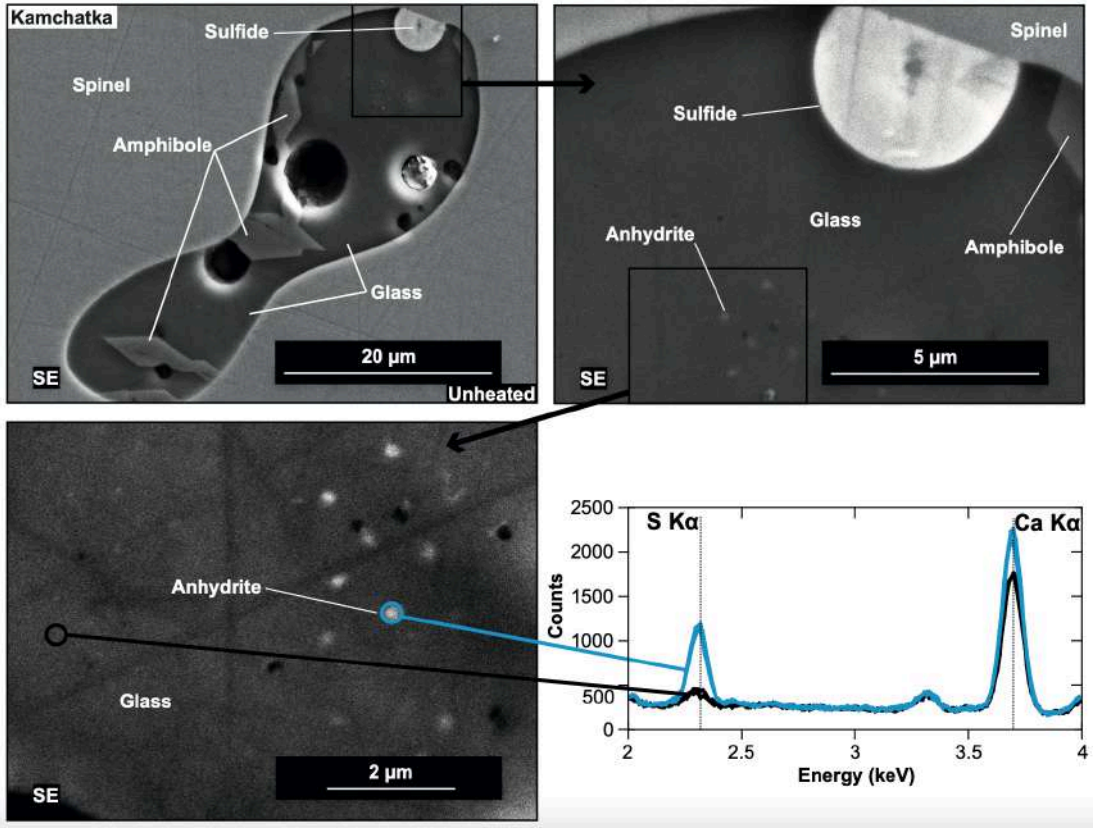
Bénard et al. (2018)



Résultat = **présence de sulfates (S^{6+}), sous la forme de microcristaux d’anhydrite ($CaSO_4$) dans le verre**

Université de Lausanne

Verres ‘mantelliques’: liens volatils-redox

30 Mai 2022

Manteau ZS ‘percolé’

University of Colorado Boulder

nature COMMUNICATIONS

ARTICLE

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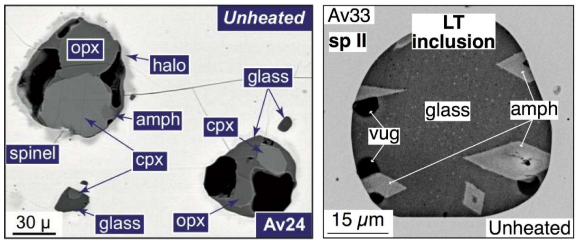
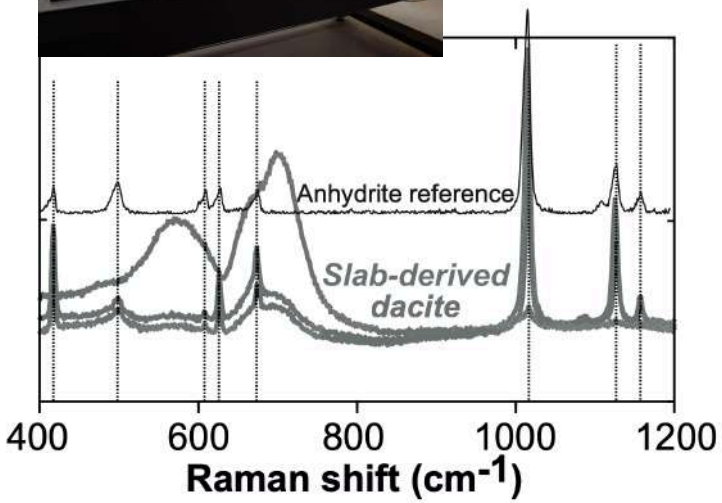
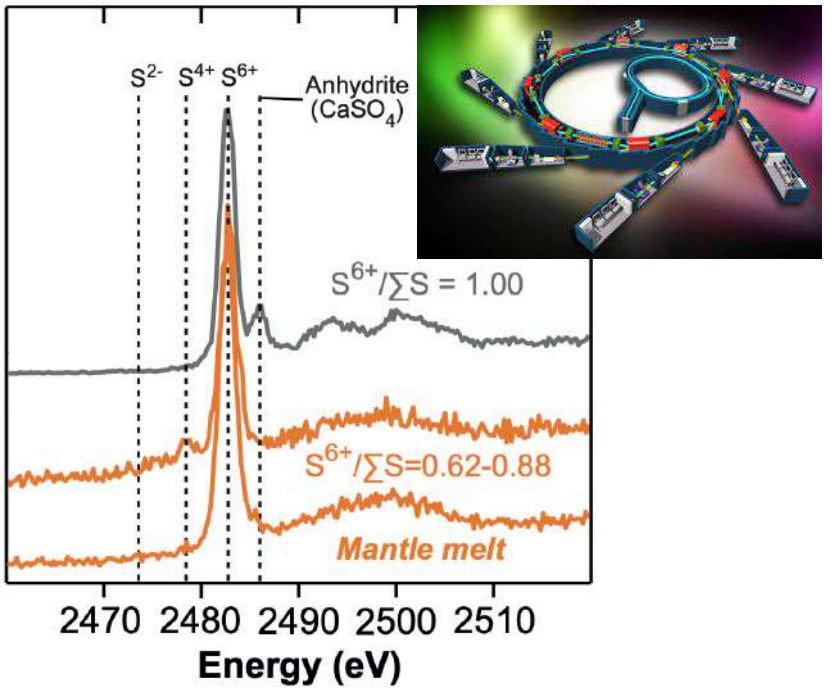
Bénard et al. (2018)







Résultat = **présence de sulfates (S^{6+}), sous forme cristalline (anhydrite) ET dissoute dans le verre**

Verres ‘mantelliques’: liens volatils-redox

30 Mai 2022

Manteau ZS ‘percolé’

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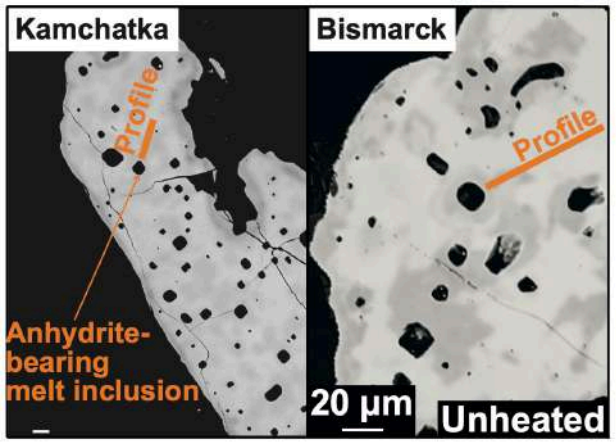
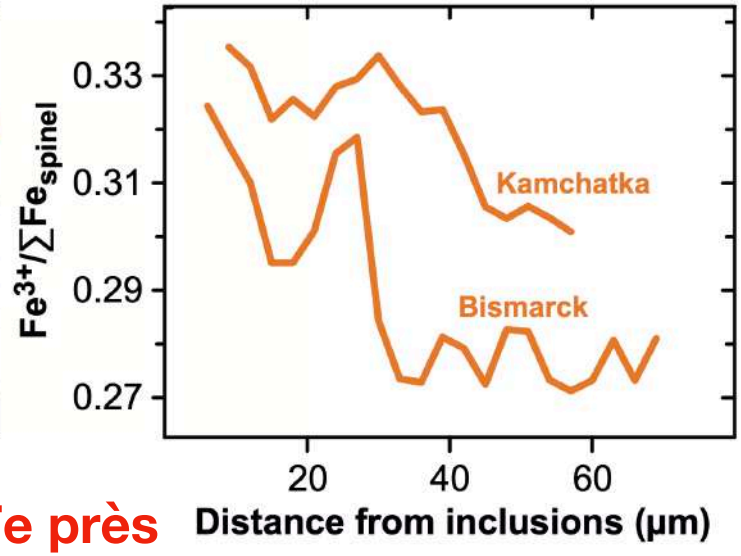
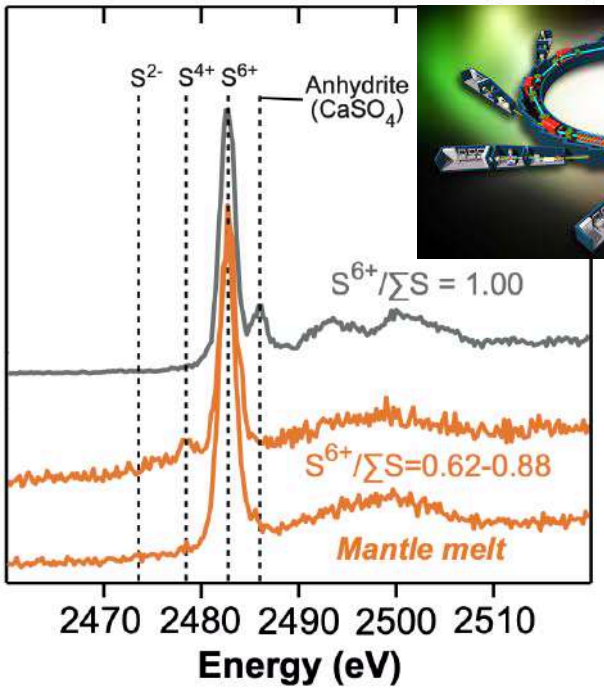
Bénard et al. (2018)

JEOL Hyperprobe







Résultat **= oxidation du Fe près des inclusions vitreuses**

Verres ‘mantelliques’: liens volatils-redox

30 Mai 2022

Manteau ZS ‘percolé’

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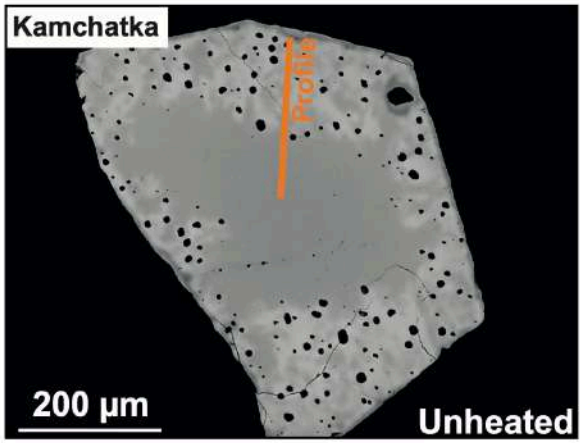
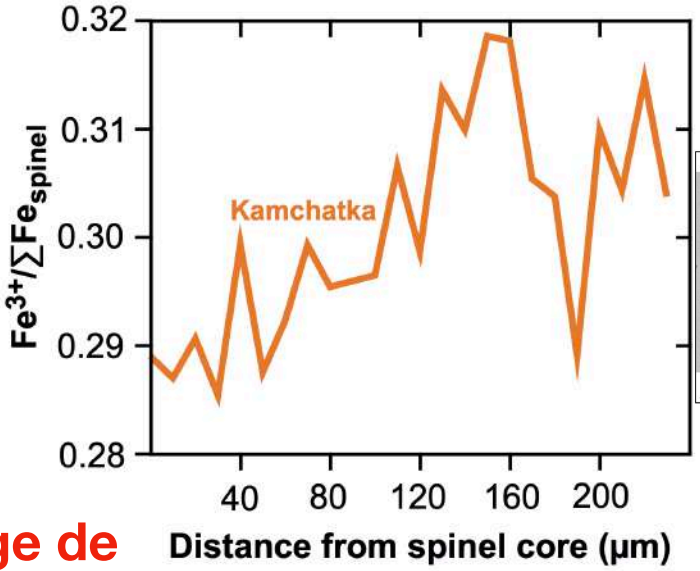
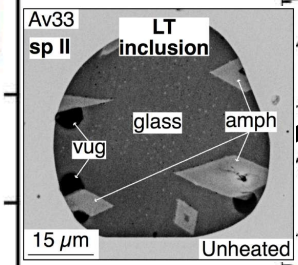
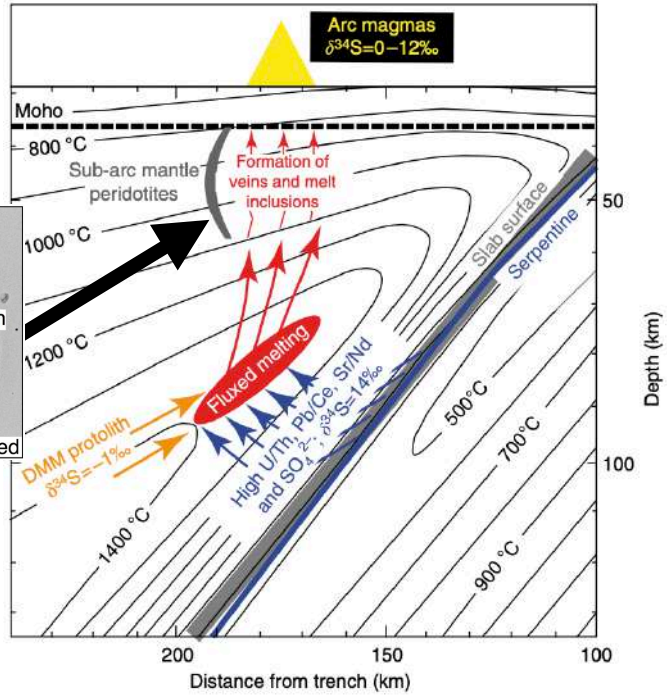
Bénard et al. (2018)

$$H_2SO_{4(m)} + 9FeO_{(m)} = FeS_{(m)} + 4Fe_2O_{3(m)} + H_2O_{(m)}$$









Implication **= recyclage de sulfates (S^{6+}) dans le manteau**

IPGP Université Paris Cité

30 Mai 2022

Messages

Verres océaniques: composition en éléments volatils du manteau asthénosphérique, histoire du recyclage et conditions redox

Verres ‘mantelliques’: nature et composition des sources mantelliques et liens redox-volatils aux ZS

Verres océaniques: conditions redox

30 Mai 2022

Rides intra-océaniques

Geochimica et Cosmochimica Acta, Vol. 69, No. 3, pp. 711–725, 2005

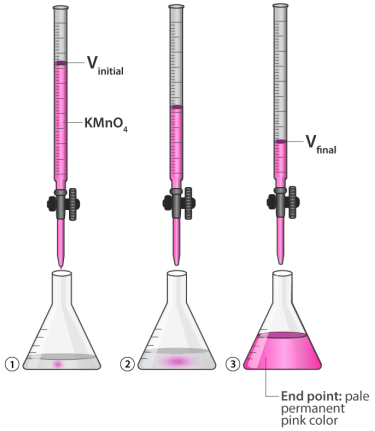
0016-7037/05 $30.00 + .00

doi:10.1016/j.gca.2004.07.026

The $Fe^{3+}/\Sigma Fe$ ratios of MORB glasses and their implications for mantle melting

Antoine Bézos*† and Eric Humler
Laboratoire des Géosciences Marines-IPGP, case 89, 4 place Jussieu, 75252 Paris, France

Bézos and Humler (2005)
=> chimie en phase liquide+titration



Earth and Planetary Science Letters 305 (2011) 270–282

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

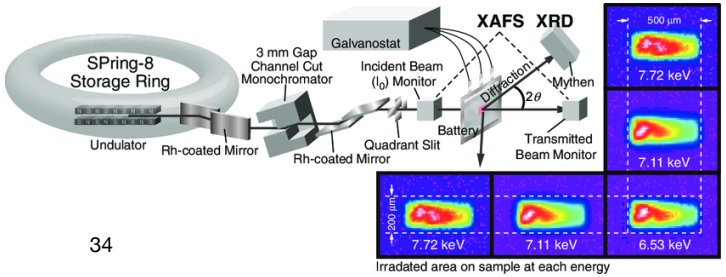
journal homepage: www.elsevier.com/locate/epsl

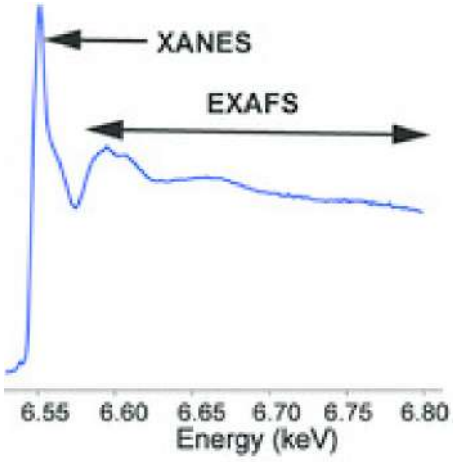
The oxidation state of Fe in MORB glasses and the oxygen fugacity of the upper mantle

Elizabeth Cottrell [a,*], Katherine A. Kelley [b]

Cottrell and Kelley (2011) => XANES

ESRF (France)





Verres océaniques: conditions redox

30 Mai 2022

Rides intra-océaniques

Earth and Planetary Science Letters 483 (2018) 114–123

Contents lists available at ScienceDirect

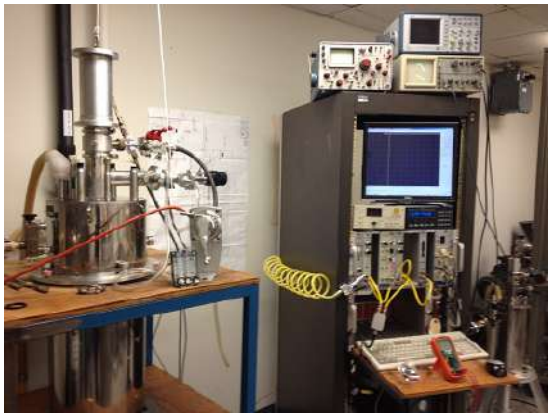
Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

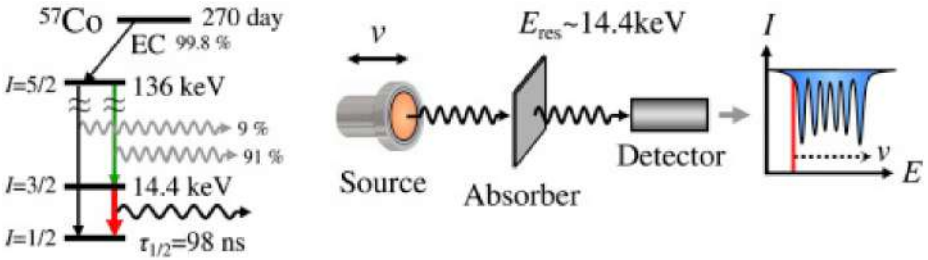
A re-assessment of the oxidation state of iron in MORB glasses

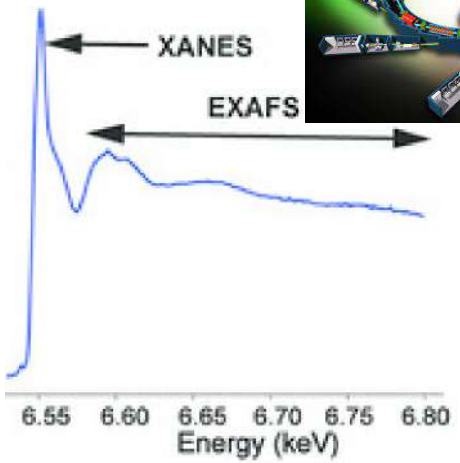
Andrew J. Berry [a,b,*], Glen A. Stewart [c], Hugh St.C. O'Neill [a], Guilherme Mallmann [a], J. Fred W. Mosselmans [d]

Berry et al. (2018)



University of Idaho





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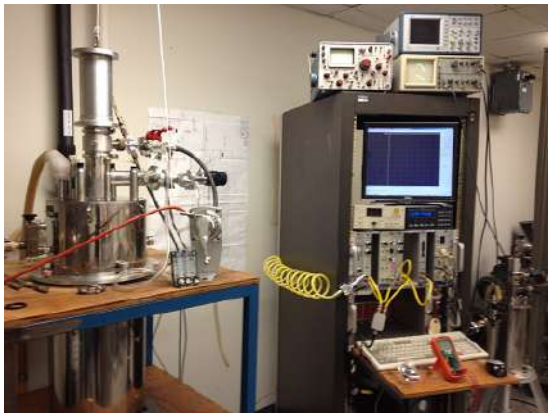
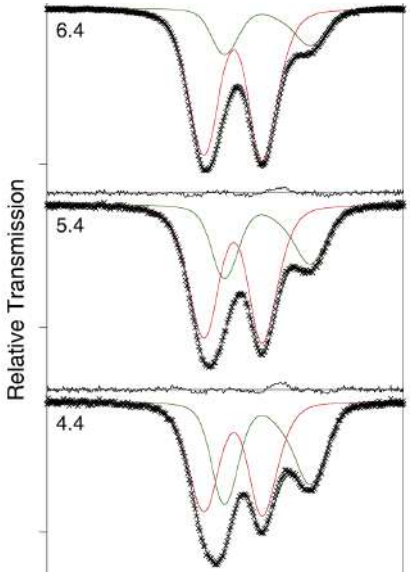
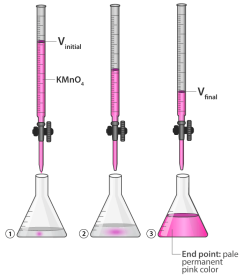
Berry et al. (2018) => XANES

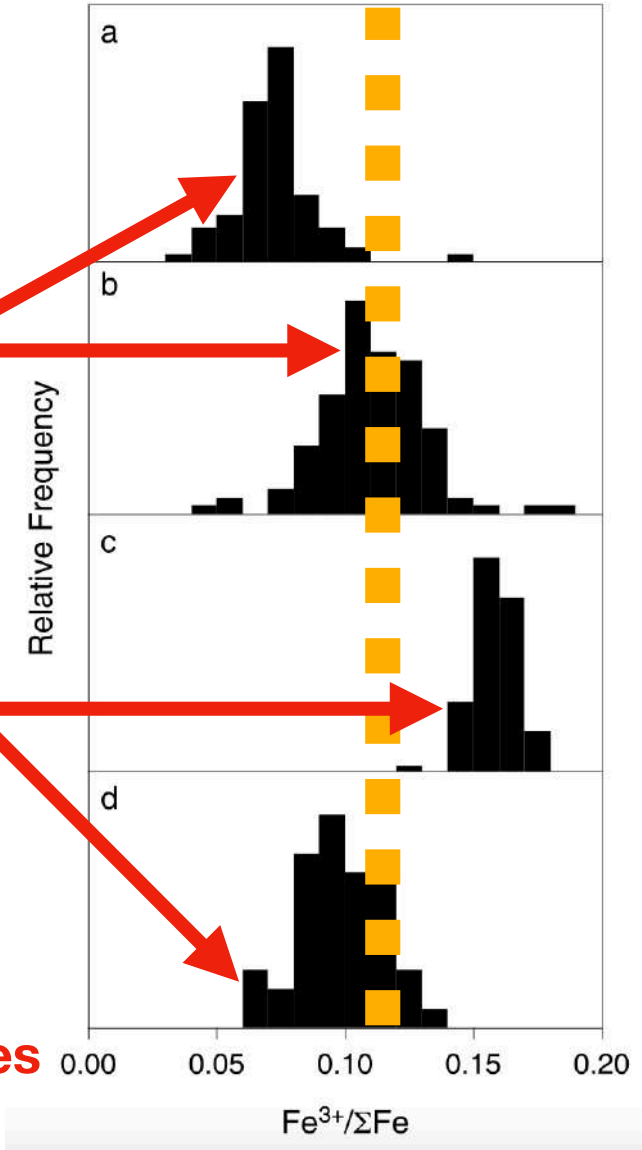


University of Idaho





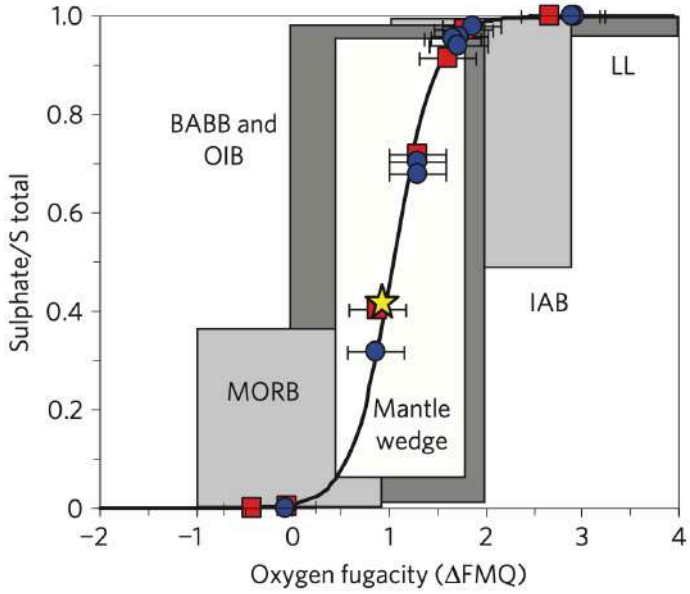
Résultat **= verres océaniques => évaluation de différentes techniques analytiques**



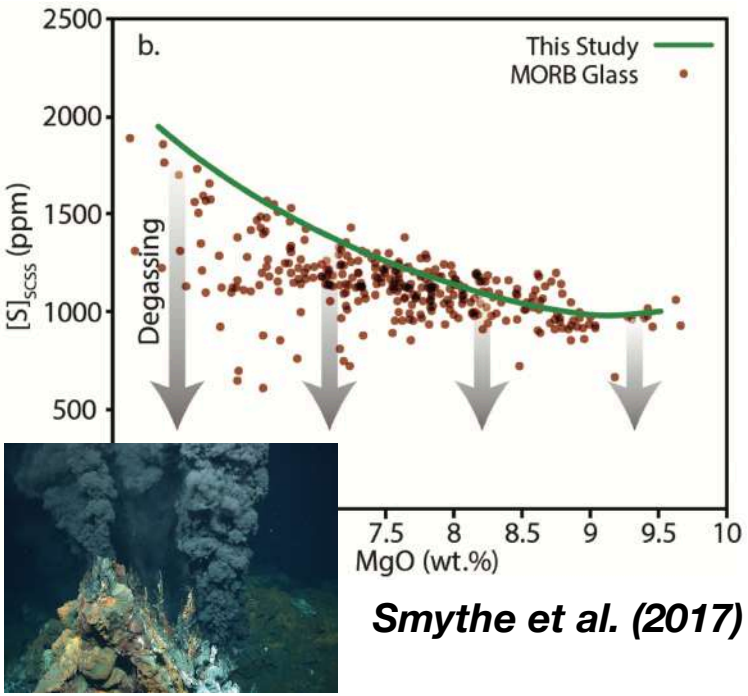
Verres océaniques: liens redox-volatils

30 Mai 2022

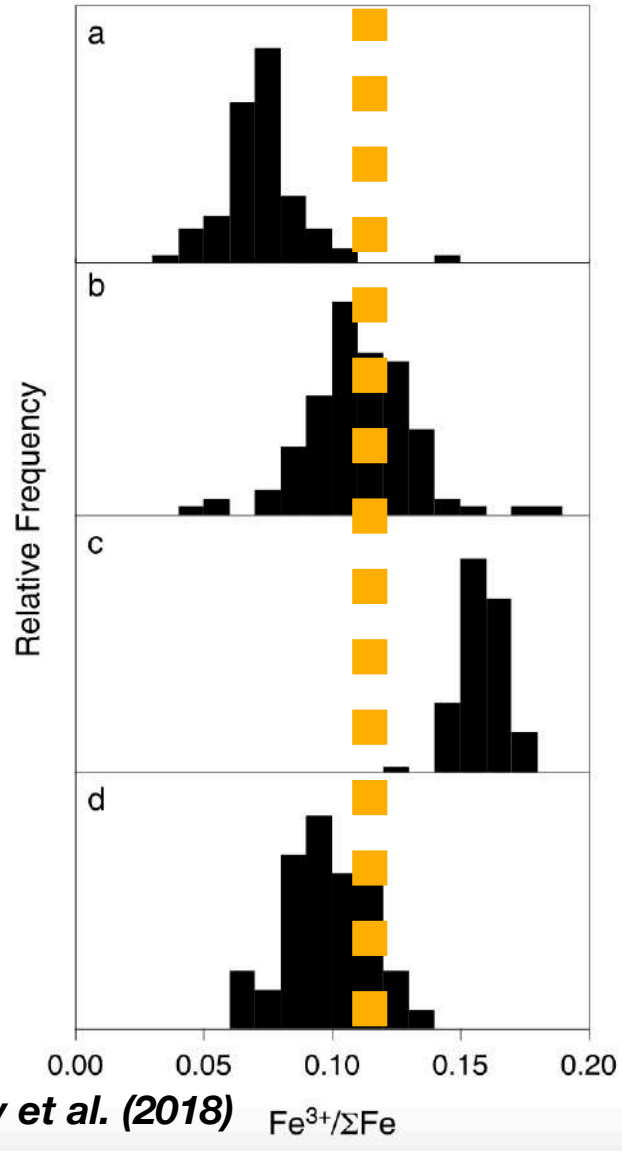
Rides intra-océaniques



Botcharnikov et al. (2011)



Smythe et al. (2017)



Berry et al. (2018)

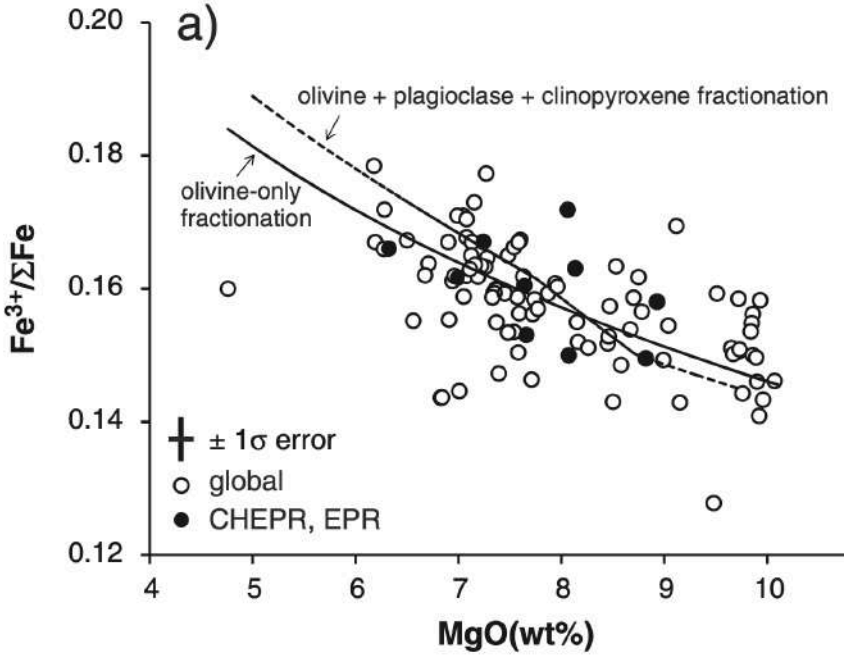
Implications **= verres océaniques => estimation directe de l'état d'oxydation du manteau asthénosphérique 'appauvri', solubilité et transport du soufre, métallogénie…**

Verres océaniques: liens volatils-redox

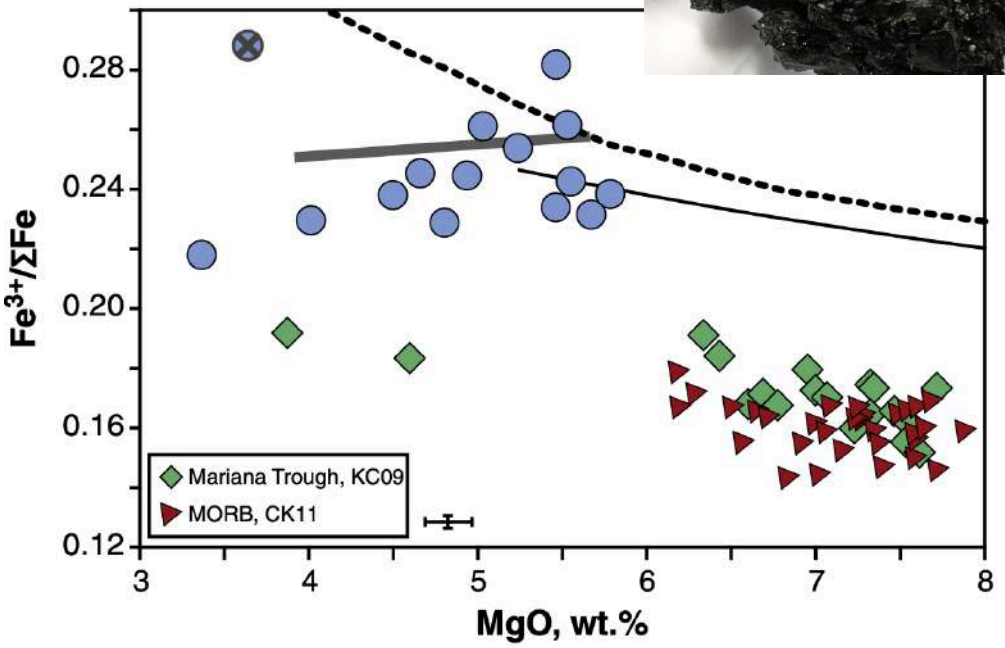
30 Mai 2022

Zones de subduction

Cottrell and Kelley (2011)



Kelley and Cottrell (2012)



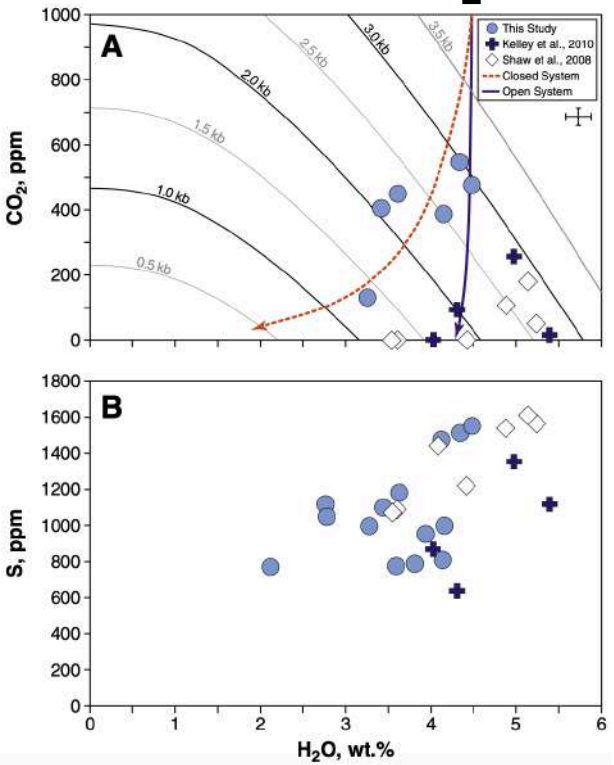
?

Problème = **différenciation par cristallisation fractionnée affecte Fe^{3+}/Fe_{tot} => quelle composition pour les liquides primaires de ZS?**

Verres océaniques: liens volatils-redox

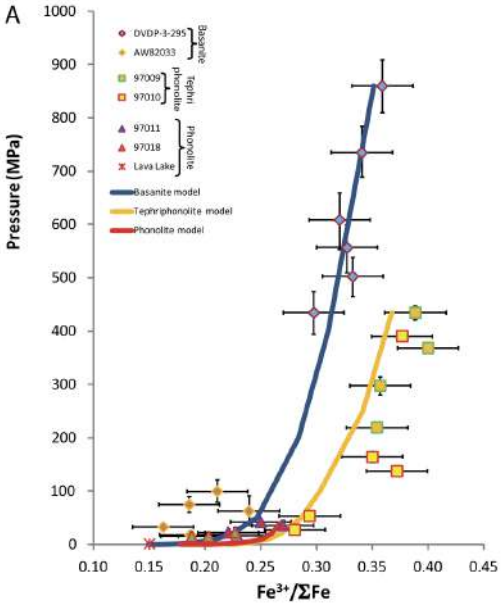
30 Mai 2022

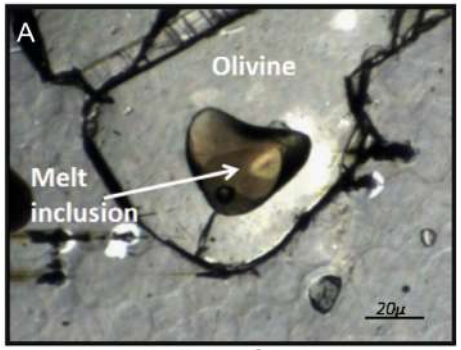
?

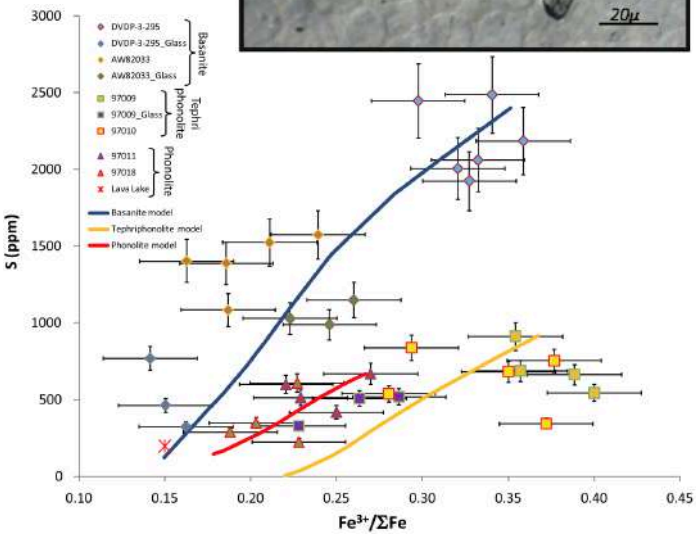


Kelley and Cottrell (2012)

Zones de subduction







Moussallam et al. (2014)

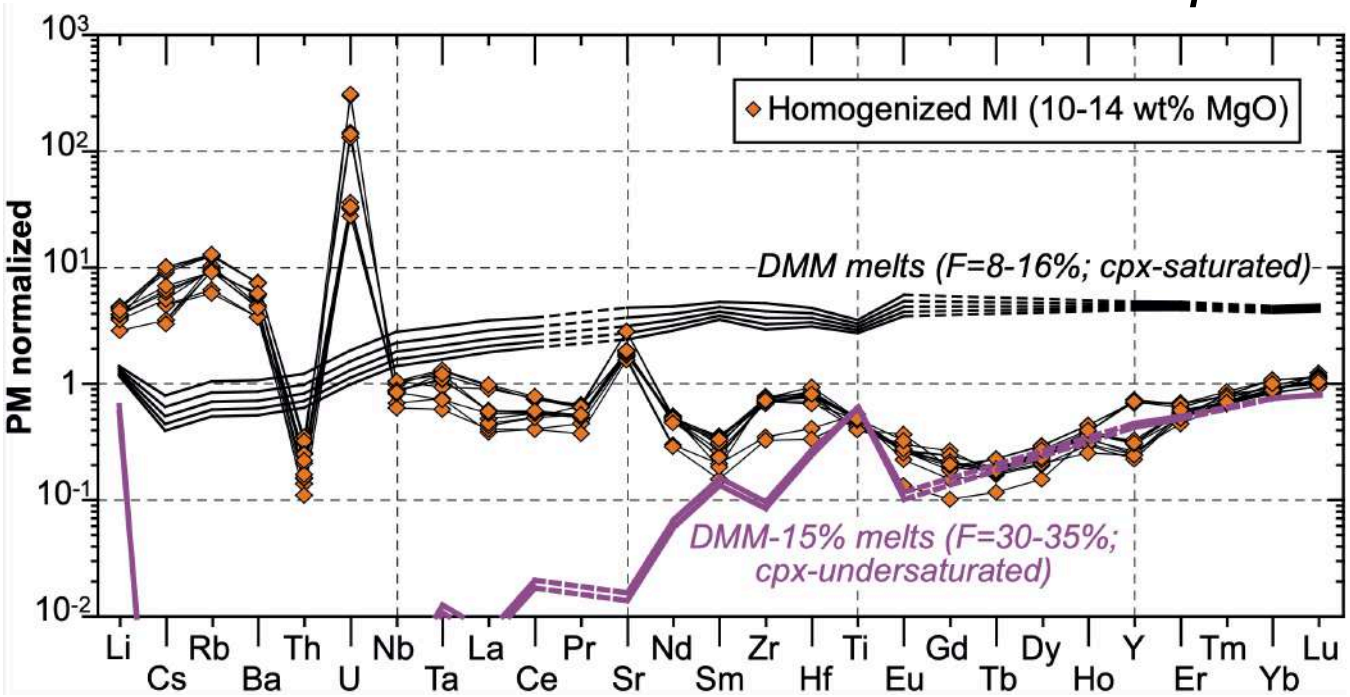
$$S^{2-}_{(melt)} + Fe^{3+}_{2}O_{3(melt)} = SO_{2(gas)} + 6Fe^{2+}O_{(melt)} + O^{2-}_{(melt)}$$

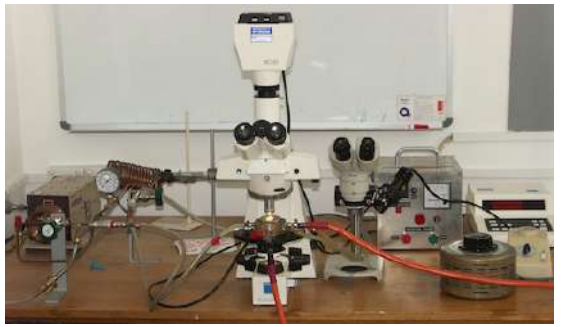
Problème **= dégazage affecte Fe^{3+}/Fe_{tot} => quelle spéciation pour les éléments volatils (et conditions redox) dans les liquides primaires de ZS?**

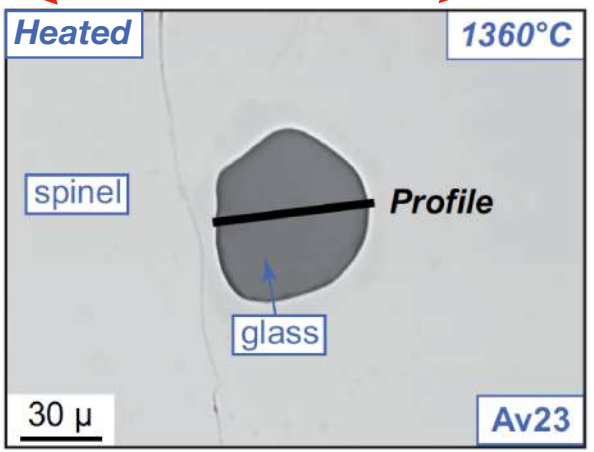
Verres ‘mantelliques’: nature des liquides

30 Mai 2022

Manteau ZS ‘percolé’







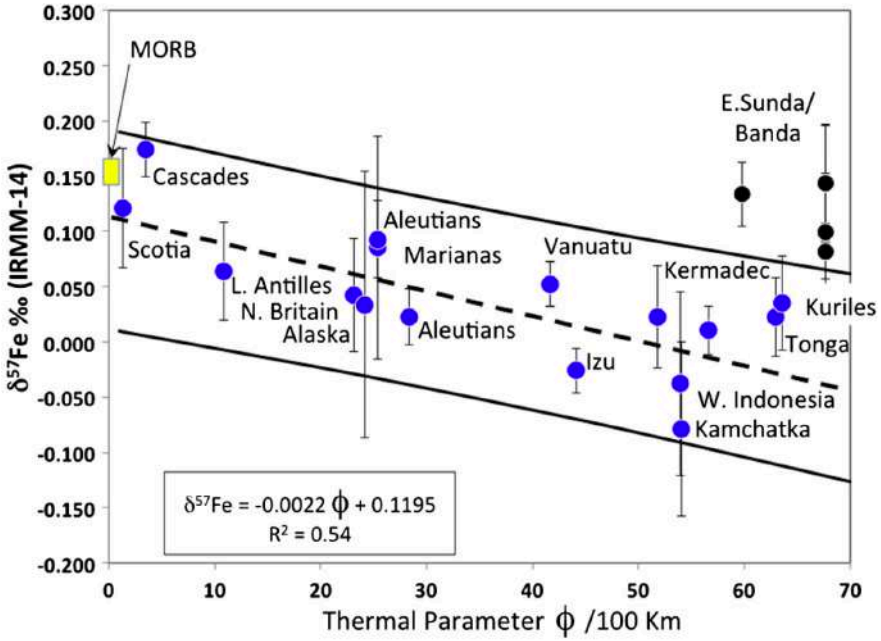
Bénard et al. (2016)

Résultat = **identification de la nature pétrologique et de la composition géochimique (ex. éléments en trace lithophages) de la source de magmas primitifs**

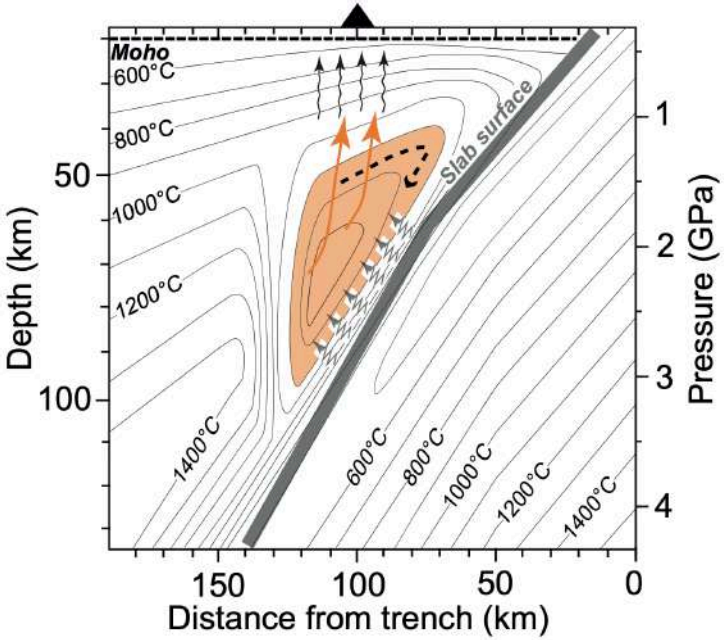
Verres ‘mantelliques’: nature des liquides

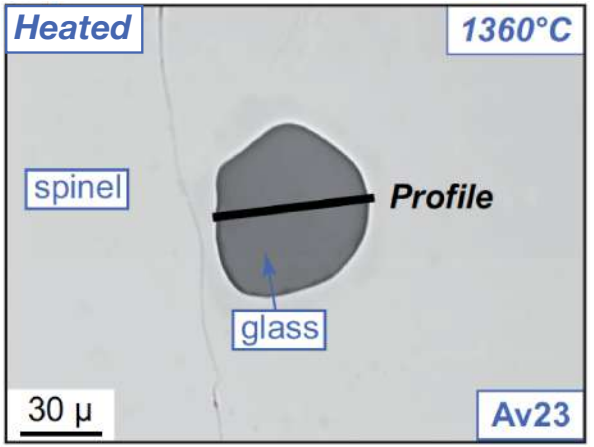
30 Mai 2022

Manteau ZS ‘percolé’



Foden et al. (2018)





Bénard et al. (2016)

Implication **= la source des magmas des zones de subduction est plus appauvrie que celle des MORB => bilans de masse manteau/recyclage…**