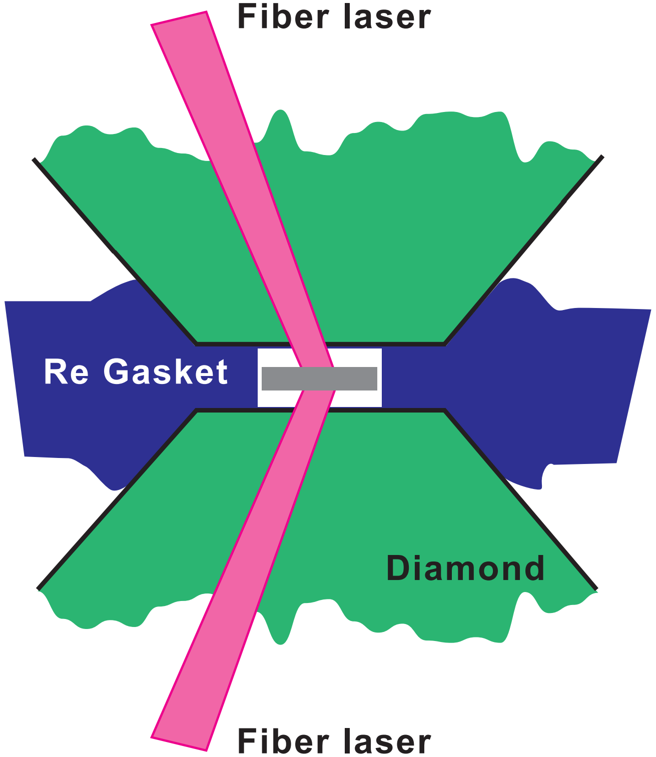
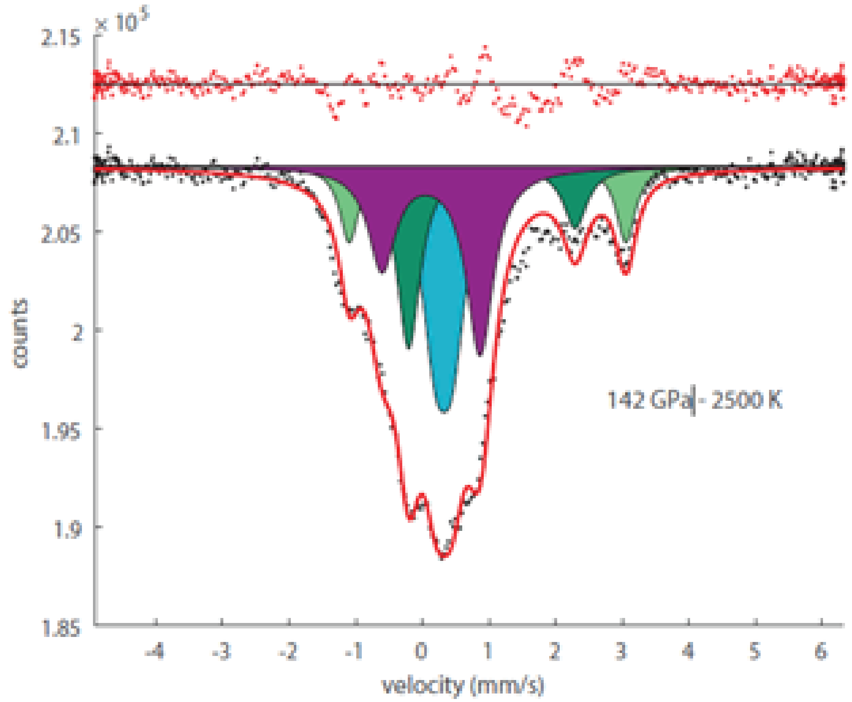
Probing the redox state of the deep primitive mantle using laser heated diamond anvil cell and synchrotron Mossbauer

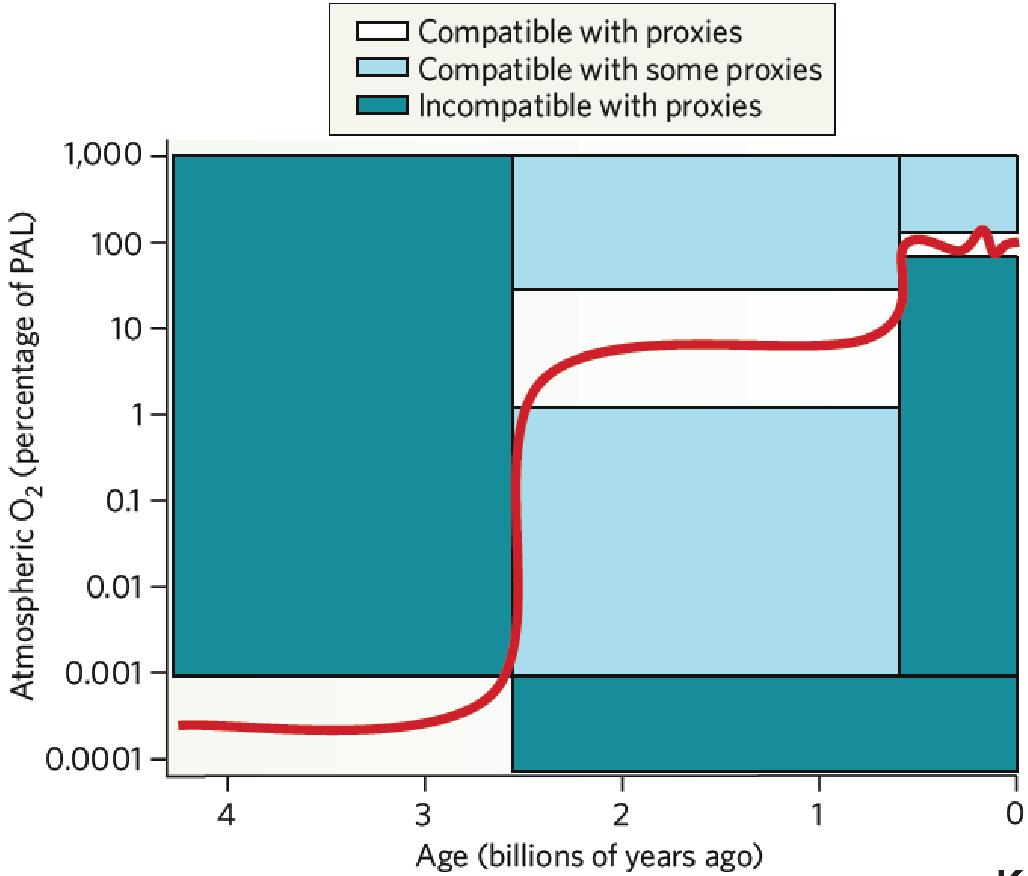
D. Andrault, M. Munoz, G. Pesce, V. Cerantola, A. Chumakov,
I. Kantor, S. Pascarelli, R. Ruffer, L. Hennet



Synchrotron Mossbauer Spectroscopy
ID-18 at ESRF



Could the Great Oxygenation Event (GOE) be correlated with the dynamics of the Earth's interior ?



e.g. Kump, 2008

The proposed model is based on 3 independent ingredients

1

Change in mantle dynamics 2.5 Ga ago

From «stagnant lid» to «plate tectonics»

And many other articles ...

- Condie_Onset-Plate-Tectonic_GF-16.pdf
- Davies_emergence-plate-tectonics_Geol-32.pdf
- Doglioni_asymmetric-mantle-flow-LVZ_GSA616.pdf
- Doglioni_Lithos–asthenos-coupling_PEPI-11.pdf
- ETH-Workshop-2016_Origin-plate-tectonics.pdf
- Foley_Initiation-plate-tectonics_JGR-14.pdf
- Gerya_Plate-Tecto-subduc_Nature-15.pdf
- Gerya_Precambrian-geodynamics_GR-14.pdf
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- Laurent_onset-plate-tectonics_EPSL-14.pdf
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- Moyen_Achaean-tectonic_G-12.pdf
- ONeill_Hadean–archaean geodynamics_EPSL-14.pdf
- Piper_Lid-Tectonics-before-plate_Tecto-13.pdf
- Turner_Start-subduction_Geol-14.pdf
- VanHunen_Archean-Tectonic_AREPS-12.pdf
- Wilde_first-continental-crust_Nature-01.pdf

A planetary perspective on Earth evolution: Lid Tectonics before Plate Tectonics

Tectonophysics, 2013

John D.A. Piper *

Geomagnetism Laboratory, Geology and Geophysics, School of Environmental Sciences, University of Liverpool, Liverpool L69 7ZE, UK

A planet in transition: The onset of plate tectonics on Earth between 3 and 2 Ga?

Geoscience Frontiers, 2016

Kent C. Condie

Department of Earth and Environmental Science, New Mexico Tech, Socorro, NM 87801, USA

The diversity and evolution of late-Archean granitoids: Evidence for the onset of "modern-style" plate tectonics between 3.0 and 2.5 Ga

O. Laurent [a,b,c,*], H. Martin [a,b,c], J.F. Moyen [a,b,c,d], R. Doucelance [a,b,c]

[a] *Clermont Université, Université Blaise Pascal, Laboratoire Magmas et Volcans, BP 10448, F-63000 Clermont-Ferrand, France*
[b] *CNRS, UMR6524, LMV, F-63038 Clermont-Ferrand, France*
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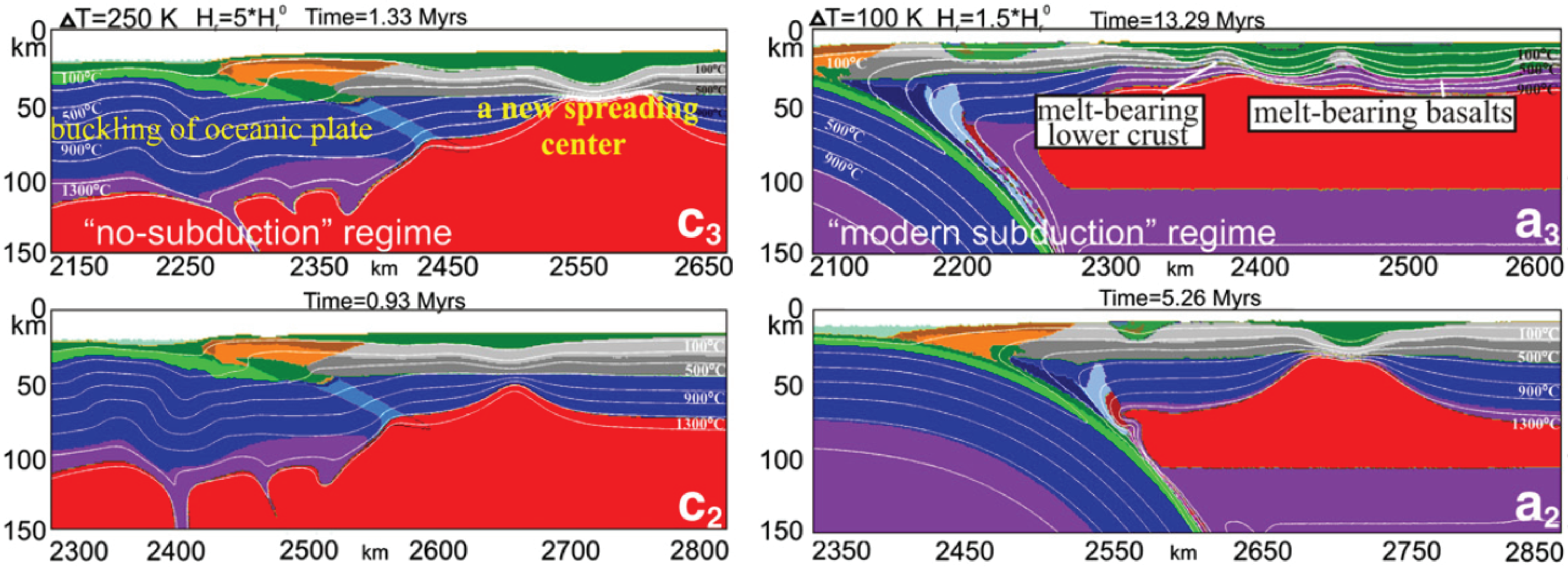
Lithos, 2014

Geodynamical modelling

Sizova et al., 2010

Mantle temperature 250 K above the present day

Mantle temperature 100 K above the present day

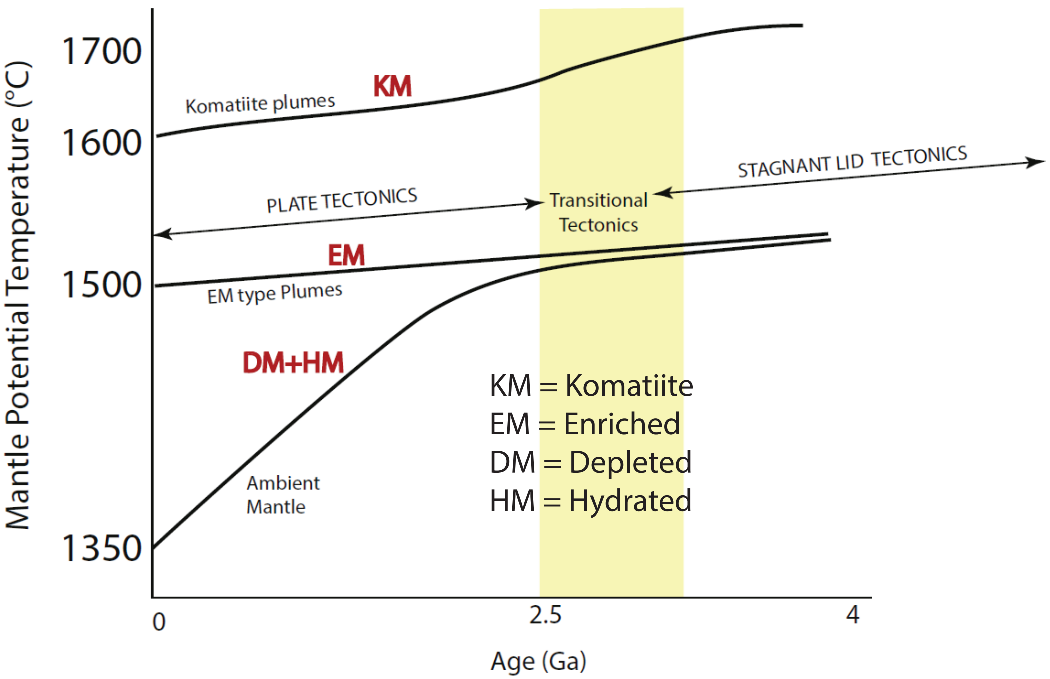


Change of mantle dynamics from «no-subduction» to «Modern subduction» regime with decreasing the mantle potential surface temperature (Tp)

The change in mantle dynamics occurs also occurs ~2.5 Ga ago, like the Great oxygen event

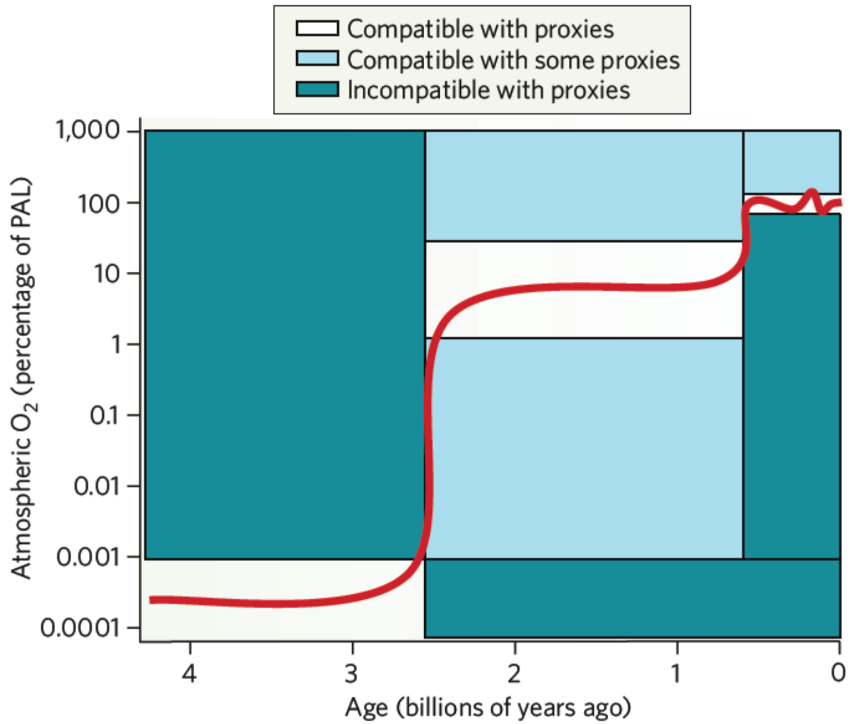
Change in mantle dynamics

e.g. Condie, 2016



Great Oxygenation Event (GOE)

e.g. Kump, 2008



Ingredient

2

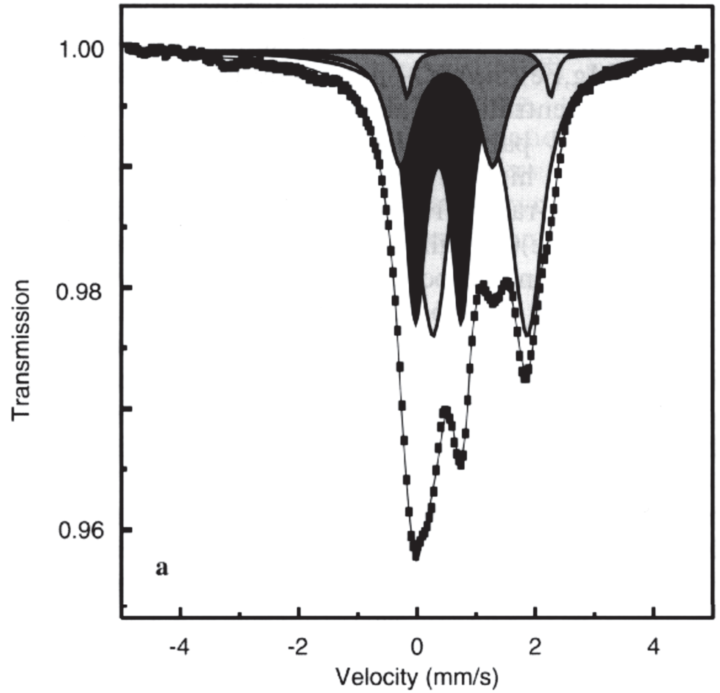
The lower mantle bridgmanite phase $(MgFe)(SiAl)O_3$ can integrate high amount of ferric Fe (3+)

Perovskite as a possible sink for ferric iron in the lower mantle Nature, 1997

Catherine McCammon

Bayerisches Geoinstitut, Universität Bayreuth, D-95440 Bayreuth, Germany

Mossbauer determination of the Fe redox state in quenched bridgmanite samples up to 70% Fe^{3+}, potentially



Recent reports proposed controversial values between 10 and 60% for the true Fe^{3+} content in the bridgmanite in the deep mantle as reviewed by Shim et al., 2017

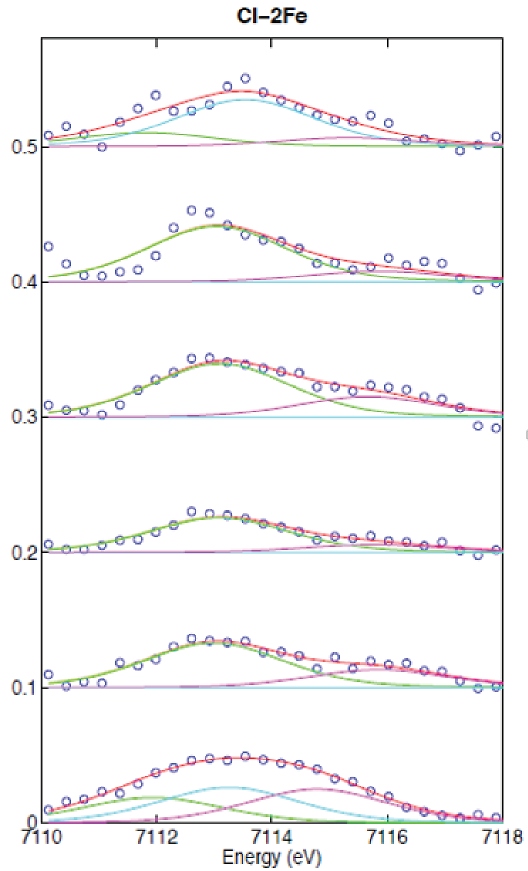
Our new measurements

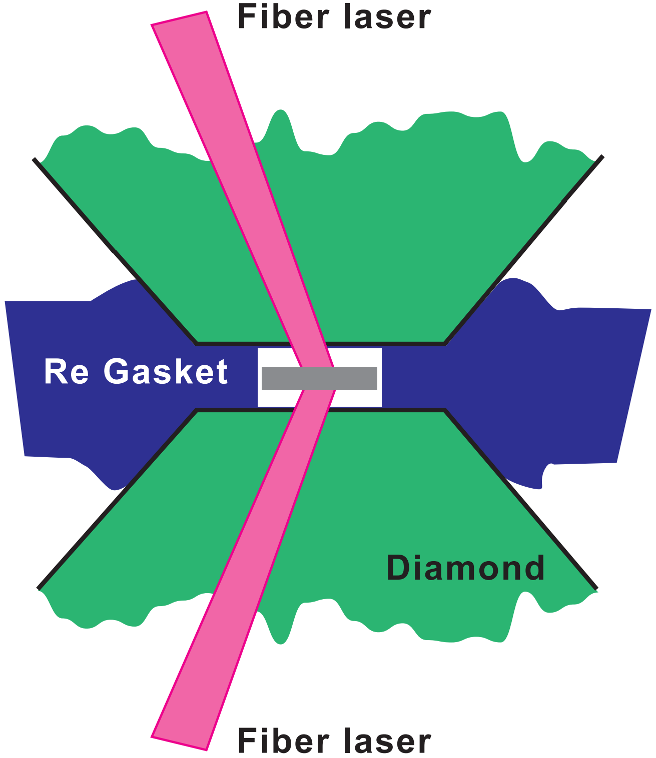
Samples are a glass of chondritic-type mantle (close to pyrolite)

We synthesized 1 sample for each pressure condition

The initial Fe^{3+}-content is 7-8 %

X-ray absorption spectroscopy
at the Fe K-edge
ID-24 at ESRF





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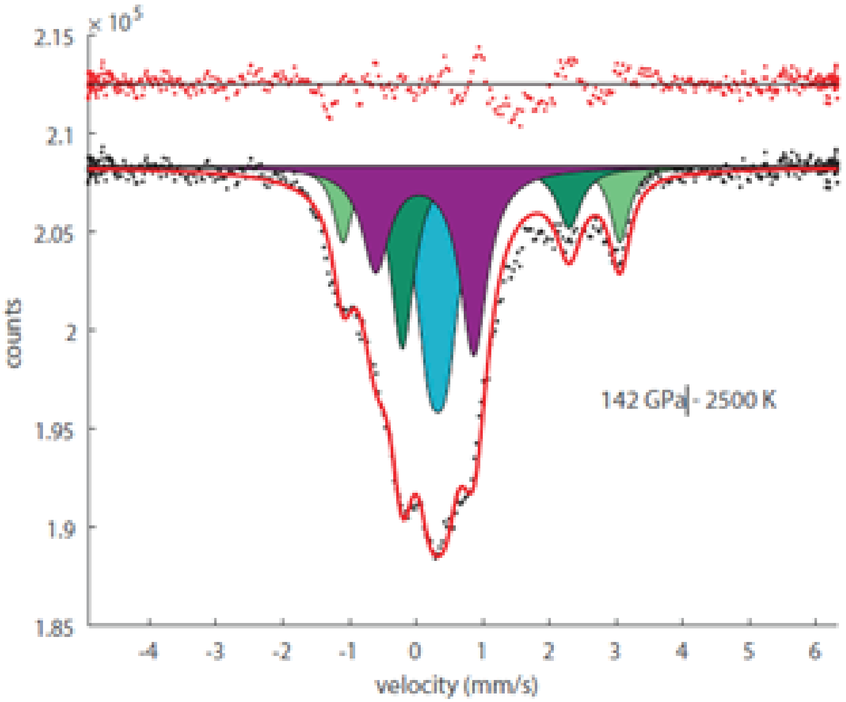
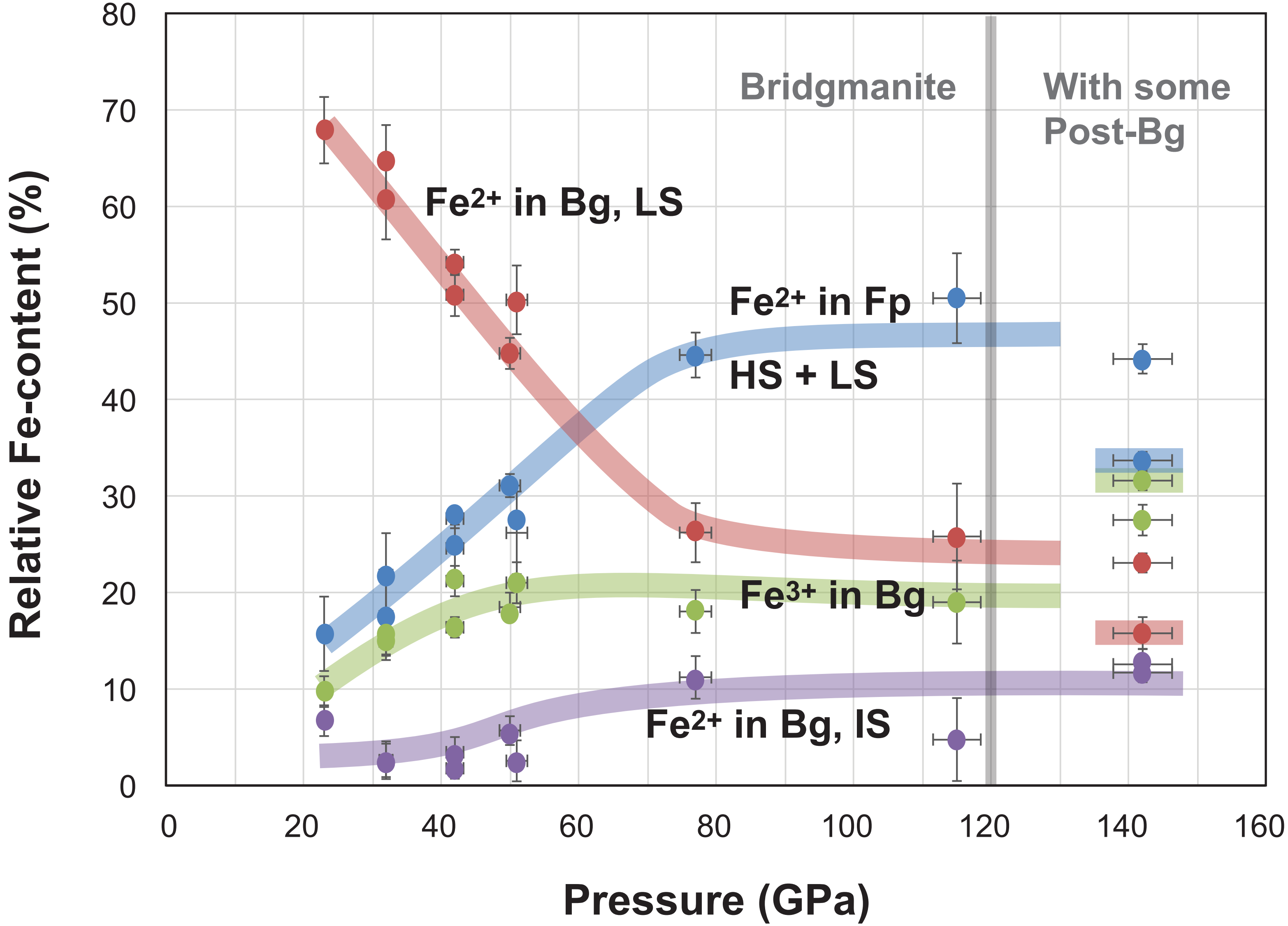
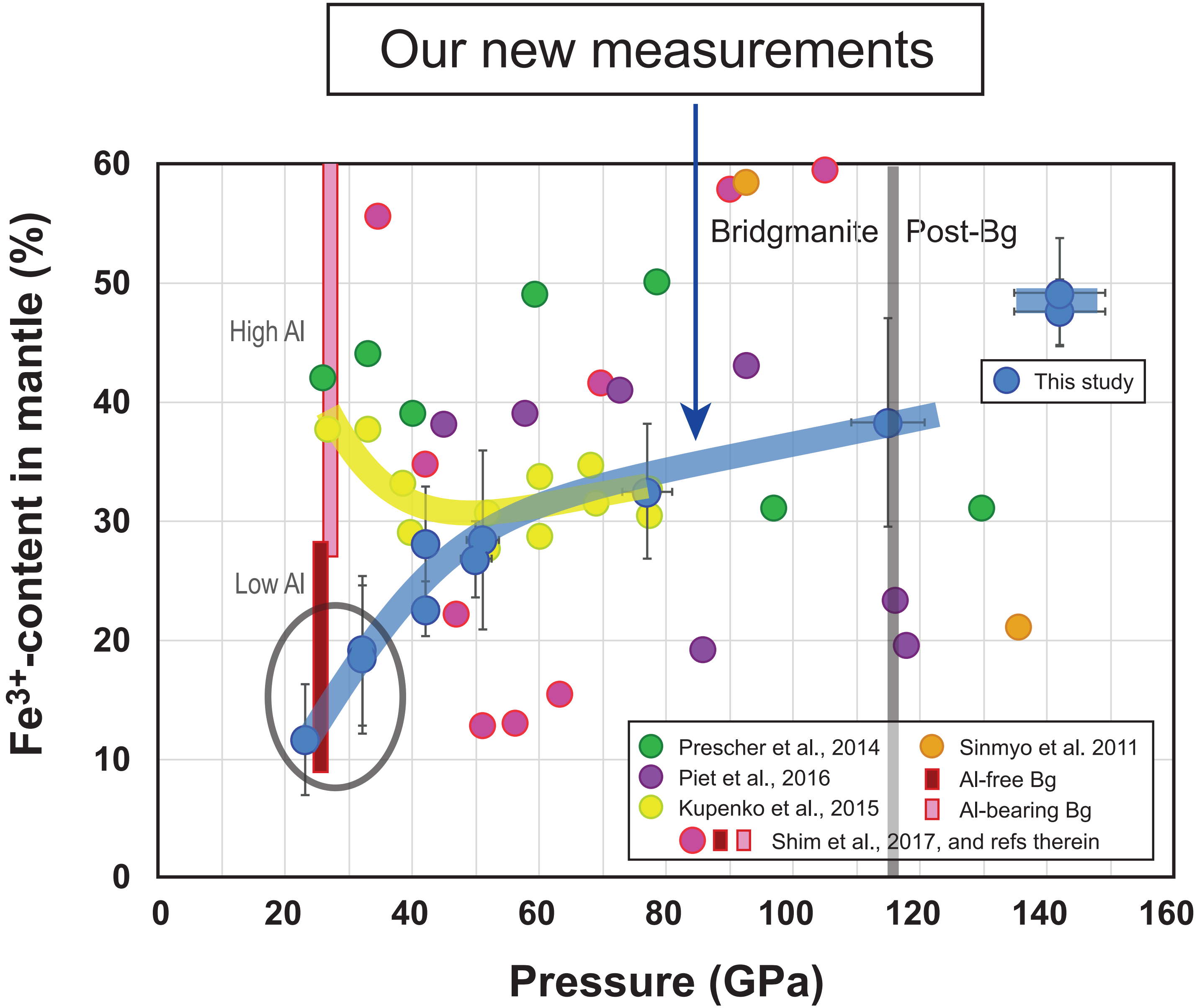


The data treatment was largely based on QS and CS already published for Fe^{2+} and Fe^{3+} in ferropericlase and bridgmanite as a function of pressure.
e.g. Kantor et al., Kupenko et al.

Mossbauer results:
Fe abundances in the available cationic sites





=> About 35% of the Fe is Ferric (3+) in the lower mantle

TODAY

The Fe^{3+}-bearing bridgmanite appears below the 670 km seismic discontinuity.

Formation of Bg from a bulk mantle material containing only 2-3 % of Fe^{3+}
induces a large Fe^{2+} disproportionation into Fe^{3+} and Fe^{0}

$$3\ Fe^{2+} <=> 2Fe^{3+} + Fe^{0}$$

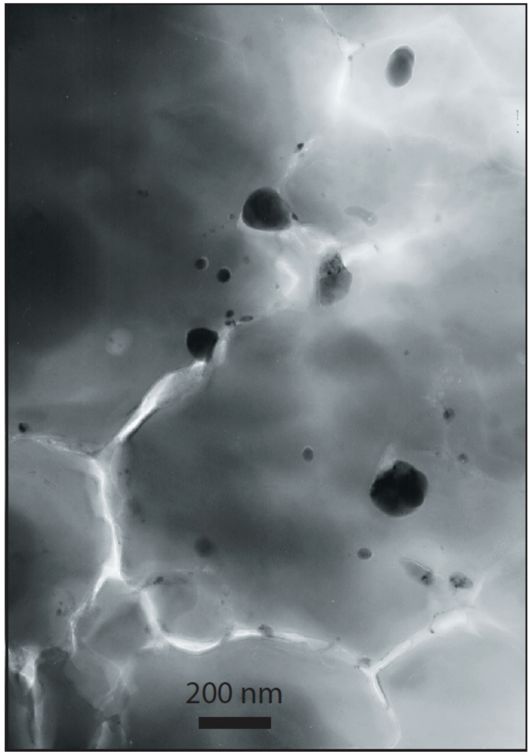
It induces the presence of some metallic Fe^{0} in the lower mantle

Experimental evidence for the existence of iron-rich metal in the Earth's lower mantle

Nature 2004

Daniel J. Frost[1], Christian Liebske[1], Falko Langenhorst[1], Catherine A. McCammon[1], Reidar G. Trønnes[1,2] & David C. Rubie[1]

[1] *Bayerisches Geoinstitut, University of Bayreuth, D-95440 Bayreuth, Germany*
[2] *Nordic Volcanological Institute, Natural Sciences Building, University of Iceland, IS-101, Reykjavík, Iceland*



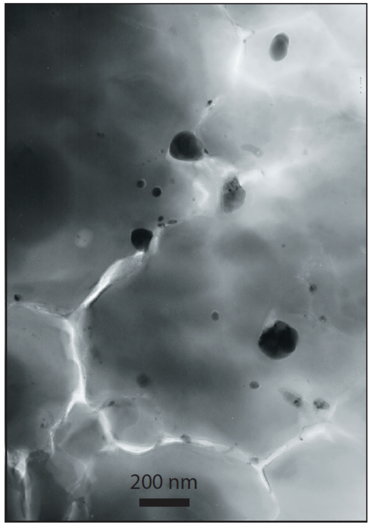
Fe^{0} blobs into Bg
after synthesis in LH-DAC
Sample is 90% $(Mg_{0.9},Fe_{0.1})SiO_3$ + 10% Al_2O_3

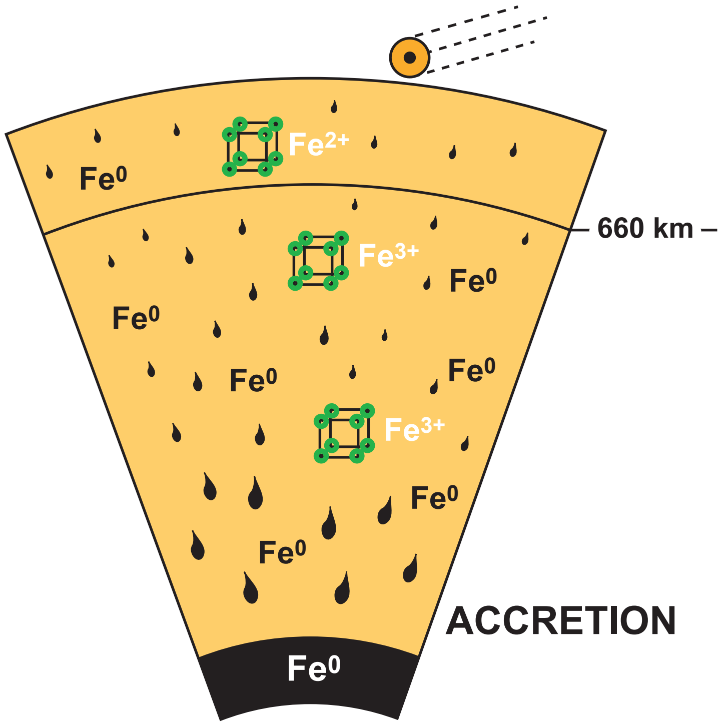
Ingredient

3

Removal of a fraction of Fe^0 during core formation

Upon magma ocean crystallization

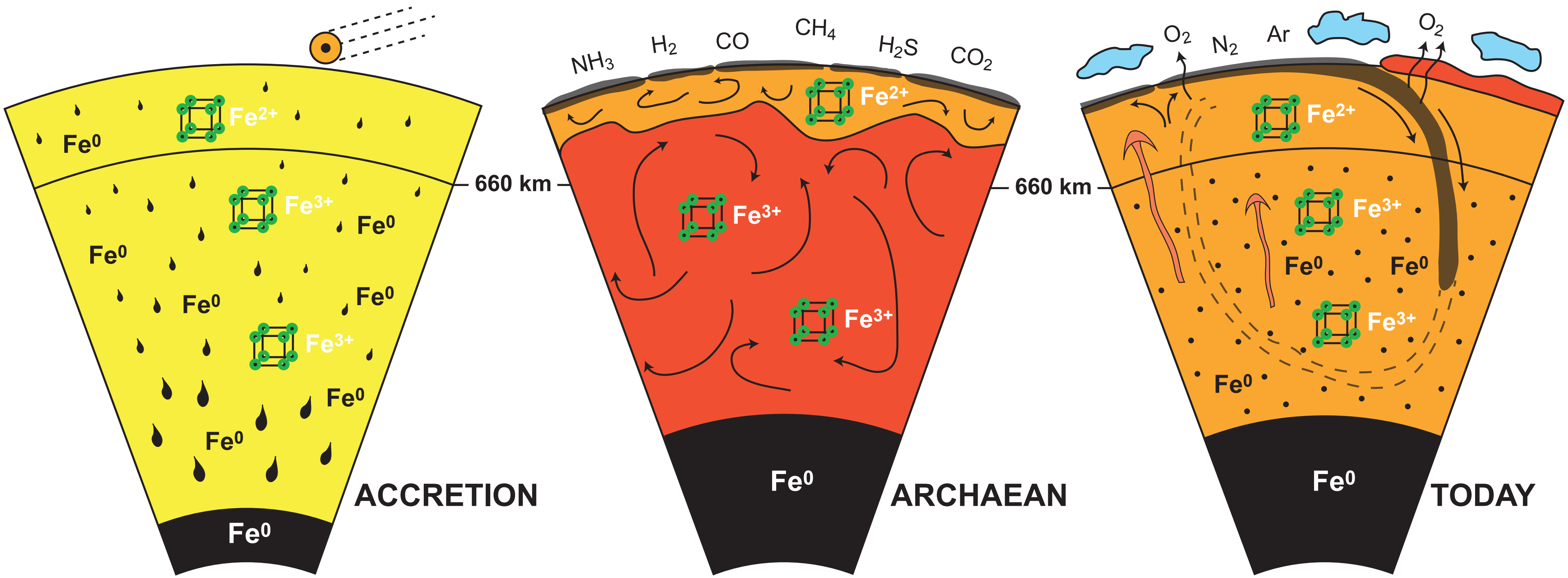




Removing some of the Fe^0-blobs results in enriching the deep primitive mantle in Fe3+

An entire removal of the primordial Fe^0 would leave an excess oxygen of ~10^{12} moles corresponding to ~3000 times the O_2 into our atmosphere

Model = (early draining of Fe^0) + (excess Fe^{3+} in Bg) + (change in tectonic regim)



During the Archaean, due to lack of major slab subduction, the oxydized lower mantle remained relatively insulated from the lithosphere

2-3 Ga ago, when slab suduction became major, mantle mixing induced the uprising of the oxydized lower mantle material

The amount of extra-oxygen available in the deep mantle can be 500-1000 the oxygen content in the current atmosphere