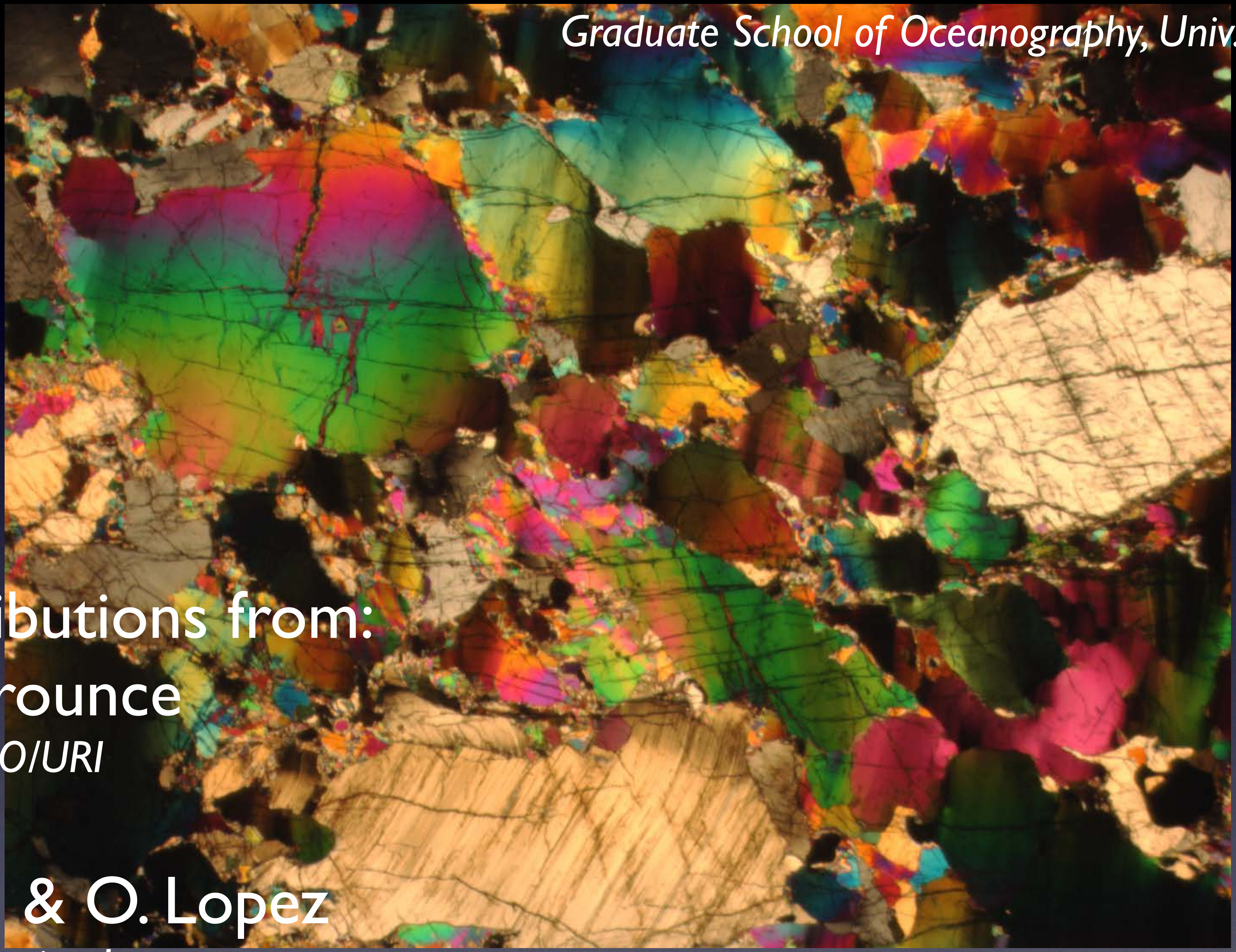
Mantle Wedge Oxygen Fugacity

Katherine A. Kelley

Graduate School of Oceanography, Univ. of Rhode Island



With contributions from:

M. Brounce

GSO/URI

E. Cottrell & O. Lopez

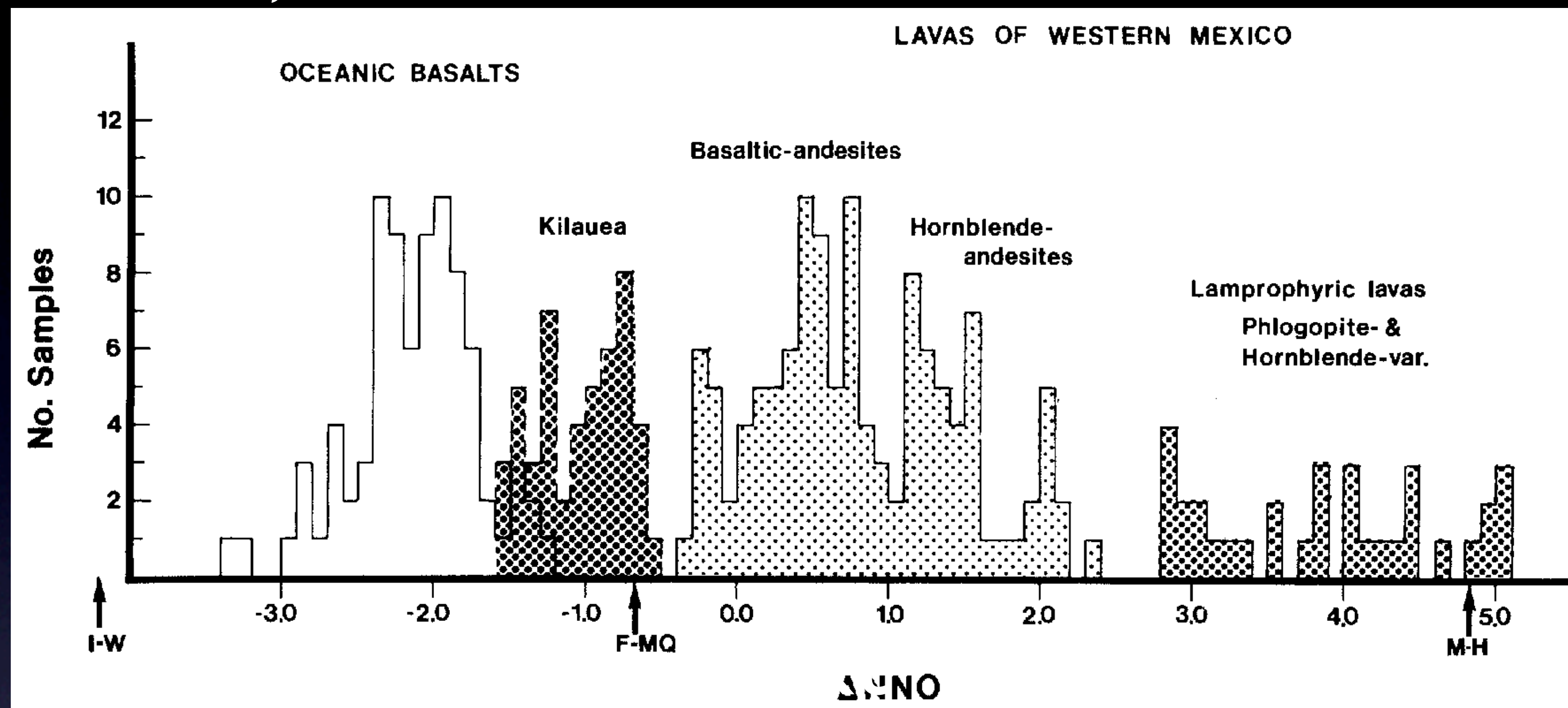
Smithsonian Inst.

J. Warren & S. Birner

Stanford Univ.

Mantle Redox: Proxies and Puzzles

Carmichael, 1991



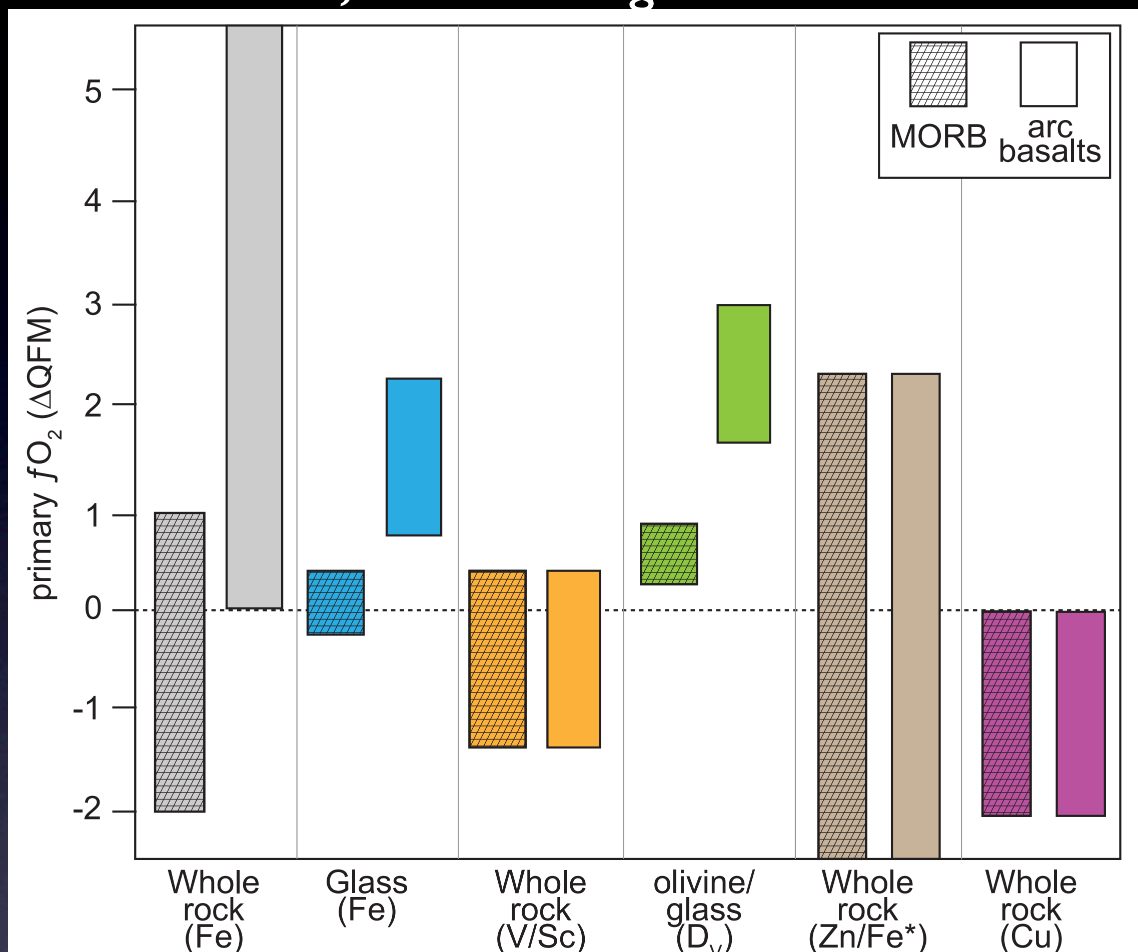
Basis: bulk $Fe^{3+}/\sum Fe$ (wet chemistry)

"...the range of oxygen fugacities typical of basic lavas will have an equivalent range in their respective source regions."

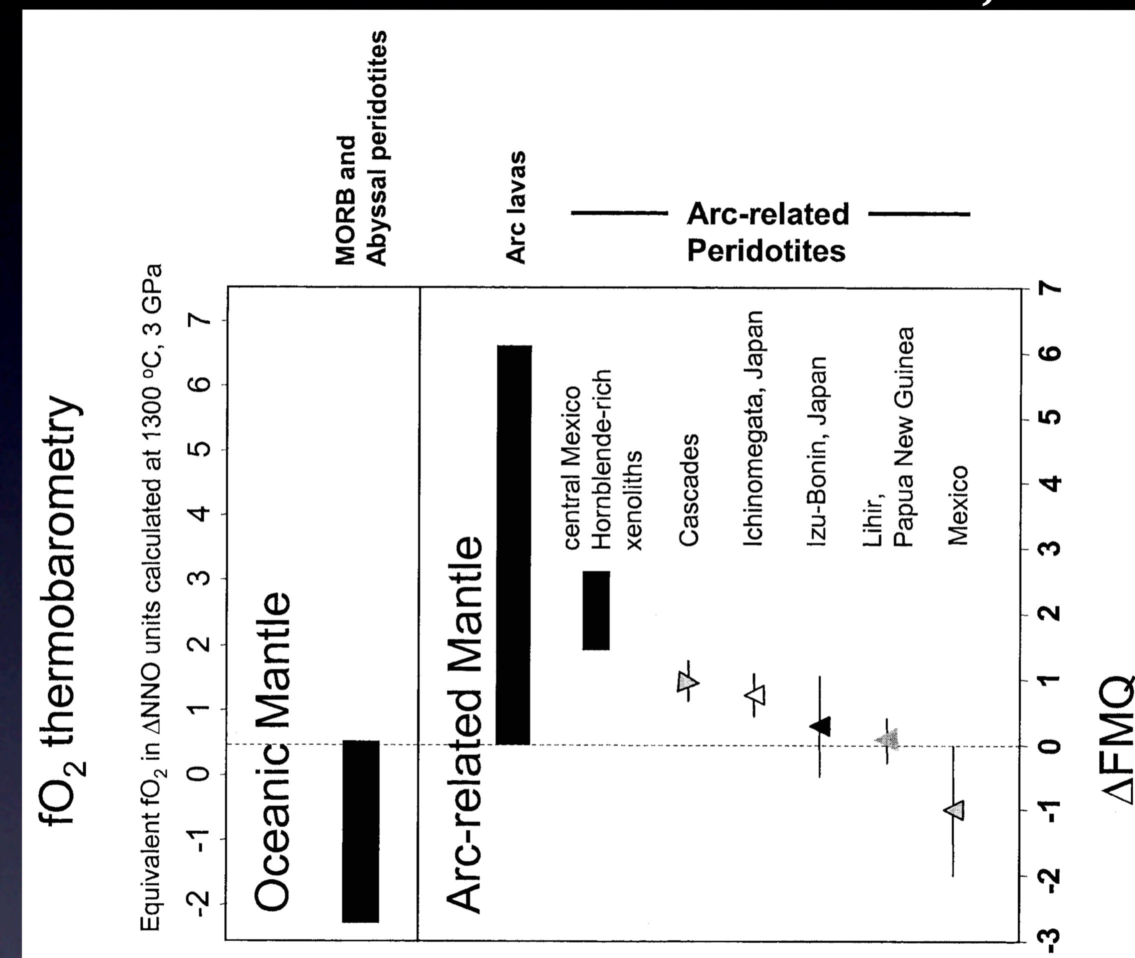
- Arc magmas are more oxidized than those from other settings

Mantle Redox: Proxies and Puzzles

Brounce et al., this meeting



Lee et al., 2003



- Different fO_2 proxies give different answers

(see Brounce et al., Tues 10:30 AM for more)

- Some arc peridotites (mostly xenoliths) are oxidized, others are not

Why does wedge fO2 matter?

- Formation of arc crust/continents at subduction zones

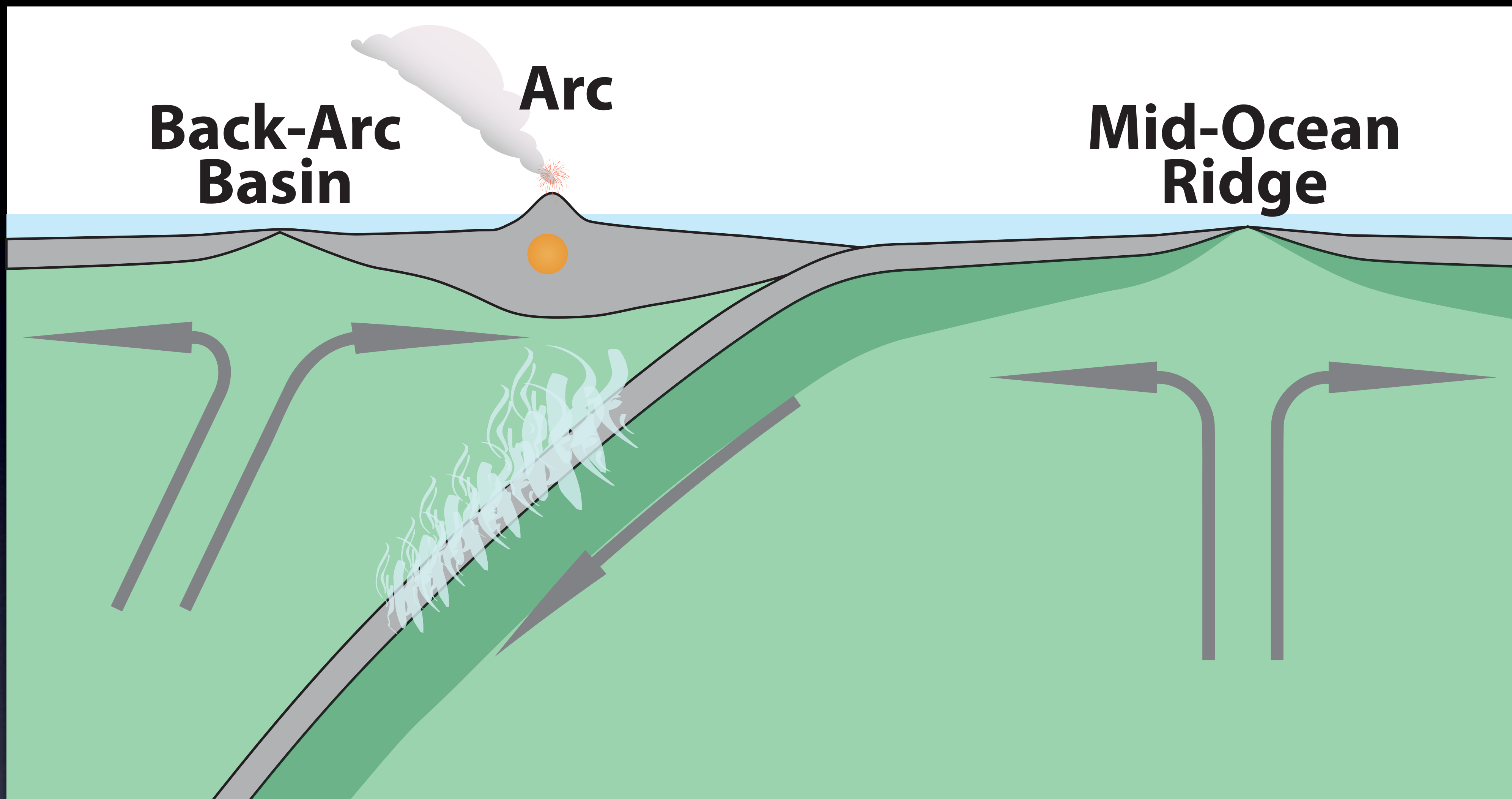
- Mantle evolution - residues of subduction recycled to the deep

- If wedge oxidation is linked to the slab, then possibly linked to redox of Earth's surface (e.g., atmosphere)

- If wedge redox is independent of slab, what crustal processes change magmatic redox, why are they exclusive to subduction zones and and how can we observe?

(See Grocke et al., Tues. 10:15 AM for more)

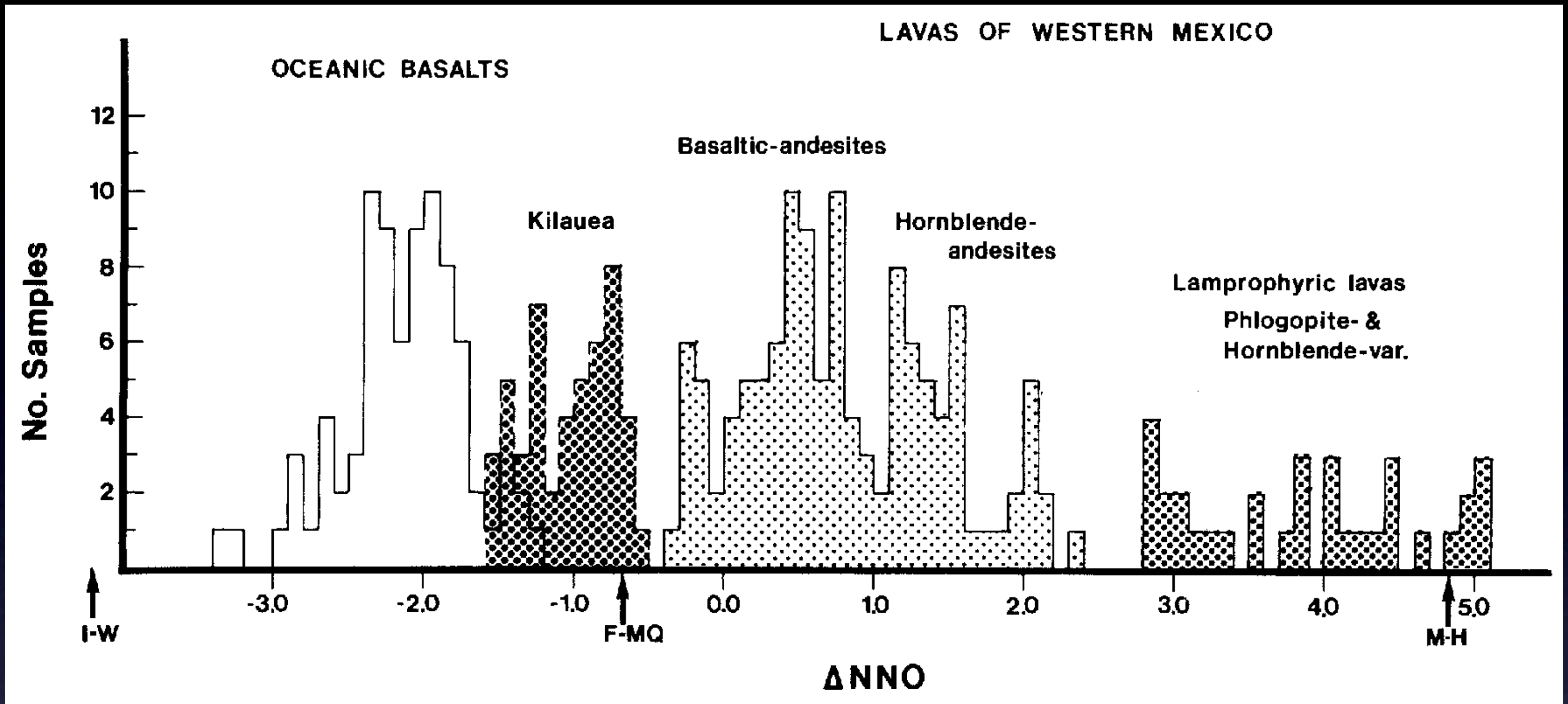
How Do We Access the Wedge?



- Xenoliths and exhumed sections are rare
- Most accessible is to look at mantle-derived magmas

Mantle Redox: The Magmatic Record

Carmichael, 1991



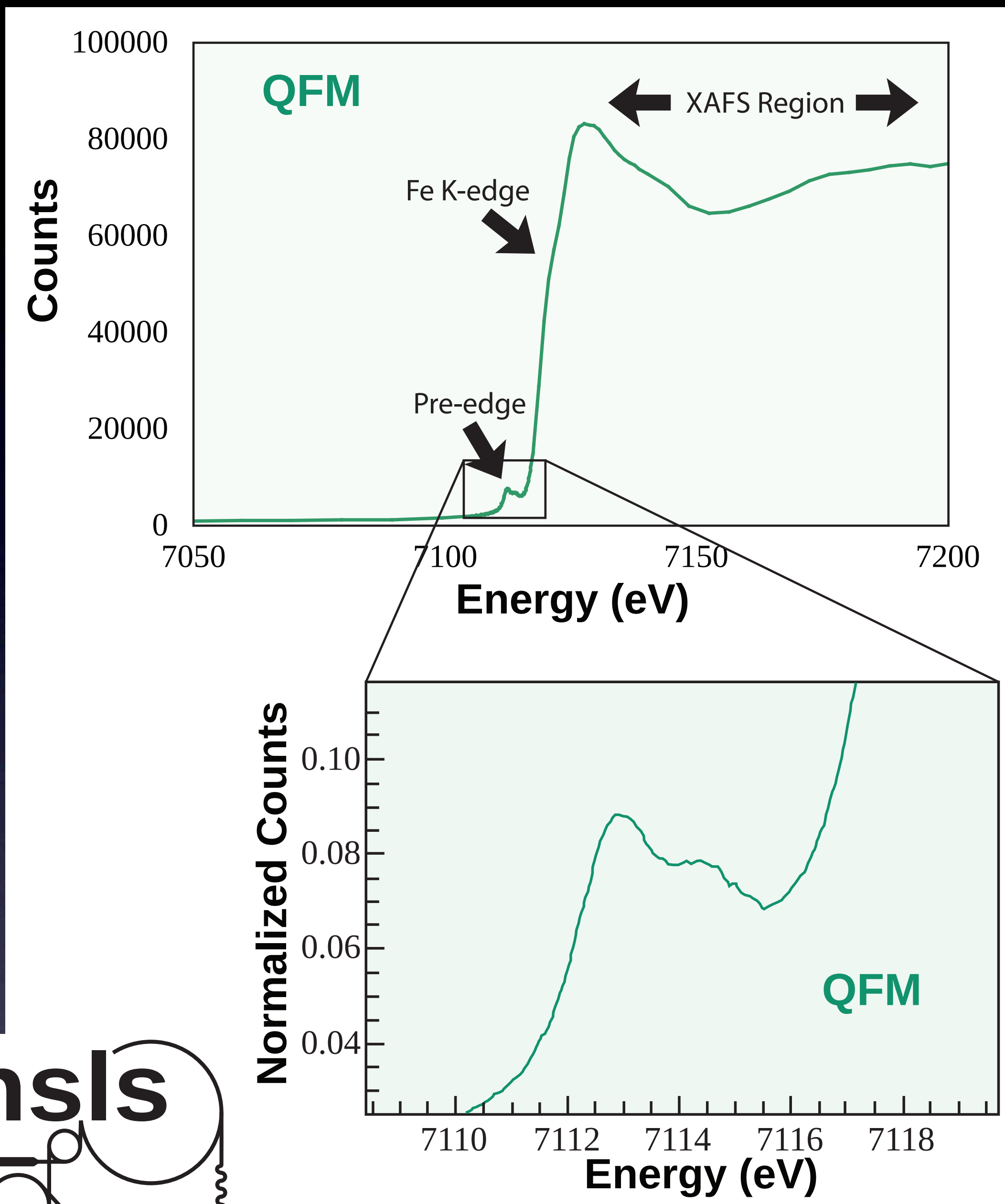
Basis: bulk $Fe^{3+}/\sum Fe$ (wet chemistry)

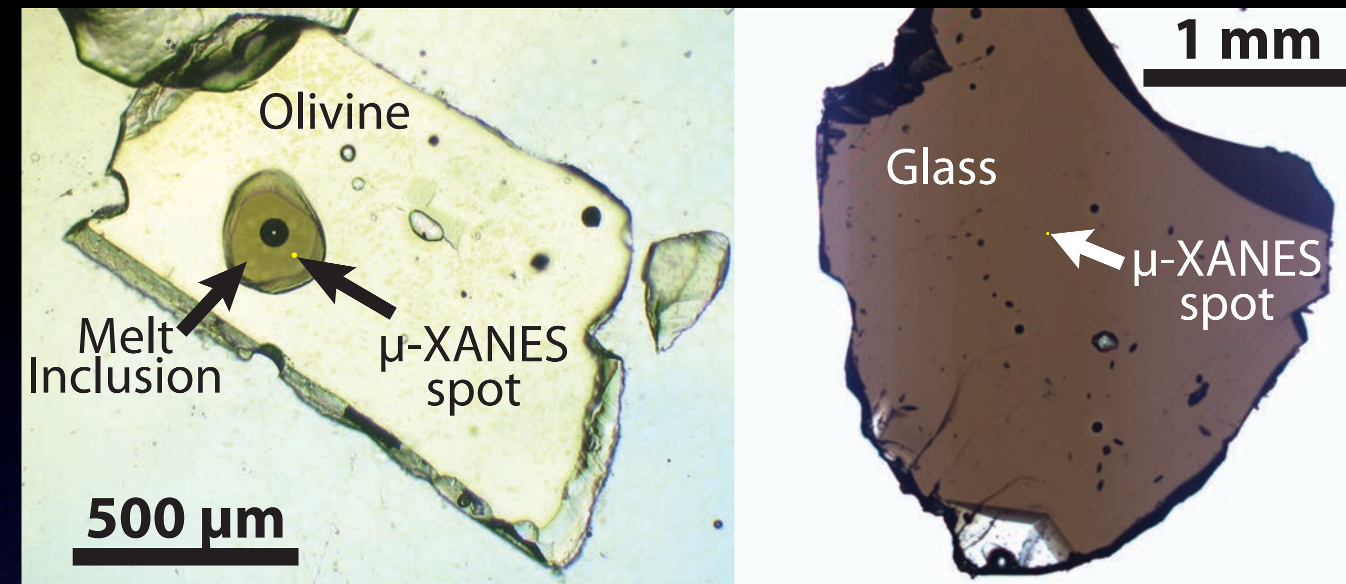
- Classic observation: arc magmas are more oxidized than those at other settings

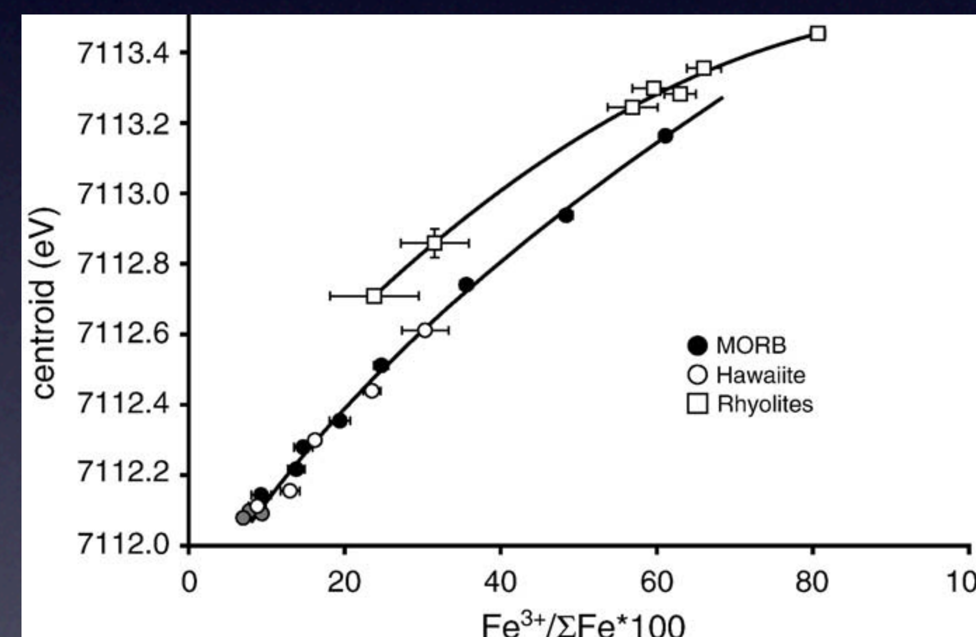
- What are the factors that control magmatic redox? What are the links between magmatic and mantle redox?

- Oxidation state of Fe is a good proxy

Mantle Redox: The Magmatic Record



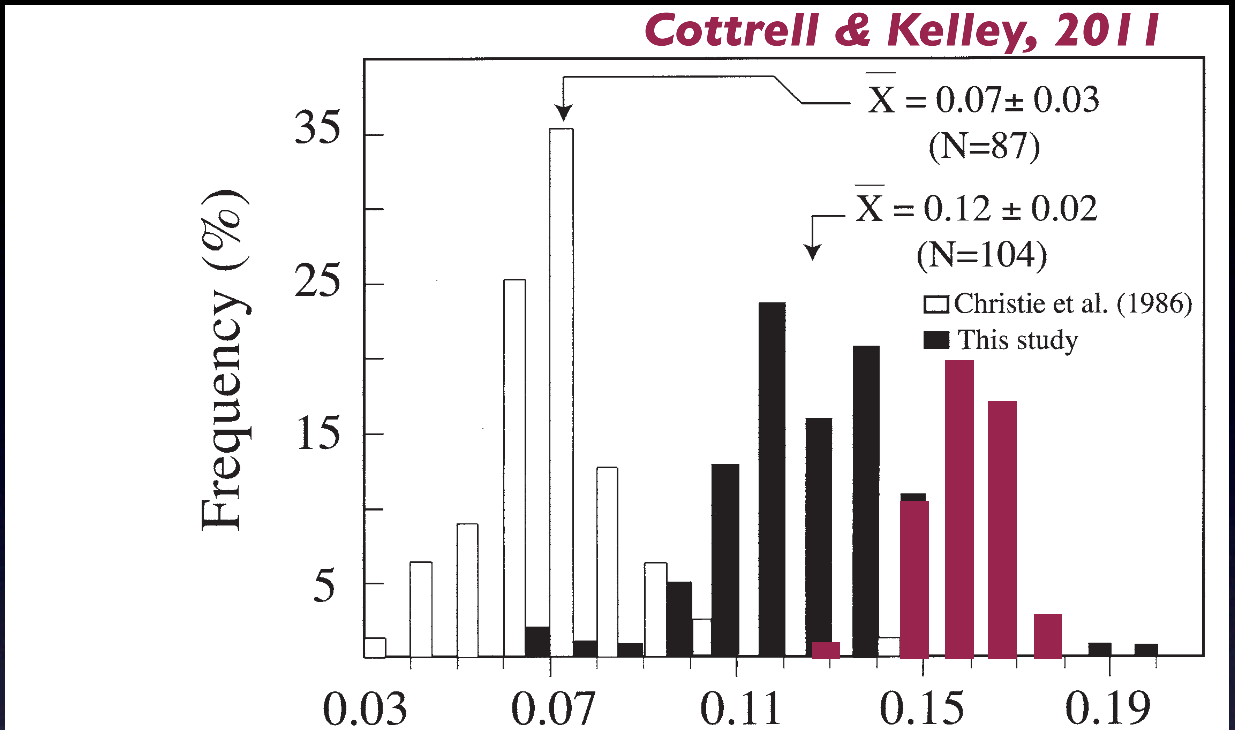




Cottrell et al., 2009

- Microbeam advances have streamlined analysis of $Fe^{3+}/\sum Fe$ in glass
- Magmatic redox can be explored on smaller scales

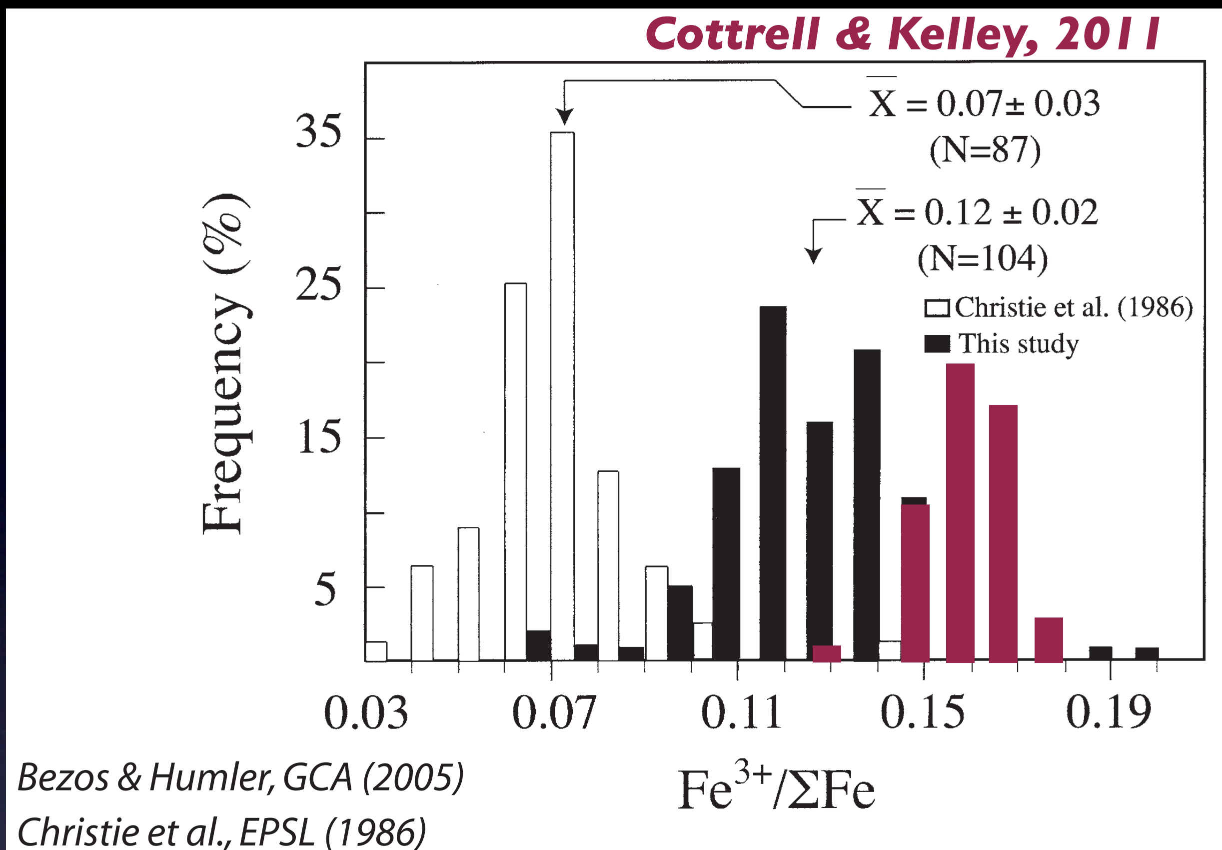
Fe Redox in Natural Glasses

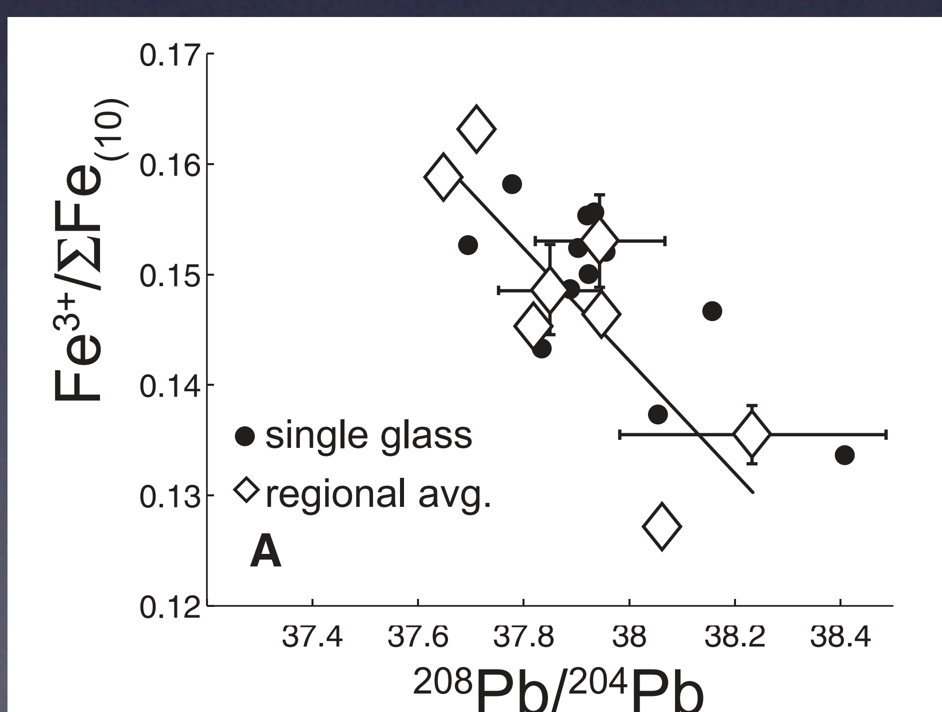


Bezos & Humler, GCA (2005)
Christie et al., EPSL (1986)

- MORBs are more oxidized than previously thought *(Cottrell & Kelley, 2011)*

Fe Redox in Natural Glasses

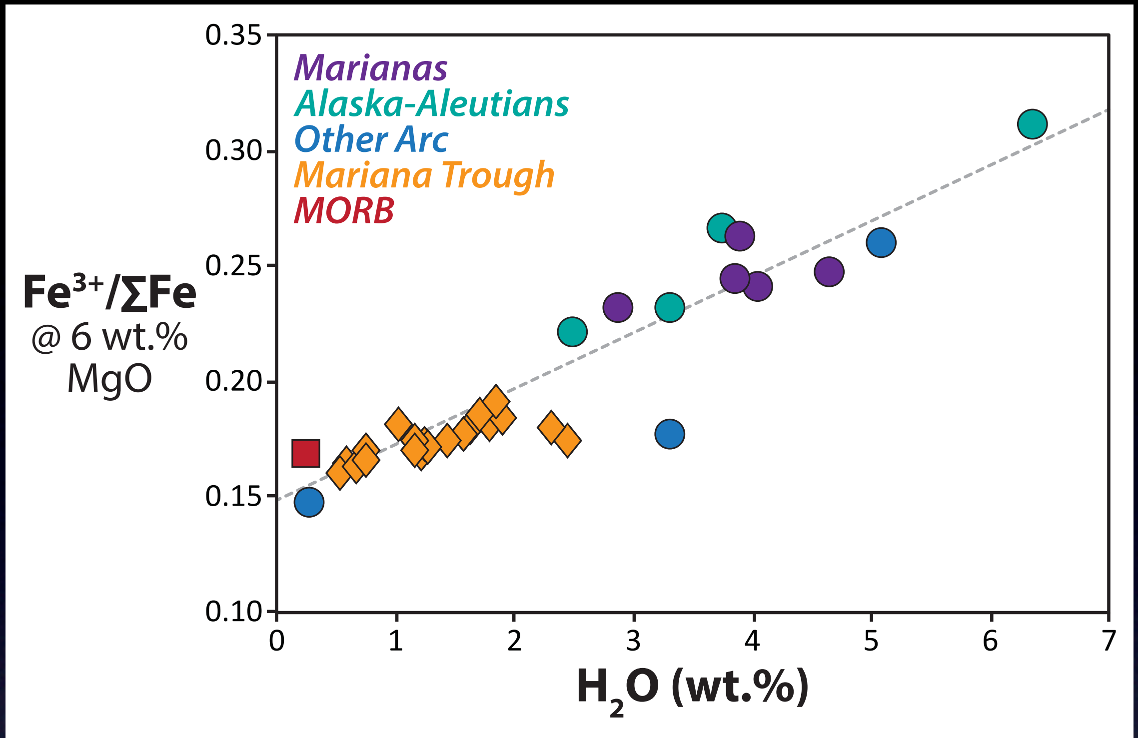




- MORBs are more oxidized than previously thought
  (Cottrell & Kelley, 2011)

- $Fe^{3+}/\sum Fe$ ratios in MORBs vary with source composition
  (Cottrell & Kelley, 2013, and Mon. 15:45 talk for more)

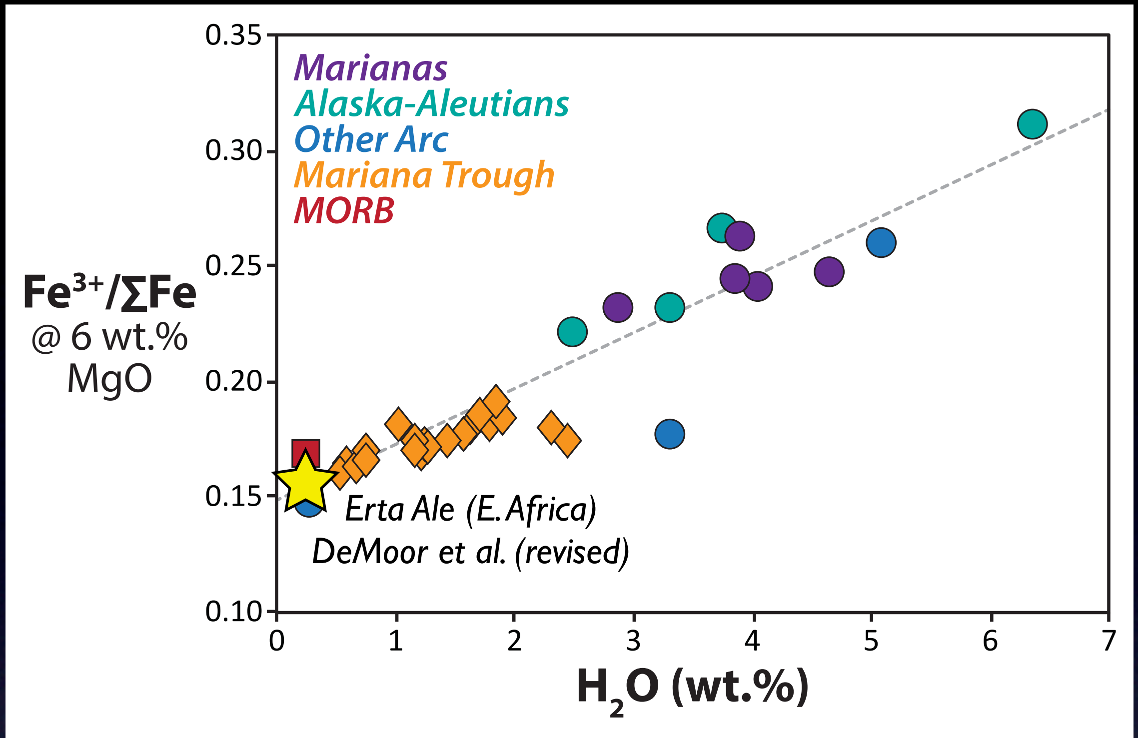
Fe Redox in Natural Glasses



- Fe redox varies globally with subduction influence, esp. H_2O content

(Kelley & Cottrell, 2009)

Fe Redox in Natural Glasses



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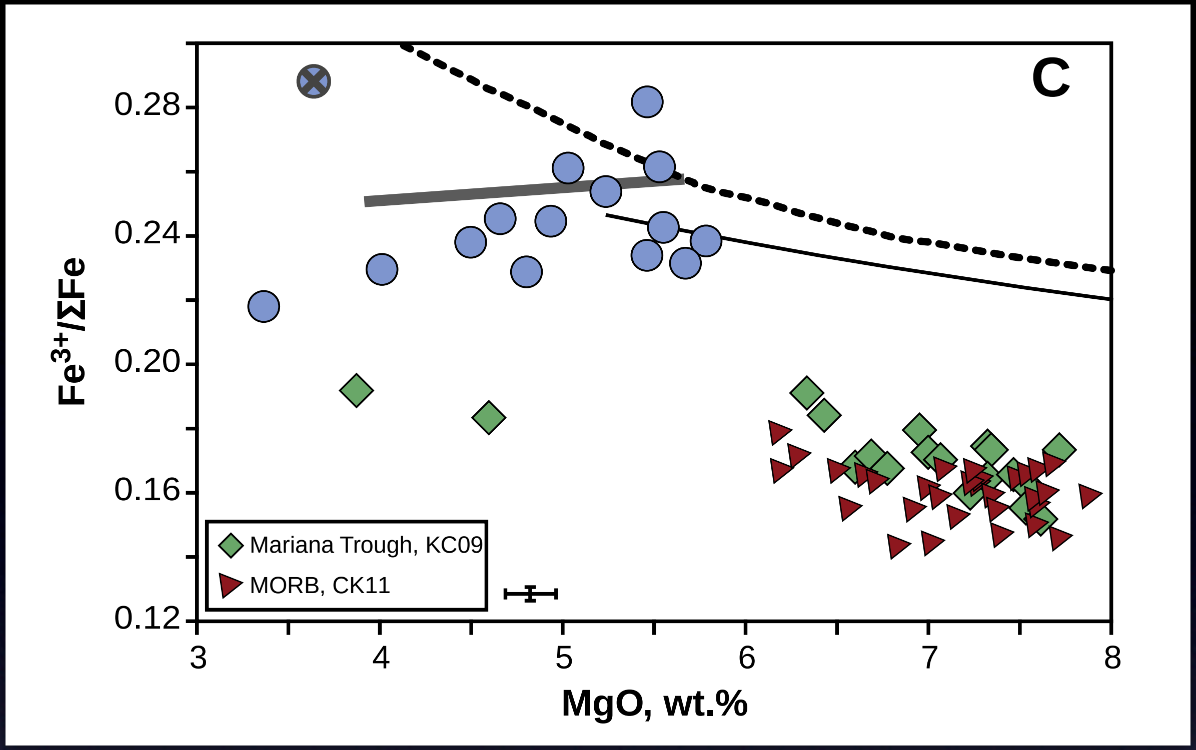
(Kelley & Cottrell, 2009)

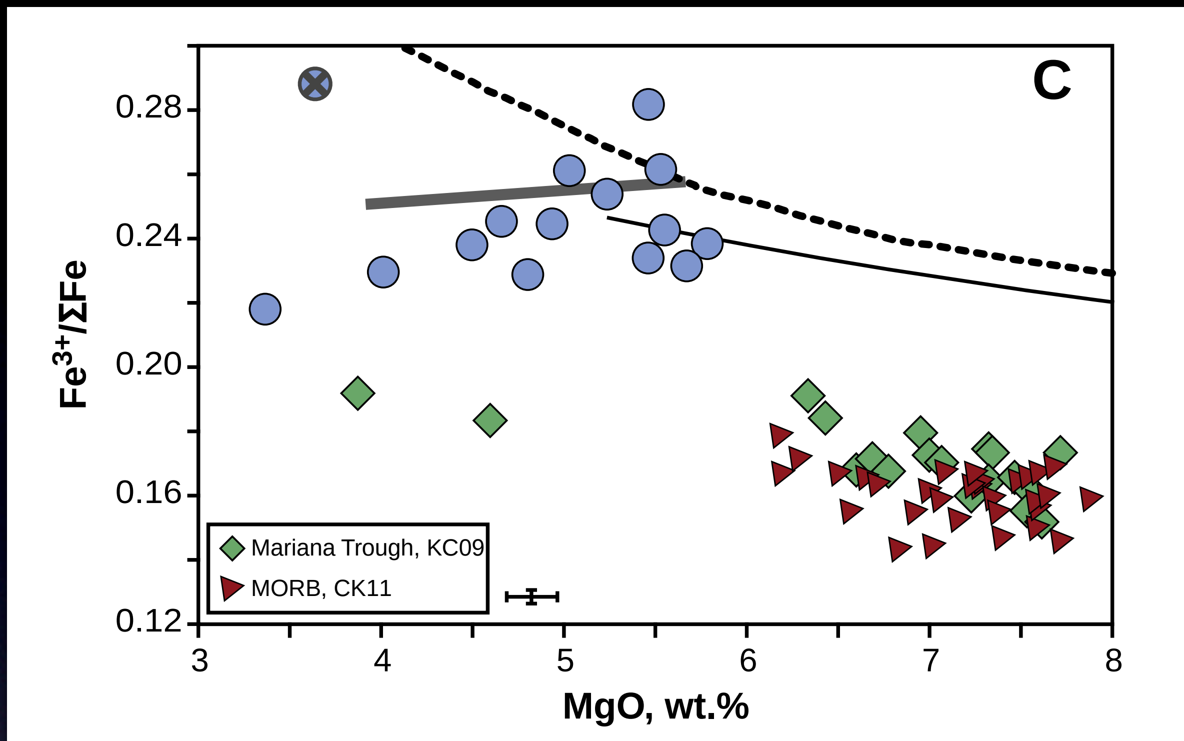
Fe Redox in Natural Glasses

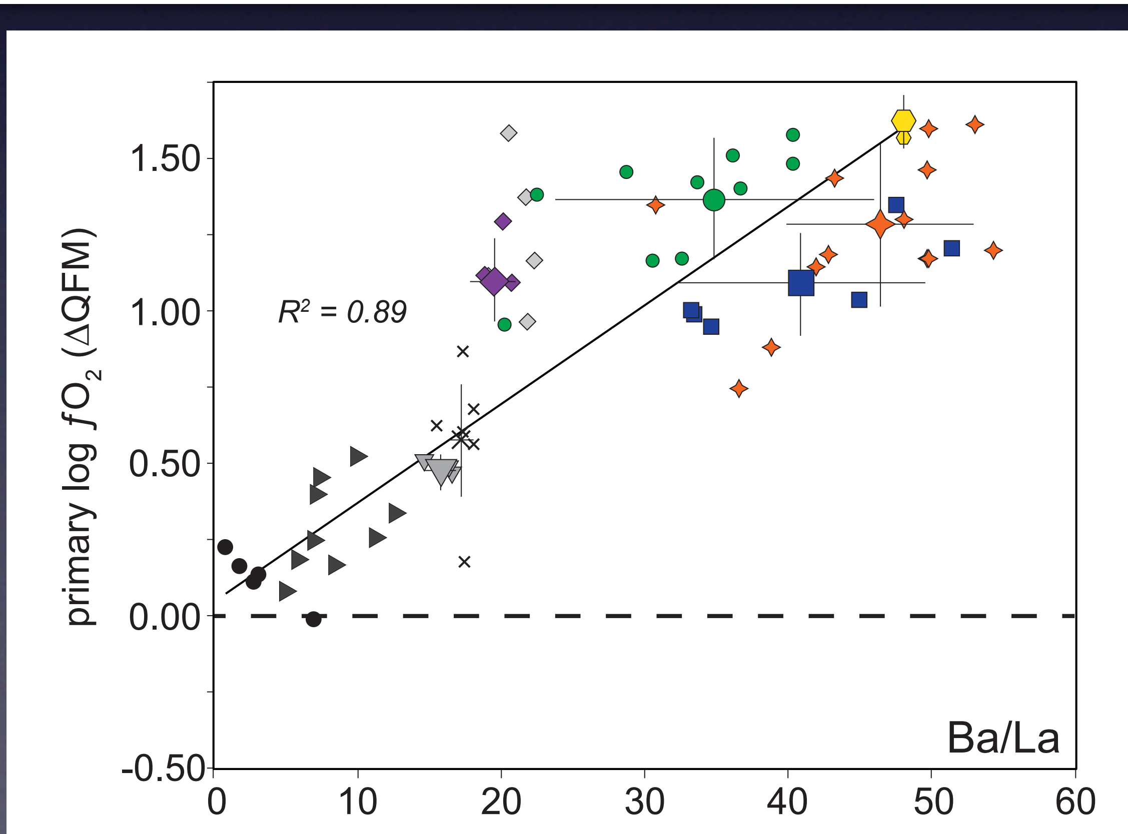


- Where resolvable, no oxidizing differentiation is evident

(Kelley & Cottrell, 2012)

Fe Redox in Natural Glasses

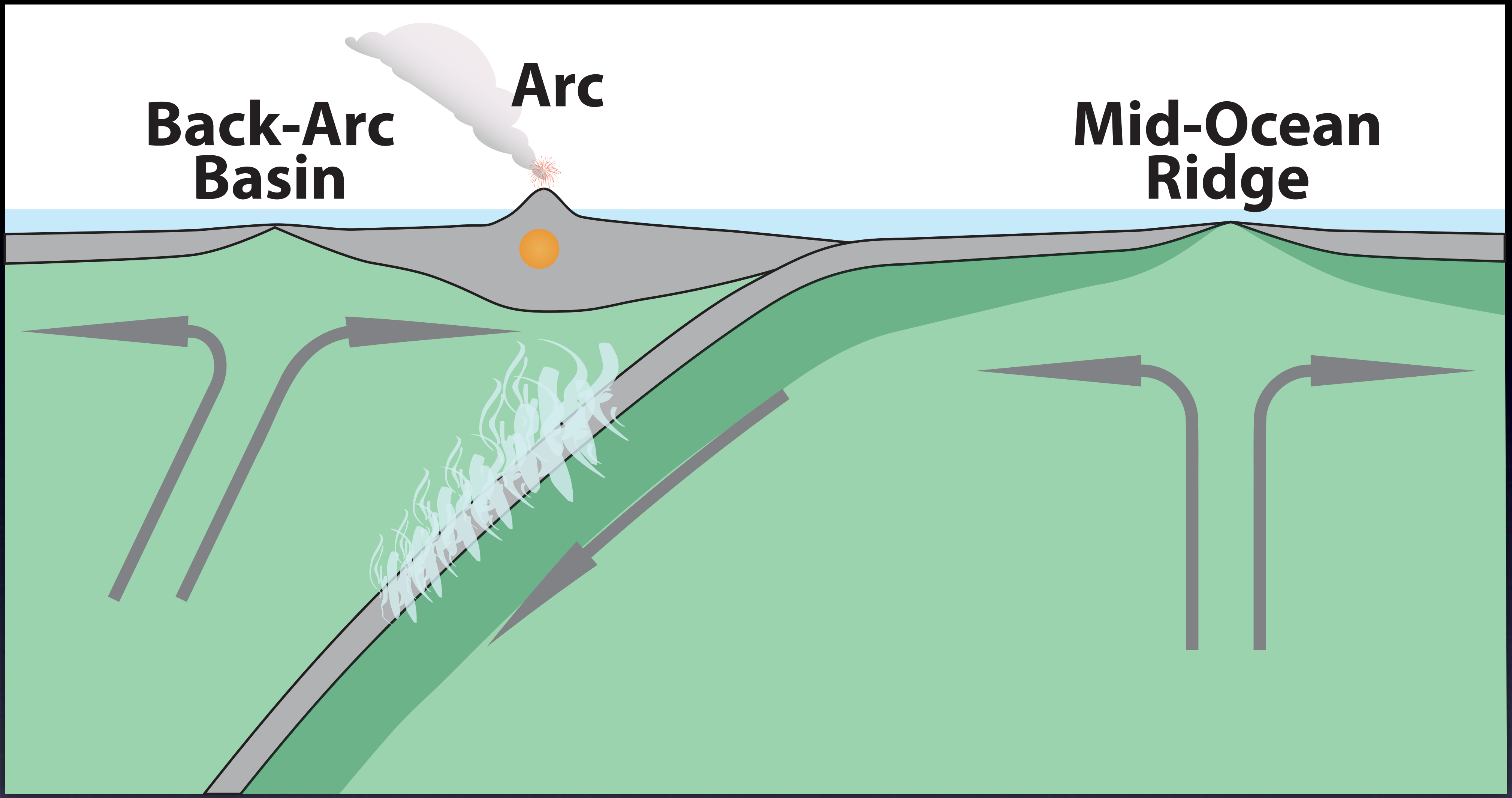




- Where resolvable, no oxidizing differentiation is evident
  (Kelley & Cottrell, 2012)

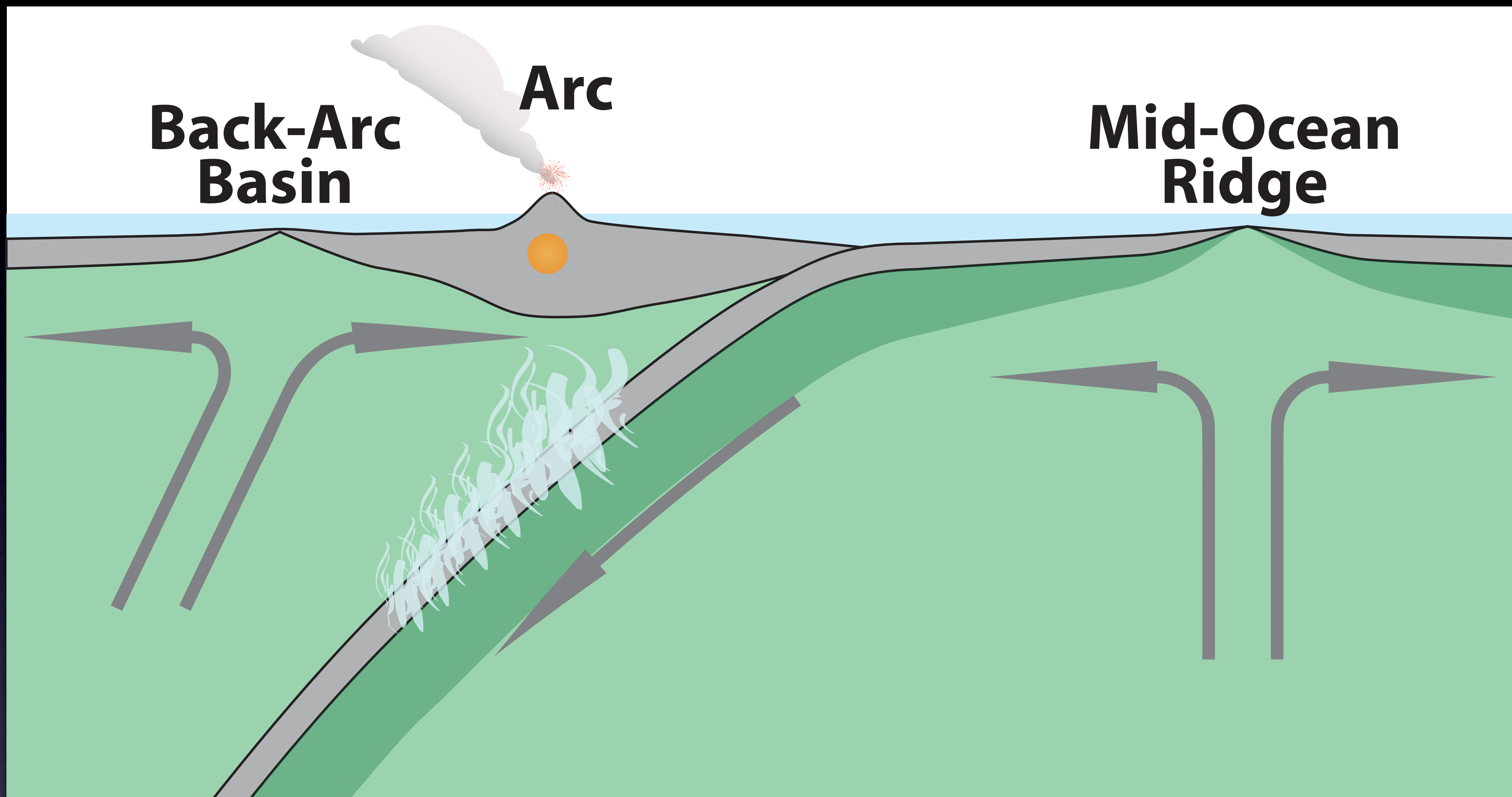
- Within an arc, modeled source fO_2 correlates with slab tracers
  (Brounce et al., in prep.)

How Well Do Magmas Preserve Wedge Redox?



- But even primitive arc magmas are still physically far removed from the mantle wedge
- No strongly oxidizing magmatic differentiation process has yet been observed

How Well Do Magmas Preserve Wedge Redox?



- What about arc peridotites?

Oxygen Fugacity of Spinel Peridotites

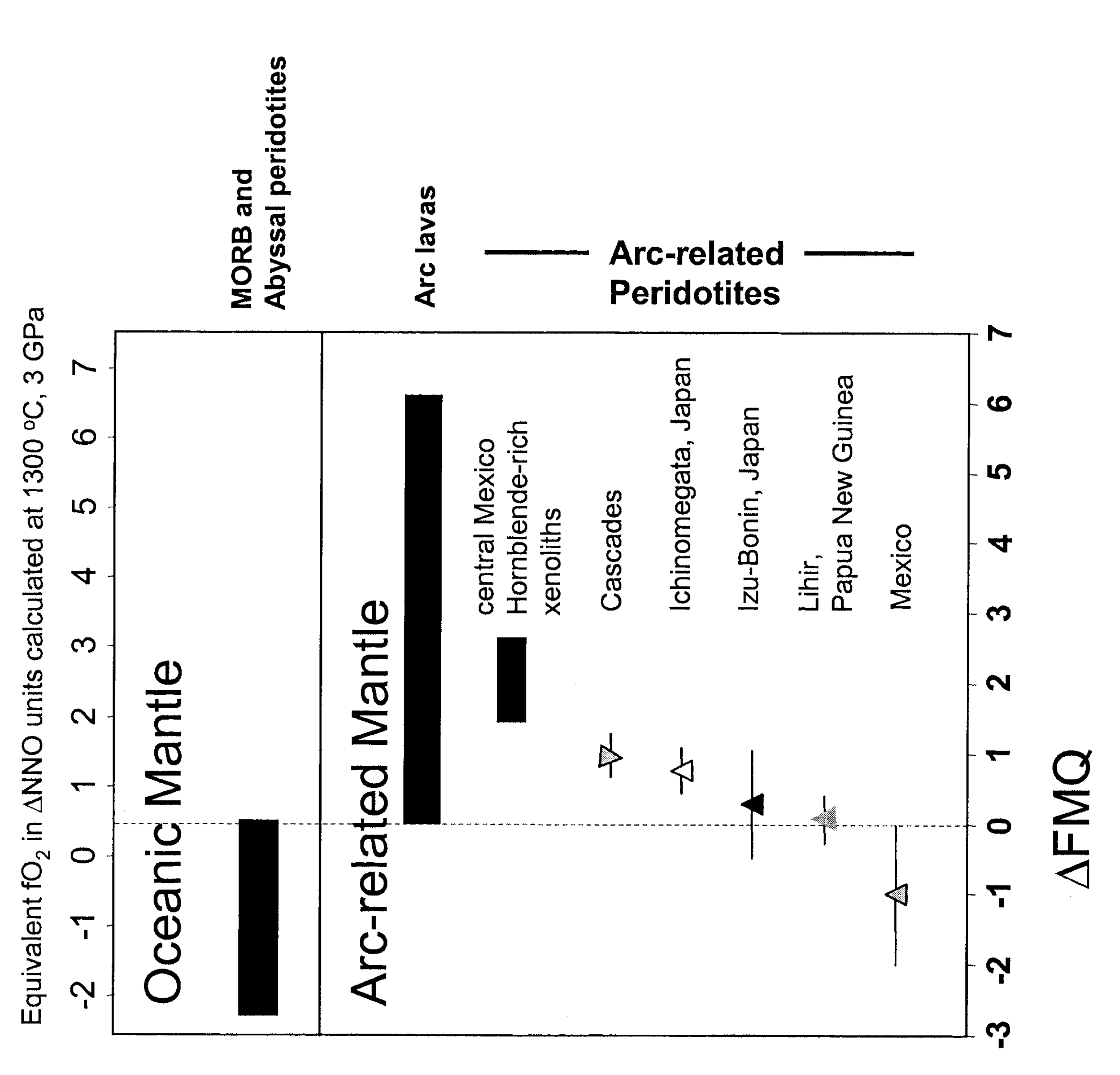
$$\underset{ol}{6Fe_2SiO_4} + O_2 = \underset{opx}{3Fe_2Si_2O_6} + \underset{sp}{2Fe_2^{3+}Fe^{2+}O_4}$$

- Microprobe method for determining $Fe^{3+}/\sum Fe$ of spinels

(Wood & Virgo, 1989)

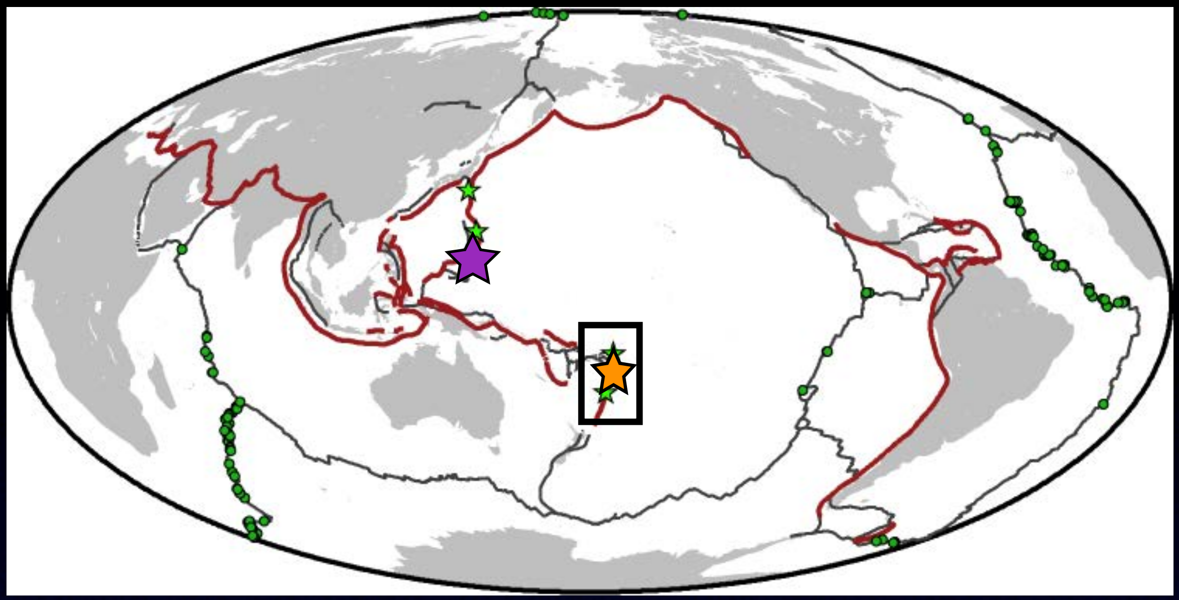
Oxygen Fugacity of Spinel Peridotites

Lee et al., 2003

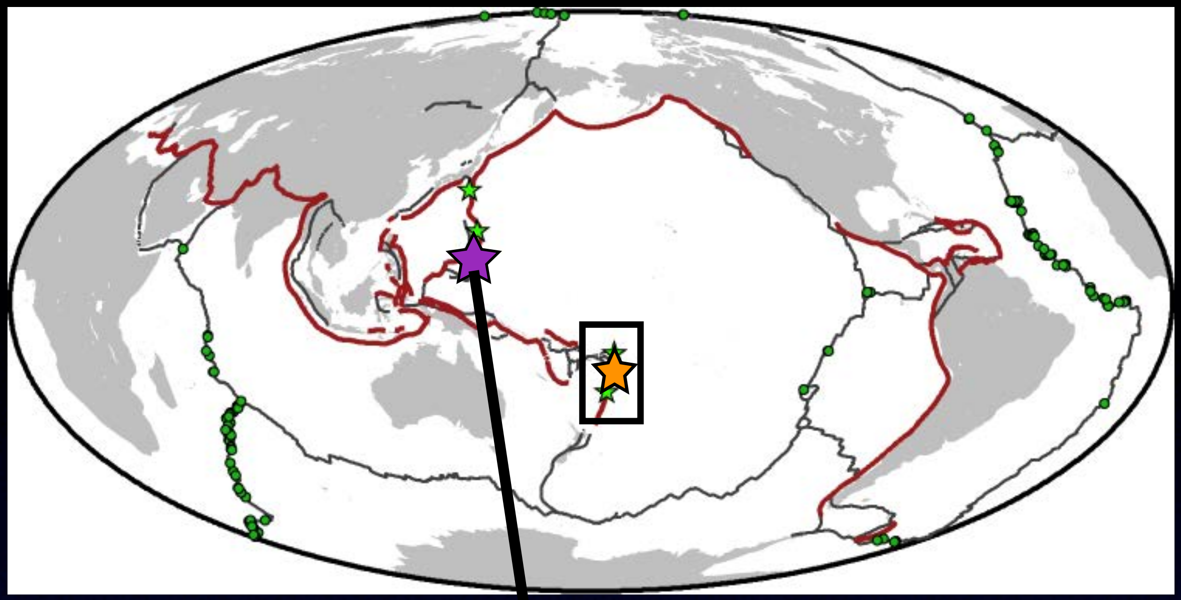


- Arc xenoliths span a range, but we lack context
- Other types of arc peridotites (e.g., exhumed terranes) may tell a different story

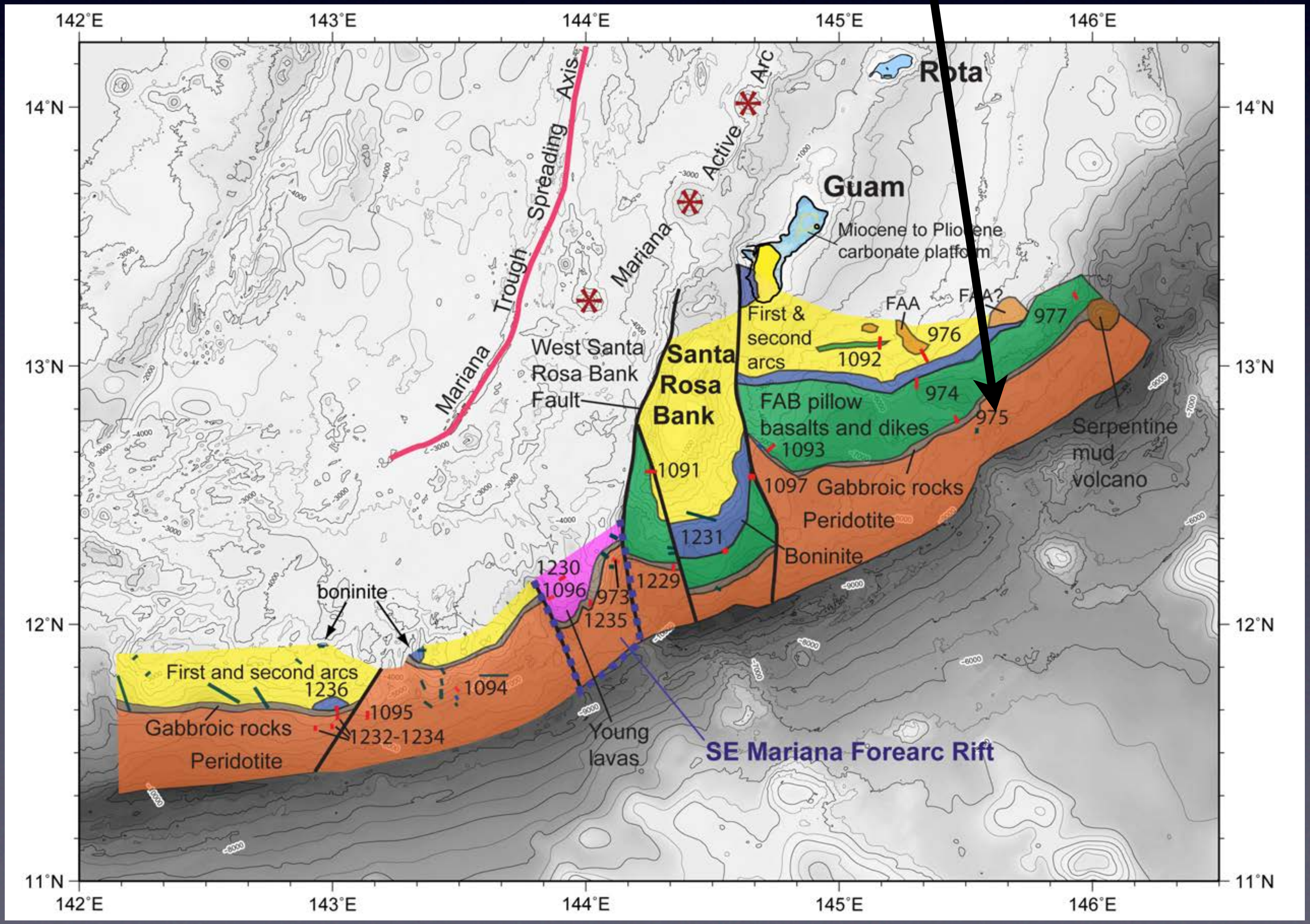
Fore-Arc Exposures of Arc Peridotite



Fore-Arc Exposures of Arc Peridotite

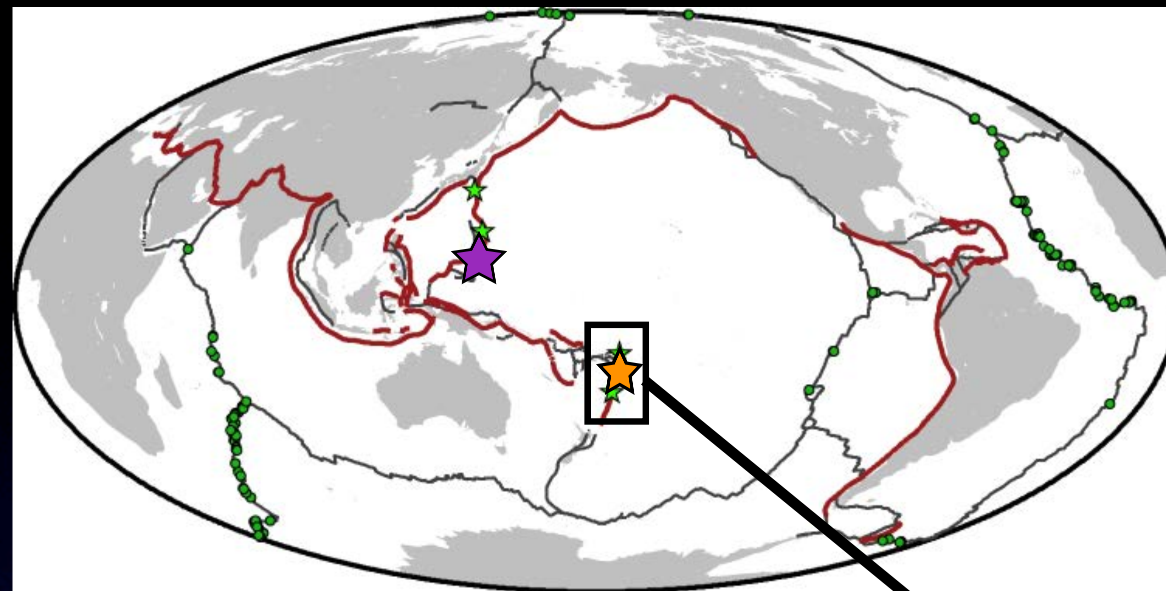


Reagan et al., in prep

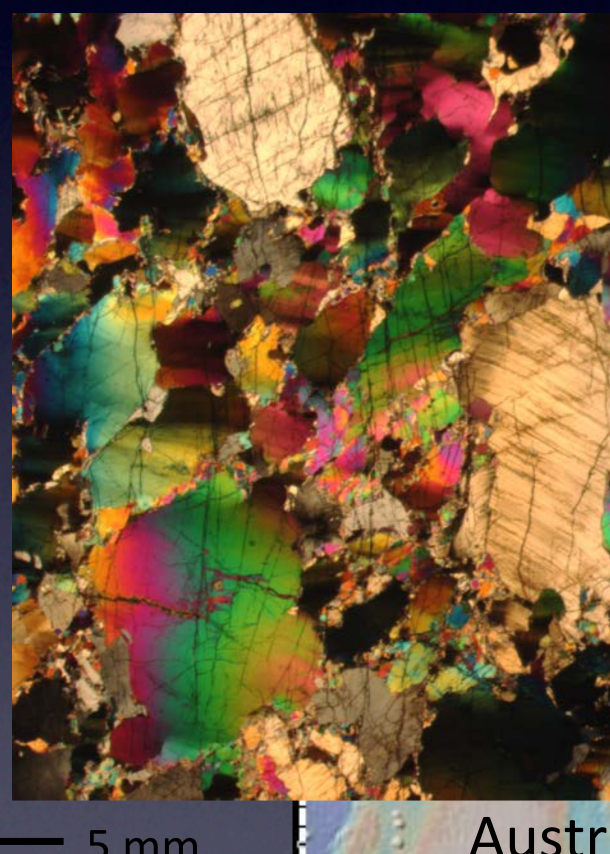


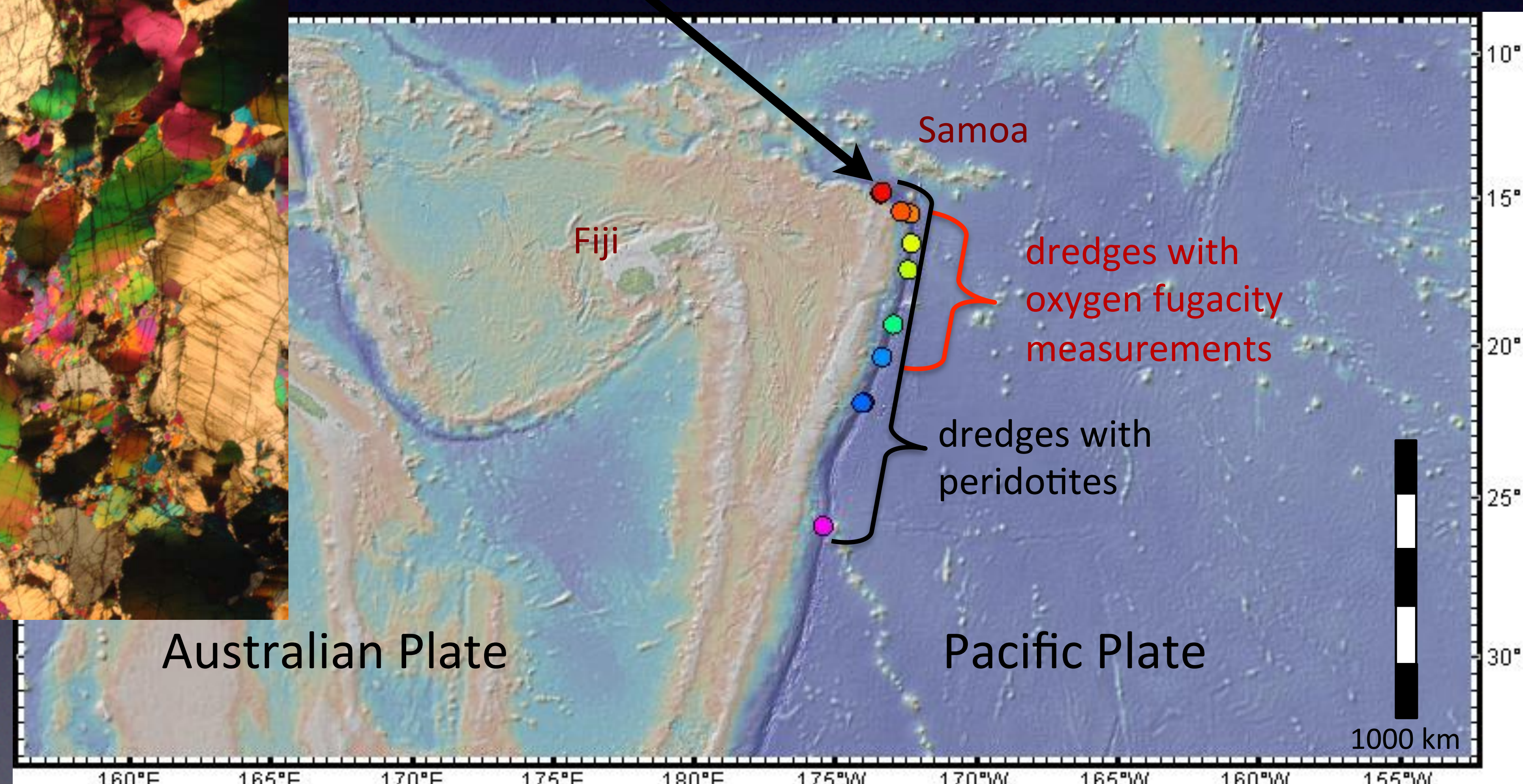
- Mariana fore-arc south of Guam
- Peridotite is exposed at the base of the early arc crustal sequence

Fore-Arc Exposures of Arc Peridotite



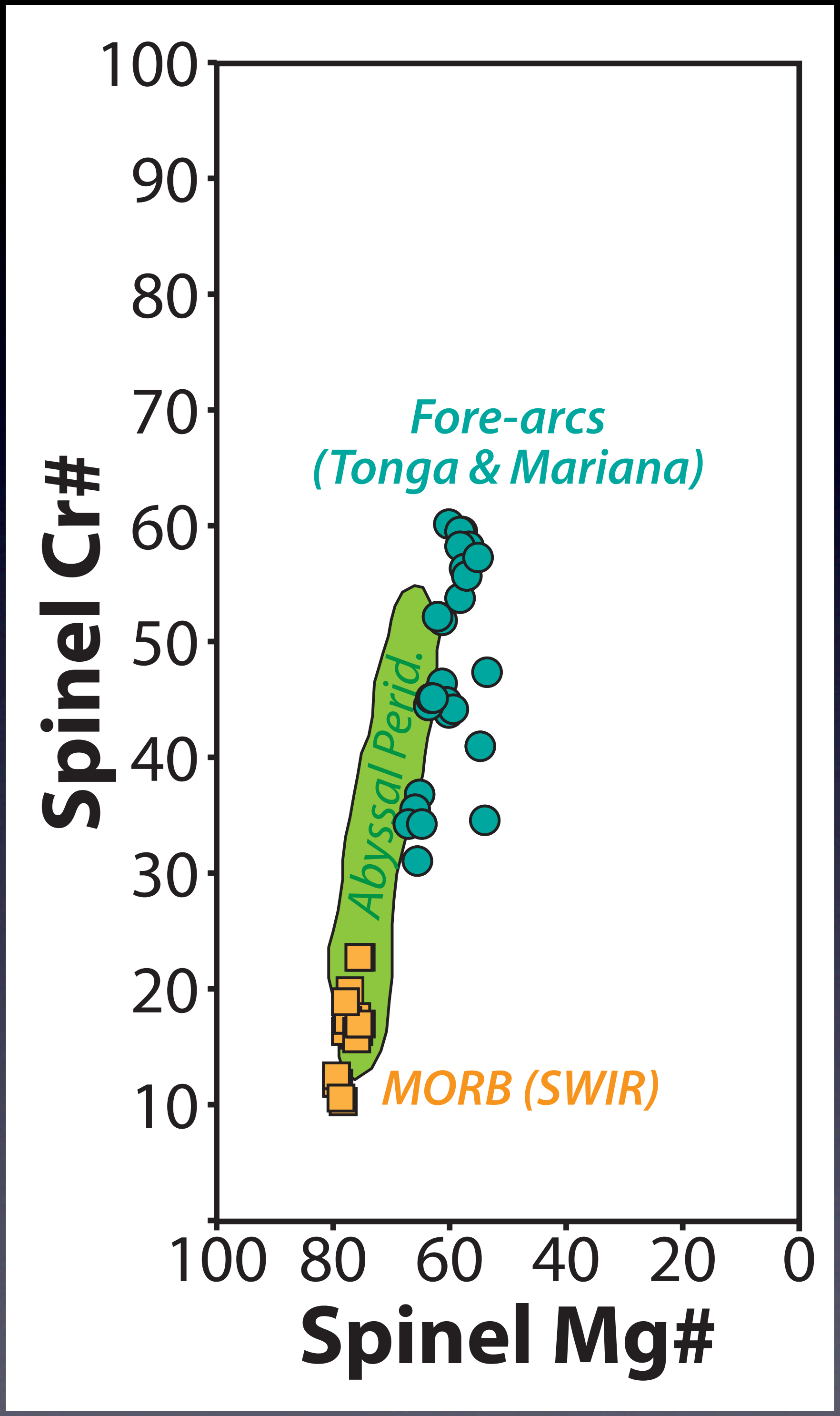
- Tonga trench





- Tonga peridotites are particularly fresh

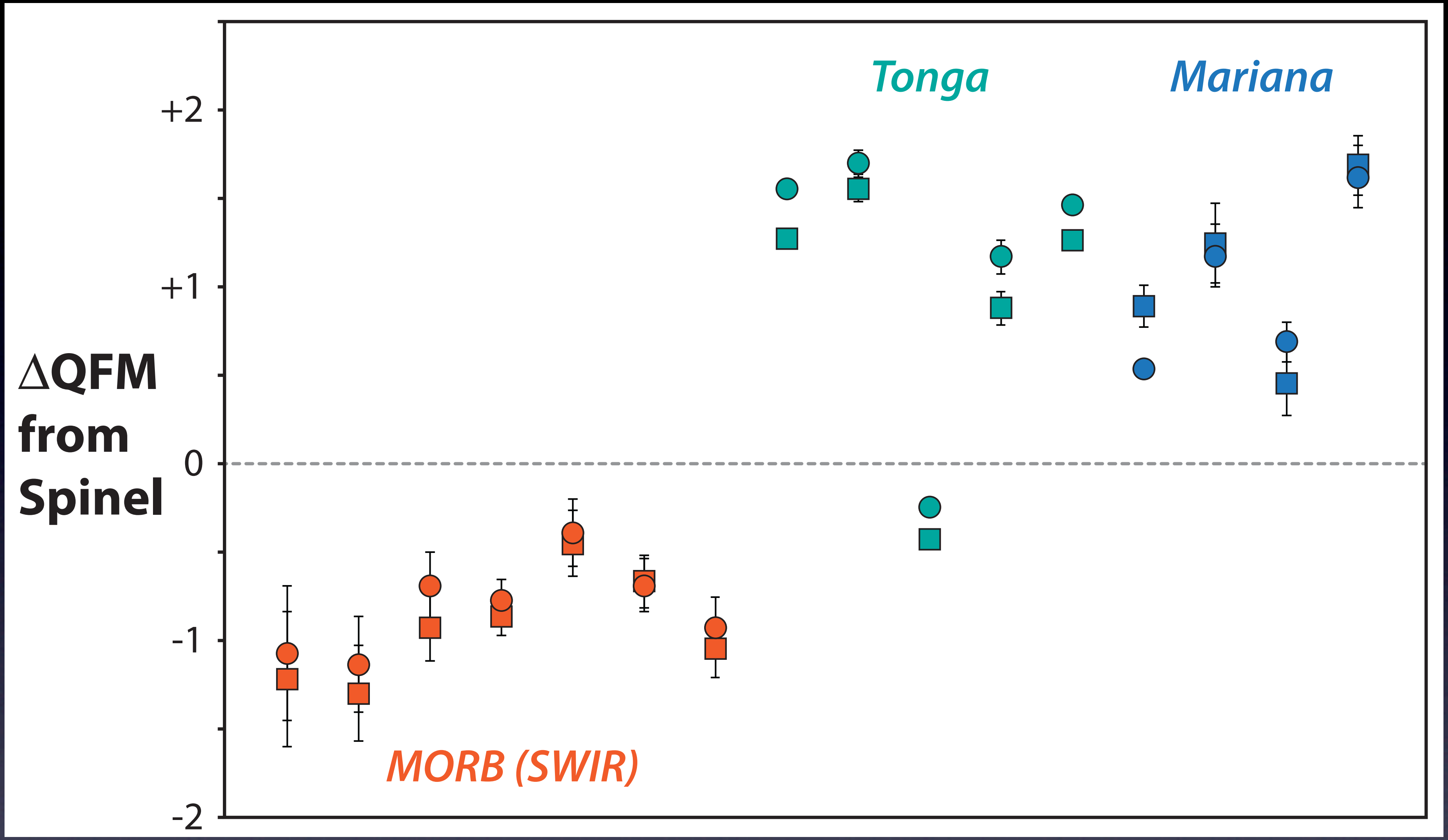
Fore-Arc Exposures of Arc Peridotite



- Fore-arc peridotites reflect greater melt extraction (higher Cr#) than abyssal peridotites

- Although lithospheric, fore-arc exposures indicate additional melt extraction at the subduction zone

Fore-Arc Exposures of Arc Peridotite



- Most fore arc peridotites are also more oxidized than abyssal peridotites

- Data suggest ~QFM+0.5-1.5, consistent with arc magmas, though there is some real heterogeneity

Where Else to Look?

- New data are just a start

- Ophiolites (e.g., Oman) provide opportunities to examine spatial variations with variable subduction influence

- Talkeetna provides context of overlying arc crustal section

- Josephine provides finer scale structures

Summary

• Mantle wedge fO_2 is a hotly debated topic, with consequences for the formation of the continents and the long-term evolution of the mantle

• Evidence from the magmatic record is mixed, though basalt $Fe^{3+}/\sum Fe$ points to oxidized wedge fO_2

• Peridotite record is sparse

• New data suggest oxidized arc mantle lithosphere that was melted beneath the arc, at fO_2 consistent with modern arc lavas

• Over what spatial scales does fO_2 vary?
How do variations relate to processes - melting, melt transport, etc.?
How do we access the asthenospheric wedge?