Mantle Wedge Oxygen Fugacity

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“...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

- 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

- 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
• Microbeam advances have streamlined analysis of $\frac{Fe^{3+}}{\Sigma Fe}$ in glass
• Magmatic redox can be explored on smaller scales
Fe Redox in Natural Glasses

• 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)*

- $\text{Fe}^{3+}/\Sigma\text{Fe}$ 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$_2$O content
  
  (Kelley & Cottrell, 2009)
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- Where resolvable, no oxidizing differentiation is evident
  
  (Kelley & Cottrell, 2012)
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• Within an arc, modeled source fO₂ 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

\[6\text{Fe}_2\text{SiO}_4 + \text{O}_2 = 3\text{Fe}_2\text{Si}_2\text{O}_6 + 2\text{Fe}^{3+}\text{Fe}^{2+}\text{O}_4\]

\text{ol} \quad \text{opp} \quad \text{sp}

• Microprobe method for determining \(\text{Fe}^{3+}/\Sigma\text{Fe}\) of spinels
  
  (Wood & Virgo, 1989)
Vanadium systematics in peridotites

Vanadium systematics in peridotites

Vanadium abundances in peridotites were modeled as a function of the degree of melting (F) and oxygen fugacity of melts, Kress and Carmichael, 1991, or the Fe3+/Fe2+ activity of various mineral phases, Ballhaus et al., 1990) are shown in Figure 1, where oxygen thermobarometric measurements between oceanic mantle peridotites and mid-ocean ridge basalts are based on Fe3+/Fe2+ ratios of lavas (Christie et al., 1986; Wooden and Miller, 1990; Carmichael, 1991). Equivalent intrinsic oxygen fugacities determined by oxygen thermobarometry (based on the Fe3+/Fe2+ activity in peridotite minerals) define the O2 conditions during melting.

Intrinsic oxygen fugacities determined by oxygen thermobarometry (based on the Fe3+/Fe2+ activity in peridotite minerals) define the O2 conditions during melting. The thermodynamic-based program pMELTS was used to calculate isobaric anhydrous partial melting paths at 1.5 GPa (Ghiorso and Sack, 1995). Equations for the degree of melting (F) and oxygen fugacity (δfO2) are given in Table 1 and used for the calculation of the melting pathways. The use of a thermodynamic approach to model melting stoichiometry at 1.5 GPa is more accurate than oceanic mantle peridotites and mid-ocean ridge basalts, which are in close proximity to present-day arcs (e.g., Izu-Bonin fore-arc). Partial melting calculations are classed as

- 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
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- 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 peridotites are particularly fresh

• Tonga trench

Tonga trench

dredges with oxygen fugacity measurements

dredges with peridotites

Australian Plate

Pacific Plate

5 mm
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 $\sim$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?