Iron isotopes in mantle and cumulate xenoliths from Adak Island, Central Aleutians

Emma S. Sosa[1], Claire E. Bucholz[1], Juan David Hernández-Montenegro[1], François L. H. Tissot[2], Michael A. Kipp[2], Suzanne M. Kay[3], Robert W. Kay[3]

[1]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125
[2]The Isotoparium, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125
[3]Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY 14850

1. Motivation

Fe isotopes of lavas and mantle rocks are effective tracers of differentiation, partial melting, and changes in oxidation state (fO_2), largely due to the respective affinities of isotopically light vs. heavy Fe for reduced (Fe^{+2}) and oxidized (Fe^{+3}) valence states. Despite higher fO_2, arc lava $\delta^{56}Fe$ values are lower than observed in MORBs (Fig 1). Understanding the source of this variability requires constraining the nature of primitive arc melts and how their $\delta^{56}Fe$ evolves during crustal ascent.

$$\delta^{56}Fe = 1000 \times \left[\frac{{}^{56}Fe/{}^{54}Fe_{\,sample}}{{}^{56}Fe/{}^{54}Fe_{\,standard}} - 1\right]$$

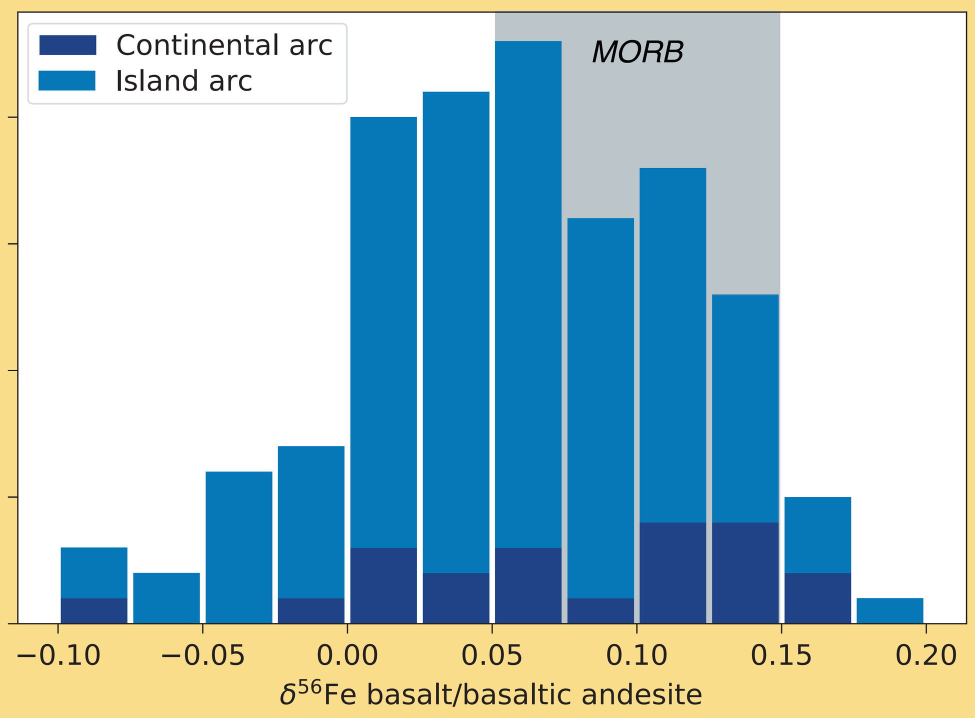

Figure 1: Frequency histogram of $\delta^{56}Fe$ in arc basalts/basaltic andesites [1,2,3,4] and MORB [5].

Primitive cumulate xenoliths record deep crustal conditions that may be overprinted by supracrustal processes in lavas. We present the second Fe isotopes study of a well-documented suite of arc cumulates. Cumulates from the Adagdak Volcano (Adak, Aleutians, Fig 2) extend to more primitive compositions than reported in the previous study (Lesser Antilles [6]; Fig 3), capturing a different but complementary interval of Fe isotope evolution in cumulates.

2. Adagdak xenolith suite

The Adagdak cumulate suite spans a wide lithological range, from primitive dunites and wehrlites to more evolved amphibole gabbros and hornblendites, and one mantle dunite (Fig 4). Mineral equilibria thermometry and oxybarometry suggests the cumulates crystallized at high temperatures (950-1100°C) from an oxidized melt (Δ FMQ 0.5-2.0), consistent with derivation from a primitive basalt in lower to mid-crustal levels [7,8].

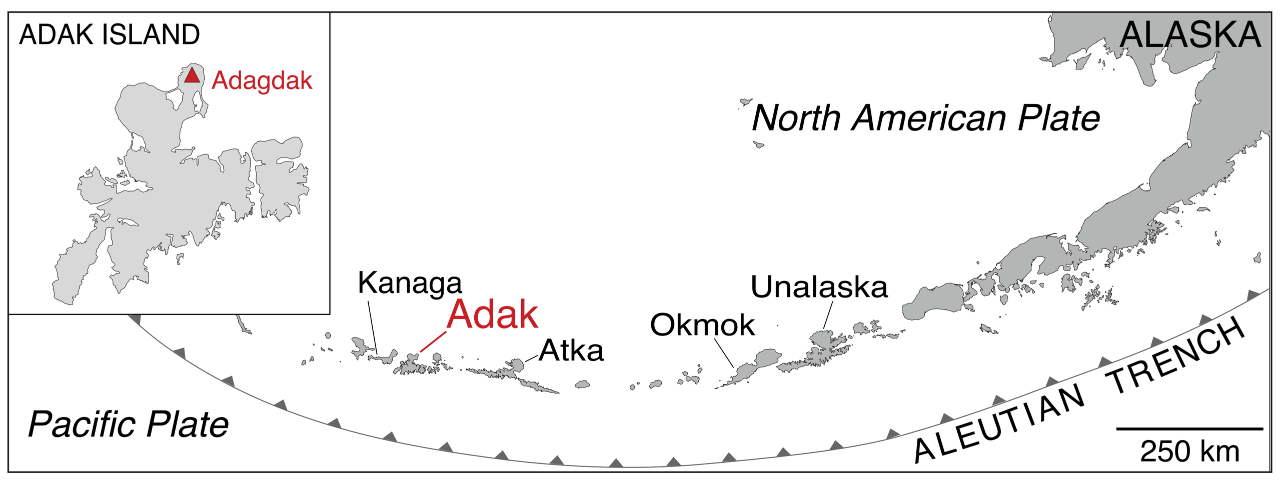

Figure 2: Map of the Aleutian Arc and Adak Island.

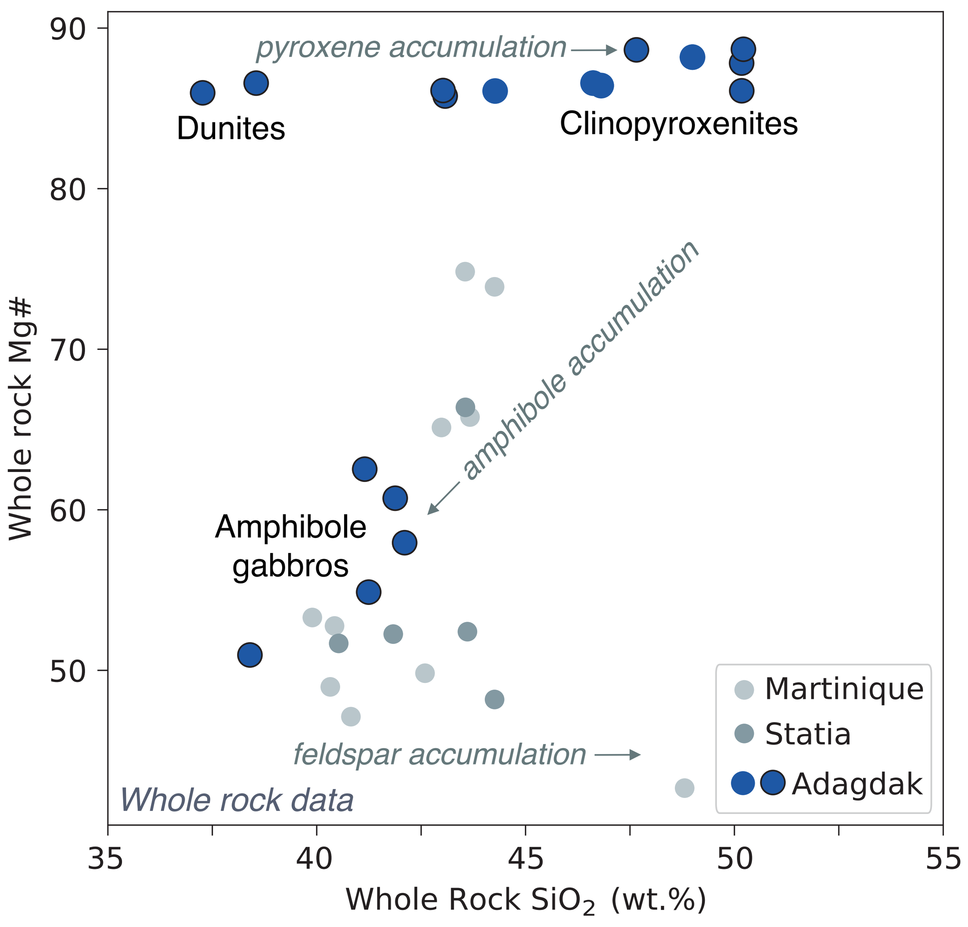

Figure 3: SiO_2 vs Mg# for cumulate xenoliths from Martinique and Statia (Lesser Antilles [6]) and Adagdak. For Adagdak: outlined circles - whole rock measurements, no outline - calculated from modal proportions and mineral chemistry.

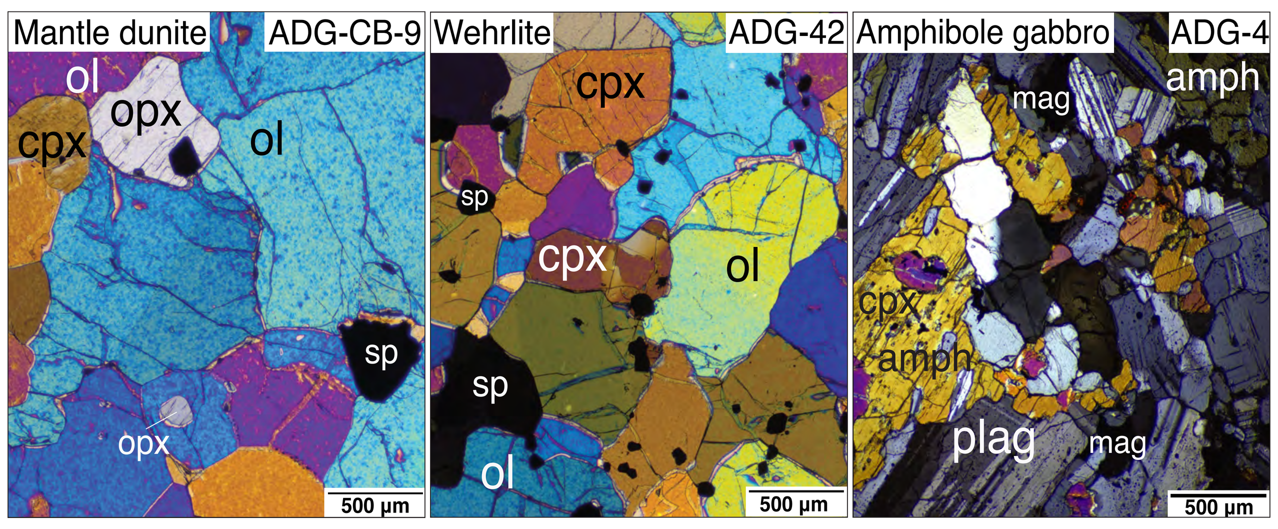

Figure 4: Photomicrographs of Adagdak xenoliths.

3. Methods and results

We analyzed minerals (spinel, clinopyroxene, olivine) and whole rock Fe isotope ratios from cumulate (and one mantle) xenoliths (Figs 5-7). Samples digestions, Fe separation and analysis were done at the Isotoparium through ion chromatography using a Neptune Plus MC-ICP-MS following established methods [9].

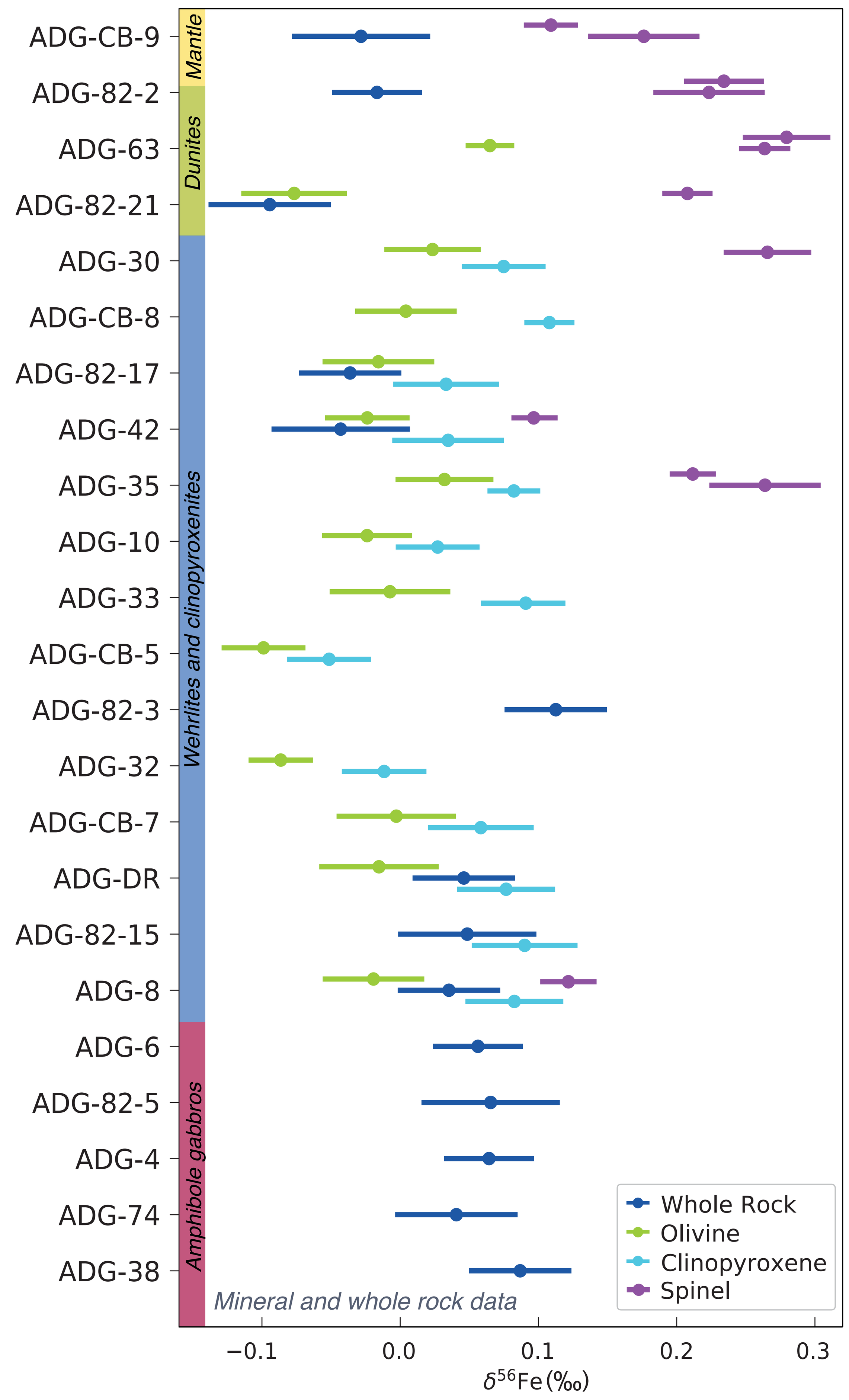

Figure 5: $\delta^{56}Fe$ for Adagdak olivine, clinopyroxene, and spinel mineral separates and whole rock. Samples organized by decreasing MgO.

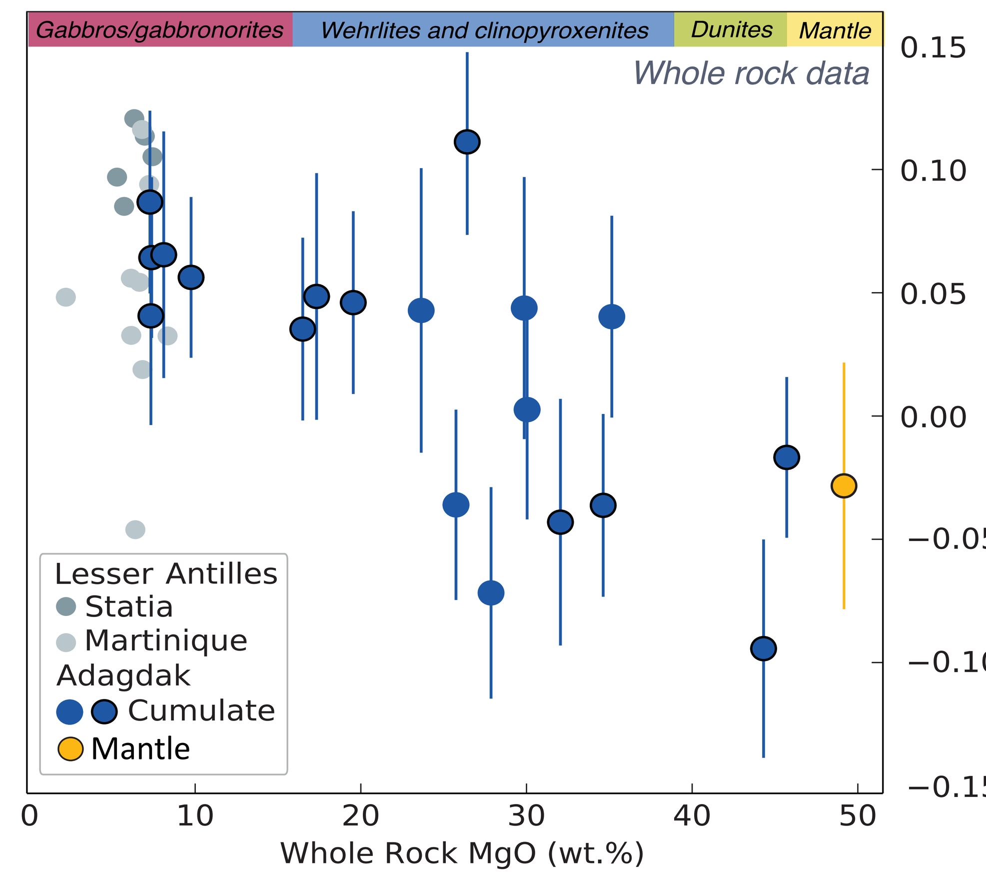

Figure 6: Whole rock MgO vs $\delta^{56}Fe$ for Adagdak and Lesser Antilles xenoliths.

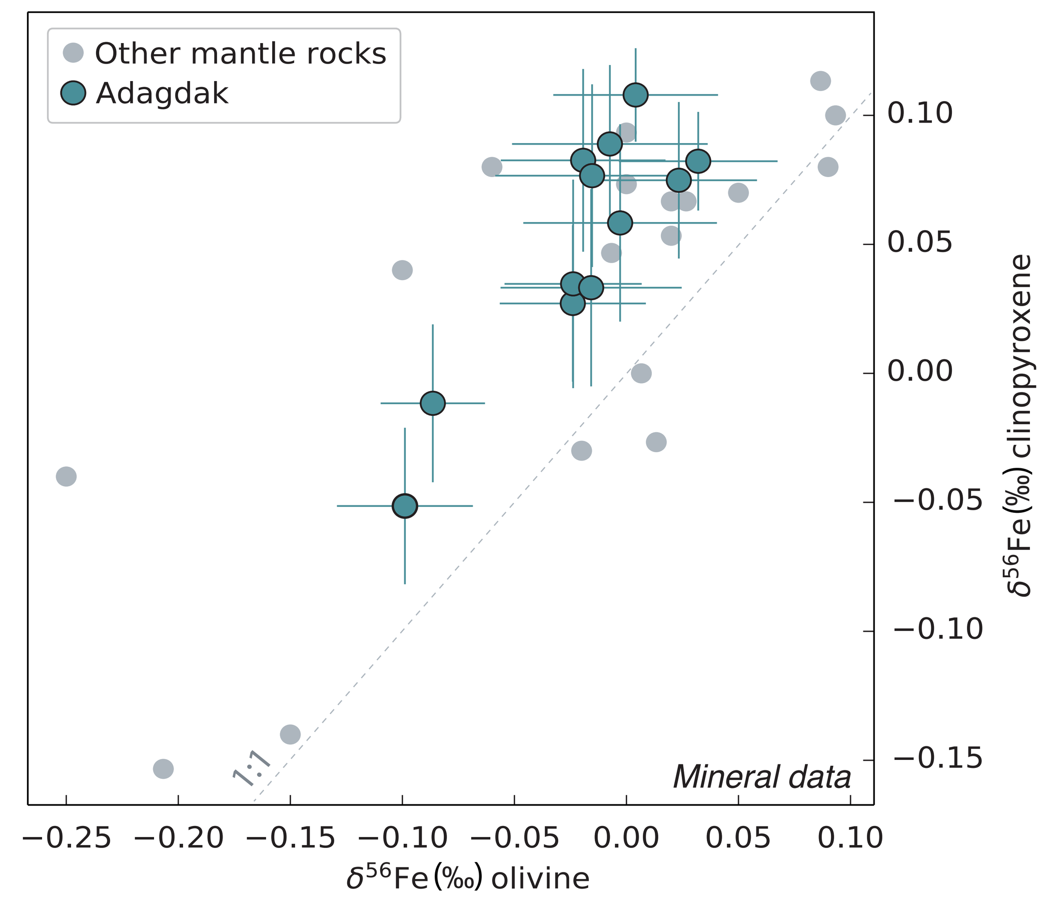

Figure 7: $\delta^{56}Fe$ in coexisting olivine and clinopyroxene for Adagdak cumulates compared to mineral separates from mantle xenoliths [10,11].

4. Modeling

Modal proportions, mineral chemistry, published Fe force constants [12], and mineral equilibria thermometry were used to calculate equilibrium Fe melt-cumulate fractionation factors ($\Delta^{56}Fe_{melt\text{-}cumulate}$), allowing us to estimate $\delta^{56}Fe$ for the parental melts to the cumulates:

$$\Delta_{melt\text{-}cumulate} = \delta_{melt} - \delta_{cumulate} = 2853\left(\frac{\langle F\rangle_{melt} - \langle F\rangle_{cumulate}}{T^2_{\,kelvin}}\right)^{[13]}$$

Mass balance modeling (Fig 8) demonstrates that only modest changes in $\delta^{56}Fe_{melt}$ can be explained by removing cumulate assemblages from primitive arc melts, and evolutionary trends are amplified in cumulate records.

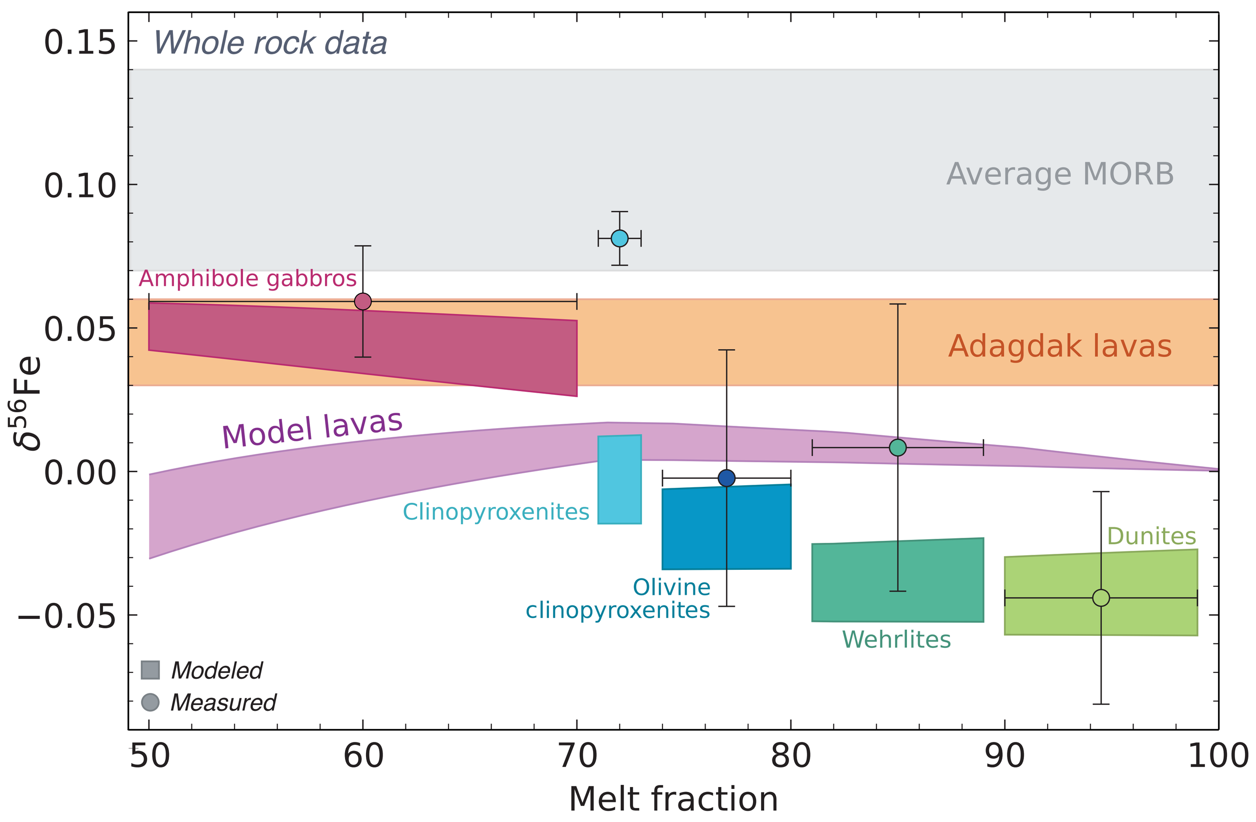

Figure 8: Fe isotope evolution model of primitive melt fractionation. Melt fraction estimates obtained through stepwise removal of cumulate assemblages from a primitive Mg-basalt. For each step, equilibrium olivine and clinopyroxene Mg#s were calculated and compared to cumulate mineralogy.

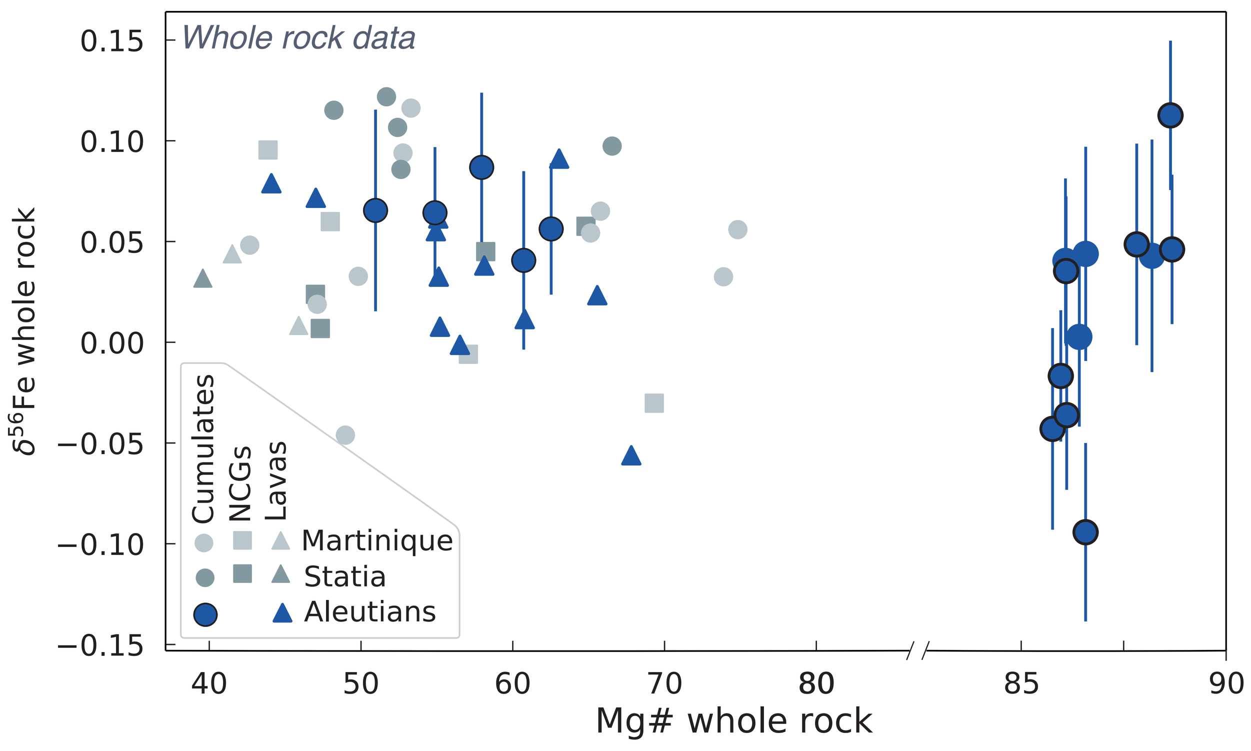

Figure 9: Whole rock Mg# vs $\delta^{56}Fe$ for non-cumulate gabbros (NCGs), cumulates, and lavas from the Lesser Antilles [6] and Aleutians [2].

5. Implications and future work

Cumulates provide robust records of Fe isotope evolution in evolving magma and highlight the role differentiation plays in Fe isotope evolution (Fig 9). Fractionation of isotopically light clinopyroxene and olivine may slightly increase $\delta^{56}Fe_{melt}$ initially, but once magnetite and amphibole saturate, removal of these isotopically heavy phases can significantly decrease $\delta^{56}Fe_{melt}$. Primitive cumulates provide a window into the $\delta^{56}Fe$ of near primary melts and should receive greater attention in future studies. As the effects of this isotopic depletion are modest, our data suggest that a depleted source melt is still a prerequisite for the low $\delta^{56}Fe$ values observed in many arc melts (Fig 1).

References: [**1**] N. Dauphas et al., EPSL 288, 255 (2009); [**2**] J. Foden et al., EPSL 494, 190 (2018); [**3**] H. M. Wiliams et al., GCA 226, 224 (2018); [**4**] D. H. Du et al., Geology (2022); [**5**] F. Z. Teng et al., GCA 107, 12 (2013); [**6**] G. F. Cooper and E. C. Inglis, Frontiers in Earth Science 9, (2022); [**7**] S. Debari et al., The Journal of Geology 95, 329 (1987); [**8**] Sosa et al., in prep; [**9**] N. Dauphas et al., Analytical Chemistry 76, 5855 (2004); [**10**] H. M. Williams et al., EPSL 235, 435 (2005); [**11**] H. M. Williams and M. Bizimis, EPSL 404, 396 (2014); [**12**] N. Dauphas et al., GCA 94, 254 (2012); [**13**] N. Dauphas et al., EPSL 329, 127 (2014).