Reconciling ^{210}Pb deficits with the physics of melt extraction

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Short-lived intermediate daughters in the uranium decay series have a broad range of half-lives suitable for timing melt production and transport processes beneath mid-ocean ridges. The discovery two decades ago of ^{226}Ra excesses in mid-ocean ridge basalts constrained the time between Ra-Th fractionation and eruption to be on the order of 1000 years or less. The recent discovery of ^{210}Pb deficits, correlated with ^{226}Ra excesses in mid-ocean ridge basalts [1], indicates that the timescale must be much shorter still—less than 100 years.

A critical question is what part of the melting process the ^{210}Pb-^{226}Ra disequilibrium is timing. If the fractionation can only be produced during partial melting in the mantle, then the observed disequilibrium implies melt transport rates on the order of km/yr, which would present a serious challenge to our physical understanding of melt extraction. Another possibility is that the ^{210}Pb-^{226}Ra disequilibrium results from crustal processing. Numerical models have shown that shallow-level diffusive exchange with gabbroic cumulates is capable of producing ^{226}Ra excesses (or deficits) in the melt [2,3]. We have found that the same process leads to ^{210}Pb deficits.

A plagioclase or clinopyroxene grain interacting with its surroundings develops internal steady-state daughter concentration profiles, which represent a balance of radioactive production and decay and diffusive fluxes[3]. Because the half-life of ^{210}Pb is short compared to the timescale for Pb diffusion, the spatial distribution of ^{210}Pb activity within each mineral closely follows that of ^{226}Ra. Ra is much less compatible than Pb, and ^{210}Pb is thus more depleted within the interior of the mineral grain than it would be if partitioning equilibrium were achieved. The result is that ^{210}Pb is absorbed far more readily than ^{226}Ra from any melt it comes in contact with, leaving the melt with a ^{210}Pb deficit. This deficit develops rapidly, and reaches a steady-state value on a timescale comparable to the half-life of ^{210}Pb, about 20 years. The magnitude of the deficit is only weakly dependent on the enrichment of the melt and on the relative diffusivities of Ra and Pb in the minerals, but is senstitive to the melt/rock ratio and to the relative mineral/melt partition coefficients of Ra and Pb. A typical value of the ^{210}Pb/^{226}Ra activity ratio following gabbro exchange is ~ 0.1.

References

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Carbon and iron isotopic evidence for photosynthesis in a 3.5 Ga old shallow marine depositional environment

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Different abiologic and biologic models exist for the oxidation of Fe(II)aq in the upper part of the Archean ocean; UV-induced photochemical reactions, anoxygenic photosynthetic iron oxidation, or reaction with free oxygen generated by oxygenic photosynthesis. In the O_2-poor, and CO_2-rich Archean ocean these processes would have competed with direct precipitation of Fe-carbonates. Here we discuss the origin of Fe-oxides that occur in the 3.49 Ga old Chert-Barite-Unit of the Dresser Formation at North Pole (Pilbara Drilling Project, Western Australia). This unit represents a shallow water depositional environment within a volcanic caldera, and has experienced low-grade metamorphism (<350°C). It consists from bottom to top of bedded cherts, barite-sulfide beds, and bedded Fe-rich carbonates. An underlying network of barite- and silica-feeder dikes suggests synsedimentary hydrothermal activity. Towards the top of the unit, a succession of thin alternating bands of hematite and Fe-rich carbonate occurs, that includes kerogenous laminations that resemble typical microbial mats. These laminations display a δ^{13}C (-30 to -18‰), that is distinctly different from the δ^{13}C of kerogen in the underlying silica dikes (-34 to -31‰). The isotopic discrepancy between these two pools of kerogen cannot be explained by metamorphism. The hematite bands display a strong positive δ^{56}Fe (+0.1 to +1‰), compared to the Fe-rich carbonates (-0.6 to +0.4‰) and underlying barite-sulfide beds (-0.7 to -0.4‰). These petrographic and isotopic observations exclude abiologic oxidation of Fe(II)aq by UV-induced photolysis, and suggest that oxygenic and/or anoxygenic photosynthesis were directly involved in the formation of Fe-oxides in this Early Archean shallow marine depositional environment.