Live(?) $^{60}$Fe During Aqueous Alteration of Chondrite Parent Bodies: Evidence from UOCs and CV Chondrites

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How Useful is $^{60}$Fe as an Early Solar System Chronometer?

The short-lived radionuclide $^{60}$Fe decays to $^{56}$Ni with a half-life of 2.6 Myr. It has the potential to date events in the first 10-15 Myrs of solar system history! However, Fe and Ni are readily mobilized upon heating, particularly in the presence of water [1,2].

- Requires chondrules to undergo no/low alteration after formation.
- Even some chondrules from lowest petrologic grade (3.0) chondrites are affected [1].

Ubiquitous alteration on chondrite parent bodies produced new phases, such as Magnetite and Fayalite, that might be amenable to Fe-Ni dating. In addition to their high Fe content, these phases are relatively pure, with trace Ni content.

If the formation of secondary minerals occurred within a few million years after solar system formation, it is plausible the $^{60}$Fe signature would be measurable in the form of $^{56}$Ni excesses in secondary phases.

We present preliminary results of our investigation of magnetite and fayalite:
- **Fayalite** ($\text{Fe}_2\text{SiO}_4$) from Kaba (CV3.1), Vicência (LL3.2), and MAC 88107 (CO3-like).
- **Magnetite** ($\text{Fe}_3\text{O}_4$) from Kaba and Semarkona (LL3.0).

Results - Internal Isochrons

![Figure 3: Internal isochrons from investigated samples. (a) Semarkona magnetite from this study (circles) compared to a previous investigation (squares; [10]); (b) Kaba fayalite and magnetite; (c) MAC 88107 fayalite; (d) Vicência fayalite. Dashed lines are upper limits. Solid gray line is terrestrial $^{56}$Ni/$^{56}$Fe ratio.](image)

Radiogenic $^{56}$Ni from $^{56}$Fe decay is calculated from a plot of $^{56}$Ni/$^{56}$Fe versus $^{56}$Fe/$^{56}$Ni (Fig. 3).
- Positive correlation of $^{56}$Ni/$^{56}$Fe ratios with $^{56}$Fe/$^{56}$Ni is indicative of in situ decay of $^{56}$Fe.
- Yields $^{56}$Fe/$^{56}$Ni at the time of mineral formation.
- A zero or negative slope indicates no $^{56}$Ni, or a disturbed system.

All determinations of radiogenic $^{56}$Ni were unresolved from zero within 2o uncertainties (Fig. 3), as were the initial $^{56}$Fe/$^{56}$Ni ratios.

We calculated one-sided upper limits of $^{56}$Fe/$^{56}$Ni ratios (dashed line, Fig. 3), wherein the probability is 95% that the actual ratio falls below the upper limit.
- (a) Semarkona: < 5.9 × 10$^{-10}$
- (b) Kaba: < 7.8 × 10$^{-10}$
- (c) MAC 88107: < 9.4 × 10$^{-10}$
- (d) Vicência: Did not calculate (one grain).

Conclusions and Future Work

- At present, from this study of secondary phases we are only able to place upper limits on the initial $^{56}$Fe/$^{56}$Ni ratio.
- Our values for initial solar system $^{56}$Fe/$^{56}$Ni are not inconsistent with the estimated ratios from chondrules from [11].
- Canonical $^{56}$Fe/$^{56}$Ni ratios of a significant portion of investigated samples are likely compromised:
  - CAIs - isotopic anomalies.
  - Chondrules - Fe-Ni redistribution.
- Secondary phases phase tentatively upper limits on initial $^{56}$Fe/$^{56}$Ni ratio of < 3×10$^{-10}$.

- Constraining the solar system initial abundance still holds promise if the right sample is found, and instrument techniques continue to improve.
- We continue to search for ideal samples and phases for study.
- We purchased an unprocessed 4.9-cm section of a我相信 that the formation of secondary phases occurred within a few million years after solar system formation.

Challenges: Analysis of Small Grains

Fayalite grains were identified in almost every meteorite examined, but few were of sufficient size for SIMS analyses. Additional challenges arise from fayalite associated with magnetite and FeNi-metal, as accidentally ablating these would yield low Fe/Ni ratios.

- We are investigating methods to limit incidental sampling of surrounding phases. Preliminary experiments are underway.

Placing Results in Solar System Context

Our upper limits are within the range of initial $^{56}$Fe/$^{56}$Ni ratios inferred from chondrules of unequilibrated ordinary chondrites from Krymka [11] (Fig. 4).

Several previous studies are not represented on Fig. 4 because they have been shown to suffer from mass-independent isotope anomalies (e.g., Ni in CAIs), ratio bias (c.f. [12]) or remobilization of Fe-Ni (c.f. [1]). This filters out all except angrites (bulk, chondrules), Gujba (CB) chondrules, Krymka (LL) chondrules, and the eucrite Bouvonte (bulk rock and mineral separates). The Semarkona magnetite value [10] is shown in Fig. 4 for comparison.

The timing of magnetite formation in Semarkona has not been directly determined. The age (2.4 ± 0.2 Myr) is from $^{56}$Ni/$^{56}$Fe dating of the fayalite in EET 90161 (LL3.0), assuming a similar timing [13,14]. Similarly, the date for secondary fayalite formation in Kaba was assumed to be the same as Asuka 881317 (CV3) at 4.2 ± 0.8 Myr [13].

References