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The search for ^{60}Fe in secondary fayalite and magnetite

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Motivation

Short-lived radionuclide ^{60}Fe decays to ^{60}Ni with a half-life of 2.6 Myr.
- Date events in the first 10-15 Myrs of solar system history?
- Requires low/no alteration between then and now.

Fe and Ni are readily mobile, particularly in the presence of water [1,2].

However, the ubiquitous alteration has produced new phases, such as magnetite and fayalite, that might be amenable to ^{60}Fe-^{60}Ni dating.

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 ^{60}Ni excesses in secondary phases.

To date, we have investigated secondary phases in three meteorites:
- Fayalite (Fe_2SiO_4) from Kaba (CV3.1) and Vicência (LL3.2);
- Magnetite (Fe_3O_4) from Kaba and Semarkona (LL3.0).

Methods

Secondary Ion Mass Spectrometry

Instrument:	Cameca ims 1280 ion microprobe
Mode:	Combined multi-collection jump-scanning
Masses measured:	^{56}Fe, ^{60}Ni, ^{61}Ni, ^{62}Ni
Mass resolving power:	~4800
Beam size:	~10 µm, with halo is <20µm
Beam current:	1.9 to 3.4 nA
Pre-sputter:	1.5 to 3 min
Sensitivity Factor correction:	Synthetic fayalite (Fa_{99}; [3]) and terrestrial magnetite (Fe# = 97.5)

Data Reduction

Isotopes ratios were calculated from total counts to reduce the effect of ratio bias [4].

Isotope ratios expressed as delta notation normalized to ^{61}Ni:

$$\delta^{60}\mathrm{Ni} = \frac{(^{60}\mathrm{Ni}/^{61}\mathrm{Ni})_{Sample} - (^{60}\mathrm{Ni}/^{61}\mathrm{Ni})_{Ref}}{(^{60}\mathrm{Ni}/^{61}\mathrm{Ni})_{Ref}} \times 1000\ (‰)$$

$$\delta^{62}\mathrm{Ni} = \frac{(^{62}\mathrm{Ni}/^{61}\mathrm{Ni})_{Sample} - (^{62}\mathrm{Ni}/^{61}\mathrm{Ni})_{Ref}}{(^{62}\mathrm{Ni}/^{61}\mathrm{Ni})_{Ref}} \times 1000\ (‰)$$

Using reference [5] values ^{60}Ni/^{61}Ni = 23.0047 and ^{62}Ni/^{61}Ni = 3.1884 [Baum10].

Internal mass-fractionation correction:

$$\Delta^{60}\mathrm{Ni} = \delta^{60}\mathrm{Ni} - (-\delta^{62}\mathrm{Ni})$$

Radiogenic ^{60}Ni (^{60}Ni*) from ^{60}Fe decay is calculated from slope of ^{60}Ni/^{61}Ni versus ^{56}Fe/^{61}Ni.
- Yields ^{60}Fe/^{56}Fe at the time of formation/alteration.
- A zero slope for ^{60}Fe/^{56}Fe indicates no excess ^{60}Fe* in the sample.

Results

Semarkona (LL3.0) Magnetite

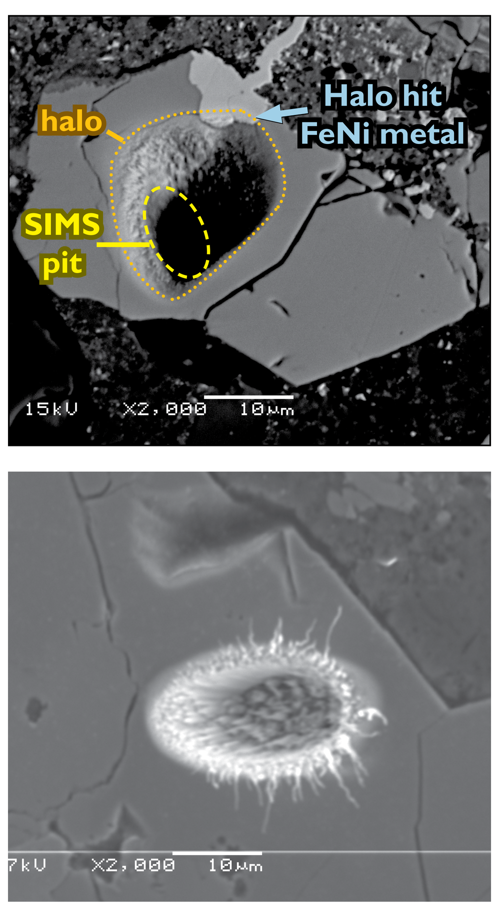

Fig. 1: Magnetite is abundant but typically contains large cracks and Fe-rich inclusions. Our first set of analyses (a) had a ~10µm beam spot but large halo. A later series (b) had a larger spot but smaller halo.

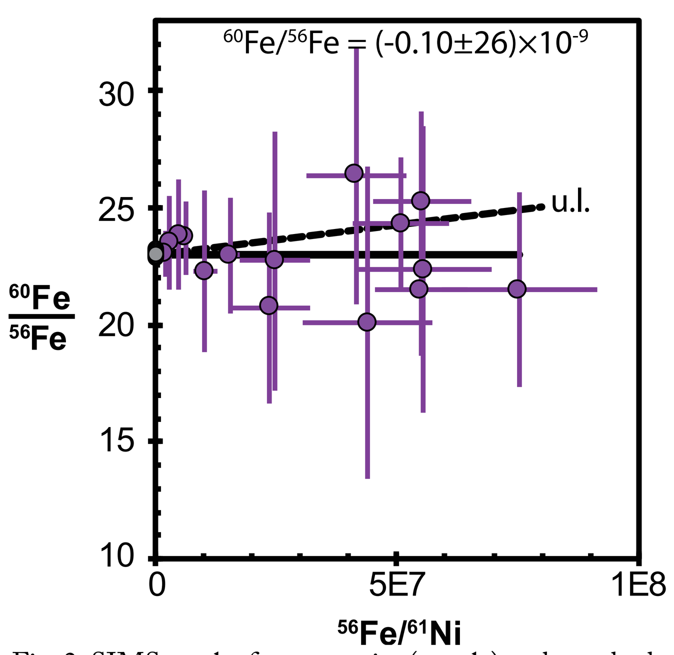

Fig. 2: SIMS results for magnetite (purple) and standards (gray) with best fit line and upper limit (u.l.).

Thirteen magnetite grains analyzed
- ^{56}Fe/^{61}Ni ratios of (0.21 - 7.5) × 10^7.

Radiogenic ^{60}Ni unresolved from zero. Upper limit on $(^{60}\mathrm{Fe}/^{56}\mathrm{Fe})_0$ of <7.3×10^{-8}.

Fayalitic olivine (<Fa_{40}) was investigated, but the Fe/Ni ratio was too low (<3000) for our measuremetnts.

Kaba (CV3.1) Magnetite & Fayalite

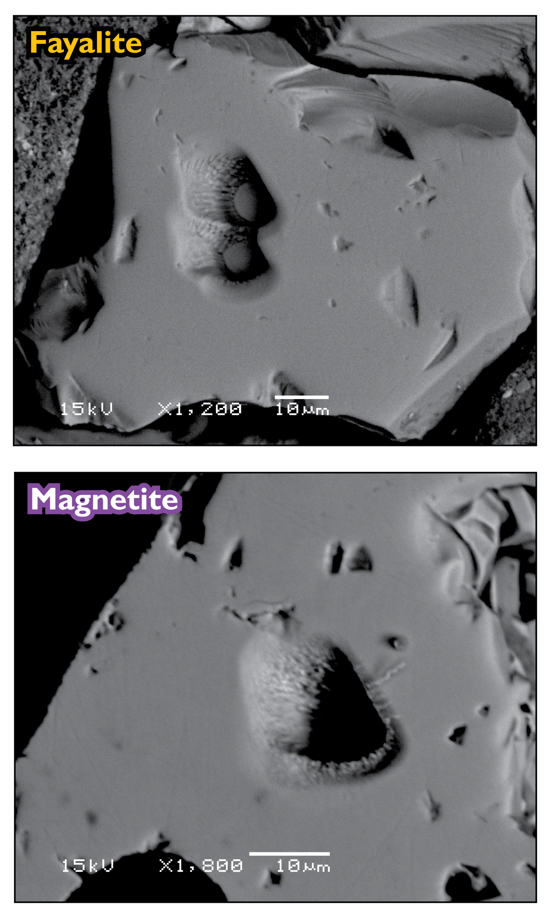

Fig. 3: Large secondary grains of (a) fayalite and (b) magnetite are ideal for SIMS investigation.

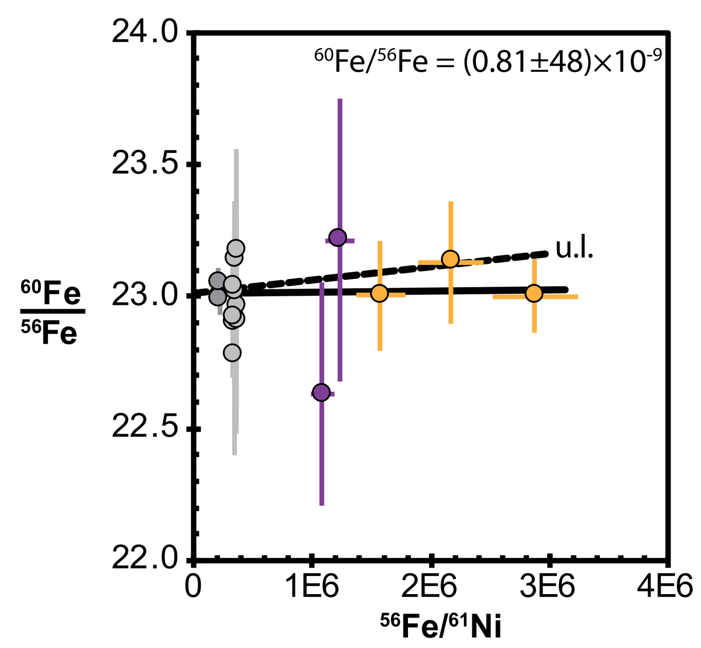

Fig. 4: SIMS results for magnetite (purple), fayalite (orange), and standards (gray) with best fit line and upper limit (u.l.).

Two magnetite grains analyzed
- ^{56}Fe/^{61}Ni ratios of (1.1 and 1.2) × 10^6.

Three fayalite grains analyzed
- ^{56}Fe/^{61}Ni ratios of (1.6 - 2.9) × 10^6.

Radiogenic ^{60}Ni unresolved from zero. Upper limit on $(^{60}\mathrm{Fe}/^{56}\mathrm{Fe})_0$ of <8×10^{-8}.

Vicência (LL3.2) Fayalite

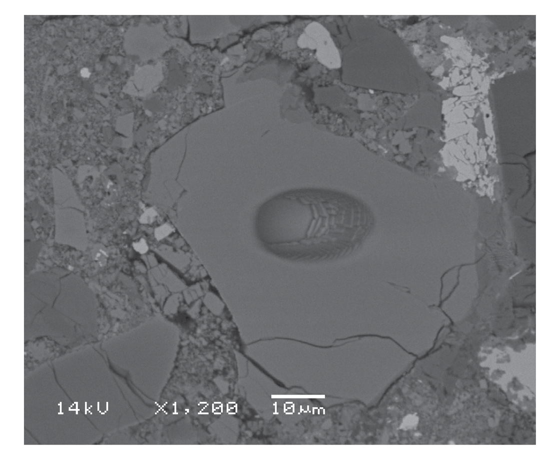

Fig. 5: Fayalite is large enough for SIMS analysis but has lower Fe compared to Kaba (Fa_{40-80} vs Fa_{100}), yielding lower Fe/Ni ratios.

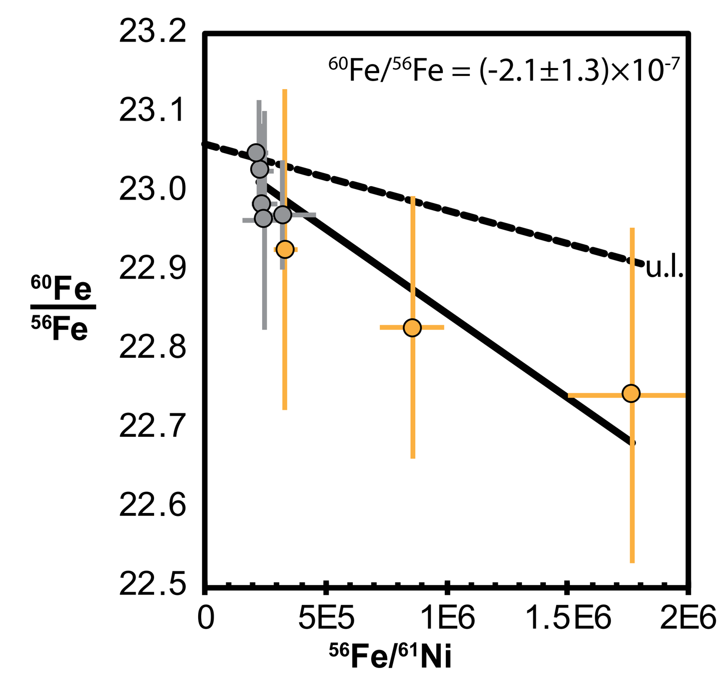

Fig. 6: SIMS results for fayalite (orange) and standards (gray) with best fit line and upper limit (u.l.).

Three fayalite grains analyzed
- ^{56}Fe/^{61}Ni ratios of (0.33 - 1.8) × 10^6.

Radiogenic ^{60}Ni unresolved from zero.

Negative ^{60}Ni* - isotope fractionation?

Early solar system context

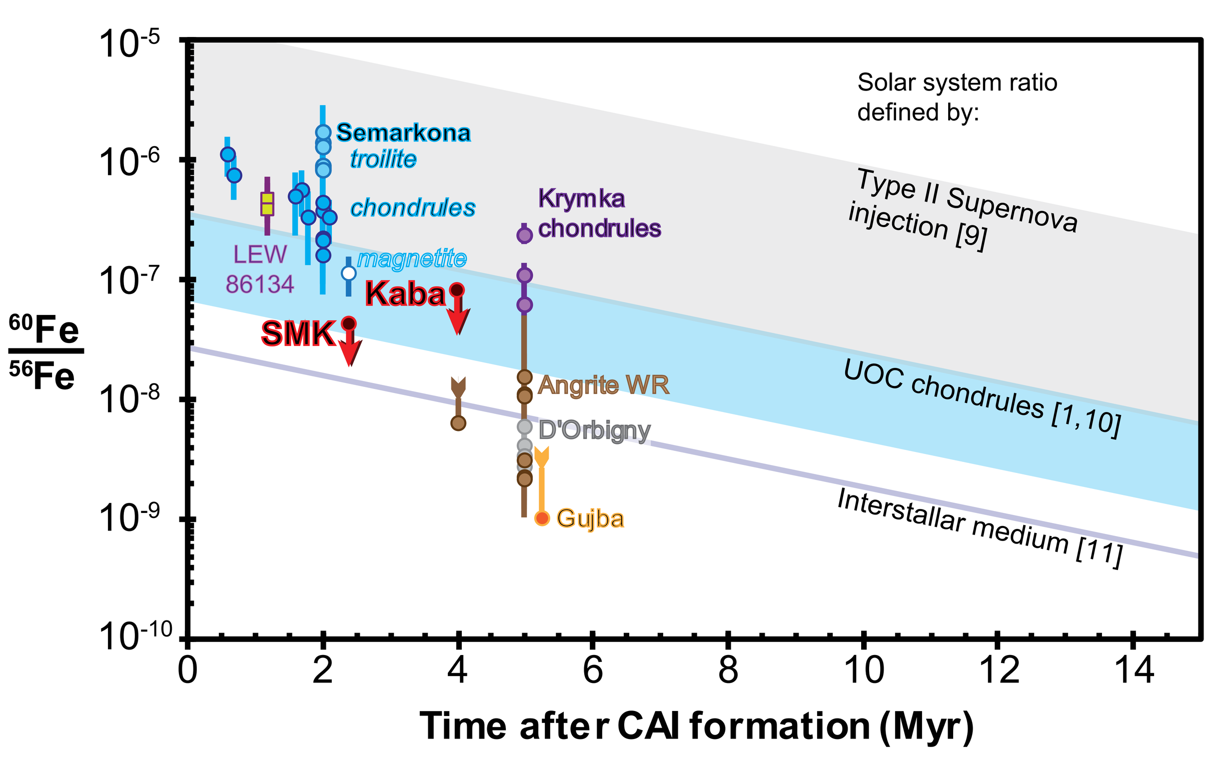

Fig. 7: Selected published ^{60}Fe/^{56}Fe ratios compared to upper limits from this study (red) at the time of secondary mineral formation. Times of alteration are 2.4 Myr for Semarkona [6,7] and 4 Myr for Kaba [6]. Data sources from [8] and references therein.

Our upper limits are consistent with low initial ^{60}Fe/^{56}Fe ratios from chondrules of unequilibrated ordinary chondrites (Fig. 7).

These results indicate ^{60}Fe is too low to have originated as injection by supernova.

Implications for ^{60}Fe investigations

- Ready mobilization of Fe and Ni will likely prevent ^{60}Fe from becoming a useful chronometer.
- Canonical ^{60}Fe/^{56}Fe ratios of a significant portion of investigated samples (Fig. 7) are likely compromised:
  - CAIs - Ni isotopic anomalies.
  - Chondrules - Fe-Ni redistribution.
  - Secondary phases place tentative upper limits on initial ^{60}Fe/^{56}Fe the order of <8×10^{-8}.
- 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.

Use of secondary phases

Semarkona magnetite was of interest because of the resolved ^{60}Fe/^{56}Fe reported by [12]. Fayalite in Kaba and Vicência have good Mn-Cr ages [6,13], suggesting little post-formation alteration. However,
- Vicência results suggest subsequent mobilization and/or Fe-Ni fractionation.
- Kaba and Semarkona magnetite and fayalite did not reveal resolved ^{60}Ni*.

Possibility of Fe/Ni mobilization
- Alteration in primary olivine and pyroxene grains observed by [2].
- Fe and Ni are more mobile in magnetite compared to olivine.
- Fe-Ni system can be disturbed more easily (e.g., lower temperature) than Mn-Cr and O.

References

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