Mn-Cr Isotope Systematics of Fayalite-Silica Intergrowths from the Stardust Mission to Comet 81P/Wild 2

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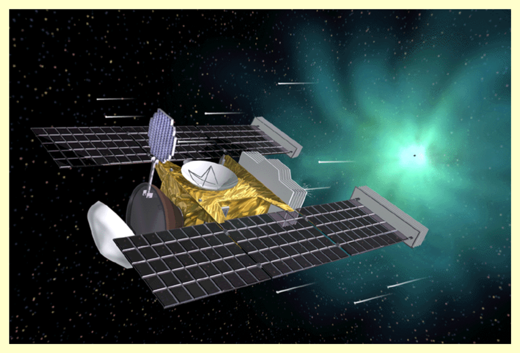
INTRODUCTION

Among the dust particles returned by NASA's Stardust mission to the coma of comet 81P/Wild 2 are several fragments of a particle referred to as "Ada". These fragments exhibit distinctive fayalite-silica intergrowths (Fig. 1) which are similar to the occurrence of fayalite in chondrule rims and the matrices of ordinary and carbonaceous chondrites. Two competing models for the origin of fayalite in chondrites have been proposed: (1) high temperature (>1000˚C) gas-solid condensation under highly oxidizing conditions in the protoplanetary disk following chondrule formation (e.g. [1]), or (2) low temperature (<300˚C) formation during fluid-assisted thermal metamorphism on a chondrite parent body (e.g. [2]). Aqueous activity is thought to have begun several million years after CAI formation on carbonaceous chondrite parent bodies and persisted, perhaps episodically, for 10-15 Ma [3, 4].

In this study, we measured the Cr isotopic composition of Ada fayalite in order to detect radiogenic ^{53}Cr produced from the decay of short-lived ^{53}Mn. Developing a Mn-Cr chronology for fayalite-bearing fragments from Comet Wild 2 may distinguish between formation mechanisms and further constrain the timeframe during which inner solar system materials were incorporated into Comet Wild 2.



An artist's rendition of the Stardust spacecraft with its collector deployed. Image courtesy of stardust.jpl.nasa.gov.

PETROGRAPHY

Back-scattered electron images of the Ada fragments reveal fine-scale intergrowths of fayalite and silica and Fe-Cr sulfide grains around the periphery of the fragments. STEM images of microtome slices also show nm-sized Fe-sulfide grains in fayalite and chromite around the margin of the fragments.

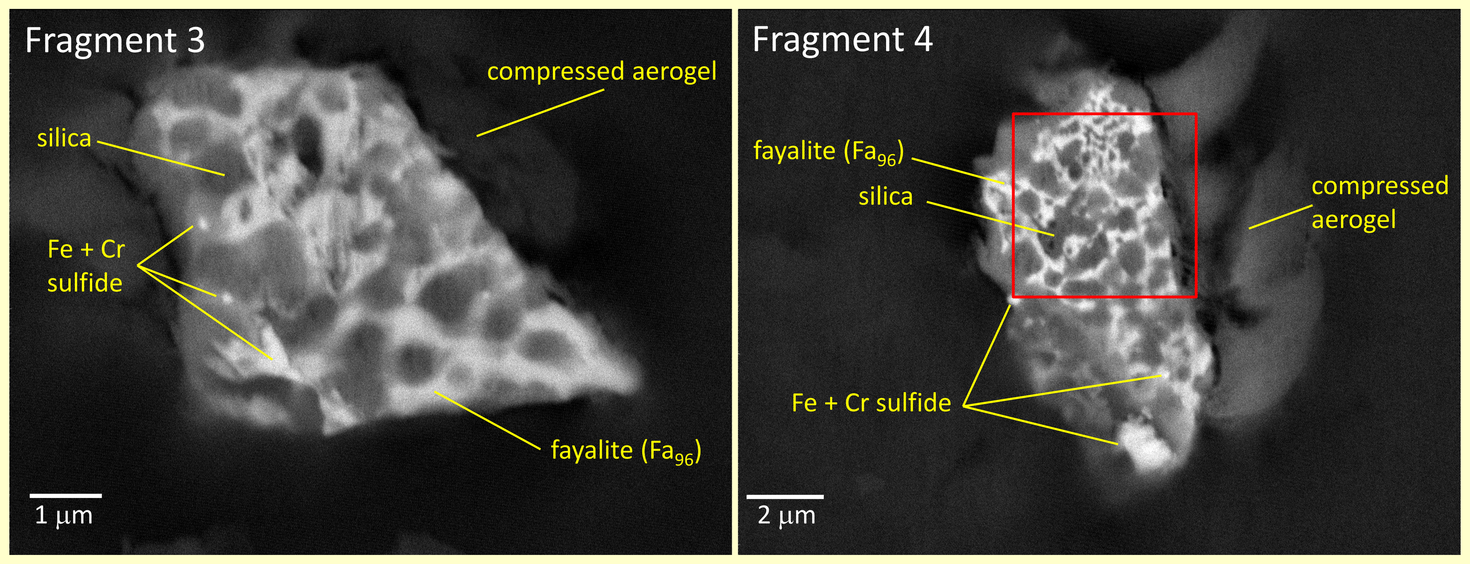


Figure 1. Back-scattered electron images of Ada-C fragments 3 and 4. The region in fragment 4 outlined in red is shown in the second column of the ion images in figure 3.

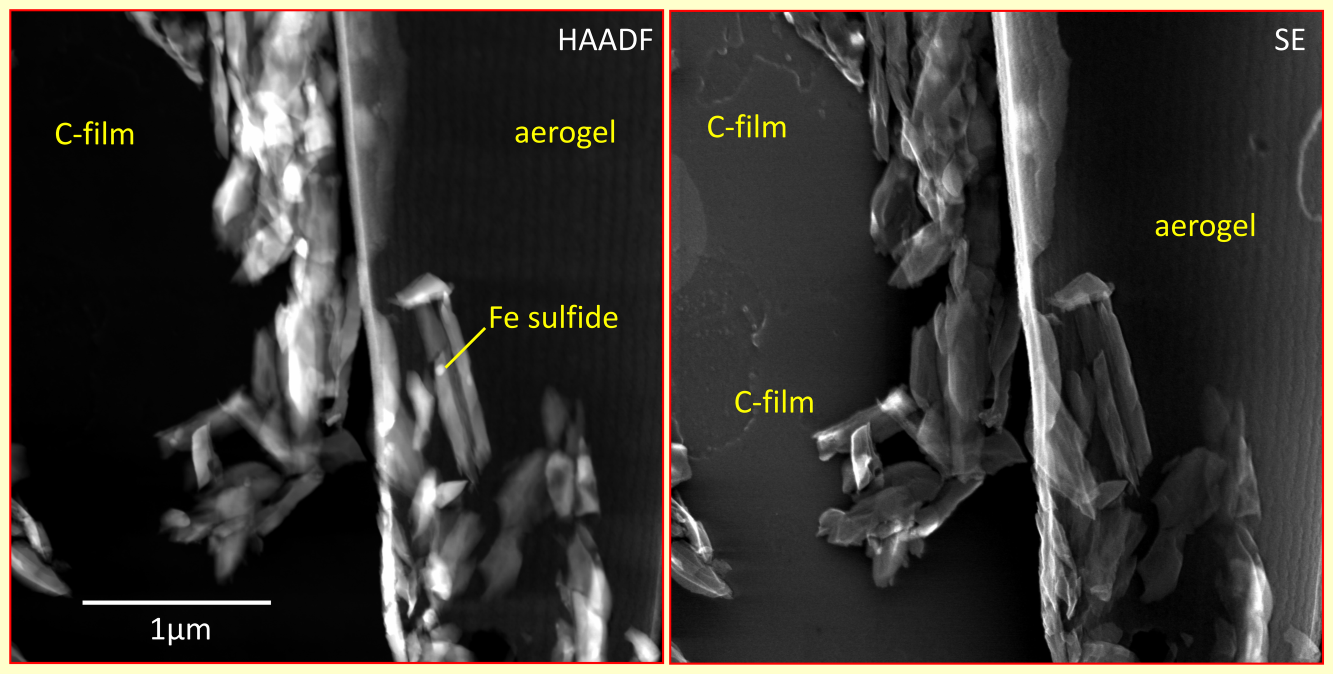


Figure 2. Scanning TEM images of a microtome slice from Ada-B-4-1A-A. High angle annular dark field (HAADF) image is on the left, and secondary electron (SE) image is on the right. A nanometer-sized Fe-sulfide grain is visible in the HAADF image along the margin of the fragment.

METHODS

Mn and Cr isotope measurements were made using the NanoSIMS 50 at LLNL during two analytical sessions. The analyses were performed using a $^{16}O^-$ primary ion beam rastered over areas of 5µm^2 to 8 µm^2. Secondary ion intensities were measured by combined multicollection and magnetic field peak jumping. The primary difference between the two analytical sessions reflected a change in the ion source used to generate the O^- primary ion beam. In the first session, the standard Cameca duoplasmatron ion source was used to generate a 2 pA ion beam focused to an ~250 nm spot size. In the second session, a new Hyperion II ion source (Oregon Physics) was used to generate a 3 pA primary ion beam focused to ~140 nm spot size.

RESULTS

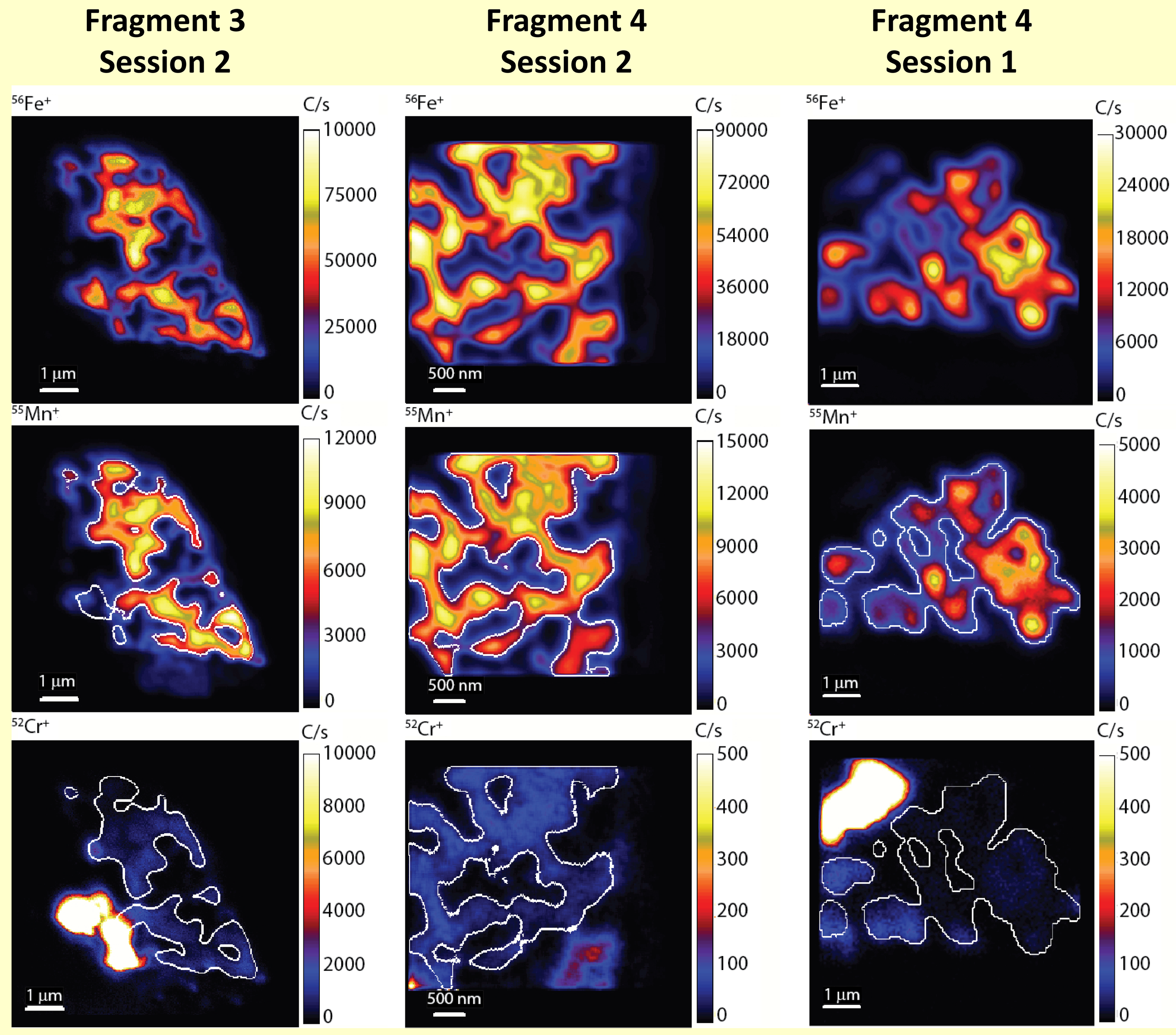


Figure 3. Quantitative images of ion intensity from Ada-C fragments 3 and 4 collected during two analytical sessions (see methods). The images from session 1 are rotated approximately 90˚ counter-clockwise relative to session 2. The white line in each $^{55}Mn^+$ image is the region defined as fayalite based on the $^{56}Fe^+$ image. The white line in each $^{52}Cr^+$ image surrounds the pixels used to calculate the $^{55}Mn/^{52}Cr$ and $^{53}Cr/^{52}Cr$ ratios shown in figure 4.

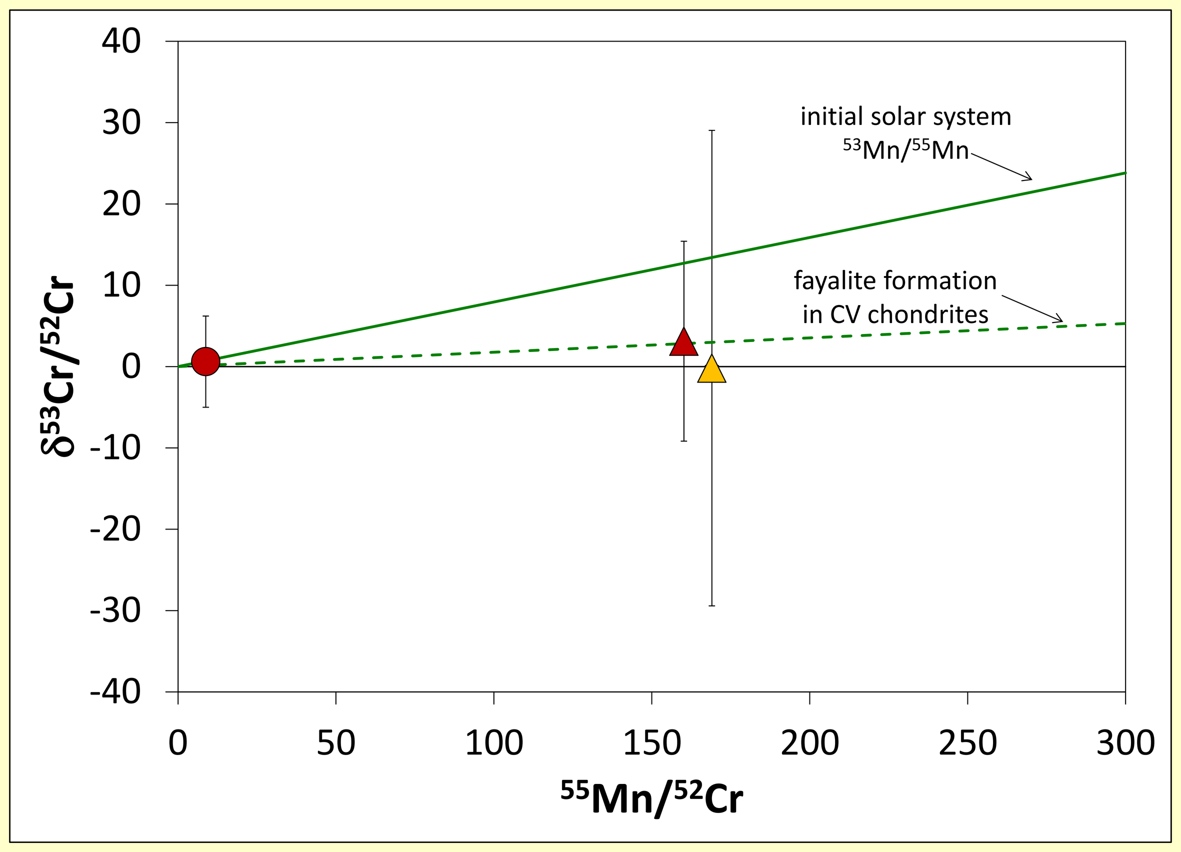


Figure 4. Mn-Cr isotope measurements from Ada-C fragments 3 (red circle) and 4 (red and orange triangles). Data collected during the second analytical session are shown in red. The initial solar system $^{53}Mn/^{55}Mn$ ratio ($9e^{-6}$) and the approximate $^{53}Mn/^{55}Mn$ ratio at the time of fayalite formation in CV chondrites ($2e^{-6}$) are shown for reference. Error bars are 2σ.

CONCLUSIONS

Fayalite-silica assemblages in the Stardust materials are comparable to fayalite assemblages found in the chondrule rims and the matrices of ordinary and carbonaceous chondrites. Unlike fayalite occurences in chondrites, however, the relatively high Cr content of fayalite in Ada obscures chronological interpretation of the Mn-Cr short-lived isotope system. No radiogenic ^{53}Cr was detected outside analytical uncertainty.

REFERENCES

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