ION MICROPROBE STUDY OF ^{60}FE-^{60}NI SYSTEM IN FERROMAGNESIAN PYROXENE CHONDRULES IN KRYMKA (LL3.1) BY MULTICOLLECTION. S. Tachibana[1], G. R. Huss[2], and K. Nagashima[2] [1]Department of Earth and Planetary Science, University of Tokyo (7-3-1 Hongo, Tokyo 113-0033, Japan; tachi@eps.s.u-tokyo.ac.jp), [2]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Manoa (1680 East-West Road, POST 504, Honolulu, HI, 96822, USA).

Introduction: Iron-60 decays to ^{60}Ni with a half-life of 1.5 Ma. Evidence for its presence in the early solar system has been found in chondritic and differentiated meteorites [1-6]. Because it is not synthesized efficiently at all by energetic-particle irradiation, its presence in the early solar system indicates that stellar nucleosynthesis contributed to the inventory of short-lived radionuclides. Our best estimate of the initial ^{60}Fe/^{56}Fe ratio in the solar system is (0.5-1)×10^{-6} [4]. A recent estimate of the ^{60}Fe/^{56}Fe ratio in the average interstellar medium, based on the γ-ray observations of [7] (1.4×10^{-7} [8]) is a factor of >3 lower than our solar system estimate, but is close enough to it that [8] have questioned whether a late stellar source is in fact required. However, both ratios have large uncertainties. The estimate for the interstellar medium depends on assumptions about galactic metallicity and Al/Fe ratio and may be much lower (see [9] for a discussion of this issue). Our current efforts are designed to improve the precision of the estimate for the early solar system.

We have been studying ^{60}Fe-^{60}Ni systems in ferromagnesian pyroxene-rich chondrules from two of the least equilibrated ordinary chondrites, Semarkona (LL3.0) and Bishunpur (LL3.1), in which silicates have suffered little or no secondary thermal or aqueous processing [4, 5]. The inferred ^{60}Fe/^{56}Fe ratios in these chondrules can be translated back to the time of solar system formation by assuming that the chondrules formed 1.5-2.0 Ma after CAIs, an assumption that has apparently been confirmed by measuring the ^{26}Al/^{26}Mg system in chondrules containing evidence for ^{60}Fe [10, 11]. The biggest weakness the ^{60}Fe data from chondrules is that the precision of the measurements is not high enough to yield precise initial ^{60}Fe/^{56}Fe ratios or to evaluate the degree to which the isotopic system in the chondrules might have been disturbed. We therefore have been working to develop a multicollection technique for the ims 1280 that will improve the counting statistics by a factor of ~4 relative to our previous measurements. In this abstract, we report our first multicollection ^{60}Fe-^{60}Ni data for ferromagnesian pyroxene-rich chondrules from Krymka (LL3.1).

Experimental: Nickel isotopic analyses were carried out using the Cameca ims 1280 ion microprobe at University of Hawai'i. A focused, 15-30 μm, 3-5 nA, primary O^- beam was rastered over a 20×20 μm^2 square on samples and standards. The secondary mass spectrometer was operated at 10 kV with a 50 eV energy window. Sample voltage offset was adjusted during the measurement compensate for sample charging. Secondary ions of $^{56}Fe^+$, $^{57}Fe^+$, $^{60}Ni^+$, $^{61}Ni^+$ and $^{62}Ni^+$ were simultaneously counted on Faraday cups ($^{56}Fe^+$ and $^{57}Fe^+$) and electron multipliers ($^{60}Ni^+$, $^{61}Ni^+$ and $^{62}Ni^+$) for 30 seconds in each cycle. Nuclear magnetic resonance (NMR) field control was used to stabilize the magnetic field. The mass resolving power was ~5000, which was sufficient to resolve all interferences except for hydrides. The contributions from hydrides on nickel isotopes were confirmed to be negligible.

Each spot was measured for two hours. Data were corrected for Faraday Cup backgrounds and electron multiplier dead-times. Relative gains of the multicollector electron multipliers were found to change relatively quickly with time (especially the newest multiplier). We therefore measured a chondrule with relatively low Fe/Ni ratio, assumed to contain little excesses of ^{60}Ni, as a secondary standard on the thin section to check shifts of relative gains. All the data reported here were corrected for gain shifts.

The relative sensitivity correction for the Fe/Ni elemental ratio was done using terrestrial hypersthene. Instrumental mass fractionation for the measured ^{60}Ni/^{62}Ni was corrected internally using ^{61}Ni/^{62}Ni.

Results: Here we report data for three pyroxene-rich chondrules from Krymka (LL3.1). Chondrule KRM3-1 is an FeO-rich, fine-grained, radial pyroxene chondrule (~1000 μm × ~700 μm). The chondrule, which has Fe/Ni elemental ratios up to ~10^4, shows excesses of ^{60}Ni that roughly correlate with the Fe/Ni ratio, and the initial ^{60}Fe/^{56}Fe ratio for KRM3-1 is estimated to be (8.8±3.1)×10^{-8} (Fig. 1a) with assuming no ^{60}Ni excess at ^{56}Fe/^{62}Ni=0.

In chondrule KRM3-9, an FeO-rich radial pyroxene chondrule (~1000 μm in diameter), the ^{60}Fe-^{60}Ni system has probably been disturbed. The higher Fe/Ni part show almost no excess of ^{60}Ni, but the data for the lower Fe/Ni part seem to show excesses of ^{60}Ni correlating with the Fe/Ni ratio. The low ^{60}Fe/^{56}Fe points give an initial ^{60}Fe/^{56}Fe ratio of (1.4±1.1)×10^{-7}, assuming no ^{60}Ni excess at ^{56}Fe/^{62}Ni=0 (Fig. 1b).

An FeO-rich radial pyroxene chondrule KRM3-11 (~2000 μm × ~1500 μm) appears to have excesses of ^{60}Ni, and an initial ^{60}Fe/^{56}Fe ratio of (2.5±0.7)×10^{-7} can be estimated from the isochron plot with the assumption of no ^{60}Ni excess at ^{56}Fe/^{62}Ni=0 (Fig. 1c). However, the ^{60}Ni excess for the highest Fe/Ni ratio is not as high as that expected from the data with lower Fe/Ni ratios (Fig. 1c), and this chondrule may have a nearly uniform enrichment of ^{60}Ni, irrespective of Fe/Ni ratios. The ^{60}Fe-^{60}Ni system in KRM3-11 may also have been disturbed.

Discussion: The initial ^{60}Fe/^{56}Fe ratios of ferromagnesian chondrules in Semarkona (LL3.0) and Bishunpur (LL3.1), both of which are unequilibrated ordinary chondrites, range from 1.2×10^{-7} to 3.7×10^{-7} [3, 4]. Although some chondrules with low Fe/Ni ratios show no resolvable excess of ^{60}Ni, this may be due to large analytical uncertainties relative to expected amounts of ^{60}Ni excesses [4]. On the other hand, the ^{60}Fe/^{56}Fe ratio estimated for the chondrule KRM3-1 is $(8.8\pm3.1)\times10^{-8}$, which is lower than the lowest end of the inferred range of ^{60}Fe/^{56}Fe in chondrules and even lower than ^{60}Fe/^{56}Fe ratios obtained for troilites in Krymka ($(1.6\text{-}1.8)\times10^{-7}$; [1]). We previously interpreted the troilite ratios as reflecting the abundance of ^{60}Fe at the time of alteration/metamorphism in a parent body [2,4]. Moreover, the ^{60}Fe-^{60}Ni systems in the chondrules KRM3-9 and KRM3-11 appear to be disturbed.

These observations imply that silicates in Krymka chondrules suffered a higher degree of alteration in a parent body than those in Semarkona and Bishunpur, and that the ^{60}Fe-^{60}Ni systems in chondrules recorded the timing of alteration events (KRM3-1) or were partially reset by alteration processes (KRM3-9 and KRM3-11). Because excesses of ^{60}Ni tend to be smaller for higher Fe/Ni ratios, leaching of Ni with equilibration of Ni isotopes might be a possible process to disturb the ^{60}Fe-^{60}Ni system, although more-detailed petrographical investigation is needed.

The ^{60}Fe-^{60}Ni systems in fine-grained or radial pyroxene chondrules from Krymka may thus not be good targets to estimate the initial abundance of ^{60}Fe at the timing of chondrule formation. Detailed petrographical and mineralogical inspections of chondrules are required to choose suitable chondrules in Krymka; cores of large phenocrysts within porphyritic chondrules may be candidates for further analyses.

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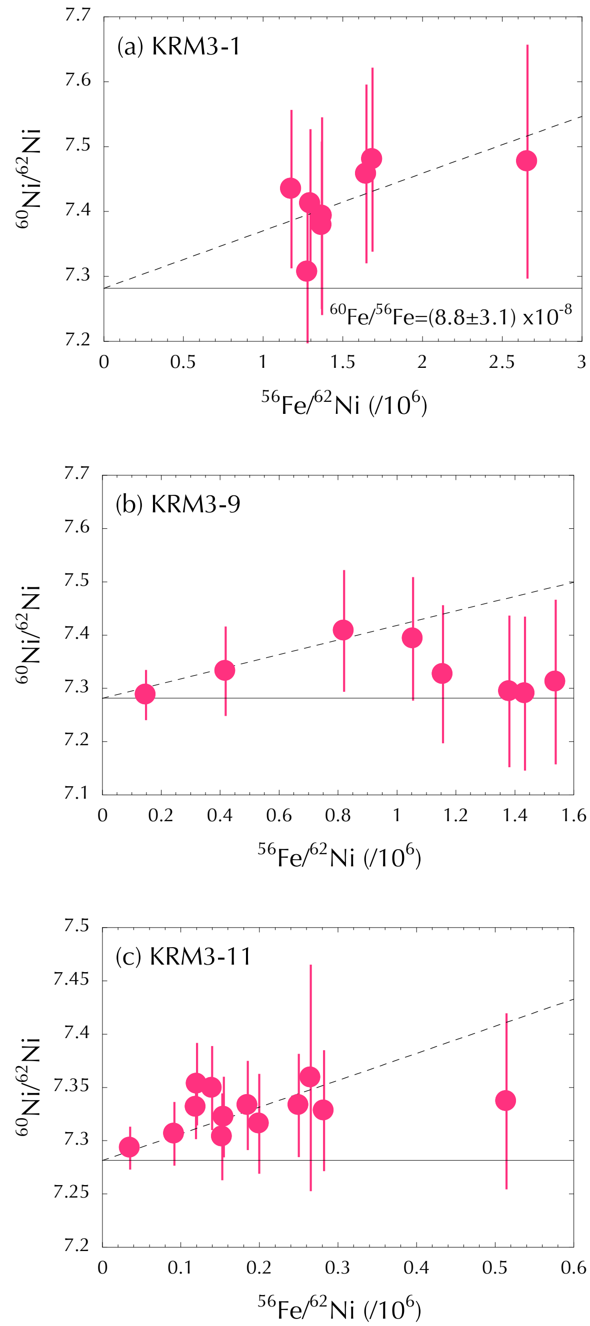

Figure 1. Isochron plots for the ^{60}Fe-^{60}Ni systems in Krymka chondrules. (a) KRM3-1. (b) KRM3-9. The dotted line is drawn for four data points with low Fe/Ni ratios ($(^{60}Fe/^{56}Fe)_0=(1.4\pm1.1)\times10^{-7}$). (c) KRM3-11.