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Iron-60 in the early solar system

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Short-lived radionuclides can serve as high-resolution chronometers for events in the early solar system. They were synthesized either by irradiation with energetic particles or by stellar nucleosynthesis. Here we report clear evidence for 60Fe (half-life = 1.49 million years (My)) from troilite (FeS) in unequilibrated chondrites, Bishunpur (LL3.1) and Krymka (LL3.1). Evidence for 60Fe was found previously only in eucrites (e.g.,[1]), which experienced a large degree of melting in their parent body and thus are not primitive, but not in chondrites (e.g.,[2]). The presence of 10Be, which is only produced by particle irradiation, in calcium-aluminum-rich inclusions (CAIs) [3] suggests that particle irradiation played an important role in synthesis of short-lived radionuclides. The initial 60Fe/56Fe inferred from our data, however, requires a stellar contribution to short-lived radionuclides in the early solar system because particle irradiation does not efficiently synthesize 60Fe.

Iron and Ni isotopes in 10 troilite grains and associated metal grains in Bishunpur and Krymka were measured using the ASU Cameca ims-6f ion microprobe. The sensitivity corrections for the Fe/Ni ratios of troilite and metal were done using terrestrial pyrrhotite and stainless steel. The instrumental mass fractionation for the measured 60Ni/61Ni was corrected internally using the measured 62Ni/61Ni.

Clear evidence for 60Fe was found in three troilites from Bishunpr and two troilites from Krymka.

Bishunpur 2359-6-TR41, located between two chondrules and includes a couple of kamacite grains, exhibits resolved 60Ni excesses (60Ni*). A correlated-error-weighted least-squares regression through the data for co-existing metal and troilite gives (60Fe/56Fe)_0 = (1.06+/-0.28)x10-7.

Bishunpur 2359-6-TR2 is an opaque assemblage consisting of troilite and kamacite at the rim of a high-FeO chondrule. It contains inclusions of chromite and FeO-rich olivine. 2359-6-TR2 also shows resolved 60Ni*, which correlates with the Fe/Ni ratio, and the inferred (60Fe/56Fe)_0 is (1.00+/-0.52)x10-7.

Bishunpur 2359-6-TR47 is an irregular-shaped troilite containing pyroxene inclusions. It is associated with kamacite in matrix. It also shows a 60Ni*, and its (60Fe/56Fe)_0 is (1.28+/-0.58)x10-7.

Krymka 1729-3-TR1 is a sulfide rim of a FeO-rich olivine-pyroxene chondrule. It includes a few metal grains. The 60Ni excess is observed not only in 1729-3-TR1 but also in a troilite inside the chondrule, and 60Ni* is clearly correlated with the Fe/Ni ratio. The least-squares fitting of the data for 1729-3-TR1 and the small troilite shows the (60Fe/56Fe)_0 of (1.81+/-0.72)x10-7.

Krymka 1729-3-TR12 is an S-shaped troilite, located at the rim of compound olivine-rich chondrules. The highest Ni content in this troilite is Fe/Ni of 2.3x105, which is the highest among the measured troilites. The inferred (60Fe/56Fe)_0 is (1.64+/-0.78)x10-7.

Combining our data with upper limits established previously on (60Fe/56Fe)_0 for a chondrule in Semarkona (LL3.0) [2] and for troilites in Ste. Marguerite (H4) [4] and the 26Al ages for the same objects seems to produce a coherent chronology for CAIs, chondrules, troilites, and Ste. Marguerite. This chronology implies that troilites in Krymka would have formed almost at the same time as chondrules (1-2 My after CAIs), probably prior to accretion of their parent body. This infers that the initial (60Fe/56Fe)_0 at the time of the solar system formation would have been in the range of 2.8x10-7 to 4x10-7. This is at or below the low end of predictions for a supernova source [5].

References: [1] Shukolyukov & Lugmair 1993a, Science 259, 1138. [2] Kita et al. 2000, GCA 64, 3913. [3] McKeegan et al. 2000, Science 289, 1334. [4] Shukolyukov & Lugmair 1993b, EPSL 119, 159. [5] Wasserburg et al. 1998, ApJ 500, L198.