RADIAL HETEROGENEITY OF ^{53}MN IN THE EARLY SOLAR SYSTEM?

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Our recent studies of ^{53}Mn - ^{53}Cr systematics ($T_{½}$ of ^{53}Mn = 3.7 My) in angrites (LEW 86010, Angra dos Reis) and eucrites (Chervony Kut [CK], Juvinas [JUV]) have shown that the resolution of small age differences between these differentiated objects is possible and that the eucrites are ~5.5 My older than the angrites (4.5578 Ga) [1, 2, 3]. The main assumption underlying this chronology is that ^{53}Mn was homogeneously distributed at least in that region of the solar nebula where the meteorite parent bodies formed. We have further found that the present day and the initial ^{53}Cr/^{52}Cr ratios in both meteorite classes are significantly higher than the terrestrial value. This difference in the ^{53}Cr/^{52}Cr ratios was originally thought to be due to Mn/Cr fractionation in the parent planetesimals of these meteorites at a time when most of the ^{53}Mn was still extant, possibly during the core formation process. However, a more quantitative reevaluation of the plausibility for this to occur [4] has suggested that the major portion of this difference in the ^{53}Cr/^{52}Cr ratios may be difficult to obtain during planetary differentiation and that its cause may not necessarily be found by probing only the evolution of the meteorite parent bodies.

What if the earth with its present day lower ^{53}Cr/^{52}Cr ratio is actually 'anomalous'? Is it possible that this could be a reflection of the earth's large depletion of Mn relative to Cr? But if this were the case then the Mn depletion must have occurred very early in earth's history or rather, because of the short half life of ^{53}Mn, around the time of accretion of its parent planetesimals. Is it possible that this 'lack' of the ^{53}Mn decay product on the earth was caused by a radial heterogeneity of ^{53}Mn during the late stage of the solar nebula? Where do bulk chondrites, the putative ultimate building blocks of the earth and the parent bodies of the differentiated meteorites, fit into this puzzle? If the elevated ^{53}Cr/^{52}Cr ratios in the differentiated meteorites are mostly a consequence of the indigenous ^{53}Mn/Cr abundance in solar system matter present in the region where they formed, and if the chondritic meteorites collected on earth come from the same region, then chondrites should also carry a similar isotopic signature.

In order to provide answers to many of these important questions we have measured the ^{53}Mn - ^{53}Cr systematics in samples from ordinary chondrites. Our first results come from Dimmit (H3,4) and Plainview (H5) and are displayed in the Figure. The approach was primarily to obtain ^{53}Cr/^{52}Cr and Mn/Cr data on relatively large bulk samples and compare these with the data from the differentiated meteorites. It is clear from the Figure that the ^{53}Cr/^{52}Cr ratios in these bulk samples are significantly higher than the terrestrial value (by 0.5 ε units; typical uncertainties are 0.10 to 0.15 ε; $1\varepsilon = 1\times10^{-4}$). Simple 'mineral separates' obtained by partial dissolution of bulk samples, "Sil" (silicate portion) and "Sp" (HF dissolution residues, primarily spinel), have slightly higher and lower ^{53}Cr/^{52}Cr ratios than the bulk samples and correlate with their respective Mn/Cr ratios. Best fit lines through the data points for both chondrites have the same slope and are parallel to that for the angrite LEW 86010. One may be tempted to interpret this slope, and the corresponding ^{53}Mn/^{55}Mn ratio which, of course, is also the same as that of LEW, as indicating the time of the last Mn and Cr isotopic equilibration 4.558 Ga ago. However, these chondrites are only partially equilibrated so that this best fit line may simply reflect a mixture of equilibration times for the individual chondritic components. Thus, it would be clearly premature to attach true chronological meaning to these data.

The important results for now are: the earth and its precursor material contained significantly less ^{53}Mn (relative to Cr) than the chondrites and the achondrites. The main portion of the earth cannot have formed from the same type of chondritic material that (presumably) formed the achondrites. Preliminary data on lunar samples obtained by us on 60025 and by [5] on 15555 indicate a ^{53}Cr/^{52}Cr ratio for the moon which is within error the same as that of the earth; if confirmed by further measurements this would prove the close genetic relationship between the two planets. Apparently, there still is an excess of ^{53}Cr/^{52}Cr in achondrites relative to chondrites which needs further exploration with refined experimental techniques.

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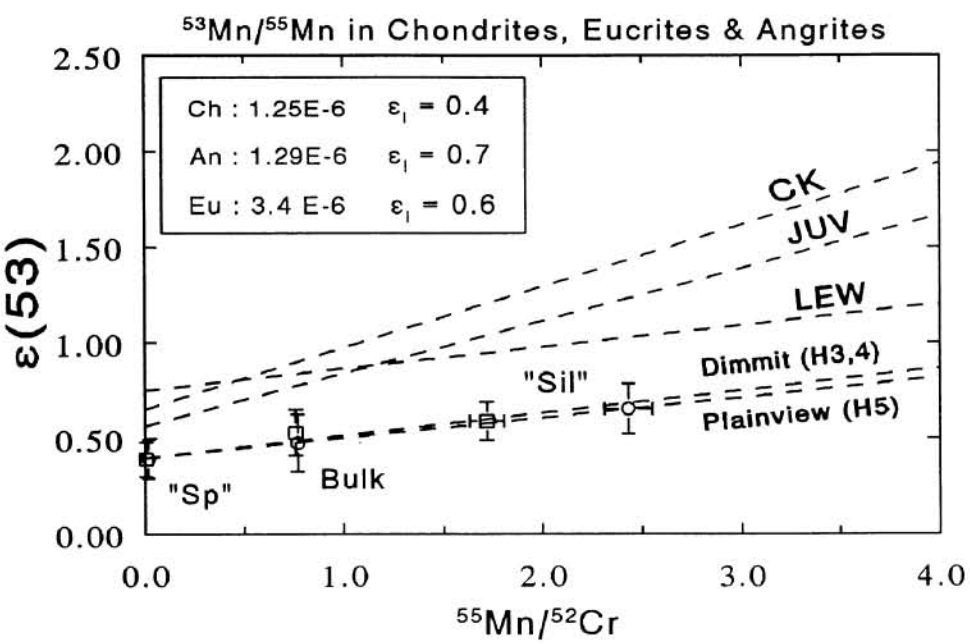
This will have important bearings on the assumption of ^{53}Mn homogeneity within the 'meteorite forming regions' of the solar nebula and relative meteorite chronologies.

Nevertheless, some of the questions posed above are resolved by the present results, but some only partially, and new ones arise. Is the depletion of ^{53}Mn at about 1 AU a consequence of Mn volatility (and its transport to greater distances from the sun which would have had to occur already at a late nebular stage) or was its indigenous distribution radially heterogeneous? If the latter were the case then this would probably also be true for other short lived nuclei such as ^{26}Al and ^{60}Fe, if they come from the same nearby stellar source(s). However, a test of this hypothesis using these nuclei may be quite difficult. Regardless, because of a most probably late stage injection of these short lived nuclei into the nabula one would expect that stable nuclei of other elements accompanying the short lived species would alter previously more pronounced anomalies in neutron rich isotopes such as observed in Allende CAI; a resulting inverse relationship between, for example, ^{26}Al effects and ^{50}Ti or ^{48}Ca anomalies may be resolvable.

References: [1] Lugmair G. W., MacIsaac Ch., Shukolyukov A. (1992), LPS **XXIII**, 823. [2] Lugmair G. W., MacIsaac Ch., Shukolyukov A. (1994), LPS **XXV**, 813 and Meteoritics **29**, 493. [3] Lugmair G. W., Galer S. J. G. (1992), GCA **56**, 1673. [4] Drake M. *et al.* (1989), GCA **53**, 2101, and personal comm.; Dreibus G., Wänke H. (1979), LPS **X**, 315 and (1980), Z. Naturforsch. **35a,** 204. [5] Harper C. L., Wiesmann H. (1992), **XXIII,** 489.



Significant excesses of ^{53}Cr/^{52}Cr ratios (shown in ε units; 1ε = 1x10^{-4}) relative to the terrestrial value are found in chondritic samples. They are slightly lower but similar to values observed previously in differentiated meteorites. Thus, the earth has a substantial deficit in the decay product of ^{53}Mn when compared to the meteorites. The slopes of the lines shown for the various meteorites correspond to the ^{53}Mn/^{55}Mn ratios at the time when these meteorites formed with initial values of ε_I (inset). However, for the chondritic samples presented here this may not strictly be true (see text).