# $^{60}Fe$ IN EUCRITE NWA 4523: EVIDENCES FOR SECONDARY REDISTRIBUTION OF Ni AND FOR SECONDARY APPARENT HIGH $^{60}Fe/^{56}Fe$ RATIOS IN TROILITE

M. Chaussidon[1] and J.-A. Barrat[2], [1]CRPG-Nancy Université-CNRS, UPR 2300, 15 Rue Notre-Dame des Pauvres, BP 20, 54501 Vandoeuvre-lès-Nancy, France (chocho@crpg.cnrs-nancy.fr), [2]CNRS UMR 6538, UBO-IUEM, Place Nicolas Copernic, 29280 Plouzané Cedex, France (barrat@univ.brest-fr).

**Introduction:** $^{60}Fe$ ($T_{1/2}$= 1.49 My) is a key a short-lived radioactive nuclide because it is the only one for which an origin from irradiation by cosmic rays is impossible. $^{60}Fe$ is a neutron-rich nuclei and its production rate during irradiation processes around the early Sun (because of the low cross sections of appropriate reactions and of the low abundance of targets) is at least two orders of magnitude too low to explain the observed abundance [1].

The problem is however that, though several evidences do exist for the presence of lived $^{60}Fe$ in the early solar system, the inferred intial $^{60}Fe/^{56}Fe$ ratios span a large range due either to an heterogeneity in the distribution of $^{60}Fe$ or to perturbations of the $^{60}Fe$-$^{60}Ni$ system in various meteoritic components, or to both. The presence of $^{60}Fe$ has been discovered from the existence of $^{60}Ni$ excesses in CAIs [2] and in eucrites [3]. However, because of the presence of nucleosynthetic Ni isotope anomalies in CAIs [2, 4] no initial $^{60}Fe/^{56}Fe$ ratio can be determined precisely: an upper limit of $1.6 \pm 0.5 \times 10^{-6}$ has been proposed by [2] and a value of $4.7 \pm 2.9 \times 10^{-6}$ has been tentatively proposed by [4] from the analysis of CAIs with no $^{62}Ni$ nucleosynthetic anomaly. Clear $^{60}Fe$ isochrons have been obtained for troilite and magnetite in the matrix of Semarkona [5] and for pyroxene-rich chondrules from Semarkona and Bishunpur [6]. The problem is that the different $^{60}Fe/^{56}Fe$ ratios are difficult to reconcile. Pyroxene-rich chondrules show a $^{60}Fe/^{56}Fe$ ratio of $2.2\text{-}3.7 \times 10^{-7}$ while the $^{60}Fe/^{56}Fe$ ratio in the troilite in the matrix of Semarkona is of $0.9 \pm 0.2 \times 10^{-6}$, i.e. higher by a factor of ≈ 3 to 4 compared to chondrules. Because high-precision Ni isotopic analyses of metal in chondrites and iron meteorites [7] limit the possible $^{60}Fe$ heterogeneity in the inner solar system to less than 10%, the differences observed between the different components of Semarkona may be a sign of previously unrecognized secondary perturbations of the $^{60}Fe$-$^{60}Ni$ system. Thus the initial $^{60}Fe/^{56}Fe$ of the solar system remains at present quite unconstrained.

Better constrains on the initial $^{60}Fe/^{56}Fe$ of the Solar system are required in the use of $^{60}Fe$ as a smoking gun for injection of supernova products in the early solar system. Recent measurement of the γ-ray lines of $^{60}Fe$ in the interstellar medium gives a value of 0.148±0.06 for the galactic $^{60}Fe/^{26}Al$ ratio [8] which, using the present day average galactic $^{26}Al/^{27}Al$ ratio of $8.6 \times 10^{-6}$ [9] would imply a galactic background for $^{60}Fe/^{56}Fe$ perhaps as high as $\approx 1.4 \times 10^{-7}$. This is not one order of magnitude lower than initial $^{60}Fe/^{56}Fe$ inferred from meteorites.

In order to bring additional constraints on the initial $^{60}Fe/^{56}Fe$ ratio and on the possible perturbations of the $^{60}Fe$-$^{60}Ni$ system, we looked for $^{60}Fe$ in sulfides oxides and silicates from the eucrite NWA 4523.

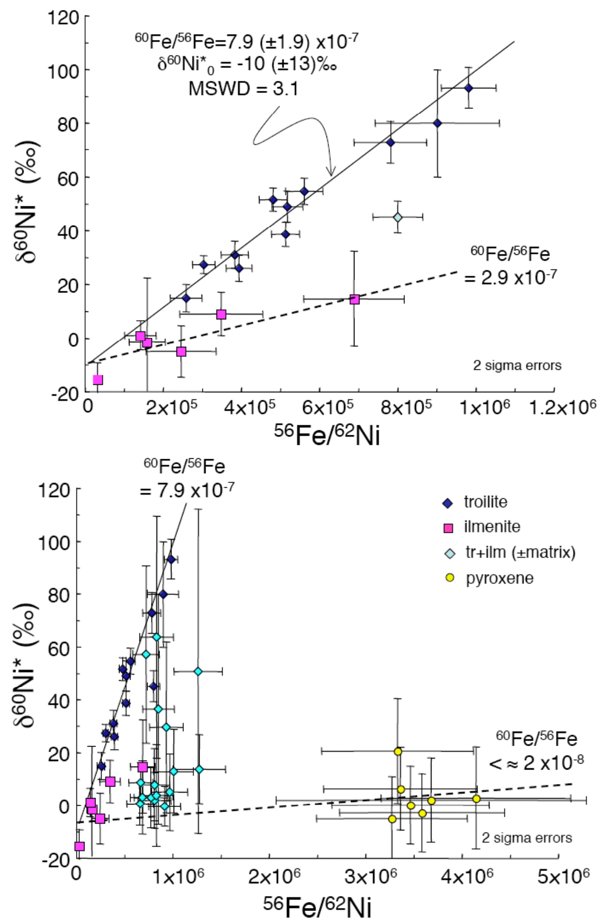


Fig 1: Isochron diagram showing $^{60}Ni$ excesses versus $^{56}Fe/^{62}Ni$ ratios for different phases, presumed co-magmatic, in eucrite NWA 4523. The top diagram is a blow up showing the nice apparent $^{60}Fe$ isochron for the troilite. The bottom diagram shows that the $^{60}Ni$ excesses in pyroxene are at odds with those which would be inferred from the troilite in case of simple closed system evolution of both phases.

**Samples and analytical techniques:** NWA 4523 is a monomict eucritic breccia belonging to the Stannern trend [10]. It contains medium grain clasts with troilite, chromite and ilmenite crystals between ≈10 and 100µm size. This sample was chosen for a search of $^{60}Fe$ because (i) eucrites being differenciated objects high Fe/Ni ratios are present in the various phases and (ii) the petrography suggests that troilite and oxides are magmatic phases. The Ni isotope analyses were done with the CRPG-CNRS (Nancy, France) ims 1270 ion microprobe in monocollection mode at a mass resolution of 7000. Special care was taken to check for possible interferences due to peak tailing on the Ni isotope peaks. Three Ni isotopes at masses 60, 61, 62 were measured. Numerous analyses of terrestrial pyrhotite and olivine standards show that the $^{60}Ni$ excesses can be determined at a precision of ± 1.5 to ±2‰ (2 sigma). Errors on the NWA 4523 are mostly due to counting statistics.

**Results and discussion:** Results are shown in Fig 1. Large $^{60}Ni$ excesses were found in troilite with a perfect apparent isochron suggesting a $^{60}Fe/^{56}Fe$ slope of $7.9\pm1.9\times10^{-7}$. The other phases show smaller $^{60}Ni$ excesses with apparent $^{60}Fe/^{56}Fe$ slopes of $2.9\times10^{-7}$ in magnetite and at maximum of $2\times10^{-8}$ in silicates.

It is obvious that a $^{60}Fe/^{56}Fe$ ratio of $7.9\times10^{-7}$ makes no sense for a eucrite. A eucrite is coming from a differenciated body which has been homogenized by melting. Taking a bulk FeO content for eucrites of ≈ 17 wt% and a bulk Ni content of ≈ 4 ppm, for a $^{60}Fe/^{56}Fe$ ratio of $7.9\times10^{-7}$, $^{60}Ni$ excesses of ≈ 90‰ should be present in bulk !

Such extreme $^{60}Ni$ excesses do not exist in eucrites in bulk [e. g. 11]. Thus the nice $^{60}Fe$ isochron shown by troilite in NWA 4523 must be secondary.

One way to produce such a secondary isochron would be to exchange Ni between troilite and surrounding phases during metamorphism after the decay of $^{60}Fe$ (the only way to increase the slope of the $^{60}Fe$ isochron is to decrease the Fe/Ni ratio after the decay of $^{60}Fe$). First order models of Ni exchange between troilite and oxides show that this is feasible. A proof for the fact that troilite cannot be considered as a closed system during metamorphism is the Cr and Ti diffusion profiles observed at contact with chromite and ilmenite (Fig 2). Such a redistribution of Ni may also explain part of the differences in $^{60}Fe/^{56}Fe$ observed in the different phases in Semarkona (difference between troilite in the matrix and pyroxenes in chondrules, see above).

Correlations between $^{60}Ni$ excesses and 1/[Ni] (mixing lines) imply that most of the present data in NWA 4523 can be explained by a redistribution of Ni after the decay of $^{60}Fe$ if the $^{60}Fe/^{56}Fe$ at the time of metal-silicate differenciation on the eucrite parent body was at maximum of $1\text{-}4\times10^{-8}$.

This seems consistent with a $^{60}Fe/^{56}Fe$ of ≈ $4\times10^{-10}$ at the end of metamorphism [3, 11]. If eucrites differenciated ≈ 4 Ma after the formation of CAIs [12, 13], then the solar system initial $^{60}Fe/^{56}Fe$ which would be implied by the present data is of $0.7\text{-}3\times10^{-7}$.

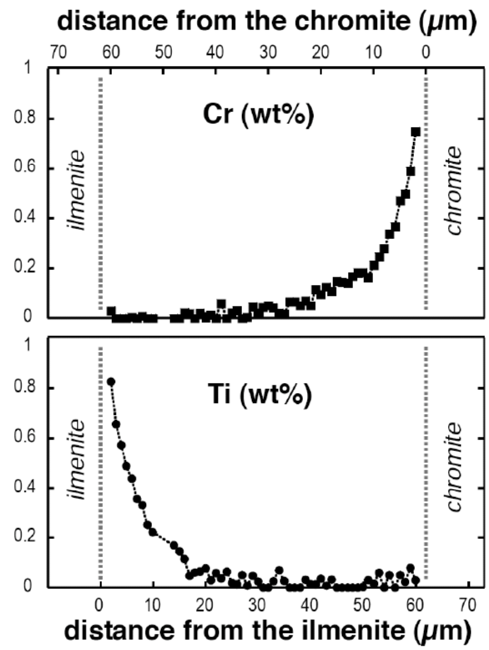


Fig 2: Cr and Ti concentration profiles in a troilite grain adjacent to an ilmenite grain (on the left) and to a chromite grain (on the right). Diffusion of Cr from the chromite and of Ti from the ilmenite into the troilite are obvious. This strongly suggests that troilite cannot be considered as a closed system relative to Ni diffusion.

**References:** [1] Lee T. (1998) *ApJ, 506,* 898-912. [2] Birck J.-L. & Lugmair G.W. (1988) *Earth Planet Sci. Lett. 90*, 131-143. [3] Shukolyukov A. & Lugmair G.W. (1993) *Science 259*, 1138-1142. [4] Quitté G. et al. (2007) *ApJ 655*, 678-684.[5] Mostéfaoui S. et al. (2005) *ApJ 625*, 217-277. [6] Tachibana S. et al. (2006) *ApJ 639*, L87-L90. [7] Dauphas N. et al. (2008) *ApJ 686*, 560-569. [8] Wang W. et al. (2007) *Astron. Astrophys. 469*, 1005-1012. [9] Diehl R. et al. (2006) *Nature 439*, 45-47. [10] Barrat J.-A. (2007) *Geochim. Cosmochim. Acta 71*, 4108-4124. [11] Quitté G. et al. (2005) *LPSC XXXVI*, #1827. [12] Lugmair G. & Shukolyukov A. G (1998) *Geochim. Cosmochim. Acta 62*, 2863-2886. [13] Kleine T. (2004) *Geochim. Cosmochim. Acta 68*, 2935-2946.