NICKEL ISOTOPIC COMPOSITIONS IN PALLASITES AND IRON METEORITES.

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We report Ni isotope ratio results for Ni from metal in iron meteorites and from metal and olivine in pallasites. The investigation of pallasites was undertaken because (1) previous work on pallasites showed evidence for *in situ* decay of ^{53}Mn ($t_{½}$ = 3.7 Ma) in olivines [1,2] and of ^{107}Pd ($t_{½}$ =6.5 Ma) in metal [3]; (2) evidence for the *in situ* decay of ^{60}Fe ($t_{½}$ = 1.5 Ma) in eucrites [4,5]; (3) possible early formation of pallasites from Re-Os data [6]; and (4) very high Fe/Ni ratios in pallasite olivines [5,7]. Recently, we reported Ni isotopic data, for $^{58,60\text{-}62}$Ni, on (1) FeNi metal and sulfides in different groups of iron meteorites, (2) sulfides and a whole rock sample of the St. Séverin chondrite, and (3) chondrules from the Chainpur chondrite [8]. No evidence was found for resolved radiogenic or general Ni isotope anomalies at the resolution levels of 0.2 εu and 0.5 εu (εu = 0.01%) for ^{60}Ni/^{58}Ni and ^{61}Ni/^{58}Ni, respectively. From the ^{56}Fe/^{58}Ni ratios and ε^{60}Ni values, we obtained upper limits for the initial value of $(^{60}\text{Fe}/^{56}\text{Fe})_0$ of a) <2.7±10^{-7} for Chainpur chondrules, b) <10^{-8} for the St. Séverin sulfide, and c) <4x10^{-9} for sulfides from iron meteorites. The purpose of this study is to identify potential general isotope anomalies in Ni and direct evidence for the *in situ* decay of ^{60}Fe in pallasites and iron meteorites. The pallasite olivine samples we analyzed were prepared by G. Srinivasan, free from rust and impurities as described in Papanastassiou et al. (1997) [7]. We followed the Ni analytical procedures developed in Chen et al. (2009) [8].

The results are shown in Table 1 and indicate that the ε^{60}Ni and ε^{61}Ni values of all pallasite samples (FeNi metals and olivines) are, respectively, within 0.2 εu and 0.4 εu of terrestrial standards. From the Fe/Ni ratios and error limits of ε^{60}Ni, we calculated bounds on the values of initial $(^{60}\text{Fe}/^{56}\text{Fe})_0$ for the meteorite parent bodies (Table 1). In an ε^{60}Ni versus ^{56}Fe/^{58}Ni diagram (Fig. 1), for pallasites olivines, we show the inferred initial $(^{60}\text{Fe}/^{56}\text{Fe})_0$ for Salta is < 10^{-9} and for Brenham and for Thiel Mountain <8x10^{-10} based on the observed ^{60}Ni/^{58}Ni and extremely high ^{56}Fe/^{58}Ni (6600 to 17000). The Fe/Ni for the pallasite metals are slightly lower than that of Orgueil (Fig. 2), but the pallasite metals do not show a significant deficit in ε^{60}Ni. The new high precision results show no excess in ^{60}Ni and agree with the less precise and lower Fe/Ni data reported previously for Omolon olivines and Thiel Mountain olivines [2, 7]. The pallasite Ni data suggest no evidence for the *in situ* decay of ^{60}Fe in the meteorite parent bodies or a long interval between the injection of ^{60}Fe and formation of the pallasite parent bodies. Alternatively, the pallasites cooled over a sufficiently long time (more than 10 Ma) for the Ni in the olivine to equilibrate with the FeNi. Previously, we reported excess ^{107}Ag in metal of Brenham (ε^{107}Ag = 52±7). The inferred $(^{107}\text{Pd}/^{108}\text{Pd})_0$ for Brenham, (1.1±0.14)x10^{-5} suggests a formation time of ~7 Ma after formation of Gibeon (VIA iron). This isolation time is long enough to prevent any resolvable effect to be detected within our current precision for ε^{60}Ni. Previously published Ni isotopic data for pallasite metals show either normal values (Eagle Station, Albin, Brenham and Molong in [9] and Molong in [10]) or anomalous values (Admire, Esquel and Brahin in [11]). So far we have analyzed only one (Brenham) of the same meteorite samples reported in these studies. With the precision of our current data, we also do not support nor exclude [8] the conclusions based on the Ni isotopic anomalies on iron meteorite metal reported by Bizzarro et al. (2007)[11].

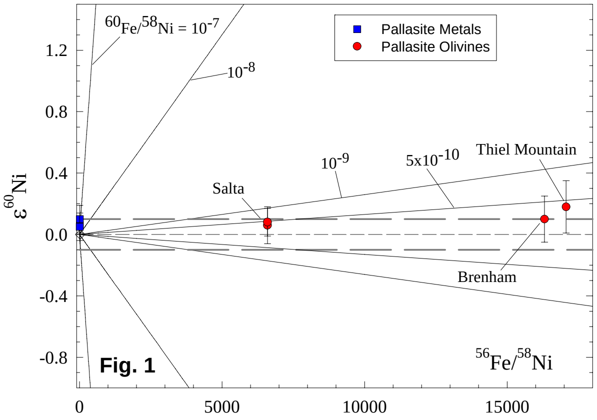

Fig. 1

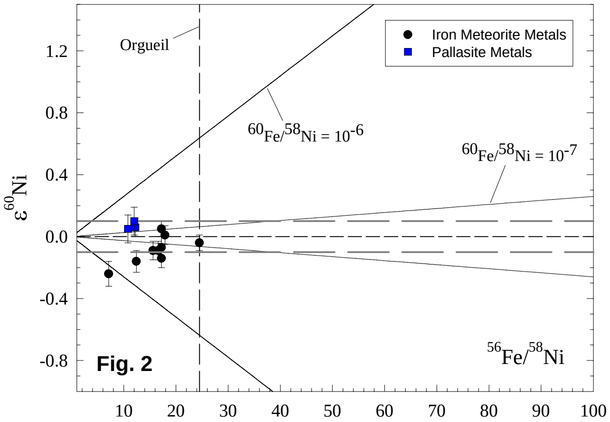

Fig. 2

The variations of ε^{60}Ni versus ^{56}Fe/^{58}Ni for the FeNi metal samples (data from [8]) from iron meteorites are shown in Fig. 3. The dashed lines represent calculated values for closed system decay of ^{60}Fe from (^{60}Fe/^{56}Fe)$_0$ = 5x10^{-7}, after isolation (and Fe/Ni fractionation) of the sample from the parent body having the CI chondrite composition at different times, ranging from 0 Ma to 5 Ma. It is clear that, if the isolation time is longer than ~2 half lives (~3 Ma), there is no resolvable effect within our current precision of ± 0.1 εu for ε^{60}Ni. The apparent data array for a few metal samples (Piñon, Bella Roca, Mundrabilla, and Bennett County) suggest isolation or metal segregation in their parent bodies within 0-0.5 Ma. It is possible that the deficiencies that appear in ^{60}Ni for some of these samples, in particular our earlier data on Piñon, may indicate the presence of ^{60}Fe in the abundance used. We reanalyzed another sample of this meteorite. The results (Piñon-2, Table 1 and Fig. 3) indicate a normal ^{60,61}Ni isotopic composition.

In conclusion, despite extremely high Fe/Ni ratios in the pallasite olivines, we do not detect any isotopic anomaly in either metal or olivine from three pallasites. The new FeNi data from these pallasites yield strict upper limits of 8x10^{-10} to 10^{-9} for the initial (^{60}Fe/^{56}Fe)$_0$ in the pallasite parent bodies.

In contrast to the ^{60}Fe-^{60}Ni system, there is some evidence in pallasites for the *in situ* decay of ^{53}Mn [2, 12, 13]. Ion probe data [12] show relatively high (^{53}Mn/^{55}Mn)$_0$ ratios, (1.2 to 4.2)×10^{-5}, for Sprinwater, Albin, and Brenham, while [13] and [14] report no resolved effects in Albin, Brahin, Springwater and Imilac. In comparison, TIMS data on Omolon [2] show (^{53}Mn/^{55}Mn)$_0$ of (1.3±0.2)×10^{-6}. These differences may reflect the effects of Ni diffusion (or redistribution) and variations in Mn/Cr on a local scale (for SIMS) as opposed to the bulk olivine Mn/Cr measured for TIMS work. For sulfides in unequilibrated ordinary chondrites, ion probe data showed (^{60}Fe/^{56}Fe)$_0$ of 1.1×10^{-7} and 1.7×10^{-7} [14] or 7.3×10^{-7} [15]. Based on the very high Fe/Ni ratios we obtained for the pallasite olivines, our lowest upper limit for (^{60}Fe/^{56}Fe)$_0$ is 8×10^{-10}. This corresponds to about a factor of 1000 below the values for unequilibrated ordinary chondrite sulfides or a time interval of 15 Ma. Hence, the pallasites could have formed and cooled relatively shortly after the time defined by the ^{60}Fe-^{60}Ni system for unequilibrated ordinary chondrites.

References: [1]Birck and Allegre (1985) *Geophy. Res. Lett. 12*, 745-748. [2]Shukolyukov A. and Lugmair G. W. (1998) *GCA 62*, 2863. [3]Chen J. H. & Wasserburg G. J. (1996) *AGU Geophy. Monograph 95*, 1. [4]Shukolyukov A. & Lugmair G. W. (1993) *Science, 259*, 1138. [5]Shukolyukov A. & Lugmair G. W. (1993) *EPSL, 119*, 159. [6]Chen J. H. et al. (2002) *GCA 66*, 3793. [7]Papanastassiou D. A. et. al. (1997) *Meteor.& Planet. Sci., 32,* A103. [8]Chen J. H. et al. (2009) *GCA 73*, in press. [9]Cook D. L. et al. (2008) *Geophy. Res. Lett. 35,* L01203. [10]Dauphas N. et al. (2008) *Ap. J. 686*, 560. [11]Bizzarro M. et al. (2007) *Science 316*, 1178. [12]Hsu et al. (1997) *LPS 28*, 1783. [13]Tomiyama & Huss (2005) *LPS 36*, 2071. [14]Tomiyama et al. (2007) *LPS 38,* 2007. [15] Tachibana & Huss (2003) *ApJ 588*, L41. [16] Mostefaoui et al. (2004) *New Astron. Rev. 48*, 155.

Acknowledgement. This work was supported by NASA Cosmochemistry.

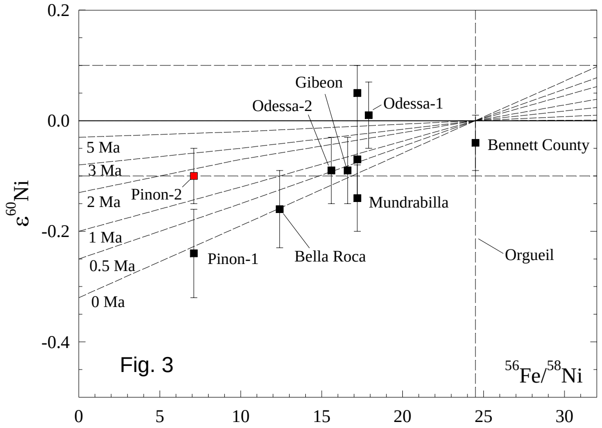

Fig. 3

Table 1. Fe/Ni and Ni isotopic data in pallasites and iron meteorites[a].

Samples		^{56}Fe/^{58}Ni	ε^{60}Ni [b]	ε^{61}Ni [b]	^{60}Fe/^{56}Fe
Pallasites: Salta	Olivine-1a	6595	0.06±0.12	-0.3±0.66	1.05x10^{-9}
	Olivine-1b	6595	0.08±0.09	0.26±0.55	1.0x10^{-9}
	Metal	12.2	0.06±0.06	0.19±0.28	
Thiel Mountain	Olivine	17068	0.18±0.17	0.38±0.63	7.9x10^{-10}
	Metal	12.0	0.10±0.09	0.25±0.49	
Brenham	Olivine	16310	0.10±0.15	0.37±0.66	5.9x10^{-10}
	Metal	10.8	0.05±0.09	0.39±0.45	
Iron Meteorite: Piñon	Metal-1[c]	7.10	-0.24±0.08	0.31±0.34	
	Metal-2	7.10	-0.10±0.05	0.34±0.29	

[a] All ratios are normalized to ^{62}Ni/^{58}Ni=0.05338858. [b] The ε values are calculated as the deviation relative to the standard expressed in parts per 10^4. [c] From Chen et. al. (2009) [8].