
In a recent report [1], we presented evidence for excesses (*) of $^{107}$Ag due to $^{107}$Pd decay ($\tau = 6.5$ Ma) in a wide variety of iron meteorites, some pallasites and mesosiderites. They provide unambiguous evidence of the in situ decay of $^{107}$Pd in planetary differentiates. A key problem of early solar system chronologies has been the ability to interrelate different short-lived and long-lived chronometers. Evidence for the presence of both live $^{107}$Pd and $^{53}$Mn ($\tau = 5.3$ Ma) in the early solar system has been found in several meteorites [1]. However, there appear to be major discrepancies between the $^{107}$Pd and $^{53}$Mn chronometers [1]. New Re-Os data [2-4] on iron meteorites seem to support the small time differences for formation of iron meteorites as inferred by the Pd-Ag system. In this study, we selected samples on which Re-Os data were available. These include Coahuila (IIA) metal and Tres Castillos (IIIA) metal and sulfide. The results are shown in Table 1. In both $^{108}$Ag-Ni and Pd-Ni diagrams, Coahuila and Tres Castillos plot within the fields of group IIA,B and IIIA,B irons confirming the classification of these samples based on other criteria and showing the close correlation between Pd and Ni. The $^{108}$Ag contents in both meteorites are factors of $10^2$-$10^3$ lower than the solar abundance while Pd contents are nearly solar. The $^{108}$Pd/$^{109}$Ag ratio in Coahuila is lower than in all other group II and III irons, but the $^{108}$Ag/$^{109}$Ag value in Coahuila is $7.3 \pm 3.1$%, higher than $^{108}$Ag/$^{109}$Ag. For two metal samples of Tres Castillos, the Pd-Ag results are somewhat different from each other: $^{108}$Pd/$^{109}$Ag ratios range from $924 \pm 6$ (#1) to $1115 \pm 7$ (#2) and $^{108}$Ag from $11.1 \pm 1.0$ (#1) to $6.8 \pm 1.6$ (#2). In a Pd-Ag diagram (Fig. 1), the Tres Castillos samples plot below the correlation line ($^{108}$Ag*/$^{109}$Ag = 1.5x$10^{-3}$ to 2.0x$10^{-3}$) for other IIIA,B irons. To better study this problem, we analyzed a sulfide sample from a nodule from the slab of metal #2. The sulfide sample shows a high Ag and a very low $^{108}$Pd/$^{109}$Ag = 0.048. However, the $^{108}$Ag/$^{109}$Ag ratio in the sulfide gives a slightly elevated $^{108}$Ag*/$^{109}$Ag = 3.8±1.6%. The ($^{108}$Ag*/$^{109}$Ag)$_{\odot}$ = 1.0812 ± 0.0016 (Faraday cup) determined for the normal Ag (NIST SRM 978) along with this sulfide sample is the same as determined previously in our laboratory. The existence of excess $^{108}$Ag* in sulfide has been found in several other meteorites (e.g., Gibeon, Santa Clara, and Duchesne). It indicates that Ag in Tres Castillos involves later

![Figure 1. Pd-Ag systemsatics.](image)

reequilibration between FeNi and FeS. The Re-Os systematics of the schreibersite-FeNi pair on Tres Castillos [3-4] also suggest disturbances over prolonged times. The meteorite data indicate a very large fractionation between Pd and Ag (factors of $10^3$) in different objects of the solar system. The mechanisms of Pd-Ag fractionation includes nebular fractionation, FeS-FeNi segregation in planets and fractional crystallization of FeNi melts. The full interpretation of $^{107}$Pd-$^{107}$Ag time scales depends on the nature and site of the chemical fractionation of Pd and Ag. As discussed in [1], the low abundances of sulfide in iron meteorites and the relatively low distribution coefficient of Ag between sulfide and metal cannot account for the large fractionation between Pd and Ag in many iron meteorites. For some meteorites with high Pd/Ag ratio, if the melting, equilibration and segregation between metal and sulfide occurred at some later time, then some of the radiogenic $^{107}$Ag would be in the sulfide and should produce sulfide masses with very high $^{107}$Ag/$^{109}$Ag ratios. Sulfide-rich meteorites are very rare. Soroti is one such meteorite and contains large areas (>65%) of troilite in a sponge-like structure of metal and sulfide. Our results on Soroti metal indicate that it has close to the solar Pd/Ni ratio and has $10^2$ less than the solar $^{108}$Ag/Ni ratio. The $^{108}$Pd/$^{109}$Ag ratio (115.4±0.4) in Soroti metal is much lower than in group II and III irons. The Soroti sulfide also has a very low $^{108}$Pd/$^{109}$Ag value (0.015). Both metal and sulfide of Soroti have the same $^{108}$Ag/$^{109}$Ag ratio as in normal Ag (Table 1 and Fig. 1). We have thus found no evidence for $^{108}$Ag* in FeS-rich meteorites. The variation in $^{108}$Ag*/$^{108}$Pd among meteorites can be used to calculate a relative chronology. For a large number of
LIVE $^{107}\text{Pd}$ IN IRON METEORITES: CHEN J. H. & WASSERBURG G. J.

meteorites this appears to be restricted to a time window of 10 million years (Fig. 2). The Re-Os data from
group IA, IIA, IIIA, IVA, and IVB yield an age of $4.61 \pm 0.02$ AE [3-4], using $\lambda (^{187}\text{Re}) = 1.64 \times 10^{-11}$ a$^{-1}$.

However, Re-Os data on individual groups of iron meteorites such as IIA versus IVA suggest that the IIA
and IVA irons may have a difference in formation ages of $60 \pm 45$ my, with the IVA's being older [3-4].

In contrast, a study by Smolar and Walker [2] suggests that
IVA irons are younger than IIA, although analyses of
some IVA irons did not fall on an isochron. Our new
Pd-Ag data suggest that the formation time difference
between IIA and IVA is less than ~5 my. We conclude
that the IVA and IVB resulted from chemical fractionation in
the nebulae with Pd in FeNi condensates and separation of late condensing Ag from metal. Later
remelting of metal will not alter the ratio of $^{107}\text{Ag}/^{108}\text{Pd}$.

It follows that a planetary core formed from such metal
could reflect nebular abundances of $^{107}\text{Pd}/^{108}\text{Pd}$.

Recent studies showed that the $e(\text{Hf}/\text{W})$ values in
3 iron meteorites (Toluca, Arispe and Coya Norte), were
from (-3.7$\pm$1.0)$ \times 10^{-4}$ to (-4.7$\pm$2.2)$ \times 10^{-4}$ lower than
terrestrial, lunar and chondritic samples [5,6] This corresponds to an initial $^{182}\text{Hf}/^{184}\text{Hf}$ value of $\geq (2.61 \pm 0.13) \times 10^{-8}$ [6], which is precisely what is expected from nucleosynthetic considerations [7].

Tocopilla is a synonym of Coya Norte or North Chile (IIA) which shows an elevated $\delta^{107}\text{Ag}$ value $= 5.8 \pm 0.6$ % (Fig. 1).

$^{107}\text{Pd}$ can be attributed to either the s- or r-process, whereas $^{182}\text{Hf}$ is a pure r-process product. The
question of whether the deficiency in $^{182}\text{W}$ in iron meteorites is resulted from Hf-W fractionation by nebular processes or by planetary differentiation when $^{182}\text{Hf}$ was still present is not fully clear. If it is possible to form FeNi aggregates containing W and no Hf under nebular conditions (analogous to the Pd-Ag problem) then the depletion in $^{182}\text{W}/^{184}\text{W}$ may not refer to a time of core formation. The difficulty with this scenario
is that Hf and W condense at very high temperatures, 1652$^o$K and 1802$^o$K, respectively. This is before FeNi
and any major silicate condensation, so that Hf, W and other ultra refractories will be present as metals. It follows that if the processes are nebular, then a mix of some silicate dust with the metal followed by melting
is necessary to provide an early Hf extraction into silicates. If one assumes that it is a planetary process, then
the time scale for planetesimal core formation must be short and commensurate with the Pd-Ag time scale.
There must also exist complementary differentiated stony meteorites that are highly enriched in $^{182}\text{W}/^{184}\text{W}$.

Figure 2. $\Delta T$ vs. Ge contents

Table 1. Palladium and Silver Abundances in Meteorites

<table>
<thead>
<tr>
<th>Sample</th>
<th>$^{107}\text{Pd}$ (10$^{-15}$ atoms/g)</th>
<th>$^{107}\text{Ag}$ (10$^{-11}$ atoms/g)</th>
<th>$^{107}\text{Ag}/^{106}\text{Pd}$*</th>
<th>$^{107}\text{Pd}/^{109}\text{Ag}$</th>
<th>$^{107}\text{Ag}/^{108}\text{Pd}$ (10$^*$)</th>
<th>$\Delta T$ (MY)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coahuila metal</td>
<td>2.643$\pm$0.007</td>
<td>95.5$\pm$0.64</td>
<td>1.089$\pm$0.0033</td>
<td>276.7$\pm$2.0</td>
<td>2.86$\pm$1.2</td>
<td>1.6$\pm$3.3</td>
</tr>
<tr>
<td>Tres Castillos metal-1</td>
<td>6.801$\pm$0.016</td>
<td>73.6$\pm$0.42</td>
<td>1.093$\pm$0.0011</td>
<td>923.7$\pm$5.7</td>
<td>1.3$\pm$0.1</td>
<td>-6.2$\pm$0.8</td>
</tr>
<tr>
<td>Tres Castillos metal-2</td>
<td>6.304$\pm$0.015</td>
<td>56.5$\pm$0.34</td>
<td>1.088$\pm$0.0018</td>
<td>1115$\pm$7.3</td>
<td>0.66$\pm$0.16</td>
<td>-12$\pm$2</td>
</tr>
<tr>
<td>Tres Castillos sulfide</td>
<td>0.0019</td>
<td>394.4$\pm$1.0</td>
<td>1.085$\pm$0.0017</td>
<td>0.048</td>
<td>&lt;8600</td>
<td>&lt;76</td>
</tr>
<tr>
<td>Soroti metal</td>
<td>8.621$\pm$0.026</td>
<td>747.1$\pm$0.10</td>
<td>1.080$\pm$0.0014</td>
<td>115.4$\pm$0.4</td>
<td>&lt;0.7</td>
<td>&lt;12</td>
</tr>
<tr>
<td>Soroti sulfide</td>
<td>0.002</td>
<td>1317$\pm$1.4</td>
<td>1.082$\pm$0.0014</td>
<td>0.015</td>
<td>&lt;1.5$\times$10$^{1}$</td>
<td>&lt;80</td>
</tr>
</tbody>
</table>

* $^{107}\text{Ag}/^{106}\text{Pd}$ ratios are Faraday cup (FC) data. For Normal (NIST SRM 978), $^{107}\text{Ag}/^{108}\text{Pd}$ = 1.0811$\pm$0.0017.

**Formation time difference relative to Gibeon.