パラサイト隕石 Brenham の Hf-W 年代学

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Hf-W chronology of the Brenham pallasite

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Pallasites are stony-iron meteorites consisting mainly of huge olivine and FeNi metal, thus thought to have representing the core-mantle boundary of their parent body (e.g. [1]). Determining the forming age of pallasites is important to understand the process occurred at the core-mantle boundary of their parent bodies. The Hf-W chronometer is useful to constrain the timing of events accompanied by Hf/W fractionation in the early solar system, such as silicate-metal segregation. Yet the precise and accurate Hf-W age of pallasites is to be determined. Moreover, the formation process of pallasite meteorites is still controversial. There are two major hypotheses for the formation mechanism, which are fractional crystallization of olivine at the core-mantle boundary [1] and core-mantle mixing by a catastrophic impact [2]. Determining the precise age of the constituent phases of pallasites is key to constraining the formation process and the nature of the parent bodies. Quitté and co-workers [3] carried out W isotope analyses of pallasite metals and found that the metals, even those of main-group pallasite, have variable $\varepsilon^{182}W$ values, some of which are lower than that of CAIs. The observation suggests that the W isotope compositions reflect not only radiogenic decay from ^{182}Hf but also other processes. More recently, it has been shown that W isotopes in other meteorites are variable due to effects of nucleosynthetic anomaly and neutron capture reactions [4]. Therefore, to obtain reliable Hf-W age of pallasites, we need to not only measure W isotopes in pallasites but also evaluate possible effects of nucleosynthetic anomaly and neutron capture.

In this study, Hf-W isotopic analyses have been performed on metal and olivine fractions of Brenham, a main group pallasite. The sample was first crushed in an agate mortar. Then the sample was separated by ferrite magnet, and olivine was hand-picked from the non-magnetic fractions under a stereoscopic microscope. After digesting the metal and olivine fractions in 1M HF, Bio-Rad AG1-X8 anionic resin (#200-400, chloride form) was used to separate W from the bulk solution. W isotopic measurement was performed on a Thermo Fisher Scientific Neptune plus multi-collector ICP-MS equipped with the Ni-Jet sampler and the Ni-X skimmer cones. The solution was introduced by a CETAC Aridus II desolvating nebulizer system. Every sample analysis was bracketed by NIST SRM 3163 standard solution. The instrumental mass bias was corrected to $^{186}W/^{184}W = 0.92763$ using the exponential law.

The results of W isotopic analyses of Brenham metal are shown in figure 1. The metal fraction yielded an $\varepsilon^{182}W$ value of -3.43 ± 0.15 relative to the standard solution. The obtained $\varepsilon^{183}W$ value of Brenham metal was in agreement with the standard solution, indicating that there is no nucleosynthetic anomaly in Brenham. The model age calculated from the $\varepsilon^{182}W$ value is 0.49 ± 1.53 Myr after the CAI formation. The possible effect of neutron capture was estimated from reported data of the abundance of ^{3}He and the cosmic exposure age [5]. The possible neutron capture effect on $\varepsilon^{182}W$ estimated from these reported data is -0.15ε. Considering this effect, it is indicated that the core of the parent body had segregated within 3.3 Myr after the CAI formation. This estimated metal segregation age is consistent with the early accretion of magmatic iron meteorites and apparently older than non-magmatic (impact origin) iron meteorites, such as IIE irons (Figure 2). The age consistency and inconsistency between the Brenham metal and two types of iron meteorites imply that the Brenham metal formed during the early metal segregation on its parent body, rather than a catastrophic impact.

We further reveal that the olivine fractions yielded substantially higher $\varepsilon^{182}W$ values than the CAIs. The Hf/W ratio of each sample, which was not processed for isotope-dilution nor chemical separation, was measured by iCAP-Q quadrupole mass spectrometer, since there was a problem in preparing olivine sample as below. The gained isochron using the metal and olivine fraction data yields an age of -5.22 ± 5.06 Myr after the CAI formation (Figure 3). The isochron age apparently older than the CAIs is inconsistent with the current view of planetary evolution, suggesting problem(s) in analyzing the olivine fractions. There are two possible problems: 1) the effect of neutron capture in the olivine fraction and 2) the loss of Hf during the sample dissolution in which Hf can be substantially partitioned into precipitated fluorides. The former problem can be solved by measuring Hf stable isotope ratios, which are also sensitive to neutrons of similar energies that affect W isotope ratios [8]. The

Hf loss resulting from Hf co-precipitation with fluorides can be circumvented by utilizing the Al-addition method which results in little Hf partition into fluorides [9].

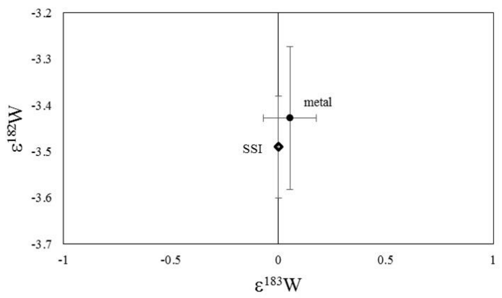

Figure 1. W isotopic data for the Brenham metal. SSI: the solar system initial $\varepsilon^{182}W$ value deduced from the measurement of CAIs

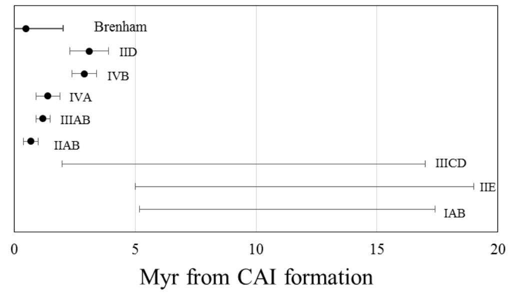

Figure 2. Hf-W age comparison between the Brenham metal and iron meteorites. The model age of Brenham is consistent with magmatic irons rather than non-magmatic irons [6][7].

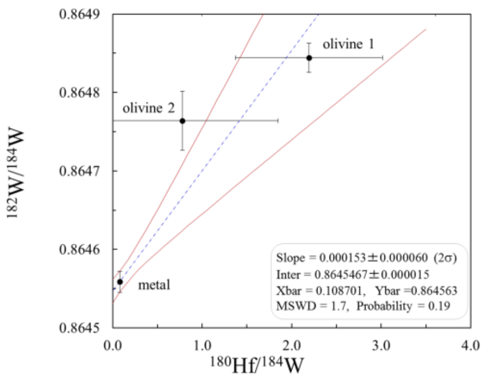

Figure 3. The internal isochron derived from the metal and olivine fractions of Brenham. The Hf/W ratios were measured by iCAP-Q ICP-MS.

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