THE TUNGSTEN ISOTOPE COMPOSITION OF WINONAITES – EVIDENCE FOR LATE STAGE EQUILIBRATION ON THE WINONAITE PARENT BODY - Schulz T.[1,2,3], Münker C.[2,3], Mezger K.[3] and Palme H.[1], [1]Institut für Geologie und Mineralogie, Universität zu Köln, Zülpicherstr. 49b, D–50674, Köln; [2]Mineralogisch-Petrologisches Institut, Universität Bonn, Poppelsdorfer Schloss, 53115 Bonn; [3]Zentrallabor für Geochronologie, Institut für Mineralogie, Universität Münster, Corrensstr.24, D–48149 Münster

Abstract: The ^{182}Hf-^{182}W decay system (half-live 8.9 million years) can be used to date metal-silicate separation in early solar system materials. The siderophile W preferentially partitions into the metal phase, whereas the lithophile Hf prefers the silicates. After metal-silicate separation, radiogenic ^{182}W accumulates in the silicate, whereas ^{182}W in metal remains unchanged.

We have recently shown that silicate inclusions in IAB iron meteorites display distinctly different W isotope compositions than the host metals, indicating that the exchange of W between metal and silicates ceased within the lifetime of ^{182}Hf. The metals have ε_W values around -3.0 and the corresponding silicates have excesses of up to +35 ε units [1]. Here we present data for four members of the Winonaite group, which is interpreted to be closely related to the silicates of the IAB iron meteorite group [2]. The W isotope composition of two analysed metal phases (around ~ -2.5 ε units) is slightly more radiogenic compared to IAB metals. The silicate fractions of the Winonaites show variable excesses in ^{182}W of up to ~ + 2.7 ε units. These systematics are consistent with late stage equilibration terminating at 4553.1 ± 2.7 Myr.

Introduction: Winonaites are rare primitive achondrites with basically chondritic chemistry. Mineral equilibria and textures indicate metamorphism and small degrees of partial melting. Benedix et al. introduced three criteria to classify Winonaites: (1) their highly reduced mineralogy (Fa < 10), (2) their oxygen isotope compositions, and (3) the abundances and distribution of metal and troilite [3]. Although their oxygen isotope composition links them to the silicate inclusions of IAB iron meteorites, the relationship of these two groups of meteorites is unclear. The parent body of the Winonaites was essentially chondritic, whereas most silicate inclusions in IAB-irons are low in siderophile elements. Further evidence for the chondritic nature of the precursor material is the presence of relict chondrules in several Winonaites [4]. Winonaites experienced varying degrees of metamorphism, partial melting and incomplete differentiation at temperatures around 950°C and above [5,6]. They lack significant shock features, but appear to have been brecciated.

Since Winonaites are reduced rocks most of the W is concentrated in the metal. At temperatures above 1000°C radiogenic ^{182}W produced in silicates will exchange with W in the metal. During cooling, isotope equilibration will cease and in silicates ^{182}W excesses will develop within the lifetime of ^{182}Hf. In an ideal case the ^{182}W/^{184}W ratios will lie along an isochron, defining the age of the last metal silicate equilibration. We have applied the Hf/W chronometer to Winonaites by systematic analyses of separates with different Hf/W ratios.

Samples and analytical methods: So far we have analysed bulk samples and separates from four Winonaites (Hammadah al Hamra 193, Mount Morris, Winona and NWA 4024). From each of the selected Winonaites a few chips were cleaned with steel-free abrasives and put in an ultrasonic bath before leaching in 0.05M HNO_3 for several minutes. All samples were powdered in an agate mortar to reduce grain size. During this procedure magnetic fractions were continuously separated from the non-magnetic residue using a hand magnet. In the case of NWA 4024 we obtained a pure metal phase that was visibly free of silicates. Separation of Hf and W from the matrix was performed by conventional anion exchange techniques [7]. All isotope compositions were determined using the Micromass IsoProbe MC-ICP-MS at the University of Münster [7].

Results: W isotope ratios for single metal fragments from NWA 4024 and Winona of ~ -2.5 ε_W are slightly more radiogenic than the signature of the IAB metals [8]. The silicates in Winonaites show tiny excesses in ^{182}W/^{184}W of up to ~ + 2.7 ε units. Some silicate fractions seem to be completely equilibrated with the metal and have values of around ~ -2.6 ε_W. The initial ε_W derived from the isochron is -2.4 ± 0.4 ε_W. The data for all analysed separates are shown in the Figure 1.

Discussion: Most data-points define an isochron yielding an age of 4553.1 ± 2.7 Myr which most likely dates the last W exchange between metal and silicate, i.e. the end of metal-silicate equilibration during cooling of the Winonaite parent body or a probably impact induced late re-equilibration. However, the resulting age is ~14 Myr after CAI-formation (similar to cooling ages of chondrite parent bodies [9]). Assuming a common history for IAB iron meteorites and Winonaites on the same parent body, this age postdates the major mantle fractionation event in the IAB parent body by ~11 Myr [1,8]. We have previously shown that most unprocessed silicate separates from IAB iron meteorites define a Hf/W isochron with an age of ~3 Myr after CAI formation. This age was interpreted as a major mantle fractionation event on the IAB parent body [1].

Despite their low Hf/W ratios two of the analysed separates from Winona and Mount Morris show radiogenic ε_W values and do not plot on the isochron defined by all other sample splits. A possible explanation for this discrepancy is that a local second stage metal-silicate equilibration event affected these samples. This could have been the result of an impact on the Winonaite parent body. For Mount Morris we have only one metal fraction with radiogenic W-isotopes. In Winona, however, there must be at least two types of metal. The points on the isochron reflect only the more unprocessed metal-type. The presence of two distinct metal generations was not identified so far, but the highly reduced compositions of the Winonaites and the presence of second stage metals in other achondrites make this explanation plausible.

Conclusion: Winonaites are only slightly processed chondritic meteorites. They have been affected by temperatures somewhat above those recorded by type 6 ordinary chondrites. The main metal phase in Winonaites has an unradiogenic ^{182}W signature at around -2.6 ε_W, somewhat lower than unequilibrated OC-metal [10] and IAB metals [8]. This is in agreement with late metal-silicate equilbration in the parent body of Winonaites. This value is indistinguishable from the ε_W-initial of an isochron defined by five silicate separates from different Winonaites (4-8 in the Figure 1). The age of this isochron postdates the CAI formation by ~14 Ma. This is similar to cooling histories of chondrite parent bodies, that experienced varying cooling rates depending on the size of their parent body, the initial burial depth of these meteorites and the thickness of the regolith cover of their parent body. The slightly more radiogenic ε_W-intercept of the Winonaite isochron compared to most chondrites [10] indicates slower cooling and maybe a deeper burial of these samples within their parent body.

It is also possible to assume a common IAB/Winonaite parent body. The thermal event that affected the Winonaites, in this case interpreted as a late stage re-distribution, then postdates most thermal equilibration events in previously analysed IAB silicates [1,7] but predates the equilibration event in the IAB iron meteorite Lueders, which occurred when ^{182}Hf was already near extinction [1].

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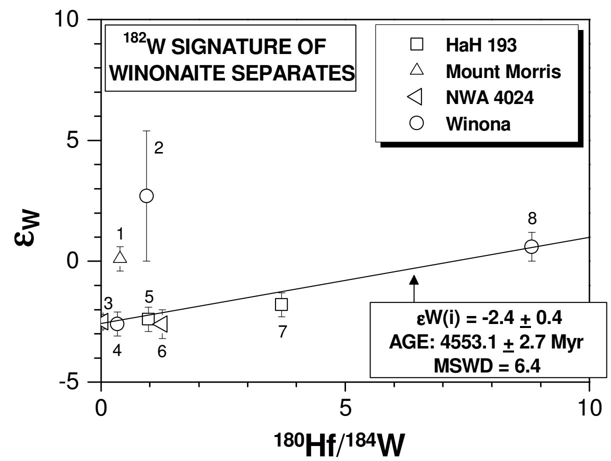

Figure 1: A Winonaite isochron defined by silicate fractions from four different meteorites. The ε_W units represent the deviation of W isotope ratios in the sample from the terrestrial standard value in parts per 10.000. HaH 193 = Hammadah al Hamra 193; NWA 4024 = Northwest Africa.