# HF-W CHRONOMETRY OF ANGRITES: CONSTRAINTS ON THE ABSOLUTE AGE OF CAIS AND PLANETESIMAL ACCRETION TIMESCALES.

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**Introduction:** One of the key issues in cosmochronology is to combine the timescales obtained from long-lived chronometers (e.g., $^{207}$Pb-$^{206}$Pb) with those derived from short-lived chronometers (e.g., $^{182}$Hf-$^{182}$W, $^{26}$Al-$^{26}$Mg). This is essential for constraining the sequence of events in the early solar system, such as the duration of chondrule formation and the timescales for the accretion of planetesimals. The $^{182}$Hf-$^{182}$W system is a powerful tool for dating processes in the early solar system and here we calibrate the $^{182}$Hf-$^{182}$W system to an absolute timescale using angrites. These meteorites are well suited for this task because (i) they cooled rapidly, such that differences in closure temperatures among different chronometers do not result in resolvable age differences, and (ii) they exhibit high U/Pb ratios, such that precise Pb-Pb ages are available [1]. Amelin [1] recently reported precise $^{207}$Pb-$^{206}$Pb ages for several angrites that reveal an age dispersion of ~7 Ma.. This range in ages makes it possible to intercalibrate the $^{182}$Hf-$^{182}$W and $^{207}$Pb-$^{206}$Pb systems. Here we present internal Hf-W isochrons for the angrites Northwest Africa 4590 and 4801 and use these to constrain the absolute age of CAIs as well as the timescales for the accretion of chondrite parent bodies.

**Methods:** Pyroxene, olivine, and plagioclase separates were obtained using heavy liquids and handpicking, and were washed in ethanol. Small metal grains were removed using a hand-magnet. All samples were dissolved in Savillex beakers using HF-HNO$_3$ at 120°C on a hotplate. After drying, samples were redissolved several times in HNO$_3$-H$_2$O$_2$ and finally in 6 M HCl-0.06 M HF. At this stage complete dissolution was achieved and a ~10% aliquot was spiked with a mixed $^{180}$Hf-$^{183}$W tracer for isotope dilution measurements. All measurements were performed using a *Nu Plasma* MC-ICPMS at ETH Zurich. Tungsten isotope ratios of the samples were determined relative to two bracketing measurements of the W standard and are expressed in $\varepsilon^{182}$W, which is the 0.01% deviation from the terrestrial $^{182}$W/$^{184}$W. Each run was performed with 1.5-2 V for $^{182}$W, resulting in an external reproducibility of ±0.3-0.4 $\varepsilon^{182}$W ($2\sigma$).

**Results:** Olivine and plagioclase separates from both angrites have low $^{180}$Hf/$^{184}$W and $^{182}$W/$^{184}$W ratios, whereas the pyroxenes exhibit high $^{180}$Hf/$^{184}$W and radiogenic $^{182}$W/$^{184}$W ratios. These radiogenic W isotope compositions make it possible to obtain high precision ages. For both angrites, the Hf-W data for the mineral separates define precise isochrons (Figure 1). For NWA 4801, the fines and a mix fraction also plot on the isochron, whereas for NWA 4590 these fractions plot off the isochron, indicating a slight disturbance of the Hf-W system in this sample.

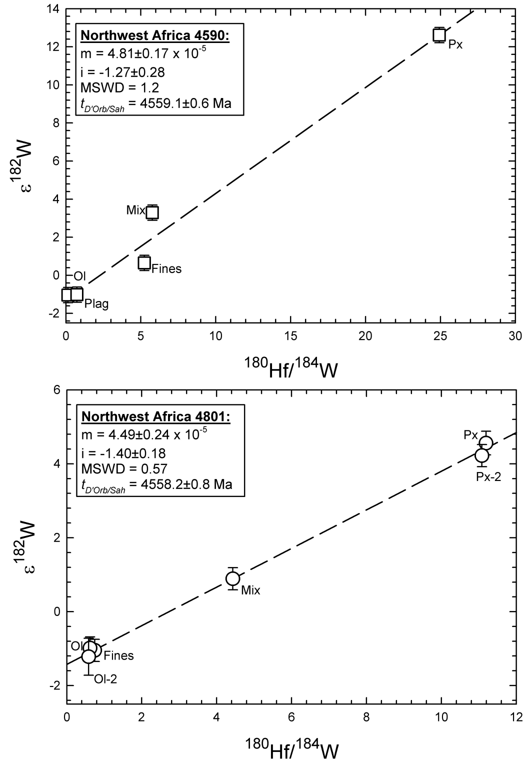

Figure 1: Hf-W isochrons for angrites. m = initial $^{182}$Hf/$^{180}$Hf; i = initial $\varepsilon^{182}$W. $t_{D'Orb/Sah}$ is calculated relative the $^{182}$Hf/$^{180}$Hf ratio and Pb-Pb age of angrites D'Orbigny and Sahara 99555 [1, 2].

**Discussion:** *Comparison to Pb-Pb ages and the absolute age of CAIs.* In Figure 2, the initial $^{182}$Hf/$^{180}$Hf ratios of angrites are plotted against their Pb-Pb ages. The angrites D'Orbigny and Sahara 99555 as well as Northwest Africa 4590 and 4801 plot on a straight line, whose slope is identical to the one predicted from the $^{182}$Hf half-life. Northwest Africa 2999 plots slightly below but within uncertainty of this line. This might reflect a slight disturbance of the Hf-W system in this sample [2]. Figure 2 reveals that the calibration of the Hf-W system onto an absolute timescale yields consistent results regardless of which of the four angrites D'Orbigny, Sahara 99555, Northwest Africa 4590 or

4801 is used. This provides compelling evidence that the absolute Hf-W ages calculated relative to these angrites are robust and accurate. This approach yields an absolute Hf-W age of 4568.6±0.7 Ma for CAIs [3], ~1.5 Ma older than the 4567.11±0.16 Ma Pb-Pb age for Efremovka CAI E60 [4].

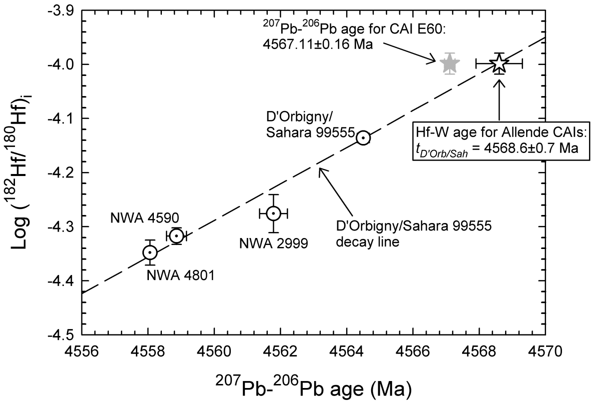

Figure 2: Initial $^{182}$Hf/$^{180}$Hf vs. Pb-Pb ages. Pb-Pb ages for angrites are from [1] and J. Connelly [pers. comm.], Hf-W data for D'Orbigny, Sahara 99555, and Northwest Africa 2999 from [2]. Hf-W data for CAIs from [3].

*Planetesimal accretion timescales.* The upward revision of the absolute age of CAIs has important implications for determining the formation intervals of chondrules based on Pb-Pb chronometry and their comparison to relative Al-Mg ages for chondrules. Relative to the Pb-Pb age for Efremovka CAI E60 of 4567.11±0.16 Ma [4] the Pb-Pb ages for Allende [5], Acfer 059 [6], and Gujba [7] chondrules correspond to Pb-Pb formation intervals of ~1.7, ~2.4, and ~4.4 Ma. However, the absolute age of CAIs determined here is ~1.5 Ma older than the currently used age of 4567.11±0.16 Ma [4], indicating that Pb-Pb formation intervals for chondrules are ~1.5 Ma older: Allende chondrules formed 3.15±0.83 Ma, Acfer 059 chondrules 3.90±0.92 Ma, and Gujba chondrules 5.90±0.86 Ma after CAI formation. These new results reveal that chondrules from these carbonaceous chondrites formed distinctly later than chondrules from ordinary chondrites, which have Al-Mg ages of ~2 Ma after CAI formation [8, 9].

In Figure 3 the formation ages for chondrules from ordinary and carbonaceous chondrites are plotted against the peak temperature reached inside their parent bodies. The peak temperatures are derived from the most metamorphosed rocks from each chondrite group. These rocks resided deep inside the parent body, whereas those samples suitable for chondrule dating resided near the surface and were not metamorphosed. Figure 3 reveals that there is an inverse trend between chondrule formation age and maximum temperature reached inside the parent body. If the chondrite parent bodies accreted soon after chondrule formation, this correlation is most readily explained by $^{26}$Al decay being the dominant heat source in the early evolution of chondrite parent asteroids. This is because the energy released by $^{26}$Al decay will have raised the temperature close to the peak temperature for each of the chondrite parent bodies.

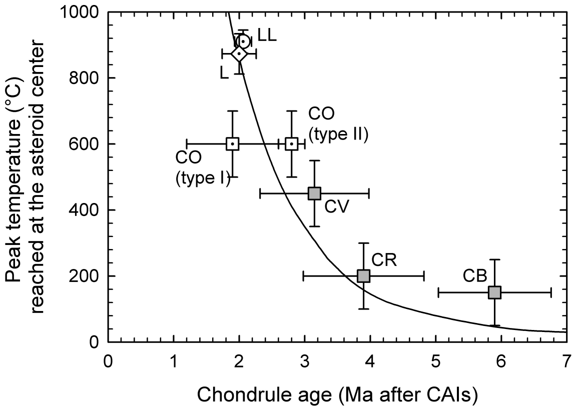

Figure 3: Peak temperature in the asteroid center vs. chondrule ages. The solid line shows the peak temperature reached in the centre of a spherical asteroid (r~100 km) that was heated by $^{26}$Al decay and accreted instantaneously 0.7 Ma after chondrule formation. Al-Mg ages for L and LL chondrites from [8, 9] and for CO chondrites from [10, 11]. See text for references on the Pb-Pb ages of CV, CR and CB chondrules.

**Conclusions:** The Hf-W data for angrites presented here provide a robust calibration of the Hf-W system onto an absolute timescale. Using this calibration, the absolute Hf-W age of CAIs is 4568.6±0.7 Ma, ~1.5 Ma older than a Pb-Pb age for Efremovka CAIs [4]. The upward revision of the absolute age of CAIs indicates that CV, CR and CB chondrules formed later than L and LL chondrules, most likely indicating that the parent bodies of carbonaceous chondrites accreted later than those of the ordinary chondrites. This can account for the lower peak temperatures reached inside the former.

**References:** [1] Amelin Y. (2008), *GCA 72*. [2] Markowski A. et al. (2007), *EPSL 262*. [3] Burkhardt C. et al. (2008), *GCA submitted*. [4] Amelin Y. et al. (2006), *LPSC XXXVII*. [5] Connelly J.N. et al. (2007) in: *Workshop on the chronology of meteorites*. [6] Amelin Y. et al. (2002), *Science 297*. [7] Krot A.N. et al. (2005), *Nature 436*. [8] Kita N.T. et al. (2000), *GCA 64*. [9] Rudraswami N.G. and Goswami J.N. (2007), *EPSL 257*. [10] Kunihiro T. et al. (2004), *GCA 68*. [11] Kurahashi E. et al. (2004), *LPSC XXXV*.