HAFNIUM–TUNGSTEN AGES OF METEORITES. T. Kleine[1], C. Burkhardt[2], P. Sprung[2] and T. Krujier[2], [1]Institute for Planetology, Wilhelm-Klemm-Str. 10, 48149 Muenster, Germany (thorsten.kleine@uni-muenster.de), [2]Institute for Geochemistry and Petrology, ETH Zurich, Clausiusstrasse 25, 8092 Zurich, Switzerland.

Introduction: Chronometers based on the decay of short-lived, now extinct radionuclides are powerful tools for determining the timing of important events during the early evolution of the solar system. The application of short-lived nuclides as chronometers is based on the assumption that they were distributed homogeneously in the region of the solar system where the meteorite parent bodies and their components had formed. Such a homogeneous distribution cannot be assumed *a priori* but must be tested by comparing ages obtained from different chronometers for a set of well-characterized samples [1].

Among the short-lived chronometers, the decay of ^{182}Hf to ^{182}W ($t_{1/2}$ = 8.9 Myr) has been primarily used to date planetary accretion and core formation [2]. More recently, however, the Hf–W system has also been applied to date individual meteorites and their components. The Hf/W ratios vary substantially among the constituent minerals of meteorites (and their components), such that precise internal isochrons can be obtained. For instance, the high Hf/W of high-Ca pyroxenes in angrites and Ca-Al-rich inclusions (CAI) makes it possible to obtain precise internal isochrons for these samples [2-4]. Likewise, the low Hf/W in metals combined with the corresponding high Hf/W in silicate-rich fractions allows precise dating of metal-bearing chondrites [5, 6]. Here we summarize available Hf–W ages for meteorites as obtained from internal isochrons and compare these ages to results from other short-lived chronometers and the Pb–Pb system.

Summary of Hf–W ages: Internal Hf–W isochrons are available for CAI, angrites, one metal-rich eucrites, one metal-rich CH chondrite, several equilibrated H and L ordinary chondrites, and a few primitive achondrites. Here we will focus on CAI, angrites and ordinary chondrites.

CAI. An isochron based on Hf–W data for mineral separates and bulk samples from about ten CAI from Allende and one CAI from the NWA 2364 CV chondrite yields an initial ^{182}Hf/^{180}Hf of (9.72±0.44)×10^{-5} [3]. All Hf–W ages are calculated relative to this initial ^{182}Hf/^{180}Hf of CAI and are given as Δt_{CAI}, *i.e.*, the time elapsed since CAI formation.

Chondrites. Hf–W ages are available for several ordinary chondrites [5], but no unequilibrated samples have yet been dated. The Hf–W ages for equilibrated H chondrites of petrologic types 4–6 range from Δt_{CAI} ~1.7 to ~10 Myr and provide the time of isotopic closure during thermal metamorphism of these chondrites [5]. Since the Hf–W closure temperature is similar to the peak metamorphic temperatures, the Hf–W ages correspond closely to the time of the thermal peak in the H chondrite parent body. Metamorphic temperatures of type 4 chondrites were probably too low to reset the Hf–W system, so that the Hf–W age for the H4 chondrite Ste. Marguerite may date the time of chondrule formation [5]. As to whether Hf–W ages for type 4 chondrites reliably constrain the time of chondrule formation needs to be evaluated with more Hf–W studies on type 4 chondrites. Note however that the Hf–W age for Ste. Marguerite of Δt_{CAI} ~1.7 Myr is consistent with Al–Mg ages for ordinary chondrite chondrules [7, 8].

Angrites: Angrites can be readily dated with the Hf–W system because the fassaitic pyroxene in these meteorites has high ^{180}Hf/^{184}W ratios of up to ~70. Internal Hf–W isochrons are available for eight angrites and their initial ^{182}Hf/^{180}Hf ratios range from ~7×10^{-5} to ~4×10^{-5}, corresponding to Hf–W ages, Δt_{CAI}, of ~4 to ~11 Myr after CAI formation [2].

Comparison to ages obtained from other chronometers: Two features make CAI and angrites ideally suited for testing the consistency of ages obtained from different short-lived chronometers and the Pb–Pb system. First, both CAI and angrites have cooled rapidly, so that differences in closure temperatures among the chronometers could not result in resolvable age differences. Second, both groups of samples are characterized by very high U/Pb ratios, which make it possible to determine precise Pb–Pb ages [9, 10].

Hf–W vs. Pb–Pb. All eight angrites have concordant Hf–W and Pb–Pb ages, once the Pb–Pb ages are corrected for U isotopic variations. The 'absolute' Hf–W age for CAI, calculated using the relative Hf–W and absolute Pb–Pb ages of the angrites and the initial ^{182}Hf/^{180}Hf of CAI, average at 4567.5±0.8 Ma. This age overlaps with both the Pb–Pb age for CAI SJ101 of 4567.2±0.5 Ma [10] and the Pb–Pb age of 4568.2±0.2 Ma for CAI 2364 B-1 [11]. Thus, the Hf–W ages currently have insufficient precision to distinguish which of these two Pb–Pb dates for CAI better represents their absolute age. However, the comparison of the relative Hf–W ages, Δt_{CAI}, of the individual angrites shows that the Hf–W data seem to be more consistent with an absolute age of ~4567.2 Ma for CAI. All the Pb–Pb formation intervals of the angrites calculated relative to a Pb–Pb age of 4567.2±0.5 Ma are consistent with their Hf–W formation intervals. In contrast, the Pb–Pb formation intervals calculated relative to a Pb–Pb age of 4568.2±0.2 Ma for CAI 2364 B-1 tend to be slightly longer than those obtained from the Hf–W system. Clearly, U isotopic data for CAI 2364 B-1 are required to fully assess the significance of its Pb–Pb age.

Hf–W vs. Mn–Cr. Mn–Cr data are available for four of the angrites that also have been studied with the Hf–W system (see summary in [1]). For these four angrites initial ^{182}Hf/^{180}Hf and ^{53}Mn/^{55}Mn ratios vary as expected from the ^{182}Hf and ^{53}Mn half-lives. The initial ^{53}Mn/^{55}Mn at the initial ^{182}Hf/^{180}Hf of CAI is ~7×10^{-6}, consistent with the initial ^{53}Mn/^{55}Mn of the solar system estimated based on Mn–Cr data for Orgueil [12].

Hf–W vs. Al–Mg. The Hf–W formation interval between angrites D'Orbigny/Sahara 99555 and CAI is ~4 Myr and, hence, shorter than the ~5 Myr Al–Mg interval between these two angrites and CAI [13, 14]. Fig. 1 shows that the Pb–Pb age difference between D'Orbigny/Sahara 99555 and CAI SJ101 also is shorter than that obtained from the Al–Mg data. However, the Pb–Pb formation interval between these two angrites and CAI 2364 B-1 is consistent with the Al–Mg results.

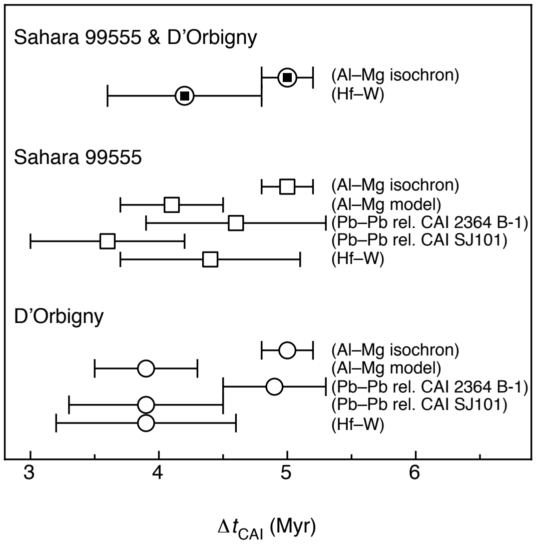

Fig. 1: Comparison of Hf–W, Al–Mg and Pb–Pb ages for angrites D'Orbigny and Sahara 99555.

The disparity between the Hf–W and Al–Mg formation intervals of D'Orbigny and Sahara 99555 may either reflect a disturbance of the internal Al–Mg systematics of these angrites or a lower-than-canonical ^{26}Al/^{27}Al in the angrite precursor material. The former interpretation is supported by the observation that the Al–Mg whole-rock model ages [13] of these angrites are consistent with the Hf–W ages (Fig. 1). However, there is no clear textural evidence for a disturbance of the Al–Mg systematics in the angrites. Nevertheless, such a disturbance is difficult to exclude and this interpretation has been advanced by Schiller et al. [13]. The second of the aforementioned options would be consistent with a recent proposal for a heterogeneous distribution of ^{26}Al in the solar nebula [15]. In this case, the good agreement between the Al–Mg isochron ages of D'Orbigny and Sahara 99555 and the Pb–Pb intervals of these angrites relative to CAI 2364 B-1 would be fortuitous.

Ultimately, it should be possible to distinguish between the two explanations discussed above, once precise Pb–Pb ages and U isotopic data are available for several CAI. Furthermore, it will be important to obtain more Hf–W data for CAI, to better define the initial ^{182}Hf/^{180}Hf at the time of CAI formation.

In summary, there is good agreement between Hf–W, Mn-Cr and Pb–Pb ages for angrites, and between the 'absolute' Hf–W age of CAI and the Pb–Pb age for CAI SJ101. Moreover, the inferred initial ^{53}Mn/^{55}Mn at the solar system initial ^{182}Hf/^{180}Hf is consistent with the solar system initial ^{53}Mn/^{55}Mn determined based on Orgueil. However, a higher solar system initial ^{53}Mn/^{55}Mn has also been proposed [*e.g.*, 1]. Al–Mg ages for D'Orbigny and Sahara 99555 are inconsistent with the Hf–W results and also with some Pb–Pb ages. The reasons for this disparity are yet not fully understood, however.

References:

[1] Nyquist L.E. et al. (2009) *Geochim. Cosmochim. Acta*, *73*, 5115–5136. [2] Kleine T. et al. (2009) *Geochim. Cosmochim. Acta*, *73*, 5150-5188. [3] Burkhardt C. et al. (2008) *Geochim. Cosmochim. Acta*, *72*, 6177-6197. [4] Markowski A. et al. (2007) *Earth Planet. Sci. Lett.*, *262*, 214-229. [5] Kleine T. et al. (2008) *Earth Planet. Sci. Lett.*, *270*, 106-118. [6] Touboul M. et al. (2009) *Earth Planet. Sci. Lett.*, *284*, 168-178. [7] Kita N.T. et al. (2000) *Geochim. Cosmochim. Acta*, *64*, 3913-3922. [8] Rudraswami N.G. and Goswami J.N. (2007) *Earth Planet. Sci. Lett.*, *257*, 231-244. [9] Amelin Y. (2008) *Geochim. Cosmochim. Acta*, *72*, 221-232. [10] Amelin Y. et al. (2010) *Earth Planet. Sci. Lett.*, *300*, 343-350. [11] Bouvier A. and Wadhwa M. (2010) *Nature Geosci*, *3*, 637-641. [12] Trinquier A. et al. (2009) *Science*, *324*, 374-376. [13] Schiller M., Baker J.A., and Bizzarro M. (2010) *Geochim. Cosmochim. Acta*, *74*, 4844-4864.[14] Spivak-Birndorf L., Wadhwa M., and Janney P.E. (2008) *Geochim. Cosmochim. Acta*, *73*, 5202-5211. [15] Larsen K. et al. (2011) *Astrophys. J.*, *735*, L35.