HF-W CHRONOLOGY OF THE ANGRITE PARENT BODY: TIMING OF ACCRETION, CORE FORMATION AND MAGMATISM.

T. Kleine[1], B. Bourdon[1], and A. J. Irving[2], [1]Institute of Isotope Geochemistry and Mineral Resources, ETH Zurich, 8092 Zurich (kleine@erdw.ethz.ch). [2]Department of Earth & Space Sciences, University of Washington, Seattle, WA 98195, USA.

Introduction: Key issues regarding the early evolution of planetesimals include the timescales of accretion, core formation, and magmatism. The short-lived ^{182}Hf-^{182}W system has proven particularly useful as a chronometer for these early planetary processes. For instance, W model ages for magmatic iron meteorites reveal that core formation in their parent bodies occurred within ~1 Myr after formation of Ca,Al-rich inclusions (CAIs) [e.g., 1,3]. The application of the ^{182}Hf-^{182}W system to date core formation in the parent bodies of basaltic achondrites is less straightforward because the Hf-W systematics of these rocks may not only reflect Hf-W fractionation due to core formation but additional Hf-W fractionation during later events. This makes it difficult to estimate the ^{180}Hf/^{184}W and ^{182}W/^{184}W ratios of the bulk mantle, which need to be known for calculating core formation ages.

An alternative approach is to determine the W isotope evolution of the mantle of a differentiated planetesimal using the initial ^{182}W/^{184}W and ^{182}Hf/^{180}Hf ratios obtained from internal isochrons. Angrites are ideally suited for this approach because (i) they formed over a period that is sufficiently long for a resolvable evolution of the ^{182}W/^{184}W ratio, (ii) their isotope systematics do not seem to be significantly disturbed by thermal and impact metamorphism, and (iii) precise internal Hf-W isochrons can be obtained due to the high Hf/W ratios of angrite pyroxenes. We present Hf-W mineral isochrons for a suite of angrites including D'Orbigny, Sahara 99555, NWA 4590, NWA 4801 and LEW 86010 and use these data to constrain the chronology of the accretion and earliest differentiation of their parent body.

Methods and results: All angrites were gently crushed in an agate mortar and pyroxene, olivine, and plagioclase separates were obtained using heavy liquids and hand-picking, and were washed in ethanol. Sample dissolution, W purification and Hf-W concentration measurements followed our previously established techniques [e.g., 3]. 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 ε^{182}W, which is the 0.01% deviation from the terrestrial ^{182}W/^{184}W.

Olivine and plagioclase separates from all 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 up to ~15 ε^{182}W. For all angrites, the Hf-W data for the mineral separates define precise isochron that yield the initial ^{182}W/^{184}W and ^{182}Hf/^{180}Hf ratios at the time of Hf-W closure.

Discussion: *Comparison of Hf-W to Pb-Pb, Al-Mg, and Mn-Cr ages.* The Hf-W isochron ages for angrites are not only important for determining the chronology of the angrite parent body but also allow a comparison to results from the ^{53}Mn-^{53}Cr, ^{26}Al-^{26}Mg, and ^{207}Pb-^{206}Pb systems, all of which have also been applied to several of the angrites. In Fig. 1, the initial ^{182}Hf/^{180}Hf ratios of angrites are plotted against their Pb-Pb ages. All angrites plot on a straight line, whose slope is identical to the one predicted from the ^{182}Hf half-life. The excellent agreement between the Hf-W and Pb-Pb ages provide evidence that both Hf-W and Pb-Pb systematics provide reliable ages for angrite formation.

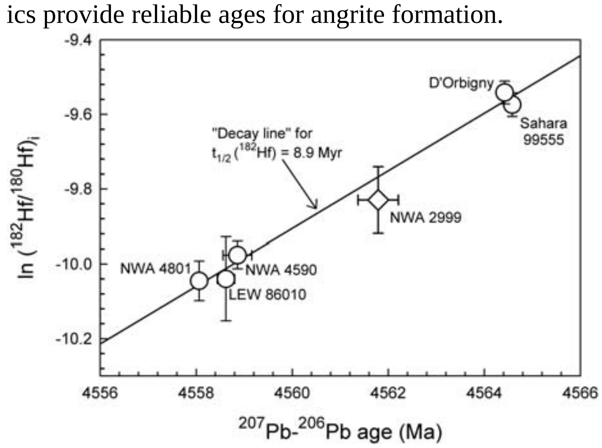

Figure 1: Initial ^{182}Hf/^{180}Hf vs. Pb-Pb ages [2] for angrites.

Fig. 2 illustrates that the Hf-W formation interval between D'Orbigny/Sahara 99555 and CAIs is consistent with the Al-Mg age difference between these two samples [3]. In contrast, the Hf-W and Mn-Cr age differences between angrites LEW 86010 and D'Orbigny are only marginally consistent with one another. Due to the fast cooling of angrites this cannot reflect differences in closure temperatures but may be caused by a partial resetting of the Mn-Cr systematics in LEW 86010. This could also account for the slight offset in the Mn-Cr ages reported for this angrite [5,7] and for the offset between the Pb-Pb and Mn-Cr age differences between D'Orbigny and LEW 86010 [2].

Hf-W chronology of the angrite parent body. At the time of their formation all angrites have ε^{182}W values that are elevated relative to chondrites (Fig. 3), indicating that the angrite magmas derive from source regions that had previously evolved with superchrondritic Hf/W. Fig. 3 illustrates that Sahara 99555, D'Orbigny, NWA 4590, NWA 4801, and LEW 86010 may represent batches of magma derived from a mantle source that evolved with ^{180}Hf/^{184}W~3-4. This Hf/W ratio is similar to those measured for bulk rock angrites, suggesting that the partial melting that produced the angrites did not lead to substantial Hf/W fractionations, consistent with the unfractionated trace element pattern of angrites. The source of the aforementioned angrites probably separated from the chondritic evolution line within ~2 Myr after formation of CAIs (Fig. 3) and acquired its elevated Hf/W ratio most likely as a result of core formation.

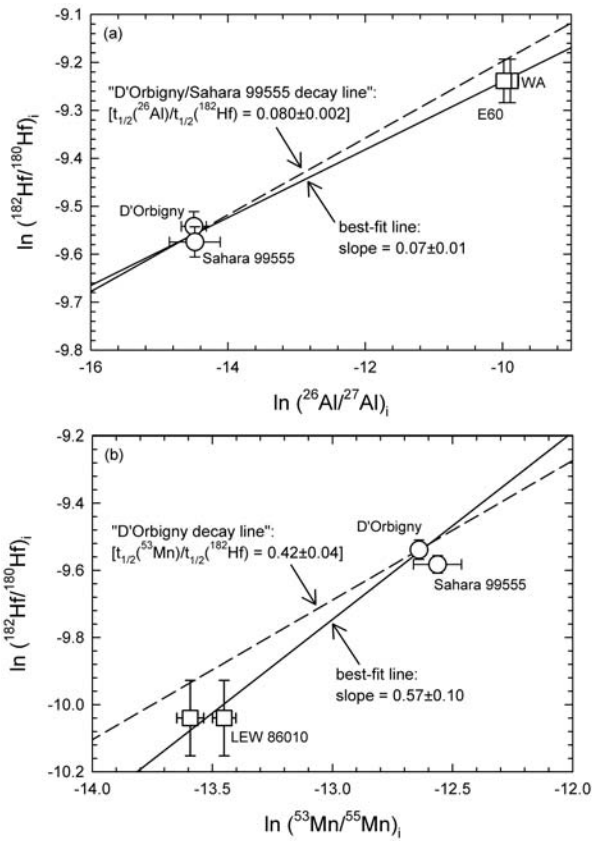

Figure 2: Initial ^{182}Hf/^{180}Hf vs. initial ^{26}Al/^{27}Al and ^{53}Mn/^{55}Mn. (a) from [3]; (b) Mn-Cr data are from [4-7]

It was noted earlier that AdoR has an unusual chemistry compared to the other angrites. The Hf-W systematics also reveal clear differences and show that AdoR must derive from a source that had evolved with much higher Hf/W than the other angrites. Likewise, NWA 2999 is different from the other angrites in its unusual abundance of siderophile elements (and its high metal content) and also requires a prehistory with high Hf/W. Both AdoR and NWA 2999 may derive from a mantle reservoir that formed by core formation from a chondritic source within the first ~3 Myr after CAI formation (Fig. 3). However, given that early accreted planetesimals probably were globally molten due to heating from abundant ^{26}Al, it is more likely that the NWA 2999/AdoR source formed after core formation by differentiation within the angrite mantle at ~3-4 Myr (Fig. 3). The elevated Hf/W ratio of the NWA 2999/AdoR source compared to the bulk mantle may then reflect a previous melt removal from this source.

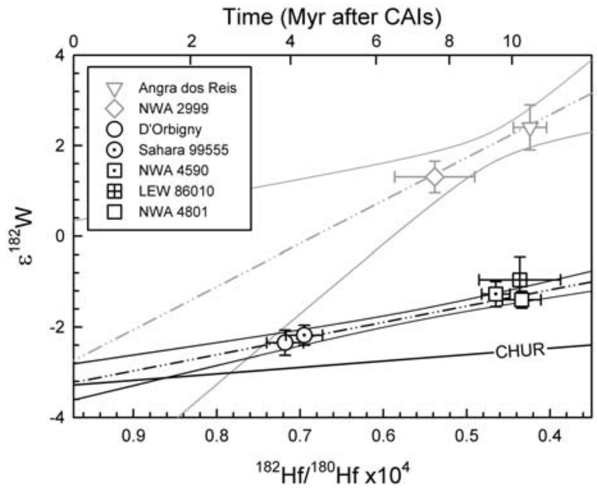

Figure 3: W isotope evolution of the angrite parent body. Data for Angra dos Reis are calculated using its Pb-Pb age [2] and the whole-rock analyses from [9]. Data for NWA 2999 are from [8]. Evolution of the chondritic uniform reservoir (CHUR) is shown for comparison.

Conclusions: Core formation in the angrite parent body probably occurred within the first ~2 Myr after CAI formation. This timescale is consistent with a Rb-Sr model age for separation of the angrite parent body from a hot solar nebula [10] and with Hf-W model ages for magmatic iron meteorites [e.g., 1,3]. Collectively, these chronological constraints demonstrate that accretion of differentiated planetesimals predated chondrule formation and accretion of chondrite parent bodies and that ^{26}Al decay was the dominant heat source for the early differentiation of meteorite parent bodies. Furthermore, the timescale of magmatism on the angrite parent body of ~4 to ~10 Myr after CAI formation is consistent with predictions from thermal models of asteroids that accreted within the first ~2 Myr after CAI formation [11].

References: [1] Kleine T. et al. (2005), *GCA*, *69*, 5805. [2] Amelin Y. (2008), *GCA*, *72*, 221. [3] Burkhardt C. et al. (2008), *GCA*, *72*, 6177. [4] Glavin D.P. et al. (2004) *MAPS*, *39*, 693. [5] Lugmair G.W. and Shukolyukov A. (1998) *GCA*, *62*, 2863. [6] McKibbin S.J. et al. (2008), *MAPS 43*, A96. [7] Nyquist L.E. et al. (1994) *Meteoritics*, *29*, 872. [8] Markowski A. et al. (2007) *EPSL*, *262*, 214. [9] Quitte G. et al. (2000) *EPSL*, *184*, 83. [10] Hans U. et al. (2009), *this volume*. [11] Sahijpal S. et al. (2007), *MAPS*, *42*, 1529.