HF-W EVIDENCE FOR RAPID ACCRETION AND FAST COOLING OF THE ACAPULCOITE PARENT BODY .

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Introduction: Acapulcoites have mineral modes similar to ordinary chondrites and exhibit broadly chondritic bulk compositions. The formation of acapulcoites however involved substantially higher temperatures than those of ordinary chondrites. The textures of acapulcoites reflect extensive solid-state recrystallization. There is also evidence for melting at the Fe,Ni-FeS cotectic and partial melting of silicates [1, 2].

Recent advances in the chronology of the early solar system reveal that differentiation of asteroids occurred early (<1.5 Myr after CAIs) and predated the accretion of chondrite parent bodies. This sequence of events suggests that the early evolution of planetary bodies was driven by the amount of ^{26}Al present at the time of accretion. The higher peak temperatures reached within the acapulcoite parent body may therefore indicate that accretion of the acapulcoite parent body occurred between the accretion of the parent bodies of differentiated meteorites and chondrites. To determine the timescales of the accretion and metamorphism of the acapulcoite parent body, we applied the ^{182}Hf–^{182}W chronometer (half-life = 8.9 Myr) to the acapulcoites NWA 2656, NWA 2775, Dhofar 125. We also analyzed NWA 2627, which now is suggested to be a transitional lodranite [3].

Methods: Samples were cleaned with abrasive paper and 0.05M HNO_3 in an ultrasonic bath. Between 0.5-1g of the sample was powdered in an agate mortar to obtain a representative whole rock powder. The remaining 2-4g were gently crushed in an agate mortar and sieved into several grain size fractions. Metals were separated using a handmagnet, further purified by grinding and ultrasonication in ethanol. For all samples except NWA 2656 sufficient metal for precise Hf-W analyses could be separated. Although most of the metals could be separated using this technique, some metal grains remained in the silicate-enriched fractions. The latter were thus further separated into weakly- and non-magnetic fractions. Dissolution and chemical separation techniques follow those described in Kleine et al. [4]. All isotope measurements were performed using the Nu Plasma MC-ICPMS at ETH Zurich. The W isotope compositons of the samples are determined relative to an ALFA AESEAR standard solution and are expressed in ε_W, which is the deviation of the ^{182}W/^{184}W ratio of the sample from the terrestrial standard value. Instrumental mass bias is corrected by normalizing to ^{186}W/^{183}W = 1.9859 and ^{186}W/^{184}W = 0.92767 using the exponential law. Osmium interferences on masses 186 and 184 are corrected by monitoring ^{188}Os but corrections were found to be insignificant. ^{183}W/^{184}W ratios were used as a monitor of accurate measurements. They agree for all samples analyzed here to within ±0.5 ε units with the terrestrial standard.

Results: Metals separated from Dhofar 125, NWA 2775, NWA 2627 are enriched in W (0.8-1.3 ppm) and have identical ε_W values with an average of –3.0 ± 0.1. The purity of metal fractions is indicated by their low Hf/W ratios (<0.05). Whole-rock analyses for NWA 2627, Dhofar 125, and NWA 2775 yield Hf/W ratios of ~0.6, ~1.7, and ~1.0 and ε_W values of -1.9±0.4, -1.6± 0.3, and -2.3±0.4, respectively. The weakly and non-magnetic separates for Dhofar 125 have high Hf/W ratios (up to ~20) and together with the whole-rock and metal data plot on a well-defined Hf-W isochron (MSWD=1.5). The slope of this isochron corresponds to an initial ^{182}Hf/^{180}Hf of (6.55 ± 0.41)×10^{-5}. The non-magnetic fractions from NWA 2775 exhibit even higher Hf/W ratios (up to ~55) and the NWA 2775 data also define an isochron (MSWD=1.3). The initial ^{182}Hf/^{180}Hf ratio of the NWA 2775 isochron is (6.38 ± 0.39)×10^{-5}. The Dhofar 125 and NWA 2775 isochrons are indistinguishable from each other and all data from both samples combined define an isochron (MSWD=1.3), whose slope corresponds to an initial ^{182}Hf/^{180}Hf ratio of (6.50 ± 0.23)×10^{-5} (Fig. 1).

The separates from NWA 2656 do not show a correlation between ε_W and ^{180}Hf/^{184}W, indicating disturbance of the Hf-W systematics in this sample.

Discussion: The Hf/W ratios of the NWA 2627, NWA 2775 and Dhofar 125 whole-rocks are in the same range than values for chondrites [5]. This is consistent with a chondritic bulk composition of the acapulcoites and lodranites. Differences in Hf/W and ε_W between NWA 2627, NWA 2775 and Dhofar 125 might reflect sample heterogeneities but may also be due to differences in the chemical composition. The enrichment of W in the acapulcoite metal is similar to that observed for metals in equilibrated ordinary chondrites, indicating transfer of W from silicates into metal during thermal metamorphism.
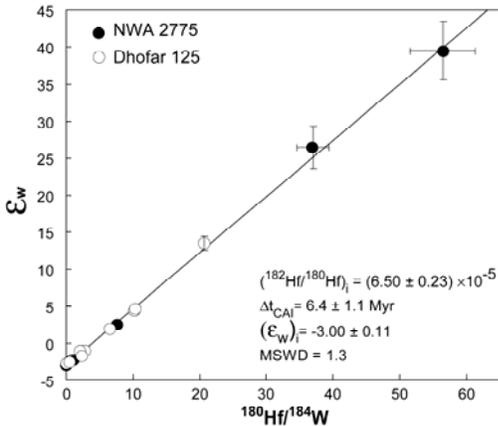
Fig. 1: Combined Hf-W isochron for acapulcoites Dhofar 125 and NWA 2775

The initial $^{182}Hf/^{180}Hf$ ratio obtained from the combined Dhofar 125-NWA2775 isochron corresponds to a time interval of 6.4±1.3 Myr after CAIs (using $^{182}Hf/^{180}Hf = (1.07\pm0.10) \times 10^{-4}$ for Allende CAIs [6]). Combining this formation interval with the absolute age of CAIs (4568.5±0.5 Ma, [7]) results in an absolute Hf-W age of 4562.1±1.4 Ma. This age is older than a Pb-Pb age for phosphates (4557±2 Ma [8]) and a Mn-Cr age for oxides and silicates from Acapulco (4555±1, [9]). This is consistent with the relatively high Hf-W closure temperature of >700 °C [10].
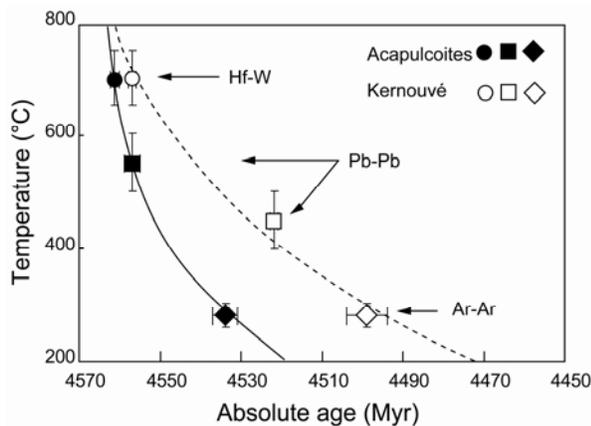

Fig. 2: Cooling history of acapulcoites (solid curve) compared to those of the H6 chondrite Kernouvé [11] (dashed curve), assuming a secular cooling hypothesis. The Ar-Ar ages are taken from [12].

The age differences between the Hf-W, Pb-Pb, and Ar-Ar chronometers can be used to constrain the cooling history of the acapulcoite parent body (Fig. 2). The difference in Hf-W and Pb-Pb ages for acapulcoites indicate a fast cooling of ~100°C/Myr at high temperatures (~400-700°C), consistent with cooling rates deduced from Ca distribution in Acapulco minerals [8].

Our new Hf-W data reveal that acapulcoites cooled more rapidly than H6 chondrites (Fig. 2), suggesting that either the acapulcoite parent body is smaller than the H chondrite parent body or that the burial depth of acapulcoites has been shallower. In any case, the higher peak temperatures reached within the acapulcoite parent body must have been caused by a higher amount of ^{26}Al, indicating that the acapulcoite parent body accreted earlier than the chondrite parent bodies. Acapulcoites thus derive from a planetary body that accreted in a narrow time interval between the accretion of the parent bodies of differentiated asteroids (<1.5 Myr, [6, 13, 14, 15]) and chondrites (~3 Myr, [16]). The chronological constraints are therefore consistent with the petrological evidence that places acapulcoites as intermediate between differentiated and undifferentiated meteorites.

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