EVIDENCE FOR EXCESS HAFNIUM-176 IN EUCRITE QUE 97053. M. Righter[1], T. J. Lapen[1], and R. Andreasen[1], [1]Department of Earth and Atmospheric Science, University of Houston, Houston TX 77204-5007 (mrighter@central.uh.edu).

Introduction: The long-lived ^{176}Lu-^{176}Hf decay system is an important and versatile tool for studying terrestrial evolution as well as the evolution of the early Solar System and planetary bodies. However, there are still uncertainties in the Lu-Hf systematics that need to be sorted out. There has been significant controversy surrounding both the ^{176}Lu decay constant and the initial ^{176}Hf/^{177}Hf ratio of bulk silicate earth. The ^{176}Lu decay constant of 1.867x 10^{-11} year^{-1} was determined using carefully selected terrestrial igneous rocks dated by the conventional U-Pb method [1] and a value has been confirmed by [2] using a 4557 Ma meteorite sample. However there are perplexing apparent excesses of ^{176}Hf that are correlated with Lu/Hf ratios observed in some achondrite meteorites that yield ages that are about 4% too old (~4.8 Ga) and initial ^{176}Hf/^{177}Hf ratios that are lower than CHUR [2-5].

These excesses have been attributed to the influx of solar or supernova(e)-generated gamma radiation that induced formation of the ^{176}Lu isomer (^{176m}Lu) at energies greater than 839 keV. The ^{176m}Lu decays to ^{176}Hf with a half life of 3.7 hr [4]. The difficulty with this scenario is that gamma rays have a shallow penetration depth of up to tens of centimeters in rocks. This suggests that the acceleration of the beta decay due to excitation by gamma rays would have to occur when the ^{176}Lu resided in very small bodies, most likely dust grains [4]. Previously reported internal ^{176}Lu-^{177}Hf isochron for angrite SAH99555 [2] seems to preclude gamma rays. Petrographic features of quenched angrites such as SAH99555 suggest cooling rates of 10-50 C /hour, indicating that these basaltic meteorites crystallized at depths ~0.5–2 m. Thus, solar or supernova(e)- generated gamma radiation cannot account for the excess ^{176}Hf in SAH99555.

Alternatively, a cosmic-ray irradiation model was proposed by [2] in which objects that formed prior to the cosmic-ray event, existed within ca. 200 m of the surface of their parent body, and were facing the cosmic ray source may display direct evidence of excess ^{176}Hf. Here we have sought a reliable confirmation for accelerated decay of ^{176}Lu using carefully selected unbrecciated eucrites CMS 04049 and QUE 97053.

Methods: Roughly 2g aliquots of QUE 97053 and CMS 04049 were gently crushed with a boron carbide mortar and pestle and sieved. Material in the size range of 100-200 and 200-300 mesh (~200mg) were separated by heavy liquids into plagioclase, pyroxene and oxide fractions. After heavy liquid separation, all fractions were carefully hand picked under a binocular microscope. About 40 mg was taken as a 'whole rock' fraction from an aliquot of the <300 mesh materials. All chemical separation procedures were carried out in clean lab facilities and all isotope analyses were carried out using the Nu Plasma II MC-ICP-MS at University of Houston. Total procedure blanks are <80 pg and <15 pg for Hf and Lu, respectively and are negligible.

Results:

CMS 04049: Figure 1 shows ^{176}Lu/^{177}Hf and ^{176}Hf/^{177}Hf data for three mineral samples (oxide, pyroxene and plagioclase) of CMS 04049 (Figure 1). The isochron defines a slope of 0.08855 ± 50 and intercept of 0.279696 ± 0.000013 (2σ). Using the decay constant of ^{176}Lu of 1.867 x 10^{-11} a^{-1}, we calculate a ^{176}Lu-^{176}Hf age of 4549 ± 25 Ma (2σ; MSWD = 0.14.

QUE 97053: The Lu-Hf isochron regression for four mineral fractions (plag, oxide, and dirty plag) and bulk rock yields a slope of 0.0938 ± 0.0014 and an intercept of 0.279696 ± 0.000013 (2σ). This corresponds to an age of 4808 ± 69 Ma (MSWD = 2.6) using the ^{176}Lu decay constant of 1.867 x 10^{-11} a^{-1}.

Discussion: The Lu-Hf isochron of CMS 04049 yields an age close to the inferred formation interval of most eucrites based on U-Pb zircon ages from basaltic eucrites reported by [6, 7]. It does not show an excess slope that can be attributed the accelerated decay of ^{176}Lu. On the other hand, the internal Lu-Hf isochron of QUE 97053 is approximately 240 Myr older than the currently accepted age of the solar system and cannot represent the true crystallization age of QUE 97053.

Two scenarios can explain the fact that CMS 04049 does not show excess ^{176}Hf and QUE 97053 shows excess ^{176}Hf. First, CMS 04049 and QUE 97053 formed at different times. In other words, QUE 97053 formed before the cosmic-ray event, so this meteorite contains ^{176}Hf excess that correlated with Lu/Hf ratios. CMS 04049 formed after the cosmic-ray event, so an internal isochron shows the true crystallization age. The cosmic-ray event occurred sometime between 4564.5Ma [2] to 4557 Ma [8]. Thus, we could say that CMS 04049 was formed sometime after 4557 Ma, which agrees with the CMS Lu-Hf isochron age of 4549 Ma.

Second, CMS 04049 and QUE 97053 were formed at the same time, but CMS 04049 was shielded from cosmic-ray irradiation. CMS 04049 and QUE 97053 have similar basaltic textures, but CMS 04049 has a slightly coarser grain size. The average equilibration temperature of CMS 04049 (880°C) is higher than QUE 97053 (800°C) [9]. The absence of the excess slope of CMS 04049 can be taken as evidence that CMS 04049 may have crystallized at greater depths sufficient to shield the rock from penetration of cosmic rays [2] or was positioned in a cosmic ray shadow during the excitation event.

Initial $^{176}Hf/^{177}Hf$ ratio determined here by the internal isochron approach are lower by ~4 to 5 ε units compared to that back-calculated from the present-day Lu-Hf parameters of bulk chondrite meteorites base on [5, 10] but consistant with SAH99555 value [2] within error. This indicates that there are variations in Hf isotope composition in some of the earliest formed solar system materials.

Summary: The internal isochrons were obtained from two eucrites: CMS 04049 and QUE 97053. The isochron of CMS 04049 shows that this meteorite crystallized at 4549 ± 25Myr. QUE 97053 isochron shows evidence of excess ^{176}Hf in proportion to Lu/Hf ratios. Excess ^{176}Hf is documented now on both the angrite [2] and eucrite parent bodies. Further isotopic work is underway to understand Lu-Hf isotope evolution of eucrite and early solar system materials.

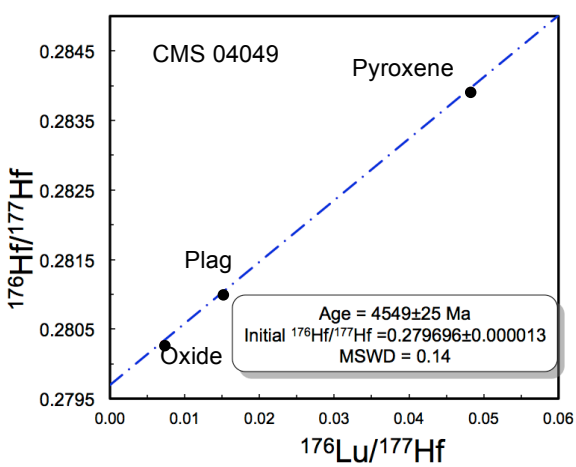

Figure 1. Lu-Hf isochron diagram of unbrecciated eucrite CMS 04049. Data points represent the average of two duplicate analyses of the same mineral aliquots. Oxide = a bulk oxide mineral fraction; Plag = hand-picked plagioclase fraction; Pyroxene = hand-picked pyroxene fraction.

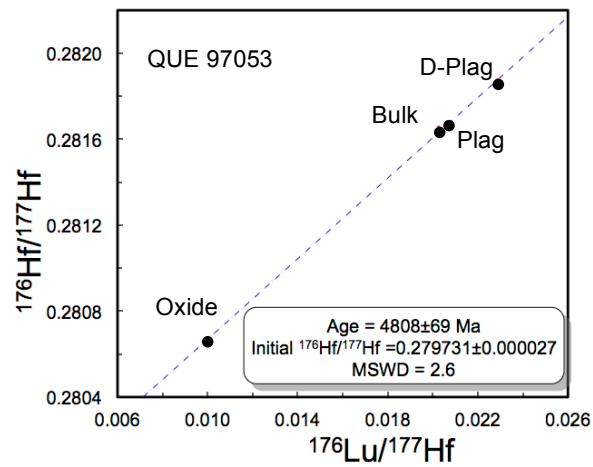

Figure 2. Lu-Hf isochron diagram of unbrecciated eucrite QUE 97053. Data points represent the average of two duplicate analyses of the same mineral aliquots. Oxide = a bulk oxide mineral fraction; Plag = hand-picked plagioclase fraction; D-Plag = 2.96 < ρ < 4.0 fraction; Bulk = bulk rock. All data are presented with 2 uncertainties.

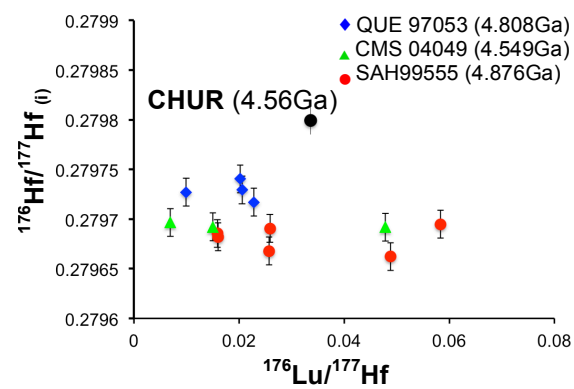

Figure 3. The back-calculated $^{176}Hf/^{177}Hf$ initial values versus $^{176}Lu/^{177}Hf$ of each data points from CMS 04049, QUE 97053 and SAH99555 [3].

References: [1] Söderlund U. et al. (2004) *Earth Planet. Sci. Lett., 219,* 311-324. [2] Thrane et al. (2010) *ApJ, 717,* 861-867. [3] Bizzarro M. et al. (2012) *G³, 13,* Q03002. [4] Albarede F at al. (2006) *GCA, 70,* 1261-1270. [5] Bouvier A. et al. (2008) *Earth Planet. Sci. Lett., 273,* 48-57. [6] Misawa K. et. al. (2005) *GCA, 69,* 5847–5861. [7] Righter M. et al. (2011) *LPS XVII,* Abstract #2740. [8] Amelin Y. et al. (2005) *Science 310*, 839-841. [9] Righter M. (2010) *LPS XVI,* Abstract #2629. [10] Blichert-Toft J. and Albarede F. (1997) *Contrib. Mineral. Petrol., 127,* 248-260.