PETROLOGY AND OXYGEN ISOTOPES IN NEW ENSTATITE CHONDRITE FRAGMENTS FROM THE ALMAHATA SITTA FALL: IMPLICATIONS FOR THE NATURE OF "THEIA"?

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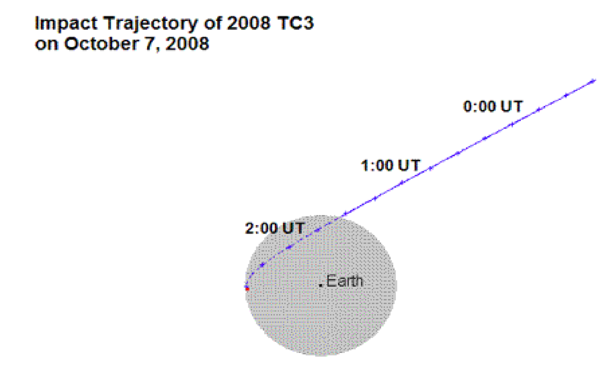
Introduction: **In October 2008, asteroid 2008TC3 was tracked by the Catalina Sky Survey and impacted on Earth in Sudan. The meteorites collected from the site of the fall are known as Almahata Sitta (AhS). These samples show that the asteroid was a fragmented and brecciated body which contained a variety of clasts (rock fragments) [1]. We have investigated 5 new enstatite chondrite (EC). Enstatite chondrites are rare types of meteorites that come from at least four parent bodies, and all have the same oxygen isotope composition as the Earth-Moon system. It has been suggested that Theia, the impactor responsible for the formation of the Moon in the Giant Impact Hypothesis, was formed of an Enstatite Chondrite.**

***Petrography and Mineralogy*:** Figure 1 shows the texture and mineralogy of one of our EC samples. All contain abundant enstatite ($Mg_2Si_2O_6$)-rich chondrules in a matrix of enstatite, metal and sulfides. The samples contain metals and sulfides, often associated with each other. Si is present in the metal, indicating low oxygen fugacity conditions (formed in a highly reduced part of the Solar Nebula). All samples contain sulfides including CaS, FeS, MgS, MnS (Fig. 2), and Cr is found in the FeS, also indicators of reduced conditions.



Asteroid 2008 TC3 was first identified by the Catalina Sky Survey as an 80-ton Near-Earth Object (Apollo-type asteroid) with 100% chance of impacting on Earth. It hit Northern Sudan on October 7 2008.

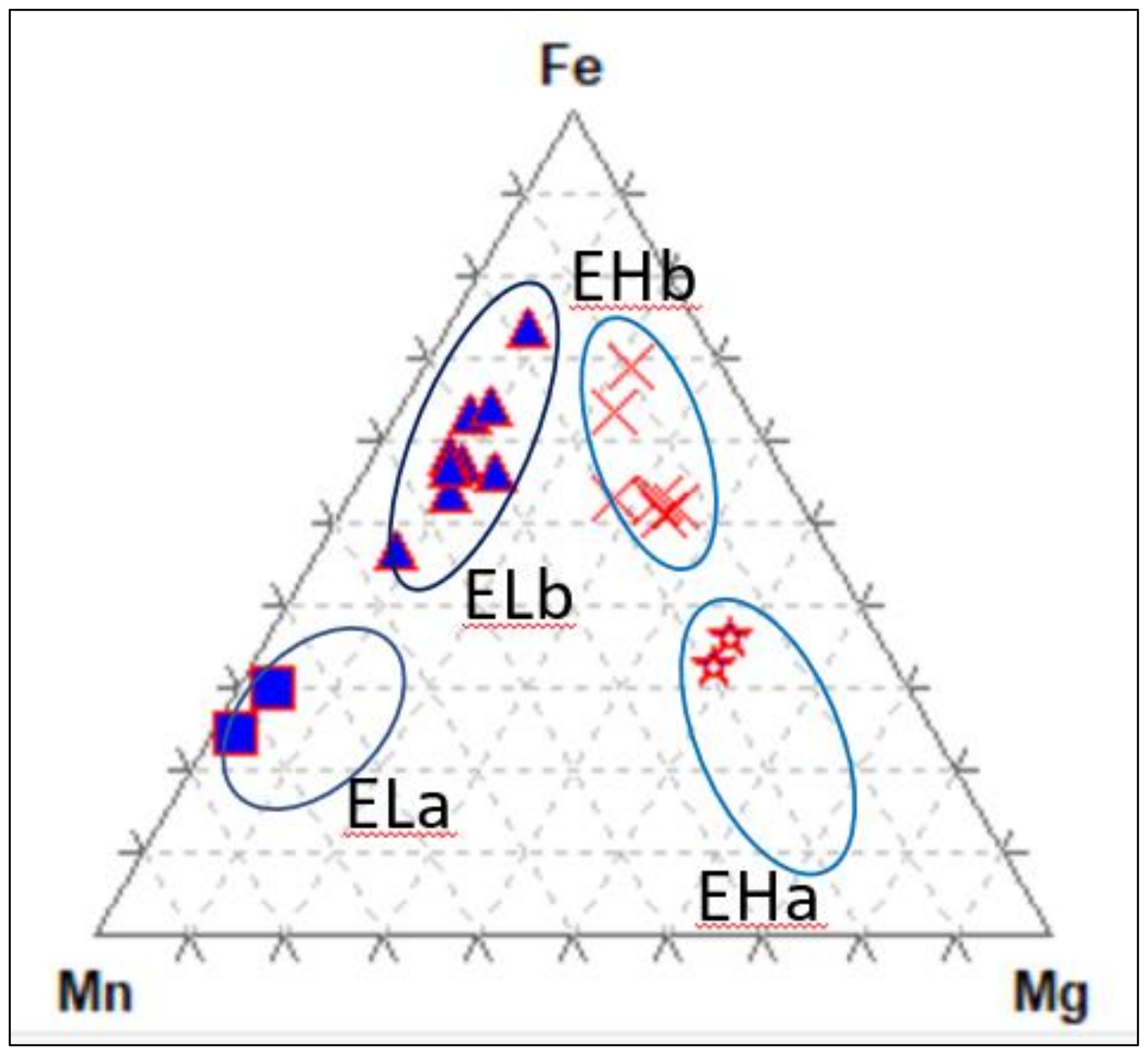


Figure 2. Compositions of sulfides in EC samples, related to fields for data from the recently established four parent bodies of Enstatite Chondrites [4] designated Eha, Ela etc

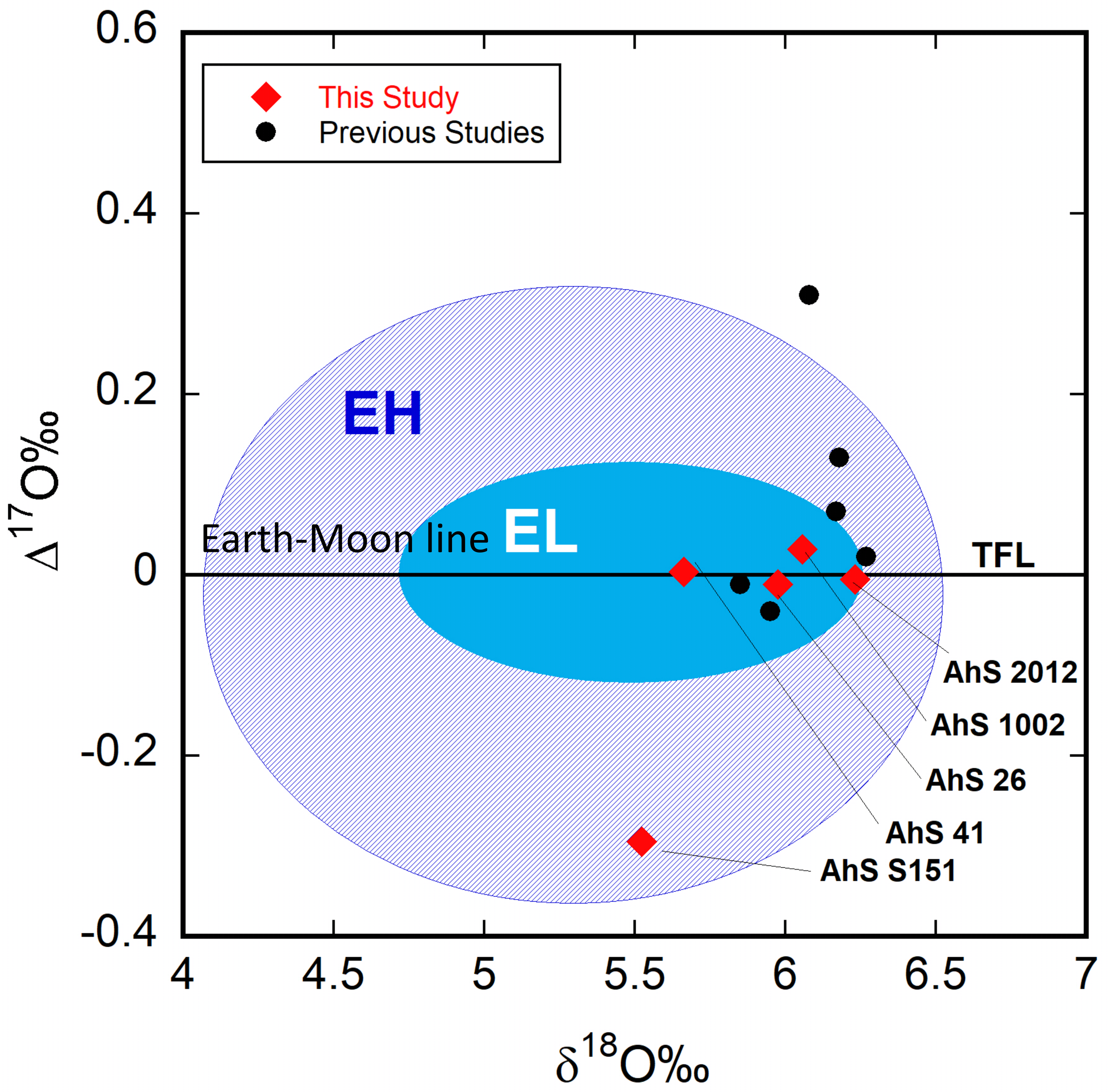


Figure 3. Oxygen isotope data for AhS enstatite chondrite analyzed in this study and by [5], compared with fields for ECs [6].

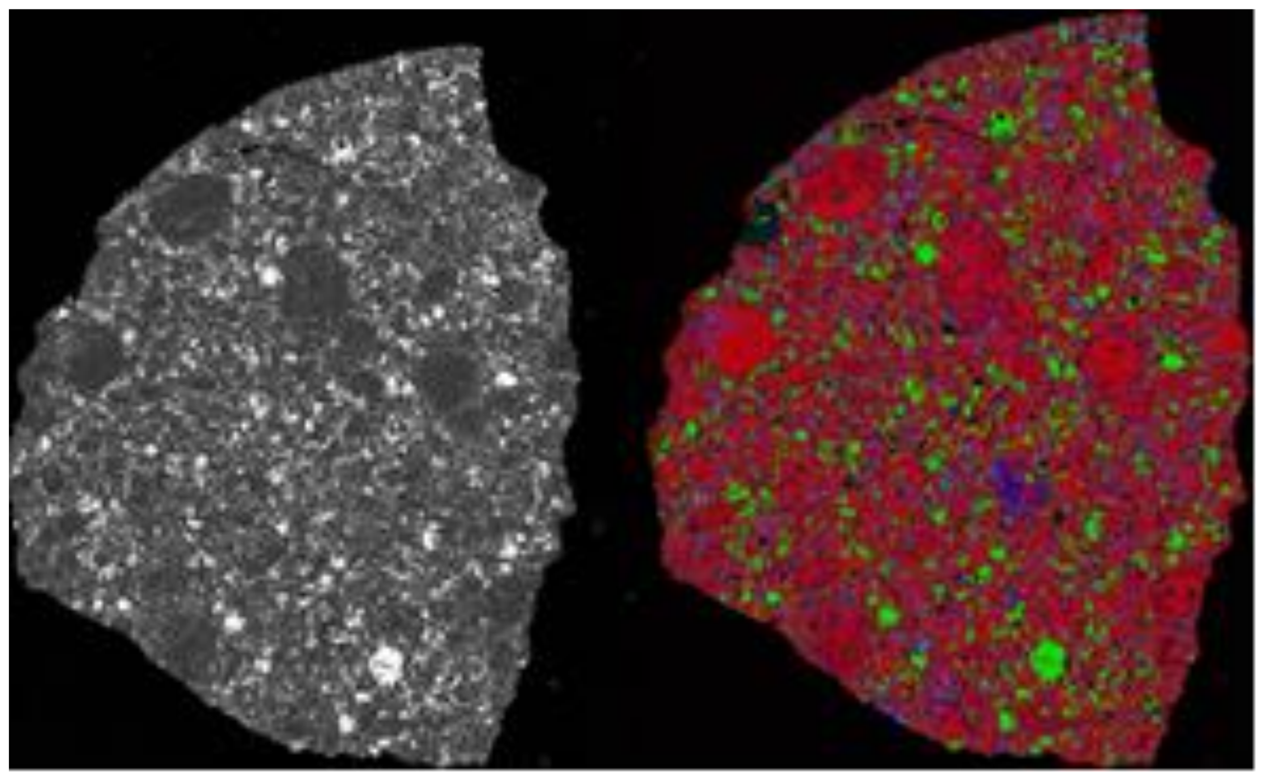
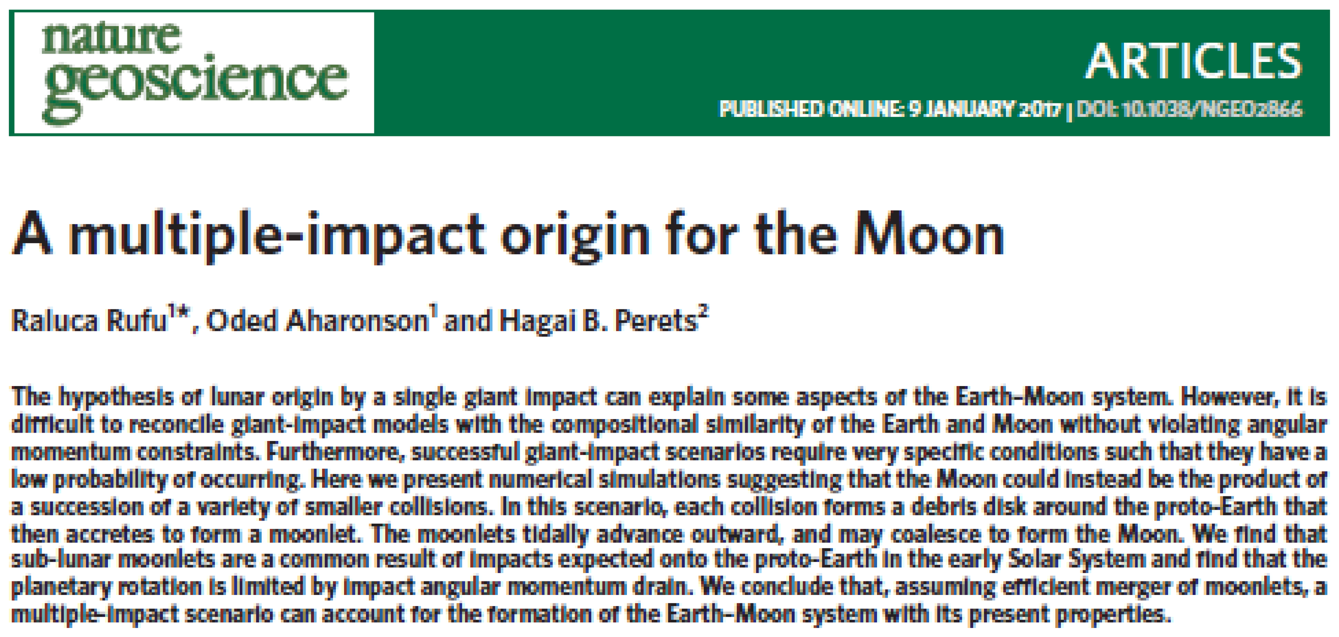


Figure 1. Back-Scattered Electron (left) and X-Ray map (right) of EH4-5 sample AhS 2012 (Mg=red; Fe=green; S=blue)

Classification: From petrography and mineralogy, these and other EC samples from asteroid 2008 TC3 are typical Enstatite Chondrites <u>but mineral compositions show that they derived from the four different Enstatite Chondrite parent bodies.</u>

Oxygen isotopes: Oxygen isotopes (Fig. 3) are typical of Enstatite Chondrites [6], forming a tight field around the $\Delta^{17}O$ = 0‰ line (Earth-Moon oxygen isotope fractionation line = TFL) but showing slight inhomogeneity.



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A multiple-impact origin for the Moon

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The hypothesis of lunar origin by a single giant impact can explain some aspects of the Earth–Moon system. However, it is difficult to reconcile giant-impact models with the compositional similarity of the Earth and Moon without violating angular momentum constraints. Furthermore, successful giant-impact scenarios require very specific conditions such that they have a low probability of occurring. Here we present numerical simulations suggesting that the Moon could instead be the product of a succession of a variety of smaller collisions. In this scenario, each collision forms a debris disk around the proto-Earth that then accretes to form a moonlet. The moonlets tidally advance outward, and may coalesce to form the Moon. We find that sub-lunar moonlets are a common result of impacts expected onto the proto-Earth in the early Solar System and find that the planetary rotation is limited by impact angular momentum drain. We conclude that, assuming efficient merger of moonlets, a multiple-impact scenario can account for the formation of the Earth–Moon system with its present properties.

Why is this important?

One theory about why the Earth-Moon system has the same isotopic composition as Enstatite Chondrite meteorites is that the Giant Impactor ("Theia") was an Enstatite Chondrite planetesimal. That theory assumed that there was only one EC parent body, but we now know that there are at least 4 such parent bodies [4], each with a slightly different mineralogy, from which EC meteorites on Earth are derived. Amazingly, the same 4 separate parent bodies have also shed EC meteorites onto the parent asteroid 2008 TC3. So the parent asteroid of 2008 TC3 must have been in close to all four of the parent asteroids of the Enstatite Chondrites when they were fragmented.

Is it possible that Theia was actually a series of multiple impacts, as described by Rufu et al (2017), and the impactors were all four Enstatite Chondrite parent planetesimals? It also suggests that the parent planetesimal of 2008 TC3 was in the same part of the Solar System when the Giant Impact occurred.

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References: [1] Fioretti A M et al. (2017). 48th LPSC Abst #1846. [2] Shaddad M et al., (2010). *Meteoritics & Planetary Science* 45, 1557-1589. [3] Horstmann M et al. (2014). *Geochimica et Cosmochimica Acta* 140 720-744. [4] Weyrauch et al (2018). *Meteoritics and Planetary Sciences* 53, 394-415; [5] Horstmann M and Bischoff A (2014). *Chemie der Erde*, 74, 149-183. [6] Newton J et al. (2000). *Meteoritics & Planetary Science* 35, 689-698.