TRACING BUILDING BLOCKS OF PROTOEARTH AND THEIA WITH NICKEL NUCLEOSYNTHETIC VARIABILITY.

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Introduction: Nucleosynthetic isotope variability on a bulk meteorite level is observed for many elements. It can be used to fingerprint planetary building blocks and infer genetic relationships between various Solar System bodies. Nickel (Ni), a major siderophile element present in measurable amounts in a wide variety of differentiated and primitive early Solar System materials, is of particular interest for that purpose because it has five stable isotopes that enable the fingerprinting of various materials by a multi-isotopic nucleosynthetic signature. Here we present a high-precision mass-independent Ni isotope study of a large suite of iron meteorites, including ~25 ungrouped irons. Due to the ungrouped nature of these meteorites, this sample set substantially increases the amount of the meteorite parent bodies sampled compared to earlier studies, e.g. [1]. Collectively the sample set is predominantly composed of magmatic irons and, thus represents cores of planetesimals formed in the first Myr of the Solar System.

Methods: The Ni purification protocol used in this study comprises of four different steps. First, Ni was separated from Fe and Co using TEVA resin and high molarity HCl acid. Second, Ni-specific resin (DMG) was used to separate Ni from the remaining matrix elements. Third, samples were cleaned for trace amounts of Ti using anion resin and HCl with trace of HF. Lastly, a Zn-clean-up was performed with anion resin. High precision Ni isotope analysis was performed on the Thermo Scientific Neoma MC-ICP-MS at StarPlan, University of Copenhagen.

Results & Discussion: The sample set studied records positively correlated $\mu^{58}Ni_{62/61}$ and $\mu^{60}Ni_{62/61}$ compositions covering the whole range of known isotope compositions for iron meteorites [1]. Importantly, the samples cover and extend the range of isotopic compositions previously reported for carbonaceous and non-carbonaceous iron meteorites with no discernable gap between carbonaceous and non-carbonaceous compositions. The $\mu^{60}Ni_{62/61}$-values do not correlate with Fe/Ni ratios implying negligeable radiogenic contribution to the $\mu^{60}Ni_{62/61}$ variability. Thus, we interpret the $\mu^{60}Ni_{62/61}$-variations as nucleosynthetic in origin.

The nature of the observed variability. The observed continuous Ni isotope variability recorded by iron meteorites either represents a temporal change in the Ni isotope composition in the protoplanetary disk during the formation of their parent bodies or requires a Ni isotope gradient in the disk where the iron meteorite parent bodies formed at variable heliocentric distances. Given that the streaming instability, the most likely mechanism to form the initial planetesimal population, is a localised process [2], it is unlikely that it could have generated planetesimals within the short time window indicted by the differentiation ages of iron meteorites [3] across a wide range of heliocentric radii required if the nucleosynthetic variability was predominantly a function of accretion region in the protoplanetary disk. Given that iron meteorites parent bodies may have been up to 1000 km in radii, we suggest instead that the observed variability was generated by the parent bodies reaching different final masses by accretion of infalling disk material following their initial formation by streaming instabilities and, thus having incorporated variable amounts of carbonaceous material [4].

Implications for planet formation. When compared to the bulk chondrite and terrestrial Ni isotope data, our results reveal that both the Earth and the CI chondrites have compositions that do not fall on the correlation line for the irons. If we consider the studied sample set as representative of the planetesimals available to fuel the growth of planets, the terrestrial mantle composition is consistent with accreting CI-like material. This is in line with accretion of outer Solar System material to the planet formation region during the disk lifetime, implying growth by pebble accretion [5].

Conflict between Fe and Ni nucleosynthetic signatures and re-equilibration during the Moon-forming giant impact. The terrestrial mantle has a CI-like Fe isotope composition, indicating that its Fe budget is dominated by outer Solar System material [6]. This is in apparent conflict with the Ni isotope composition of the terrestrial mantle, which is not CI-like, but instead is intermediate between inner and outer Solar System compositions [7]. We propose that during the Moon-forming giant impact, the composition of the terrestrial mantle was overprinted by the composition of the Theia's core. The effect of such overprint is significantly stronger for Ni compared to Fe because Ni is much more siderophile and metal-silicate partition ratio is highly sensitive to the pressure of equilibration [8].

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