

NUCLEOSYNTHETIC AND MASS-DEPENDENT TITANIUM ISOTOPE VARIATIONS IN INDIVIDUAL CHONDRULES OF ORDINARY CHONDRITES. M. Schönbachler¹, K. K. Bauer¹, M. A. Fehr¹, N. Chaumard² and B. Zanda³, ¹Institute for Geochemistry and Petrology, ETH Zürich, Switzerland (mariasc@ethz.ch); ²WiscSIMS, Department of Geoscience, University of Wisconsin-Madison, USA; ³IMPMC-MNHN, UMR-CNRS-7590, Paris, France

Introduction: Chondrules formed during the early stages of solar system evolution in the protoplanetary disk. For this reason, they carry invaluable information about the conditions in the solar nebula and protoplanetary disks in general. Their old formation ages (4564.7–4567.3 Ma e.g., [1]) coincide with the earliest stages of planet formation, and as such chondrules may provide constraints on the planet formation process itself. The origin of chondrules is debated. Various models have been proposed, which broadly can be divided in two groups: (i) chondrule formation during collisions of planetesimals, or (ii) in the solar nebula using shock waves or lightening.

In this study, we separated individual chondrules from the ordinary chondrites (OC) Tieschitz (H/L3.6), Parnallee (LL3.6) and Saratov (L4) and used nucleosynthetic Ti isotope variations to determine their genetic relationship within a single meteorite and between different OC groups. This provides useful information about mixing and transport processes in the protoplanetary disk. Titanium isotopes are powerful tracers because Ti is a refractory element that displays well-documented nucleosynthetic variations in ⁴⁶Ti and ⁵⁰Ti in solar system materials, which are of different nucleosynthetic origin [2,3]. Moreover, we also determined the mass-dependent Ti isotope composition to quantify possible fractionation processes during chondrule formation and parent body metamorphism. Experiments have shown that Ti isotope fractionation can occur, for example, during evaporation of perovskite in a vacuum furnace [4].

Analytical methods: Separated chondrules and chondrule fragments were characterized using CT scanning. Fourteen chondrules were selected for mass-independent Ti isotope analyses, while seven of these were also analyzed for mass-dependent Ti isotope compositions. The chondrules were powdered and dissolved by Parr bomb acid digestion. Titanium was separated using a three-step column chemistry procedure [5]. The Ti isotope compositions were determined on a Neptune Plus MC-ICPMS. For the mass-independent analyses, the data were internally normalized to ⁴⁹Ti/⁴⁷Ti = 0.749766 [6]. Terrestrial standard rocks and bulk rocks of several OCs (St. Severin, Richardton, Allegan) were analyzed to assess data accuracy and precision. For mass-dependent analyses, we employed the ⁴⁷Ti-⁴⁹Ti double spike method of [7].

Results and Discussion:

Nucleosynthetic Ti isotope variations. The fourteen chondrules from Tieschitz (H/L3.6), Parnallee (LL3.6) and Saratov (L4) span a range of nucleosynthetic Ti isotope compositions with $\epsilon^{50}\text{Ti}$ from -1.1 to +0.1. The data scatter around the value for bulk ordinary chondrites ($\epsilon^{50}\text{Ti} = -0.5 \pm 0.2$). Each meteorite exhibit chondrules with various distinct Ti isotope compositions, that are resolved from each other and with a similar spread around the bulk OC value. This entails that each chondrule has sampled a unique, but yet similar mix of precursor materials. This is difficult to reconcile with chondrule formation from molten planetesimals, but is consistent with formation during collisions of partially molten bodies [8]. The precursor material of OC chondrules is clearly distinct from that of carbonaceous chondrites. For example, the isotopic composition of a chondrule separate from the carbonaceous chondrite Allende display a distinct positive composition ($\epsilon^{50}\text{Ti} = +4.6 \pm 0.1$) [7]. This further substantiates the previous observation that each chondrite class accreted a unique mixture of chondrules that were little mixed with those of other chondrite classes [9]. This indicates that chondrule formation was on-going in relatively isolated regions in the protoplanetary disk.

Mass-independent Ti isotope variations. These data are very uniform for all analyzed chondrules and overlap with those of terrestrial basalts. Thus, no significant stable isotope fractionation has taken place in the solar nebula and during chondrule formation. The exception are chondrules from the most strongly metamorphosed sample analyzed: Saratov chondrules are depleted in heavy isotopes ($\delta^{49}\text{Ti}/^{47}\text{Ti} = -0.4$ to -0.6 relative to other chondrules and the terrestrial basalts). These variations are best explained by the crystallization of Ti-bearing chondrule mesostasis that resulted in loss of heavy Ti isotopes.

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