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Formation condition of fine-grained CAIs inferred from their REE patterns-II

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Rare earth elements (REEs) in refractory inclusions often show large volatility-controlled fractionation, suggesting that gas-dust (fine-grained particles) separation frequently occurred in the early hot solar nebula. For example, Group II REE pattern depleted in heavy REEs (HREEs) can be explained by condensation from the fractionated gas after removal of HREE-enriched ultra-refractory dust. In the last conference, we have presented ion microprobe REE data for fine-grained CAIs from Ningqiang, Y81020 and Efremovka carbonaceous chondrites and discussed the origin of REE patterns with positive Ce-Eu-Yb anomalies, often accompanied by HREE-depletion (named as Modified Group II). We proposed a model, in which Group II-like (HREE-depleted) CAIs or their precursors (e.g., fine-grained dust) were formed first, and then they moved into a Ce-Eu-Yb-rich gas region, where later condensation of Ce, Eu and Yb occurred and produced REE patterns with positive Ce-Eu-Yb anomalies (Hiyagon, Yamakawa, Ushikubo, Lin and Kimura, 2009, 2010). Here, REE data were further examined in detail if there are any correlations among positive or negative anomalies in REE patterns. It was found that Group II and Modified Group II show no difference both in the degree of HREE depletions and in the degree of fractionation among HREEs. The results suggest that HREE-depletion and positive Ce anomaly were produced through two independent processes. This is consistent with the proposed model. This model requires a certain scale in space (at least two different regions with different REE characteristics) and in time (requiring for migration of inclusions or their precursors from one region to another) for the formation of fine-grained CAIs. A short-time, single-stage model, e.g., X-wind model, cannot explain the observed REE patterns in fine-grained CAIs. Fine-grained CAIs probably formed in the region(s) near the early Sun through dynamic processes including migration of solid materials from one region to another.

Keywords: refractory inclusion, rare earth elements, ion microprobe, solar nebula, condensation, fractionation