NUCLEOSYNTHETIC STRONTIUM–NEODYMIUM ISOTOPE CORRELATION IN CHONDRITES: EVIDENCE FOR NEBULAR THERMAL PROCESSING AND DUST TRANSPORTATION IN THE EARLY SOLAR SYSTEM. R. Fukai[1] and T. Yokoyama[1], [1]Department of Earth and Planetary Sciences, Tokyo Institute of Technology (mail: fukai.r.aa@m.titech.ac.jp).

Introduction: The finding of planetary-scale isotopic variability for refractory heavy elements in bulk meteorites revealed that the early Solar System was not isotopically homogeneous as was previously thought. Warren [1] proposed a nucleosynthetic "isotopic dichotomy" observed in O, Ti, and Cr between carbonaceous chondrites (CCs) and non-carbonaceous meteorites (NCs). Subsequent studies reported such a dichotomy for the various isotopic systems including Mo [e.g., 2] and Nd [3]. However, the origin of isotopic dichotomy between CCs and NCs is still controversial.

Strontium is an intriguing element for studying the origin of isotopic dichotomy observed in meteorites. Previous studies found variabilities in ^{84}Sr/^{86}Sr ratios among different classes of CCs and NCs [4,5]. However, the carrier phases responsible for the observed variations are still uncertain, which hindered to construct a model that explains the origin of observed Sr isotope heterogeneity. The ^{84}Sr/^{86}Sr ratios of meteorites vary depending on the involvement of multiple components originated from the stellar nucleosynthesis of main-*s*, weak-*s*, *r*, and *p*-processes. Therefore, coupling of Sr isotopic data with the other isotope systems obtained from single meteorite aliquots is important to investigate the origin of Sr isotopic heterogeneity.

In this study, we revisited high precision Sr isotope analysis of bulk chondrites coupled with a robust sample digestion technique that confirmed complete dissolution of presolar grains [5]. Furthermore, we coupled Sr isotope anomalies in chondrites with Nd isotope anomalies newly measured and reported in [3] that were obtained from the same meteorite aliquots. With the new comprehensive dataset for Sr and Nd isotopic compositions in bulk chondrites, we propose a new disk evolutionary model that accounts for the planetary-scale Sr and Nd isotope heterogeneities in the early Solar System.

Experimental: We selected meteorite samples that are classified into fall or Antarctic meteorites to avoid the effect of contamination of terrestrial Sr by alteration. We investigated two terrestrial basalts (JB-1a and JB-3), four carbonaceous chondrites (Orgueil, CI; Murchison, CM2; Kainsaz, CO3; Allende, CV3), five ordinary chondrites (Forest City, H5; Saratov, L4; Modoc (1905), L6; Tuxtuac, LL5; Saint-Séverin, LL6), and two enstatite chondrites (Y-691, EH3; Y-980223, EH6). The meteorites with a petrologic grade greater than 3.6 were dissolved by a conventional acid digestion method with HF + HNO_3 + $HClO_4$ [6]. For carbonaceous chondrites and EH3 chondrites, each sample was digested using a high-pressure digestion system (DAB-2, Berghof) with HF + HNO_3 + H_2SO_4 to completely dissolve acid resistant presolar grains.

The Sr and Nd isotope compositions were measured by TIMS (Triton *Plus*, Tokyo Tech). ^{84}Sr/^{86}Sr ratio was obtained by the dynamic method with the reproducibility at ±20–30 ppm (2 SD). ^{142}Nd/^{144}Nd, ^{148}Nd/^{144}Nd, and ^{150}Nd/^{144}Nd ratios were simultaneously obtained by the dynamic method with the reproducibilities at ±4.8 ppm, ±5.6 ppm, ±10 ppm, respectively.

Results and Discussion: The Sr and Nd isotope ratios are reported in the μM notation that is parts par 10^6 relative deviations from the standard (NIST 987 for Sr, JNdi-1 for Nd). The Sr and Nd isotopic compositions for enstatite, ordinary, and individual types of carbonaceous chondrites (CI, CM, CO, and CV) are shown in Fig. 1. Our data suggest that enstatite and ordinary chondrites possess small, but resolvable isotopic shifts of μ^{84}Sr values from the terrestrial rocks. In Fig. 1, these samples are plotted on the mixing line of *s*-process endmember and terrestrial rocks. The Sr and Nd isotopic anomalies observed in enstatite and ordinary chondrites were caused by the heterogeneous distribution of *s*-process enriched materials in the early Solar System.

Carbonaceous chondrites display variable μ^{84}Sr values (–1.3 to +67 ppm). These meteorites are not plotted on the *s*-process versus terrestrial mixing line in the Sr–Nd diagrams (Fig. 1). CAIs (Calcium- and Aluminum-rich inclusions), the additional anomalous carriers of refractory heavy elements in bulk carbonaceous chondrites, could induce the offset observed in the results of carbonaceous chondrites. To evaluate this possibility, we conducted a mass-balance calculation in which the contribution of CAIs was subtracted from the bulk carbonaceous chondrites. Consequently, the Sr and Nd isotopic compositions of CAI subtracted-carbonaceous chondrites are generally plotted on the *s*-process mixing line (Fig. 2). This observation suggests that Sr and Nd isotopic dichotomy observed between NCs and CCs was caused by the incorporation of CAIs into the location where parent bodies of carbonaceous chondrites were formed.

Based on the results, we propose a new disk evolutionary model that accounts for the correlated nucleosynthetic isotope anomalies between Sr and Nd. First, we assume an isotopically homogeneous molecular cloud core and early solar nebula. We consider two carrier phases for Sr and Nd that existed in the early Solar System, based on the leaching experiments for carbonaceous chondrites [e.g., 5]. One plausible carrier grain is the mainstream presolar SiC that possess *s*-process enriched isotopic compositions. In addition, to explain the bulk Sr and Nd isotopic compositions for CAI-subtracted carbonaceous chondrites, we need another phase that is depleted in *s*-process. We consider that the carrier phase of positive μ^{84}Sr and $\mu^{148,150}$Nd values is not an intact presolar grain but would be dust grains that have experienced multiple physical processes including evaporation, mixing, and recondensation in the solar nebula and/or molecular cloud. Such grains, called "recycled silicates", were widespread in the solar nebula as a result of grain circulation that was triggered most likely by the turbulent diffusion [7]. Because most of the presolar SiC grains have condensed at ~1600 K in AGB stars [8], SiC grains would be more refractory compared to the recycled silicates. By the progressive heating in the inner Solar System, recycled silicates would have been destroyed selectively. As the nebular temperature is expected to decrease along with the heliocentric distance, Earth has been accreted from the most thermally-processed (i.e., *s*-process rich) materials, while the parent bodies of carbonaceous chondrites has been accreted from the least-processed (i.e., *s*-process depleted) materials that represent the mean Sr and Nd isotopic compositions in the early Solar System. This scenario explains the observed isotopic variation across the Earth, NC parent bodies, and CAI-subtracted CC parent bodies.

As the temperature of the solar nebula decreased, the nebular thermal processing has terminated. On the other hand, recycled silicates continued to circulate throughout the solar nebula. The isotopic reservoirs of non-carbonaceous meteorites and carbonaceous chondrites have been separated, possibly due to the presence of Jupiter core that formed by ~1 Myr after CAI condensation [2]. If this is the case, recycled silicates should be concentrated at the outside of Jupiter, because the pressure bump by the mass of Jupiter core concentrated the drifting dusts. Consequently, the parent bodies of CC should have acquired recycled silicates that are depleted in the *s*-process isotopes. This heterogeneous incorporation of recycled silicates accounts for the isotopic variation between CAI-subtracted CV chondrites and CM-CO chondrites, assuming that CV parent bodies were located closer to the Sun than CM-CO parent bodies. This transportation system in the solar nebula would explain the gradient of CAI abundances for individual types of carbonaceous chondrites [8]. Exceptionally, CI chondrites are not explained by our disk evolutionary model, most likely due to the injection of supernovae materials and/or input of materials from the molecular cloud.

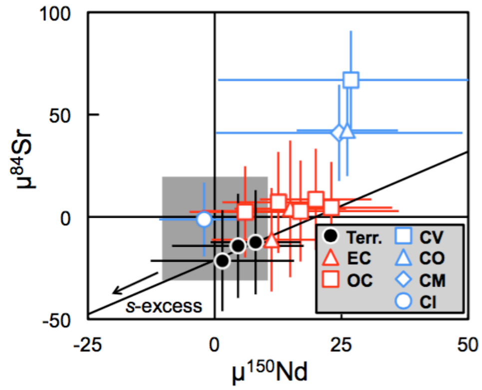

Fig. 1: Diagram of μ^{84}Sr versus μ^{150}Nd values plotting the data for terrestrial rocks, enstatite, ordinary, and carbonaceous chondrites measured in this study. Error bars represent the uncertainties for individual samples (2 SD). Gray zones represent uncertainties of the terrestrial standards (2 SD; NIST 987 for Sr, JNdi-1 for Nd). Bold lines are mixing lines between the *s*-process enriched component [9] and terrestrial rocks.

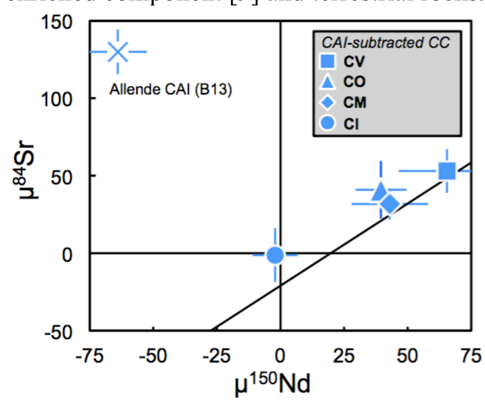

Fig. 2: Diagram of μ^{84}Sr versus μ^{150}Nd values plotting the data for CAI subtracted-carbonaceous chondrites. Error bars represent uncertainties (2 SE) derived by propagating the analytical errors from Sr and Nd isotopic measurements on CAIs. Crosses are data for CAIs with analytical errors (2 SE) obtained in the previous study [10].

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