REDISTRIBUTION OF TRACE ELEMENTS DURING METAMORPHISM OF ORDINARY CHONDRITES; M. Ebihara, K. Shinotsuka and P. Kong, Department of Chemistry, Faculty of Science, Tokyo Metropolitan University, Hachioji, Tokyo 192-03, Japan

Introduction: In ordinary chondrites, contents of volatile elements, e.g., carbon and noble gases, are known to be variable; their contents decrease with increasing of petrologic types. Indeed, the bulk contents of these volatiles were proposed as parameters usable for the subclassification of unequilibrated ordinary chondrites (UOCs) [1]. In contrast, the bulk contents of refractory elements are highly uniform in chondritic meteorites, regardless of their chemical and petrological groups. In this study, we traced the distribution trends of refractory trace elements in UOCs and EOCs and attempted to characterize the metamorphism of ordinary chondrites based on the distribution of trace elements in constituent minerals in chondrites. Mo and W were focused as refractory siderophiles and REEs, Th and U were focused as refractory lithophiles.

W and Mo are cosmochemically grouped as refractory siderophile elements. Condensation calculations predict that these elements condense as metals in the canonical solar nebula at high temperature [2, 3]. However, W and Mo do not behave loyally even in high temperature condensates; Mo is usually found as MoS2 in Ca, Al-rich inclusions (CAIs) and W is significantly depleted in some Fremdlinge of the Allende CAIs compared with other refractory siderophiles [4, 5]. Thus, Mo is less abundant than W and other refractory elements in CAIs. Fegley and Palme [3] suggested that under a highly oxidizing condition Mo oxide (gas) would become stable at the condensation temperature of CAIs and, hence, the abundance of Mo was lowered relative to other refractory siderophile elements in these CAIs. During igneous processes, Mo and W behave as incompatible elements, with Mo being more siderophile and chalcophile than W [6, 7].

Rare earth elements (REEs), Th and U are typical refractory lithophile elements. Although their bulk contents are uniform in ordinary chondrites, the distribution of these elements are largely different between UOCs and equilibrated ordinary chondrites (EOCs) [8, 9]. In UOCs, REEs, Th and U are mostly hosted by chondrule mesostasis (Ca, Al-rich glasses) whereas these elements (except Eu) are concentrated in the Ca-phosphate minerals and Eu is mostly in plagioclase in EOCs. It is thus obvious that REE and some actinoids must have migrated from glassy mesostasis to individual minerals during thermal metamorphism on the chondrite parent body(ies) [9].

Experiments: In order to obtain the distribution of Mo and W between metal and non-metal phases, the metal fractions were separated from all petrologic and chemical groups of ordinary chondrites. The magnetic fraction was first separated by a hand magnet and further purified with HF [10]. The resulting metal fractions were estimated to contain less than 3 wt. % of impurities and were confirmed to remain unfractionated in relative abundances of kamacite and taenite [11]. The chemical composition of the bulk metals obtained were measured by INAA. The distribution of REEs, Th and U in ordinary chondrites can be simply figured out between acid-soluble and acid-insoluble phases. The former phase is representative of the Ca-phosphate mineral as a carrier phase of REEs, Th and U. The latter phase consists of pyroxene, plagioclase and glass. The powdered chondrites were leached several times with HCl. The residual fraction was analyzed by either RNAA or ICP-MS for REEs, Th and U.

Results and Discussion: A significant difference in metal/non-metal partitioning of W was recognized between UOCs and EOCs of all chemical groups, but no correlation between the W partitioning and the petrographic type was observed among EOCs. Although the proportions of W and Mo in the metals decrease from H, to and to LL chondrites in EOCs, the Mo/W abundance ratios in the metals remain nearly constant for all chemical groups. This is shown in Fig. 1, where EOCs are well located on or near a straight line. In contrast, UOCs are off (below) the line. Dhajala (H3.8) and EET 87778 (H3.9) stay on the line, suggesting that W has achieved equilibrium in these two UOCs having high petrologic subtypes. This implies that the W equilibrium among minerals was achieved even in some H UOC of high petrologic type (≥3.8). Thus, the W partitioning among phases may provide a clue to estimate metamorphic temperatures intervening between EOCs and UOCs.

REEs also are known to have been redistributed among constituent minerals of ordinary chondrites during metamorphism. Shinotsuka and Ebihara [9] presented a scenario for the redistribution of REE, Th and U in ordinary chondrites. They pointed out that both positive and negative Eu anomalies were present on the chondrite-normalized abundance patterns of REEs for the acid residues of UOCs. For the EOC residues, it was observed that the REE abundances patterns were highly fractionated, being characterized by a large positive Eu anomaly. Fig. 2 shows a relationship between the degree of Eu anomaly and the content of ^{36}Ar. As clearly shown, the Eu anomaly

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changes from negative to positive with increasing the petrologic type. Ebihara et al. [8] once pointed out that there might be a gap in the degree of Eu anomaly between UOCs and EOCs. Such a gap, however, seems to be more apparent than real, possibly caused by insufficient numbers of data. The gradual and continuous change of Eu anomaly between UOCs and EOCs suggests that such a change was caused by thermal metamorphism on the chondrite parent body(ies). A fairly good correlation between the TL sensitivity and the degree of Eu anomaly supports this possibility. An excellent correlation between Eu anomaly and ^{36}Ar content (Fig. 2) further suggests that the ^{36}Ar content contents in ordinary chondrites is highly dependent upon the degree of metamorphism. If this is the case (and we believe so), the content of volatile elements in ordinary chondrites was not necessary to be variable between UOCs ands EOCs when the parent body was formed. Volatile elements were later expelled from the parent body during the course of thermal metamorphism. Volatile contents in UOCs were proposed to be a measure of primitiveness, in principle reflecting accretion conditions from the solar nebula [1]. Our data, however, apparently do not support such a view. As there is an obvious disagreement between TL-based and volatile-based classifications of UOCs, an appropriate explanation need to be presented.

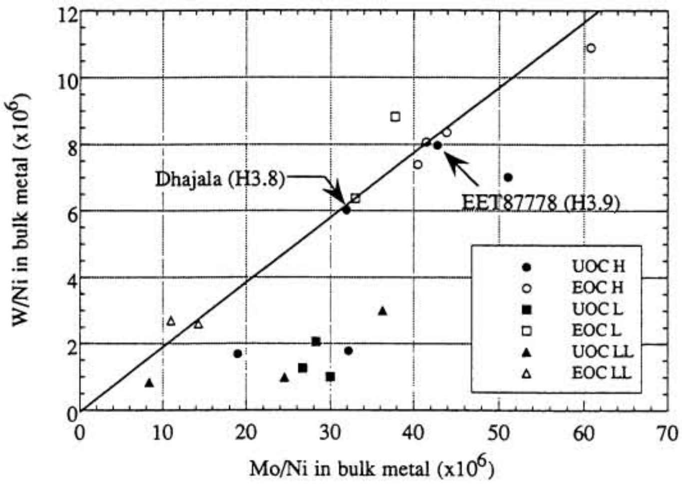

Fig. 1 Correlation of Ni-normalized W and Mo abundances in the bulk metals between EOCs and UOCs. EOCs are well located on a straight line whereas UOCs are mostly below the line. Dhajala (H3.8) and EET 87778 (H 3.9) stay on the line, suggesting that W achieved equilibrium in these two UOCs.

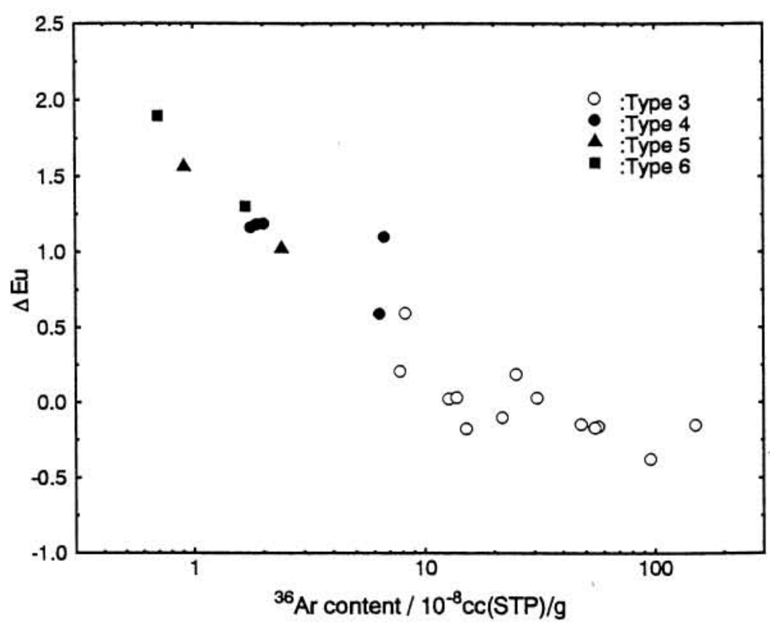

Fig. 2 Correlation between the degree of Eu anomaly (ΔEu) and the ^{36}Ar content for ordinary chondrites. An excellent correlation suggests that the ^{36}Ar content is highly dependent on the degree of metamorphism meteorites experienced.

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