Mineralogical study of TCIs in CM carbonaceous chondrites and implications to the formation processes.

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Introduction: TCIs, fine intergrowths of tochilinite ($6(Fe_{0.9}S)\cdot 5[(Mg,Fe)(OH)_2]$) and cronstedtite (Fe-bearing serpentine), are characteristic objects within CM chondrites. TCIs are considered to be aqueous alteration products on the parent bodies, and divided into two types based on the textural feature. Type I TCI is generally found in the chondrules and believed to be altered from iron metal because they often contain kamacite inside [e.g., 1]. On the other hand, type-II exhibit fibrous, fluffy textures found within the matrices. Although several formation processes of type-II have been proposed [e.g., 2,3], the argument has not yet been settled. TCIs potentially provide important information regarding aqueous environments on chondrite parent bodies. Here, we report microtextures of type-II TCIs in five CM chondrites and discuss the formation processes.

Materials and methods: We observed the following five CM chondrites; QUE 97990 (2.6), Murchison (2.5), Murray (2.4-2.5) , Cold Bokkeveld (2.2), Nogoya (2.2). The numbers in parenthesis are the alteration index for CM chondrites proposed by Rubin et al. (2007) [4], in which the index is defined ranging from 2.6 (less altered) to 2.0 (highly altered). Textural observation and chemical analyses were performed using an SEM-EDS (JEOL, JSM-6480LAII), and nanometer-scale observations using an STEM-EDS (JEOL, JEM-2100F) after processing into thin films using an FIB (FEI, Quanta 3DS).

Results and discussion: In the less altered CM chondrites (QUE 97990 and Murchison), the type-II TCIs showed a similar texture. Both are widely distributed in the matrices as aggregates of a few hundred nm-sized tochilinite and cronstedtite (Fig. 1a). From the TEM observations, thin veins of tochilinite were developped inside cracks or cleavages of cronstedtite (Fig. 1b), suggesting that tochilinite had been crystallized after the formation of cronstedtite. In contrast, the TCIs in Cold Bokkeveld (highly altered) showed core-rim structure (Fig. 1c). The core region (upper-left in Fig. 1d) is often rich in mixed layer phase (MLP; alternately stacked phase of tochilinite/cronstedtite layer in nanometer scale), and the rim (lower-right in Fig. 1d) mainly consists of coarse-grained tochilinite and cronstedtite, which resembles those of the less altered meteorites. Another highly altered me-teorite Nogoya (2.2) also has TCIs with zonal texture where very fine (several tens of nm) serpentine rich material is located around core, and toward rim, gradually changed to fibrous cronstedtite and MLP. Murray, intemidiately al-tered CM, has both type of TCIs seen in less and highly altered ones as noted above, indicating Murray was at an intermediate stage during the course of TCIs formation.

All observed type-II TCIs in the present study do not include any precursor minerals such as anhydrous silicates or iron metal. TCIs of the two highly altered CM chondrites (Cold Bokkeveld and Nogoya) showed fluffy texuture at their core region. These results probably suggest that (at least fluffy) type-II TCIs were not formed directly from solid material (like type-I), but crystallized under mobile environments such as water solution. In the case, changes of the fluid condition during the TCI formation resulted in the zonal texture as seen in the highly altered meteorites (Fig. 1c). The fact that the TCIs in QUE 97990 and Murchison resembles the coarse-grained rim of those in Cold Bokkeveld indicates the two less altered meteorites had experienced aqueous alteration similar to the last stage of aqueous alteration that Cold Bokkeveld had experienced.

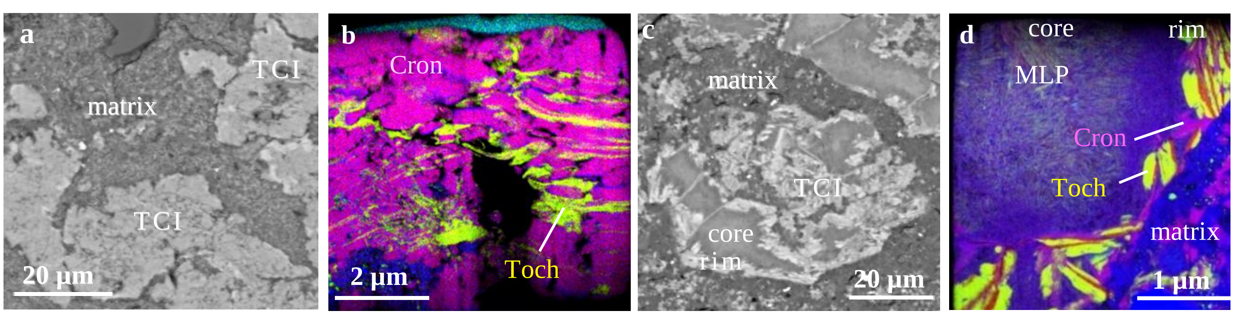

Figure 1: SEM-BEIs and STEM-EDS elemental maps (red:Fe, green:S, blue:Si) of TCIs (tochilinite-crondstedite intergrowths) in Murchison (a, b) and Cold Bokkeveld (c, d). Toch: tochilinite, Cron: cronstedtite, MLP: mixed layer phase.

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