

Na-metasomatism in the Ningqiang carbonaceous chondrite : A TEM and SR-XRD study

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Ca-Al-rich inclusions (CAIs) and chondrules in carbonaceous chondrites are known to be an initial condensate from the early solar nebula at high temperatures. However, they often include various amounts of nepheline ($[\text{Na,K}]\text{AlSiO}_4$), which condenses under relatively low temperatures. The nepheline in CAIs and chondrules is, therefore, widely believed to be a secondary mineral which have formed by replacing the primary condensate phases through the process called Na-metasomatism. Recent studies [1,2] showed that a degree of Na-metasomatism is correlated with the petrologic subtype, and thus suggested that the Na-metasomatism occurred on the meteorite parent bodies. In the case, matrix, the major part of meteorite parent bodies, could not have escaped the process. Nonetheless, previous studies did not refer to the Na-metasomatism in the matrix. The Ningqiang carbonaceous chondrite is known to be rich in bulk Na content compared to typical CV chondrites [3], and its CAIs include large amount of nepheline [4]. Here, we will report detailed mineralogical characteristics of the chondrules and the matrix in the Ningqiang chondrite concerning its signature of the Na-metasomatism. The sample used in this study is one polished thin section of the Ningqiang chondrite ($\sim 560 \text{ mm}^2$ total area). They were examined with a scanning electron microscope (SEM) equipped with an energy-dispersive X-ray spectrometer (EDS), a transmission electron microscope (TEM) equipped with an EDS, and a synchrotron radiation X-ray diffraction (SR-XRD).

The SEM and TEM observations revealed that more than 90 percent of the chondrules (39/41) include nepheline by replacement of plagioclase in their mesostasis. Small amounts of sodalite have been also observed. In many chondrules, plagioclase has been completely replaced by nepheline and sodalite, suggesting that the degrees of Na-metasomatism of the chondrules are probably high. The SR-XRD and X-ray mapping analyses revealed that about 10 vol.% of the matrix is composed of nepheline and sodalite. The abundance of nepheline and sodalite in the matrix is so large as not to be seen in other chondrites. These minerals are distributed throughout the matrix as fine grains (< 10 micron). The estimated value of bulk Na content ($\sim 4 \text{ mg/g}$) from the matrix volume (~ 40 vol.%) and the nepheline/sodalite abundance is consistent with the previous study ($\sim 3.76 \text{ mg/g}$) [3]. These mean that nepheline and sodalite are the major host minerals of Na content of the Ningqiang chondrite.

In the Ningqiang chondrite, the most of CAIs and chondrules, and matrix include abundant nepheline and sodalite. These results indicate that Na-metasomatism on the Ningqiang parent body has extensively and ubiquitously taken place. Na-metasomatism might be an ordinary process which has occurred on many meteorite parent bodies. Although the most of previous studies had found the evidence of Na-metasomatism in CAIs and chondrules, further studies that focus on matrix may also give a new clue to solve the process of Na-metasomatism.

References: [1] Kojima et al. (1995) *Meteoritics & Planetary Science* 30, 1139-1146. [2] Tomeoka and Itoh (2004) *Meteoritics & Planetary Science* 39, 1359-1373. [3] Rubin et al. (1988) *Meteoritics* 23, 13-23. [4] Sugita et al. (2009) *Journal of Mineralogical and*

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