A NEW KIND OF PLAGIOCLASE-RICH INCLUSIONS IN THE NINGQIANG CARBONACEOUS CHONDRITE. Lin Y.T.1,2 and Kimura M.2. 1Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou, P. R. China. 2Department of Earth Sciences, Ibaraki University, Mito, Japan.

Introduction Plagioclase-olivine rich inclusions [1], Ca-, Al-rich inclusions (CAIs) of type C, and CA chondrules [2] are the known plagioclase-rich inclusions in carbonaceous chondrites. In addition, type B CAIs commonly contain plagioclase [3]. Here, we report a new kind of plagioclase-rich inclusions in the Ningqiang carbonaceous chondrite, anomalous CV3 [4] or anomalous CK3 [5]. These plagioclase-rich inclusions consist of 45-49 vol% spinel, 30-40 vol% anorthite, 8-12 vol% Ca-pyroxenes, and 3-6 vol% melilite with minor perovskite, nepheline and hedenbergite. All of the inclusions show zoned structure, and are classified into compact and fluffy subtypes. Petrographical and mineralogical evidences indicate that these inclusions were subjected to high-temperature alteration. In addition, after the alteration, the compact subtype experienced a heating event.

Petrography Five plagioclase-rich inclusions were found in 3 out of 21 sections, suggesting its heterogeneous distribution in the Ningqiang chondrite. Three of the inclusions are mm-sized (1.0×1.6, >1.1×2.4, >2.8×3.6 mm). Four of the plagioclase-rich inclusions are compact subtype and the other is fluffy one. Both of the two subtypes have a similar modal composition as mentioned above. They have zoned structure, consisting of spinel-nodule core, thick anorthite-spinel mantle and spinel-melilite crust (Fig. 1). Major element abundances of the individual zones were measured using defocused beam, indicative of overlapping between the two subtypes. Only bulk CaO, Na2O and MgO contents of the mantle are higher in the fluffy inclusion (1.5 wt% and 1.8 wt%, respectively) than the compact ones (0.8 wt% and 0.3 wt%, respectively). In compact inclusions, the core is aggregate of spinel-nodules (30-70 μm in diameter), each rimmed by melilite and Ca-pyroxene in sequence, like a fine-grained spinel-rich inclusions in Kainsaz (CO3) [6]. The mantle is predominant part of the inclusions, and consists of sinuous spinel anorthite, Ca-pyroxene and irregular voids (Fig. 2). We found mineral sequence in order of spinel, anorthite and Ca-pyroxene towards the voids. Width from the void to center of the spinel is about 4-12 μm. The crust is about 50-150 μm thick and composed of sinuous melilite in a matrix of spinel. Small fassaite in melilite and perovskite in spinel are found in the crust. Anorthite replacing melilite is encountered along boundaries between the different zones. Accessory hedenbergite and nepheline mainly occur in the mantle near the crust. In the fluffy inclusion, the core consists of loosely packed spinel-nodules (20-50 μm in diameter), each rimmed also by melilite and pyroxene in sequence. The mantle consists of plenty of zoned grains (6-15 μm in diameter). Each grain has a spinel core and anorthite-Ca-pyroxene rim. The crust is similar to that of the compact subtype. Nepheline and hedenbergite are more abundant in the fluffy subtype than the compact ones. Ca-pyroxene inclusions in melilite in the crust abundantly occur, relative to the compact subtype.

Mineral chemistry Anorthite is An99.5-100 in composition. Spinel shows relationship between composition and occurrence. For the compact subtype, spinels in the mantle and the core have V2O3-content below the detect limit (0.07 wt%). In comparison, V2O3 is detected in spinel in the core (<0.20 wt%). V2O3-depletion in the core and the mantle is also found in the fluffy inclusion. However, the V2O3-contents in the core and mantle (0.09 wt%) and in the crust (0.29±0.08 wt%) are systematically higher than those of the compact ones. Cr2O3-content is higher in the mantle (0.17 - 0.55 wt% in compact subtype and 0.47-1.01 wt% in the fluffy one) than the other occurrences (<0.35 wt%). FeO-content of spinel is the lowest in the core (<0.14 wt%) in both subtypes, but the highest in the mantle of the fluffy inclusion (3.27-15.1 wt%). Spinel in the other occurrences contain less than 4.31 wt% FeO. Melilite has similar Ak-content between the fluffy inclusion (5.8-19.0, av. 14.0±4.0 mol%) and 3 of the compact one (6.9-21.4, av. 12.6±3.2 mol%), but more Ak-rich in the other (21.8±8.4 mol% in the core, 14.6±6.1 mol% in the crust). Ca-pyroxenes also show relationship between composition and occurrence. Grains enclosed in melilite in the crust of the fluffy inclusion are characterized by higher concentrations of TiO2, Al2O3 and V2O3 (13.0±1.9 wt%, 23.4±2.1 wt% and 0.44±0.16 wt%, respectively, in comparison with the compact ones (8.4±1.34 wt%, 19.1±0.2 wt% and <0.12 wt%, respectively). Al2O3-content of Ca-pyroxene rim around anorthite ranges up to 22.6 wt%, but TiO2-content is <4.86 wt% and V2O3 undetectable. Ca-pyroxene rim covering the crust contains the lowest Al2O3 and TiO2 (<4.36 wt%, <0.55 wt%, respectively). Nepheline contains CaO (0.1-0.8 wt%) and K2O (<1.2 wt%), and hedenbergite (En2.2Fs48Wo49.9) contains Al2O3 (3.5 wt%), Na2O (<1.1 wt%) and MgO (<0.6 wt%).

Discussion Genetic relationship between the compact and fluffy subtypes: From similar modal composition, structure, bulk compositions of individual zones and mineral chemistry, we argue for a
close genetic relationship between the two subtypes. The only remarkable difference between them is loose texture of the fluffy one while sinuous texture of the compact one which, however, could be formed through sintering fine-grained aggregates of the fluffy subtype in a heating episode. The same distribution of grain sizes and mineral sequence in order of spinel, anorthite and Ca-pyroxene towards the voids between the two subtypes support this idea. High-temperature alteration of the new type of plagioclase-rich inclusions. The sequence of spinel-anorthite-Ca-pyroxene in the zoned grains can not be explained by condensation models in the solar nebula [7, 8]. Such mineral sequence and the fluffy texture support neither distillation nor crystallization from melt proposed for the known plagioclase-bearing inclusions [1, 2, 9]. We propose that the association of spinel-anorthite-Ca-pyroxene is alteration product of spinel-melilite grain in the early nebula by a following reaction:

$$2\text{Ca}_2\text{Al}_2\text{Si}_7\text{O}_{22}(\text{Ge}) + \text{MgAl}_2\text{O}_4(\text{Sp}) + 6\text{SiO}_2(\text{vapor}) = 3\text{CaAl}_2\text{Si}_2\text{O}_8(\text{An}) + \text{CaMgSi}_2\text{O}_6(\text{Di})$$

This is consistent with the modal ratio of anorthite/Ca-pyroxene. In addition, anorthite abundantly replaces melilitite. In contrast with melilite-bearing inclusions in the other CV3 chondrites [10, 11], the abundances of nepheline and hedenbergite are low, and wollastone, grossular and sodalite were never encountered in these plagioclase-rich inclusions. Spinel poorly contains FeO. These observations suggest that the Ningqiang plagioclase-rich inclusions were subjected to the alteration at high temperatures. They hardly experienced low-temperature reaction with alkali elements and FeO. Magnesian spinels in these inclusions directly contact with FeO-rich matrix, evidently suggesting that the alteration reaction occurred before accretion to the parent body.

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References

Figure 1. Back scattered electron image of a compact plagioclase-rich inclusion, consisting of spinel-nodule core, thick spinel-anorthite mantle (inset see Fig. 2), and spinel-melilite crust.

Figure 1. Representative texture of the mantle (inset of Fig. 1), note mineral sequence in order of spinel (Sp), anorthite (An) and Ca-pyroxene (Px) towards the voids (completely dark). Minor nepheline (Nep) and hedenbergite (Hed) are found in the voids. Two veins of crack cross the photo. The scale bar on the left is 10 μm.