Primary mineralogy and secondary alteration characteristics observed in Antarctic CR chondrites

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Introduction

CR chondrites are a primitive group of carbonaceous chondrites that preserve records of formation of their components in the solar nebula [e.g., 1-3]. Although they do not show much evidence for thermal metamorphism, they have been affected by variable degrees of aqueous alteration [4]. We have been investigating the petrologic variations among the CR chondrites in the NIPR Antarctic meteorite collection. In this study, we focus on the secondary alteration characteristics of chondrules and matrices in CR chondrites in order to understand the secondary processing of CR chondrite parent body(-ies).

Methods

Polished thin sections of nine CR chondrites Y-790112, Y-791498, Y-792518, Y-793261, Y-793495, Y 982405, A-8449, A-881828, and A-881595 were studied using JEOL JSM-7100F FE-SEM and JEOL JX-8200 EPMA at NIPR. The extent of aqueous alteration was estimated from preservation of glass in chondrule mesostasis, textural replacement of chondrule phenocrysts, alteration of primary anorthite and metal in amoeboid olivine aggregates (AOAs). The degree of thermal metamorphism of the meteorites was examined using Raman spectra of matrix grains collected with a JASCO NRS-1000 Raman Spectrometer at NIPR. The Raman constraint on metamorphic temperature is based on the G- and D-bands (associated with graphite and defects, respectively) in carbonaceous matter. With increasing metamorphic temperature, the full-width at half-maximum (FWHM) of the D-band decreases and the intensity ratio I_D/I_G increases [5-8].

Results and Discussion

Petrology of chondrule rim

CR chondrites are composed of chondrules, refractory inclusions, mineral fragments, and fine-grained matrix. They show variable degrees of aqueous alteration that resulted in replacement of chondrule glass and matrix by phyllosilicates, and of Fe,Ni-metal by magnetite and Fe-sulfides; olivine and pyroxene phenocrysts in chondrules are also replaced by Fe-rich phases in the heavy altered samples.

Many chondrules in CR chondrites have rims composed of Fe-rich phases. Sometimes they are hard to distinguish from terrestrial weathering Fe-oxides, but they are somewhat different from pre-terrestrial Fe-oxides; terrestrial weathering phases occur as rims around the metal or veins that crosscut into the matrix. In the samples with weak aqueous alteration, clear boundary rims around chondrules are easily recognized (Fig. 1 a-c). This type of smooth two-layered rim is also described in slightly altered CR samples QUE 99177, MET 00426 and LAP 02342 [9]. The boundary layer also occurs around igneous rim with "honeycomb"structure described by [9] (Fig. 1b) and silica-rich rim [10;11; Fig. 1c]. Boundary layers become less clear in the samples with mild aqueous alteration (Fig. 1 d), and are not observed in the sample with heavy aqueous alteration (Fig. 1f). Boundary layers were not observed in Y 982405. In this sample olivine grains in chondrules show Fe-enrichment in the grain boudary, suggesting the Fe introduction probably due to thermal processing (Fig. 1f).

Maturation Grade of Organic Materials

Raman spectra were collected on randomly-selected matrix areas in a polished thin section of each samples. All CR chondrites except Y982405 show wide FWHM-D and low I_D/I_G ratios, indicating that this meteorite experienced only weak thermal metamorphism. [12] collected Raman spectra from a wide suite of chondrites, including CR chondrites, and [13] collected CR and CM chondrites; their data for CRs overlap with our results, but have a higher range of I_D/I_G (Fig. 2). Differences from the two data sets are not surprising given that (1) they are based on different CR meteorites, (2) the spectra in [12] were collected from extracted insoluble organic matter whereas our data were collected from matrix areas of polished thin sections, and (3) the data were collected with different Raman spectrometers.

Raman spectra of Y 982405 have lower FWHM-D and higher I_D/I_G ratios than those of the other CRs studied. Similar Raman spectra are also reported in the CR chondrites GRO 03116 and GRO 06100 [14] and heated CM chondrites [13], and are attributed to short-duration impact heating (Fig. 2). Considering that olivine grains in chondrules have Fe-enrichment in the grain boundaries, it is likely that Y 982405 experienced thermal processing probably due to impact heating.

Although we do not observe any correlation between the maturation grade and the degree of aqueous alteration, the low thermal maturity of organic matter indicated by Raman spectra from datasets in [12] and [13] show that most CR chondrites, did not undergo thermal metamorphism to the same extent as most ordinary, CO and CV chondrites (Fig. 2), confirming the supposition that CR chondrites have a high probability of preserving minerals and textures of nebular origin. In addition, it should be noted that some CR chondrites experienced short duration impact heating.

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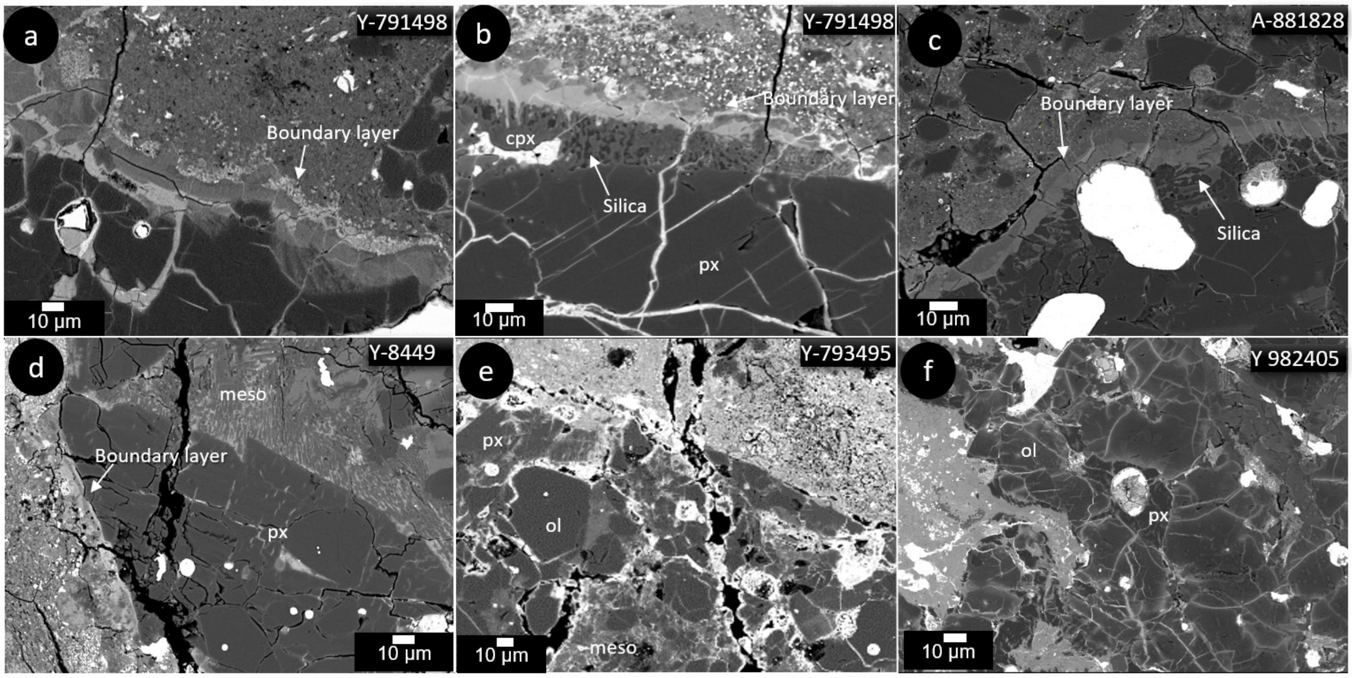

Fig.1. BSE images of chondrule rims from CR chondrites in this study. (a-c) Chondrule rims from the sample with little aqueous alteration. (d) Chondrule with mild aqueous alteration. (e) chondrule with heavy aqueous alteration. (f) No rims are observed in Y 982405. Chondrule olivines in this sample show Fe enrichment toward the grain boundary.

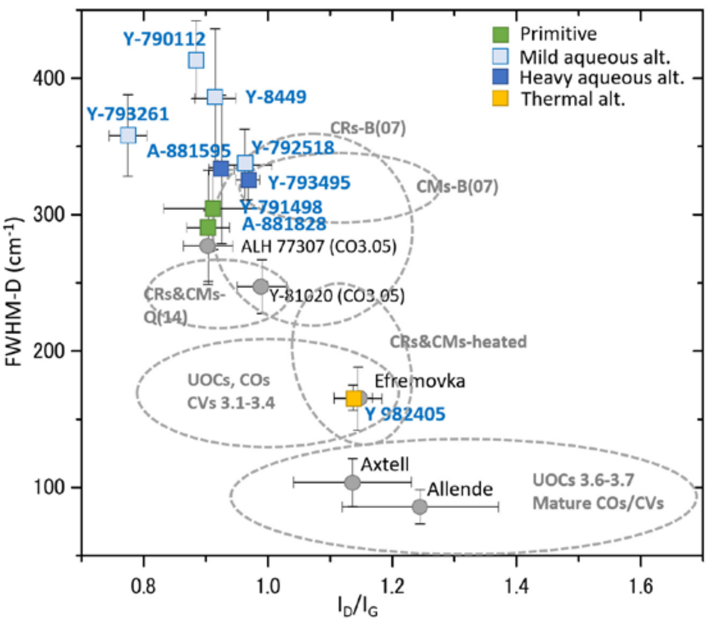

Fig. 2. Spectral parameters of Raman bands of carbonaceous matter from matrix of CR chondrites in this study compared with other carbonaceous and type 3 ordinary chondrites. Analyses shown in colored squares and gray circles were conducted at NIPR; error bars show ±1σ uncertainty based on approximately 20 analyses per sample. Fields outlined in gray summarize data from: (1) for CR chondrites analyzed by [12] (labelled CRs-B07); (2) CR chondrites analyzed by [13] (labelled CRs&CMs-Q(14)); (3) CR chondrites with impact heating [14] and dehydrated CM chondrites [13] (labelled CRs&CMs-heated); (4) unequilibrated ordinary chondrites (UOCs), CVs and COs of petrologic types 3.1 to 3.4 vs. types ≥ 3.6 [5-7] (labelled UOCs 3.6-3.7; Mature COs/CVs).