BULK CHARACTERIZATION OF ORDINARY CHONDRITES USING THE X-RAY DIFFRACTION METHOD

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Introduction: Modal abundances of constituent minerals for ordinary chondrites (OCs) have been determined by the bulk X-ray diffraction method using the homogenized powder, enabling the classification [1]. However, the application of this method for irregular shaped coarse samples has been limited. It is also important directly to examine the chemical group and the petrologic type under the various sample conditions, because this approach may apply for the undestructive and rapid identification of the extraterrestrial materials or the fragment surface. In addition, the distinction among orthopyroxene (Opx) and low-Ca clinopyroxene (Cpx) has not been taken into consideration [1]. This is indispensable to the identification among unequilibrated and equilibrated OCs (UOCs and EOCs). In the present study, OCs of the three chemical groups with five petrologic types (3 to 6, and shock melt) were examined to explore the classification using the X-ray diffractometer, focusing on (1) the olivine (130) peak, (2) the full width at half maximum (FWHM) of Opx (511), (3) the relative intensity of troilite (114) and kamacite (110).

Experiments: The X-ray diffractometer (RIGAKU, SmartLab) was used for the present study, installed at NIPR in 2014. Cu Kα1 (λ=0.15406 nm) X-ray was used. X-ray tube voltage was 40 kV, and tube current was 30 mA. One-dimensional solid-state detector (D/teX Ultra 250) was used for the X-ray counting. The scan speed of the goniometer was normally 0.4 º/min.

Broad beam measurements: Focusing method was used for the optical geometry. Cu Kβ was removed using the Ni filter. Polished thin sections mainly of Antarctic meteorites (23 H, 21 L, and 16 LL) were used for obtaining the powder diffraction pattern by the in-plane rotation at 100 rpm. Auto sample changer (ASC10) was set for the attachment of the sample holder. The slit size for the incident X-ray was 10×10 mm.

Focused beam measurements: The incident X-ray (parallel beam method) was focused using the CBO-f unit to be 0.4 mm in beam diameter. This was applied to the bulk characterization of an internal irregular shaped fragment of the Jilin H5 chondrite (~0.04 g in weight) and obtained the powder diffraction pattern, by the in-plane rotation of the focused area at 20 rpm. The measurement position was adjusted using the movable sample stage with the attached CCD camera.

Results and discussion:

Broad beam measurements: *Olivine.* The major diffractions of OCs are originated from olivines. The mean compositions of olivines were determined from the 2θ of the olivine (130) peak [2], with the slight correction of the composition using the synthetic forsterite as the standard (2θ=32.32º) [3]. Olivine (130) correlates with the chemical group for EOCs. While, the peak for UOCs is splitted or has large FWHM. *Low-Ca pyroxenes.* Two polymorphs for low-Ca pyroxene, Opx and Cpx, were distinguished from mainly two peaks: Opx (321) 30.3º and Opx (511) 31.5º since Cpx is absent from both peaks. However, Opx (321) is overlapped with high-Ca Cpx ($\bar{3}$10), although high-Ca Cpx is minor. Low-Ca Cpx (22$\bar{1}$) locates at 2θ=~30º, which is not overlapped with the peak of Opx, but is overlapped with olivine (002) and high-Ca Cpx ($\bar{2}$21). Thus a reliable peak identifying Opx is Opx (511). FWHM of Opx (511) was then used for the analyses in order to avoid the effect of slight differences of the surface area (~1 cm^2) and the thickness (~30μm) among the polished thin sections. The weak correlations of FWHM of Opx (511) with the petrologic type were then observed. Opx (511) was absent or minor from UOCs. *Fe-Ni alloys and troilite.* The ratio of the integrated intensities of troilite (114) (2θ=43.1º) to kamacite (110) (2θ=~44.6º) is used for the analyses. The intensity ratios of troilite to kamacite for petrologic types tend to correlate. *Shock effect.* The diffraction pattern of the shock melted LL chondrites is characterized of abundant homogeneous olivines (small FWHM) and dominant Cpx (e.g., Y-790522).

Focused beam measurements: The diffraction pattern by the focused measurement of the Jilin H5 chondrite fragment using the CBO-f unit is consistent with the measurements by the broad bulk X-ray using the polished thin section of the same sample. Thus, the present criterion for the classification is generally applicable to the small samples.

In summary, the bulk X-ray diffraction method is useful to determine the bulk mineralogy of OCs, but it is limited uniquely to determine the classification of OCs consisting of 15 classes by the combination of 3 chemical groups and 5 petrologic types.

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