Toward the classification of chondrites using the powder X-ray diffraction method, a preliminary report. N. Imae, National Institute of Polar Research, Tachikawa, Tokyo 190-8518, Japan. e-mail: imae@nipr.ac.jp.

Introduction: The technique obtaining the modal compositions by the whole pattern profile matching procedure using the powder X-ray diffraction method [1] have been applied to chondrites; equilibrated ordinary chondrites [2], unequilibrated ordinary chondrites [3], and carbonaceous chondrites [e.g., 4]. However, the distinction of the three pyroxene phases and its connection with the equilibrated and unequilibrated chondrites are not enough. This is indispensable for the classification of stony meteorites. In the present study, I examined the availability for the general classification of chondrites, considering the compositional variation of olivines and the relative abundances of olivine and three pyroxene phases.

Experiments: The X-ray diffractometer (SmartLab Rigaku) was used in the present study. The analytical conditions were as follows: the tube current 30 mA, the tube voltage 40 kV, the target Cu, the Ni filter for the removal of Kβ, the 2θ scan speed 2^o/min, the solid-state detector (D/teX Ultra 250), the glass sample holder with the sample space of the 9 mm in diameter and 0.2 mm in depth (< ~50 mg), focusing method as an optical system of the diffractometer. Homogeneous fine-grained powders of Antarctic chondrites removed magnetic minerals were used for the analyses, 16 ordinary (4 H; 6 L; 6 LL) and carbonaceous chondrites (2 CO3; 1 CV3; 1 CM2), which were the residues originally prepared and consumed for the wet-chemical analyses by H. Haramura [5]. The powder of Allende (CV3), NWA 1465 (ungrouped C), and Jbilet Winselwan (CM2) were also prepared using an agate mortar in the present study. Similarly, reference powder samples were also prepared, olivines from San Carlos (Arizona, USA) and synthetic forsterite [6], low-Ca orthopyroxenes from Bamble (Norway), Mpwapwa (Tanzania), and Morogoro (Tanzania).

Results: The peak of olivine (130) for all chondrites appears at 2θ=~32^o, but the variations of the positions, peak width, and peak intensity are observed (Fig. 1). The three peaks of there pyroxene phases were mainly used for the analyses, 2θ=29.8^o, 30.3^o, and 31^o, corresponding to 0(absent), 50(321), and 90(610) for Ca-poor opx, 50(22$\bar{1}$), 0(absent), and 100(310) for Ca-poor cpx, and 100($\bar{2}$21), 32(310), 37($\bar{3}$11) for Ca-rich px, respectively, where the number is relative intensity with plane indices. Then, the heights of the peak of 29.8^o and 31^o are similar each other for the carbonaceous and unequilibrated ordinary chondrites, lacking in the peak of 30.3^o (Fig. 1). The peak of 31^o is the highest among the three peaks for the equilibrated ordinary chondrites (Fig. 1). The peak of 29.8^o is the highest among the three peaks for the shock melted LL chondrites, lacking in the peak of 30.3^o (Fig. 1). The peak of orthopyroxene (321) at 2θ=~30.3^o, which is indicator of equilibrated chondrite, was observed from 10 chondrites but not from 12 chondrites (Table 1; Fig. 2). The peak of plagioclase at 2θ=~22^o was observed from 11 (+2 ambiguous) chondrites (Table 1).

Discussion: The peak positions of olivine (130) suggest the Mg/Fe ratio and have been empirically inverted to the Fa (mol%) [e.g., 7-8]. Overall, the peaks of olivine (130) of the equilibrated ordinary and shock melted chondrites are smooth and sharp, but those of the carbonaceous and unequilibrated chondrites are rough and broad. The peak intensity and the peak width may also suggest the compositional variation because these are strongly correlated with the petrologic type (Fig. 1; Table 1), in spite of the many possible factors affecting on the peak height and width. However, the shock degrees in the studied samples are not so significant and the mean grain sizes of the powder are similar, and also the analytical conditions are identical with each other. The inverted representative compositional variation is plotted in Fig. 2. This variation thus enables the distinction between equilibrated and unequilibrated chondrites. Some of the carbonaceous chondrites have the ferroan peak originating from the matrix olivine of Fa40 for ALH-77003, Fa50 for A-882094, and Fa47 (and Fa5) for Y-86751, and so on. While, the unequilibrated ordinary chondrites have magnesian peak of Fa15 for Y-791558, and so on. The difference enables the distinction between the two unequilibrated chondrites.

The existence of the peak of orthopyroxene (321) is well correlated with the equilibrated chondrites determined from the olivine heterogeneity based on the peak of olivine (130) (Table 1). The minor amount of Ca-rich pyroxenes (310) has the similar 2θ for opx (321). The relative peak height of 31^o (pyroxenes) and ~32^o (olivine) is distinguishable for H with the similar height and L chondrites being ~32^o higher than 31^o, corresponding the modal difference. The distinction of L4, L5, and L6 may be possible since the 31^o peak to 29.8^o and 30.3^o for pyroxenes decreases to this order. The five chondrites (Y-790522, Y-790757, Y-790532, Y-790782, and Y-790489) indicating the equilibrated chondrites from the peak of olivine (130) lack the peak of orthopyroxene (321) (Table 1). The five chondrites correspond to the shock melted chondrites, confirmed from the textures under the polished thin sections observed under an optical microscope.

Summary: The X-ray diffraction method is very powerful technique for classifying chondrites (and also achondrites), however, it is furthermore necessary quantitatively to study it for detailed classification.

References: [1] Cressey G. and Schofield P. F. (1995) *Powder Diffraction, 11*, 35-39. [2] Dunn T. L. et al. (2010) *Meteorit. Planet. Sci., 45*, 123-134. [3] Menzies O. N. et al. (2005) *Meteorit. Planet. Sci., 40*, 1023-1042. [4] Howard K. T. et al. (2011) *Geochim. Cosmochim. Acta, 75*, 2735-2751. [5] Yanai K. and Kojima H. (1995) Catalog of the Antarctic Meteorites. [6] Takei H. and Kobayashi T. (1974) *JCR, 23,* 121-124. [7] Brown, Jr. G. E. (1982) *Reviews in Mineralogy, 5,* 275-381. [8] Yoder, Jr. H. S. and Sahama T. G. (1957) *Amer. Min., 42*, 475-491.

Table 1. Studied chondrites and their results.

Meteorite name	Published classification	Noticed texture on PTS	X-ray results				
			Olivine (130)	Orthopyroxene (321)	Plagioclase	Chemical group	Classification
Y-86051	H4		Equilibrated	+	+	H	H4, H5, H6
Y-86186	H4		Equilibrated	+	+	H	H4, H5, H6
Y-86271	H4		Equilibrated	+	+	H	H4, H5, H6
Y-86272	H4		Equilibrated	+	+	H	H4, H5, H6
Y-86055	L3.8		Equilibrated-Unequilibrated	+	+	L	L3 (higher subtype)
Y-791545	L4		Equilibrated	+	+	L	L4, L5, L6
Y-86036	L5		Equilibrated	+	+	L	L4, L5, L6
Y-790740	L5		Equilibrated	+	+	L	L4, L5, L6
ALH-769	L6		Equilibrated	+	+	L	L4, L5, L6
Y-790489	L	Shock melt	Equilibrated	-	(+)	LL	LL (shock melt)
Y-791835	LL3.7		Unequilibrated	(+)	+	Unequilibrated chondrite	LL3 (higher subtype)
Y-791558	LL3.15		Unequilibrated	-	-	Unequilibrated chondrite	LL3 (lower subtype)
Y-790522	LL4	Shock melt	Equilibrated	-	(+)	LL	LL (shock melt)
Y-790757	LL	Shock melt	Equilibrated	-	-	LL	LL (shock melt)
Y-790532	LL5	Shock melt	Equilibrated	-	+	LL	LL (shock melt)
Y-790782	LL6	Shock melt	Equilibrated	-	+	LL	LL (shock melt)
ALH-77003	CO3		Unequilibrated	-	-	Unequilibrated chondrite	C chondrite
A-882094	CO3		Unequilibrated	-	-	Unequilibrated chondrite	C chondrite
Y-86720	CM2		Unequilibrated	-	-	Unequilibrated chondrite	C chondrite
Y-86751	CV3		Unequilibrated	-	-	Unequilibrated chondrite	C chondrite
Allende	CV3		Unequilibrated	-	-	Unequilibrated chondrite	C chondrite
NWA 1465	C(ung)		Unequilibrated	-	-	Unequilibrated chondrite	C chondrite
Jbilet Winselwan	CM2		Forsterite	(+)	-	Unequilibrated chondrite	C chondrite

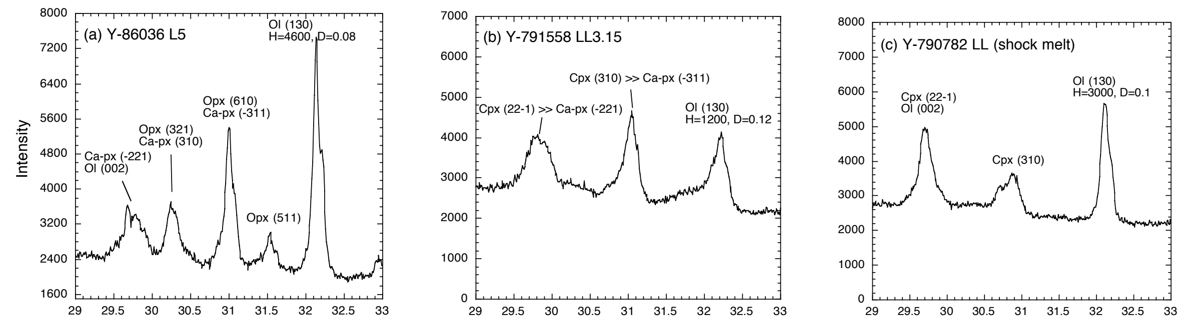

Fig. 1. The olivine (130) peaks (2θ=~32º). The orthopyroxene (321) peaks (2θ =30.3º) and the common peaks of pyroxenes of Ca-poor ortho, Ca-poor clino, and Ca-rich (2θ =~31º). Note that the peak of 2θ =29.8º is overlapped with the olivine (002) peak. The combination of pyroxenes gives the phase assemblage of (a) opx>Ca-px, (b) cpx, and (c) mainly cpx.

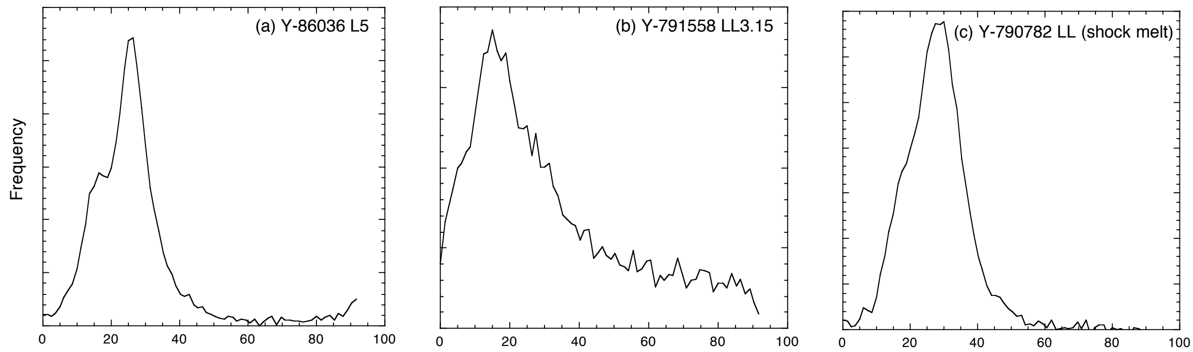

Fig. 2. Inverted compositions of olivines from the 2θ variation with the intensity.