PYROXENES IN EARLY CRUSTAL CUMULATES FOUND IN ACHONDRITES AND LUNAR HIGHLAND ROCKS. Hiroshi Takeda, Mineralogical Institute, Faculty of Science, University of Tokyo, Hongo, Tokyo 113, T. Ishii, Ocean Research Institute, University of Tokyo, Nakano-ku, Tokyo 164, and M. Miyamoto, Department of Earth Sciences, Kobe University, Nada-ku, Kobe 657, Japan.

Comparative studies of pyroxenes in achondrites and pristine non-mare lunar rocks have been promoting a better understanding of the nature and evolution of planetary crusts(1,2). Relatively rapidly cooled pyroxenes in lunar KREEP basalts and eucrites have been investigated(3). To characterize more slowly cooled pyroxenes from the above two crusts of different compositions and thicknesses, we investigated pyroxenes in a pristine nonmare lunar (L-) rock 62236,12 (2), quartz monzodiorite L-15405,148 (4) and highland rock (LMB) L-60016,97, and Yamato(Y-) eucrites(5,6) and a new diogenite from Allan Hills (ALHA77256,6) by electron microprobe and single-crystal X-ray diffraction techniques.

Pyroxene crystals were separated from unfinished thin sections(UTS) of about 0.1mm thick and small rock chips. Prior to the separation, microprobe analyses were made of pyroxenes in the UTSs. The crystals were mounted along c^*, and the precession photographs of $h0l$, and $0kl$ nets were taken using Zr-filtered, Mo $K\alpha$ radiation. The oriented single-crystal probe mounts of pyroxenes in L-15405, Y-74450 and ALHA77256 and pyroxenes in thin section, L-60016 ,97 were analysed by a microprobe.

Y-75015 is a polymict breccia of common eucritic composition and it is composed of mineral clasts common for known eucrites in various proportions. Pasamonte-like clasts are not rare. Based on their chemistry alone, one may misidentify two types of Mg-rich pyroxene fragments in Y-75015 as orthopyroxenes in some howardites. A few fragments over 0.5mm in diameter with the bulk composition intermediate between those of Binda and Moama (Table 1, Fig. 1) and with blebby augite inclusions similar to those in these eucrites have been confirmed as an orthopyroxene by the X-ray method. This finding is the first confirmation of orthopyroxene inverted from pigeonite of the Binda-type (1,7) in the eucritic polymict breccias. The precession photographs show weak reflections of augite with ($\bar{1}00$) in common. The texture and bulk composition indicate that they are originally low-Ca pigeonites. The Binda-type pyroxene has been considered to represent cumulates in a eucritic crust(1). Y-75015 includes the pyroxenes which could have come from the deepest layer of the eucritic crust.

The second type of the Mg-rich pyroxenes in Y-75015 is similar to large pyroxene phenocrysts found in Y-74450(3). One such crystal (P in Fig. 2) display a homogeneous core $Ca_5Mg_{67}Fe_{28}$ and slight Fe-enrichment at the rim $Ca_{10}Mg_{50}Fe_{40}$ and show the X-ray diffraction pattern of pigeonite with very small amounts of exsolved augite reflections with (001) in common. These features are similar to those represented by the Pasamonte pigeonites which were produced by rapid cooling near the surface of the eucritic crust(3). The degree of exsolution is smaller than those of more Fe-rich crystal (B in Fig. 2) $Ca_9Mg_{46}Fe_{45}$ with a uniform chemical composition and with augite exsolution lamellae slightly resolvable by the microprobe scan. Three new thin sections of Y-74450 exhibit more polymict brecciated nature than previously thought, but are composed of components crystallized and cooled much shallower than those of Y-75015.

In Y-75015 and other eucritic polymict breccias, a very common component is the uninverted pigeonite with uniform composition and exsolution lamellae a few microns thick. This type of pigeonite is common among the known

eucrites (e.g. Juvinas) and eucritic enclaves in some mesosiderites (e.g. Mt. Padbury) but is rare in Antarctic achondrites and lunar samples up to date. We identified one very small eucrite (10.0g) of this type, Y-74356 in the Yamato collections(6). The chemical and crystallographic feature of pigeonites in the quartz monzodiorite clasts, L-15405 (Table 1, Fig. 2) is the only lunar analogue so far studied.

Significance of low-Ca inverted pigeonites in crystallization of achondritic and lunar pyroxenes has been pointed out by us (7). ALHA77256 is a monomict diogenite but preserves textures annealed deep within the crust. It composed of orthopyroxene $Ca_{1.7}Mg_{74.3}Fe_{24.0}$ uniform within 0.95% mean deviation, and minute grains of augite $Ca_{46}Mg_{45}Fe_{9}$ at grain boundaries or within some orthopyroxene crystals. The latter resembles a low-Ca inverted pigeonite found in the most Fe-rich diogenite, Y-75032 (7), but seems to be annealed for very long periods of time. The ALHA77256 orthopyroxene shows no reflection of the exsolved augite with (100) in common.

Warren and Wasson (2) brought an occurrence of the Binda-like pyroxene in a troctoritic anorthosite, L-62236,5 to our attention. Our electron microprobe study of UTS L-62236,12 indicated that the pyroxene is not abundant and the composition of a pyroxene with blebby inclusions of augite (Table 1, Fig. 1) is close to this type of inverted pigeonites reported for L-15459 (8), L-77215 (9), Y-75032 (7) and Binda (1). Orthopyroxenes slightly more Mg-rich than the above are also present in L-62236,12. The Lunar inverted pigeonites of the Binda type are located between the trends of anorthosites and norites in the pyroxene quadrilateral of the pristine nonmare rocks(2,8,9), and may be used as a key to identify the crystallization trend.

Keeping such idea in mind, we have surveyed Binda-like pyroxenes in pyroxene clasts in a thin section of a light matrix breccia, L-60016,97. The pyroxenes display a range of composition from about $Ca_{5}Mg_{75}Fe_{20}$ to $Ca_{8}Mg_{45}Fe_{47}$, for which troctorites-norites and anorthosites may be contributing rock types (Fig. 3), but the Binda-like pyroxene is rare within the thin section examined.

In conclusion, the above evidence supports our previous conclusion that some eucritic polymict breccias (e.g. Y-75015) are composed of all component-pyroxenes within the primordial achondritic crust, including the most deep-seated cumulates. A least-metamorphosed lunar highland breccia still preservesapparent remnants of pyroxenes in pristine nonmare rocks although they may be somewhat altered or biased (Fig. 4).

We thank Profs. T. Nagata, Y. Matsumoto and K. Yanai for the meteorite samples, and Drs. M. B. Duke and P. H. Warren for discussion.

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Pyroxenes in crustal cumulates

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Table 1. Chemical compositions of lunar(L-) and Yamato(Y-) pyroxenes.

	L-62236			Y-75015			Y-74450	L-15405	Y-74356
	Opx	Bulk	Aug	Opx	Bulk	Aug	Pig	Pig	Pig
SiO_2	52.4	51.8	52.4	52.4	52.1	50.8	49.5	50.2	48.3
Al_2O_3	0.59	0.68	0.77	0.57	0.64	0.94	0.98	0.43	0.37
TiO_2	0.27	0.25	0.31	0.18	0.24	0.36	0.24	0.40	0.37
Cr_2O_3	0.33	0.27	0.35	0.44	0.41	0.55	0.63	0.18	0.74
FeO	21.8	20.7	8.34	21.8	19.56	10.06	26.8	33.7	33.3
MnO	0.39	0.36	0.17	0.79	0.73	0.46	0.82	0.60	1.04
MgO	22.9	21.5	15.19	21.6	20.3	14.60	15.51	12.49	12.02
CaO	1.13	3.09	22.3	1.65	4.96	20.8	4.18	2.12	3.41
Na_2O	0.00	0.01	0.00	0.02	0.03	0.11	0.00	0.00	0.00
Total	99.81	98.66	99.83	99.45	98.97	98.68	98.66	100.12	99.55

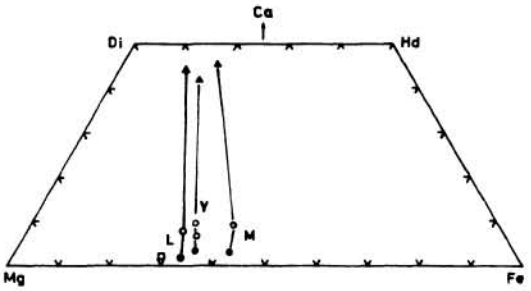

Fig. 1. Pyroxene quadrilateral plots of low-Ca inverted pigeonites in crustal cumulates.
L: L-62236,12, Binda and Y-75032 locate at the same position;
Y: Y-75015; M: Moama.
□: Opx., ○: bulk, ●: host,
△: blebby augite inclusions.

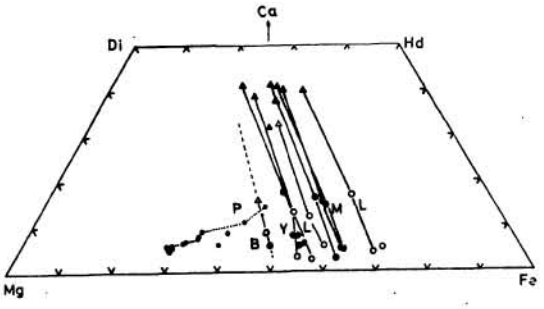

Fig. 2. Pigeonite compositions from the Yamato eucrites Y-74450 (P, B) and Y-74356 (Y), and lunar quartz monzodiorite L-15405 (L).
The symbols are same as in Fig. 1.
The tie lines indicate host and augite lamellae (△) pairs.

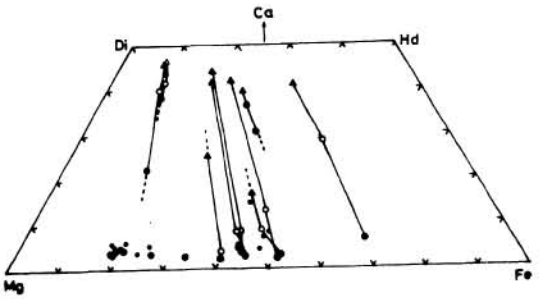

Fig. 3. Pyroxenes in L-60016,97.
The symbols are same as in Fig. 2.
Small dots: individual measurements.

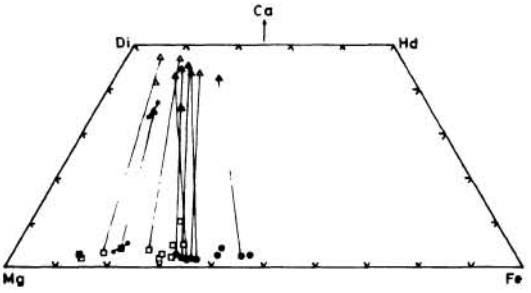

Fig. 4. Pyroxenes in pristine nonmare lunar rocks (2).
■: dunite, □: troctolite, norite,
●: anorthosite, △: augite.
Source of data: Ryder G. and Norman M.(1978) NASA catalog. JSC 14565.