TYPICAL PROCESSES OF EXSOLUTION, DECOMPOSITION AND INVERSION OF PYROXENES AND ITS BEARING ON THERMAL HISTORY OF LUNAR ROCKS, Hiroshi Takeda, Mineralogical Institute, and Teruaki Ishii, Geological Institute, Faculty of Science, University of Tokyo, Hongo, Tokyo 113, Japan.

In spite of extensive accumulation of data on epitaxy, exsolution, and inversion of lunar pyroxenes, it has been generally difficult to draw a definite conclusion on the thermal history of lunar rocks. Both theoretical and experimental approaches to increase our basic understandings of these phenomena are indispensable to use lunar minerals as a petrologic probe. In view of these facts, Ishii and Takeda(1) clarified three typical processes of inversion, decomposition, and exsolution of the calcium-poor pyroxenes which are in cotectic relation with calcium-rich pyroxene during crystallization. We have examined thin sections 15455, 28; 72255, 108 and 76250,5 to see how well thermal histories of the lunar pyroxenes fit into these three typical processes. Microprobe analyses were carried out on grain mount 14310, 413(RY1) to see the composition gap between orthopyroxene and pigeonite.

The proposed processes especially refer to 'pigeonite eutectoid reaction' (PER) line, which is the lower stability limit of pigeonites, and can be summarized as: (A) Exsolution of augite from orthopyroxene on (100), crystallized below the stability field of opx-pig-aug assemblage(below the PER line) upon slow cooling (orthopyroxene of the Bushveld type); (B) decomposition of pigeonite, which was crystallized at or slightly above the PER line, into orthopyroxene and augite at the PER line producing blebby augite sharing (100) with the host orthopyroxene ('decomposed pigeonite' or orthopyroxene of the Kintoki-san type); and (C) exsolution of the (001) augite from pigeonite along the stable and metastable extension of the pigeonite solvus, well below the PER line. Then the host clinohypersthene inverts isochemically to orthopyroxene (inverted pigeonite or orthopyroxene of the Stillwater type).

In addition to these three processes, a process(D), which has so far been found only in a lunar low-calcium pigeonite(2) is proposed in this paper. For convenience, we divide the pigeonite into two groups: low-calcium pigeonite with calcium content less than that of pigeonite on the PER line, and high-calcium one with that higher than this limit. Such low-calcium pigeonite, crystallized on the pigeonite solidus, may unmix augite possibly on (100) with or without the (001) augite, after it reaches the metastable extension of the pigeonite solvus. Upon slow cooling, it will unmix orthopyroxene, when it reaches immiscibility gap between low-calcium pigeonite and orthopyroxene(1,2). One grain of such unmixed pyroxene was found in breccia 14321,22 by Kushiro et al.(2). Since low-calcium pigeonites are found to be common in lunar rocks such as 12065(3), 15476(4), and 15495(5), process D should be an important one for lunar pyroxenes.

All these processes(A-D) are closely related to the PER line, and the trace of this reaction point in the system CaSiO$_3$-MgSiO$_3$-FeSiO$_3$ is an isobaric univariant line, where pigeonite, orthopyroxene and augite coexist. Therefore if composition of the pigeonite is known, the temperature range, where these processes are taking place could be estimated. On the basis of the three-pyroxene assemblage in some lavas of known crystallization temperature and on the experimental data on the join MgSiO$_3$-CaMgSi$_2$O$_6$, Ishii(6) has estimated
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the temperature of the PER line near 1 atm. Using his equation $T = 1276 - 500X_{Fe}$ (where $T$ is temperature in °C and $X_{Fe}$ is the ratio Fe/(Mg+Fe) in atom), and the compositions of pyroxenes in the literatures, the temperatures at which the pigeonites begin to crystallize, have been estimated for some lunar rocks: 14310,413 (above 1145°C); 14310,22 (ca.1100°C)(2); 68416 (above 1150°C)(7); 60025 (above 1050°C)(7); 61156 (above 1150°C)(8) and 77135 (above 1175°C)(9). It should be noted that the temperature of process B can be estimated fairly accurately because this 'decomposed pigeonite' has been understood to be produced just on or slightly above the PER line(1). The temperature of crystallization of such decomposed pigeonite from a clast of anorthositic gabbro in lunar rock 15459(10) is estimated to be above 1090°C, on the assumption that it crystallized near 1 atm.

We have surveyed the slowly cooled low-calcium pyroxenes in lunar crustal rocks and compared them with those of achondrites(11). Figure 1 is a collection of photomicrographs of additional examples of such pyroxenes with exsolution patterns produced by the processes proposed by us(1).

It is known that if the primary pigeonite reacts to orthopyroxene by intergranular recrystallization(12) such as described by Bonnichsen(13), then any previously unmixed (001) or (100) augite will be generally in random orientation with respect to the host orthopyroxene. Our X-ray study(1,10) on the typical Stillwater inverted pigeonite shows that the augite-orthopyroxene orientation is still maintained in some cases along certain direction.

Photograph d in Fig. 1 exhibits a good example of intragranular recrystallization involved in process C. The orientation of the thin (100) augite lamellae indicates that the lower one third of the grain bound by two thick lamellae seems to retain the ideal orientation between orthopyroxene and the remnant (001) augite previously exsolved from primary pigeonite as described by Poldervaart and Hess(14) for classical orthopyroxene of the Stillwater type. Whereas, in the upper two thirds of the grain mutual orientation is different from the lower region.

By more detailed works on the kinetics of the proposed processes of decomposition and inversion, one will be able to unravel the events taken place in lunar crust formation and the subsequent brecciation and metamorphic events.

REFERENCES

5. Takeda, H., Miyamoto, M. and Ishii, T., 1975, (This volume).
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Fig. 1. Photomicrographs of pyroxenes. Cross polarizers. Bars indicate 10 μ.
(a) Orthopyroxene of the Bushveld type (process A) in thin section 72255,108, a fragment of 'Civet Cat' clast in Boulder 1, Station 2, Apollo 17.
(b) Possible 'decomposed pigeonite' (Process B) in Binda (photo by A. M. Reid)
(c) Inverted pigeonite in thin section 76250,5 (Process C).
(d) Another grain of inverted pigeonite in 76250,5. Explanation in the text.