INVERTED PIGEONITES FROM A CLAST OF ROCK 15459. Hiroshi Takeda*, W. I. Ridley, Arch M. Reid and Robin Brett, NASA Manned Spacecraft Center, Houston, TX 77058 (*Present address: Mineralogical Institute, University of Tokyo, Hongo, Tokyo 113, Japan).

Exsolution patterns of most lunar pyroxenes described thus far appear to have formed in near surface lavas by relatively rapid cooling. A few slowly cooled lunar pyroxenes that may correspond to some terrestrial plutonic pyroxenes, have been found in non-mare rocks. The first inverted pigeonites in lunar samples were recognized in Apollo 14 samples[1] and studied in detail by Papike and Bence[2]. However, since these inverted pigeonites are mineral clasts in a breccia, no information on the coexisting assemblage is available.

We report here the occurrence of inverted pigeonites in a gabbroic anorthosite clast (15459,38). The highly fractured clast has a granulitic texture and contains orthopyroxene and plagioclase grains up to 1 mm in diameter. Glass is abundant in the matrix of the breccia. The orthopyroxene contains lamellae and irregular masses of augite up to 10 microns in width in two directions. The ratio of orthopyroxene to augite is about 5:1. In addition, the rock contains many other pyroxenes with either few lamellae or none at all; these are interpreted as the result of progressive annealing of augite lamellae during pyrometamorphism. Those pyroxenes without lamellae are pigeonites with approx. 15 mole % Wo. The plagioclase coexisting with the inverted pigeonite gave X-ray diffraction patterns similar to those from eucrites or from 14310 plagioclase; it shows sharp $\underline{a}$ and $\underline{b}$ type reflections and diffuse but strong $\underline{c}$ reflections. In this respect, it is different from the anorthite from anorthosite 15415[4].

Detailed electron microprobe analyses were made on the thin section of the clast (15459,125). Single crystals for X-ray diffraction studies were separated from the same clast and microprobe analyses were also made on one crystal after the X-ray study. In order to characterize the orientational relationship between augite and orthopyroxene in inverted pigeonite, typical inverted pigeonites from the Stillwater Complex, Montana and from eucrites and mesosiderites were also studied. The compositions of the 15459 inverted pigeonite, En61 Fs36 Wo3 for orthopyroxene and En43 Fs14 Wo43 for augite are similar to those of the inverted pigeonite from breccia 14082[2] and from the Stillwater intrusion.

The $\underline{h0l}$ precession photograph of the 15459 inverted pigeonite (Fig. 1a) shows large amounts of augite with common $\underline{a}$*, and many other spots diffracted from inclusions. However, no (001) augite lamellae characteristic of an inverted pigeonite were detected. Note that the intensity of the 802 reflection of the (100) augite is intermediate between those of the 17.0.2 and 18.0.2 reflections of the orthopyroxenes. A typical pattern of (100) augite exsolved from Stillwater orthopyroxene (Fig. 1b), revealed that the intensity of the 802 reflection is weaker than those of both 17.0.2 and 18.0.2. The CaO content of this orthopyroxene is 2.5 wt. % (Wo 4.4%). We therefore suggest that the 15459 pyroxenes were originally pigeonite, and the orientation of the augite lamellae is parallel to (100). This conclusion is supported by microscopic observations of significant amounts of (100) augite lamellae with respect to (001) lamellae in the thin section. The intensity of the (001)

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augite reflection in the typical inverted pigeonite of the Stillwater type is comparable to that of the 15459 inverted pigeonite but the $h0\bar{1}$ net of the augite is not contained in the $h0\bar{1}$ net of the orthopyroxene (Fig. 1c) inverted from pigeonite.

None of the typical Stillwater inverted pigeonite retains the classical orientational relationships. The orientations differ from grain to grain but some crystallographic orientations between orthopyroxene and augite is still maintained (Fig. 2). Moore County pigeonite, only partly inverted to orthopyroxene with common a^*, shows two generations of (001) augite lamellae, a classical example of the Stillwater type. However, even in this case, the c^* of the coarse lamellae is rotated 1.50° toward $+a^*$. Many iron-rich pigeonites in eucrites have exsolved almost all the calcium without being inverted[3].

A terrestrial example of an inverted pigeonite containing (100) augite lamellae was reported from the Hakone volcano[5]. This pigeonite originally grew rimming orthopyroxene, and it is suggested[5] that the (100) augite grew on the orthopyroxene core using it as a seed for epitaxial growth. Thus the 15459 orthopyroxene with the (100) augite does not appear to be an impossible orientation for inverted pigeonite.

The pyroxenes in some Apollo 16 samples have similar composition (Fe/(Fe+Mg)=0.3 to 0.4) to those of the 15459 pyroxenes, but none of them show reflections of orthopyroxene. The 65015 augite (b=8.92A, β=106°31') shows only faint reflections of pigeonite (β=108°55'). The patterns resemble those of pyroxene in most metamorphosed lunar breccias. From the intensity of the reflection it can be estimated that the 68415 pigeonite (b=8.90A, β=108°31') has exsolved about 25 percent of the augite (β=106°11') relative to that of the host pyroxene. Unlike the 15459 pyroxene, none of the Apollo 16 pyroxenes studied indicate very slow cooling.

The orientational relationship between augite lamellae originally exsolved in the pigeonite and the orthopyroxene host inverted from pigeonite, depends on many factors, such as temperature of inversion, cooling rate, and kinetics. However, it appears that the 15459 gabbroic anorthosite clast containing inverted pigeonites with the (100) augite lamellae represents further evidence that slowly cooled (plutonic?) rocks exist in the lunar highlands.

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Fig. 1(a)

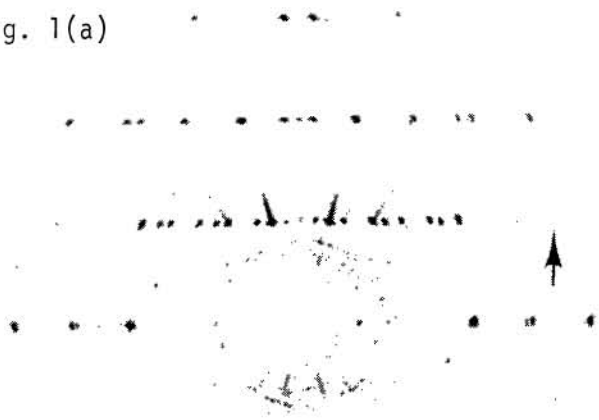

Fig. 1. Precession photographs of the ($\underline{h}0\underline{l}$) reciprocal lattice plane of orthopyroxenes. Zr-filtered Mo-radiation. The $\underline{a}$* axes are horizontal. Arrows indicate the 802 reflections of exsolved augite. (a) 15459,38 inverted pigeonite, (b) bronzite from Stillwater, and (c) inverted pigeonite (68BB1) from Stillwater.

Fig 1(b)

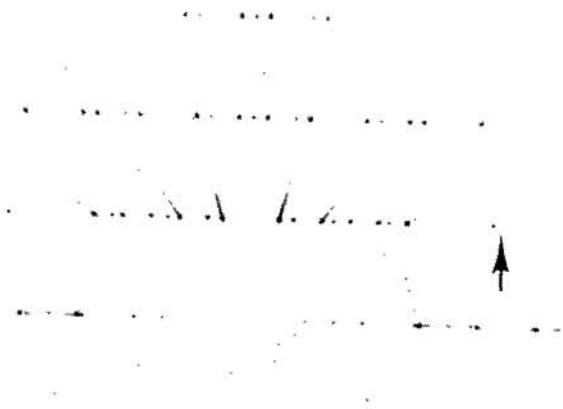

Fig 1(c)

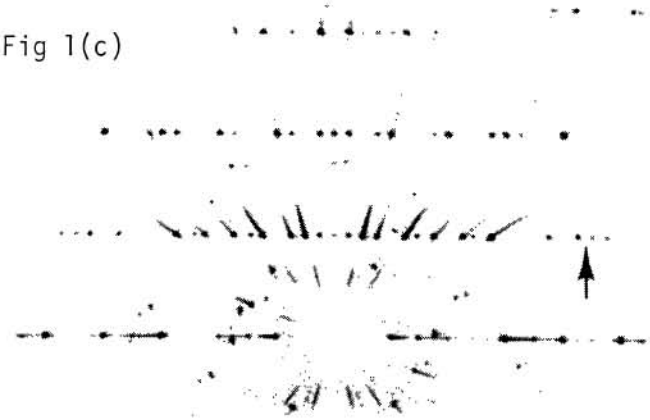

Fig. 2

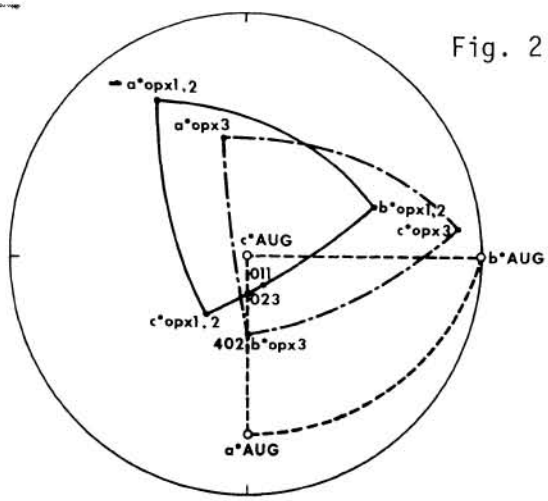

Fig. 2. Stereographic projection of the orientations of orthopyroxenes (inverted pigeonites) with respect to augite lamellae. The orientation of the augites is plotted common for all three grains.