MINERALOGICAL STUDIES OF LUNAR METEORITES AND THEIR LUNAR ANALOGS.

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The first lunar meteorite had been recovered from Yamato Mountains by JARE (Japanese Antarctic Research Expedition) party in 1979, but the sample (Yamato 791197) was kept in refrigerated stock room at National Institute of Polar Research in Tokyo, Japan before it was characterized. Meanwhile, a small unusual meteorite collected from Allan Hills, Antarctica (ALHA81005), by the U.S. party, was recognized as a 'lunar meteorite', a meteorite brought from the moon (e.g. 1). Now all lunar and planetary scientists and meteoriticists believe that ALH81005 is of lunar origin (1). Subsequently, Yamato 791197 and another sample recovered in 1982, Yamato 82192 have been described as second and third lunar meteorites by Yanai and Kojima (2) and by Yanai et al. (3). All these samples are solidified soils of lunar highland, what lunar scientists called regolith breccia. The closest precedents have been proposed to be the Apollo-16 and Lunar-20 regolith (1).

In the previous studies on lunar meteorites, scientists have made effort to prove they are of lunar origin. No extensive study has been undertaken to find and compare them with closest lunar analogs of lunar meteorites among lunar samples collected by the Apollo missions. In order to locate the impact location of the lunar meteorites, or to find that all lunar meteorites are derived from the same meteorite impacts on the lunar surface, or that they are pieces of a single meteorite fall over the Antarctic continents, we have to study regolith breccias recovered by the Apollo missions. This kind of lunar rocks have been very poorly characterized up to date, because many lunar scientists are more interested in pristine, crystalline rocks which formed primary lunar crust in the earliest history of the solar system.

Comparisons of three lunar meteorites are also extremely important, because they inform us about portions of the Moon's crust never sampled by either the U.S. Apollo or the Soviet Lunar missions. Those missions provided samples from only a tiny region near the center of the near side, comprising about 4.7% of the entire lunar surface (personal communication, Dr. P. H. Warren). Thus, the probability that meteorite such as Y791197 originated from outside of the Apollo-Lunar sampling area is about 95%; and we can be virtually certain that careful study will provide important new clues to the Moon's composition, origin and evolution. If all three lunar meteorites were different, each sample would be worth while one lunar mission.

In 1979, we studied an Apollo 16 regolith breccia, 60016,97, which is one of the few highland regolith breccias studied by mineralogists and petrologists. We investigated, chemical compositions and textures of a mineral called pyroxene, and reported that it contained almost all types of pyroxenes known in lunar highland rocks. Lunar meteorite, ALH81005 also show similar trends. Because there was more glass in the matrix of ALH 81005 than 60016, we investigated another samples which resembles more lunar meteorites. NASA scientists informed us that 60019 may be a better candidate to be studied (Dr. D. Mckay, personal communication, 1984). We also investigated ALH81005 by analytical transmission electron microscope (ATEM), which is capable of analysing the chemical composition, texture and atomic arrangements of a region as small as 800 A. We tried to see whether the glass matrix was produced by an impact which produced this breccia or by an impact which excavated this sample to leave the Moon to come to Earth.

Yamato 791197 has been briefly described by Yanai and Kojima (2). Now, international consortium studies on this lunar meteorite are underway. The first result will be presented at the 10th Anniversary Symporsium on the Antarctic Meteorites, which will be held at the end of March, 1985, in Tokyo. Only preliminary comparison will be made.

Among the polished thin sections we examined, large areas of lunar regolith breccias 60019, 14, 75, 80 and 91 are similar to lunar meteorites ALH81005 and Y791197. They are characterized by brown glass matrix, varieties of lithic and mineral fragments and glassy components of lunar highland regoliths. A lunar light matrix breccia, 60016 has smaller amounts of such glass matrices than 60019, but the clast materials are similar. Because smaller amounts of glass will help us to study clast materials, we investigated 60016, extensively.

60016,97 consists of the fine-grained comminuted constituents of the regolith such as rock, mineral and glass fragments, glass spherules with mineral fragments, glassy agglutinates. These are agglomerated to a coherent rock by sintering of hot glass or by shock lithification. Some portions of the glass matrix clasts with plagioclase and mafic mineral fragments are more similar to the lunar meteorite than the over all PTS. Large lithic clasts with mafic minerals are less abundant than ALHA81005. Abundance of large clasts in ALH81005 is also higher than that of Y791197 (2). A clast with hedenbergite (Hd) and Plagioclase in Y791197 (2) (4) should be compared with Hd in 14321, 993 (5), and spinel-plagioclase clast with spinel troctolite. These are uncommon rock types on the Moon.

The glass bulk compositions of the breccia matrices and matrices of glassy clasts of 60016 and ALH81005 were obtained by a broad beam (40 microns) microprobe analyses (average of 5 to 10 points) and are plotted in Al_2O_3 vs. CaO (wt. %) diagram and in the Silica-Olivine-Plagioclase pseudo-ternary system. Two groups distribute in a similar region. Because glasses were produced by heating of fine-grained fragmental materials of lunar highland rocks, similarity in glass compositions suggests that they were derived from similar source materials.

Pyroxene is a silicate mineral, with various amounts of calcium, magnesium and iron. Their compositional variations are plotted in so called "pyroxene quadrilateral, which is a portion of triangle with these three components at the corners. This mineral is probably a mineral which gives us the most valuable information on the components of lunar highland regoliths, because their compositions and inversion and exsolution textures are often unique signatures of certain rock types.

The chemical compositions of all pyroxene grains analysed by electron microprobe are plotted in a pyroxene quadrilateral and were compared previously with those of pyroxenes in nonmare pristine rocks complied by Ryder and Norman (6). They are also compared with those of ALH81005 (7) and Y791197 (2). The compositions are distributed over a wide range in the quadrilateral, covering almost all known pyroxenes in nonmare pristine rocks. Pyroxenes of rapidly cooled KREEP basalts and of the most Mg-rich troctolites are not present. The olivine compositions of 60016 studied previously (6) also show that they represent those of the above rock type.

The distribution of the plagioclase compositions of large fragments in the matrix of the entire PTS, fragments in the glassy clasts of 60016 are also similar but some plagioclases in glassy clasts show higher potassium contents. The number of ALH81005 plagioclase is too small to compare them with 60016, but the variation within 60016 is larger than within ALH81005.

The study of glass in the lunar meteorites suggests that the glass was not produced by a meteorite impact which excavated tha mass into the orbit towards the Earth. The glass had been devitrified on the lunar surface before the excavation, and new glass was not produced by the last impact. This conclusion was obtained by the following facts.

The ATEM study of suevite-like glass veins in ALH81005, revealed that apparently glass-like materials are fine recrystallized plagioclase. The plagioclase show a texture called twinning. The fact indicates that the glass is devitrified in ATEM scale. No true glass was found in portions of ALH81005 we examined. Olivine and pyroxene crystals distribute as islands, showig poikilitic anorthosite-like texture. The size of the olivine crystal is about a few microns. Some pyroxenes show fine exsolution texture, indicating spinodal decomposition in the Ca-rich areas. The tweed-like texture turns into exsolution by coasening of certain lamellae. This indicates rapid cooling within a surface regolith breccia. Some of the features observed in ALH81005 are similar to those of breccias observed by Christie et al.(8).

The compositional and textural variation of lithic clasts and pyroxene types in 60016 and lunar meteorites is larger than in all other lunar breccia types. This variation may be due to the intense impact gardening of the regolith materials. In order to locate the impact location of the lunar meteorites or to find all lunar meteorites are derived from the same impact or are pieces of a single fall, we have to study more lunar regolith breccias, employing the exsolution-inversion textures and the compositions of pyroxene as signature of the nonmare pristine rocks. Such approach has been successful in studying howardites and polymict eucrites (9). Our study presented here is a first step to do such investigation. Our experience with Apollo lunar samples has taught us that data obtained on different samples from a single stone are often not suitable for comparison, because most highland rocks are heterogeneous mixtures of fragments of older rocks. Discoveries of three lunar rocks may activate renewed interests in lunar regolith breccias, which have not been studied extensively in the last fifteen years.

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