ELECTRON PETROGRAPHY OF APOLLO 14 AND 15 SAMPLES

by

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Comparative optical and high-voltage (up to 1 mev) electron petrographic analyses have been conducted on basalt and breccia samples from Apollo 14 and anorthosite from Apollo 15. The analyses were complemented by localised chemical analysis on the same specimen areas by electron microprobe and scanning microscopy techniques. We report here the preliminary results for four samples - including each of the above types.

Sample 14310/159 (basalt):

The optical structure in thin sections of this crystalline rock exhibited principally plagioclase and pyroxene with an intersertal texture. Only minor amounts of opaque phases are present. The pyroxene occurs as both ortho and clino-pyroxene and zoning from the former to the latter is apparent. In the electron microscope, the density of dislocations in both the plagioclase and pyroxene is comparable to that we observed earlier in the igneous rocks from Apollo 11 and 12 [1,2]. Fine-scale exsolution is present in the pyroxene. Under appropriate electron diffraction conditions, antiphase domain boundaries (APB's) can be imaged in the same areas and are found to be coarser in scale than the exsolution. In the plagioclase also, a fine-scale exsolution has been identified. These substructural features indicate that 14310/159 resembles the mare basalt samples examined from the earlier landings in that it exhibits little or no evidence of mechanical deformation. The presence of exsolution in the plagioclase and its absence in Apollo 11 and 12 basaltic plagioclases indicates a slower cooling history, or re-heating, for rock 14310.

Sample 14321/42 (breccia):

This sample is seen in optical thin sections to contain fragments of igneous rocks, previously consolidated breccia and individual mineral crystals ranging from centimetre dimensions to the limit of optical resolution. The finest material in the matrix surrounding these features is optically isotropic, denoting that it is either amorphous or composed of submicroscopic crystallites. Shock-induced deformation features (twinning and bending in plagioclase and pyroxene) are apparent,
with considerable evidence of local annealing or recovery, notably near the outer surface of large mineral fragments, but also in the interior as indicated by partially resorbed twins. In electron transmission, the optically isotropic matrix could be resolved and was found to consist of a heterogeneous mixture of pyroxene and plagioclase crystallites containing a small amount (of the order of 10%) of glass. Virtually no porosity was present. The substructural features indicative of deformation are likewise distributed extremely heterogeneously, with regions of very heavy deformation containing recrystallization nuclei existing adjacent to largely recovered structures. Deformation/recrystallization processes appear to have been particularly active at grain contacts both in the matrix and at the matrix-clast interfaces. Mechanical twins, indicative of shock deformation, are also present. In addition, plagioclase in both the clasts and the matrix exhibits more extensive fine-scale exsolution than in 14310. The pyroxenes showed a well-developed APB structure. Both of these features are indicative of reheating following deformation. We conclude that in this breccia sample cohesion was achieved by deformation and subsequent or simultaneous recrystallization caused by the high pressures and temperatures associated with impact events on the lunar surface. This process we termed "shock sintering" [3]. The glass present in the matrix was probably also formed by the shock events, but is not thought to play a major role in the consolidation.

Sample 14161/38 (coarse fines): Two specimens from this sample were examined in detail as they differed significantly from the breccia 14321. Sample 14161/38/4 is a vesicular brown glass containing angular mineral fragments. In the electron microscope tabular, micron-size plagioclase crystals produced by devitrification were common. Fine metallic particles observed throughout the glass and mineral fragments were shown by electron diffraction to be iron-nickel alloys in the f.c.c. phase field. Sample 14161/38/7 consists of angular mineral fragments with about 10% of vesicular glass. The glass, which contains abundant fine (-100Å) metal spherules, welded all the mineral fragments and the glass-mineral boundaries appeared gradational rather than sharp. A puzzling feature of this sample is the high density of particle tracks in many mineral fragments at depths up to 1 mm. from the surface of the sample. The track densities are in the range of 3 to 7×10^10 per cm^2. We consider that the tracks must have formed in the fragments before consolidation. It is difficult to understand how this glass welded breccia was formed without annealing the particle tracks.

Sample 15415 (anorthite): Only plagioclase fragments (less than 1 mm) from this rock have been available to us to date. Using a new technique, the fragments have been mounted and thin-sectioned.
Optically the fragments were variably twinned and appeared to be homogeneous chemically and lacking in evidence of deformation. Electron probe analysis indicated a composition of An$_{93}$-An$_{95}$. The electron microscopy showed the dislocation density to be distinctly less than igneous rocks of Apollo 11, 12 and 14. No other evidence of deformation was present, although abundant submicroscopic growth twins were evident in some fragments. The most striking substructural features were easily resolved "c"-type domain boundaries, much larger than "c"-type domains in other more albitic lunar plagioclase. The large size of these domains is ascribed mainly to the high An content. Inclusions of calcic augite are present in the plagioclase on a microscopic scale and submicroscopic precipitates of clinopyroxene have been observed on plagioclase twin-boundaries.

REFERENCES