A MINERALOGICAL STUDY OF ROCK 70017, AN ILMENITE-RICH BASALT, BY HIGH VOLTAGE ELECTRON MICROSCOPY

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High voltage (800-1000kv) transmission electron microscopy (HVEM) in conjunction with electron-diffraction, microprobe and optical petrography have been conducted on an ilmenite-rich basalt, 70017. Our aim has been to elucidate its thermal and mechanical histories by observing the substructures produced during phase transformations, growth, and mechanical deformation and by comparing these with synthetic analogs when available of some of the minerals. Preliminary results are reported in this paper.

Rock 70017 is a hypidiomorphic granular basalt containing large clinopyroxenes with included armalcolite, ilmenite and olivine; lath-shaped to equi-granular plagioclase with included euhedral olivine, ilmenite and clinopyroxene; a large (1mm) olivine embayed by clinopyroxene; aggregates of interstitial cristobalite; 1mm long ilmenites, some arranged in layers and always with exsolved rutile and spinel; and metallic Fe, troilite, and a fine crystal-rich mesostasis. Electron microscopic observations of each of the principal mineral phases follows: Clinopyroxenes - Irregular sector zoning, rotation of subgrains about $[0\bar{1}0]$ and high Al and Ti contents characterize the clinopyroxenes which have augite cores. Near the centers of individual augites, the sector boundaries are typically crystallographic and show no misorientation; these invariably change to a low angle boundary or boundaries (fig. 1), especially when encountering an armalcolite inclusion. High angle boundaries (fig. 2) are common as well where rapid cooling promoted growth of other orientations. Both (001) and (100) pigeonite exsolution lamellae have nucleated on the boundaries, the area of fig. 1 having a composition of Fs_{17}, Wo_{33}. The pigeonite lamellae have as expected, transformed from $C2/c$ to $P2_1/c$ symmetry as seen by the antiphase domains (APD's) of fig. 3. Plagioclase - APD's, imaged in fig. 4, from the larger plagioclases which range from An_{84} to An_{78} are caused by the $C\bar{1} \rightarrow I\bar{1}$ transformation and are uniform in size, ~1500Å. No exsolution has as yet been found in the plagioclase. APD size in a synthetic plagioclase, An_{78-80}, grown by G. Lofgren was found to be ~300Å and can be compared to that seen in the compositionally similar plagioclase of 70017. The synthetic plagioclase was crystallized at 1100°C and cooled through the transformation at 2°C/hour. Since the APD's of 70017 are ~5x larger, it must have cooled through the $C\bar{1} \rightarrow I\bar{1}$ transformation temperature at a slower rate. Cristobalite - 0.5mm size cristobalites occur between grains and are rarely included in plagioclase. Fig. 5 shows that they contain stacking faults (S), twin boundaries (T), and boundaries separating enantiomorphic parallel axis twins (d). The twins originated during the $\beta \rightarrow \alpha$ transformation at 268°C. Rutile and spinel are present, probably as exsolution products from ilmenite supersaturated with Mg, Ti and Al (abundant textural evidence indicates that ilmenite replaced armalcolite). The observed microstructures in rutile (fig. 6) are similar to those found in oxygen-deficient, nonstoichiometric rutile (1), the oxygen deficiency having been accommodated by the production of planar defects.

Some Similiarities and Differences Between Apollo 11 and Apollo 17 Ilmenite-Rich Basalts - Although the optical structure (sectoral zoning, radiating and rotated subgrains) of the Apollo 11 and 17 mare basalts clinopyroxenes is similar, the suboptical structure is not. The augites of 10029 exhibit irregular blocky subgrains, 2-10μm in size having misorientations of 1 to 5° and the exsolution commonly changed from the (100) type to the (001) type across the low-angle subgrain boundaries (2). This contrasts with the continuation of the (001) exsolution across the low-angle boundaries in Fig. 1. The exsolved pigeonite APD size compares well -- 500A-2000A in 70017 and 500A-1000A in 10029. The b-type APD's imaged in both 70017 and 10029 are are 1500A and 5000-10,000A respectively but the plagioclase of 10029 is more anorthitic, having diffuse "c" reflections; thus the sizes cannot be compared unambiguiously. No exsolution in plagioclase was found in either rock.

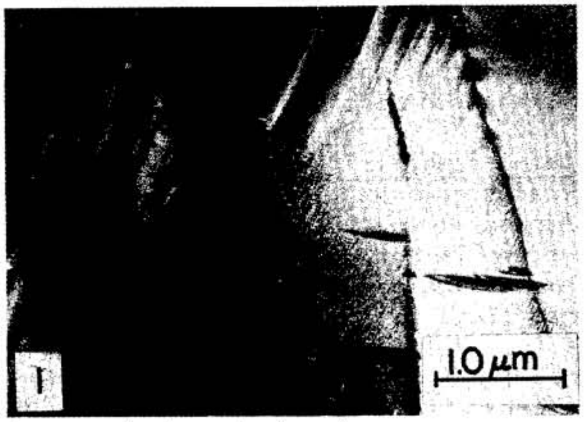
Conclusions - Rock 70017 has undergone a single-stage cooling history. No evidence of recovery of the pyroxene defect structure nor evidence of two-stage exsolution was detected. The plagioclase APD size by comparison with a synthetic example, indicates a subsolidus cooling rate slower than 2°C/hour.

(1) Anderson, J.S. and Tilley, R.J.D. (1970) Crystallographic Shear in Oxygen-Deficient Rutile: An Electron Microscope Study. Jour. Solid State Chem., 2, pp. 472-482.

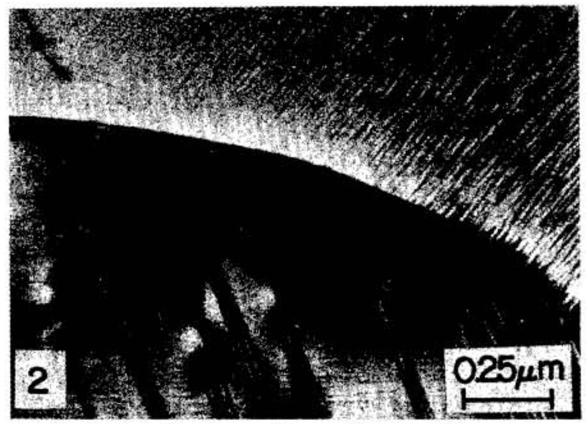
(2) Radcliffe, S.V., A.H.Heuer, R.M.Fisher, J.M.Christie and D.T.Griggs, (1970) High Voltage (800 kV) Electron Petrography of Type B Rock From Apollo 11. Geochim. et Cosmochim. Acta. Suppl. I, Vol. 1, pp. 731-748.

HIGH VOLTAGE ELECTRON MICROSCOPY - 70017

Nord, G.L. et al.



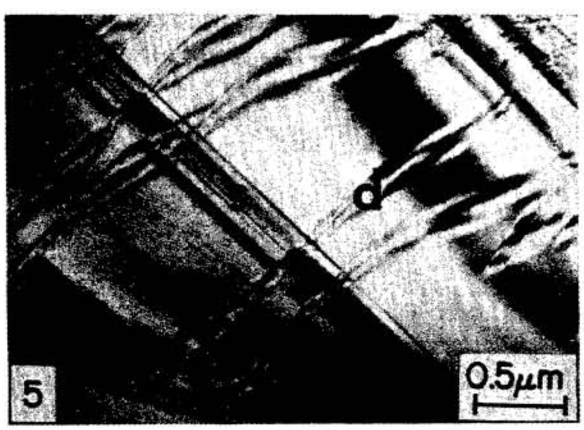
Low angle boundaries in augite.



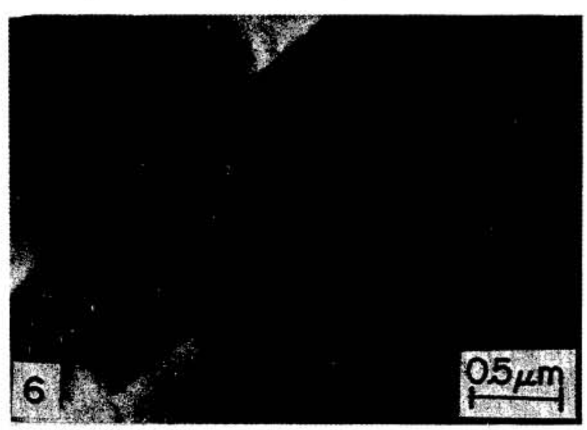
High angle boundary in augite.

M-T APB's in pigeonite.

b-type APB's in plagioclase.



Twins (t,d), stacking faults (s), in cristobalite.



Rutile lamellae in ilmenite.