THERMAL AND MECHANICAL HISTORY OF GRANULATED NORITE AND PYROXENE ANORTHOSITE CLASTS IN BRECCIA 73255: G.L. Nord, Jr. and J.J. McGee, U.S. Geological Survey, 959 National Center, Reston, VA 22092.

Two ANT suite clasts from light-gray breccia 73255 have been examined by transmission electron microscopy (TEM). Both clasts are relatively coarse grained (0.3-2mm) and retain textures that suggest an igneous origin; complete petrographic descriptions are given by James and McGee (1). The clasts are subjects of detailed chemical and isotopic analysis by the 73255 consortium members because it appears from petrographic studies (1) that they have had simple histories and may therefore retain easily interpretable isotopic and compositional data.

Pyroxene anorthosite 73255,27,80

Light optical observations. The major minerals are plagioclase ($An_{93.1}Ab_{6.2}Or_{0.7}$) and orthopyroxene ($En_{72.9}Fs_{24.9}Wo_{2.2}$) (fig. 1). Plagioclase contains abundant primary inclusions of K-feldspar, silica phases and oxides whereas orthopyroxene contains abundant inclusions of ilmenite and chromite which are concentrated within narrow continuous augite exsolution lamellae. Optical evidence for deformation in plagioclase consists of deformation lamellae and a fine domain microstructure which exhibits aggregate extinction suggesting a strong shock event but not to the point of fusion. In orthopyroxene, weak undulatory extinction is the only light optical evidence for deformation.

TEM observations. The microstructure in plagioclase is complex and variable (fig. 2), however, within the area of the primary single crystal, the original crystallographic orientation is retained to within a few degrees rotation. The most abundant microstructures are wide deformation lamellae that are not twins but have a slightly different orientation than the host (fig. 2). Within both the lamellae and host is a high density of narrow albite and pericline twins. Some of the plagioclase was converted to glass by the shock event. Glass lamellae in both the host plagioclase and in K-feldspar inclusions have been observed as well as circular microstructures (fig. 2) which are common crystallization textures of shock-produced plagioclase glass (2). Evidence for very minor subsequent recovery of the shock deformation microstructure can also be seen in figure 2 as a dislocation-free area. Orthopyroxene contains widely separated augite lamellae and a moderate density of deformation-induced (100) stacking faults (fig. 3); no evidence for recovery or recrystallization was observed in this mineral.

Thermal and shock history. The pyroxene anorthosite clast appears to have cooled slowly from the time of primary crystallization, at least slowly enough for the exsolution of narrow augite lamellae from orthopyroxene. There is evidence that at least one shock event affected the clast with maximum shock pressures in the 100-200 kbar range (3) and a minimum temperature spike >840°C (the anorthite glass transition temperature). Cooling from the shock-induced temperature rise was slow enough for almost complete devitrification of the shock-produced glass but rapid enough for no significant recovery or recrystallization of the shocked minerals. Diffusion distances during and after the shock event therefore were probably on the order of a few hundred angstroms. No evidence for reheating after this event was observed.

Granulated norite 73255,27,45

Light optical observations. Major minerals in this clast are orthopyroxene ($En_{71}Fs_{25}Wo_{4}$), plagioclase ($An_{88.6}Ab_{11.0}Or_{0.4}$) and augite (fig. 4). The clast is strongly granulated and has high porosity and friability. Primary features in these minerals are widely spaced narrow augite lamellae and oxide inclusions in orthopyroxene and (001) growth twins and "(001)" and "(100)" exsolution lamellae of low calcium pyroxene in augite. Plagioclase is featureless. Evidence for deformation in these minerals consists of local weak undulatory extinction in orthopyroxene.

TEM observations. Plagioclase grains examined are devoid of defects, having a defect density no greater than that found in plagioclase from mare basalts (4). Augite contains primary exsolution lamellae. Coarse lamellae along "(100)" consist of an orthopyroxene-pigeonite intergrowth and along "(001)" consist of pigeonite only with abundant (100) stacking faults. Between the two sets of coarse lamellae are narrow zig-zag-shaped pigeonite lamellae that have orientations near (001) and (100) (fig. 5). These latter features formed after the coarse exsolution lamellae and at a lower temperature. Narrow shock-induced twins along (100) cut all the exsolution lamellae and are the only evidence for deformation in augite. No basal twins were observed in TEM or optically. Primary exsolution features observed in orthopyroxene include narrow augite lamellae and a moderate density of 1-unit cell wide Guinier-Preston zones. Deformation-induced features in orthopyroxene consist of abundant (100) stacking faults (fig. 6) in a density similar to that in the orthopyroxene from the pyroxene anorthosite (compare fig. 3 with fig. 6). No evidence was found for recovery or recrystallization in any of the three phases examined in the granulated norite clast.

Thermal and shock history. The primary exsolution features in both augite and orthopyroxene are similar to those found in these minerals from the Bushveld igneous complex (5,6) and the postcrystallization cooling rates may be comparable. After cooling from crystallization a shock event produced (100) twins in augite and (100) faults in orthopyroxene. Experimental shock studies on diopside indicate (001) twins are produced at shock pressures of >50 kbars (7). As only (100) twins have been observed the shock pressure was <50 kbars. There is no evidence to place a limit on the temperature spike associated with the shock event. The absence of any recrystallization or recovery features in the most strongly deformed mineral, orthopyroxene, suggests that the spike was <1000°C and subsequent cooling was rapid with no significant reheating.

Conclusions

TEM and light optical observations are consistent with a history of igneous crystallization followed by a period of cooling for both the pyroxene anorthosite and granulated norite clasts. Similarities of the subsolidus exsolution microstructures in augite and orthopyroxene with those of the Bushveld complex minerals suggest comparable cooling rates. Observations on the shock-induced microstructures in both clasts are consistent with each clast being affected by a single shock event although it is not known if the shock event was simultaneous with the breccia-forming event or preceded it by some appreciable time interval. The pyroxene anorthosite was strongly shocked to pressures in the range 100-200kb and heated to >840°C, whereas the granulated norite was weakly shocked to pressures below 50 kb. The temperature rise associated with the shock deformation of each clast dropped rapidly and no microstructure indicative of any subsequent reheating was observed.

References: (1) James, O.B. and McGee, J.J., this volume; (2) Nord, Jr., G.L., et al., (1977) THE MOON 17, 217-231; (3) Christie, J.M., et al. (1973) Proc. 4th Lunar Sci. Conf., p. 365-382; (4) Nord, G.L., Jr. et al. (1973) Proc. 4th Lunar Sci. Conf., p. 953-970; (5) Robinson, P. et al.; (6) Champness, P.E. and Lorimer, G.W. (1974) Phil. Mag. 30, 357-365; (7) Hornemann, U. and Müller, W.F. (1971) N. Jahr. für Mineral. Monatshefte 6, p. 247-256.

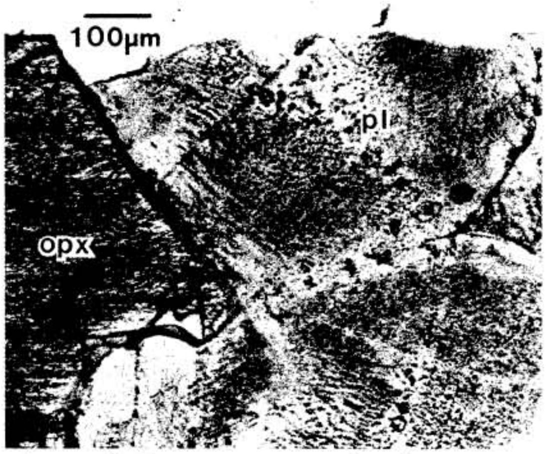

Figure 1 Pyroxene anorthosite 73255,27,80 containing orthopyroxene (opx) and plagioclase (pl).

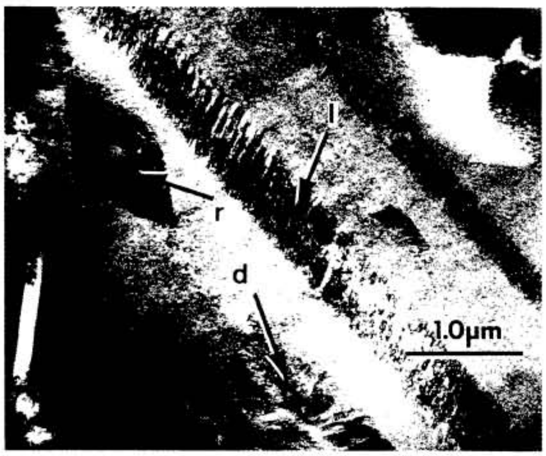

Figure 2 Anorthite with deformation lamellae (l) devitrification textures (d) and recovered area (r). B.F. electron micrograph, 200kV.

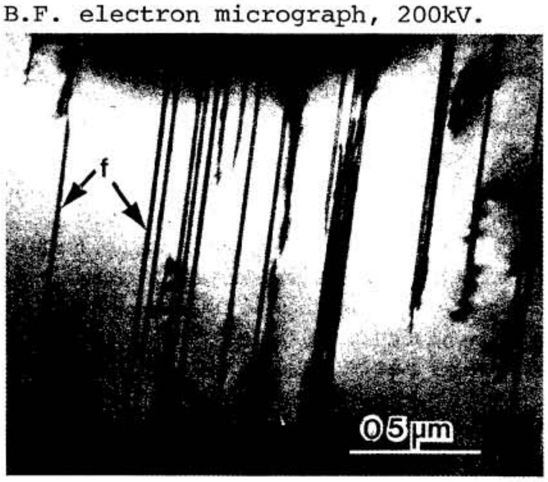

Figure 3 Orthopyroxene with (100) stacking faults (f) and dislocations B.F. electron micrograph, 200 kV.

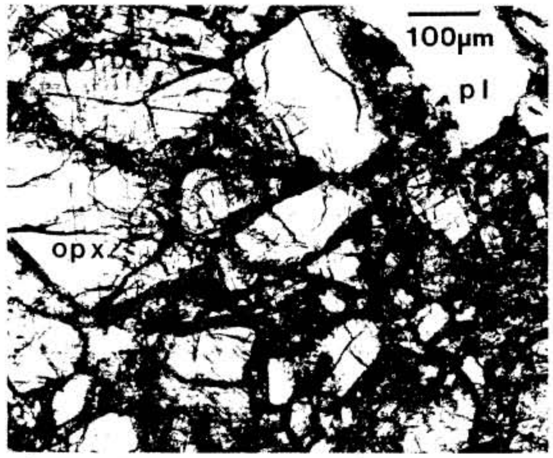

Figure 4 Granulated norite 73255,27,45 containing orthopyroxene (opx) and plagioclase (pl).

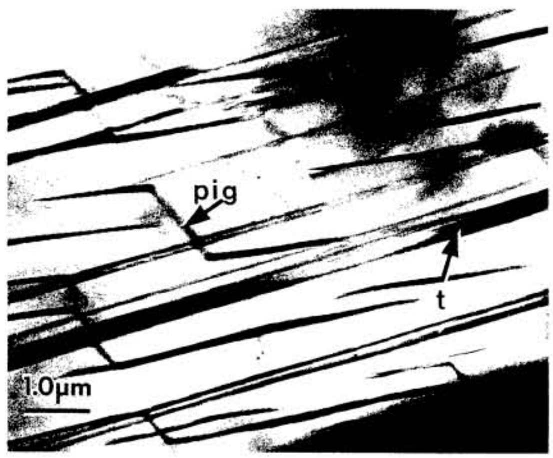

Figure 5 Augite with zig-zag pigeonite lamellae (pig) and (100) twins (t). B.F. electron micrograph, 200kV.

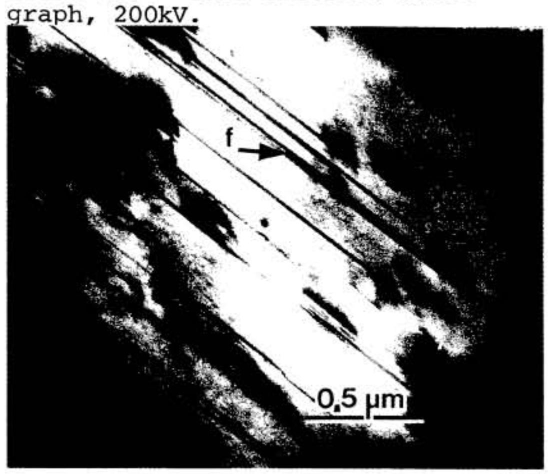

Figure 6 Orthopyroxene with (100) stacking faults (f) and dislocations B.F. electron micrograph, 200 kV.