THE NATURE AND CONDITIONS OF FORMATION OF GRANULITE FACIES XENOLITHS FROM THE MATSOKU KIMBERLITE PIPE, LESOTHO

P.M. Jackson (Grant Institute of Geology, Edinburgh University, West Mains Road, Edinburgh EH9 3JW, Scotland)
B. Harte (Grant Institute of Geology, Edinburgh University, West Mains Road, Edinburgh EH9 3JW, Scotland)

Introduction and Petrology

Granulite facies xenoliths in kimberlite provide information regarding the upper part of the lithosphere at the time of kimberlite eruption and their conditions of formation may be explored using various geothermometers and geobarometers.

The granulite facies xenoliths from the Matsoku kimberlite pipe show the assemblages:

(a) garnet+clinopyroxene±rutile±amphibole±biotite±apatite
(b) garnet+orthopyroxene±clinopyroxene+rutile
(c) garnet+clinopyroxene+plagioclase/scapolite±rutile± quartz±biotite± amphibole
(d) garnet+clinopyroxene+plagioclase/scapolite+rutile+quartz+kyanite+biotite
(e) garnet+plagioclase/scapolite+kyanite+sphene
(f) garnet+orthopyroxene+amphibole+biotite+rutile

The plagioclase is oligoclase to andesine in composition, scapolites are of mizzonitic composition, amphiboles are edenitic and pargasitic hornblendes and biotite is dominantly phlogopitic. Coexisting garnets and pyroxenes are shown in the Ca-Mg-(Fe+Mn) projection in fig. 1. Clinopyroxenes have high molecular proportions of jadeite (10.00-32.9%) and relatively low molecular proportions of tschermakite ($<12\%$). Al_2O_3 in orthopyroxenes ranges from 1.40 to 2.58 wt.%.

Average grain sizes range from 1 to 2 mm, textures appear granoblastic polygonal and are occasionally seriate. Mineral grains, which are largely unstrained, show some alteration along their boundaries and plagioclase is often completely altered. Where kyanite is present in rocks of assemblage (d) it typically occurs as needles which form radiating sheafs in association with quartz which are located at plagioclase-garnet grain boundaries. Assemblage (e) is found in only one xenolith in which kyanite predominantly occurs as stumpy prismatic crystals which are present as both inclusions in garnet and as independent matrix grains. In addition this assemblage shows some of the acicular sheaf-like kyanite noted for assemblage (d). The acicular kyanite found in these nodules forms a notable departure from the general characteristic of extreme textural equilibrium shown by the xenoliths and indicates the reaction

$$3 \text{ anorthite} \longrightarrow \text{grossular} + 2 \text{ kyanite} + \text{quartz} \qquad \text{——— (1)}$$

The nodules frequently show modal banding on a scale of up to 1 cm. In this gneissose structure the layers usually show diffuse margins but an extremely sharp contact separates orthopyroxene and plagioclase bearing layers in the one specimen where both minerals are present. This feature conforms with the lack of association of orthopyroxene and plagioclase in the xenoliths and indicates relatively high pressure granulite facies conditions bracketed by orthopyroxene and plagioclase instability and the lower pressure limit of the eclogite facies.

Conditions of Formation

The distribution of Fe and Mg between adjacent garnet and clinopyroxene crystals for the assemblages (a) to (d) is plotted in fig. 2, and shows a very restricted range in Kd, around 4.13, which suggests closely similar temperatures of formation for all the specimens analysed. The formation of all the xenoliths under similar conditions is supported in fig. 1 by the generally compatible arrangement of tie lines.

Fig. 2 includes data from specimens displaying reaction (1) and implies that no major change in Fe/Mg distribution between garnet and clinopyroxene occurred in association with the kyanite reaction, although it is possible that the slight tendency for lower Kd values in rim rather than core compositions in fig. 2 is associated with this reaction. It must be noted that this reaction is more sensitive to pressure than to temperature (Hariya and Kennedy 1968). The pressures and temperatures of equilibration calculated for co-existing pyroxenes and garnet in assemblage (b) following Wood and Banno (1973) and Wood (1974) are 839°C and 32 kilobars for adjacent rim compositions. At these temperatures the pyroxene solvus is only slightly temperature sensitive and this in conjunction with the uncertainties in pressure estimates (Howells and O'Hara 1977) demands caution in accepting the above P-T values. Use of the Raheim and Green (1974) geothermometer in conjunction with the data of fig. 2 yields temperatures in the range 729-767°C at an assumed pressure of 10 kbar, and from 872-915°C for an assumed pressure of 30 kbar.

Another approach to the determination of pressure may be made by using reaction (1) assuming only minor changes from pre-reaction pressure values and a temperature based on Fe/Mg distribution between garnet and clinopyroxene rims. Employing a temperature of 839°C in conjunction with the method of Schmidt and Wood (1976) yields pressures of 21.5 kbar for two rocks containing assemblage (d). The same calculation performed using data wholly from Robie and Waldbaum (1968) yields pressures of 17 kbar. The result is clearly dependent on the exact entropy and enthalpy values adopted.

These data indicate that the Matsoku granulite suite may have equilibrated at a depth below the present day Moho in southern Africa which has been located at approximately 37 kilometers (Hales and Sacks 1959). The crust-mantle stratigraphic cross-section for Lesotho may have been similar to that envisaged by Brookins and Meyer (1974) for Kansas, USA where granulite facies xenoliths are believed to straddle the Moho. If the occurrence of granulites to depths of 70 kms is substantiated then the apparent gap in lithospheric stratigraphy between the Moho and the shallowest depths recorded by garnet lherzolite nodules in Lesotho kimberlites would be reduced. The presence of plagioclase granulites to such depths would also necessitate a recalculation of the geotherm for the Lesotho area.

References

Brookins D.G. & Meyer H.O.A. (1974) Geophys. Res. Lett. 1, 269-272. Hales A.L. & Sacks I.S. (1959) Geophys. J. Roy. Astron. Soc. 2, 15-33. Hariya Y. & Kennedy G.C. (1968) Amer. J. Sci. 266, 193-203. Howells S. & O'Hara M.J. (1977) Phil. Trans. R. Soc. Ser. B (in press). Robie R.A. & Waldbaum D.R. (1968) U.S. Geol. Surv. Bull. 1259. Wood B.J. (1974) Contr. Min. Pet. 46, 1-15. Wood B.J. & Banno S. (1973) Contr. Min. Pet. 42, 109-124. Schmidt R. & Wood B.J. (1976) Contr. Min. Pet. 54, 255-279.

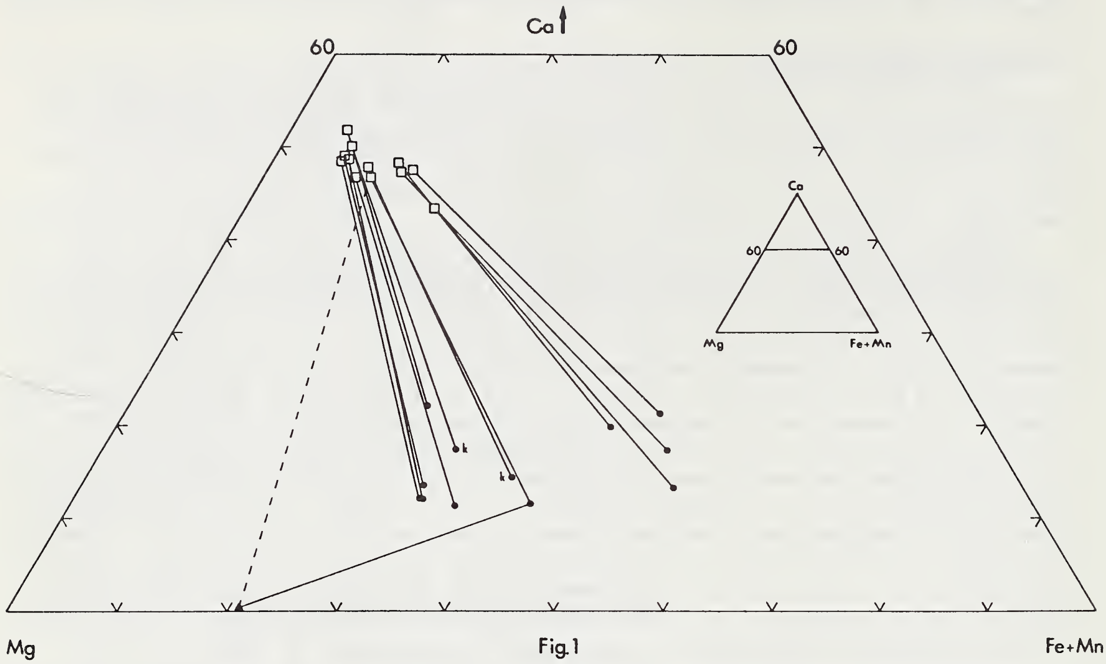

Fig. 1. Ca-Mg-(Fe+Mn) projection showing garnets (filled circles) clinopyroxenes (squares) and orthopyroxene (triangle). Coexisting phases for the same assemblage are connected by tie lines. Kyanite bearing assemblages marked k.

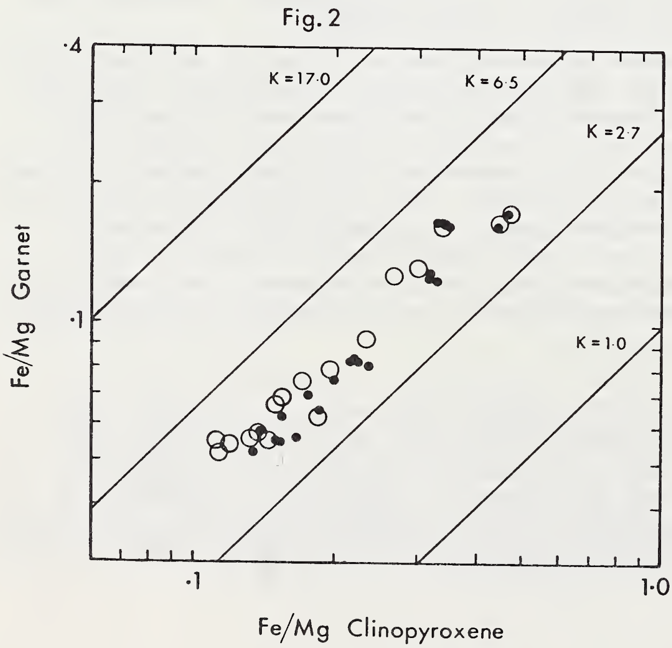

Fig. 2. (Fe/Mg)gt vs (Fe/Mg)cpx plotted for coexisting cores (filled circles) and rims (open circles).