THE CHEMISTRY AND MINERALOGY OF TWO ECLOGITES FROM THE ROBERTS VICTOR PIPE, ORANGE FREE STATE, SOUTH AFRICA

By

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Microprobe and bulk chemical analyses are presented for two eclogites. Both contain relatively Ca-rich garnets (25-45% grossular) and Na-rich (approximately 50% jadeite), tschermakite poor (less than 1% $Al^{[4]}$) clinopyroxenes which have however about 30% excess $Al^{[6]}$.

The first eclogite (6913) is foliated and layered. Garnet-clinopyroxene pairs, identified by numbers in Figs. 1 and 2, were analysed across the layering. The layers consist of garnet-clinopyroxene (analyses 1-5), a 10 mm thick layer of garnet-clinopyroxene-(kyanite) (analyses 6-7) in which almost all garnet forms overgrowths on kyanite in a fashion similar to the diablastic intergrowths of Sobolev et al. (1968), and garnet-clinopyroxene-kyanite. In the latter layer, only one thin overgrowth rim was seen (analysis 9A). Otherwise the three phases seem to be in mutual equilibrium (analyses 8, 9B, 10-12).

The second eclogite (6914) contains garnet, clinopyroxene and apparently primary graphite. The minerals of 6914 have lower Fe/Mg ratios than those of 6913 (Fig. 1). The garnet is unusually Ca-rich for a kyanite-free assemblage. The occurrence of graphite in Siberian alumina-rich assemblages has been noted by Sobolev (1971). Switzer and Melson (1969) however note the occurrence of diamond in a Roberts Victor kyanite eclogite. The general similarities of fabric and mineralogy of 6913 and 6914 suggest that they represent similar conditions of equilibration in the vicinity of the graphite/diamond equilibrium curve. Both specimens show extensive alteration which resembles the interstitial quenched melts described by Switzer and Melson (1969).

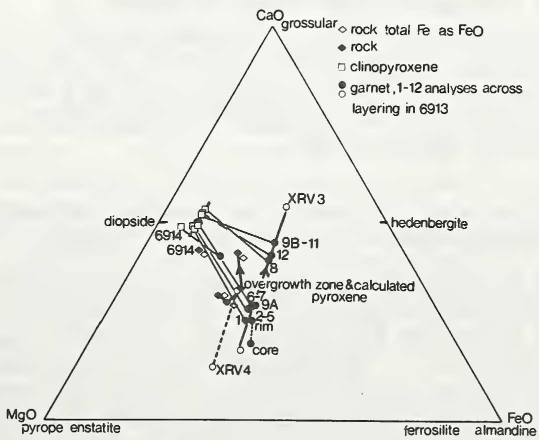

Fig. 1 Mol% CaO, MgO, FeO diagram. The trends of bulk compositions, garnet and clinopyroxene compositions for 6913 are shown as solid arrowed lines.

Cryptic variations in mineral compositions occur in 6913, seen largely through variations in Ca and Mg in garnets (Fig. 1). The garnets from the overgrowth layer (6,7), and also 9A, are slightly but distinctly, different from the gt-cpx layer (1-5) and markedly different from those of the gt-cpx-ky layer (9B-11). Within the latter layer garnets with lower Ca occur near the layer inerface (8) and at the edge of the specimen (12). The compositional trends for these garnets are similar to those found in another Roberts Victor layered eclogite (XRV3, Rickwood et al., 1968) whilst XRV4 shows a similar trend in garnets of lower Fe/Mg ratios (Fig 1). Some of the garnets of the gt-cpx layer are zoned with small (100-400 microns wide) cores somewhat enriched in Mg and depleted in Ca. (Figs. 1 and 2).

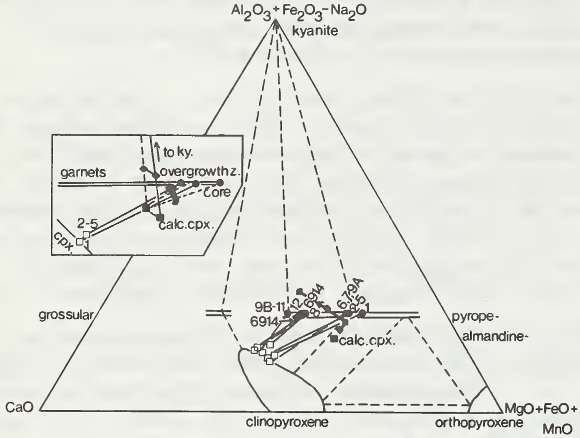

Fig 2 Mol% A, C, F diagram showing the synoptic relationships amongst Roberts Victor eclogites (MacGregor and Carter, 1970). The inset shows probable bulk compositional trends within the gt-cpx layer of 6913. The modified compositions of cpx_1 and the overgrowth layer are shown together with possible high T-P tie lines (dashed lines).

The clinopyroxenes of 6913 show a less marked, but sympathetic variation, when compared with the garnets. (Figs. 1 and 2).

Conditions of equilibration are estimated from the distribution function K'= (Fe/Mg)gt/ (Fe/Mg) cpx modified so that all iron is given as Fe^{2+}. Average K' values are 6913 gt-cpx and overgrowth layer 3.8, gt-cpx-ky 4.7, and 6914 3.5. Equilibration temperatures derived from these K' values using curves of Banno (1970) and Mysen and Heier (1970) give temperatures in the range 750-900°C with a mean value about 850°C. Pressures at these temperatures are defined by the graphite/diamond curve (Bundy et al., 1961) and by appropriate eclogite equilibrium curves (Green, 1967). A reasonable range would be 22-32 kilobars with a maximum pressure of 30 kilobars at highest temperatures for the graphite bearing sample 6914.

The garnet overgrowths on kyanite and the zonation in garnet (?) provide information about processes prior to this subsolidus equilibration. The overgrowth garnets (6,7,9A) cannot form by reaction between the analysed clinopyroxenes and kyanite (Fig. 2). This reaction can thus be interpreted as an open system one where clinopyroxene and kyanite have reacted with a fluid of defined chemical potential. Alternatively a closed system reaction of the type

$$cpx_1 + ky \longrightarrow cpx_2 + gt + ky$$

must be invoked. The cryptic variations suggest the presence of local bulk systems and limited diffusional volumes (as do the overgrowth textures) more in keeping with a closed system reaction. The composition of cpx_1 for the overgrowth layer was calculated on the basis of the above equation from analysed minerals (6,7) and a modal analysis (and assuming pyroxene stoichiometry). The structural formula of this pyroxene is Si 1.698, $Al^{[4]}$ 0.302, $Al^{[6]}$ 0.477, Ti 0.004, Fe^{2+} 0.352, Mn 0.004, Mg. 0.530, Ca 0.444, Na 0.189.

This calculated pyroxene is plotted in Figs. 1 and 2 where its position relative to the bulk compositional trends in 6913 might indicate whether a similar clinopyroxene was stable within adjacent layers. Four bulk analyses are available for 6913, two from the gt-cpx layer, one calculated bulk composition of the overgrowth layer, and one from the gt-cpx-ky layer. These bulk compositions do not lie on appropriate gt-cpx tie lines in Figs. 1 and 2. This is not due to analytical error but is the result of the extensive alteration of the primary minerals when the rocks have become depleted in Fe and Ca and enriched in Mg (and also K, H_2O and CO_2). An attempt has been made to make some allowance for this alteration and for the presence in Fe^{3+} in cpx_1 (see inset of Fig. 2). The bulk compositions of the gt-cpx layer can be represented by mixtures of cpx_1 and garnets whose compositions range from those found in the Ca-depleted cores to the typical compositions of this layer. In a similar way the composition of the gt-cpx-ky layer can be represented by mixtures of cpx_1, kyanite and a garnet of Ca content similar to that found (Fig. 2) but somewhat enriched in Mg relative to Fe (Fig. 1). Mg-rich cores were not found in microprobe traverses of garnets in this layer.

The general reaction for this layered eclogite is thus

$$cpx_1 \pm gt_1 \pm ky \longrightarrow cpx_2 + gt_2 \pm ky.$$

This reaction involves a marked decrease in the amount of clinopyroxene and an increase in the amount of garnet together with a small decrease in the amount of kyanite, if present. The early clinopyroxene is tschermakite and orthopyroxene rich and jadeite poor relative to the analysed pyroxenes and thus has high P liquidus characteristics. Early garnets may be somewhat enriched in Mg. The distribution coefficient K' for cpx_1/core gt is small (1.2) and supports the high T origins of the possible early assemblage. The conditions under which early assemblages might form can be assessed relative to the later subsolidus equilibration. Increasing proportions of garnet relative to clinopyroxene will be favoured by decreasing temperature and increasing pressure (Green 1967). The increasing amount of jadeite in clinopyroxenes and the possible increase in Fe/Mg ratio of the garnets could result from isobaric cooling but both reactions would be favoured by an increment of pressure. T-P conditions of 1400-1500°C and 26-28 kilobars seem appropriate since eclogites of similar composition are stable at the solidus (Green, 1967) and, provided higher pressure estimates are favoured for the subsolidus equilibration (say 28-32 kilobars), an increase of pressure is involved.

The fabric of the layered eclogite suggests that this incremental pressure is of tectonic origin. The kyanites have abundant strain bands. Deep embayments of garnet into kyanite occur in the vicinity of these strain bands within the overgrowth layer. The strain bands are considered to be regions of preferential garnet nucleation and reaction. Thus the tectonic processes causing strain must precede the development of overgrowths. It seems likely that the foliated fabric of the eclogite, defined by elongate aggregates of garnet and clinopyroxene and by elongate kyanites, formed at this stage of tectonic development. MacGregor and Carter (1970) have classified Roberts Victor eclogites into two types, 1 and 2, on a basis of fabric, mineralogy and chemistry. Specimen 6913 has the layering and mineralogy said to be characteristic of Type 1 eclogites but is also foliated, a feature restricted to Type 2 eclogites. These authors suggest that the Type 1 eclogites, because of their layering and textures (sunhedral to anhedral garnets and poikilitic clinopyroxenes) are formed by igneous cumulate processes. In specimen 6913, however, the best formed garnets occur in the overgrowth layer and are formed by subsolidus processes.

The cryptic mineral variations in 6913 are considered to reflect gradual compositional variations within the layering. Such variations, together with the gross layering, provide stronger evidence for cumulate processes at the temperatures and pressures outlined above. The sequence of primary cumulate minerals would be clinopyroxene and minor garnet, clinopyroxene and minor kyanite and then clinopyroxene, kyanite and minor garnet. Little can be said about the magma from which these phases crystallised except that the relatively high Fe/Mg ratio of the early pyroxene and the variable but high Ca contents of possible early garnets suggest an evolved magma relative to possible high pressure primitive partial melts (O'Hara 1968).

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