

CRUSTAL SIGNATURES IN MANTLE ECLOGITES: REE PATTERNS OF CLINOPYROXENE AND GARNET BY SIMS AND INAA.

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INTRODUCTION The origin of eclogite xenoliths in kimberlites and alkali basalts is at present the subject of much controversy. There are three contrasting petrogeneses proposed for these "mantle-derived" eclogites: 1) as high-pressure igneous cumulates (garnet pyroxenites) within the upper mantle [e.g., McGregor & Carter, 1970; Smyth et al., 1989; Caporuscio & Smyth, 1990]; 2) as relicts of the Earth's primary differentiation shortly after accretion [e.g., Anderson, 1981; McCulloch, 1989], and 3) as metamorphic products of a subducted oceanic crustal protolith [e.g., Jagoutz et al., 1984; MacGregor & Manton, 1986; Shervais et al., 1988; Taylor & Neal, 1989; Neal et al., 1990]. Basically, it is the last-named genesis which stands in direct opposition to the others. And it has been the premise of our studies that crustal progenitors of some of these eclogites will impart distinctive chemical characteristics upon these rocks and that these signatures remain even after metamorphism, metasomatism, and melting.

CHARACTERISTICS OF BELLSBANK ECLOGITES

	GROUP A	GROUP B	GROUP C
	MANTLE CUMULATE	SUBDUCTED OCEANIC CRUST	
		MORB	CUMULATE
Clinopyroxene			
Na ₂ O	0.6-2.8	3.7-5.7	7.6-8.7
Al ₂ O ₃	0.9-3.5	5.5-8.6	14.8-17.0
Cr ₂ O ₃	0.1-1.3	< 0.1	< 0.1
Garnet			
Comps.	Mg-rich	Fe-rich	Ca-rich
Cr ₂ O ₃	1.0-2.2	< 0.1	< 0.1
Mineral MG#'s			
Garnet	78-93	57-59	67-73
Cpx	90-96	86-89	90-93
Opx	89-93	—	—
Whole-Rock MG#	82-89	61-67	72-78
REE's	LREE-enriched	LREE-depleted	LREE-depleted
Eu Anomaly	HREE-depleted No	HREE-enriched No	HREE-depleted YES
Isotopic Comps.			
δ ¹⁸ O	+5.1 to +5.6	+2.9 to +4.0	+3.4 to +4.7
ε ¹⁴ N	-19 to -16	+39 to +241	+46 to +112
87Sr/86Sr	0.7042-0.7046	0.7086-0.7100	0.7083-0.7101

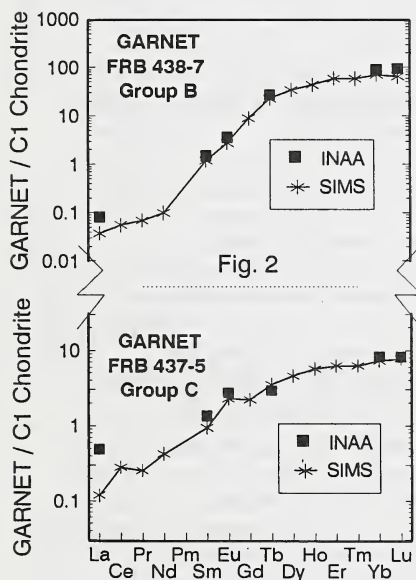
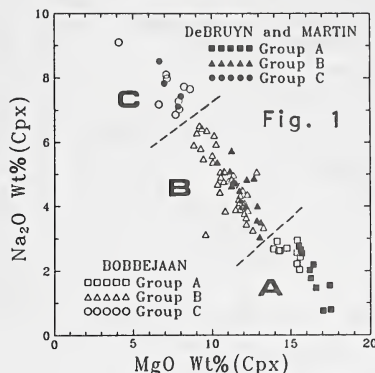
Table 1. Compiled from Taylor & Neal (1989) and Neal et al. (1990).

SOUTH AFRICAN ECLOGITES

We have determined the mineral chemistry from 28 eclogite samples from the Bellsbank kimberlite DeBryun and Martin Mine, So. Africa. All eclogites have experienced metasomatism, witnessed by interstitial phlogopite, amphibole, K-feldspar, and celsian. Nine of the freshest samples were chosen for "ultrapure" mineral separation and whole rock (INAA and XRF) analysis. Isotope (Sr, Nd, O) and INA analyses were performed on these separates. These data have allowed a three-fold classification of eclo-

gites to be constructed, i.e., Groups A, B, and C. [The chemistry of these groups are based upon the classification of Coleman et al. (1965).] From these data, petrogeneses of these eclogites can be approximated [Taylor & Neal, 1989; Neal et al., 1990; Table 1].

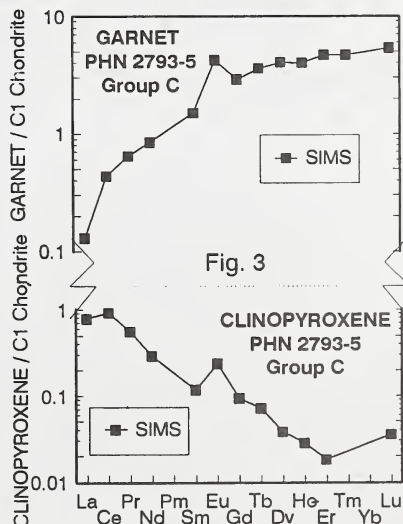
The mineral chemistry of the three eclogite groups suggests a petrogenesis by fractionation from an evolving magma. Smyth and Caporuscio (1984) have performed an extensive mineralogical investigation of the pyroxenes and garnets in eclogites from the Bobbejaan kimberlite (a different fissure of the Bellsbank kimberlite). Figure 1 shows the compositions of the Bobbejaan pyroxenes (after Smyth & Caporuscio, 1984), along with 28 from our DeBruyn and Martin eclogites. Although three groups are shown after Taylor and Neal (1989), Smyth et al. (1989) insist that the entire trend is attributed to simple fractionation. However, we have maintained that REE, in addition to whole-rock, mineral, and isotopic compositions are not consistent with such a petrogenesis [Taylor & Neal, 1989; Neal et al., 1990; Neal & Taylor, 1990].



SYNOPSIS OF GEOCHEMICAL DATA Group B and C eclogites have low $\delta^{18}\text{O}$ values of 2.9–4.7 ‰, high $^{87}\text{Sr}/^{86}\text{Sr}$ of 0.7083–0.7101, and extreme ϵ_{Nd} values +39 to +241. Group C minerals and eclogites possess positive Eu anomalies. Group A eclogites exhibit $\delta^{18}\text{O}$ of 5.1–5.6 ‰, near the mantle value of 5.7, lower Sr of 0.7042–0.7046, and ϵ_{Nd} values of -19 to -16. Major-element, whole-rock chemistries of Group B and C eclogites are similar to MORB and high-alumina basalt or gabbro, and the $\delta^{18}\text{O}$ values are consistent with high-temperature hydrothermal alteration of an oceanic crustal component (e.g., basalt and anorthositic gabbro). Also, this sea-water interaction could have been the source of the high radiogenic Sr. The extreme ϵ_{Nd} values could represent the effects of volatilization and metamorphism associated with the basalt/eclogite transition of the down-going plate. Thus, our eclogite investigations tend to support an

oceanic crustal origin for Group B and C eclogites (Shervais, 1988; Taylor & Neal, 1989; Neal & Taylor, 1990; Neal et al., 1990), but Group A eclogites are probably high-pressure mantle cumulates (e.g., high $\text{Mg}\#$'s, high Cr contents of minerals, and $\delta^{18}\text{O} \approx$ mantle values).

DIFFERENCE OF INTERPRETATION Smyth et al. (1989) and Caporuscio and Smyth (1990) contended that these same eclogites are the products of accumulation of hyper-aluminous clinopyroxene -- i.e., mantle origin. Herein lies a controversy! At the center of this dilemma lies the nature of the REE patterns. We claim to observe a positive Eu anomaly, whereas Caporuscio and Smyth (1990) stated that the REE pattern is simply a function of MREE enrichment. Such an enrichment implies both a LREE and HREE depletion, resulting in a convex upward profile to the garnet and



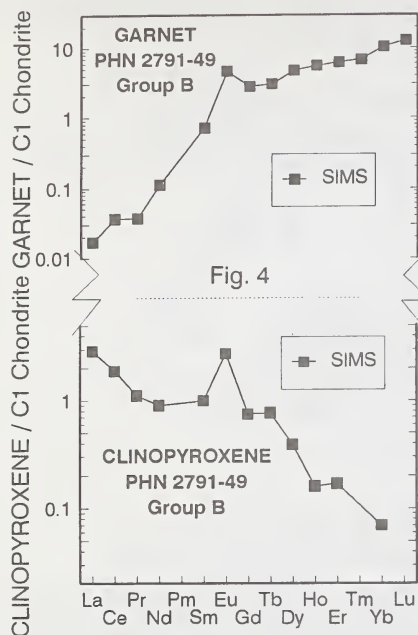


Fig. 4

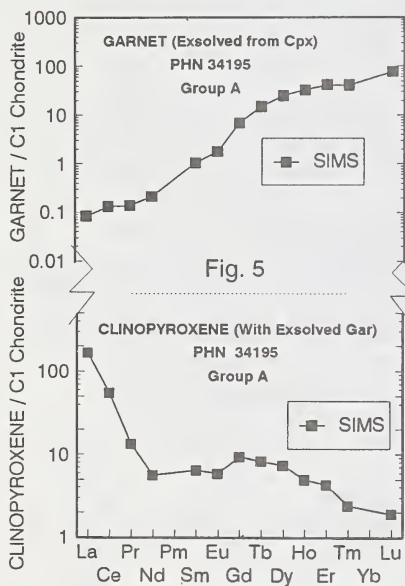


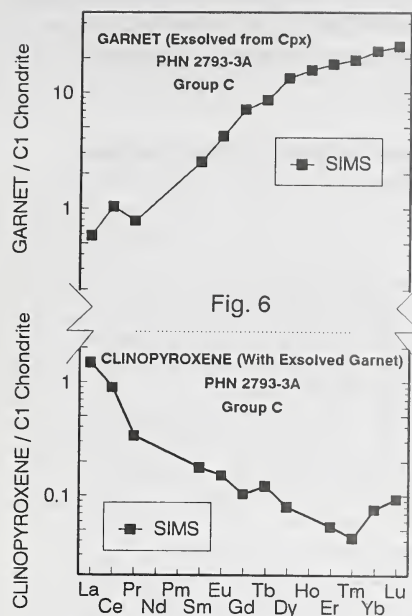
Fig. 5

clinopyroxene patterns. Which interpretation of the patterns is correct??

SIMS ANALYSES In an attempt to establish the credibility of the INA analyses on ultrapure mineral separates, several clinopyroxene and garnet grains were analyzed by SIMS at Washington University. Fig. 2 shows excellent agreement between previous INAA results and the SIMS analyses. Notice that the pattern for Group B garnet is smooth, whereas the Group C garnet displays a positive Eu anomaly, albeit small. To us, this does not look like simple MREE enrichment.

Fig. 3 shows interesting REE patterns from a "new" eclogite. The group designation is placed upon the eclogites by the mineral compositions, after Taylor and Neal (1989). Figure 3 depicts the patterns for another Group C eclogite, wherein a positive Eu anomaly is apparent for both the Cpx and garnet. Figure 4 shows some unexpected results, with REE patterns for a Group B eclogite containing Cpx and garnet with positive Eu anomalies. The positive Eu anomaly is present and distinct in each of these coexisting minerals from a Group B eclogite. This finding adds some additional complications to the petrogenesis in that there was apparent plagioclase involvement in a progenitor where the final eclogite is not extremely aluminous. In other words, does the presence of a positive Eu anomaly always signify involvement of plagioclase??

GARNET EXSOLUTION FROM CPX Several of the eclogites from Bellsbank contain Cpx which has evolved garnet + minor amounts of corundum and/or kyanite. Based upon our data and compositions for exsolved garnet/Cpx pairs reported by Smyth and Caporuscio (1984), it would seem that this exsolution occurs in all three eclogite groups (i.e., A, B, & C). The Na_2O and Al_2O_3 contents of Cpx vary across the whole gamut of eclogite compositions. Garnet occurs in two distinct



textures: 1) as elongate, discontinuous blebs and lamellae; and 2) as xenomorphic crystals, both as inclusions in matrix Cpx and between Cpx grains. Locally, garnet lamellae tend to merge into larger, xenomorphic inclusions. Garnet and Cpx exhibit inter- and intra-granular homogeneity, including exsolved lamellae & matrix grains, & imply thorough subsolidus reequilibration. These relations contrast with the inhomogeneity reported from exsolution intergrowths in Roberts-Victor gneisses (Harte & Gurney, 1975).

SIMS analyses were performed on both the Cpx and the exsolved garnets from several samples. Figures 5 & 6 show the REE patterns for garnet and Cpx in a Group A and a Group C eclogite. In all samples, Cpx and garnet show relative enrichment of LREE and HREE, resp. This is identical to eclogites which show no evidence of exsolution. As shown by Figure 6, these SIMS analyses complicate the interpretations. REE patterns from Cpx/garnet exsolution in Group C eclogites show no Eu anomaly.

These inconsistent Eu anomalies are puzzling and may be related to the exsolution process. But, this does not explain the Group B eclogite with the positive Eu anomaly (Fig. 4). As Group B eclogites are thought to derive from altered oceanic basalt (Taylor & Neal, 1989), perhaps some protoliths were high-Al basalts in which part of the plagioclase was of cumulate origin.

CONCLUSIONS

- o The Eu anomaly in REE patterns of mantle eclogites and their minerals is real and is not simply a MREE enrichment; it is a crustal signature;
- o A positive Eu anomaly is indicative of a plag-bearing crustal progenitor;
- o Exsolution of garnet from Cpx occurs in all three eclogite Groups;
- o Group B eclogites can have positive Eu anomalies; some Group C eclogites do not - it appears that a continuum exists between Groups B and C.

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