14 Sodium in garnet and potassium in clinopyroxene: criteria for classifying mantle eclogites

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ABSTRACT

MacGregor and Carter (1970) recognized two groups of eclogites at Roberts Victor, distinguished largely according to textural differences, which were not always readily apparent (Hatton 1978). Eclogitic inclusions in diamond contain potassium-enriched clinopyroxene and sodium-enriched garnet, as do diamondiferous eclogites. Robinson *et al* (1984) suggested that this may be used to classify eclogites.

This study re-examines the Roberts Victor eclogites, and shows that Group I garnets average 0.10 ± 0.02 wt% Na_2O and Group II garnets average 0.05 ± 0.03 wt% Na_2O. Group I clinopyroxenes average 0.12 ± 0.03 wt% K_2O, while Group II clinopyroxenes average 0.04 ± 0.05 wt% K_2O. Eclogites with average $K_2O_{cpx} \geq 0.08$ wt% or $Na_2O_{gt} \geq 0.09$ wt% are considered as of Group I, and eclogites with levels below these are of Group II. Using these guidelines, over 90% of the Roberts Victor eclogites are placed correctly into Group I or II, without reference to texture.

Average Na_2O_{gt} and K_2O_{cpx} of Group I and diamondiferous eclogites are nearly identical, suggesting that Group I eclogites formed under conditions similar to those required for diamond genesis. Group I eclogites, and the garnets and clinopyroxenes derived from them, may therefore be useful tools in the prospecting and evaluation of kimberlites, where the eclogitic diamond paragenesis occurs.

Key words: diamond eclogite, Group I, Group II, K_2O in clinopyroxene, Na_2O in garnet.

14.1 INTRODUCTION

MacGregor and Carter (1970) recognized two groups of eclogites at Roberts Victor, distinguished largely according to textural differences. Group I eclogites have large, cloudy, subhedral to rounded garnets set in a matrix of clinopyroxene. Some garnets may be poikilitically enclosed in clinopyroxene, and some clinopyroxene may contain exsolution lamellae. Group II eclogites have an interlocking texture of anhedral garnet and clinopyroxene, and the minerals are less altered than in Group I eclogites. Chemical variations include greater amounts of Cr_2O_3, CaO, FeO and MnO in the clinopyroxenes, and more MgO, NiO, Li_2O and Na_2O in the garnets of the Group I eclogites. It was also noted that Group II clinopyroxenes are lower in K_2O than those in Group I eclogites, a feature also noted by Erlank (1970).

Hatton (1978), in an extensive study of 700 Roberts Victor eclogites, continued to apply the MacGregor and Carter (1970) scheme. He found that although 75% of the eclogites could be regarded as of Group I, many could not be placed in either category according to texture alone. He relied heavily on the fresh appearance of minerals as a distinguishing criteria, and included eclogites with fresh, unaltered grains in the Group II category, though their textures varied.

Several workers have found that eclogitic inclusions in diamond contain potassium-enriched clinopyroxene and sodium-enriched garnet (Sobolev *et al* 1972; Gurney *et al* 1979; Tsai *et al* 1979; Moore & Gurney 1985). Similar enrichment occurs in the garnet and clinopyroxene of diamondiferous eclogites (Reid *et al* 1976). Robinson *et al* (1984) suggested that this may be used to classify eclogites.

This investigation returns to the eclogites of Roberts Victor, to demonstrate that sodium in garnet and potassium in clinopyroxene are useful criteria for discriminating between two groups of mantle eclogites. Diamondiferous eclogites from several localities are also examined in the light of this new scheme.

14.2 METHODS

A total of 564 garnet and pyroxene microprobe analyses were obtained from polished thin sections of Group I, Group II and diamondiferous eclogites. The Group I and II eclogites are from the suite previously studied by Hatton (1978), and include megacryst-bearing, chrome-rich and inhomogeneous varieties. The diamondiferous eclogites are from the Roberts Victor, Orapa, Star, Jagersfontein, Newlands, Ardo (Excelsior), Mitchemanskraal and Sloan 2 kimberlites, with some containing both diamond and graphite. Where possible, five grains each of garnet and pyroxene from each eclogite were analysed. In cases of severe alteration, more than one analysis was taken from available grains. All analyses were obtained on the Cameca microprobe at the University of Cape Town. Natural and synthetic standards were used, and matrix effects were corrected for using the method of Bence and Albee (1968). Hornblende from Kakanui, New Zealand (USNM 143965), provided the standard for Na_2O in garnet and K_2O in clinopyroxene, with 2.05 wt% K_2O and 2.60 wt% Na_2O (Jarosewich *et al* 1979). For the major and minor elements, 10 s counting times resulted in lower limits of detection ranging from 0.03–0.08 wt%, and a maximum 2 sigma of 0.24 wt%. Sixty seconds on the element peak, with 60 s background counts, were taken for each analysis of sodium in garnet and potassium in clinopyroxene. This ensured a lower limit of detection of 0.01 wt%, with 0.01 wt% 2 sigma.

14.3 OBSERVATIONS AND RESULTS

On the basis of the original classification of Hatton (1978) the results show that sodium in garnet (Na_2O_{gt}) and potassium in clinopyroxene (K_2O_{cpx}) are significantly enriched in Group I eclogites and depleted in Group II eclogites. Sodium in Group I garnets averages 0.10 ± 0.02 wt% Na_2O (Fig. 14.1a). In contrast, Group II garnets have an average sodium content of 0.05 ± 0.03 wt% Na_2O (Fig. 14.lb). Group I clinopyroxenes have an average potassium content of 0.12 ± 0.03 wt% K_2O, while Group II clinopyroxenes average 0.04 ± 0.05 wt% K_2O (Figs 14.2a,b; Table 14.1).

It can be seen from Figs 14.1 and 14.2 that the oxide ranges of the two eclogite groups overlap.

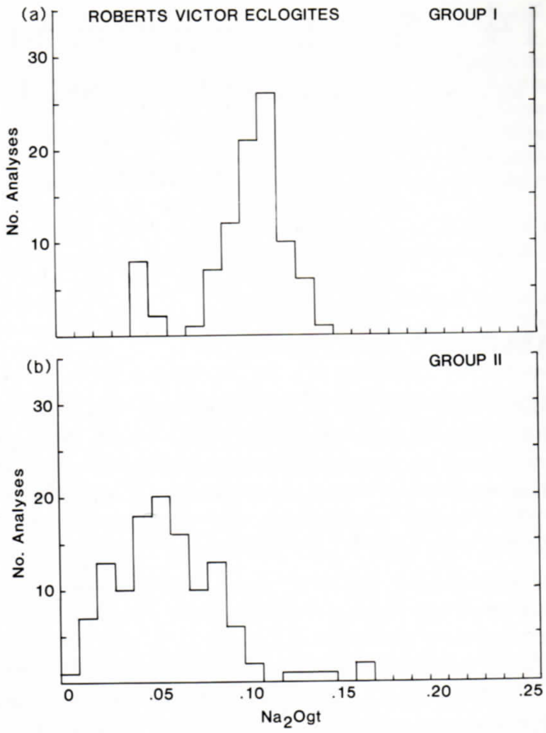

Fig. 14.1 Histograms showing distribution of sodium in garnet in eclogites from Roberts Victor (values in weight percent). (a) Group I eclogites. Low Na_2O_{gt} levels represent metasomatized eclogites. (b) Group II eclogites. High Na_2O_{gt} levels represent largely kyanite eclogites.

For the Group I eclogites, low levels of Na_2O_{gt} and K_2O_{cpx} are present only in metasomatized nodules (recognized by the presence of abundant secondary phlogopite in the rock (Hatton 1978)). It is possible that sodium has been removed from the garnet during metasomatism or other alteration processes. Potassium depletion in eclogitic clinopyroxene from metasomatism or decompression melting has been reported elsewhere (Switzer & Melson 1969; Mysen & Griffin 1973; Reid *et al* 1976). Measured K_2O in clinopyroxene can also vary with crystallographic orientation (McCandless & Collins 1987). The high K_2O_{cpx} and Na_2O_{gt} values of Group II eclogites are largely those of kyanite-bearing eclogites. These eclogites were classified as belonging to Group II on the basis of their fresh appearance (Hatton 1978), while MacGregor and Carter (1970) found that all kyanite-bearing eclogites were of Group I, possibly on the basis of texture rather than lack of

TABLE 14.1 Compositional statistics for garnet and clinopyroxene from Group I, Group II and diamondiferous eclogites, and for eclogitic inclusions in diamonds. Eclogite data from this study, inclusions from unpublished analyses. s.d. standard deviation.

	Garnets							
	Min.	Max.	Mean	s.d.	Min.	Max	Mean	s.d.
	Group I eclogites $n = 95$				Group II elcogites $n = 120$			
SiO_2	39.72	41.79	40.77	0.45	38.31	42.68	41.29	1.04
TiO_2	0.13	0.41	0.28	0.06	0.05	0.43	0.20	0.09
Al_2O_3	21.49	23.79	22.76	0.51	21.02	23.95	22.89	0.64
Cr_2O_3	0.01	1.00	0.14	0.16	0.00	3.90	0.67	0.81
FeO	9.11	19.40	14.65	2.45	7.22	20.41	10.93	3.66
MnO	0.11	0.94	0.51	0.22	0.16	0.52	0.33	0.09
MgO	13.24	16.80	15.13	0.89	8.17	21.46	17.23	4.46
CaO	3.17	10.75	5.92	2.21	3.04	15.68	6.40	3.46
Na_2O	0.04	0.14	0.10	0.02	0.00	0.16	0.05	0.03
	Diamondiferous eclogites $n = 72$				Inclusions in diamonds $n = 129$			
SiO_2	38.72	42.21	40.65	0.69	37.96	42.56	39.89	0.84
TiO_2	0.12	0.55	0.32	0.11	0.07	2.36	0.54	0.28
Al_2O_3	21.69	23.89	23.16	0.48	17.50	23.24	21.91	0.84
Cr_2O_3	0.01	0.16	0.07	0.04	0.00	2.75	0.20	0.43
FeO	6.85	19.17	12.74	3.15	10.09	24.58	17.02	2.96
MnO	0.11	0.55	0.31	0.11	0.00	1.42	0.40	0.27
MgO	9.23	18.66	13.44	2.28	7.29	18.95	11.94	2.91
CaO	3.37	15.67	9.64	3.57	1.52	15.27	7.65	3.13
Na_2O	0.08	0.17	0.11	0.02	0.00	0.38	0.15	0.08
	Clinopyroxenes							
	Group I eclogites $n = 90$				Group II eclogites $n = 119$			
SiO_2	53.49	56.68	55.33	0.76	46.66	56.37	54.74	1.44
TiO_2	0.01	0.43	0.32	0.09	0.00	0.61	0.21	0.12
Al_2O_3	1.50	14.80	8.82	3.51	0.79	16.28	6.13	4.23
Cr_2O_3	0.05	0.84	0.16	0.15	0.01	2.35	0.49	0.57
FeO	1.43	7.55	4.38	1.63	1.34	6.11	3.12	1.23
MnO	0.01	0.26	0.10	0.08	0.00	0.17	0.04	0.05
MgO	7.80	17.38	11.52	2.35	6.09	18.31	13.96	3.49
CaO	11.00	20.04	13.95	2.02	9.82	22.70	17.66	3.20
Na_2O	1.37	6.93	4.91	1.41	0.66	7.95	3.25	1.85
K_2O	0.04	0.16	0.12	0.03	0.00	0.21	0.04	0.05
	Diamondiferous eclogites $n = 68$				Inclusions in diamonds $n = 178$			
SiO_2	50.46	56.50	55.05	0.89	48.60	56.64	54.61	0.96
TiO_2	0.09	0.61	0.32	0.12	0.01	1.23	0.37	0.20
Al_2O_3	6.18	20.91	10.95	3.46	0.52	19.79	7.07	3.88
Cr_2O_3	0.01	0.18	0.07	0.05	0.01	0.72	0.10	0.09
FeO	1.56	6.15	3.17	1.21	2.21	28.89	6.74	2.63
MnO	0.00	0.19	0.05	0.05	0.00	0.85	0.11	0.10
MgO	4.70	13.98	10.50	2.23	0.17	21.83	12.84	3.62
CaO	8.91	19.16	14.32	2.40	0.48	24.10	14.01	3.49
Na_2O	2.76	8.89	5.38	1.37	0.22	14.10	3.73	1.83
K_2O	0.01	0.23	0.10	0.04	0.01	1.18	0.18	0.21

alteration. Using our proposed criteria, we agree with the latter.

Even with these samples included in their original groups as defined by Hatton (1978), however, it is found that 81% of the garnets from Group I eclogites contain 0.09 wt% or more Na_2O, while 89% of the Group II garnets contain less than this quantity. In the case of K_2O in clinopyroxene, 94% of the Group I clinopyroxenes contain 0.08 wt% or more K_2O, with 76% of the Group II clinopyroxenes containing lesser amounts. When the metasomatized Group I and

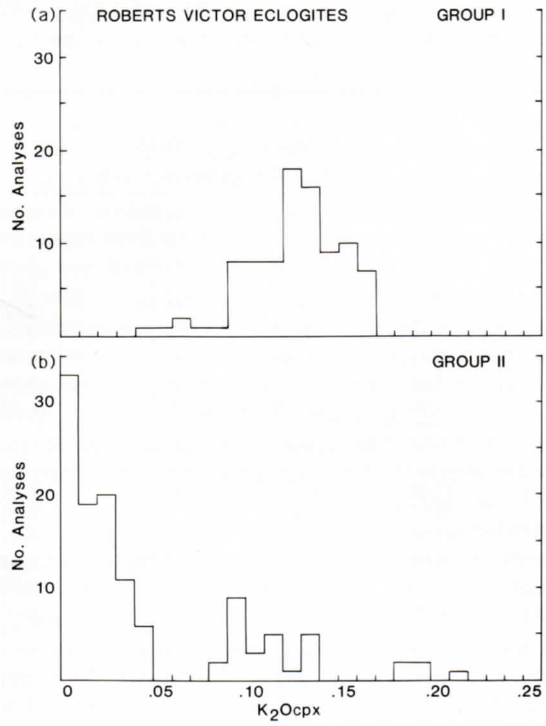

Fig. 14.2 Histograms showing distribution of potassium in clinopyroxene in eclogites from Roberts Victor (values in weight percent). (a) Group I eclogites. Low K_2O_{cpx} levels represent metasomatized eclogites. (b) Group II eclogites. High K_2O_{cpx} levels represent largely kyanite eclogites.

kyanite-bearing Group II eclogites are excluded, 91% of the Group I garnets contain 0.09 wt% or more Na_2O, and 96% of garnets in Group II eclogites contain less than this. In the case of the Group I clinopyroxenes, 99% have levels of K_2O of or above 0.08 wt%, and 86% of the Group II clinopyroxenes have levels below this.

It is proposed that the values of 0.08 wt% K_2O in clinopyroxene and 0.09 wt% Na_2O in garnet can be used as criteria for classifying mantle eclogites. Eclogites with average contents of $K_2O_{cpx} \geq 0.08$ wt% or $Na_2O_{gt} \geq 0.09$ wt% are considered as belonging to Group I, and eclogites with lesser contents belong to Group II. For reasons previously discussed, either value may be low in a Group I eclogite, in which case the presence of either enriched garnet or clinopyroxene is considered significant. By applying these guidelines to the eclogites at Roberts Victor, over 90% can be placed correctly in the same Group I or II category as indicated by the original criteria; but the trace element concentrations have the advantage of being more quantitative and therefore less subjective to apply. They also allow the classification of small samples, even individual grains, in respect of which textural evidence is lacking. This is a highly successful result. It remains to be shown how widely applicable these criteria will prove to be, although eclogites which can be distinguished on the basis of these criteria are found at other localities (Robinson *et al* 1984; McCandless & Collins 1988; Moore & Gurney 1988).

Potassium in clinopyroxene has been shown to be pressure dependent (Erlank & Kushiro 1970). It has also been noted that diamondiferous eclogites contain K_2O-enriched clinopyroxene and Na_2O-enriched garnet (Reid *et al* 1976; Sobolev *et al* 1972; Robinson *et al* 1984). The average levels of these oxides in diamondiferous eclogites are nearly identical to those in Group I eclogites. Na_2O in garnet makes up 0.11 ± 0.02 wt%, and K_2O in clinopyroxene constitutes 0.10 ± 0.04 wt% (Figs 14.3a, b). The low levels of K_2O_{cpx} in the diamondiferous eclogites are believed to be due to partial melting or metasomatic processes like those believed to be responsible for low levels in Roberts Victor Group I eclogites. Some evidence of K_2O loss in clinopyroxene has been seen in other studies, where K_2O_{cpx} levels in inclusions in diamonds from a diamondiferous eclogite are up to four times higher than those in the xenolith (Sobolev *et al* 1972). Average K_2O levels in eclogitic clinopyroxenes included in diamonds are also higher than those reported here for diamondiferous eclogites (0.18 ± 0.21 wt%; Table 1, from unpublished analyses), which further suggests that some K_2O loss from the xenolith clinopyroxenes occurs. Thus, based on K_2O_{cpx} alone, only 65% of the diamondiferous eclogites would be classified as Group I. Sodium in garnet appears to be less affected by these processes, and in considering Na_2O_{gt}, *all* of the diamondiferous eclogites are of Group I, using the cut-off limits expressed above. It is believed that all of the diamondiferous eclogites of this study are Group I eclogites, on the basis of these results. Conversely, this suggests that Group I eclogites formed under conditions similar to those required for diamond genesis.

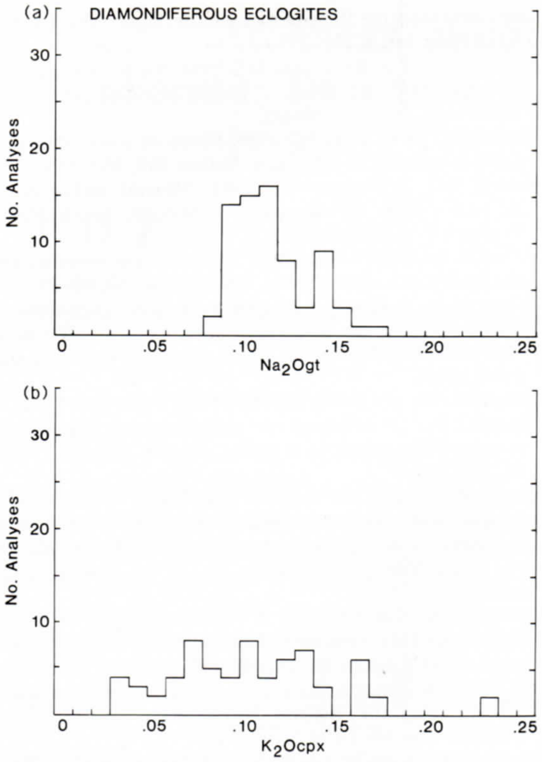

Fig. 14.3 Histograms showing distribution in diamondiferous eclogites of (a) sodium in garnet and (b) potassium in clinopyroxene. Values in weight percent.

14.4 DISCUSSION

One model proposed for the origin of the Roberts Victor eclogites is that they represent a cumulate (Group I)/liquid (Group II) relationship (MacGregor & Carter 1970). The high K_2O_{cpx} levels of Group I eclogites and low K_2O_{cpx} levels of Group II eclogites are the reverse of those expected in the case of such a relationship, however. More recently, it has been proposed that the Group I eclogites formed from volatile-induced partial melting of garnet lherzolite, in which K_2O was one of the volatile elements. The Group I eclogites formed where phlogopite was unstable, hence K_2O was incorporated into clinopyroxene (Hatton & Gurney 1987). Group II eclogites formed as a separate group, through partial melting, contamination and metamorphism of garnet lherzolite which surrounded the Group I magma. As primary phlogopite is present in Group II eclogites, it would have taken up K_2O rather than the clinopyroxene (Hatton & Gurney 1987). The results of this study show that, with respect to K_2O_{cpx}, Roberts Victor Group I and Group II eclogites are separate and distinct groups, which supports the latter model.

The presence of secondary phlogopite in metasomatized Group I eclogites is also significant. This indicates that conditions have changed to allow phlogopite stability since the formation of the Group I eclogites in Archaean time. The change could have been a lowering of temperature or decrease in pressure. A temperature decrease has been documented in eclogites from Roberts Victor (Harte & Gurney 1975), where garnet exsolution from clinopyroxene has occurred over an approximately 200°C interval. A decrease in pressure is also possible, but considered less likely.

The application of peridotitic garnet chemistry to evaluate the presence of diamond in kimberlites has been successfully demonstrated (Gurney 1984). An increasing number of kimberlites are now recognized as having eclogitic diamonds, on the basis of associated mineral inclusions (Otter & Gurney 1988; Moore & Gurney 1985, 1988; Harris & Gurney submitted). The similar enrichment patterns of K_2O in clinopyroxene and Na_2O in garnet in respect of Group I and diamondiferous eclogites has been demonstrated. Group I eclogites, and the minerals derived from them, may therefore be useful tools in the prospecting and evaluation of kimberlites, where the eclogitic diamond paragenesis is important.

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