10IKC–341

CLINOPYROXENE MACROCRYSTS IN PROTEROZOIC KIMBERLITES FROM SOUTHERN INDIA

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INTRODUCTION

Kimberlites contain indicator minerals such as pyrope garnet, Cr-rich clinopyroxene, and spinel which are derived from disaggregated mantle xenoliths, commonly of peridotite, eclogite and pyroxenite, sampled by the kimberlite magmas during their ascent. Clinopyroxenes that are typically associated with kimberlites have traditionally been identified by using simple Cr_2O_3 thresholds. Different cut-off values of Cr_2O_3, viz. 0.5 wt%, 1 wt% and 1.5 wt% have been used by different workers to identify kimberlitic clinopyroxenes. However, since clinopyroxenes from kimberlites show wide variation in Cr_2O_3 content ranging from low (< 0.2 wt%) to high values (> 5 wt%) and compositionally overlap with clinopyroxenes from several other rock types, this approach is ineffective and can be misleading. Stephens and Dawson (1977) observed a positive correlation between Na_2O and Al_2O_3, and Na_2O and Cr_2O_3 in pyroxenes from kimberlites and their associated xenoliths. Morris et al. (2002) demonstrated that the entry of Cr, Al and Na into clinopyroxenes of kimberlite association is controlled by jadeite–kosmochlor substitution and suggested that Al–Na–Cr ternary plot be used to screen such compositions.

In the present investigation, we examine the variation in composition of clinopyroxene macrocrysts recovered from heavy mineral concentrates of kimberlites in two major kimberlite fields of southern India: one diamondiferous and another almost barren. We discuss the affiliation of the clinopyroxenes to possible mantle lithologies. For the barren kimberlite field we report the occurrence of a population of clinopyroxenes with composition that deviates from the usual jadeite–kosmochlor trend and discuss its implication.

SOUTHERN INDIAN KIMBERLITES

Kimberlites discovered in southern India till date are restricted to the Eastern Dharwar Craton (EDC) and are distributed in four fields, viz. Wajrakarur Kimberlite Field (WKF), Narayanpet Kimberlite Field (NKF), Raichur Kimberlite Field (RKF), and Tungabhadra Kimberlite Field (TKF) (Inset of Fig. 1). In addition, there are three lamproite fields in the EDC, viz. Krishna Lamproite Field, Nallamalai Lamproite Field, and Ramadugu Lamproite Field.

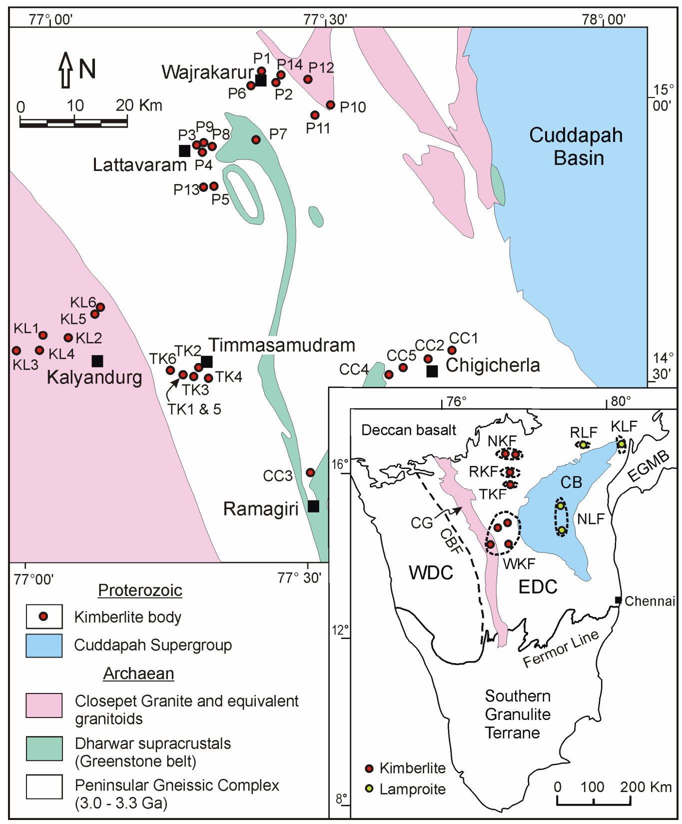

Fig.1. Generalised geological map of Wajrakarur Kimberlite Field (WKF). Inset shows sketch map of southern India with location of kimberlite and lamproite fields in the Eastern Dharwar Craton (EDC). CB = Cuddapah Basin; CBF = Chitradurga Boundary Fault; CG = Closepet Granite; KLF = Krishna Lamproite Field; NKF = Narayanpet Kimberlite Field; NLF = Nallamalai Lamproite Field; RLF = Ramadugu Lamproite Field; TKF = Tungabhadra Kimberlite Field; WDC = Western Dharwar Craton.

The WKF has a dimension of ~ 80 km × 70 km, and contains 45 kimberlite intrusions, 31 of which are distributed in four clusters, viz. Wajrakarur–Lattavaram (14 intrusions, P1–P14), Chigicherla (5 intrusions, CC1–CC5), Kalyandurg (6 intrusions, KL1–KL6), and Timmasamudram (6 intrusions, TK1–TK6) (Fig. 1). Most of these 31 intrusions were discovered by the Geological Survey of India (GSI) in the last few decades. The other 14 intrusions (WK1–WK14) have recently been discovered by M/s Rio Tinto Exploration (Chatterjee et al., 2008), but their locations remain undisclosed. The WKF kimberlites are usually small intrusions (surface area < 5 ha) except for a few large bodies. The NKF has a dimension of ~ 60 km × 40 km and contains 34 intrusions discovered by the GSI has which are spread over four clusters, viz. Narayanpet (10 intrusions; NK1 to NK10), Maddur (11 intrusions; MK1 to MK11), Kotakonda (7 intrusions; KK1 to KK7) and Bhima (6 intrusions, BK1 to BK6) (Fig. 2). In addition, M/s De Beers India Pvt. Ltd. reported 29 intrusions occurring in two clusters in the western part of the NKF (Lynn, 2005).

Most of the WKF kimberlites are poorly diamondiferous, whereas the NKF kimberlites are almost barren except for a few diamonds reported by Lynn (2005) in surface heavy mineral samples from the kimberlites occurring southwest of Bewanahalli.

Radiometric ages of southern Indian kimberlites reported by different workers indicate that the rocks intruded in the Mesoproterozoic, mostly around 1100 Ma.

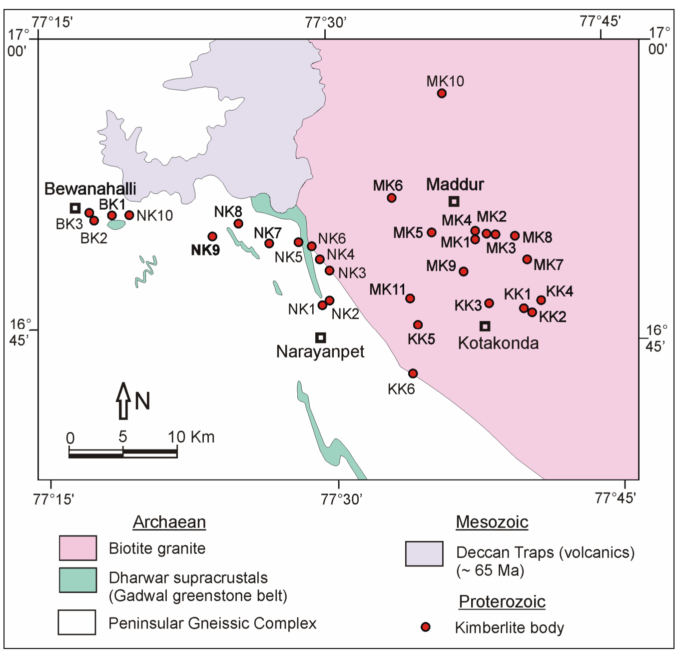

Fig.2. Generalised geological map of Narayanpet Kimberlite Field.

KIMBERLITE INDICATOR MINERALS

The GSI processed large quantities of weathered kimberlite and soil samples from different southern Indian kimberlites for recovering heavy minerals. Heavy concentrates from the WKF kimberlites yielded abundant pyrope, chrome-diopside, ilmenite and spinel (Fig. 3), whereas those from the NKF kimberlites were dominated by chrome-diopside with subordinate spinel and ilmenite. Appreciable quantities of garnets were recovered only from the NK3 and KK2 kimberlites of the NKF.

Clinopyroxene grains in the kimberlite concentrates are pale green to emerald green in colour and vary from tabular to blocky and irregular in shape. The grains mostly fall in the size range of 2–4 mm.

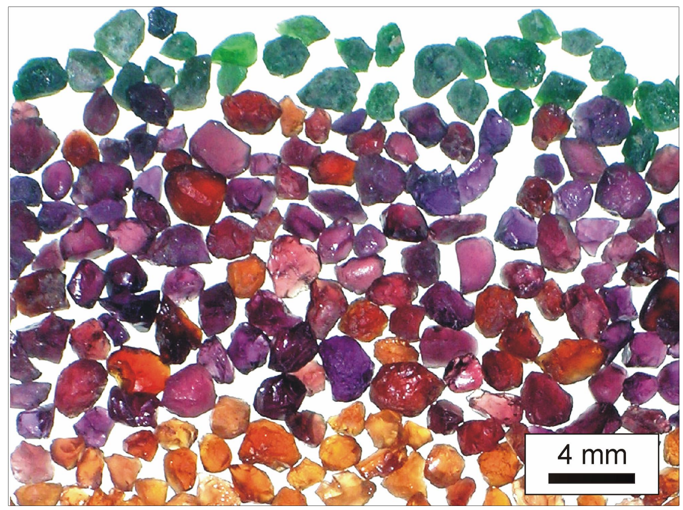

Fig.3. Photograph of indicator minerals from the heavy concentrate of WKF kimberlites. Green macrocrysts are clinopyroxene; other macrocrysts are garnet.

CLINOPYROXENE COMPOSITION

Electron probe microanalyses of different concentrate minerals (garnet, clinopyroxene, spinel and ilmenite) from the southern Indian kimberlites were reported by Sastry et al. (2005). However, they did not give any interpretation of the data. In the present study we focus on the compositional characteristics of concentrate clinopyroxenes (discrete macrocrysts) from the kimberlites. The studied data set includes 85 macrocysts from the diamondiferous WKF and 41 macrocrysts from the almost barren NKF. We compare the composition of these macrocrysts with that of clinopyroxenes in mafic xenoliths (eclogite and garnet pyroxenite) (Patel et al., 2006, 2009) and mica–amphibole–rutile–ilmenite–diopside (MARID)-type xenoliths (Patel et al., 2012) from southern

Indian kimberlites, and in MARID xenoliths from South African kimberlites (Dawson and Smith, 1977).

The concentrate clinopyroxenes from the WKF and NKF have highly variable contents of CaO (12.0–24.0 wt%), Cr_2O_3 (0.1–3.9 wt%) and Na_2O (0.5–7.0 wt%). Although most clinopyroxenes have Cr_2O_3 content above 0.5 wt% and can be termed *chromian*, a small population (11 macrocrysts from WKF and NKF each) is marked by low Cr_2O_3 (0.1–0.5 wt%). In general the WKF clinopyroxenes are richer in Cr (average 1.79 wt% Cr_2O_3) than the NKF clinopyroxenes (average 1.24 wt% Cr_2O_3). On the Cr_2O_3–CaO plot, clinopyroxenes from both WKF and NKF are distributed inside as well as outside the diamond inclusion field defined by Fipke et al. (1989) (Fig. 4). Cinopyroxenes from the two fields cannot be discriminated on this diagram.

The Al_2O_3 content of the concentrate clinopyroxenes is in the range of 0.2–5.8 wt%, except for a few macrocrysts from the WKF (3 out of 85) which have high values (8–12.5 wt% Al_2O_3). There is a broad positive correlation between Na_2O and Al_2O_3 for all the clinopyroxenes (Fig. 5). The clinopyroxene macrocrysts with Al-rich composition (> 8 wt% Al_2O_3) are also rich in Na_2O (> 5 wt%), and are comparable to clinopyroxene in eclogite xenoliths from southern Indian kimberlites (Patel et al., 2006).

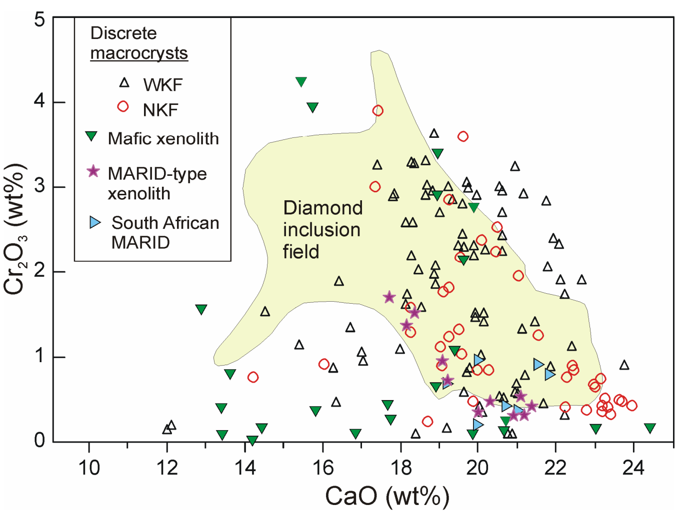

Fig.4. Composition of concentrate clinopyroxenes from NKF and WKF kimberlites (Sastry et al., 2005) compared with that of clinopyroxenes in MARID-type xenoliths from NKF and RKF (Patel et al., 2012), South African MARIDs (Dawson and Smith, 1977) and mafic xenoliths from WKF and NKF (Patel et al., 2006, 2009). Diamond inclusion field after Fipke et al. (1989).

The concentrate clinopyroxenes have Mg number [= Mg / (Mg + Fe)] in the range of 0.86–1.00 except for a few grains which are somewhat Fe-richer. On the plot of Cr_2O_3 vs Mg number, the clinopyroxenes show a weak trend of chromite–clinopyroxene–garnet equilibrium (CCGE) that was proposed by Kopylova et al. (1999) for clinopyroxenes from the Jericho kimberlite of Canada (Fig. 6). This is taken to indicate that some of the clinopyroxenes with high Mg numbers equilibrated with coexisting garnet and chromite in the mantle source region. However, the CCGE trend is not reflected by concentrate garnets from the same southern Indian kimberlites (Patel et al., 2010). Clinopyroxenes in MARID-type xenoliths from southern Indian kimberlites have Mg number in the range of 0.81–0.84 and are Fe-richer than the concentrate clinopyroxenes (Fig. 6). Clinopyroxenes in the South African MARID xenoliths vary from relatively Fe-rich to moderately Mg-rich compositions with Mg number between 0.82 and 0.90.

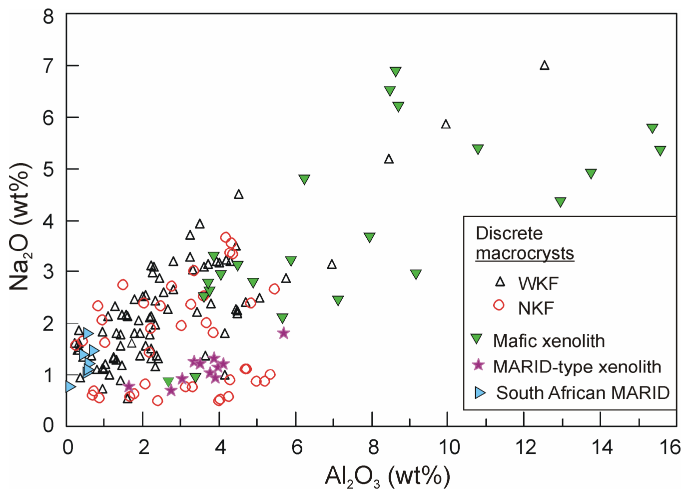

Fig.5. Na_2O vs Al_2O_3 plot of concentrate clinopyroxenes from NKF and WKF kimberlites. Data sources same as in Fig. 4.

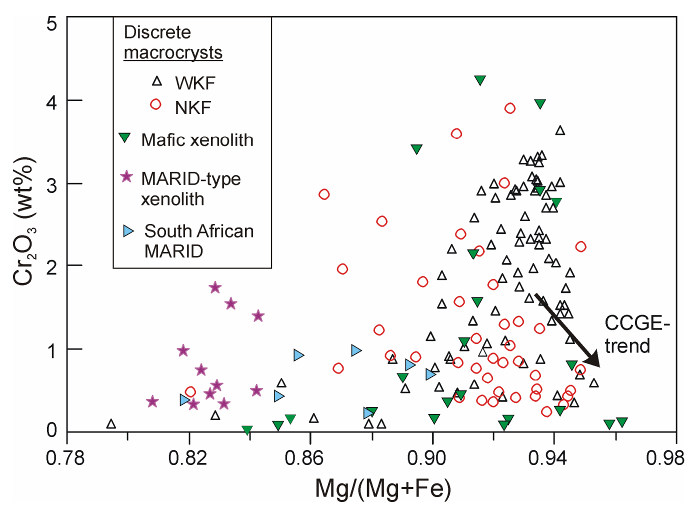

Fig.6. Cr_2O_3 vs Mg number plot of concentrate clinopyroxenes from NKF and WKF kimberlites. Data sources same as in Fig. 4.

The Ca number [= Ca / (Ca + Mg + Fe)] of the concentrate clinopyroxenes ranges from 0.31 to 0.50. On the $CaMgSi_2O_6$–$CaFeSi_2O_6$–$Mg_2Si_2O_6$–$Fe_2Si_2O_6$ quadrilateral for classification of pyroxenes, the concentrate clinopyroxenes mostly fall in the diopside field, while some are encompassed in the endiopside field and a few in the salite field (Fig. 7). On a ternary diagram representing atomic proportions of Cr, Al and Na, the WKF clinopyroxenes broadly trend from the mid portion of the Na–Al axis to the mid portion of the Na–Cr axis (Fig. 8). This trend is consistent with the jadeite ($NaAlSi_2O_6$)–kosmochlor ($NaCrSi_2O_6$) control on the entry of these elements into the mineral structure. The NKF clinopyroxenes show two distinct populations, one distributed along the jadeite–kosmochlor join, and the other forming a cluster on the ternary diagram with significant amounts of jadeite, Ca-tschermak ($CaAlAlSiO_6$) and CrCa-tschermak ($CaAlCrSiO_6$) components. The latter population compositionally overlaps with clinopyroxenes in MARID-type xenoliths from the NKF and RKF kimberlites (Patel et al., 2012), and is referred to as M-type clinopyroxenes (for metasomatic type composition).

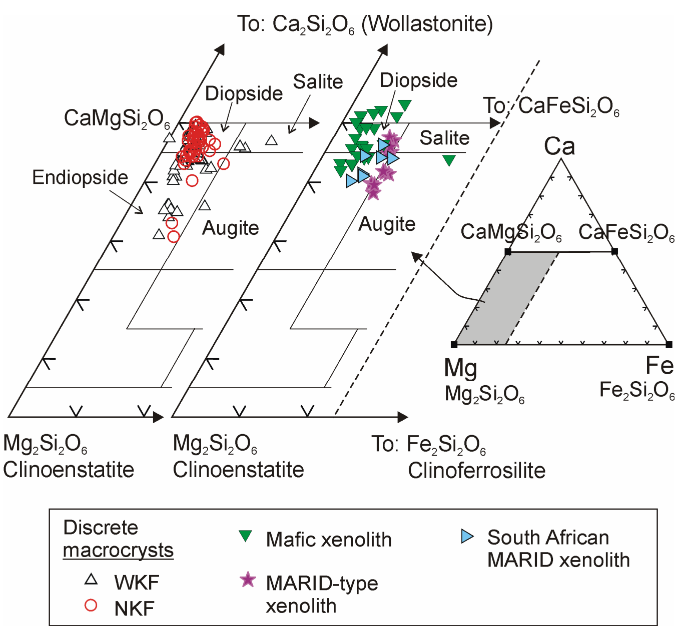

Fig.7. Concentrate clinopyroxenes from NKF and WKF kimberlites plotted on $CaMgSi_2O_6$–$CaFeSi_2O_6$–$Mg_2Si_2O_6$–$Fe_2Si_2O_6$ quadrilateral. Fields of diopside, endiopside, salite and augite after Deer et al. (1963). Data sources same as in Fig. 4.

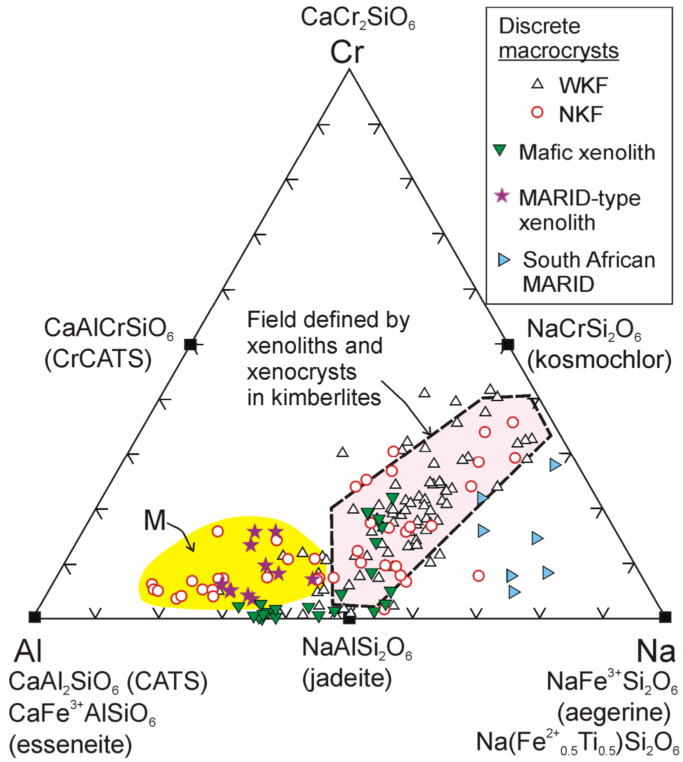

Fig.8. Concentrate clinopyroxenes from NKF and WKF kimberlites on Cr–Al–Na ternary plot. ‘M’ is the field metasomatic type clinopyroxenes from the NKF. Data sources same as in Fig. 4.

DISCUSSION

A few concentrate clinopyroxenes from the WKF are highly sodic as well as Al-rich and are likely to be derived from eclogitic source. A sizable population of concentrate clinopyroxenes (M-type) from the NKF deviate from the conventional jadeite–kosmochlor substitutional trend on Cr–Al–Na plot and show compositional similarity with clinopyroxenes in MARID-type xenoliths from southern Indian kimberlites. However, these M-type clinopyroxenes differ from the southern Indian MARID-type clinopyroxenes in their Mg number, the latter being relatively Fe-rich. Clinopyroxenes in xenoliths of eclogite and garnet pyroxenite from southern Indian kimberlites do not exhibit compositional similarity with the M-type clinopyroxenes in Cr–Al–Na space and therefore these xenoliths are not considered probable parent rocks for such clinopyroxenes.

The most likely parent rock of the M-type clinopyroxenes is a metasomatised peridotite. Erlank et al. (1987) reported a suite of metasomatised peridotites in which the clinopyroxenes have Mg numbers comparable to that in the M-type clinopyroxenes. However, the latter differ from the former in terms of Cr–Al–Na contents.

Based on the occurrence of MARID-type xenoliths in the NKF kimberlites and of concentrate clinopyroxenes with M-type composition, we propose extensive metasomatism of the mantle wall-rocks beneath the NKF compared to those beneath the WKF.

Concentrate clinopyroxenes with compositions spread along the jadeite–kosmochlor join in Cr–Al–Na space are interpreted to be derived mostly from mantle peridotites and to a small extent from eclogitic sources. The solubility of jadeite in the clinopyroxene structure is known to be strongly dependent on pressure. Experimental work in the system Si–Al–Na–O has shown that albite breaks down to form jadeite plus quartz at about 30 kbar (Bell and Roseboom, 1969). Vredevoogd and Forbes (1975) investigated the influence of pressure on the solubility of kosmochlor in diopside and suggested that the solubility decreases with increasing pressure and that the limit of solubility can be extrapolated to about 45 kbar. However, Sobolev et al. (1975) reported high solubility of kosmochlor (up to 44% $NaCrSi_2O_6$) in diopside intergrown with diamond in a very high pressure paragenesis which is at variance with the experimental results of Vredevoogd and Forbes (1975).

There is no experimental work on solubility of kosmochlor in omphacite. Cr-bearing omphacites have been documented in eclogite xenoliths from southern Indian kimberlites which record pressures mostly in the range of 35–40 kbar (Patel et al., 2006, 2009). These pressures were calculated from the CrCa-tschermak–in–clinopyroxene geobarometer of Nimis and Taylor (2000). Cr-bearing diopsides in garnet pyroxenite xenoliths from southern Indian kimberlites yield pressures mostly in the range of 25–35 kbar (Patel et al., 2009). From these values of pressures, it is likely that the concentrate clinopyroxenes from the WKF and NKF have equilibrated at pressures up to 40 kbar.

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