



# Crystalline inclusions and C isotope ratios in diamonds from the Snap Lake/King Lake kimberlite dyke system: evidence of ultradeep and enriched lithospheric mantle

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## Abstract

U-type paragenesis inclusions predominate (94.7%) among the crystalline inclusion suite of 115 diamonds (−4+2 mm) obtained from the recently discovered Snap Lake/King Lake (SKL) kimberlite dyke system, Southern Slave, Canada. The most common inclusions are olivine (90) and enstatite (22). Sulfide, Cr-pyrope, chromite and Cr-diopside inclusion are less abundant (15, 10, 5 and 1, respectively). Results of the inclusion composition study demonstrate the following. (a) The relatively enriched character of the mantle parent rocks of the U-type diamonds. The average Mg# of olivine inclusions is 92.1, and of enstatite inclusions average 93.3. CaO content in Cr-pyrope inclusions is relatively high (3.73–5.75 wt.%). (b) Four of ten U-type Cr-rich pyrope inclusions contain a majoritic component up to 16.8 mol.% which requires pressures of ~110 kbar. Carbon isotope compositions for 34 diamonds with U-type inclusions have a  $\delta^{13}\text{C}$  range from −3.2‰ to −9‰ with a strong peak around −3.5‰. This is much heavier than the ratios of U-type diamonds from Siberia and South Africa (~4.5‰). Diamonds with olivine inclusions can be divided into two groups based on their  $\delta^{13}\text{C}$  values as well as the Mg# and Ni/Fe ratio in the olivines. Most show a narrow range of  $\delta^{13}\text{C}$  values from −3.2‰ to −4.8‰ (average −3.72‰) and have olivine inclusions with Mg# less than 92.3 and relatively high Fe/Ni ratios. A second group is characterized by a much wider variation of C isotope composition ( $\delta^{13}\text{C}$  varies from −3.8‰ to −9.0‰, average −5.97‰), and the olivine inclusions having a higher Mg# (up to 93.6) and relatively low Fe/Ni ratios. This difference in the C isotope composition may have several explanations: (a) peculiarities of asthenosphere degassing coupled with an abnormal thickness of lithosphere; (b) the abnormal thickness and enriched character of lithospheric mantle; (c) involvement of subducted C of crustal origin in the processes of the diamond formation. The presence of subcalcic Cr-rich majorite (up to 17 mol.%) pyropes of low-Ca harzburgite paragenesis among the crystalline inclusion suite of SKL diamonds is strong evidence for the existence of diamondiferous depleted peridotite in lithospheric mantle at depth near 300 km beneath Southern Slave area and is postulated to be one of the main reasons for the much heavier C isotope composition of SKL U-type diamonds in comparison with those from Siberian and South African kimberlites.

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**Keywords:** Crystalline inclusions; Carbon isotopes; Diamonds; Lithospheric mantle; Slave Craton

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## 1. Introduction

The kimberlite dyke system of the Snap Lake/King Lake (SKL) area, Southern Slave Craton, Canada was discovered by Winspear Resources, a junior Canadian exploration company, in 1997. In terms of kimberlite characteristics and geometry of ore-bodies it represents a new type of large primary diamond deposits (Pokhilenko et al., 1998, 2000). The age of SKL kimberlite emplacement was estimated as near 540 Ma (Agashev et al., 2001), much older compared to kimberlites of Central and Northern Slave (47–84 and –170 Ma, respectively) and similar to neighboring Kennady Lake area kimberlites (Carlson et al., 1999). Petrochemical, geochemical and isotope features of SKL kimberlites are different from both Group 1 and Group 2 kimberlites (Agashev et al., 2001). An abnormally wide range of Cr<sub>2</sub>O<sub>3</sub> (up to 17 wt.%) in garnets, and a very high proportion of high-Cr chromites (up to 27% of chromites with >62 wt.% Cr<sub>2</sub>O<sub>3</sub>) together with other specific geochemical and isotope characteristics of the kimberlites allowed to propose an abnormal thickness of lithosphere beneath the SKL area (Pokhilenko et al., 2000, 2001; Agashev et al., 2001; McLean et al., 2001).

A preliminary study of the SKL diamonds and their inclusions provided additional evidence for a relatively undepleted and abnormally thick predominantly peridotitic lithosphere beneath the Southern Slave (Pokhilenko et al., 2001). It showed a significant increase of <sup>13</sup>C proportion in the SKL U-type diamonds isotope composition (Reutsky et al., 2002) compared to world-wide data for diamonds of the same type of paragenesis (Van Heerden et al., 1995), and this feature can also be connected with abnormal thickness of the SKL area lithosphere. Further evidence for an increasing thickness of the lithosphere beneath the Slave Craton from north to south is based on a comparative study of peculiarities of the pyrope composition distribution in the craton kimberlites (Grütter et al., 1999), and the petrology and geochemistry of upper mantle xenoliths in these kimberlites (Kopylova and Garo, 2001; Kopylova et al., 1999).

A preliminary data suggesting about the abnormally thick and relatively undepleted lithospheric mantle beneath the Southern Slave, and especially beneath the Snap Lake area, is an important additional information on this region lithosphere structure and com-

position. A valuable data of this kind for the most deep-seated portion of the lithosphere cross-section can be obtained from a complex study of diamonds from the Southern Slave kimberlites. This paper includes results of detail study of crystalline inclusions and C isotope composition of representative collection of the SKL diamonds.

## 2. Methods

Major elements were obtained with a CAMEBAX electron microprobe using a wide range of natural minerals and synthetic glass standards at the Analytical Center of the United Institute of Geology, Geophysics and Mineralogy (UIGGM), Siberian Branch of Russian Academy of Sciences, Novosibirsk, Russia. Most inclusions were recovered for analysis after burning of their host diamond crystals, but more than 20 diamonds were polished to expose their inclusions. Special attention was paid to the analysis of the majorite-bearing subcalcic Cr-pyropes: 7–23 high precision analyses each were performed for the accurate determination of Si excess.

Some of inclusions were re-analyzed for a major-elements with a CAMECA SX-50 electron microprobe at the University of Tennessee. As it was shown before (Taylor et al., 1996) there are no signs of any influence of the burning of diamonds on composition of their garnet and Cpx inclusions.

C-isotopes were also analyzed at the UIGGM Analytical Center using a Finigan-MAT Delta mass spectrometer with a typical precision of  $\delta^{13}\text{C} < 0.2\%$ . Methods and techniques of diamond crystal preparation were described in detail previously (Reutsky et al., 1999). Isotopic composition is given in delta notation (parts per thousand) as the deviation from the VPDB standard.

## 3. Distribution and composition of mineral inclusions in SKL diamonds

Mineral inclusions from 115 diamonds from the SKL dyke system have been studied. All studied diamonds are –4+2 mm in size, 75% of them are colorless octahedrons, the rest are crystals of transitional habit (octahedral to dodecahedra) and spinel

twins. Rare crystals have a pale smoky and greenish tint.

Inclusions of U-type paragenesis predominate (94.7%) and most common are olivines. They were found in 90 diamonds. In 65 crystals olivine is present alone with up to five separate inclusions in a single diamond, and in 25 diamonds olivine coexist with other U-type paragenesis mineral. Enstatites were found in 22 crystals, and in 10 it is present as a monomineral inclusion (up to three separate inclusions within a single diamond crystal). Sulfide, Cr-pyrope, chromite and Cr-diopside are less abundant (in 15, 10, 5 and 1 diamond, respectively). U-type mineral associations in single diamonds are: olivine + sulfide (9), olivine + enstatite (8), Cr-pyrope + olivine (4), chromite + sulfide (2), Cr-pyrope + olivine + enstatite (2), chromite + olivine + enstatite (1), olivine + chromite (1), Cr-pyrope + sulfide (1) and enstatite + Cr-diopside (1).

E-type inclusions are represented by clinopyroxene (5 diamonds), yellow-orange garnet (2) and sulfide (1) with the following associations in single diamonds: garnet + clinopyroxene + sulfide (1) and garnet + clinopyroxene (1).

### 3.1. Olivine inclusions

Olivine inclusions are characterized by a relatively narrow range in composition (Fig. 1; Table 1). About 80% have Mg# from 91.8 to 93.0, and one inclusion has Mg# less than 91 (SL<sub>5</sub>-44 = 90.7). Olivine inclusions in two diamonds have Mg# higher than 93 (SL<sub>3</sub>-20 = 93.6; SL<sub>5</sub>-14 = 95.2). NiO varies in from 0.29 to 0.43 wt.% but more than 80% have NiO contents from 0.33 to 0.37 wt.%. There is unusual tendency of the negative correlation of NiO content and Mg# (Fig. 1).

Cr<sub>2</sub>O<sub>3</sub> varies from 0.01 to 0.07 wt.%; CaO—from 0.01 to 0.05 wt.%. The maximum compositional variation of separate multiple olivine inclusions within a single diamond is 0.3 in their Mg#, and usually they are less than 0.3, and only in two samples these differences reach 0.5: SL<sub>5</sub>-51 (five separate olivine inclusions, Mg# varies from 92.2 to 92.7); SL-00/133 (two inclusions, Mg#: 92.2–92.7).

### 3.2. Enstatite inclusions

Thirty separate enstatites from 20 diamonds (one to three within a single diamond) mostly have a narrow

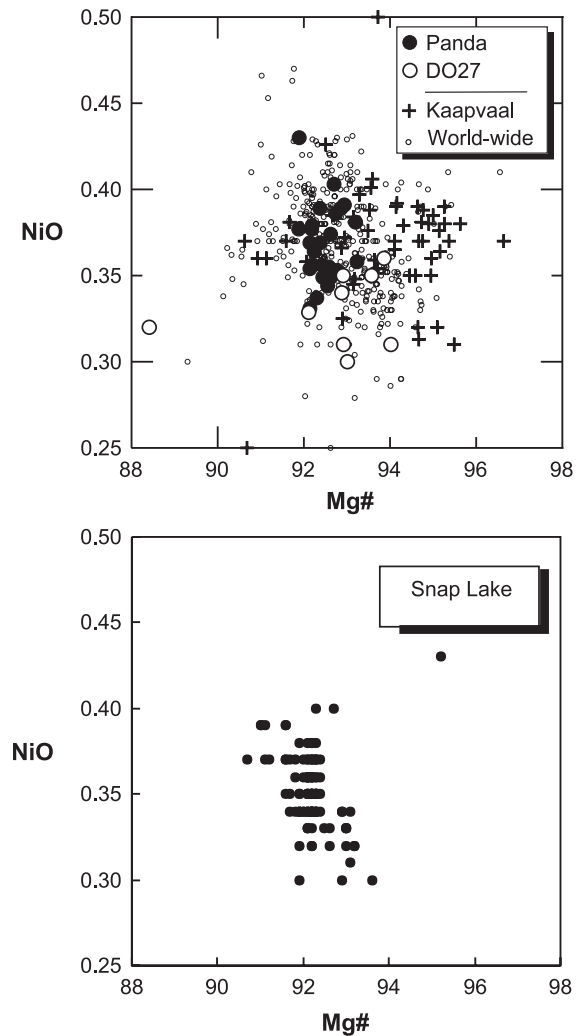


Fig. 1. Mg# vs. NiO for olivine inclusions from diamonds of Panda and DO27 (Slave Craton, Canada), the Kaapvaal Craton and World-wide (all from Stachel et al., 2003), and from the SKL diamonds.

range of composition: in 15 diamonds FeO content ranges from 4.4 to 4.8 wt.%, and only in inclusions from five diamonds these values are outside of this range (3.01, 3.97, 3.98, 4.34 and 6.29 wt.%, respectively; Figs. 2 and 3; Table 2). Al<sub>2</sub>O<sub>3</sub> contents of enstatites inclusions from 18 diamonds vary from 0.4 to 0.6 wt.%. The lowest value (0.35 wt.%) was obtained for an enstatite-Cr-diopside intergrowth (SL5-100, Table 2), which also has lowest Cr<sub>2</sub>O<sub>3</sub> content (0.26 wt.%) but highest-CaO (0.42 wt.%)

Table 1  
Representative analyses of olivine inclusions in SKL diamonds

	SL5-14	SL3-20	SL5-64	SL3-28	SL-00/133	SL3-31	SL5-8	SL3-12	SL3-37	SL5-44
SiO <sub>2</sub>	41.7	41.0	41.7	40.9	40.6	41.7	41.3	40.9	41.6	41.0
Cr <sub>2</sub> O <sub>3</sub>	0.07	0.02	0.02	0.02	0.03	0.07	0.02	0.03	0.07	0.07
FeO	4.70	6.34	6.69	7.13	7.13	7.51	7.83	7.83	7.42	9.09
MnO	0.05	0.10	0.09	0.09	0.08	0.11	0.12	0.10	0.11	0.13
MgO	52.4	52.1	51.2	51.7	51.0	50.2	50.0	50.8	50.0	49.5
CaO	0.01	0.01	0.01	0.02	0.02	0.03	0.02	0.01	0.03	0.01
NiO	0.43	0.29	0.32	0.30	0.40	0.34	0.38	0.34	0.37	0.37
Total	99.4	99.9	100.0	100.2	99.3	100.0	99.7	100.0	100.1	100.2
Mg#	95.2	93.6	93.2	92.8	92.7	92.3	91.9	92.0	91.8	90.7

and FeO (6.29 wt.%). Sample SL5-96 has the highest Al<sub>2</sub>O<sub>3</sub> (0.68 wt.%) and Cr<sub>2</sub>O<sub>3</sub> (0.49 wt.%) content and the lowest CaO (0.16 wt.%) and FeO (3.98 wt.%). There is definite negative correlation of Al<sub>2</sub>O<sub>3</sub> and FeO contents (Fig. 2).

The majority of the enstatites have Cr<sub>2</sub>O<sub>3</sub> and CaO contents between 0.3 and 0.4 wt.%. Practically all the multiple (2–3) separate enstatite inclusions within a single diamond have very similar composition. Only in one diamond crystal three enstatite inclusions show a range in Mg# from 92.9 to 93.7.

### 3.3. Garnet inclusions

Thirteen garnet inclusions from 12 diamond crystals were analyzed (Table 3, Figs. 4 and 5), 11 of them are Cr-pyropes (from 10 diamonds), and two are E-type garnets. Cr<sub>2</sub>O<sub>3</sub> content in Cr-pyrope

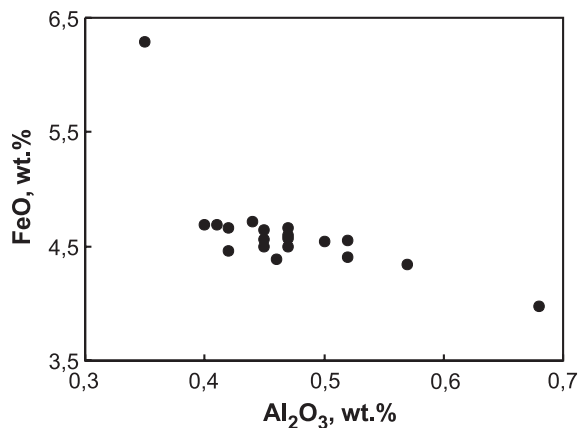


Fig. 2. Al<sub>2</sub>O<sub>3</sub> vs. FeO for enstatite inclusions from the SKL diamonds: there is negative correlation of Al and Fe contents.

inclusions varies from 7.71 to 12.8 wt.%, CaO from 3.73 to 5.75 wt.%, TiO<sub>2</sub> from <0.01 to 0.19 wt.%, and Mg# from 82.9 to 86.7. One E-type garnet (SL5-

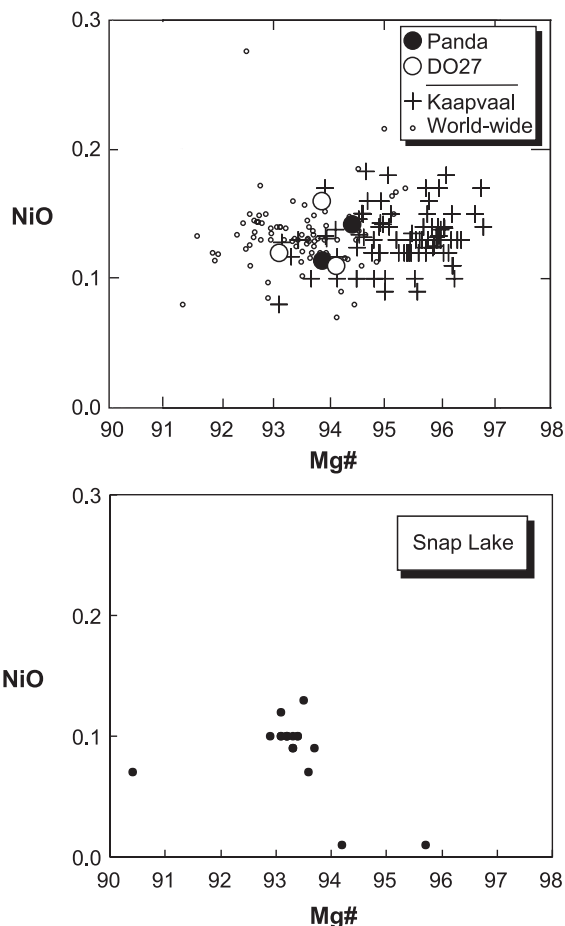


Fig. 3. Mg# vs. NiO for enstatite inclusions in diamonds from Panda and DO27 (Slave Craton, Canada), the Kaapvaal Craton and World-wide (all from Stachel et al., 2003), and from the SKL diamonds.

Table 2  
Representative analyses of enstatite and clinopyroxene inclusions in SKL diamonds

	SL <sub>5</sub> -14	SL <sub>5</sub> -96	SL <sub>3</sub> -41	SL <sub>5</sub> -8	SL <sub>3</sub> -12	SL <sub>5</sub> -100	SL <sub>5</sub> -86	SL <sub>5</sub> -6	SL <sub>5</sub> -52
SiO <sub>2</sub>	57.2	57.3	58.7	57.4	58.4	58.0	55.4	55.0	55.1
TiO <sub>2</sub>	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.49	0.45
Al <sub>2</sub> O <sub>3</sub>	0.32	0.68	0.57	0.42	0.41	0.35	0.82	7.42	8.66
Cr <sub>2</sub> O <sub>3</sub>	0.46	0.49	0.34	0.30	0.33	0.26	1.36	0.02	0.04
FeO	3.01	3.98	4.34	4.66	4.69	6.29	2.53	8.18	6.73
MnO	0.09	0.08	0.12	0.12	0.12	0.15	0.12	0.10	0.12
MgO	38.3	36.4	35.7	36.0	36.1	33.4	16.7	9.10	11.8
CaO	0.26	0.16	0.35	0.37	0.35	0.42	21.2	15.0	9.20
Na <sub>2</sub> O	0.04	0.02	0.04	0.06	0.06	0.03	0.42	4.16	5.16
K <sub>2</sub> O	–	–	–	–	–	–	0.71	0.03	0.23
NiO	n.d.	n.d.	0.07	0.10	0.10	0.07	n.d.	n.d.	n.d.
Total	99.7	99.1	100.2	99.4	100.6	99.0	99.3	99.5	98.2
Mg#	93.4	94.2	93.6	93.2	93.2	90.4	92.2	66.5	75.8

86) has very low Mg# (38.8) combined with high TiO<sub>2</sub> (1.44 wt.%), CaO (10.6 wt.%) Na<sub>2</sub>O (0.38 wt.%). The second (SL<sub>5</sub>-6) is practically twice in Mg# (65.5), has less than 1/3 TiO<sub>2</sub> (0.44 wt.%) and CaO (3.03 wt.%), but comparable Na<sub>2</sub>O (0.33 wt.%). Both have Si excess (3.061 and 3.050, respectively) corresponding to a majorite component of 6.1 and 5.0 mol%, respectively.

The majorite component is highest in two Cr-rich, high-Mg, subcalcic pyrope inclusions (SL<sub>3</sub>-31 and SL<sub>3</sub>-30, Table 3). Excess Si is 3.116 and 3.168 corresponding to 11.6 and 16.8 mol% majorite, respectively). Excess of Si in the structural formulae of these Cr-pyropes perfectly corresponds to the deficit of Al+Cr (1.755 and 1.590).

### 3.4. Clinopyroxene inclusions

Clinopyroxene inclusions were found in 6 SKL diamonds, and in five they are E-type clinopyroxenes (Table 2). They are omphacites (jadeite component content from 24.9 to 36.2 mol%, Mg# from 66.5 to 75.8) with high TiO<sub>2</sub> contents (up to 0.49 wt.% and most of all high K<sub>2</sub>O: two discrete inclusions in a single diamond (SL<sub>5</sub>-52) contain 1.27 and 1.37 wt.% K<sub>2</sub>O and the omphacite in diamond SL<sub>5</sub>-92 contains 1.05 wt.% of K<sub>2</sub>O. The highest K<sub>2</sub>O content in the studied omphacite inclusion is more than extreme values for the clinopyroxene inclusions in diamonds of the Guaniamo area, Venezuela, and less than in diamonds from the Argyle pipe (Fig. 6).

Table 3  
Representative analyses of garnet inclusions in SKL diamonds

Sample	SL-00/133	SL <sub>5</sub> -8	SL <sub>5</sub> -5	SL <sub>5</sub> -2	SL <sub>3</sub> -12	SL <sub>3</sub> -5	SL <sub>3</sub> -3	SL <sub>3</sub> -31 $\bar{x}_{23}(\delta)$	SL <sub>3</sub> -30 $\bar{x}_7(\delta)$	SL <sub>5</sub> -6	SL <sub>5</sub> -86
Paragenesis	U-type Cr-pyropes									E-type garnets	
SiO <sub>2</sub>	41.2	41.1	42.0	41.5	41.3	40.5	40.9	42.2 (0.28)	42.3 (0.22)	42.1	40.1
TiO <sub>2</sub>	0.05	<0.01	0.06	0.06	0.13	0.16	0.03	0.19 (0.01)	0.06 (0.01)	0.44	1.44
Al <sub>2</sub> O <sub>3</sub>	16.7	16.3	17.2	16.2	15.2	13.9	14.7	12.3 (0.12)	9.46 (0.09)	21.7	19.9
Cr <sub>2</sub> O <sub>3</sub>	7.71	8.01	8.37	9.03	10.2	11.2	11.5	11.8 (0.19)	12.8 (0.16)	0.07	0.02
FeO	7.38	6.46	6.06	6.38	6.5	6.52	21.2	6.52 (0.09)	7.64 (0.18)	15.5	20.2
MnO	0.33	0.29	0.28	0.32	0.32	0.32	0.28	0.32 (0.02)	0.33 (0.02)	0.34	0.36
MgO	20.0	21.5	22.2	21.5	21.1	19.9	21.2	21.1 (0.17)	21.2 (0.10)	16.6	7.19
CaO	5.75	4.68	3.73	4.39	4.76	5.91	4.44	4.68 (0.10)	5.11 (0.07)	3.03	10.6
Na <sub>2</sub> O	0.02	0.02	<0.01	0.03	0.03	0.02	0.02	0.03 (0.02)	0.01 (0.01)	0.33	0.38
Total	99.1	99.0	99.9	99.4	99.5	98.4	99.4	99.1 (0.32)	99.0 (0.21)	100.1	100.2
Mg#	82.9	85.5	86.7	85.7	85.2	84.4	85.9	85.2	83.2	65.5	38.8
MJ. mol.%	2.2	–	2.3	1.0	0.9	0.8	0.4	11.6	16.8	5.0	6.1

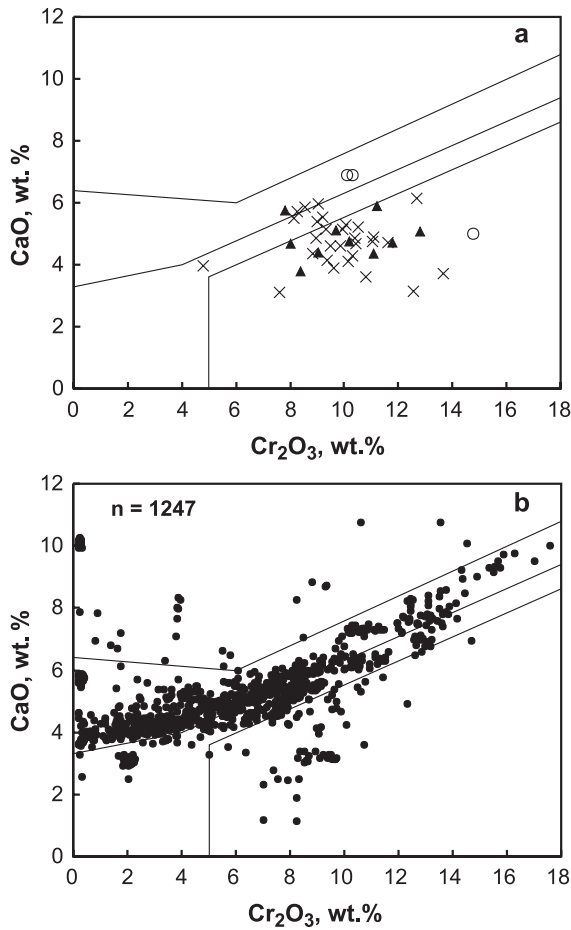
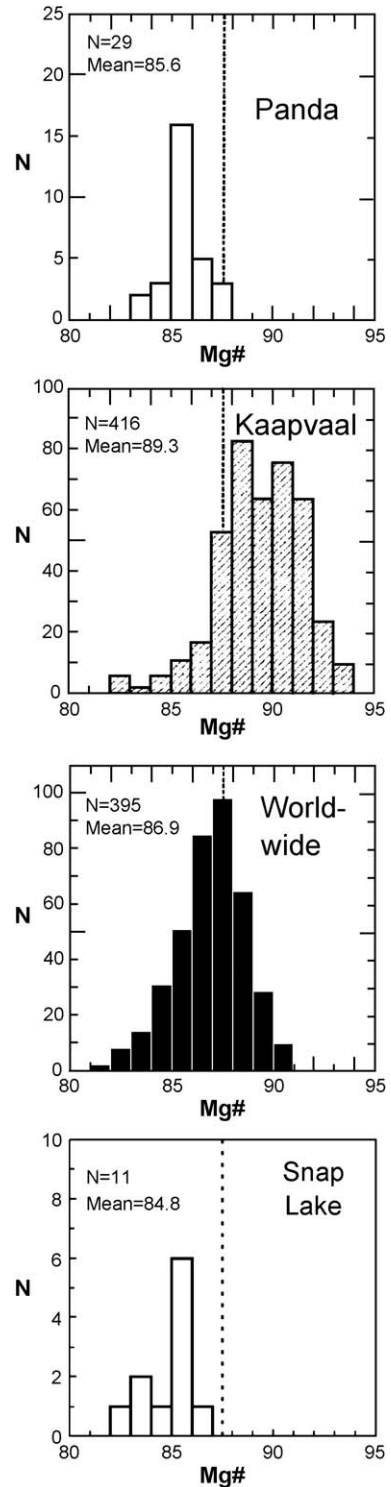


Fig. 4.  $\text{Cr}_2\text{O}_3$  vs.  $\text{CaO}$  (plot after Sobolev et al., 1973) for Cr-pyrope inclusions from the SKL diamonds (solid triangles), Panda Pipe diamonds ( $\times$ , from Stachel et al., in press), and DO27 Pipe diamonds (open circles, from Davies et al., 1999) (a), and Cr-pyropes from concentrate of the SKL kimberlite (b).

A single inclusion of U-type clinopyroxene in diamond SL<sub>5</sub>-100 has a quite unusual composition:  $\text{K}_2\text{O}$  (0.71 wt.%) is significantly higher than  $\text{Na}_2\text{O}$  (0.42 wt.%). This feature makes the inclusion unique among previously studied U-type clinopyroxene inclusions in diamonds.

Fig. 5. Histogram showing the distribution of Mg# for Cr-pyrope inclusions from diamonds of the Panda pipe, Kaapvaal Craton, World-wide data (all from Stachel et al., 2003), and from the SKL diamonds.





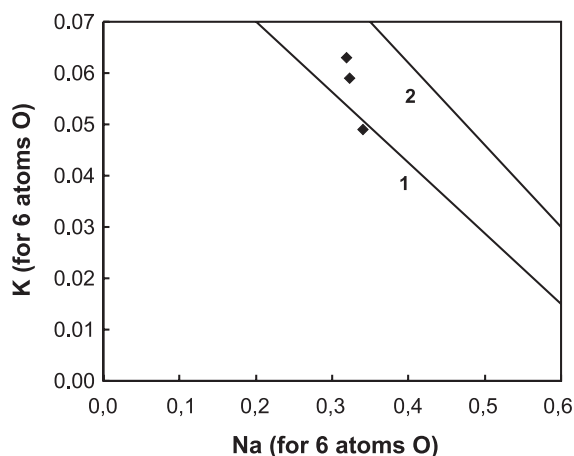


Fig. 6. Na vs. K in molecules of K-enriched clinopyroxene inclusions in the SKL diamonds (see Table 2 for analyses). Lines 1 and 2 bound estimated solubility limits of K in clinopyroxenes from Guaniamo diamonds (Venezuela), and Argyle diamonds (Western Australia), respectively (Sobolev et al., 1998).

### 3.5. Mg-chromite inclusions

Chromite inclusions were identified in six diamonds: in one sample as monomineral inclusion, in two samples in association with sulfides, in one in association with separate olivines, and in another as intergrowth with olivine and enstatite (SL<sub>5</sub>-14). Quite unusual is the presence of relatively low-Cr inclusions in two diamonds (SL<sub>5</sub>-64-55.6 wt.% Cr<sub>2</sub>O<sub>3</sub> and SL<sub>5</sub>-104-59.1 wt.% Cr<sub>2</sub>O<sub>3</sub>, Table 4). Two separate inclusions in diamond SL<sub>5</sub>-64 are significantly different in composition (SL<sub>5</sub>-64a and SL<sub>5</sub>-64b) with 55.6 and 64.4 wt.% Cr<sub>2</sub>O<sub>3</sub>, 12.5 and 4.79 wt.% Al<sub>2</sub>O<sub>3</sub>, –14.3 and 13.8 wt.% MgO, respectively. An abnormal difference in Cr<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub> contents in chromite inclusions from a single diamond makes this situation unique worldwide diamond makes this situation unique worldwide (Sobolev and Yefimova, 1998; Bulanova, 1995) and demonstrate a significant evolution of the upper mantle matter composition along the diamond growth history. All chromite inclusions have low TiO<sub>2</sub> content (0.05–0.11 wt.%).

## 4. Carbon isotope composition

Carbon isotopes have been determined for 34 diamonds with U-type inclusions (olivine, enstatite), one

with E-type inclusions (garnet + cpx), and four without inclusions (Table 5). The E-type diamond has  $\delta^{13}\text{C} = -13.4\text{‰}$ . Most of U-type diamonds have a narrow range of  $\delta^{13}\text{C}$  –3.2‰ to –5.1‰ (37 diamonds) with a strong peak at –3.5‰ to –4.5‰ (Fig. 7), and only one diamond has  $\delta^{13}\text{C}$  of –9.0‰. An average for the U-type SKL diamonds is –4.02‰. This is definitely heavier compared to U-type diamonds from Siberia and South Africa (around –4.5‰) (Fig. 7).

The predominate diamonds with the narrow range of  $\delta^{13}\text{C}$  from –3.2‰ to –4.8‰ ( $n=24$ , average –3.72‰) have olivine inclusions with Mg# less than 92.3 and relatively high Fe/Ni ratios (Reutsky et al., 2002). Diamonds with higher  $\delta^{13}\text{C}$  but also some from the heavier group have higher Mg# of their olivines (up to 93.6) and relatively low Fe/Ni ratios (Fig. 8).

## 5. Discussion

The small proportion of E-type mineral inclusions in SKL diamonds, and the dominance of depleted peridotites point to a mostly harzburgitic lithospheric mantle beneath the SKL area at depth corresponding to the diamond stability field. Also previous studies of the Slave Craton kimberlites, diamond inclusions and upper mantle xenoliths point to a significant increase in lithosphere thickness toward the south of the craton which may reach 300 km at time of kimberlite emplacement (Cambrian) (Pokhilenko et al., 1998, 2000, 2001;

Table 4  
Representative analyses of chromite inclusions in SKL diamonds

	SL <sub>5</sub> -64a	SL <sub>5</sub> -64b	SL <sub>5</sub> -104	SL <sub>3</sub> -14	SL <sub>5</sub> -14
SiO <sub>2</sub>	0.26	0.24	0.10	0.11	0.09
TiO <sub>2</sub>	0.09	0.11	0.05	0.08	0.11
Al <sub>2</sub> O <sub>3</sub>	12.5	4.79	11.2	7.37	7.40
Cr <sub>2</sub> O <sub>3</sub>	55.6	64.4	59.1	62.6	63.3
FeO	15.5	15.3	14.5	15.7	13.6
MnO	0.12	0.19	0.14	0.20	0.17
MgO	14.3	13.8	14.9	13.8	14.4
NiO	0.13	0.13	0.13	0.11	0.11
Total	98.5	99.0	100.1	100.0	99.2
Mg#	62.2	61.6	64.7	61.0	65.4
Ca/(Ca + Al)	74.9	90.0	78.0	85.1	85.2

Table 5  
Carbon isotope composition of the SKL diamonds

Sample	$\delta^{13}\text{C}$ , ‰	Mineral inclusions (type of paragenesis)	Sample	$\delta^{13}\text{C}$ , ‰	Mineral inclusions (type of paragenesis)
SL <sub>5</sub> -21/00	– 3.2	Ol + Enst (U)	SL <sub>5</sub> -40/00	– 3.8	Ol (U)
SL <sub>5</sub> -25/00	– 3.2	Ol (U)	SL <sub>3</sub> -13/00	– 3.9	Ol (U)
SL <sub>5</sub> -36/00	– 3.2	Ol (U)	SL <sub>5</sub> -37/00	– 3.9	Ol + Enst (U)
SL <sub>5</sub> -22/00	– 3.3	Ol (U)	SL <sub>5</sub> -49/00	– 3.9	Ol (U)
SL <sub>5</sub> -38/00	– 3.3	Ol (U)	SL <sub>3</sub> -7/00	– 4.0	Ol (U)
SL <sub>5</sub> -42/00	– 3.3	Enst (U)	SL <sub>5</sub> -31/00	– 4.0	Ol + Enst (U)
SL <sub>5</sub> -58/00	– 3.3	Ol (U)	SL <sub>5</sub> -13/00	– 4.2	Ol (U)
SL <sub>5</sub> -60/00	– 3.3	Ol (U)	SL <sub>5</sub> -45/00	– 4.2	Ol (U)
SL <sub>5</sub> -95/00	– 3.3	–(?)	SL <sub>5</sub> -94/00	– 4.2	Ol (U)
SL <sub>3</sub> -27/00	– 3.4	Enst (U)	SL <sub>5</sub> -74/00	– 4.3	Ol (U)
SL <sub>3</sub> -3/00	– 3.5	Pyr (U)	SL <sub>5</sub> -61/00	– 4.5	Ol + Enst (U)
SL <sub>5</sub> -76/00	– 3.5	Ol (U)	SL-00/47	– 4.8	–(?)
SL <sub>3</sub> -18/00	– 3.6	Ol (U)	SL <sub>5</sub> -24/00	– 4.8	Ol (U)
SL <sub>5</sub> -59/00	– 3.6	Ol + Enst (U)	SL <sub>5</sub> -32/00	– 4.9	Ol (U)
SL <sub>3</sub> -4/00	– 3.7	Ol (U)	SL <sub>5</sub> -39/00	– 4.9	Enst (U)
SL <sub>3</sub> -12/00	– 3.7	Ol + Enst + Pyr (U)	SL-00/10	– 5.1	–(?)
SL <sub>3</sub> -29/00	– 3.7	Ol (U)	SL <sub>3</sub> -20/00	– 5.1	Ol (U)
SL <sub>5</sub> -8/00	– 3.7	Ol + Enst + Pyr (U)	SL <sub>3</sub> -28/00	– 9.0	Ol (U)
SL <sub>5</sub> -30/00	– 3.7	Ol (U)	SL <sub>5</sub> -86/00	– 13.9	Gt + Cpx (E)
SL-00/12	– 3.8	–(?)			

Agashev et al., 2001). Upper mantle xenoliths studies allow to conclude that lithospheric thickness was 160–190 km in the northern part of the Slave Craton (Kopylova et al., 1999), near 200 km in the central Slave (Pearson et al., 1999), and at a minimum 230 km in the southern part (Kennedy Lake area) of the Slave Craton (Kopylova and Garo, 2001). Also evaluation of the garnet compositions in Slave Craton kimberlites demonstrate a progressive increase of maximum Cr<sub>2</sub>O<sub>3</sub> content in pyropes from northern to southern kimberlites of the craton (Grütter et al., 1999).

Presence of high-Cr high-Mg subcalcic pyrope inclusions in SKL diamonds is definitely related to diamondiferous depleted ultramafic rocks of the lithospheric mantle, and SKL diamonds were at least in part formed at depths exceeding 300 km. From experiments modeling natural ultramafic systems, pressures of at least 110 kbar are required to achieve dissolution of 16–17 mol% majorite component in a magnesian garnet (Irifune, 1987, Fig. 9), and such pressures correspond to depth over 300 km. Other indications that some SKL diamonds were formed at very high pressures are: (a) cpx inclusions with high K<sub>2</sub>O in both E-type (up to

1.37 wt.%) and U-type (0.71 wt.%) paragenesis: the values which are among the highest recorded for diamond inclusions worldwide (Fig. 6); (b) both E-type garnets contain significant Na<sub>2</sub>O, and one of them (SL<sub>5</sub>-6) has Na content (0.046 for 12 atoms of O) significantly higher than Ti (0.024 for 12 atoms of O). Furthermore absence of *P* (<0.001 for 12 atoms of O) suggests that the reaction R<sup>2+</sup>Alk→NaSi may occur accompanied by partitioning of Si into octahedrally coordinated sites (Sobolev and Lavrent'ev, 1971). Thus about 1/3 of all analyzed U-type garnets from SKL diamonds demonstrate the presence of majorite component. This is in contrast with the data for diamond inclusions from Siberian kimberlites where only few microdiamonds contain majoritic garnet inclusions (Sobolev et al., 2004).

The lithospheric mantle beneath the SKL area is depleted but not to such an extent as, e.g., beneath the Kaapvaal Craton or the Siberian Craton as shown by: (a) by relatively low Mg# of olivine, enstatite and pyrope inclusions as well as by relatively high CaO contents of Cr-pyrope inclusions (average = 4.6 wt.%); (b) by the very uniform composition of olivines and enstatites (Figs. 1–3), as well as a



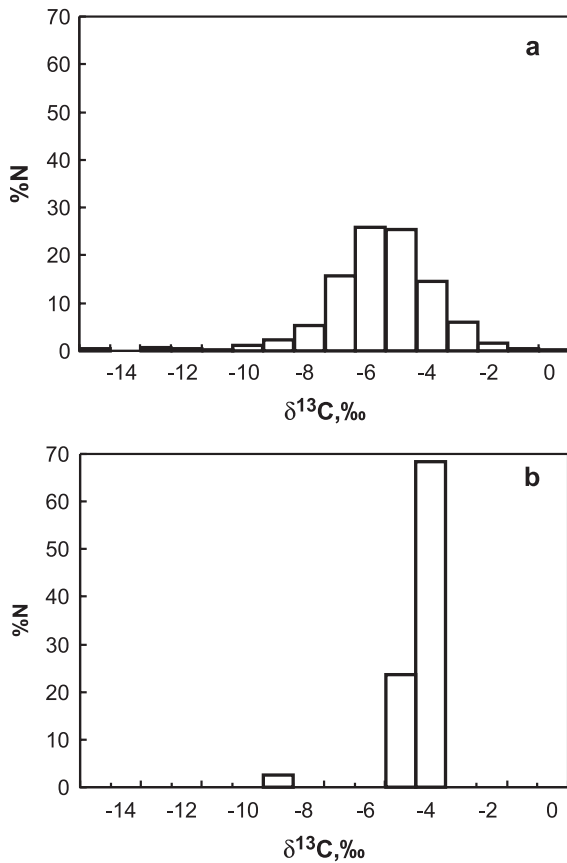


Fig. 7. Histogram showing distribution of C isotope composition of U-paragenesis diamonds worldwide (Van Heerden et al., 1995) (a), and U-paragenesis diamonds of SKL kimberlites (b).

comparative high abundance of enstatite inclusions in SKL diamonds.

As it was shown in the Galimov’s model (Galimov, 1991) the rising carbon-bearing fluid of asthenosphere origin is reduced and consists mainly of methane, and its carbon isotope composition is around  $\delta^{13}\text{C}$ -4.6‰. Methane oxidizes during its moving to the Earth surface with generation of  $\text{H}_2\text{O}$  and  $\text{CO}$ . A coefficient of carbon fractionation between the  $\text{CO}_2$  and  $\text{CH}_4$  in the diamond stability field is 1.004 (Galimov, 1991), and their carbon isotope composition will be related to proportion of these components. So, at  $\text{CO}_2/\text{CH}_4=0.1$   $\delta^{13}\text{C}$  of  $\text{CO}_2$  will be around  $-1\text{‰}$  and  $\text{CH}_4 \sim -5\text{‰}$ , and at  $\text{CO}_2/\text{CH}_4=0.5$   $\delta^{13}\text{C}$  will be  $\sim -3\text{‰}$  and  $-7\text{‰}$ , respectively. Thus it is possible to expect a decrease of  $^{13}\text{C}$

in  $\text{CO}_2$  toward the surface in the lithospheric mantle. It means that diamonds of the most deep-seated origin will be enriched by  $^{13}\text{C}$  if compare with less deep-seated ones.

The unusual distribution of  $\delta^{13}\text{C}$  and the heavy nature the carbon isotope composition of one group of SKL diamonds may be due to a number of reasons: (a) peculiarities of asthenosphere degassing causing fractionation of carbon isotopes during the oxidation of  $\text{CH}_4$  producing decrease of role of  $^{13}\text{C}$  with decrease of depth inside the lithospheric mantle cross-section (Galimov, 1991) coupled with abnormal thickness of the SKL region lithosphere; (b) abnormal thickness and relatively enriched character of the SKL area lithospheric mantle, and the second can be related with increase of  $^{13}\text{C}$  role in diamond C isotope composition (Van Heerden et al., 1995); (c) involve of subducted C of crustal origin in processes of diamond formation (Sobolev and Sobolev, 1980).

Formation of subcalcic Cr-pyrope inclusions with up to 17 mol% of a majorite component is firm evidence of existence of diamondiferous depleted peridotites within lithospheric mantle at depth not less than 300 km beneath the SKL area, and this feature may be the most important among the main reasons of

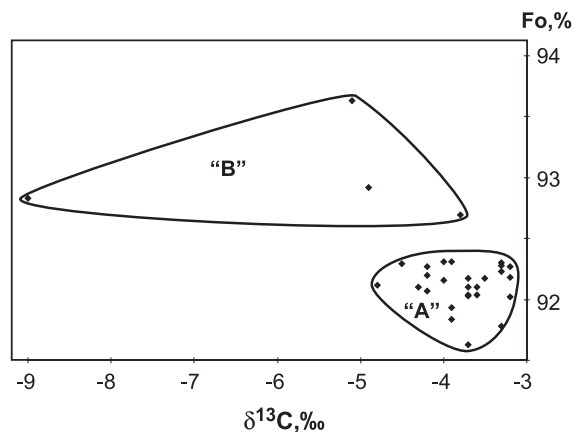


Fig. 8. Carbon isotope composition of SKL diamonds vs. Fo content of their olivine inclusions. “A”-group of diamonds ( $n=24$ ) with narrow variation of C-isotope composition and relatively low Fo olivine inclusions; “B”-diamonds ( $n=4$ ) with wide variation of C-isotope composition and relatively high-Fo olivine inclusions.

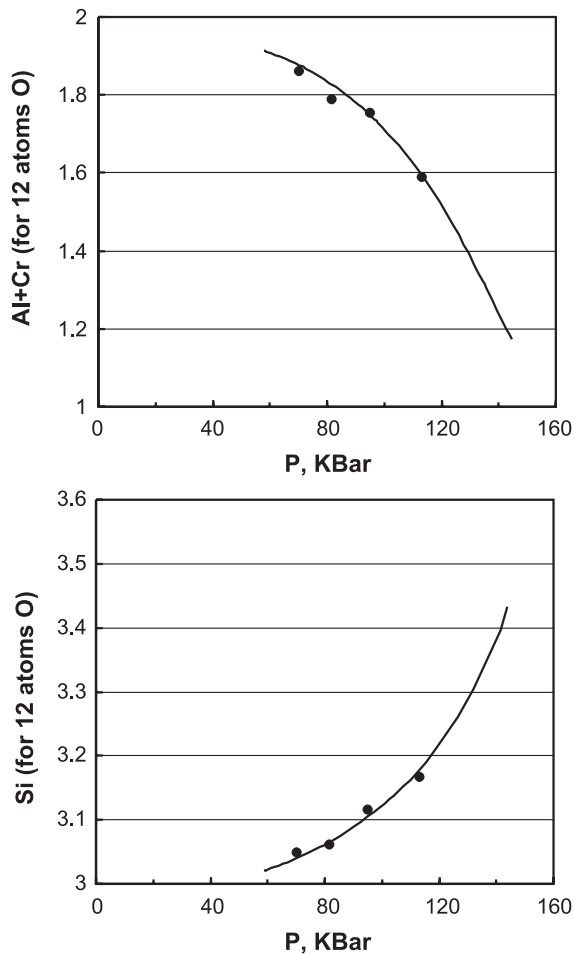


Fig. 9. Distribution of Si and Al+Cr in the structural formulae of majorite bearing garnet inclusions in the SKL diamonds. Calibration curves from (Irifune, 1987).

much heavier C isotope composition of the SKL kimberlite diamond population.

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