MINERALOGY OF THE MANTLE XENOCRYSTS FROM KL-1 (KELSEY LAKE) KIMBERLITE PIPE, COLORADO

IGOR VICTOROVICH ASHCHEPKOV¹, NIKOLAI VASILIEVICH VLADYKIN², ROGER H. MITCHELL³,
HOWARD COOPERSMITH³, GARANIN VICTOR GENADIEVICH¹, ANATOLIY ILIYCH SAPRYKIN¹, OLGA
STEPANOVNA KHMELNIKOVA¹ & GENADIY NIKITOVICH ANOSHIN¹

ABSTRACT Garnets, clinopyroxenes, spinels and ilmenites from the concentrate of KL-1 kimberlite pipe, (Kelsey lake) Front Range group, were analyzed to reconstruct the mantle section and the processes in the mantle beneath Wyoming craton. Garnets show a trend up to 12% Cr₂O₃ within the lherzolite field with decreasing frequency for deeper garnets. Several TiO₂ trends passing through all the Cr₂O₃ range suggest separate pulses of melt percolation. Their amount coincides with the amount of groups for Cr-diopsides. Deformed garnets – clinopyroxene intergrowths higher in TiO₂ are more heated (to 40-45 mv/m²) than individual grains. Ilmenites showing a long (polybaric) differentiation trend became more Cr-rich but spinels are essentially more Ti-rich Al-rich (shallow level) varieties. Trace elements for Cr-diopsides suggest participation of subduction-related material with high U content increase and HREE decrease according to AFC with garnet dissolution.

INTRODUCTION The concentrate of deep-seated minerals from the Colorado kimberlite pipe KL-1 (Kelsey Lake) was analyzed by EPMA in UIGGM SD RAS.

RESULTS Garnets (fraction +1) from this pipe reveal a long trend on the Cr₂O₃ – CaO diagram (up to 12% Cr₂O₃). (Fig.1) (Table.1).

From the beginning to 1% the pyropes with the elevated Fe# correspond to pyroxenites. The 1- 3% Cr₂O₃ interval parallel to Cr axis refers to lherzolites from Ga-Sp facies. In this diagram the pyropes from 4% Cr₂O₃ show a joint rise of the Cr₂O₃-CaO crossing the common lherzolite trend (Sobolev 1974). Variable inclination of garnet trends is a common feature found for kimberlite garnets in S.Africa (Burgess & Harte 2000), Jericho pipe (Kopylova *et al.* 1999) and Aldan kimberlites (Ashchepkov *et al.* 2000). This feature is evidently seen in garnet diagrams from the nearby located Iron Mountain kimberlite (Hausel 1998, WSGS web page) that have high proportion of G10 garnets possibly analyzed from a finer fraction.

Presence of separate clots (5) in linear trend is determined by capturing from the separate pressure intervals and mantle sections since the Cr- content is variable. Deviation to lower CaO values corresponds to the deformed garnet grains found in intergrowths with clinopyroxenes and spinels. They are also more ferriferous and their Fe# can't be explained by heating. (Fig.1). The frequency of the Cr- in garnets decreases in hyperbolic function reflecting the amount of the deep peridotite xenogenic material or it may be explained by the dissolving or lost of the deeper garnets or loss during magma upwelling. The Cr-Fe-Ti relations (Fig.1) suggests that even in the same pressure interval the lithology of the mantle substrate was not homogeneous and the rocks from the same interval were

probably modified by several stages of melt percolation (Cr-Ti trends). Relative amount of depleted rocks commonly rises with the depth. Cr-rich subcalcic garnet usually refer to depleted harzburgite affinity. But in this concentrate deformed garnets with intermediate Cr concentration found in intergrowth with spinels have lower CaO and TiO₂. They show a flat FeO trend on the Cr₂O₃-FeO diagram and are derived from the heated lherzolites relatively enriched in Fe but low in Ti.

Clinopyroxenes found in concentrate occurs in two main varieties. Those found in intergrowth with the fractured garnets are enriched in the Na₂O, Al₂O₃, Cr₂O₃ and FeO. Individual bright grains of Cr-diopsides have relatively low concentration of these components but higher TiO₂ content (Fig. 2)(Table.1).

Ilmenites from this pipe have Ti values that sometimes exceed the 1.0 in structural formula (Fig. 3, Table 1). Most of larger ilmenites contain irregular rutile exsolutions. These ilmenites came from desintegrated larger polycrystalline nodules (5-3 mm or more). Those polycrystalline fine grain aggregates sometimes include rounded rutile grains in intergranular space between polygonal ilmenites. More rarely these aggregates contain apatite and perovskite. One quartz grain (coesite originally) was found in contact with ilmenites.

In the variation diagrams at least 3-4 groups may be found judging on Ni, Al and Cr content. Trends with the different Al₂O₃ concentration suggest the differentiation of the liquid derived different proportion of garnets. Different Cr₂O₃-enrichment suggests diverse degree of contamination in wall rock peridotites and possibly varying lithology. Polycrystalline aggregates containing garnets and essential amount of serpentine have very high Cr₂O₃ concentration in ilmenite (>7%) and garnet (~11%). Two serpentine varieties – with

1 United Institute of Geology Geophysics and Mineralogy, SD RASc, 630090 Novosibirsk, academic V.A.Koptyug ave.3, garnet@uiggm.nsc.ru

2 Institute of the Geochemistry, SD RASc, 664033 Favorskii str.1a, vlad@ige.irk.ru

3 Lakehead University, 955 Oliver Rd., Thunder Bay, Ontario, Canada P7B 5E1 rmitchel@gale.lakeheadu.ca

high (56%) and low (~40%) SiO₂ content substitute Opx and Ol respectively (Table 2.). Origin of other Cr- bearing groups is problematic. Intermediate compositions between rutiles and common Ilmenites are explained by tiny exsolutions (Fig. 3)

Chromites from concentrate of this pipe reveal two main modes (Fig. 4, Table 1), but a more detailed histogram shows that there are at least 4-5 peaks and possibly capturing intervals. The highest contents of Cr₂O₃ (65-50%) probably refer to the minerals entrained from the deeper part of the mantle section (50-70 kbar) while 30-50% Cr₂O₃ should come from the rocks from the middle part, which refer to 3-5% Cr₂O₃ in garnets locating in the beginning of the ascending Cr₂O₃-CaO trend for the pyropes. The Ti enrichment rise in the less chromian spinels, which may suggest the evolution of parental melts and enrichment by metasomatic agents in the rising system. The chromites found in the intergrowth with garnets are located exactly on the mantle array and shows rather restricted compositional range (55-60% Cr₂O₃) that corresponds here to 5-7% in coexisting garnets.

TP conditions for mantle peridotites were determined using clinopyroxene thermobarometry (Nimis & Taylor 2000) and new Jd-Di barometer (Ashchepkov 2001). Separate grains of Cr- diopsides are located close to 35 mv/m² and between 35-40 mv/m² geotherms within the 30-50 kbar interval, but the clinopyroxenes in intergrowths with garnets produce the more heated branch (or branches) close to 45 mv/m². It suggests also at least two heating events which coincides with the amount of trends for Cpx and garnets (Fig. 5).

Trace elements determined by LAM ICP MS for four clinopyroxenes demonstrate common REE patterns for lithospheric mantle peridotites patterns with high La/Yb_n

ratios and divergent HREE. Trace element spidergram demonstrate no strong minima in HREE except for Ta and smaller for Nb but they reveal evident peak in U, Ba, Sr, which is typical for the subduction processes and was determined for mantle peridotites from Somerset island kimberlite (Schmidberger & Francis 2001) (Fig. 6, Table 3). Some fluctuations near Eu in one Cpx and some other minerals may suggest participation of the subducted material in melting and pyroxenite generation. Pyroxene found in intergrowth with garnets reveal lower HREE and lack of Sr and other peaks, which suggest the dissolution of garnet possibly by AFC process.

CONCLUSIONS Mantle section beneath the pipe KL-1 was subjected to several (at least two) stages of melt percolation that produced also the heating of mantle column. The earliest was followed by Ti- enrichment in minerals and should be produced by plume- related melts while the latest was followed by the Na, Al, Cr enrichment in pyroxenes and deformations in garnets. This section has no sheared lherzolites typical for the Lesotho (Nixon & Boyd 1973) or Udachnaya pipe (Boyd *et al.* 1997). It consists from 3 or 4 major units (probably Pxt+Ga-SpLhz - Ga-Lhz+deplLhz -Ga-Lhz+deformed Lhz +Hrz -Lhz +Ilm -Hrz). It is nearly continuously captured by the host kimberlites but the main portion of xenoliths was carried from 30-50 kbar interval where the lenses of coarse eclogite - like pyroxenites similar to the mantle beneath Jericho pipe (Kopylova *et al.* 1999), Chompolo field (Ashchepkov *et al.* 2000), and Aldan should exist. Subduction - related material participated in generation of Al-rich Cr- bearing pyroxenites and melt that produced the megacrysts .

References

- Ashchepkov I., Vladykin N., Ovchinnikov Yu., Anoshin G., Gerasimov P., Saprykin A. 2000. Thermal Gradient, Mantle Layering and Geochemistry beneath Aldan Shield According to the Kimberlitic Deep Seated Disintegrated Inclusions. *J. Confer. Abstr.*, v.5/2:162-163
- Ashchepkov I.V. 2001. Clinopyroxene Jd barometer for mantle peridotites and eclogites and thermal conditions of the lithospheric keels of cratons and their surroundings. Abstracts of annual GSA meeting, Boston 2001. November. Abstract ID 11658.
- Boyd F.R., Pokhilenko N.P., Pearson D.G., Mertzman S.A., Sobolev N.V., Finger L.W. 1997. Composition of the Siberian cratonic mantle: evidence from Udachnaya peridotites xenoliths. *Contrib. Mineral. Petrol.*, 128:228-246.
- Burgess R. & Harte B. Tracing Lithosphere Evolution through the Analysis of Heterogeneous G9/G10 Garnets in Peridotite xenoliths. I Major Element Chemistry. Proceedings of the VII International Kimberlite Conference. The P.H. Nixon volume. Pp.61-80.
- Hausel W.D. 1998. Diamonds and mantle source rocks in the Wyoming Craton, with a discussion of other US occurrences: Wyoming State Geological Survey Report of Investigations 53, 93 p.
- Kopylova M.G., Russell J.K., Cookenboo H. 1999. Petrology of peridotite and pyroxenite xenoliths from the Jericho kimberlite: Implications for the thermal state of the mantle beneath the Slave craton, northern Canada. *J. Petrol.*, 40:79-104.
- Nixon P.H. & Boyd F.R. 1973. Petrogenesis of the granular and sheared ultrabasic nodule suite in kimberlite. In: P.H. Nixon (ed.) *Lesotho Kimberlites*. Cape and Transvaal, Cape Town, pp. 48-56.
- Schmidberger S. S. & Francis D. 2001. Constraints on the Trace Element Composition of the Archean Mantle Root beneath Somerset Island, Arctic Canada. *J. Petrology.*, 42:1095-1117.
- Sobolev N.V. 1974. Deep-Seated Inclusions in Kimberlites and the Problem of the Composition of the Upper Mantle (in Russian). Nauka Press, Novosibirsk, 264 pp. [English Translation (1977), ed. by F.R. Boyd, American Geophysical Union, Washington, DC, 279 pp.]
- Ryan C.G., Griffin W.L., Pearson N. 1996. Garnet Geotherms: a technique for derivation of P-T data from Cr-pyroxene garnets. *J. Geophys. Res.*, 101:5611-5625.

Manuscrito NB-34

Recebido em 18 de novembro de 2001

Revisão dos autores em 27 de dezembro de 2001

Revisão aceita em 29 de dezembro de 2001

Figure 1 - Cr_2O_3 -CaO -FeO- TiO_2 (wt%) plots and Cr frequency histograms for the garnets from KI-1 pipe. 1- separate grains; 2. - intergrowths with clinopyroxenes and garnets; 3. garnet from Ilm – serpentine nodules.

Figure 2 - Composition of Ilmenites from KI-1 pipe and the frequency histogram for major components. Solid dots - intergrowth, open dots - individual grains.

Figure 3 - Composition of Cr- spinels from KI-1 pipe, and frequency histograms for Cr_2O_3 . 1. Separate spinels; 2. intergrowths with Cpx and Gar.

Figure 4 - Variations of the clinopyroxenes from KL-1 pipe. 1-2 the same as for Fig.3.

Figure 5 - TP plot for the clinopyroxenes determined by Nimis and Taylor, 2001 method: 1. separate grains; 2 integrowths; determined by the Jd-Di barometer Ashchepkov, 2001. 3- single grains; 4- integrowths.

Figure 6 - TRE patterns for the clinopyroxenes and some garnets in intergrowth with Cpx and Spinels and TRE patterns for the melts parental for these phases.

Table 1. Representative analyses of the minerals from the KL-1 pipe, Colorado. Separate grains.

Oxides	5-11	3-47	3-47	3-47	3-39	3-60	3-92	2-27	4-16	2-32	2-44	3-53	3-37
Pyrope													
SiO ₂	40.88	40.04	40.92	40.51	41.03	41.29	41.23	41.37	41.63	41.60	42.01	41.3	41.49
TiO ₂	0.00	0.49	0.40	0.14	0.42	0.09	0.25	0.85	0.51	0.52	0.27	0.793	0.85
Al ₂ O ₃	14.85	13.31	14.79	15.59	16.50	17.66	17.67	17.88	19.11	19.47	21.16	21.13	21.15
Cr ₂ O ₃	12.14	11.88	10.62	9.85	8.25	7.16	6.89	5.84	4.41	3.65	2.83	1.24	0.51
FeO	6.44	6.74	6.71	7.19	6.62	6.16	6.46	6.85	7.45	7.60	5.86	10.44	9.80
MnO	0.32		0.00										0.00
MgO	20.76	18.20	18.35	17.97	19.72	20.57	20.82	20.28	20.80	20.72	22.43	19.72	19.24
CaO	4.96	8.12	7.77	7.32	6.68	5.60	6.15	6.25	5.54	5.38	4.64	4.54	4.68
Na ₂ O	0.02	0.06	0.04	0.05	0.05	0.02	0.04	0.07	0.06	0.05	0.06	0.064	0.09
K ₂ O	0.00	0.04	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.07	0.007	0.00
NiO		0.02	0.00	0.02	0.014	0.017	0.018	0.03	0.02	0.00	0.01	0.006	0.00
Total	100.37	98.87	99.59	98.62	99.27	98.56	99.51	99.39	99.52	98.99	99.33	99.23	97.82
Fe/(Fe+Mg)%	14.83	17.21	17.04	18.34	15.85	14.39	14.83	15.93	16.74	17.07	12.79	22.90	22.24

Oxides	1KL1	2KL1	5KL1	10KL1	12KL1	7KL1	8KL1	9KL1	22KL1	13KL1	19KL1	20KL1	21KL1	22KL1
Cr-Diopside														
SiO ₂	54.74	54.02	54.82	53.95	54.98	54.55	54.40	55.13	55.49	54.73	55.11	55.06	55.07	55.49
TiO ₂	0.16	0.09	0.21	0.17	0.08	0.18	0.16	0.14	0.09	0.12	0.17	0.15	0.20	0.09
Al ₂ O ₃	2.61	2.27	2.78	1.21	3.76	1.91	1.97	0.48	0.45	2.15	1.95	0.57	2.36	0.45
Cr ₂ O ₃	3.26	2.58	3.14	1.77	3.94	2.50	2.86	1.31	1.63	2.77	3.28	3.08	1.35	1.63
FeO	2.39	2.34	2.62	3.46	2.52	2.50	2.52	2.28	2.14	2.15	2.48	2.26	2.28	2.14
MnO	0.10	0.08	0.10	0.10	0.11	0.10	0.10	0.09	0.08	0.09	0.11	0.06	0.09	0.08
MgO	15.12	15.41	14.48	15.74	13.61	16.24	15.10	16.90	17.02	15.25	15.42	16.17	15.85	17.02
CaO	18.88	19.18	18.00	21.29	16.61	19.07	19.72	23.06	22.37	19.42	18.68	20.64	20.48	22.37
Na ₂ O	2.96	2.32	3.49	1.54	4.49	2.15	2.52	1.09	1.32	2.52	3.08	2.14	2.20	1.32
K ₂ O	0.00	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00					
NiO														
Total	100.22	98.33	99.64	99.24	100.10	99.20	99.35	100.47	100.59	99.19	100.27	100.13	99.88	100.59
Fe/(Fe+Mg)%	8.15	7.85	9.22	10.98	9.41	7.95	8.56	7.04	6.59	7.33	8.28	7.27	7.47	6.59

Oxides	K11-1-16	K11-1-21	K11-1-22	K11-1-23	K11-1-26	K11-1-28	K11-1-29	K11-1-30	K11-1-31	K11-1-32
Cr-spinel										
TiO ₂	0.24	5.27	1.67	0.47	0.28	0.29	1.63	1.64	2.60	0.78
Al ₂ O ₃	18.79	6.58	6.65	2.11	19.05	26.01	7.00	9.14	6.54	7.22
Cr ₂ O ₃	39.20	44.12	57.22	62.32	42.69	37.11	58.57	53.85	59.20	60.05
FeO	27.76	36.87	22.22	25.11	24.79	22.10	21.24	26.35	20.34	19.68
MgO	13.62	6.91	11.26	10.06	13.43	15.65	12.15	9.80	9.61	12.25
Total	99.61	99.76	99.02	100.08	100.25	101.17	100.59	100.78	98.28	99.97
Fe/(Fe+Mg)%	53.36	74.96	52.54	58.34	50.88	44.21	49.51	60.13	54.30	47.42

Oxides	K11-5-76	K11-5-79	K11-5-88	K11-5-89	K11-5-90	K11-5-91	K11-5-93	K11-5-39	K11-5-40	K11-5-78
Ilmenite					Rutile					
TiO ₂	58.76	59.59	55.90	58.73	52.22	49.67	50.36	52.01	96.46	95.98
Al ₂ O ₃	0.96	1.07	1.15	0.96	0.67	0.65	0.66	0.63	0.06	0.17
Cr ₂ O ₃	1.56	2.55	4.98	1.20	0.44	0.80	0.67	0.46	0.66	0.13
FeO	27.56	24.25	24.64	27.21	39.18	42.25	42.21	38.34	0.69	2.80
MgO	12.93	11.54	13.72	12.16	4.82	7.06	5.43	7.54	0.03	0.34
Total	101.78	99.01	100.39	100.26	97.33	100.44	99.33	98.98	97.91	99.42
Fe/(Fe+Mg)%	54.47	54.11	50.19	55.65	82.02	77.05	81.35	74.06	91.94	82.37

Table 2. Representative analyses of the minerals from the K1-1 pipe, Colorado. Intergrowths.

Oxides	K11-33		K11-37		K11-39		K11-48		K11-45	
	Cpx	Gar	Sp	Cpx	Gar	Ga	CPx	Cpx	Ga	Cpx
SiO ₂	55.33	42.36	0.05	54.24	41.74	41.71	55.29	54.25	40.78	54.19
TiO ₂	0.07	0.02	0.93	0.36	0.22	0.01	0.05	0.14	0.08	0.02
Al ₂ O ₃	5.25	21.00	7.63	2.28	17.11	18.51	3.43	4.39	18.46	3.33
Cr ₂ O ₃	3.86	3.54	58.08	3.41	8.62	6.96	4.19	3.80	6.28	3.71
FeO	2.87	8.39	19.41	2.71	6.69	7.31	2.21	2.65	7.55	2.41
MnO	0.10	0.63	0.63	0.07	0.39	0.50	0.06	0.10	0.55	0.07
MgO	12.44	20.48	12.95	15.93	20.12	19.43	13.97	13.45	20.32	14.21
CaO	15.06	3.97	0.00	18.75	6.01	6.08	17.64	15.11	4.34	17.52
Na ₂ O	5.23	0.06	0.04	2.52	0.04	0.03	3.71	4.29	0.09	3.59
Total	100.21	100.44	99.72	100.26	100.95	100.53	100.55	98.17	98.46	99.06
Fe/(Fe+Mg)%	11.46	18.69	45.68	8.71	15.72	17.43	8.15	9.96	17.25	8.69

Oxides	K11-45		K11-46		K11-88		K1182		K11-85	
	Ga	Cpx	Gar	Sp	Ilm	Ga	Q	Ilm	Ilm	Rut
SiO ₂	41.27	54.32	41.14	0.78	0.13	41.04	98.25	0.30	0.26	0.85
TiO ₂	0.02	0.00	0.00	0.02	56.98	0.15	0.02	56.79	55.96	97.19
Al ₂ O ₃	18.94	3.28	19.11	9.69	0.83	15.81	0.47	1.10	0.92	0.10
Cr ₂ O ₃	5.78	3.42	5.64	55.67	1.80	9.97	0.02	1.72	0.14	0.05
FeO	7.47	2.36	7.21	20.07	26.99	6.75	0.07	29.12	31.98	0.41
MnO	0.51	0.09	0.45	0.72	0.84	0.43	0.02	1.65	0.39	0.03
MgO	20.69	14.42	20.39	11.23	11.87	19.09	0.02	7.92	9.37	0.11
CaO	4.40	17.11	4.58	0.04		6.24	0.02			0.27
Na ₂ O	0.06	3.12	0.02	0.05		0.036	0.02			0.14
Total	99.14	98.12	98.54	98.26	99.43	99.52	98.92	98.60	99.01	99.14
Fe/(Fe+Mg)%	16.85	8.41	16.56	50.08	56.06	16.56	70.95	67.34	65.69	67.39

Table 3 - Composition of major and trace elements from the clinopyroxenes and garnet from KL-1 kimberlite pipe Colorado. Note. Major components are determined on CamebaxMicro operator (O.S. Khmelnikova). TRE by LAM ICP MS, analyst Garanin V.G., Analytic Center UIGGM, SD RASc

	12KL1	14KL1	20KL1	48KL1	48KL1	72KL1
	Cpx	Cpx	Cpx	Cpx	Garnet(kel)	Garnet
SiO ₂	54.98	54.72	55.06	54.25	40.78	40.2
TiO ₂	0.08	0.22	0.15	0.14	0.08	0.21
Al ₂ O ₃	3.76	1.78	0.57	4.39	18.46	14.25
Cr ₂ O ₃	3.94	3.20	3.08	3.80	6.28	11.41
FeO	2.52	2.48	2.26	2.65	7.55	7.59
MnO	0.11	0.11	0.06	0.10	0.55	0.475
MgO	13.61	16.48	16.17	13.45	20.32	17.42
CaO	16.61	18.79	20.64	15.11	4.34	7.77
Na ₂ O	4.49	2.37	2.14	4.29	0.09	0.055
	100.10	100.15	100.13	98.17	98.46	99.38
Ba	0.55	0.22	2.29	0.61	0.33	0.07
La	1.00	1.30	0.27	0.06	1.20	0.16
Ce	2.10	3.10	0.86	0.23	3.60	0.32
Pr	0.33	0.39	0.18	0.03	0.53	0.06
Nd	1.20	1.70	0.76	0.19	2.10	0.66
Eu	0.04	0.05	0.08	0.05	0.11	0.59
Sm	0.21	0.24	0.24	0.11	0.38	0.26
Gd	0.19	0.10	0.26	0.17	0.27	1.61
Tb	0.01	0.01	0.04	0.03	0.03	0.38
Dy	0.07	0.03	0.21	0.14	0.13	3.90
Ho	0.01	0.00	0.04	0.02	0.02	0.88
Er	0.01	0.01	0.10	0.06	0.04	2.50
Tm	0.00	0.00	0.01	0.01	0.00	0.51
Yb	0.01	0.00	0.08	0.04	0.02	2.87
Lu	0.00	0.00	0.01	0.01	0.00	0.52
Hf	0.08	0.09	0.08	0.02	0.16	0.60
Ta	0.00	0.01	0.02	0.01	0.01	0.07
Pb	1.68	1.48	1.26	0.22	1.05	10.85
Th	1.20	0.90	0.51	0.09	0.16	0.46
U	1.50	0.09	0.70	0.13	0.04	0.92
Sr	202.04	278.50	60.90	2.70	438.00	0.00
Y	0.77	1.13	14.50	7.00	5.89	23.57
Zr	22.65	30.97	85.95	27.95	71.16	21.88
Nb	0.05	1.62	2.82	0.74	0.86	0.91