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Composition and thermal structure of the lithospheric mantle beneath kimberlite pipes from the Catoca cluster, Angola

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ABSTRACT

Garnet, clinopyroxene and ilmenite xenocrysts from three Angolan kimberlite pipes belonging to the Catoca cluster (Angola Caquele, Camitongo I and II, and Catoca) from the SW part of the Congo–Kasai craton, reveal similar features which suggest a similarity of mantle structure. PT estimates for pyropes, Cr-diopsides and picroilmenites reveal similar geothermal conditions of ~37–40 mW/m^2. This is slightly higher than the values determined for the Catoca pipe. Higher temperature conditions ~45 mW/m^2 were determined for low-Cr pyroxenes and omphacites. The similar general mineralogy and suggested mantle lithology, as well as reconstructed layering of the sub-continental lithospheric mantle (SCLM), are similar for Camitongo I–II as well as for Caquele and Catoca pipes. Heating at depths of 7.5–4.5 GPa (240–140 km) is a general feature of the SCLM beneath the field. The high temperature trend for low-Cr and hybrid pyroxenes from the base of the SCLM up to 30 GPa (100 km) represents the PT path of the protokimberlite melts. PT conditions for ilmenites mainly correspond to colder conditions of crystallization in wall rocks and the outer parts of magmatic channels.

Individual geochemical features of the minerals for each SCLM suggest pervasive metasomatism in lower part of the SCLM. Clinopyroxene trace element patterns from the Caquele pipe reveal a lherzolitic affinity; they are LILE-enriched with Ba peaks due to phlogopite melting, while those from Camitongo I–II show Ta–Nb enrichment and Pb troughs. The ilmenite trends trace the mantle column from deep to shallow mantle, evolving to Fe-ilmenites due to advanced AFC of protokimberlite magma that also produced abundant Fe-rich clinopyroxenes. The rise of calculated fO_2 correlates with the position of protokimberlites. Comparison with the thermal gradient derived from peridotitic inclusions from Catoca cluster is lower than for Lesotho possibly related to the thicker lithospheric roots beneath the Congo–Kasai craton.

1. Introduction

African kimberlites and their deep-seated inclusions have been extensively investigated (Bell et al., 2003; Cartigny et al., 1999; Gibson et al., 2008; Nixon, 1973, 1987; Nixon et al., 1981; Rawlinson and Dawson, 1979; Stachel & Harris, 2008; Winterburn et al., 1990; Viljoen et al., 1992; Viljoen et al., 2009 and references therein). Petrology of the sub-cratonic lithospheric mantle (SCLM) beneath Africa has been reconstructed using xenoliths and xenocrysts (Aulbach et al., 2002; De Bruin, 2005; McCammon et al., 2001; Rogers and Grütter, 2009; Rawlinson and Dawson, 1979; Shee and Gurney, 1979; Viljoen et al., 1992; Viljoen et al., 2009). Combined thermobarometric and geochemical studies, taking into account the seismic studies of the African lithosphere, allow us to deduce not only the lateral and vertical variations of the SCLM but also to suggest the variations of the petrographic and petrochemical composition with depth in the Kaapvaal and some other African cratons (Griffin et al., 2003a,b; Griffin et al., 2004; Gurney et al., 1979a,b; O'Reilly et al., 2009). The evolution of protokimberlite magma has been studied using megacryst compositions (Batumike et al., 2009; Boyd et al., 1984), though it has been suggested that megacrysts also reflect the composition of the deep mantle (Bell and Moore, 2004; Boyd et al., 1984) and represent the deepest SCLM layers. However, their isotopic signatures suggest a more complex origin for megacrysts, probably crystallized from highly contaminated plume melts that have interacted with the SCLM (Davies et al., 2001). The existence of multiple

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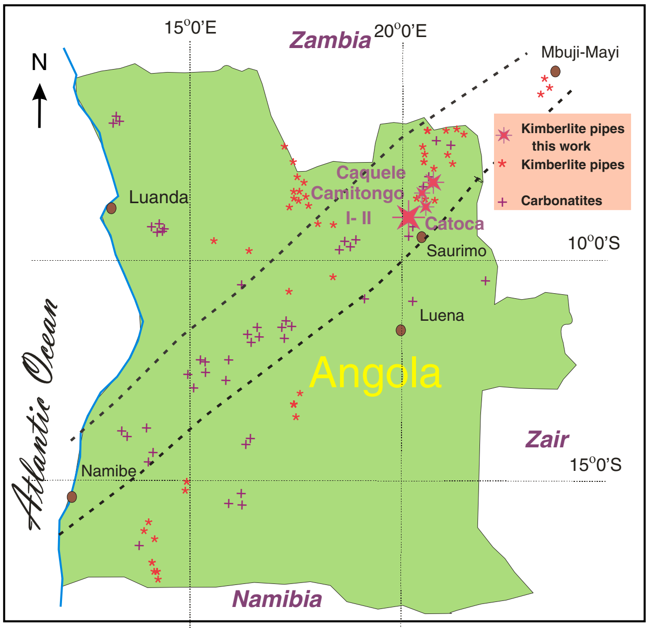

Fig. 1. Scheme of the kimberlite pipes location in Angola (after Egorov et al., 2007).

megacryst compositional groups suggests a difference in source magmas (Dawson and Stephens, 1975) and polystage origin and possibly polybaric crystallization of protokimberlite melts.

Many studies have been devoted to diamonds from African kimberlites (Boyd and Danchin, 1980; Deines et al., 1984; Kopylova et al., 1997; McDade and Harris, 1999; Tsai et al., 1979). Angola is the third most productive region for diamonds in Africa and the world. Nevertheless information about the large kimberlite fields in Angola is rather scarce (Boyd and Danchin, 1980; Egorov et al., 2007; Eley et al., 2008; Sobolev et al., 1990) compared with South Africa. Approximately 700 kimberlites have now been found in Angola. Kimberlite pipes Camafuca Camazambo, Camutue and Catoca (Ganga et al., 2003; Robles-Cruz et al., 2009; Zuev et al., 1988) are among the largest and least eroded in the world. They are of the great interest not only for mining geology but also for petrologists because they give the youngest and most representative information about the composition of the upper mantle beneath Central Africa (Leost et al., 2003; van Achterbergh et al., 2001) which has been studied less than in the Kaapvaal craton (Gregoire et al., 2003; Gregoire et al., 2003; Nixon and Boyd, 1973; Moore and Lock, 2001; Moore and Lock, 2001; van Achterbergh et al., 2001, etc.) and other parts of the African continent. The Congo–Kasai craton has one of the deepest SCLM roots in Africa extending to 400 km (O'Reilly et al., 2009). The kimberlite belt of Angola crosses the southern outer margin of the craton and the thicker SCLM is located

Table 1
Major and trace element composition of the minerals from the concentrate of Caquele pipe, Angola.

	Ilm	Cr–Di 1	Cr–Di 2	Cr–Di 3	Gar1	Gar2	Gar3	Gar4	Gar5	Gar6	Gar7		Zirc1	Zirc2
SiO_2		55.01	55.55	55.42	41.74	40.49	41.33	41.62	41.63	42.43	42.4	SiO_2	31.92	32.01
TiO_2	46.18	0.32	0.28	0.33	0.05	0.25	0.05	0.16	1.01	0.68	0.97			
Al2O3	0.55	3.31	2.18	2.03	20.39	12.98	19.4	18.24	15.85	20.05	17.78			
Cr_2O_3	0.44	3.08	0.95	1.12	5.69	13.31	5.49	6.34	7.68	2.78	6.74	ZrO_2	66.04	66.09
FeO	45.49	3.24	3.72	3.61	7.89	6.99	8.97	8.99	7.98	7.28	7.49			
MnO	0.2	0	0		0.35	0.24	0.38				0.24			
MgO	6.95	14.3	17.82	18.13	20.98	18.5	18.27	18.02	17.78	21.25	20.11			
CaO		16.78	17.51	18.21	2.95	6.46	5.37	5.79	7.14	4.59	5.06	CaO	0.016	0.038
Na_2O		3.89	1.91	2	0.11	0.11	0.11	0.05	0.10	0.09	0.11			
K_2O		0.03	0.04	0.03	0.05	0.05	0.05	0	0	0.01	0.05			
NiO	0.21	0.05	0.05	0.08				0.02	0.05	0.02		P_2O_5	1.29	1.02
	100.02	100.01	100.01	100.96	100.2	99.38	99.42	99.23	99.22	99.18	99.17		99.266	99.158
Ba	148	2154	2.28	302	0.67	0.35	1.83	0.56	7.28	1.07	1.03	Ba	26.3	55.0
La	2.17	6.38	4.5	0.53	0.04	0.05	0.046	0.045	0.072	0.132	0.068	La	0.081	0.343
Ce	6.37	23.30	16.8	1.13	0.29	0.51	0.33	0.28	0.32	0.39	0.52	Ce	0.84	0.69
Pr	1.28	4.23	3.13	0.21	0.11	0.18	0.11	0.10	0.10	0.14	0.18	Pr	0.07	0.07
Nd	6.86	21.4	16.2	1.47	1.18	1.77	1.36	2.30	1.00	1.37	1.70	Nd	0.51	0.26
Sm	2.00	5.81	4.44	0.70	0.87	1.44	0.88	0.63	0.72	1.21	1.56	Sm	1.15	0.737
Eu	0.59	1.91	1.25	0.22	0.46	0.62	0.40	0.20	0.36	0.57	0.67	Eu	0.51	0.191
Gd	1.97	5.60	3.98	0.73	2.01	2.80	2.03	0.70	1.60	2.92	3.29	Gd	2.80	1.11
Tb	0.27	0.72	0.49	0.12	0.41	0.54	0.41	0.09	0.34	0.63	0.75	Tb	0.74	0.36
Dy	1.37	3.98	2.77	0.83	3.28	4.34	3.47	0.57	2.79	5.21	6.35	Dy	8.26	4.25
Ho	0.22	0.60	0.39	0.14	0.72	0.88	0.73	0.11	0.61	1.18	1.41	Ho	2.16	1.31
Er	0.48	1.31	0.87	0.41	2.00	2.49	2.28	0.37	1.92	3.69	4.59	Er	8.22	5.52
Tm	0.06	0.14	0.09	0.06	0.30	0.38	0.34	0.07	0.30	0.58	0.70	Tm	1.56	1.03
Yb	0.29	0.77	0.44	0.48	2.10	2.45	2.20	0.55	2.01	3.73	4.81	Yb	13.9	7.4
Lu	0.03	0.09	0.06	0.10	0.33	0.36	0.34	0.12	0.32	0.62	0.78	Lu	1.89	1.39
Hf	1.04	17.02	3.26	0.23	1.43	2.61	1.77	0.62	1.29	2.58	3.43	Hf	1926	635
Ta	0.24	0.25	0.09	0.08	0.02	0.01	0.03	0.04	0.03	0.04	0.05	Ta	2.33	1.75
Pb	1.58	1.20	1.15	0.55	0.31	0.38	0.38	0.59	0.26	0.70	0.44	Pb	1.22	2.04
Th	0.52	0.60	0.12	0.14	0.03	0.01	0.02	0.05	0.021	0.018	0.03	Th	4.5	3.59
U	0.012	0.219	0.013	0.356	0.009	0.007	0.014	0.073	0.020	0.010	0.015	U	12.7	8.90
Sc	17	127	42	104	76	68	65	104	69	94	97	Sc	177	80.2
V	154	682	360	133	156	162	145	182	149	199	204	V	0.2	1.05
Co	23	47	42	24	31	26	29	21	30	37	41	Co	0.02	0.24
Cu	40.2	14.7	32.9	23.8	4.6	5.2	7.3	9.5	3.6	6.4	13.0	Cu	5.07	23.12
Ni	263	377	278	78	78	81	75	14	78	102	96	Ni	0.44	14.44
Rb	0.49	20.96	0.07	1.54	0.04	0.04	0.05	0.12	0.32	0.06	0.06	Rb	0.221	0.277
Sr	99	400	202	8.38	0.42	0.54	0.55	0.25	0.73	0.67	1.46	Sr	0.6	2.7
Y	5.4	13.8	9.2	3.9	18.5	23.2	19.2	3.0	15.2	29.9	36.1	Y	54.5	35.8
Zr	7.1	111.2	19.8	5.8	25.8	42.4	27.9	10.3	22.1	40.6	52.5	Zr	35,540	8717
Nb	1.18	4.61	0.36	0.78	0.17	0.10	0.19	0.08	0.22	0.25	0.52	Nb	2.36	2.35
Cs	0.01	0.123	0.004	0.083	0.003	0.0007	0.004	0.002	0.009	0.005	0.004	Cs	0.007	0.011