The Use of Chemistry of Garnets and Heavy Minerals Around Lalago Kimberlite Pipe in Deciphering Diamond and Non-Diamond Bearing Kimberlite Pipes in Tanzania

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Abstract: *More than three hundred kimberlite pipes have been reported in Tanzania. Only a few are diamond–bearing. A prospecting criteria to outline the diamond and non-diamond bearing kimberlites has been proposed. Bulk rock chemical analyses and chemistry of garnets and black minerals (picroilmenite, magnetite, rutile and titanite) collected around one kimberlite pipe in Tanzania were studied using Atomic Absorption Spectrophotometer (AAS) and Electron Microprobe (EMP). Although chromite and zircons occur in kimberlite pipes, they were not used in this study because they also characterize other surrounding rocks. Electron microprobe analysis of heavy minerals indicate that the ilmenites (picroilmenite) are poor in MgO contents (0.03 – 0.6 wt.%); but are rich in MnO (9.94 – 12.27wt.%). The garnets are poor in* Cr_2O_3 *with pronounced almandine content which has led to the conclusion of having a barren kimberlite source. It is suggested that combination of the chemistry of garnet and heavy minerals may be used as an exploration tool for deciphering diamond and non-diamond bearing kimberlites.*

***Key words**:* Electron microprobe, black minerals, mineral and fluid inclusions, kimberlites, garnets.

INTRODUCTION

More than three hundred kimberlite pipes are known in Tanzania (Edwards, 1970; Stiefenhofer and Farrow, 2004; Manya, *et al.,* 2012); but only 20% are diamond bearing while the majority are non-diamond bearing kimberlites. Diamond bearing kimberlite areas include Mwadui in Shinyanga, Igwisi in Tabora which are confined to the interior of the Tanzanian Craton. This craton is composed of the Dodoman system at the centre and the Nyanzian system and Kavirondian System to the north belonging to the Early Achaean (3.8-3.4 Ga) and late Achaean (3.0-2.5 Ga) respectively; all of which have undergone polyphase deformations. The Rift System which bounds the craton to the east and west is characterized by broad north-south uplifts and extensive volcanism since Tertiary. The kimberlites within Lalago, Kimali, Singida, Kiomboi and Saranda areas bordering the Eastern Rift System contain poor to non-diamond bearing kimberlites.

The largest pipe in Tanzania is the Mwadui kimberlite which was discovered by Dr. J. T. Williamson in 1940. Prior to this discovery, diamonds were recovered through small scale mining at Mabuki. Later, in 1959 and 1976 Williamson Diamonds

Company launched exploration programmes for diamonds around Lake Victoria and Central Tanzania aiming at searching for other diamond bearing kimberlites (Higgs and Mannard, 1985). However, the programme's achievements were dismal. In addition, up to date no prospecting criteria have been found to distinguish diamond bearing from non-diamond bearing kimberlites. The aim of the study was thus to find out chemical and mineralogical techniques for locating kimberlites; and further, to differentiate diamond from non-diamond bearing kimberlite pipes.

GENERAL GEOLOGY

The Precambrian geology of Tanzania mainland consists of blocks characterized by different structural trends (Kimambo, 1984). These are stratigraphically subdivided into Early Achaean (3.8 -3.0 Ga.), Late Achaean (3.0- 2.5 Ga.), Early Proterozoic (2.5- 1.6 Ga) and the Paleozoic (less than 0.75 Ga.).

The geology of Shinyanga area has been studied by Williams and Eades (1938). The oldest rocks in the area are the Nyanzian rocks (2,500 Ma) and these are mainly metamorphosed basic and acidic volcanics including banded ironstones (BIF) quartzites cross-cutting the granites of two varieties: The gneissic granites which are the oldest, are foliated in an east-west direction and occupy the northern part; and synorogenic granites in the north-south which are. Through Landsat imagery and aerial magnetic data compiled by Geosurvey International other rocks such as gabbros, dolerite dikes following the trend of granites showing strong spherical weathering were observed. Foliation in the granites trends WNW/ESE and a major shear zone ENE/WSW were recognized. Secondary shears in the area are considered to be influenced by the Rift System. Most of the kimberlitic intrusions are of Cretaceous and Tertiary to Plio-Pleistocene age (Dawson, 1967; Dawson, 1976; Edwards, 1970).

Prospecting work by the Mwadui Exploration team (1968-69) led to the discovery of two kimberlites (49K3 and 49K4). Three hundred and twenty tons of soil material from 49K3 prospect were washed, but only one piece of diamond weighing 0.05 carats was collected. From 49K4 two hundred and forty six tons of soil materials were washed and no diamond was found.

MATERIALS AND METHODS

Stream sand sampling was carried along Mangu, Lonzoi and Magogo rivers and their tributaries. A total of forty samples were collected at half a kilometer interval where possible; but attention was paid to stream confluences. Samples were labeled as average of each sampling points as shown in Table 1:

Table 1: Sampling Points and Coding of Samples

Sampling point	1 - 4	5 - 7	8-10	11- 12	13- 15	16- 17	18- 20	21- 24	25- 27
Code	A	B	C	D	E	F	G	H	I
Sampling point	28 - 32	33- 36	37 -38	39- 40					
Code	J	K	L	M					

About five kilograms were scooped by a spade, filled into plastic bags and labeled, indicating sampling locations. A total of forty loam soil samples were collected as well as stream sand samples at a grid of 20m x 40m over Lalago kimberlite ($49K_3$). These samples were washed and panned at the campsite using water as a gravitating medium. Heavy mineral concentrates were graded at mesh sizes -16 to +26, -26 to +35 and -35. Later, they were dried under the sun, packed in labeled envelops and sent to Mwadui mine for treatment with tetrabromoethane as a heavy liquid separator. Chemical analysis of heavy metals was carried at the Geological Survey of Finland using electron microprobe analyses.

RESULTS

Chemical analyses of two kimberlites $K1M_1$ from Mwadui and KIM_2 from Nyamigunga, and other two basaltic ($KIMD_3$) and micaceous ($KIMD_4$) kimberlites and Epidotized Granite analyzed by Dawson (1980) are included for comparison (Table 2).

Table 2: Chemical Composition (wt.%) of Soils over Kimberlites from Different Areas

	KIM_1	KIM_2	EPG	$KIMD_3$(Basaltic)	$KIMD_4$ (Micaceous)
SiO_2	43.83	49.67	61.36	35.20	31.10
TiO_2	0.93	7.11	0.40	2.32	2.03
Al_2O_3	6.64	10.12	12.85	4.40	4.90
Fe_2O_3	6.76	9.37	7.75	9.80	10.50
MnO	0.07	0.33	0.06	0.11	0.10
MgO	13.96	6.92	0.24	27.90	23.90
CaO	2.41	6.16	13.34	7.60	10.60
Na_2O	1.03	2.54	0.26	0.32	0.31
K_2O	1.46	2.34	0.66	0.98	2.10
P_2O_5	<0.10	< 0.10	< 0.10	0.72	0.66
LOI	10.19	10.69	1.52	10.70	13.00
Total	96.33	99.34	98.44	100.05	99.20

Total iron as Fe_2O_3

KIM_1 and KIM_2 – kimberlites from Mwadui and Nyamigunga respectively; EPG – Epidotized granite, $KIMD_3$ and KIM D_4 kimberlites (analyzed by Dawson, 1980)

The mineralogical similarities of the two kimberlites (KIM_1) and (KIM_2) are reflected in the bulk compositions. SiO_2 compositions are 43.83 wt,% and 49.69 wt.% respectively, thus being higher, $KIMD_3$ (35.20 wt.%) and $KIMD_3$ (31.10 wt.%. TiO_2 and total iron as Fe_2O_3 in kimberlites is high (Table 1). These components are contained in ilmenite and perovskite. MgO contents in KIM_1 are (13.96 wt%) and KIM_2 (6.92 wt.%). CaO in KIM_1 (2.41 wt.%) and KIM_2 (6.16 wt.%) are much lower than $KIMD_3$ (7.60 wt.%) and $KIMD_4$ (10.60 wt.%). The K/Na ratios in KIM_1 and KIM_2 are 1.35 and 0.92 respectively, which is much lower than $KIMD_3$ (3.06) and $KIMD_4$ (6.8). P_2O_5 both in KIM_1 and KIM_2 are less than 0.1% and are considered insignificant, when compared to $KIMD_3$ (0.72%) and $KIMD_4$ (0.66%) which reflects variation in phosphate mineral contents.

Table 3: Electron Microprobe Analyses ofIlmenite, Magnetite, Rutile andTitanite (wt.%) from Lalago Kmberlite Pipe

	Sampled Point												
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
SiO_2	0.22	2.02	0.02	0.03	4.61	3.55	0.60	0.02	0.13	0.01	0.02	30.13	28.95
TiO_2	50.45	49.34	50.36	48.20	0.00	0.02	1.95	97.64	95.97	93.36	91.80	36.28	34.51
Al_2O_3	0.01	0.00	0.00	0.01	0.73	0.06	0.21	0.02	0.04	0.03	0.02	1.76	1.57
Cr_2O_3	0.00	0.02	0.01	0.04	0.03	0.01	0.01	0.04	0.06	0.06	0.07	0.03	0.01
MnO	10.27	9.44	1.37	6.19	0.05	0.26	0.07	0.00	0.00	0.03	0.00	0.06	0.09
FeO	34.80	35.85	43.75	40.36	71.63	67.69	79.91	0.47	0.46	0.98	1.70	0.54	2.19
NiO	0.01	0.02	0.00	0.04	0.05	0.03	0.00	0.01	0.01	0.02	0.00	0.02	0.00
MgO	0.04	0.06	0.05	0.03	0.24	0.28	0.04	0.01	0.00	0.01	0.00	0.00	0.05
CaO	0.00	0.01	0.03	0.00	0.39	0.05	0.04	0.06	0.05	0.01	0.01	27.45	20.00
Na_2O	0.00	0.00	0.03	0.00	0.32	0.03	0.05	0.00	0.00	0.00	0.00	0.01	0.14
K_2O	0.01	0.00	0.00	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.02	0.03
ZnO	0.07	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.10
V_2O_3	0.00	0.00	0.00	0.00	0.19	0.03	0.20	0.00	0.00	0.02	0.00	1.09	0.00
Total	95.88	94.76	95.64	95.03	78.72	72.02	83.08	98.28	96.73	94.54	93.62	97.39	87.64

Heavy Mineral Studies

Heavy mineral studies rely on the survival in residual and transported soils of diagnostic suite of resistant heavy minerals, which have been derived from weathering of kimberlite pipes. It is possible to establish the distance of an anomalous sampling site from a kimberlite intrusion by careful examination of the kimberlitic indicator minerals. Electron microprobe analyses of heavy minerals ilmenite, magnetite, rutile and titanite from Lalago kimberlite pipe is indicated in Table 3.

Analyses of ilmenite show that they are MgO poor (0.03-0.06 wt. %) and MnO – rich (9.94-12.27 wt. %). This suggests that the mineral is not derived from diamond bearing kimberlite. Picroilmenites from diamond-bearing kimberlites from Orroroo pipe in South Africa, shows high MgO content (4-14 wt. %), MnO poor (0.21-0.27 wt. %), Cr_2O_3 (4.82-12.45 wt. %,) TiO_2 (0.07-1.12 wt. %) and FeO (6.69-14.82 wt. %) (Le Roex *et al.,* 2003).

Garnets particularly pyrope and eclogitic chrome diopside, picroilmenite, chromite and to a lesser extent olivine in surficial materials (till, stream sediments and loam etc.) indicate a kimberlitic source (Mosing, 1978; Gurney *et al.,* 2004). Analyses of garnets, their cation values and mole percentage end members calculated according to Deer, Howie and Zussman (1992) are indicated in Table 4, 5 and 6.

Table 4: Weight Percentages of Garnets (wt.%) from Lalago Kiberlite Pipe as Determinedby Electron Microprobe Analysis

	Sampled Point										
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
$Si0_2$	37.01	37.25	37.06	36.78	37.04	37.39	36.97	37.04	37.16	36.44	36.88
$Ti0_2$	0.04	0.02	0.00	0.04	0.11	0.02	0.22	0.08	0.04	0.02	0.34
Al_20_3	21.06	21.15	21.09	20.75	20.55	21.27	20.59	20.70	21.02	20.13	10.64
Cr_20_3	0.03	0.00	0.04	0.03	0.01	0.02	0.00	0.00	0.03	0.00	0.00
Mn0	0.75	2.17	1.46	0.59	0.15	1.00	0.15	0.51	0.12	25.06	0.58
Fe0	35.10	33.62	35.66	35.06	32.98	32.79	33.61	32.77	34.13	13.87	15.61
Ni0	0.03	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.01	0.00	0.00
Mg0	2.94	2.94	2.29	0.99	1.62	4.05	1.94	1.58	2.51	0.65	0.03
Ca0	1.11	0.99	0.94	3.50	5.65	1.37	4.42	5.81	4.10	0.73	32.16
Na_20	0.03	0.00	0.02	0.00	0.01	0.01	0.01	0.00	0.01	0.02	0.01
K_20	0.00	0.00	0.01	0.00	0.01	0.02	0.01	0.00	0.01	0.00	0.00
Zn0	0.03	0.04	0.00	0.01	0.10	0.00	0.04	0.00	0.04	0.04	0.00
V_20_3	0.02	0.01	0.00	0.03	0.01	0.00	0.00	0.02	0.02	0.03	0.03
Total	98.15	98.19	98.57	97.78	98.28	97.94	97.96	98.50	89.54	96.98	96.28

Table 5: Weight Composition in Terms of end Member "Molecules" Calculated from the Cation Percentages (Number of Atoms (0 = 24) in garnet unit cell

	Sampled Point										
	A	B	C	D	E	F	G	H	I	J	K
Si	3.038	3.054	3.043	3.054	2.987	2.904	3.041	3.026	2.689	3.077	3.019
Al	2.038	2.043	2.041	2.031	2.007	1.947	0.014	1.993	2.646	2.003	0.021
Cr	0.002	0.000	0.003	0.002	0.001	0.001	0.000	0.000	0.002	0.000	0.000
Fe^{3+}	0.000	0.000	0.000	0.000	0.004	0.242	0.000	0.000	0.000	0.000	0.893
Ti	0.002	0.001	0.000	0.002	0.007	0.001	0.014	0.005	0.002	0.001	0.021
Mg	0.360	0.359	0.280	0.123	0.200	0.469	0.238	0.192	0.271	0.082	0.004
Fe^{2+}	2.410	2.305	0.280	2.435	2.281	1.900	2.312	2.239	2.065	0.979	0.175
Mn	0.052	0.151	0.102	0.041	0.011	0.066	0.010	0.035	0.007	1.792	0.040
Ca	0.098	0.087	0.083	0.311	0.502	0.470	0.390	0.509	0.318	0.066	2.821

Table 6: Mole Percentageof end Members Calculated According to Deer, Howie andZussman (1992)

	Sampled points										
	A	B	C	D	E	F	G	H	I	J	K
Alm	82.64	79.43	84.05	83.66	76.20	65.41	78.38	75.25	77.61	33.55	5.77
Pyro	12.32	12.36	9.62	4.21	6.69	16.14	8.06	6.47	10.17	2.80	0.12
Andr	0.00	0.00	0.00	0.00	0.04	1.79	0.00	17.05	0.00	0.00	42.71
Spessa	1.79	5.19	3.49	1.43	0.35	2.26	0.35	1.19	0.28	61.39	1.32
Uvar	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.000	0.00
Gross	3.34	2.99	2.84	10.68	16.66	14.38	13.12	17.05	11.93	2.26	49.08

Key: Alm=Almandine, Pyro= pyrope, Andr = Andradite, Spessa = Spessartite, Uvav = Uvarovite, Gross = Grossular,

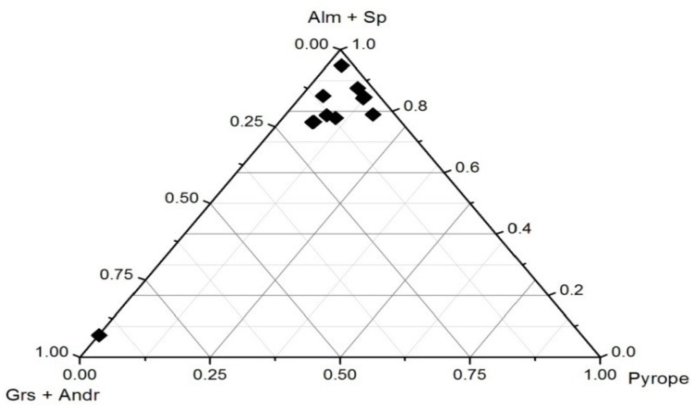

Figure1: A Ternary Plot Showing the Dominance of Almandine Garnet end Members from Lalago Kimberlite Pipe

Garnets studied from Lalago kimberlite pipe are poor in pyrope and almandine-rich end member percentages, characteristically poor in Cr_2O_3 (0.00-0.03 wt. %), FeO-rich (11.80-45.40 wt. %.). These have been plotted on Figure 1 where they concentrate on the almandine-end member.

Diamond-bearing kimberlites are characterized by garnets enriched in chromium (6-16wt. %) and are poor in iron and titanium (Sobolev *et.al.,* 1966). Thus, Lalago kimberlite is a non diamond-bearing kimberlite unlike Mwadui kimberlite pipe which has garnets with Cr_2O_3 (1.0-3.0 wt. %), TiO_2 (0.12-1.3 wt. %) and Fe (10.02-11.83 wt. %) that has been economically mined for diamonds.

DISCUSSIONS

The rock chemical analyses (Table 2) of granites indicate high CaO contents reflecting the presence of calcite as vein fillings. High silica affinity for the kimberlites (43.83 and 49.67 wt% SiO_2 (rock nos. KIM_1 and KIM_2) contrary to 35.30 and 31.10 wt. % SiO_2 suggest that these rocks are within granite/kimberlite contacts. Generally, the kimberlites have low TiO_2, Fe_2O_3 and MgO reflecting depletions through weathering of chemical elements from ilmenites and garnets. The high CaO contents in these rocks reflect presence of calcite in the groundmass. The absence of apatite as a mineral is revealed by the insignificant P_2O_5 contents ($\leq$ 0.1 wt. %). Higher loss of ignition in these rocks is characteristic to unusual amounts of volatiles in kimberlites.

Ilmenite from the analyses (Table 2) are poor in MgO (0.03-0.06 wt% and MnO rich (9.94-12.27 wt%). According to Nixon (1973) ilmenite from diamond bearing kimberlites have high MgO contents (4-14.0 wt. %) mostly (6.0-12.0 wt %) and MnO poor. Thus according to analyses obtained in Table 3 from Lalago, the ilmenites indicate that the mineral is not derived from a diamond bearing kimberlite. The electron microprobe data obtained from the garnets from Lalago pipe show that they are almandine rich end members and poor in chromium. This is indicative of a metamorphic source, not a potential diamond source (Mudaliar *et al*., 2007). Characteristically, diamond bearing kimberlites are indicated by pyrope garnets enriched in chromium (6.0-16 wt %), poor in iron and titanium.

CONCLUSIONS

It can be concluded that the findings obtained from the studied materials are in accordance to those obtained by the Mwadui exploration team during 1968-1969, that the Lalago kimberlite is most likely a diamond-poor kimberlite, although a 0.05 carat of diamond has been recovered and thus it is probably uneconomical as the mineralogical data reveals.

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References

Dawson, J. B. (1967). Geochemistry and Origin of Kimberlites. In *Ultrmafic and Related Rocks*, (Ed. P.J. Wyllie), New York pp. 269.

Dawson, J. B. (1976). A Review of Geology of Kimberlites. In *Ultramafic and Related Rocks*, (Ed. P.J. Wyllie), New York pp.241

Dawson, J.B. (1980). Kimberlites and their xenoliths. Springer: Berlin, 252 p.

Deer, W. A., Howie, R. A. and Zussman, J. (1992). *An Introduction to the Rock-Forming Minerals*. Longman Group (FE) Ltd.: Hong Kong.

Edwards, R. (1970). Geology and Sampling of Mwadui Mines, *Jour. Mwadui Eng. Assoc.* pp.30.

Gurney, J. J., Menzies, A. H. and Winter, G. F. (2004). An Updated Classification Scheme for Mantle Derived Garnet for use by Diamond Explorers, *Lithos***77**, 841-857.

Higgs, D. and Mannard, E. (1985). Loaming for kimberlites in Singida and Iramba Districts, Tanzania, Unpublished Report, Geol. Surv. Dodoma, Tanzania, pp.80

Kimambo, R. (1984). *Mining and Mineral Prospects of Tanzania*. Eastern Africa Publ. Limited: Arusha pp. 175- 189.

Le Roex, A. P., Bell, D.R. and Davis, P. (2003) Petrogenesis of Group 1 Kimberlites from Kimberley South Africa: Evidence from Bulk-Rock Geochemistry. *Journal of Petrology***44,** 2261-2286.

Manya ,S., Richard J., Brown, I., Buisman, G., Fontana, M., Field, C., Mac Niocaill, R. S. J. Sparks & F. M. Stuart (2012). Eruption of kimberlite magmas: physical volcanology, geomorphology and age of the youngest kimberlitic volcanoes known on earth (the Upper Pleistocene/Holocene Igwisi Hills volcanoes, Tanzania). *Bulletin of Volcanology*. Springer. ISSN 0258-8900

Mosing, R. W. (1978). Morphology of Indicator Minerals of Kimberlite as a Guide to Proximity of Source, Publ. Geol. Dept. and Extension Services, Univ. West. Aust. pp. 81-87.

Mudaliar G.G., Richards, J.P and Eccles, D. R. (2007). "Gold, Platinum and Diamond Placer Depositss in Alluvial Gravels, Whitecourt, Alberta". Alberta Energy and Utilities Board, EUB/AGS, SPE 089, 24p

Nixon, P. H. (1973), Lesotho Kimberlites, Lesotho National Development Corp. Maseru Cape and Transvaal Printers Ltd. Cape Town, South Africa. pp. 385.

Sobolev, N.V., Kuznetsova, I. K. and Zyunin N. D. (1966). The Chromium Bearing Minerals from the Grossular-Pyroxene Kyanite, Geol. Geofiz. SibirskOldel, Adad.,Nauk. S.S.S.R.10, 42-47 (Chem. Abstr). 19, 1322.

Stiefenhofer, J and Farrow, D.J. (2004). Geology of the Mwadui kimberlite, Shinyanga district, Tanzania. Lithos **76**, 139–160.

Williams, G.J. and Eades, F. B. (1938). Kimberlite Province and Associated Diamond Deposits of Tanganyika Territory, Dept. of Lands and Mines, Geol. Div. Bull.No.12, p. 38