



Geochemical Studies around Lattavaram Kimberlite Cluster, Eastern Dharwar Craton, India: Spatial and Statistical Analyses

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ABSTRACT

In recent years, many kimberlite pipes were discovered in Eastern Dharwar Craton by public and private organizations. Majority of diamondiferous pipe clusters occur in Anantapur District of Andhra Pradesh state. Lattavaram kimberlite cluster is one among them and the four pipes in this cluster are reported to be diamondiferous. A spatial and statistical study based on geochemistry of clay fraction (-80 mesh) of the stream sediments, in south of Lattavaram Kimberlite Cluster, for major and minor element was carried out. Subsequent data interpretations revealed that sediments in the proximity of the pipe have dominance of certain trace elements as observed in the primary kimberlite. The dispersion patterns through geochemical mapping showed that certain elements like TiO₂, CaO, Na₂O, Nb, Co, Ni, and Zr have higher pulses. Correlation exists between major oxides and minor elements from which anomalous areas can be detected. It is envisaged that stream sediment geochemistry can be used as a regional exploration tool in identifying the provenance, prioritizing the catchments and thereby locating kimberlite pipes.

1. Introduction

The primary purpose of geochemistry is to determine quantitatively the chemical composition of the Earth and its parts, and to discover the laws that control the distribution of the individual elements [1, 2]. Modern geochemistry was born in the Soviet Union in the 1930s, and the basic methodologies for regional mapping had been developed by the late 1960s, with important extensions being made in the 1980s [3].

In exploration of commodities like diamonds, gold and other precious minerals, stream sediment sampling plays a major role in regional reconnaissance surveys. Stream sediment sampling is commonly used as a preliminary step in identifying and prioritizing the catchments which will drastically narrow down the area of interest thereby facilitating further exploration. Stream sediments are mixtures of sediments, soil and rocks from the drainage basin upstream of the collection site [4]. They comprise detrital matter derived from underlying geological formations. Though in this type of studies, stream sediment samples are mostly used to examine the quality and quantity of indicator minerals, the clay/finer fractions (-80#) are stored in the sample repositories. The reasons can be attributed to managing huge database that generates, cost of geochemical assaying etc. However it can be envisaged that the major and minor element geochemistry of fines will also provide useful information in prioritizing the catchments.

The Lattavaram Kimberlite Cluster (LKC) which is distributed on an area of 1.5 sq km, is a part of Wajrakarur Kimberlite Field (WKF). The WKF extends over an area of 7.5 sq km. in parts of Anantapur Dt, Andhra Pradesh in the Eastern Dharwar Craton (EDC). There are 30 kimberlite pipes that are reported in five groups of clusters, viz., Wajrakarur (pipes 1,2,3,10 and 12), Lattavaram (pipes 3,4,5,7,8 & 9), Chigicherla (CC1 to 5), Kalyanadurgam (KL1 to 5) and Timmasamudram (TK1 to 6). The present study is focused on geochemistry of stream sediments collected in the southern part of four pipes (3, 4, 8 & 9) of the LKC.

Most exploration for kimberlitic rocks is based on indicator mineral surveys, ground and airborne geophysical surveys, and field geological mapping. Local soil and drainage geochemical surveys have also a role as a complementary technique in conjunction with other methods, particularly in areas of high geophysical contrast [5]. The geochemical

suite of elements which helps in kimberlite exploration was postulated by some workers. The element suite depends on the lithological compositions of the terrain under study. The suite of elements recommended for such surveys varies, depending on the host rock geochemistry. In laterite covered sedimentary terrain, Ni, Cr, Nb and Ti were reported to be useful as exploration guides [6]. Laterite geochemistry was also successfully applied within a regolith-landform framework has the potential to be a complementary technique for diamond exploration in deeply weathered terrain [7]. Little research has been done on the utility of stream sediment geochemistry as an exploration tool in the Indian context. In-situ calcrete has been used as an exploration guide by some workers which revealed that calcrete derived from granite and mafic rocks are mineralogically distinct with those derived from kimberlites [8]. For prospecting in WKF, for example, where kimberlites have intruded into Archean granitoids, a suitable element suite comprises Ni, Cr, Nb and Ti as indicators, to distinguish sediments from kimberlitic or granitoid provenance. A suite of six trace elements comprising those associated with ultramafic rocks (Cr and Co) and felsic rocks (Nb, La, Sm and P) can readily distinguish the kimberlitic sediments from that derived from ultramafic or felsic rocks. [9]. A combination of spatial and statistical analysis of geochemical data will reveal anomalous areas where kimberlites can be located. However the methods chosen to calculate the average value of the concentration for any geochemical element should depend on the probability distribution of the element abundance data [10].

In the present study, an attempt is made to study geochemistry of stream sediments in southern part of LKC to understand the geochemical behaviour by spatial mapping and statistical correlations of the data.

2. Experimental Methods

2.1 Study Area

The study area LKC lies 2.5 km SE of Uravakonda village of Anantapur district, Andhra Pradesh covering an area of 80 sq km. (Fig. 1) falling within 57F/5 1:50000 topo sheet (Survey of India).

2.2 Materials and Methods

Twenty four stream sediment samples (80mesh) were collected in possible best trap sites in the 1st and 2nd order streams, so as to represent the provenance, away from the recent drifted material, at a depth of 30 cm. The trap site quality can be categorized as good to moderate as the area is

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not much dissected and is observed to be more or less flat. Each sample is a composite of five to six sub-samples weighting approximately 2.0 kg, taken with 2 m wide area, using a stainless steel drill, and stored in natural jute bags. The samples were coned and quartered and about 250 g was dispatched to the laboratory retaining rest of the sample. Geochemical analysis was performed using portable XRF for major oxides, minor elements at Sree Geo Mining Services, Guntur, Andhra Pradesh. Each sample was analyzed twice to arrive at a reliable good quality data. Geochemical data thus produced was plotted spatially using Global Mapper version 13. Statistical analysis was performed to determine descriptive statistics and correlation matrices using data analysis of MS-Office Excel and threshold limit (T), critical threshold (T_{crit}) and threshold (T) values were determined using Visual Basic macro in MS-Excel developed by University of Zagreb [11].

development of a number of NS to NNW-SSE trending shears. The latter NNW-SSE shears and also the fracture systems affecting the area. Mafic dikes comprising dolerite and amphibolite are conformable to the NW-SE shears and fracture system, extending for tens of kilometers either as discontinued or continuous linear bodies.

The kimberlites of the WKF in general are highly brecciated and characterised by the abundance of xenoliths of country rock, which at times, as high as 35% of the rock. Petrologically, the xenoliths include fragments/casts of granite, gneiss, amphibolite and dolerite. Mantle xenoliths like serpentinite, peridotite and eclogite are also not uncommon. Due to metasomatic action and alternation these xenoliths appear to be bleached. The outcrops exhibit weathered yellowish or greenish kimberlite rock. All the four pipes are reported to be diamondiferous. Field disposition of these four pipes is shown in Table 1.

3. Results and Discussion

3.1 Spatial Mapping

Spatial maps were constructed to understand the dispersion patterns of selected compound/elements. In the vicinity of the kimberlite pipes, MgO is prominent (Fig. 2a). This is probably due to leaching originated from weathering of olivine minerals in the pipe rocks. It is observed that in the proximity of the pipe rocks, CaO appears to be moderately high, which is again attributed to calcification which the pipe rocks have undergone resulting into formation of calcrete (Fig. 2b). From spatial map, it is clearly visible that at the pipe rocks, Na_2O is conspicuously high due to enrichment of soda in the pipe rocks (Fig. 2c). The compound K_2O , shows a high dispersion at about 1km, on the west of the Lattavaram pipe cluster (Fig. 2d). As kimberlites are ultrapotassic rocks, K_2O dispersion can be used as a field guide in locating the pipes. Yet another element Nb shows a visible localization of enrichment around the pipe rocks (Fig. 2e).

As ultramafic rocks are reported to contain enriched content of Nb, this element can be used as a path finder in locating kimberlites/lamproite rocks. The element Ni exhibits relatively moderate to high values around the pipe rock cluster (Fig. 2f). Though Cr is considered to be high in the proximities of kimberlite pipes due to the presence of Cr-diopside, in the study area it is observed to be dispersed in low quantities (Fig. 2g). However a fairly definite trend is envisaged in the study area. The element Co displays a discretely moderate enrichment right at the location of pipes; however Co dispersion is high in the NE part of the study area which forms a mafic schistose country (Fig. 2h).

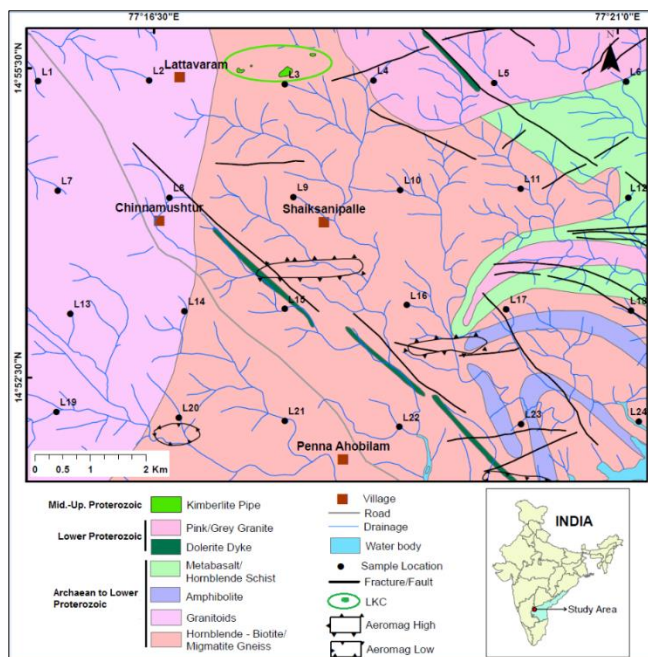


Figure 1. Study area showing simplified geology and sample locations

Table 1 Field characteristics of LKC pipes under present study

Pipe	Location	Size /Dimension	Outcrop characteristics
3	14°55'30" 77°16'45"	Semi-circular 120m x 40m	Highly weathered 1.5-2.0m thick calcrete cover.
4	14°56'35" 77°35'40"	Semi-circular 265m x 130m	Dark green scattered outcrops, covered under yellow ground.
8	14°55'30" 77°16'45"	Semi-circular 110m x 55m	Concealed under 1.5 calcrete cover.
9	14°55'30" 77°16'45"	Semi-circular 37m x 21m	Concealed under 1.5m calcrete cover.

2.3 Geological Setup & Field Disposition of Kimberlite Pipes

The study area forms a granitic country comprising old and younger granitoids along with green-stone belts in western part. The kimberlites of the study area are mainly emplaced into the granites and gneisses of the EDC. The area exposes mainly rocks of Peninsular Gneissic Complex (PGC) comprising various types of granitoids and gneisses and a prominent greenstone belt viz. Ramagiri-Penkacherla Schist Belt (RPSB) (Fig. 1). These rocks are intruded by a number of granite bodies, which are considered equivalent to the Closepet Granite (~2500 Ma). The lithological units of the RPSB and PGC show imprints of three phases of fabric represented by schistosity and gneissosity. The third phase exists in the form of broad warps along the ENEWSW trending axes. On the west of the study area, superposition of the third phase of a series of culminations in the form of domal structures viz. Marutla and Katrimala domes. The area is marked by a strong brittle-ductile deformation leading to the

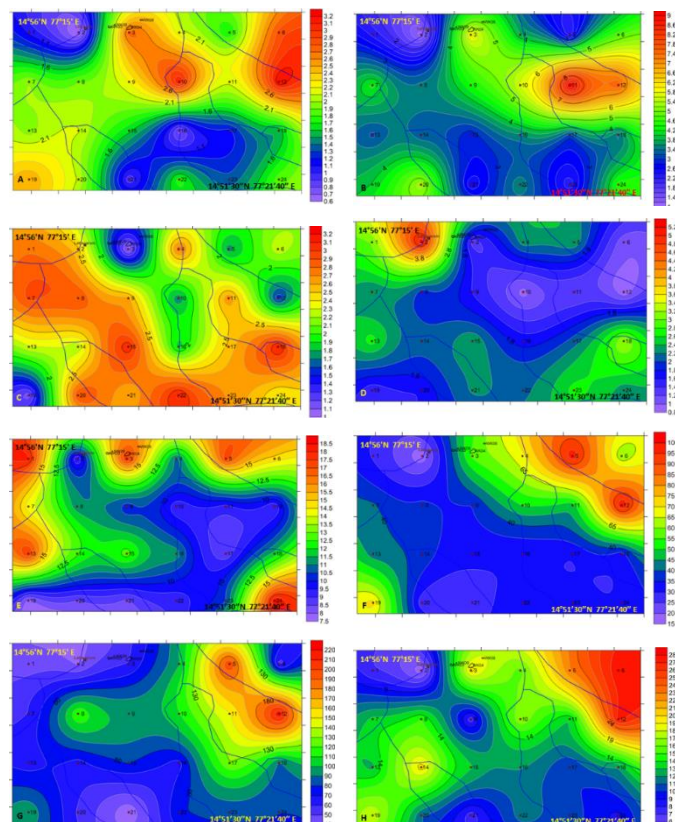


Fig. 2 Geochemical maps of selected compounds and elements a) MgO, b) CaO, c) Na_2O , d) K_2O , e) Nb, f) Ni, g) Cr and h) Co.

The composition of soils and stream sediments appears to be chiefly controlled by provenance from the same rock source but the patterns can also be related to anthropogenic factors. The elements viz., Cr, Ni, Co, Cu, Nb, Zr, Ti, P and rare earth elements (REE) are significantly enriched in the mottled zone and duricrust relative to the saprolite and fresh kimberlite. Goethite partly hosts Cr, Ni, and Co, and Nb and REE are associated with rutile/anatase. The clay fractions of the mottled zone and saprolite contain significant quantities of Cr, Co, Cu, Ni, Zr, Ga, Ti, Nb, Zn and REE. Nearly all these parameters are found to be applicable in the study area. In general the stream sediments of the study area predominantly contain granitic material. However enrichment of certain elements in stream sediments indicates influence of ultramafic rocks.

Enrichment of compounds/elements like MgO, Na₂O, CaO, Nb, and Ni is observed in the catchment comprising LKC pipes. The catchment in the

vicinity of kimberlite pipes shows a wide variance in geochemical dispersion comparatively to other catchments in the study area due to presence of kimberlite pipes in upstream, superseding other catchments in priority.

3.2 Statistical Analysis

The descriptive statistics are calculated for oxides and elements in all the samples in the study area. The compounds viz. SiO₂, MgO and Na₂O show platykurtic nature and all other compounds exhibit highly positive kurtic behaviour. While SiO₂, Al₂O₃ and Na₂O₃ are negatively skewed, all other compounds show a positive skewness (Table 2). A comparison between the major oxide geochemistry of stream sediments and that of kimberlite along with world kimberlite average is also shown.

Table 2 Descriptive statistics of major oxides

Statistical Parameter	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅
Mean	59.93	13.99	6.09	0.09	1.88	4.00	2.40	2.10	0.87	0.14
Standard Error	0.71	0.49	0.42	0.01	0.14	0.36	0.12	0.19	0.08	0.01
Median	60.15	14.34	5.83	0.08	1.93	3.57	2.56	2.12	0.78	0.13
Mode	0.00	0.00	0.00	0.08	0.00	0.00	2.78	0.00	0.65	0.13
Standard Deviation	3.47	2.39	2.07	0.03	0.70	1.78	0.60	0.91	0.38	0.06
Sample Variance	12.04	5.73	4.30	0.00	0.49	3.16	0.36	0.83	0.15	0.00
Kurtosis	-0.18	1.63	5.86	1.41	-0.34	2.19	-0.01	4.61	12.49	0.33
Skewness	-0.37	-1.06	2.01	1.23	0.05	1.25	-0.90	1.57	3.18	0.69
Range	13.65	10.19	10.04	0.13	2.63	8.06	2.10	4.31	1.86	0.24
Minimum	52.95	7.85	3.33	0.05	0.57	1.09	1.03	0.86	0.57	0.05
Maximum	66.60	18.04	13.37	0.18	3.20	9.15	3.13	5.17	2.43	0.29
Confidence Level (95%)	1.47	1.01	0.88	0.01	0.30	0.75	0.25	0.38	0.16	0.02
WKF Average	33.31	4.06	6.71	0.17	21.82	13.19	0.27	2.73	0.7	0.7
World Average	35.2	4.4	1.47	0.11	27.9	7.6	0.32	0.98	2.32	0.7

Table 3 Descriptive statistics of minor elements

Statistical Parameter	Ba	Co	Cr	Cu	Ga	Nb	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Zn	Zr
Mean	478.7	14.1	91.1	28.0	13.2	12.0	44.6	12.7	60.4	13.0	248.9	11.5	89.4	27.3	59.5	507.4
Standard Error	34.6	1.2	9.5	2.3	0.5	0.7	4.4	0.5	4.4	0.6	19.1	0.8	7.8	2.1	3.4	37.9
Median	510.4	12.9	80.7	25.6	13.9	11.0	35.8	12.7	61.3	12.9	229.9	10.4	72.1	24.8	58.8	464.6
Mode	0.0	12.1	0.0	25.6	14.4	9.2	0.0	11.1	36.6	13.0	0.0	8.5	0.0	0.0	56.6	0.0
Standard Deviation	169.7	6.0	46.4	11.3	2.3	3.5	21.5	2.6	21.5	3.2	93.7	4.1	38.3	10.4	16.9	185.6
Kurtosis	1.3	0.4	2.2	2.1	0.1	-0.9	1.7	-0.5	3.1	0.1	0.1	-0.8	6.9	-0.9	1.4	0.6
Skewness	0.3	0.8	1.5	1.4	-0.9	0.8	1.5	0.1	1.2	0.6	0.9	0.6	2.4	0.6	0.4	0.9
Range	748.7	23.3	187.4	47.6	8.6	10.7	82.8	9.9	102.0	13.0	325.7	13.3	175.5	32.5	78.5	739.6
Minimum	195.1	4.4	32.5	10.2	7.4	7.8	16.9	8.1	26.2	7.7	142.2	6.4	52.7	15.2	23.1	271.0
Maximum	943.8	27.7	219.9	57.8	16.0	18.5	99.7	18.0	128.2	20.7	467.9	19.7	228.2	47.7	101.6	1010.6
Confidence Level (95%)	71.7	2.5	19.6	4.8	1.0	1.5	9.1	1.1	9.1	1.3	39.6	1.7	16.2	4.4	7.1	78.4
WKF Average	1178.4	74.97	946.2	NA	11	389.4	784.8	NA	104.8	17.8	909.3	30	120.7	22.34	NA	2.69
World Average	1100	65	893	NA	5.7	141	965	NA	73	14	851	17	100	22	184	1.6

Table 4 Lilliefors test statistic T_1 , T_{crit} and T values of various compounds

Technique		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅
iterative2-r Technique	T_1	65.20	17.30	7.70	0.10	3.30	5.00	3.40	3.30	1.10	0.20
Distribution function	T_1	67.8	20.3	8.4	0.1	3.4	5.7	4.2	3.7	1.1	0.2
iterative2-r Technique & Calculated DF method	T_{crit}	0.19	0.19	0.19	0.19	0.19	0.20	0.19	0.19	0.19	0.19
iterative2-r Technique	T	0.035	0.090	0.040	0.039	0.042	0.025	0.049	0.083	0.052	0.008
Calculated Distribution function		0.068	0.189	0.023	0.083	0.043	0.094	0.076	0.040	0.058	0.002

Table 5 Lilliefors test statistic T_1 , T_{crit} and T values of minor elements

Technique		Ba	Co	Cr	Cu	Ga	Nb	Ni	Pb	Sr	Th	V	Y	Zn	Zr
iterative2-r Technique	T_1	740.3	20.5	121.3	34.2	16.9	19.1	38.8	17.3	309.3	17.6	100.7	48.1	76.4	795.3
Calculated Distribution function	T_1	904.9	21.1	133.1	38.8	20.4	15.1	50.9	17.6	350.9	15.3	90.2	38.3	89.8	707.1
iterative2-r Technique & Calculated DF method	T_{crit}	0.19	0.19	0.19	0.19	0.19	0.19	0.23	0.19	0.19	0.19	0.20	0.19	0.20	0.19
iterative2-r Technique	T	0.17	0.06	0.08	0.05	0.07	0.14	0.09	0.04	0.01	0.07	0.19	0.09	0.10	0.12
Calculated Distribution function		0.08	0.06	0.05	0.09	0.17	0.15	0.09	0.02	0.03	0.02	0.14	0.07	0.12	0.11

Among minor elements, Ba, Cr, Cu, Ni, V, Zn and Zr show high values of variance in assay values. This reflects that the study area possesses an uneven dispersion of various elements which might be due to differences in underlying geology. Moreover Ba, Co, Cr, Cu, Ni, Rb, V and Zn show

leptokurtic nature whereas Nb, Pb, Th and Y show platykurtic nature. At the same time, Ga, Sc, Sr and Zr exhibit mesokurtic behaviour. Except Ga, all the minor elements show positive skewness (Table 3). A comparison

between the minor element geochemistry of stream sediments and that of kimberlite along with world kimberlite average is also shown.

The threshold limit (Tl), critical threshold (Tcrit) and threshold (T) values of various compounds and elements analyzed are calculated. The macro uses two statistical methods viz., the iterative 2-r technique and the calculated distribution function methods. The Lilliefors test which is an adaptation of the Kolmogorov-Smirnov test, for level of significance $\alpha = 0.5$ is used for testing goodness of fit to a normal distribution [12] with 95% confidence. The T values calculated by two methods show minimum variation, however T_{crit} values are same by following two methods. (Table 4 and 5).

The mean and threshold limit values of both oxides and minor elements, calculated by the two methods display a similar trend (Fig. 3 A and B). As the threshold values are least, they are close to coordinate. As the samples are collected from in-situ material they represent a provenance of granitic terrain. However in sample sites, SX, SX and SX show peaks in Cao, MgO, TiO₂ which coincides with spatial distribution also.

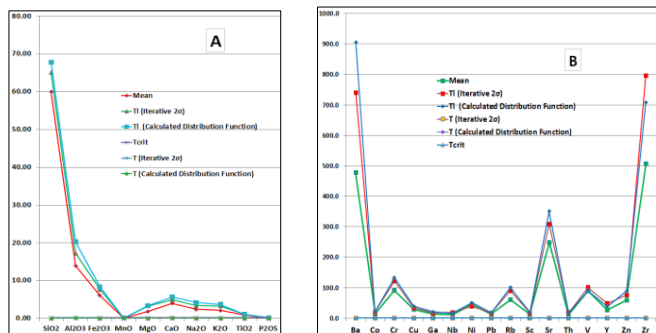


Fig. 3 Plots showing trends of mean and threshold values oxides (a) and minor elements (b).

The correlation matrix constructed for oxides shows feeble relation between certain compounds. Green, yellow, red indicate positive, intermediate and negative correlations respectively whereas the circles indicate the degree of correlation between compounds and elements. The circles indicate level of correlation between compounds/elements. A positive correlation exists between Fe₂O₃, MnO and MgO. Fe₂O₃ and TiO₂, MnO and TiO₂, MgO and CaO and Na₂O and K₂O (Fig. 4).

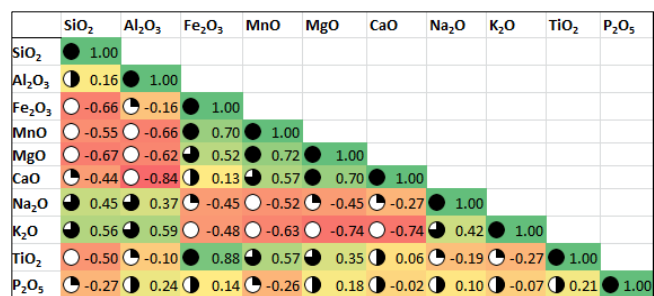


Fig. 4 Correlation matrix of oxides

The minor elements show correlation with others. The element Ba has a positive correlation with Rb, Co also behaves in positive correlation with Cr, Cu, Ni and V and feebly with Zn. Cr shows weak positive correlation with Ni, and feebly maintains same relation with other base metals Cu and Pb. In nature mostly Ni is geochemically associated with Cr, which is also observed in the study area. The element Nb exhibits a good relation with T, Y, Zn and Zr. In nature, Nb displays very low mobility under all environments, but in the most extreme conditions, due to the high stability and very low solubility of the oxide Nb₂O₅ from which niobates are derived and thus presence of Nb is reflected in sediments. However, the presence of citric, tartaric and oxalic acids increase the solubility of Nb through chelation. The maximum concentration of Nb in stream water, based on solubility calculations, is likely to be about 10 µg/l⁻¹. It is well known that alkaline rock complexes, eg., syenite, nepheline syenite, alkali granite and alkaline ultramafics, have the highest Nb content of all magmatic rocks [13]. Based on this principle, as seen in geochemical maps, it is observed that Nb in the vicinity of LKC is very discrete (Fig. 2e). On an average a 19 ppm of Nb deciphered from stream sediments can be considered as threshold. The element Sc shows a good correlation with V, Y and Zn. The elements viz., Th, V, Y and Zn do not exhibit much correlation with rest of the elements (Fig. 5).

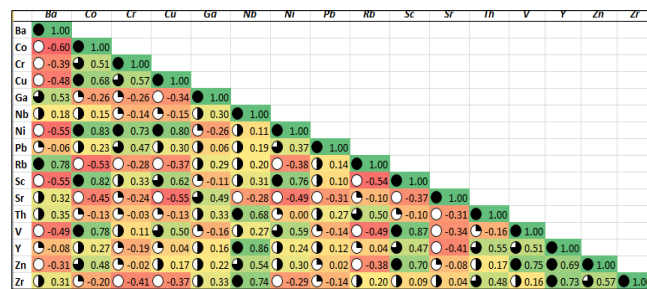


Fig. 5 Correlation matrix of minor and trace elements

The correlative comparison between major oxides and minor elements establishes certain key points, in the study area. The compound viz. SiO₂ shows positive correlation with Na₂O, K₂O as the terrain forms grey and pink granite country rocks and the resultant detrital sediments are mostly granitic in composition. The compound Al₂O₃ also shows a positive correlation with Na₂O, K₂O and Ba. The compounds viz., MnO, MgO, CaO show a moderate to feeble positive correlation with TiO₂, Co, Ni, Sc and V whereas K₂O behaves positively with Ba and Rb. The compound TiO₂ and show a positive correlation with Co, Sc, V and Y whereas P₂O₅ shows same relation with Nb, Rb and feebly correlates with Nb, Y and Zr (Fig. 6).

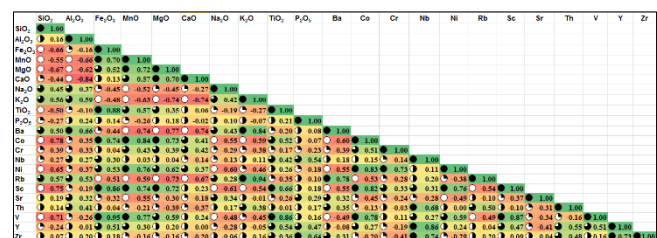


Fig. 6 Correlation matrix between major oxides and minor elements

Correlation matrices within major oxides, minor elements and between oxides and minor elements are also noticeable and show correlation with spatial dispersion of elements and compounds. Thus stream sediment geochemistry can be used as an exploration guide in regional reconnaissance in prioritizing the catchments in kimberlite search.

4. Conclusion

The composition of stream sediments appears to be chiefly controlled by provenance comprising granitoid rocks in the study area. Oxides in the sediment sample have similar trend to those in the primary country rock. Samples that are in the proximity of the pipe have trace element composition slightly mimic the pipe rock chemistry indicating the provenance from the primary pipe rock. On the basis of presented geochemical maps, enrichment of elements like TiO₂, CaO, Na₂O, Nb, Co, Ni, and Zr indicate the dispersion of these elements can be used to locate the primary source/provenance. An average above 19 ppm of Nb indicates anomalous zone to indicate an ultramafic body/kimberlite when stream sediments are used as an exploration tool. Due to their relatively high mobility, compounds and elements were enriched in the stream sediments and can play important role as pathfinder elements. Predominance of these elements indicates suspicious presence of an ultramafic body in general and kimberlite in specific, provided results of other disciplinary studies should also support. Statistical analysis showed correlations between various oxides and minor elements with respect to their spatial dispersion patterns.

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