

SOIL GEOCHEMICAL SURVEY OF KAOJE AND ENVIRONS

BAMIGBOYE O.S.¹, ADEKEYE J.I.D.², OMORINOYE, O.A.³, ADEDOYIN A.D.⁴ & ADEFILA⁵, I.

¹Department of Geology, Kwara State University, Malete, Kwara State, Nigeria

^{2, 3&4}Department of Geology and Mineral Sciences, University of Ilorin, Nigeria.

⁵National Steel Raw Materials Exploration Agency, Kaduna, Nigeria.

Abstract

Soil geochemical survey of Kaoje and its environs bounded by Long. 3°55'E and 4°10'E, Lat. 11°00'N and Lat. 11°15'N was carried out with the aim of delineating concealed mineralization beneath the earth surface. To achieve this, elemental analysis of thirty (30) selected soil samples was done. The result of the elemental analysis was thereafter subjected to Principal Component Analysis (PCA) and isograde plotting. Selected elements from the geochemical analysis were also subjected to correlation analysis.

The geochemical result shows that most of the elements analysed has their highest value in area in the southern part of the area while the least values are recorded in the samples from the southwestern part of the area. From the PCA analysis, six factor groups were distinct. These are Factor 1-6. Factor 1 of the PCA was interpreted to be related to weathering of hydrothermal sulphide ores and silicate BIF while factor 2 was interpreted to be the product of cherty rich magnetite and ores that are rich in terrigenous material. Factor 3 is related to rocks and minerals such as Phosphate -Nb deposits that are rich in rare earth elements in an evaporite environment. Factor 4 and 5 were influenced by weathered manganite and precious hydrothermal sulphide ores respectively. Factor 6 is interpreted to be related to manganite ores. The result of correlation analysis shows that Fe is negatively correlated with most of the correlated elements.

The study shows that the central part of the study area is mineralized with both manganite and goethite. Goethite mineralization also dominates the western and southern part of the study area while manganite mineralization is also enriched in the eastern part of the study area. The study further suggest that manganese mineralization is favoured by elemental association: Zn+As+Be+Bi+Co+Nb+Ni+Cs±P+Al+Ca+Cd+Li+K while iron mineralization is associated with Zr+Th+Pd+Mo+V+Sn+Cr+Ce+In±Sc+P+Pb association.

Keywords: *Manganite, Goethite, Kaoje, Exploration geochemistry and Soil survey*

Introduction

Traditional exploration geochemistry usually employed earth material such as rock, stream sediments and soil to detect unusual concentration of elements that may serve as pathfinder for concealed ore body. The distribution of the elements of interest in these media especially stream sediments and soil are govern by weathering and hydromorphic conditions of the area under investigation. Despite their dispersion, the trace and rare earth elements still retain their bedrock characteristics. These elements are adsorbed unto surfaces of weathered products such as sediment and soils and possess the ability to remain on the surfaces of these weathered particles for long periods unless they are mobilized by decomposition processes such as redox conditions (Filgueiras et al., 2004). Bowen (1979) put forward that the residence time of these elements in temperate soils vary e.g. 740-5900yrs for Pb, 70-510yrs for Zn, 13-1100yrs for Cd and 310-1500yrs for Cu while residence time in tropical soils is 40 years due to shorter rate of leaching. Soil geochemical surveys have proven to be highly effective and there has been a long and impressive history of discovering blind deposits (David, 2010).

**Corresponding author email: bamigboyeos@yahoo.com*

Bamigboye (2012) reported goethite mineralization in addition to the manganite mineralization exposures reported by Akinlolu (2007) in this area. While Akinlolu (2007) said the schist hosted manganese occurs as outcrop in Derena and Buya communities essentially, he added that the manganese ore in Buya area is relatively purer and group these manganites into Buya cluster, Derena north and Derena south cluster. Bamigboye (2012) reported in addition to the earlier reported ones, an exposure of the manganite south of Barkin-Ruwa. This exposure was unique in terms of its brown colouration as against the black colour of those in Buya and Derena clusters. In addition to this, he also reported sedimentary hosted goethite in the area. These reports did not give account of the distribution of trace and rare earth elements in the soil in Kaoje and its environs, neither is vivid account given on the possibility of discovering concealed bodies of these ores or others within Kaoje and its environs. Other work related to this include the work of Adekoya (1998), Garba (2000), Mucke (2005), Akinlolu (2007), Okorie et al (2009a and b), Fille (2014a and b) among others. This work is therefore aimed at identifying the mineralized zones in Kaoje and its environs using soil survey. The study area is bounded by Long. 3°55' and 4°10' E and Lat. 11°00' and 11°15' N covering an approximate area of 676Km².

Geology of the Study Area

The geology of the area can be grossly divided into the basement complex and the sedimentary rocks. The basement complex rocks are mainly banded gneiss, migmatite, granite gneiss, quartz-mica schist and granite (Fig. 1).

The banded gneiss occurs as elongated rock body within the schist and is seen in about 2km south-west of Buya and midway between Idowa and Derena. The banded gneisses are rich in quartz with pervasive jointing, filled by quartz and quartzofeldspathic vein in most cases. The migmatite trend in SE-NW direction mainly. The granite gneisses have a sharp contact with the mica schist. Mineralogically, quartz, biotite and sodic feldspar predominate but crystals of tourmaline are seen in some localities.

The quartz mica schist is an extensive weathered rock which covers about one-fifth of the area studied. It occurs as a low-lying exposure and stream cut exposure. Some of the schist occur as xenolith with a large pegmatitic body close to Barkin-Ruwa, along Barkin-Ruwa – Buya traverse.

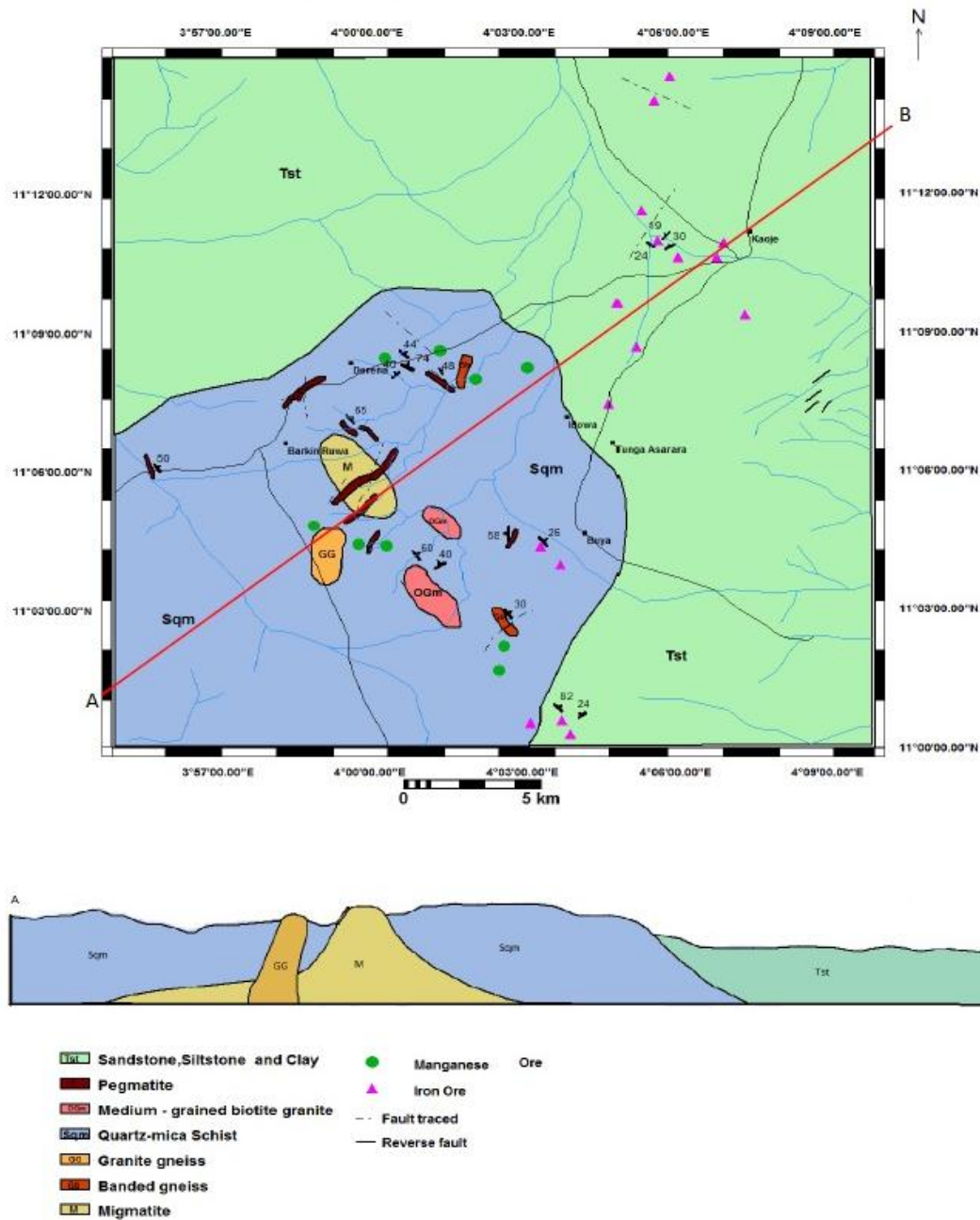
The granitic bodies occur towards the southern part of the study area. The granitic rocks occur as boulders and cobbles of rocks and are closely associated with weathered schist in the extreme southern part of the area. The pegmatitic rocks in this area are seen associated with the schist and migmatite mainly. Some of the pegmatite is also seen at the contact between the schist and the sedimentary rock in the northwestern. Mineralogically, the pegmatites are made-up of quartz, biotite, k-feldspar tourmaline (in the southeastern part) and chalcedony (in the northwestern part).

Sedimentary rocks in this area occupy more than 60% of the area studied. The rock form most of the elevated features in the area and include the Biongbe, Morongba and Koremi hill. These hills are essentially clastic sedimentary rocks and include the sandstone and silty-sandstone. Koremi and Biongbe hills are covered by weathered surfaces. In the northeastern part of Kaoje, the sedimentary rocks occur as remnant of gully eroded sedimentary rock. These rocks are finely laminated with characteristic trace fossil. Other characteristic of these rocks are their semi-consolidated nature that is typical of Taloka formation in the Sokoto basin. The rocks in this area include silty-sandstones that are finely laminated while some are massive. Other sedimentary rock type seen associated with the sandstone are kaolinitic mudstone, finely laminated siltstones and kaolinitic claystone. All these are exposed along Kaoje-Idowa road and towards the edge of the area studied in northeastern part of Kaoje. Closely associated with these fine grained sedimentary rocks are iron ore veins.

The iron ore occur as vein, boulders and sedimentary capping in the northeast and southeast mainly. It shows conspicuous alternating bands of iron and chert rich layers in most of the location while few are massive iron ore with little or no cherty contents seen. The iron is also seen in some sedimentary body.

The manganese ores occur as bodies of boudins in almost NE-SW direction from Buya through Derena to southern part of Barkin-Ruwa. These ores occur as black laminated exposures mainly around Buya- Derena axis and as brown folded brown laminated body south of Barkin-Ruwa. The Mn is associated with quartz veins.

The faults in this area range from the reverse fault to conjugate faulting where dextral and sinistral fault and subsidence are seen together. In the reverse fault, the downward displacement of the footwall is about 30cm in the sandstone southeastern Kaoje. The dextral faulting is seen in both the manganese ores, crystalline and the sedimentary rocks. In the crystalline rocks, the displacement varies from 1cm to 15cm. Similarly, the sinistral



fault displacement seen in both the ores, crystalline and sedimentary rocks have similar magnitude of displacement.

The folds seen include chevron, anticlinal, and synclinal folds. These are associated with the manganese ores close to Buya. Other types of fold seen in the area are associated with the gneisses and or migmatites. They include recumbent fold and pygmatic fold.

The sedimentary structures in the area are the clay bud. These are seen in the silty claystone. It is believed to have been caused by erosion of finer materials trapped during sedimentation thereby leaving behind a cavity. These cavities were seen to be concentrated in strata with the same sedimentary material (silty sandstone). Pinch out (Wedge out) structure is also seen associated with the sandstone in the Kaoje and its environs while hummocky cross lamination is seen preserved in the iron ore northwest of Kaoje. Bioturbation is seen close to the iron capping in most sedimentary beds in the southeastern part of Kaoje.

Methodology

During the field mapping, rocks, minerals and soils were taken on a grid of 1km by 1km. The soil samples were taken at B- horizon (Vareikiene and Lehtonen, 2004). Thirty (30) soil samples (Fig. 2) were prepared and subjected to geochemical analysis at ACME Analytical laboratory, Vancoover, Canada. In the laboratory, 0.5g of the soil samples were digested with a modified Aqua Regia solution of equal parts concentrated HCl, HNO₃ and DI H₂O for one hour in a heating block. The resulting solution was thereafter analysed by ICP-ES and ICP-MS for trace and rare-earth elemental concentration. Geochemical data was subjected to correlation and Principal Component Statistical Analysis (PCSA) using the SPSS software while isograde plotting of the data was done using Surfer 12.

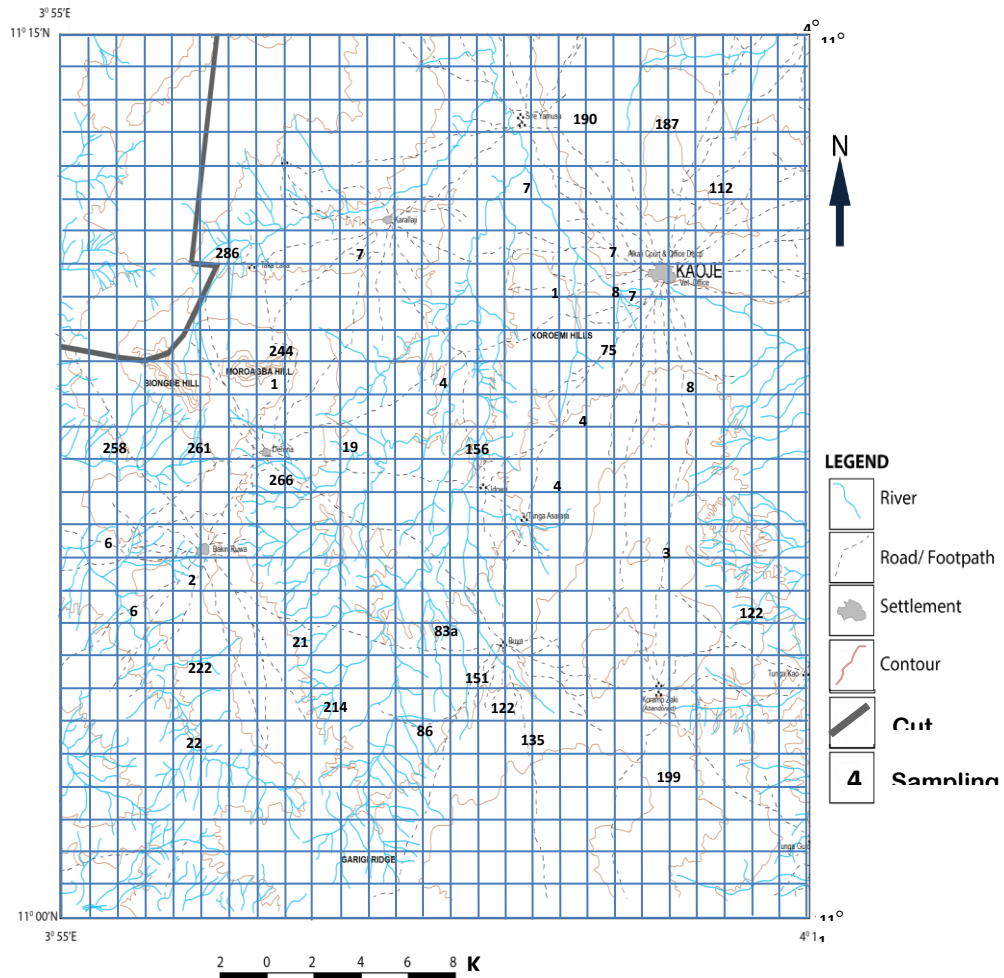


Fig. 2: Topographic map of the Kaoje and its environs showing the analysed sample locations.

Results and Interpretation

The result of the geochemical analysis of the 30 soil samples where concentration of 53 elements was determined is shown in Table1. From the result, sample 83a and 86 in the southern part of the area has the highest concentration of most of the elements while sample 64 and 222 has the lowest concentration of most of the elements. S has a constant value of <0.02 except in sample 83a where the value is 0.02%. This same sample has 0.05 ppm concentration of W as against <0.05 in the remaining samples. This is equally similar to the slight higher concentration of 0.02 ppm of Se as against <0.1 in other samples.

From the correlation result of 25 elements, the following pair of elements Mo and Fe, Mo and V, Cu and U, Cu and Bi, Cu and Al, Zn and K, Zn and Rb, Ni and Mg, Co and Mn, Fe and V, Sr and Ca, Bi and Al, P and Rb, K and Rb has a very strong correlation coefficient of ≥ 0.90 but < 1 (Table2). Ag has very low correlation

coefficient with all the correlated elements. These very low correlation coefficients of Ag with other elements are negative for 60% of the correlated elements.

From the result of the analysis, six (6) factor groups were distinct (Table 3). These are factor 1 – 6. Factor 1 with Mg, Ni, Cs, K, Te, Li, Ti, Rb, Bi, Al, Zn, Cu, Tl, U, Cr, Co, Na and Be account for a total of 43.59% before rotation and 31.86% after rotation. Following this is Factor 2 with Zr, Hf, Th, Ga, In, Sc, Sn, Fe, V, Pd, Mo, Sb, As, and Ce that account for 20.701% before rotation and 23.09% after rotation. Factor 3 has Se, Nb, Ca, Sr and P. This factor group account for 9.95% before rotation and 14.697% after rotation. Factor 4 with Ba, Pb, Y, Mn, La and Cd gave an account of 8.518% before rotation and 10.078 after rotation while Factor 5 with the following elements: Hg, Ag and Au account for 3.412% before rotation and 2.758% after rotation. Factor 6 does not have highest loading of any element. Despite this, it still account for 2.658% before rotation and 3.106% after rotation.

Table1: Geochemical result of the analyses soil samples

Samp le No	Mo (PPM)	Cu (PPM)	Pb (PPM)	Zn (PPM)	Ag (PPB)	Ni (PPM)	Co (PPM)	Mn (PPM)	Fe (%)	As (PPM)	U (PPM)	Au (PPB)	Th (PPM)	Sr (PPM)	K (%)	W (PPM)	Sc (PPM)	Tl (PPM)	S (%)
10	0.24	2.86	6.62	4.8	9	2.5	5.2	242	0.63	<0.1	0.70	3.5	4.3	3.3	0.03	<0.05	2.3	0.05	<0.02
18	0.26	3.01	9.12	6.2	19	3.8	4.0	448	0.93	0.3	0.65	0.2	5.1	12.0	0.03	<0.05	2.4	0.04	<0.02
33	0.20	1.49	6.03	4.5	97	2.3	3.5	260	0.60	0.3	0.39	1.2	4.7	2.8	0.01	<0.05	1.6	0.03	<0.02
44	0.22	4.99	4.75	11.5	11	5.7	4.5	262	0.81	0.3	0.83	1.4	4.1	3.8	0.08	<0.05	2.1	0.11	<0.02
60	0.46	4.85	10.05	5.1	13	3.0	3.6	216	1.41	0.6	1.00	1.1	5.4	6.9	0.03	<0.05	2.3	0.07	<0.02
64	0.08	1.95	3.38	2.0	47	1.1	0.7	64	0.18	<0.1	0.38	3.9	1.9	3.5	0.02	<0.05	1.0	0.03	<0.02
73	0.13	1.61	5.04	3.1	15	2.1	3.9	192	0.48	0.1	0.46	7.6	3.4	3.2	0.02	<0.05	1.3	0.04	<0.02
76	0.32	5.49	6.49	7.0	14	3.0	1.1	35	1.68	0.2	1.29	2.1	6.2	2.2	0.01	<0.05	5.2	0.04	<0.02
78	0.25	3.93	7.53	5.4	14	2.6	2.3	197	0.85	0.2	0.76	1.0	4.3	5.9	0.02	<0.05	2.7	0.03	<0.02
83a	0.38	14.68	10.83	49.6	38	8.2	5.4	309	1.91	1.2	2.10	0.8	6.0	50.3	0.42	0.05	2.0	0.33	0.02
86	0.93	18.06	13.35	41.9	19	25.8	16.6	911	2.85	1.3	2.45	2.6	5.5	12.1	0.51	<0.05	6.9	0.29	<0.02
112	0.34	2.49	7.63	6.8	5	2.9	4.7	345	1.15	0.3	0.79	1.6	6.4	5.2	0.02	<0.05	3.2	0.04	<0.02
122	0.83	9.98	15.28	10.5	8	4.6	2.3	123	3.70	1.3	1.25	1.7	14.0	1.2	0.02	<0.05	7.8	0.07	<0.02
128	0.39	2.77	7.30	5.8	23	3.6	3.4	198	1.62	0.6	0.92	1.4	4.5	7.5	0.03	<0.05	3.4	0.03	<0.02
135	0.43	3.89	9.75	7.5	13	3.9	4.8	234	1.57	0.2	1.23	2.4	10.9	2.5	0.03	<0.05	5.4	0.06	<0.02
151	0.28	4.91	8.99	15.4	23	5.2	5.6	546	0.91	0.4	1.00	0.4	4.4	11.8	0.05	<0.05	2.4	0.06	<0.02
187	0.20	2.68	6.07	4.9	19	2.8	3.9	329	0.80	0.2	0.53	1.8	4.2	5.3	0.02	<0.05	2.1	0.03	<0.02
190	0.27	2.46	7.58	7.2	7	3.8	3.2	208	1.00	0.2	0.68	0.9	6.1	3.7	0.02	<0.05	3.0	0.04	<0.02
194	0.38	6.55	10.70	9.2	38	3.7	1.3	73	2.07	0.9	0.83	4.1	11.0	1.5	0.02	<0.05	5.3	0.05	<0.02

199	0.35	2.14	9.06	7.3	19	4.3	3.7	305	1.06	0.6	0.63	4.2	7.8	9.3	0.04	<0.05	3.0	0.05	<0.02
214	0.09	5.73	8.56	13.5	53	5.0	3.6	405	0.67	<0.1	1.09	2.4	4.9	22.1	0.08	<0.05	3.1	0.10	<0.02
217a	0.14	3.68	6.53	4.9	18	2.6	2.3	144	0.53	0.2	0.80	4.9	4.3	6.1	0.03	<0.05	1.7	0.05	<0.02
219	0.39	7.78	19.85	8.3	25	5.4	13.4	958	1.73	0.4	1.38	2.1	6.7	15.6	0.03	<0.05	2.9	0.16	<0.02
222	0.03	1.84	4.27	2.0	22	1.3	0.5	25	0.10	<0.1	0.46	0.7	2.2	4.3	0.02	<0.05	1.5	0.03	<0.02
225	0.16	6.90	8.56	7.4	32	4.2	2.4	40	0.75	0.4	1.02	2.6	6.2	8.4	0.07	<0.05	3.7	0.13	<0.02
244	0.37	3.56	11.55	9.9	13	4.2	6.3	471	1.72	0.6	0.97	0.4	6.2	4.7	0.03	<0.05	3.5	0.06	<0.02
258	0.16	7.19	12.80	8.9	16	5.1	3.5	327	0.60	<0.1	1.22	<0.2	4.0	14.6	0.06	<0.05	2.6	0.06	<0.02
261	0.28	5.26	12.77	6.7	12	4.8	4.7	254	1.14	0.2	1.16	0.4	5.8	7.8	0.04	<0.05	2.9	0.06	<0.02
266	0.26	4.74	11.21	9.7	6	4.6	9.7	583	1.20	0.3	1.13	<0.2	6.3	7.0	0.04	<0.05	3.7	0.07	<0.02
286	0.41	6.51	11.53	6.2	21	4.7	4.2	145	1.48	0.4	1.41	1.3	9.7	6.5	0.04	<0.05	4.7	0.08	<0.02

Table1 cont'd (i)

Samp le No	Cd (PPM)	Sb (PPM)	Bi (PPM)	V (PPM)	Ca (%)	P (%)	La (PPM)	Cr (PPM)	Mg (%)	Ba (PPM)	Be (PPM)	B (PPM)	Al (%)	Re (PPB)	Hg (PPB)	Se (PPM)	Pt (PPB)	Ga (PPM)
10	<0.01	0.04	0.06	17	0.02	0.006	9.4	9.0	0.02	18.7	0.3	<20	0.43	<1	11	<0.1	<2	2.6
18	0.02	0.05	0.05	22	0.15	0.009	15.8	15.1	0.03	42.4	0.2	<20	0.41	<1	30	<0.1	<2	3.1
33	<0.01	0.04	0.05	14	0.02	0.004	8.9	11.3	0.02	14.5	0.1	<20	0.23	<1	6	<0.1	<2	2.1
44	<0.01	<0.02	0.11	20	0.03	0.006	12.4	12.5	0.07	40.3	0.4	<20	0.45	<1	9	<0.1	<2	2.7
60	<0.01	0.06	0.07	45	0.08	0.011	13.4	20.8	0.03	50.8	0.5	<20	0.49	<1	14	<0.1	<2	3.1
64	<0.01	<0.02	0.02	10	0.03	0.004	7.1	6.0	0.02	42.4	0.1	<20	0.14	<1	8	<0.1	<2	0.8
73	<0.01	0.02	0.04	13	0.03	0.005	7.3	8.1	0.02	33.4	0.3	<20	0.25	<1	7	<0.1	<2	1.7
76	0.01	0.03	0.05	33	0.01	0.010	10.9	21.3	0.02	15.1	0.2	<20	0.69	<1	14	<0.1	<2	5.5
78	<0.01	0.03	0.05	21	0.06	0.008	16.1	14.2	0.02	19.1	0.2	<20	0.47	<1	19	<0.1	<2	3.0
83a	0.02	<0.02	0.15	19	0.74	0.020	24.4	10.7	0.24	135.9	1.4	<20	1.55	<1	17	0.2	<2	7.2
86	0.01	<0.02	0.22	59	0.13	0.011	24.2	44.8	0.50	144.3	1.1	<20	1.98	<1	11	<0.1	<2	7.5
112	<0.01	0.05	0.05	26	0.05	0.008	14.8	17.5	0.02	26.5	0.3	<20	0.38	<1	23	<0.1	<2	3.5
122	<0.01	0.07	0.11	73	<0.01	0.010	21.0	24.7	0.01	9.1	0.2	<20	1.07	<1	23	<0.1	<2	9.5
128	<0.01	0.04	0.05	45	0.07	0.011	14.1	21.2	0.02	45.0	0.3	<20	0.55	<1	15	<0.1	<2	4.5
135	<0.01	0.05	0.09	39	0.02	0.008	15.4	19.1	0.03	14.6	0.3	<20	0.74	<1	15	<0.1	<2	7.0
151	0.01	0.04	0.06	25	0.14	0.009	17.4	11.2	0.04	86.3	0.4	<20	0.42	<1	28	<0.1	<2	2.3
187	0.02	0.04	0.03	18	0.05	0.006	12.5	14.3	0.02	30.8	0.2	<20	0.25	<1	34	<0.1	<2	2.0
190	<0.01	0.04	0.05	23	0.03	0.007	12.2	17.0	0.02	18.7	0.2	<20	0.44	<1	28	<0.1	<2	3.9
194	<0.01	0.05	0.08	43	<0.01	0.011	11.0	19.6	0.01	7.4	0.2	<20	0.87	<1	16	<0.1	<2	6.8
199	<0.01	0.05	0.06	24	0.11	0.011	17.8	18.8	0.03	17.4	0.3	<20	0.46	<1	29	<0.1	<2	4.1
214	<0.01	<0.02	0.06	17	0.26	0.007	20.0	9.5	0.11	154.3	1.0	<20	0.53	<1	22	<0.1	<2	2.3
217a	<0.01	<0.02	0.04	14	0.09	0.006	14.4	10.1	0.04	40.0	0.3	<20	0.38	<1	21	<0.1	<2	1.6
219	0.02	0.05	0.07	40	0.15	0.010	21.6	13.9	0.06	259.8	0.6	<20	0.46	<1	13	<0.1	<2	3.1
222	<0.01	<0.02	0.02	6	0.04	0.003	8.5	5.8	0.02	28.8	0.4	<20	0.17	<1	8	<0.1	<2	0.9
225	<0.01	<0.02	0.08	24	0.11	0.007	17.3	15.2	0.08	59.2	0.7	<20	0.76	<1	13	<0.1	<2	4.1
244	<0.01	0.05	0.07	36	0.04	0.011	14.9	14.9	0.03	27.4	0.4	<20	0.56	<1	20	<0.1	<2	4.5
258	0.02	0.03	0.06	18	0.11	0.010	24.5	10.8	0.07	190.6	0.7	<20	0.43	<1	27	<0.1	<2	1.9
261	0.02	0.04	0.07	29	0.09	0.009	22.9	11.6	0.04	68.9	0.4	<20	0.47	<1	25	<0.1	<2	3.5
266	0.02	0.05	0.07	30	0.08	0.013	30.6	15.6	0.04	43.8	0.4	<20	0.48	<1	29	<0.1	<2	3.7
286	0.01	0.04	0.09	42	0.06	0.009	18.3	12.6	0.03	43.9	0.4	<20	0.82	<1	21	<0.1	<2	6.0

Table1 cont'd (ii)

Samp le No	Cs (PPM)	Ge (PPM)	Hf (PPM)	Nb (PPM)	Rb (PPM)	Sn (PPM)	Ta (PPM)	Zr (PPM)	Y (PPM)	Ce (PPM)	In (PPM)	Na (%)	Ti (%)	Li (PPM)	Pd (PPB)	Te (PPM)
10	0.48	<0.1	<0.02	0.15	8.7	0.5	<0.05	1.4	8.11	33.8	0.03	<0.001	0.009	1.2	<10	<0.02
18	0.36	<0.1	0.09	0.65	7.4	0.7	<0.05	3.2	9.57	33.1	0.02	<0.001	0.019	1.2	<10	<0.02
33	0.28	<0.1	0.07	0.37	4.7	0.6	<0.05	2.8	5.35	21.8	<0.02	<0.001	0.021	0.7	<10	<0.02
44	1.16	<0.1	<0.02	0.18	17.9	0.5	<0.05	0.9	5.62	25.8	0.02	0.002	0.018	3.4	<10	<0.02
60	0.39	<0.1	0.04	0.26	8.9	0.5	<0.05	2.3	8.98	33.2	<0.02	<0.001	0.008	1.1	<10	<0.02
64	0.22	<0.1	<0.02	0.10	3.9	0.2	<0.05	0.6	3.85	12.7	<0.02	<0.001	0.004	0.6	<10	<0.02
73	0.26	<0.1	<0.02	0.17	5.1	0.3	<0.05	1.1	4.63	21.8	<0.02	<0.001	0.008	0.6	<10	<0.02
76	0.44	<0.1	0.17	0.35	2.8	0.9	<0.05	8.7	9.11	35.2	0.04	<0.001	0.014	1.0	<10	<0.02
78	0.42	<0.1	0.03	0.33	5.4	0.6	<0.05	1.9	10.48	55.0	<0.02	<0.001	0.012	1.1	<10	<0.02
83a	3.66	<0.1	0.11	2.63	57.1	1.1	<0.05	3.8	4.52	49.0	<0.02	0.003	0.068	28.8	<10	<0.02
86	4.66	<0.1	0.03	0.49	55.1	1.0	<0.05	1.7	10.84	60.8	0.03	0.003	0.096	32.2	<10	0.05
112	0.41	<0.1	0.04	0.50	7.1	0.8	<0.05	3.3	9.72	41.0	0.03	<0.001	0.023	0.9	<10	<0.02
122	0.81	<0.1	0.36	0.35	5.5	1.6	<0.05	19.6	10.67	79.6	0.05	<0.001	0.024	1.4	14	<0.02
128	0.41	<0.1	0.05	0.45	6.0	0.9	<0.05	2.4	11.38	38.4	<0.02	<0.001	0.015	1.1	<10	<0.02
135	0.75	<0.1	0.22	0.25	10.8	1.3	<0.05	11.2	9.41	85.1	0.04	<0.001	0.022	1.7	<10	<0.02
151	0.39	<0.1	0.06	0.26	9.9	0.4	<0.05	2.4	13.53	47.9	0.02	<0.001	0.009	1.2	<10	<0.02
187	0.29	<0.1	0.05	0.40	5.4	0.7	<0.05	2.9	9.95	26.0	<0.02	<0.001	0.019	0.7	<10	<0.02
190	0.42	<0.1	0.04	0.39	6.5	0.8	<0.05	3.9	8.94	40.4	0.03	<0.001	0.027	1.2	<10	<0.02
194	0.55	<0.1	0.19	0.43	5.0	1.4	<0.05	10.5	5.06	48.3	0.04	<0.001	0.013	1.5	<10	<0.02
199	0.41	<0.1	0.08	0.54	7.9	1.0	<0.05	3.4	10.10	45.8	<0.02	<0.001	0.024	1.1	<10	<0.02
214	0.46	<0.1	0.04	0.25	14.1	0.7	<0.05	2.1	15.96	43.3	<0.02	0.001	0.009	3.1	<10	<0.02
217a	0.32	<0.1	<0.02	0.13	8.0	0.3	<0.05	1.1	8.44	31.5	<0.02	<0.001	0.005	1.1	<10	0.02
219	0.50	<0.1	0.07	0.40	8.2	0.6	<0.05	3.6	17.46	78.6	0.02	0.003	0.012	1.2	<10	<0.02
222	0.26	<0.1	<0.02	0.09	4.0	0.2	<0.05	0.4	4.74	17.6	<0.02	0.002	0.005	0.6	<10	<0.02
225	0.82	<0.1	0.04	0.18	14.3	0.6	<0.05	2.0	9.58	39.4	<0.02	<0.001	0.004	3.1	<10	<0.02
244	0.56	<0.1	0.07	0.48	9.8	1.1	<0.05	4.4	10.24	54.8	<0.02	0.001	0.025	1.5	<10	0.03
258	0.44	<0.1	0.03	0.26	11.2	0.4	<0.05	1.1	24.93	48.4	<0.02	0.001	0.008	1.3	<10	<0.02
261	0.57	<0.1	0.06	0.25	8.9	0.8	<0.05	3.3	14.57	83.8	<0.02	<0.001	0.010	1.4	<10	<0.02
266	0.66	<0.1	0.04	0.53	12.4	1.2	<0.05	3.1	22.52	58.9	<0.02	<0.001	0.021	1.8	<10	<0.02
286	0.82	<0.1	0.15	0.35	10.8	1.0	<0.05	7.6	15.61	45.8	0.04	<0.001	0.011	2.1	<10	<0.02

Table 2: Result of Correlation analysis of selected elements

	Mo	Pb	Zn	Ni	Co	Mn	Fe	As	Th	Sr	Cd	Bi	V	Ca	P	Cr	Mg	Al	K	Sc	Cs	Nb	Rb	Sn	Zr	Ce	In	Be	L
Mo	1																												
Pb	0.61	1																											
Zn	0.50	0.33	1																										
Ni	0.67	0.41	0.77	1																									
Co	0.52	0.60	0.53	0.75	1																								
Mn	0.37	0.59	0.44	0.62	0.92	1																							
Fe	0.93	0.67	0.48	0.52	0.39	0.27	1																						
As	0.83	0.51	0.69	0.61	0.35	0.24	0.85	1																					
Th	0.63	0.56	0.09	0.09	0.04	-0.05	0.76	0.54	1																				
Sr	0.03	0.28	0.76	0.31	0.26	0.32	0.10	0.34	-0.11	1																			
Cd	-0.09	0.43	0.20	0.05	0.31	0.41	-0.01	-0.03	-0.10	0.47	1																		
Bi	0.76	0.50	0.83	0.87	0.63	0.44	0.69	0.77	0.38	0.40	0.03	1																	
V	0.91	0.67	0.24	0.46	0.38	0.25	0.93	0.72	0.74	-0.13	-0.11	0.58	1																
Ca	0.04	0.22	0.77	0.28	0.20	0.24	0.12	0.38	-0.07	0.99	0.43	0.40	-0.13	1															
P	0.50	0.58	0.68	0.37	0.35	0.32	0.60	0.66	0.38	0.65	0.40	0.56	0.45	0.66	1														
Cr	0.87	0.40	0.43	0.75	0.51	0.37	0.75	0.67	0.43	-0.09	-0.16	0.68	0.78	-0.10	0.37	1													
Mg	0.52	0.29	0.86	0.95	0.67	0.54	0.38	0.56	-0.07	0.50	0.09	0.84	0.26	0.48	0.38	0.60	1												
Al	0.77	0.48	0.85	0.81	0.48	0.29	0.76	0.83	0.45	0.45	0.001	0.93	0.62	0.47	0.64	0.71	0.81	1											
K	0.49	0.25	0.95	0.87	0.58	0.44	0.40	0.63	-0.03	0.65	0.15	0.85	0.21	0.66	0.53	0.50	0.96	0.85	1										
Sc	0.81	0.53	0.27	0.49	0.27	0.12	0.86	0.61	0.80	-0.16	-0.17	0.59	0.86	-0.16	0.35	0.77	0.31	0.68	0.24	1									
Cs	0.60	0.30	0.94	0.88	0.59	0.41	0.51	0.70	0.10	0.57	0.11	0.91	0.33	0.58	0.54	0.58	0.94	0.90	0.98	0.37	1								
Nb	0.21	0.22	0.76	0.24	0.17	0.16	0.31	0.53	0.12	0.84	0.41	0.44	0.02	0.88	0.78	0.06	0.39	0.53	0.62	-0.01	0.60	1							
Rb	0.45	0.27	0.96	0.81	0.57	0.43	0.38	0.61	-0.002	0.72	0.19	0.86	0.18	0.73	0.58	0.42	0.91	0.83	0.98	0.20	0.97	0.68	1						
Sn	0.68	0.51	0.32	0.26	0.19	0.09	0.81	0.64	0.86	0.06	0.05	0.50	0.72	0.09	0.60	0.55	0.13	0.59	0.19	0.80	0.31	0.36	0.22	1					
Zr	0.58	0.41	0.01	-0.03	-0.14	-0.20	0.74	0.47	0.91	-0.19	-0.12	0.24	0.70	-0.15	0.26	0.35	-0.17	0.36	-0.13	0.78	0.003	0.07	-0.12	0.77	1				
Ce	0.58	0.82	0.26	0.33	0.46	0.41	0.64	0.38	0.65	0.14	0.28	0.46	0.63	0.11	0.48	0.39	0.19	0.45	0.17	0.63	0.25	0.13	0.20	0.64	0.54	1			
In	0.57	0.24	0.02	0.10	-0.09	-0.24	0.64	0.36	0.79	-0.31	-0.33	0.30	0.63	-0.28	0.10	0.43	-0.04	0.42	-0.03	0.80	0.10	-0.07	-0.06	0.65	0.86	0.37	1		
Be	0.22	0.38	0.82	0.62	0.46	0.42	0.22	0.42	-0.07	0.83	0.26	0.66	0.08	0.79	0.55	0.19	0.77	0.65	0.81	0.09	0.75	0.58	0.85	0.07	-0.21	0.22	-0.21	1	
Li	0.51	0.25	0.96	0.84	0.55	0.40	0.43	0.66	0.01	0.65	0.14	0.84	0.23	0.67	0.55	0.50	0.93	0.86	0.99	0.26	0.99	0.66	0.98	0.24	-0.08	0.17	0.01	0.78	1
Pd	0.52	0.33	0.01	0.002	-0.12	-0.14	0.62	0.48	0.59	-0.15	-0.10	0.20	0.57	-0.12	0.08	0.25	-0.09	0.24	-0.07	0.54	0.01	-0.02	-0.09	0.45	0.74	0.35	0.55	-0.14	-0.01

Table 3: Rotated Component Matrix

	Component					
	1	2	3	4	5	6
Mg	.959					
Ni	.956					
Cs	.921		.343			
K	.909		.393			
Te	.900					
Li	.893		.430			
Ti	.881					
Rb	.854		.488			
Bi	.850	.376				
Al	.812	.481				
Zn	.795		.563			
Cu	.770	.354	.319	.315		
Tl	.769		.511			
U	.734	.351		.379		
Cr	.711	.476				
Co	.662			.576		
Na	.632		.358	.358	-.335	
Be	.628		.520	.380		.349
Zr		.969				
Hf		.948				
Th		.943				
Ga	.420	.864				
In		.845				
Sc	.388	.841				
Sn		.827				
Fe	.428	.826				
V	.347	.818				
Pd		.735				
Mo	.602	.706				
Sb	-.320	.618			.305	
As	.584	.608	.313			
Ce		.603		.542		
Se			.942			.564
Nb	.307		.914			
Ca	.311		.903			
Sr	.318		.862			
P	.350	.367	.629		.361	
Ba	.300			.843		
Pb		.518		.754		
Y				.737	.569	
Mn	.483			.663		
La	.342			.620	.511	
Cd			.455	.521	.381	
Hg					.838	
Ag					-.575	.443
Au					-.500	

Interpretation

The good correlation coefficient of Mn with Ni and Mg; and the weak correlation especially between Mn and Cu is related to Mn-rich end member. Similarly, good correlation coefficient between Fe and Ti, P coupled with the correlation between Co and Ti; the weak to low correlation between Ti and Ca, Ca and P, Ca and Co, Ca and Fe are all related to Fe-rich end member. Likewise, the strong correlation between Al, Na and K are related to aluminosilicate minerals while the fairly good correlation coefficients between Mg and Mn, Cr and Ca are related to mantle derived ultramafic materials.

Factor 1 of the principal component analysis of the soil is related to the weathering of the hydrothermal sulphide ore and silicate rich Banded Iron Formation (Levinson, 1981 and McQueen, 2004) while Factor 2 is the product of weathered cherty rich magnetite and ores that are rich in terrigenous materials. The inclusion of elements, like Sn and Mo, is an indication of weathering of granitic rocks like pegmatite that have protore of some sulphide minerals. These minerals cannot be accounted for precisely but the presence of Pd, Ce and Sb in this factor group attest to the presence of these minerals (Levinson, 1981).

Factor 3 relates to the rocks and minerals such as phosphate-Nb deposits that are rich in rare earth elements in an evaporite environment while factor 4 is interpreted as the product of weathered manganese ores. Factor 5 is related to the weathered precious metals that were originally formed from hydrothermal sulphide ore. Factor 6 has the second loading value of Mn, Sb and Co. This factor though not having the highest loading factor of any of the elements shows the weathering of Co bearing manganese ore that occur as protore and incompleteness or leakages in the system (Tsiko, 1999). This leakage typified by Factor 6 must have been well pronounced by mobility of some of the elements (Andrew-Jones, 1968). Factors 1 – 5 are strongly related to mineralization. The presence of the country rock in the factor groups as accounted for by the principal component analysis decrease from factor 1 to factor 5.

The depressions in the isograde plots (Fig. 3 to Fig. 21) are interpreted to be zones of negative anomaly while the positive anomalous zones are the peaks in the plots. The brown coloured area defines the regional threshold while the pinkish-sky blue coloured zones on the plots are interpreted as the local aureole. Deep blue zones are interpreted as the anomalous regions. The values of these zones are estimated from the corresponding values in the colour scale that is besides each plot.

Discussion

Factor 1 of the soil factor analysis is predominated by the lithophile, chalcophile and siderophile elements. In this factor group, most of the elements have mobilities which vary from low mobility to immobile (Andrew-Jones, 1968). Some of them e.g. Cu, Zn etc has varying mobilities between high to very low depending on the condition as against most of the elements that are immobile in the varying condition. The association though related to weathered hydrothermal sulphide ore and sulphide rich BIF is also aided by the mobility of the elements in fluctuating environmental conditions. The fluctuation in the condition is inferred from the inconsequential position occupied by the three types of elements that form the factor group. This scene is also repeated in the factor 2 of the soil factor analysis. Most of the elements in this group are mainly transition metals. Their varying oxidation state coupled with the varying component of the material that are coming together down the slope as the material is transported could account for the association in this group. At the beginning of this phase, the environmental condition favours the lithophile elements, this is then followed by the condition that favours the chalcophile. Mid-way into the phase, the condition became inconsistent before the condition that favours the siderophile prevails and capped by the chalcophile.

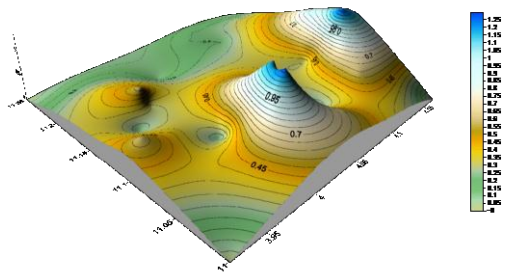


Fig. 3: 3D isograde plot of As

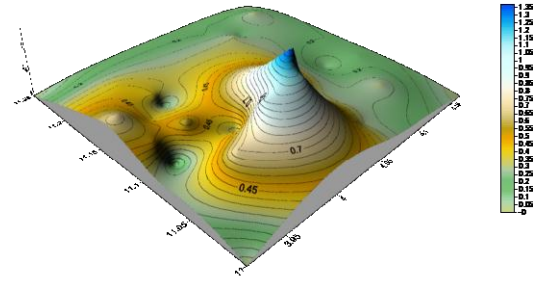


Fig. 4: 3D isograde plot of Be

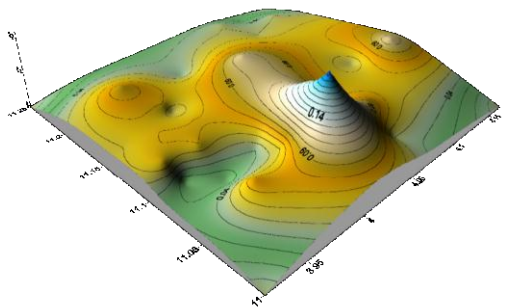


Fig. 5: 3D isograde plot of Bi

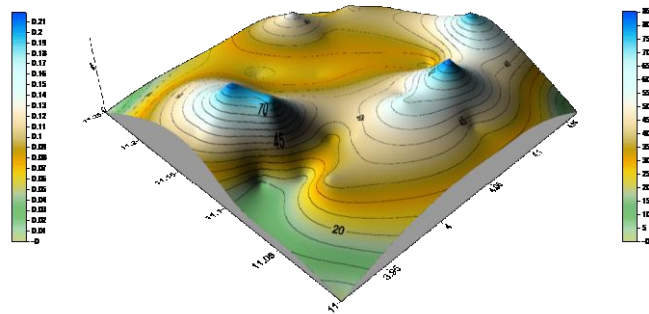


Fig.6: 3D isograde plot of Ce

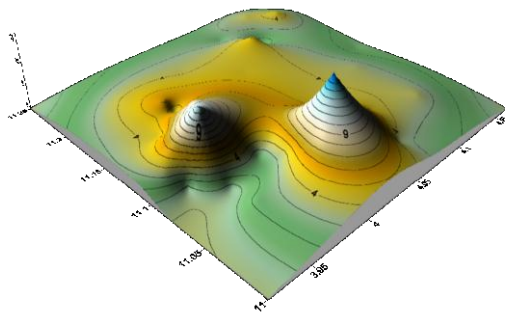


Fig. 7: 3D isograde plot of Co

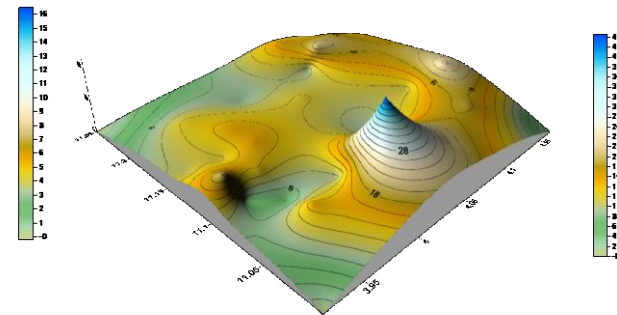


Fig. 8: 3D isograde plot of Cr

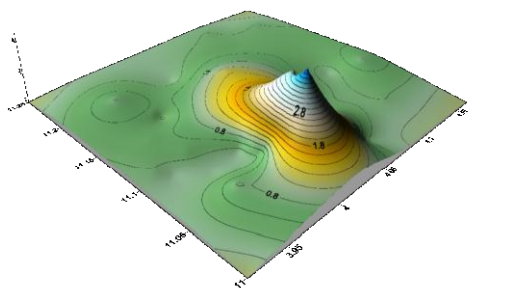


Fig. 9: 3D isograde plot of Cs

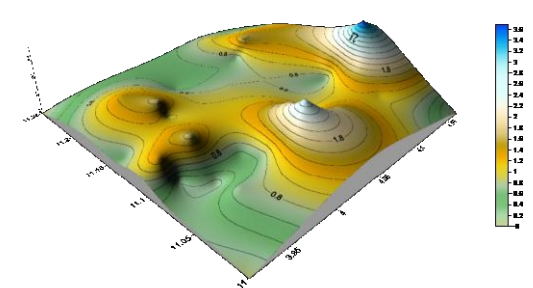


Fig. 10: 3D isograde plot of Fe

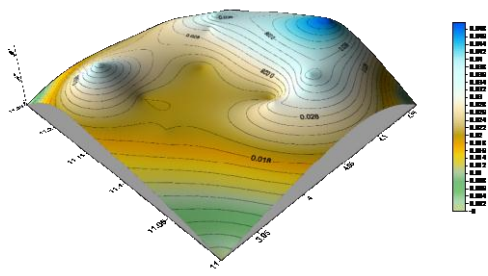


Fig. 11: 3D isograde plot of In

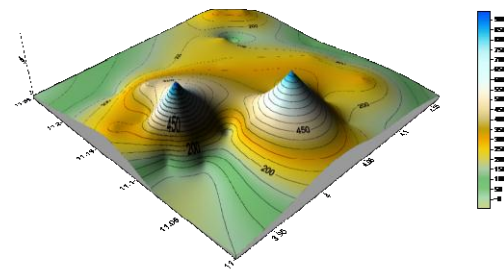


Fig. 12: 3D isograde plot of Mn

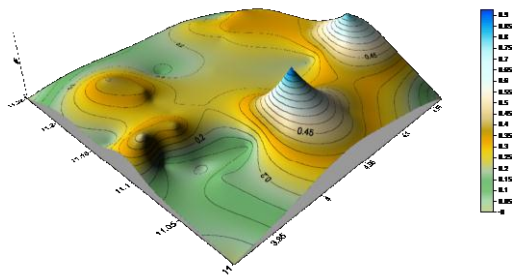


Fig. 13: 3D isograde plot of Mo

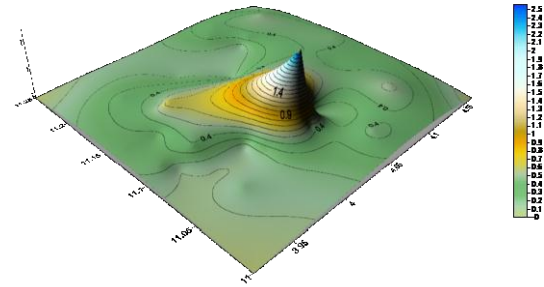


Fig. 14: 3D isograde plot of Nb

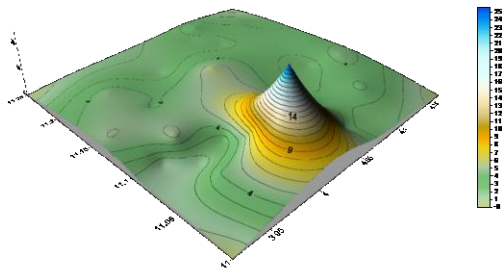


Fig. 15: 3D isograde plot of Ni

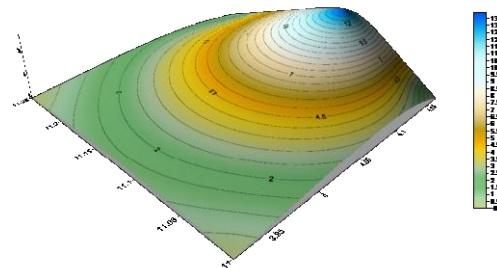


Fig. 16: 3D isograde plot of Pd

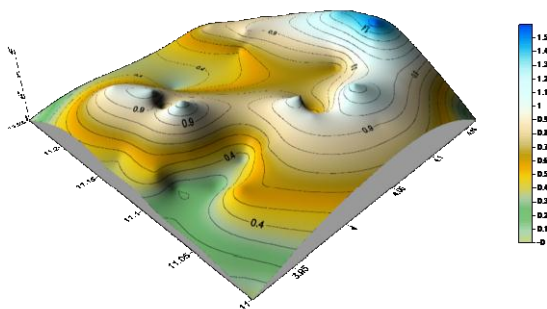


Fig. 17: 3D isograde plot of Sn

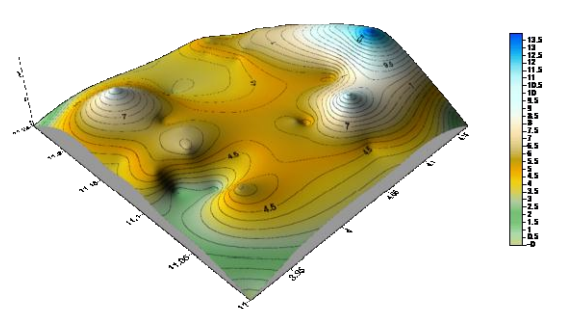


Fig. 18: 3D isograde plot of Th

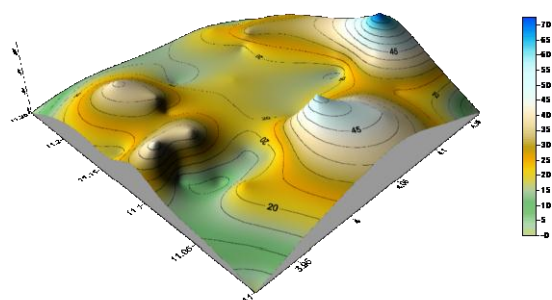


Fig. 19: 3D isograde plot of V

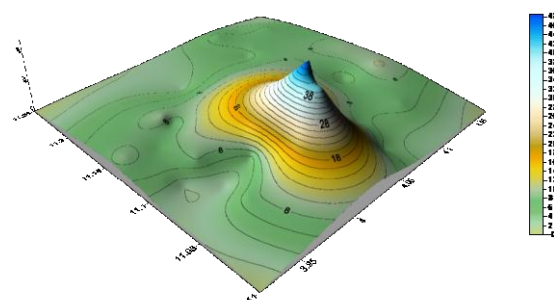


Fig. 20: 3D isograde plot of Zn

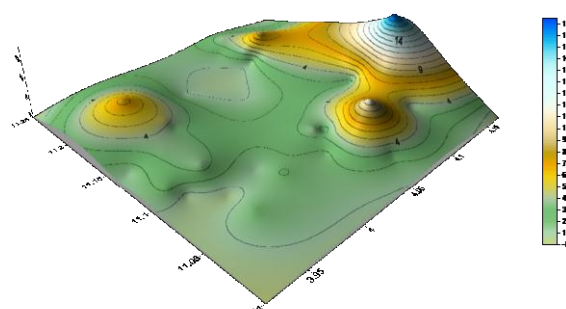


Fig. 21: 3D isograde plot of Zr

Factor 3 is typically of the lithophile elements with trapped single chalcophile elements. The mobility of the chalcophile is similar to the mobility of the lithophile thereby making it easy to be transported together down the slope through the weathering path despite the differences in their chemical affinities and chemical properties. Factor 4 is also relatively formed under unstable environmental conditions that fluctuate between the condition that favours the siderophile, chalcophile and lithophile elements. The conditions that favour the lithophile existed over a relatively long period especially towards the end of the phase and thereafter changed to the condition that favours the chalcophile elements and then capped by the siderophile favouring condition.

Ag has three (3) positive anomalies. These are in the eastern and southwestern part of the study area. The local aureoles are aligned in NW-SE and NE-SW towards the southern part of Kaoje and its environs. Closely associated with these aureoles are negative anomalies that trend parallel to the positive anomalies. Al has its anomaly at Long. 4.05°E and Lat. 11.09°N. There are other positive anomalies in the NW (Long. 3.95°E and Lat. 11.2°N) and at the eastern end (Long. 3.92°E and Lat. 11.2°N). The negative anomaly of Al is well defined at the western part of the mapped area (Long. 3.92°E, Lat. 11.09°N). These anomalies trend in NW-SE. Other spot of negative anomaly is to the right of the positive anomaly that extend from the southern part of the area towards the central part. As has its positive anomaly in almost the same place with Al. Though there are three peaks described as anomaly having the highest value, two (2) of these peaks are twinned towards the center of the area while the third one is at the eastern end of the study area. The negative anomaly that is closely associated with the twinned anomalies towards the centre is also similarly positioned like the negative anomaly in Al. At the western end of this twinned peaks are two each of positive and negative anomalies. While the positives trend in NE-SW, the negative anomalies trend perpendicular to them in NW-SE.

Au has relative different distribution patterns from Ag, Al and As. Its negative anomaly is positioned where the three elements (Ag, Al and As) has their positive anomalies. This relationship in the position of the negative anomaly of Au indicates its depletion in the minerals formed or pathfinded by the three elements. Other peaks of anomaly of Au are in the SE corner, eastern and western parts of the area. These peaks like the negative anomalies are aligned in almost east-west direction with the exception of the peak in the northern part. The three positive anomalous peaks in Ba trend essentially in NW-SE with its highest concentration point defined by Lat. 11.13°N and Long. 3.975°E. This point of highest concentration of Ba corresponds to local aureole of elements

like As, Al, Ag and Au. There is no negative anomaly except sharp decrease to the background value within the area study. These slopes flank the peaks and also separate the peaks from each other.

Like As, Be has its anomaly in the southern part extending towards the central part of the study area. There are positive anomalies that are similarly positioned in the western half of the area except that while the positive anomalies in this half trend in NE-SW for As, those in Be trend in NW-SE. In like manner, the negative anomalies in Be trend in NE-SW but those in As trend in NW-SE. Be also has a twin peak of anomaly like As but one of it is not well defined. Their distribution pattern is not identical but has similar position of their anomalies. Bi has a distribution pattern that is closely similar to that of As in terms of their positive and negative anomalies. Its anomalous point is defined by Lat. 11.075°N and Long. 4.04°E. These peaks slope towards the north. There are few negative anomalies that are evenly distributed in the four (4) quadrant of the area studied. Ca has a point of positive anomaly towards the centre of the area. This area is defined by Long. 4.05°E and Lat. 11.1°N. The negative anomaly is poorly defined in the NE and SE part of Kaoje and its environs.

Cd has ridge of anomaly that trend in NW-SE. The other anomaly is almost perpendicular to the broad NW-SE trending anomaly. Ce has its aureole in the western and SE part essentially. The extreme NE and SW part are relatively depleted in Ce. The Ce anomaly defines an arc with its curvature at the southern part. Cr has its anomaly at Lat. 4.05°E and Long. 11.075°N. Its negative anomalies trend in almost E-W direction. It shares some point of anomaly with elements like As and Bi. With the exception of slightly elevated concentration at the western part of the area (Lat. 3.965°E and Long. 11.120°N) essentially, the distribution of Co is almost identical with that of Cr. They (Cr and Co) have their anomaly in the same spot while the distribution pattern of Cs and K is identical and similar with that of Ca. Their anomalous point is defined by Lat. 4.05°E and Long. 11.06E. This anomaly trend in N-S direction. The anomaly of Ca does not cover larger area, the anomaly of Cs, K, Li and Mg covers relatively larger area compared with that of Ca, Bi and Cr. Their distribution pattern is also identical, sharing the same point of anomalous concentration. There are zones of depletion which fall generally under regional threshold. Fe has its highest concentration in the eastern part of the study area and an anomaly that is described as local aureole in the southern part of the study area. These two peaks of anomalies are also observed in the isograde plot of As. With little variations, its distribution pattern is closely related to the distribution pattern of Cr and As.

Ga and Hf have different distribution patterns but their zones of anomaly are similarly positioned in the eastern part of the area. This part is similarly shared by Fe, As and Cr essentially. While the negative anomaly in Ga trend in NW-SE direction essentially, the negative anomaly in Hf is randomly oriented. Hg has its peaks trending in NW-SE and at the extreme NE. This aureole is closely associated with negative anomaly that trend also in NW-SE. The anomaly at the extreme NE end is similarly positioned like the one in Cd while the aligned NW-SE aureoles are similar to those in Cd. In is enriched in the eastern half of the study area. There is an aureole in the NW part while the remaining area is relatively depleted in In. This depleted zone coincides with the boundary between the sedimentary rocks and the basement rock exposures. Its zones of highest concentration are in the extreme eastern part where Fe, Cd etc also have theirs. No negative anomaly is seen as the values of depression are relatively higher than the values in the extreme NW and SW part of the area.

The distribution pattern of La is similar to that of Hg. Its point of highest aureole is defined by Lat. 11.15°N and Long. 3.98°E. The aureoles in La form a poorly defined curve shape that trend mainly in NW-SE direction. The extreme SE part is also slightly enriched in La but not as high as the central to NW part of the study area; the depleted zones flank the aureoles. Mn plot is identical with that of Co; it shares the same spot of anomalous concentration with Co and one of Cr anomalous concentration area. The aureole trend in NW-SE and decreases from the SW half towards the extreme NE part. Though not identical, other elements like Cs, K, Li, Mg, Ca, Bi, Cr etc have their anomalous point in either point of the anomalous concentration of Mn or Co. Like Mn, Mo has its highest point of concentration in the southern part of the area. There is also a relatively high concentration in the eastern part where Fe has one of its aureoles. Other slightly enriched zone of Mo is the western part. The positive aureole of Mo trend almost perpendicular to the positive aureole of Mn. With the exception of two well defined peaks of aureoles, other patterns of distribution of these elements are alike.

Na has two peaks of positive anomaly. These peaks are located in the western and central parts of the area study. The western aureole is related to the western aureole of Mn though the Mn aureole is not as broad as that of Na but is more steep sided than that of Na. The area study is slightly more enriched in Na except the extreme four corners of the area. Nb has similar distribution pattern with Ca. The study area is slightly more enriched in Nb relative to Ca, although, they both have their positive aureole defined by the same latitude and longitude. The SW part of the area is more depleted in Nb while the central part is enriched and trend perfectly in NW-SE direction. At the SE end of the positive anomaly, there is a zone of negative anomaly. This zone of Nb negative anomaly coincides with the zone of the most pronounced Au negative anomaly. Other element with their positive anomaly or one of their positive anomalies defined by Lat. 11.075°N and Long. 4.05°E or closely related to that of Nb include Ca, Mg, K, Cs, Li, Be, As etc. Ni has its distribution pattern identical with that of Mg. The western part of the area is slightly depleted in Ni. The southern part of the study area is more enriched

in Ni relative to the rest of the area. The aureole has >23ppm concentration while its local aureole has a concentration value of 21ppm. Besides the fact that Li, Cs and K has a primitive peak closely associated with their aureoles, their distribution pattern and the distribution pattern of Ni is alike when their zones of anomaly are compared together. Ni also has its positive anomaly similarly positioned like the aureole of elements like Co, Bi and Al even though their distribution pattern is different. The positive aureole of Ni coincides with one of the positive aureoles in As while it is within the enriched zone of Be that trend NE-SW from the southern part. Au has its negative anomaly where Ni has its positive anomaly.

Like Nb, P has its positive aureole defined by Lat. 11.1°N and Long. 4.05°E. The spot is shared or closely related to by the aureole of other elements like Li, Al, As, Be, Ca, Cs, K etc. Its distribution pattern is similar to the distribution pattern of Mo, La, Hg, Ga, Fe and Ce essentially. Though with relatively lower concentration value and in rare case slightly high concentration, the zones of positive enrichment and depletion of these elements are closely related. Cr has relatively high enrichment in all the area where P also has its high enrichment but the zone of P depletion in the eastern part is not seen in Cr isograde plot. Pb has its highest concentration (>19ppm) in the western part of the area defined by Long. 3.35°E and Lat. 11.125°N. Like P, La, Fe, Ce etc, its distribution pattern form a poorly defined U-shape. The zone of its highest positive anomaly has negative anomalies closely associated with it in the SW and NE parts. Other positive anomalies are in the southern and extreme eastern part of the area. Its zone of highest concentration is related to the zone of highest concentration of elements like La, Ce, Cd and Ba. The peaks of positive anomaly in the western and southern parts relate very well with the two peaks of positive anomaly in Mn while the peaks of positive anomaly of Pb in the southern and eastern part is closely associated with the peaks of highest Fe concentration. Fe also has slightly elevated value in the western part where Pb has its highest concentration value. Other elements have their positive anomalies in one or more zone of Pb enrichment even though, their distribution patterns are not the same.

Pd has its aureole in the western end of the study area. Its concentration decreases gradually towards the western end of the area. The zones of its highest concentration in the eastern part of the area coincide perfectly with one of the positive aureoles of Fe, Mo, In, Ga, Hf etc. The Rb style of distribution is identical with the distribution pattern of Li, K and Cs. Its zone of highest concentration is wholly or partly shared besides the aforementioned elements by Al, As, Be, Bi, Ca, Cd, Co, Mg, Mn, Mo, Nb, Ni, P etc. The peaks of its aureoles trend essentially in NE-SW direction. The negative anomalies are not well defined but are closely associated with positive anomaly in the eastern part of the area.

Sb has its zones of highest concentration in the extreme eastern and western end of the area. Other zones of enrichment are closely associated. These two peaks define a slightly different NE-SW trending direction. The distribution pattern is relatively unique but its zone of highest concentration in the eastern end is related to the zones of highest concentration of Fe, Mo, In, Ga, Hf etc. The extreme NW and SW are the most depleted zones of Sb. Other areas have slightly elevated value relative to other elements.

With the exception of break in the ridge of positive anomaly of Sc in the western part of the area, the distribution pattern of Sc and Sn are identical. They both have a ridge of positive anomaly that rises in the NW going through the southern part and bend through the eastern part to end in the NE part of the area study. They have two peaks of positive aureoles. One of the aureoles is situated in the eastern part where elements like Fe, Mo, In, Ga, Hf etc have their or one of their positive anomalies. The second positive aureole of Sc is in the southern part of the area while that of Sn shift slightly to the SE part of the area. They have their negative anomalies trending essentially in NW-SE in the western end and NE-SW in the eastern end. Sr has slight enrichment in the western part. These enrichments trend in NW-SE terminating in the central part. Its zone of highest concentration is in the centre. This centre where it has its highest concentration is defined by Long. 4.05°E and Lat. 11.075°N. Its zone of highest concentration is similarly shared by Rb, Al, As, Be, Bi, Ca, Cd, Co, Mg, Mn, Mo, Nb, Ni, P etc. Its distribution pattern is identical with the distribution pattern of Ca.

Te distribution pattern is similar to the distribution pattern of Na. Its peak (positive anomaly) is in the central to SE part of the area. Its anomaly trends in NW-SE but generally decreases to the background value of ≤0.028ppm. Th has its highest concentration in the eastern part. Other area with relatively high concentration of Th is in the SE. The concentration of Th in the western half is also relatively high but not as high as the concentration in the eastern part. The extreme NW and SW corner of the area are relatively the most depleted zone for Th. The position of the positive anomaly of Th is the same with the position of positive anomaly of Fe, Sn, Sc, Sb, Pd, In, Hf and As. Mo and Ce has one of their positive anomaly in this eastern part but the zone of highest concentration of Ag is just slightly off the zone of Th highest concentration to the west.

Ti, Tl and U have their positive anomalies defined by Lat. 11.075°N and Long. 4.04°E; Lat. 11.08°N and Long. 4.04°E and Lat. 11.07°N and Long. 4.04°E, respectively. Though with slight variation, these elements has their positive anomalies where elements like Sr, Rb, Ni, P, Nb, Li, K, Cs, Co, Cd, Ca, Bi, Be, As, Al etc have theirs or one of their positive anomalies. This zone is also though not exactly similarly positioned like one of the Mn

positive anomaly. Ti and Tl have their highest concentration within the central part of the area. The Ti concentration is slightly high in the eastern and extreme NE part but Tl has its own concentration decreasing gradually towards the extreme west thereby making the western half slightly more enriched than the eastern half. Both Ti and Tl have sharp depression to the background value. These depressions are similarly oriented in poorly defined NWW-SEE in the western half of the area. Unlike Ti and Tl, U has its concentration in the central part and form a ridge of positive anomaly that extend from the central area to the NW of the area where it form a twin peak. The peak to the east among these two peaks has slightly higher concentration than that in the western part. There are negative anomalies in the western half and eastern part of the area. The negative anomalies in the western half that are well defined trend in NE-SW. The poorly defined negative anomaly trends with one of the well defined in NW-SE. The U negative anomalies in the eastern half of the area trend mainly in NE-SW.

V distribution pattern is similar to the distribution pattern of Th, Sc, Sn, Pb, P, Mo, La, Hg, Ga, Fe, Cr and Ce. Its zone of highest concentration (>65ppm) is in the extreme eastern part while it is also enriched in the southern part. These two zones of highest concentration are similar to the zone of highest concentration of Fe, Sc and Mo. The enrichment in the western half is almost identical with that of Fe when the position of the zones of highest enrichment and depletion are compared. The central part of the area is the most depleted zone of V. Like some other elements e.g. Hf, its distribution pattern have poorly defined U-shape. Y zone of highest concentration (>23ppm) is in the NW part of the area. This area is flanked by negative anomaly in the SW and NE part. The zone of relative high concentration of the anomaly, usually ≥ 16 ppm are restricted to the western half of the study area and trend in NW-SE direction. The extreme SW and SE corner are relatively depleted of Y (≤ 5 ppm) while other area have elevated value that range between 5 to 16ppm. The positive anomalous zone of Y is similarly enriched in Pb, La, Hg, Cd, Ce, Ba and Mn.

Zn distribution pattern is identical with the distribution pattern of Rb and almost identical with the distribution pattern of Li, K and Cs. Both Zn and Rb have two peaks at the crest of their anomalous zone in the central part of the study area. The peak in the northern part out of these two peaks is slightly more prominent than the one in the south. These two peaks are also present in the same position in the isograde plot of Tl despite the fact that its style of distribution is slightly different from that of Zn and Rb. Other similarity in the distribution pattern of Zn and Rb include the twin slightly enriched area in the NW part of the area and also the negative anomaly in their isograde plot. Other elements that have their positive anomaly where Zn has its own and with similar distribution patterns include Ti, Mg, Cs etc. Cs and K have the two peaks but their peak in the southern part is more prominent than the one in the northern part. Zone of Zn anomaly is shared by the anomaly of Al, As, Be, Bi, Ca, Cd, Co, Mn, Nb, P and Ni essentially. Zr highest concentration is ≥ 19 ppm. This concentration is in the eastern part of the area. With the exception of elevated value (≤ 9 ppm) in the NW part of the area, the enrichment of Zr is restricted to the eastern half of the area especially where Fe, Th and Pd have their highest concentration.

Conclusion

From the integration of field observation, geochemical result, statistical analysis and isograde plottings, it is concluded that the area is mineralized with goethite and manganite ores while there are minor enrichments of tourmaline and silicate minerals like chalcedony. It is also concluded that the eastern and southern parts of the study area is mineralized with goethite while the western and southern parts are mineralized with manganite. Furthermore, When exploring for iron-manganite mineralization in this area, manganite is pathfinded by or have the following associations: $\text{Zn}+\text{As}+\text{Be}+\text{Bi}+\text{Co}+\text{Nb}+\text{Ni}+\text{Cs} \pm \text{P}+\text{Al}+ \text{Ca}+\text{Cd}+\text{Rb}+\text{Li}+\text{K}$ while $\text{Zr}+\text{Th}+\text{Pd}+\text{Mo}+\text{V}+\text{Sn}+\text{Cr}+\text{Ce}+\text{In} \pm \text{Sc}+\text{P}+\text{Pb}$ associations are related to iron mineralization.

Acknowledgement

The effort of Mr. Bamidele, 'Toba of Geology and Mineral Sciences Department, University of Ilorin during the field work exercise of this work is greatly acknowledged.

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