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Petrography and Petrochemical Characteristics of Rare Metal Pegmatites around Oro, Southwestern Nigeria

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ABSTRACT

Petrographic and geochemical evaluation of pegmatite bodies occurring as discontinuous dykes have been studied in Oro area of southwestern Nigeria, with a view to determine the compositional characteristics that may be related to Ta-Nb mineralization potentials. They are found intruding semi discordantly, the older assemblages of quartz mica schist and granite gneiss. A total of twenty-eight samples comprising whole rock pegmatites and eluvial soils were analyzed for major, trace and rare earth elements using (ICP-AES) geochemical method which show the pegmatite samples to be generally highly siliceous with SiO₂ values ranging from (71.49-97.77%) with an average of 86.43% in the whole rock samples, and it also ranges from (41.88-57.99%) with an average of 48.43% in the eluvial soil samples, while Al₂O₃ content is as high as 25.87% in the eluvial soil samples and 6.86% in the whole rock samples depicting the complexity of the pegmatite rock. Variation plots of K/Rb versus Rb, Ta versus Rb, Ta versus Nb, Ta versus K/Cs, Ta versus Cs+Rb and Ta versus Cs discriminant plot indicate the potentials of rare metal mineralization.

Keywords: Pegmatite, Eluvial soils, Mineralization, Geochemical

INTRODUCTION

The study area lies within longitude 4°50'00"E- 4°52'00"E and latitude 8°09'00"N-8°16'00"N (Ilorin sheet 223NW) was studied as a result of recent increase in global demand for rare-metals pegmatites due to their ability to host many metallic, non-metallic or industrial minerals and gem mineralization, especially, those that are of immense economic importance. Oro area is located in the southwestern part of Nigeria. The area is underlain by the basement complex rocks of Nigeria, which comprises quartz mica schist and granite gneisses intruded by pegmatites veins. The Oro pegmatites occur as discordant low lying dykes intruding the host rocks which are already fairly weathered. The Precambrian pegmatites of Nigeria are known to host variety rare metals, namely tantalum, niobium, tin, tungsten, columbite, lithium as well as gem stones (beryl, tourmaline, garnet), mica, feldspar and quartz which are presently in high demand globally. In recent times, there has been a resurgence of interest in the study of these pegmatites occurrences because of their associated economic rare metal and gem

mineralization. These have led to concentration of study on discrimination of the pegmatites into rare metal mineralized and barren ones in order to elucidate modes and features of mineralization (Matheis, 1981; Matheis et.al. 1982; Kuster, 1990; Garba, 2003). Recent studies by Okunlola, (2005) also defined the metallogeny of the rare metal Ta-Nb pegmatites of Nigeria outlining seven (7) broad fields namely Kabba-Isanlu, Ijero-Aramoko, Keffi-Nasarawa, Lema-Ndeji, Oke Ogun, Ibadan- Oshogbo and Kushaka-Birnin Gwari. The Oro pegmatites occurrences which are members of the Kabba-Isanlu field occurrences have therefore been studied with the aim of elucidating their petrography and geochemical features and thus understanding their origin economic potentials in relation to other fields.

Researchers like Moller and Morteani (1987), Cerny (1989), Kuster (1990), Garba (2003) have contributed to a better understanding of southwestern and northern Nigeria pegmatite bodies distinguishing between the barren and rare metal bearing pegmatites and documenting that the pegmatites are not confined to the earlier proposed 400 km long NE-SW trending belt stretching from Wamba area (near Jos plateau) to Ilesha area. Elueze et. al. (2004) documented the industrial properties of the Olode-Falansa pegmatites in southwestern Nigeria. Okunlola and Ocan (2002) studied the Kabba mines environment, central Nigeria to look at the expected effect of the mining activities on the environment. Okunlola and Oyedokun (2009) studied the compositional trends and rare metal mineralization potential of Igbeti pegmatites southwestern Nigeria. Okunlola and King (2003) documented the process test work recovery of tantalite from Nasarawa area, central Nigeria. Other workers include; Akintola et. al. (2011) and Akintola et. al. (2012) described the compositional trends and rare metal mineralization potential of Precambrian pegmatites of Komu and Ago-Iwoye areas of southwestern Nigeria.

MATERIALS AND METHODS

The study involves systematic geological mapping on a scale of 1: 50,000 and thin section examinations of ten (10) whole rock pegmatites samples. A total of eighteen (18) eluvial soils samples were collected making the most widely available pegmatite occurrence in the study area. The sampling interval varied unavoidably as interest is on the exposures of the pegmatite rocks, therefore the sampling pattern was largely dictated by accessibility and geometry of the study area. The eluvial soil samples were collected by employing the interval sampling technique in which samples were collected at depth of 1m, 2m and 3m respectively while channel sampling technique was used to collect composite samples along the downhole exposures of the pits up to a depth of 5m. The actual sampling points were determined with the use of Global Positioning System (GPS) and later plotted on the topographical map of the study area.

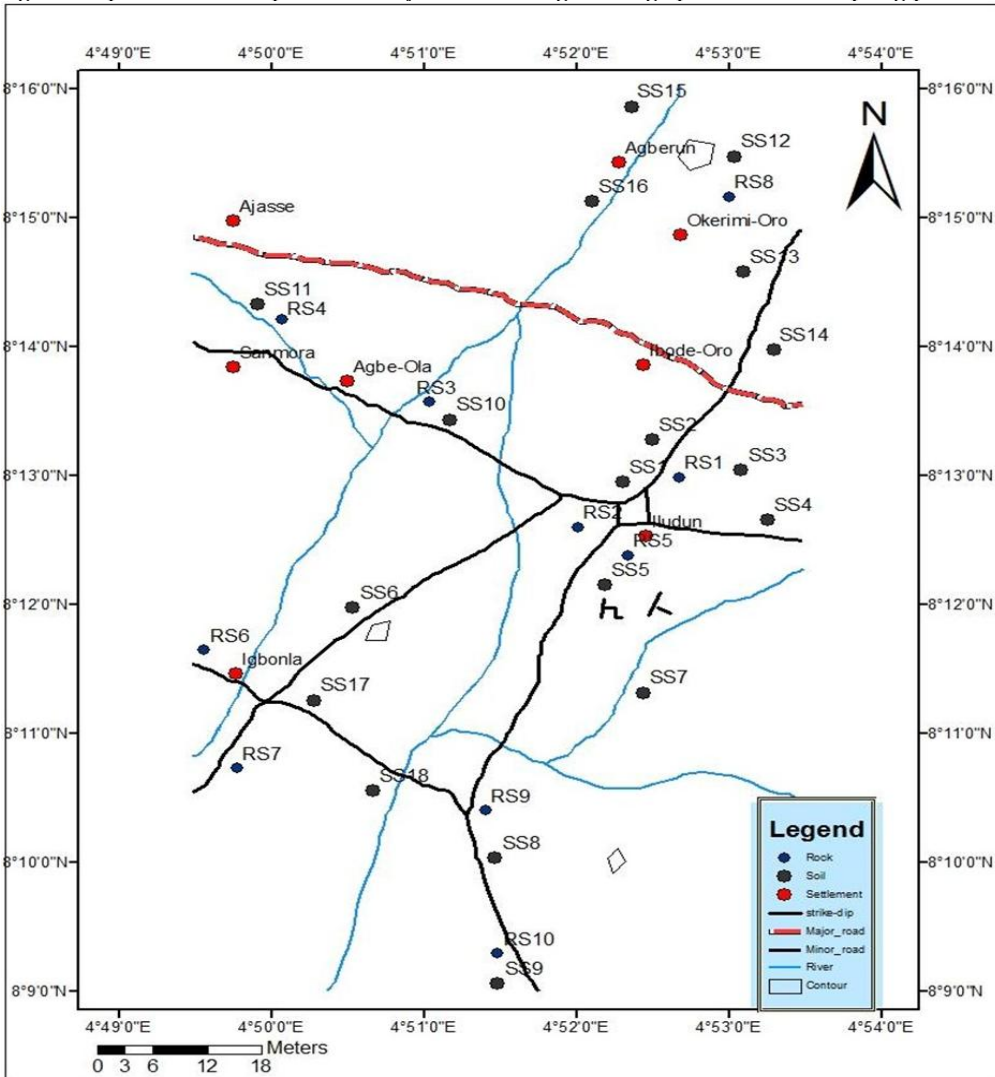
The whole rock pegmatite samples as well as the eluvial soil samples were analysed for major and trace elements at the Acme Analytical Laboratories Limited, Vancouver, British Columbia Canada using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) instrumentation method. The major elements are given in weight percent (%), while the trace elements are given in parts per million (ppm). The procedure employed involves digestion of representative sample of whole rock pegmatite and eluvial soils using nitric acid. About 0.5g of each sample was measured into the dry digested tube. 3-4 drops of distilled water was added to the wet sample. 5ml of HCl was added to wet the sample and the solution was stirred. 5ml of nitric/perchloric acid was added in the ratio 3:2 and stirred. The digesting tube was left overnight heating. The samples were leached out with 6ml HCl in a tube and made up to 20ml mark with distil water.

To avoid caking, the content was shaken vigorously and the resulting solution is referred to as stock solution. The stock solution was used directly to determine the elements. It is

becoming increasingly accepted as a tool for trace element and isotopic analysis as a result of the very low detection limits, good accuracy and precision. This technique consist of sample introduction system, referred to as Nebulizer, the ICP torch, the high frequency generator, the transfer optics, the spectrometer, the interface and computer.

A digested solution of the sample to be analyzed is introduced into the ICP torch as an aqueous aerosol, the light emitted by the atoms or ions in the ICP is converted to an electrical signal by a photomultiplier in the spectrometer. The intensity of this electrical signal is compared to a previously measured intensity of a known concentration of the element and the concentration value is then computed.

Fig.1: Sample location map of the study area showing drainage pattern and sampling points.



RESULTS AND DISCUSSION

The study area is underlain by quartz mica schists and granite gneisses, all intruded by pegmatites. The rocks are very sparse in the area and most of those mapped are already fairly weathered. The **schists** often occur as layered relicts, lensoidal or pods. Most of the original sedimentary features have been obliterated by poly phase metamorphism. They are mainly quartz mica schists, mostly light brownish to dark grey in colour. They are exposed sporadically within the pervasive pegmatite zone in virtually the whole area as horizontally -dipping oral bodies inter layered with the rare metal bearing pegmatite. The **granite gneiss** occurs mostly in the southwestern corner of the area. It is weakly foliated but poorly developed mineral lineation and banding on millimeter scale. Quartz, feldspar, biotite are the main minerals with quartz being the most abundant. The **pegmatites** of this area are obviously members of the larger NE-SW trending belt extending from Abeokuta to Wamba-Jemaa area in central Nigeria as designated by Jacobson and Webbs (1946). The main mineral assemblages are albite, microcline, quartz, muscovite, sericite, black tourmaline (shorl), columbite-tantalite. Albite is the most abundant of these minerals and forms coarse crystalline graphic intergrowth with quartz (Fig. 2). They are sometimes perthitic with microcline as patchy and feathery perthites. These may indicate local metasomatic replacement. Most of the microcline display characteristic crosshatch twinning. It occurs as irregular grains varying from colourless to milky white with occasional yellow stains. It is medium to coarse grained.

Fig. 2: Photomicrograph of Pegmatite in transmitted light showing Microcline (Mi), Quartz (Q), Biotite (B) and Albite (A)

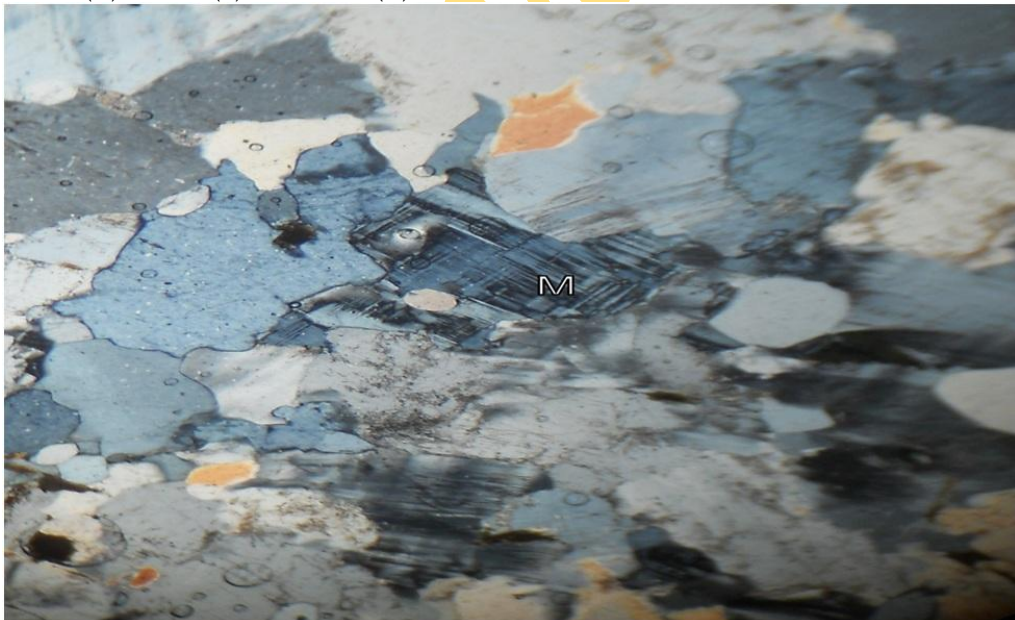
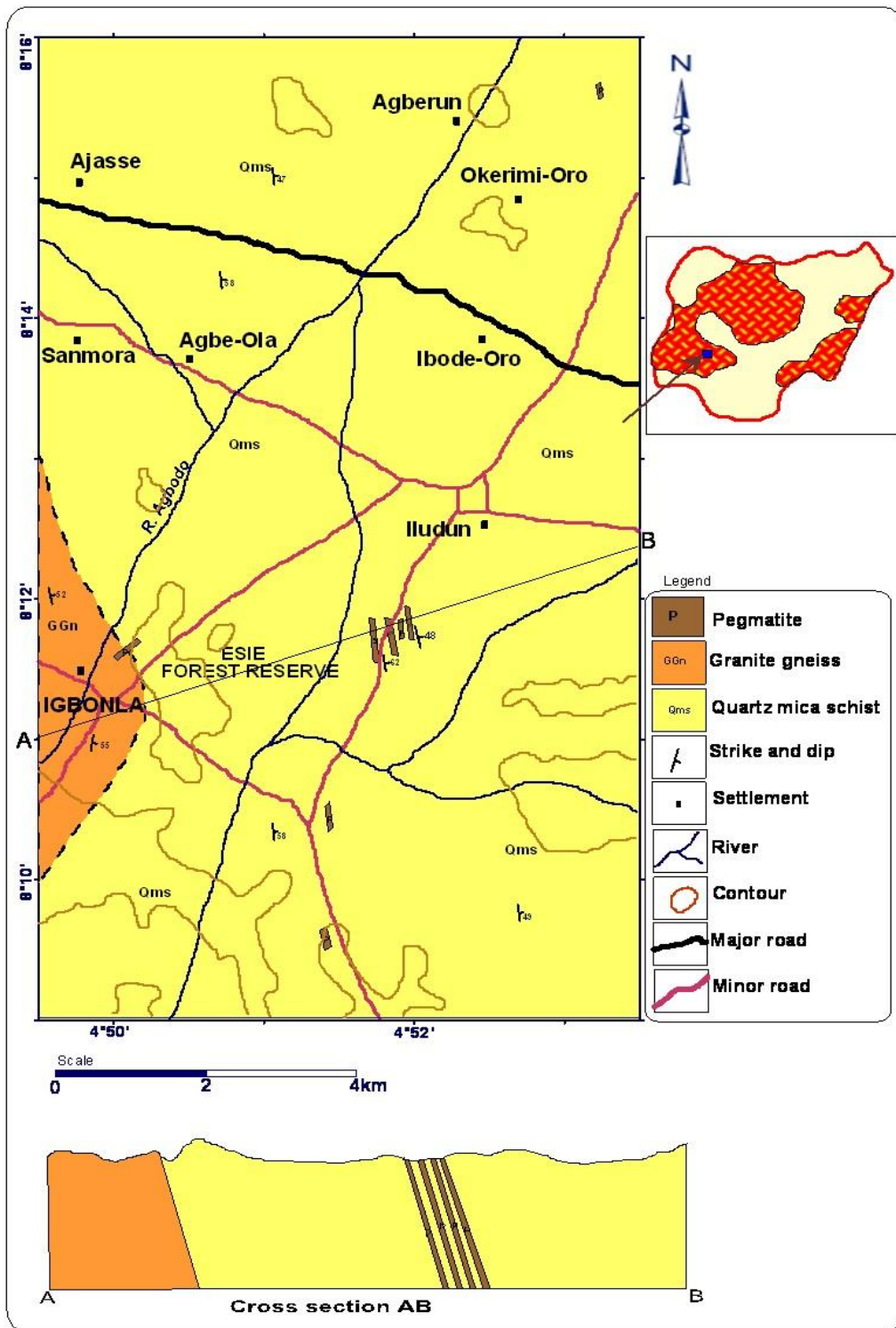


Fig 3: Geological map of the study area



The analytical results of the major oxide composition as presented in (Table 2), it shows that the samples of the Oro pegmatite are highly siliceous with SiO₂ content ranging from 71.49-97.77% with an average of 86.43% in the Oro whole rock pegmatite samples, the Al₂O₃ ranges from 0.73-15.20% with an average of 6.86%, also the Fe₂O₃ ranges from 0.45-6.09% with a mean value of 2.05%. The range and mean contents of other major oxides in the whole rock pegmatites of Oro are as follows; MnO (<0.01-0.04%, 0.03%), MgO (0.01-1.32%, 0.23%), CaO (<0.01-0.65%, 0.22%), Na₂O (0.02-6.82%, 2.09%), K₂O (0.09-0.99%, 0.45%), TiO₂ (0.02-0.87%, 0.30%), P₂O₅ (0.01-0.18%, 0.08%) and Cr₂O₃ (<0.002-0.013%, 0.006%). Also from the analytical results of the major oxide composition as presented in (Table 3), it shows that the eluvial soil samples around the Oro pegmatite are moderately siliceous with SiO₂ content ranging from 41.88-57.99% with a mean value of 48.43%, the Al₂O₃ ranges from 17.79-34.94% with an average of 25.87% in the eluvial soil around the pegmatites. This slight to sharp contrast in the values of some of the whole rock and eluvial soils for the alumina content of this study area in addition with other rare metal characteristics, confirms the complexity of the pegmatite type. These values are comparable to those observed for mineralized pegmatites of Nigeria, (Garba, 2003; Okunlola, 2005).

Table 2: Major oxide composition of Oro whole rock pegmatites (wt %)

Oxides (%)	RS1	RS2	RS3	RS4	RS5	RS6	RS7	RS8	RS9	RS10
SiO ₂	97.77	96.59	92.40	92.92	88.99	75.48	74.54	77.60	71.49	96.49
Al ₂ O ₃	0.73	1.18	2.15	2.01	5.75	13.58	15.20	13.30	13.44	1.26
Fe ₂ O ₃	0.45	0.95	2.90	2.65	1.99	2.86	0.79	0.78	6.09	1.04
CaO	<0.01	0.01	0.02	0.02	0.02	0.51	0.65	0.57	0.4	0.02
MgO	0.01	0.02	0.05	0.05	0.05	0.59	0.07	0.06	1.32	0.03
Na ₂ O	0.02	0.02	0.02	0.02	0.15	4.83	6.82	5.86	3.17	0.02
K ₂ O	0.09	0.09	0.23	0.22	0.89	0.58	0.99	0.87	0.39	0.09
TiO ₂	0.06	0.06	0.67	0.56	0.07	0.37	0.38	0.02	0.87	0.07
P ₂ O ₅	0.04	0.02	0.01	0.02	0.03	0.14	0.18	0.17	0.17	0.03
MnO	0.02	0.03	0.04	0.04	<0.01	0.03	0.03	0.03	0.03	0.04
Cr ₂ O ₃	0.003	0.004	0.013	0.012	0.003	0.006	<0.002	0.003	0.012	0.003
LOI	0.6	1.0	1.5	1.5	2.1	1.0	0.7	0.8	2.5	0.9
Total	99.79	99.97	100.00	100.04	100.04	99.08	100.35	100.06	99.88	99.99

Table 3: Major oxide composition of eluvial soils in some pits around the Oro pegmatites (wt %)

Oxides (%)	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10
SiO ₂	47.30	49.04	48.55	57.99	47.04	41.88	50.27	47.56	46.13	43.47
Al ₂ O ₃	26.38	26.79	23.65	23.61	34.94	33.31	26.38	23.07	25.35	34.15
Fe ₂ O ₃	8.60	9.20	10.20	4.82	2.35	4.08	7.58	10.64	8.60	4.17
CaO	0.06	0.05	0.15	0.02	0.05	0.05	0.07	0.17	0.06	0.05
MgO	0.19	0.23	2.57	0.07	0.08	0.15	0.18	3.08	0.36	0.15
Na ₂ O	0.05	0.02	0.07	<0.01	<0.01	<0.01	0.04	0.06	0.04	<0.01
K ₂ O	1.07	0.67	1.83	0.42	0.56	0.26	0.89	2.06	0.99	0.26
TiO ₂	1.20	0.85	0.77	0.41	0.11	0.13	0.92	0.74	1.10	0.12
P ₂ O ₅	0.07	0.05	0.07	0.06	0.12	0.05	0.05	0.07	0.06	0.04
MnO	0.12	0.03	0.10	0.02	0.02	<0.01	0.08	0.12	0.11	<0.01
Cr ₂ O ₃	0.013	0.016	0.014	0.007	0.004	0.006	0.012	0.014	0.012	0.006
LOI	14.7	12.9	11.7	12.6	14.2	20.0	13.4	12.0	17.0	17.5
Total	99.75	99.85	99.60	100.01	99.47	99.92	99.87	99.58	99.81	99.92

Oxides (%)	SS11	SS12	SS13	SS14	SS15	SS16	SS17	SS18
SiO ₂	48.99	42.50	48.91	45.15	51.04	54.87	54.94	46.07
Al ₂ O ₃	22.98	27.20	26.99	27.72	26.78	17.94	17.79	20.62
Fe ₂ O ₃	9.98	9.69	9.11	9.68	6.14	2.69	2.71	12.68
CaO	0.19	0.05	0.05	0.08	0.06	5.43	5.42	0.21
MgO	2.60	0.13	0.18	1.02	0.12	0.73	0.73	5.09

Na ₂ O	0.08	0.02	0.02	0.04	0.05	0.04	0.04	0.08
K ₂ O	1.91	0.75	0.65	1.15	0.98	3.03	3.02	2.91
TiO ₂	0.78	0.89	0.86	0.85	0.65	0.90	0.90	0.72
P ₂ O ₅	0.07	0.06	0.06	0.07	0.07	0.19	0.18	0.07
MnO	0.11	0.08	0.03	0.09	0.05	0.02	0.02	0.14
Cr ₂ O ₃	0.014	0.012	0.016	0.012	0.009	0.006	0.007	0.016
LOI	12.0	18.5	13.0	15.9	13.9	10.6	10.7	10.9
Total	99.70	99.88	99.88	101.76	99.85	96.45	96.46	99.51

Table 4: Range and average values of major oxides in the whole rock and eluvial soils in some pits around the Oro pegmatites in mass fraction (wt %)

Major Elements	Whole rock pegmatite		Eluvial soils	
	n=10		n=18	
	Range	Average	Range	Average
SiO ₂	71.49 - 97.77	86.43	41.88-57.99	48.43
Al ₂ O ₃	0.73 - 15.20	6.86	17.79-34.94	25.87
Fe ₂ O ₃	0.45 - 6.09	2.05	2.35-12.68	7.38
CaO	<0.01 - 0.65	0.22	0.02-5.43	0.68
MgO	0.01 - 1.32	0.23	0.07-5.09	0.98
Na ₂ O	0.02 - 6.82	2.09	<0.01-0.08	0.04
K ₂ O	0.09 - 0.99	0.45	0.26-3.03	1.30
TiO ₂	0.02 - 0.87	0.30	0.11-1.20	0.72
P ₂ O ₅	0.01 - 0.18	0.08	0.04-0.19	0.08
MnO	<0.01 - 0.04	0.03	<0.01-0.14	0.06
Cr ₂ O ₃	<0.002 - 0.013	0.006	0.004-0.016	0.011

Table 5: Trace and rare earth elements composition of Oro whole rock pegmatites (ppm)

Elements	RS1	RS2	RS3	RS4	RS5	RS6	RS7	RS8	RS9	RS10
Ag	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
As	<0.5	0.5	<0.5	<0.5	0.7	<0.5	<0.5	<0.5	<0.5	1.0
Au	4.8	2.9	1.7	3.8	2.2	1.2	0.9	1.5	<0.5	<0.5
Ba	38	72	64	64	26	51	19	23	143	90
Be	<1	<1	<1	<1	25	4	9	3	6	<1
Bi	<0.1	<0.1	<0.1	<0.1	81	1.2	2.1	2.0	0.7	<0.1
Cd	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ce	111.4	152.7	61.8	75.6	19.0	62.4	5.0	18.1	80.9	204.0
Co	1.8	5.1	4.7	4.3	1.7	5.9	1.0	1.3	14.1	5.6
Cs	0.1	0.3	1.2	1.1	7.1	4.4	6.0	5.5	2.8	0.5
Cu	6.9	12.0	21.1	20.9	18.0	9.9	6.8	5.3	19.6	10.4
Dy	0.17	0.45	3.17	2.63	0.67	1.80	2.44	1.01	3.86	0.50
Er	0.05	0.14	2.09	1.52	0.22	0.67	1.01	0.42	1.84	0.10
Eu	0.10	0.26	0.36	0.39	0.28	0.61	0.03	0.03	1.24	0.28
Ga	0.6	1.8	3.7	3.5	16.3	19.4	21.4	18.5	20.8	1.6
Gd	0.66	1.04	2.88	3.23	0.69	2.37	1.23	0.61	4.54	1.00
Hf	0.3	0.3	10.2	8.1	1.1	2.4	1.8	0.7	12.0	0.4
Hg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ho	0.03	0.07	0.67	0.53	0.10	0.27	0.39	0.13	0.65	0.06
La	9.7	26.7	23.7	31.5	23.4	34.7	2.6	3.1	28.9	29.3
Li	<20	<20	<20	<20	<20	21	<20	<20	43	<20
Lu	<0.01	0.02	0.42	0.28	0.06	0.10	0.16	0.05	0.28	0.03
Mo	5.6	7.5	0.3	0.3	0.3	<0.1	0.2	0.9	<0.1	9.9
Nb	1.15	1.82	16.66	15.18	99.65	35.80	44.54	35.76	40.42	1.98
Nd	8.2	12.0	20.7	29.0	10.1	24.9	1.7	1.4	31.7	12.6
Ni	1.6	2.8	6.1	6.8	2.2	5.6	0.3	0.4	11.4	3.1
Pb	10.9	8.5	3.2	3.4	2.7	4.7	5.4	2.8	1.2	9.4
Pr	1.65	3.95	5.57	7.45	3.25	6.83	0.48	0.54	7.4	4.32
Rb	4.1	5.4	14.8	13.5	383.6	85.9	102.4	87.6	36.2	5.7
Sb	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
Sc	<1	1	7	6	2	4	1	1	10	1
Se	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Sm	0.64	1.44	3.67	4.75	1.18	3.66	0.75	0.54	5.90	1.66
Sn	3.19	<1.06	1.06	2.13	14.89	8.51	10.63	9.57	8.51	<1.06
Sr	8.9	23.6	4.1	3.8	15.6	60.0	5.9	6.2	156.3	25.9
Ta	0.21	0.21	1.26	1.26	200.21	10.27	5.24	4.82	10.90	0.42
Tb	0.05	0.01	0.51	0.49	0.13	0.35	0.42	0.18	0.70	0.10
Th	1.3	1.1	8.1	11.3	1.9	10.8	0.8	0.6	6.2	1.3
Ti	0.1	0.1	<0.1	0.2	<0.1	0.2	0.1	0.2	<0.1	0.1
Tm	<0.01	0.02	0.37	0.28	0.05	0.11	0.19	0.06	0.25	0.02
U	0.2	0.3	0.9	0.8	4.4	3.3	5.3	3.7	2.1	0.3
V	<8	22	61	57	23	50	<8	<8	108	23
W	<0.5	<0.5	<0.5	<0.5	0.9	0.8	0.5	0.6	0.9	<0.5
Y	0.7	1.4	18.9	12.1	2.6	7.0	12.7	4.7	15.5	1.5
Yb	0.09	0.12	2.33	1.4	0.23	0.7	1.02	0.45	1.77	0.10
Zn	5.0	7.0	7.0	6.0	23.0	40.0	47.0	43.0	39.0	6.0
Zr	4.7	10.0	391.5	295.6	22.8	97.4	32.5	15.3	459.1	18.8

Table 6: Trace and rare earth elements composition of eluvial soils in some pits around the Oro pegmatites (ppm)

Elements	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10
Ag	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
As	1.2	2.3	1.0	1.2	<0.5	0.9	1.4	0.9	1.3	0.8
Au	1.2	1.8	2.2	1.5	0.7	1.0	<0.5	<0.5	1.6	1.3
Ba	232.0	166.0	656.0	101.0	92.0	63.0	182.0	762.0	258.0	63.0
Be	112.0	24.0	39.0	38.0	381.0	29.0	59.0	29.0	84.0	23.0
Bi	2.9	28.2	11.0	10.7	1.0	1.0	2.5	7.4	3.2	1.1
Cd	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ce	151.9	51.8	125.3	46.8	55.6	22.4	101.5	165.7	150.4	22.0
Co	12.3	8.4	21.5	4.3	1.4	2.4	12.3	24.2	12.0	2.1
Cs	22.6	14.8	71.4	7.7	14.3	5.2	20.4	78.1	24.1	5.0
Cu	32.2	20.0	98.5	13.8	8.8	13.4	30.8	107.1	34.7	12.4
Dy	5.28	2.49	9.76	2.35	3.90	1.69	3.59	12.22	5.06	1.80
Er	3.09	1.33	4.05	0.97	1.24	0.83	2.00	5.35	2.83	0.81
Eu	1.63	0.98	5.56	0.83	1.33	0.66	1.17	6.80	1.81	0.65
Ga	39.3	35.2	34.0	29.2	43.8	39.7	35.4	29.9	33.5	39.9
Gd	5.98	3.60	18.99	2.92	5.24	2.59	4.69	21.76	7.01	2.38
Hf	16.9	7.4	6.3	4.1	23.8	2.9	9.1	6.2	11.5	2.6
Hg	0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.02	<0.01
Ho	1.06	0.56	1.61	0.41	0.49	0.26	0.71	2.00	0.96	0.26
La	68.8	49.8	265.0	34.6	50.4	25.2	50.3	330.3	79.7	25.0
Li	51.0	46.0	88.0	<20.0	<20.0	<20.0	51.0	81.0	53.0	26.0
Lu	0.51	0.21	0.49	0.15	0.27	0.10	0.31	0.60	0.44	0.10
Mo	1.0	1.4	5.7	0.5	0.1	0.3	0.7	7.4	1.3	0.4
Nb	92.39	138.42	127.86	40.1	972.05	26.89	70.61	58.24	70.28	43.06
Nd	51.5	35.8	231.8	26.6	49.3	20.2	39.0	295.6	64.8	19.7
Ni	12.3	8.3	55.7	3.6	1.6	2.7	13.1	65.3	15.3	2.9
Pb	26.0	11.6	11.4	6.4	3.3	6.3	12.2	10.0	23.1	5.8
Pr	14.78	9.72	66.81	7.64	13.67	5.69	10.32	81.63	18.15	5.74
Rb	261.7	172.1	364.2	88.7	136.2	58.3	233.1	360.7	235.3	56.1
Sb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sc	19.0	11.0	26.0	7.0	7.0	6.0	16.0	30.0	18.0	6.0
Se	0.6	0.8	0.7	0.6	<0.5	<0.5	0.5	1.2	<0.5	<0.5
Sm	8.48	4.81	32.48	4.48	8.38	3.20	6.22	39.52	9.75	3.48
Sn	14.89	8.51	5.32	2.13	3.19	20.36	10.63	5.32	9.57	3.19
Sr	71.5	42.4	30.0	39.6	92.9	18.1	45.6	30.3	69.0	18.6
Ta	47.38	52.62	55.77	26.21	359.13	21.38	24.11	174.85	23.27	41.93
Tb	0.94	0.52	2.17	0.47	0.86	0.39	0.67	2.54	0.97	0.39
Th	16.7	16.1	10.1	7.7	3.3	4.1	14.8	10.1	16.0	4.3
Ti	1.0	0.2	1.9	0.1	<0.1	<0.1	0.4	2.2	1.1	<0.1
Tm	0.48	0.22	0.59	0.15	0.23	0.10	0.33	0.76	0.40	0.10
U	4.5	5.0	5.1	3.7	17.3	6.5	3.7	6.1	3.9	6.2

V	153.0	159.0	156.0	84.0	33.0	54.0	135.0	171.0	141.0	51.0
W	1.7	2.0	1.6	1.0	4.6	2.6	2.7	1.2	1.9	2.4
Y	28.1	13.3	46.4	9.7	14.4	7.8	19.5	55.3	26.5	7.9
Yb	2.93	1.35	3.74	0.88	1.94	0.67	2.09	4.44	2.53	0.59
Zn	24.0	14.0	129.0	8.0	7.0	10.0	20.0	145.0	30.0	10.0
Zr	488.2	278.0	195.5	148.1	401.0	64.2	288.2	184.1	388.9	60.2

Table 7: Range and average values of trace elements in the whole rock and eluvial soils in some pits around the Oro pegmatites in (ppm)

Trace elements	Whole rock pegmatite		Eluvial soil	
	n=10		n=18	
	Range	Average	Range	Average
Ta	0.21 - 200.21	23.48	3.56-359.13	63.98
Cs	0.1 - 7.1	2.90	5.0-116.9	29.29
Rb	4.1 - 383.6	73.92	56.1-442.8	207.19
Sn	<1.06 - 14.89	6.06	2.13-20.36	8.10
Nb	1.15 - 99.65	29.30	34.32-972.05	119.34
Li	<20 - 43	21.60	<20.0-102.0	48.44
Sr	3.8 - 156.3	26.31	18.1-570.2	107.74
Y	0.7 - 18.9	7.71	7.8-71.2	27.53
Ba	19 - 143	59	63.0-3022.0	626.19
W	<0.5 - 0.9	0.57	1.0-4.6	1.84
Be	<1 - 25	4.70	3.0-381.0	63.67
Zr	4.7 - 459.1	164.02	60.2-488.2	255.71
Ga	0.6 - 21.4	10.76	23.9-43.8	33.78

Ginsburg et al., (1979) Ginsburg (1984) started to classify pegmatites based on the orogen-related association, it is only the rare-element pegmatite class that includes tantalum deposits. The abyssal and muscovite classes have no significant tantalum mineralization; the miarolitic class, as originally characterized by Ginsburg et al., (1979) and as directly redefined by London (1986) has the potential, but so far no well-defined examples of economic Ta contents are known.

Most pegmatite types of the rare-element class may contain significant tantalum mineralization. In accordance with the classification developed by Beus (1960), Rudenko et al. (1975) and Cerny (1988), the pertinent pegmatite types and subtypes and subtypes can be categorized for the purpose of characterizing tantalum mineralization as follows;

- (i) Beryl type, with beryl-columbite and beryl-columbite-phosphate subtypes;
- (ii) Complex type, including spodumene, pentallite and amblygonite subtypes;
- (iii) Complex type, lepidolite subtype;
- (iv) Albite-spodumene type; and
- (v) Albite type.

The criteria for the classification are bulk chemistry, geochemical signature of accessory minerals, internal structure and pressure/temperature conditions of crystallization (Cerny, 1991). Classification can also be based on the molecular proportions of $Al_2O_3/(CaO+Na_2O+K_2O)$ allows peralkaline ($A < NK$), metaluminous ($CNK > A > NK$) and peraluminous ($A > CNK$) varieties to be recognized.

From field evidence, bulk chemistry signatures and the Ta/(Ta+Nb) versus Mn/(Mn+Fe) plot, the Oro pegmatite is a complex pegmatite, of the rare element class and displays typical characteristic of the Lithium, Cesium and Tantalite (LTC) family. Apart from the silicic and peraluminous $\{A/CNK > 1\}$ where A: Al_2O_3 , CNK: $(CaO+Na_2O+K_2O)$ character supports this ascertainment (Cerny, 1991b; London 2005). LCT pegmatites as in this study are also known to contain moderate to abundant Ta-Nb mineralization, gemstones and industrial minerals (Cerny 1989).

Rare metal granitic pegmatites are products extreme differentiation of large reservoir of granitic magma. The proportion of rare metals in such pegmatites is an indication of the level of fractionation achieved in the final stages of granitic differentiation (Cerny, 1991). The geochemical characteristics of these rock suites are determined through the use of variation diagrams generated from the plots of certain elemental ratios of some selected elements. The following relationships are used in the plotting of the variation diagrams used in this study; K/Rb vs Cs, Ta vs Ga, K/Rb vs Rb, Na₂O/Al₂O₃ vs K₂O/Al₂O₃, Ta vs Cs, Ta vs Rb, Ta vs (Cs+Rb), Ta vs Nb, Ta vs K/Cs, Ta/W vs Cs, Rb vs (Y+Nb), Zr vs SiO₂, Sr vs Rb, Rb vs Sr and Ta/(Ta+Nb) vs Mn/(Mn+Fe).

Table 8: Elemental ratios of some selected elements of whole rock pegmatites of Oro

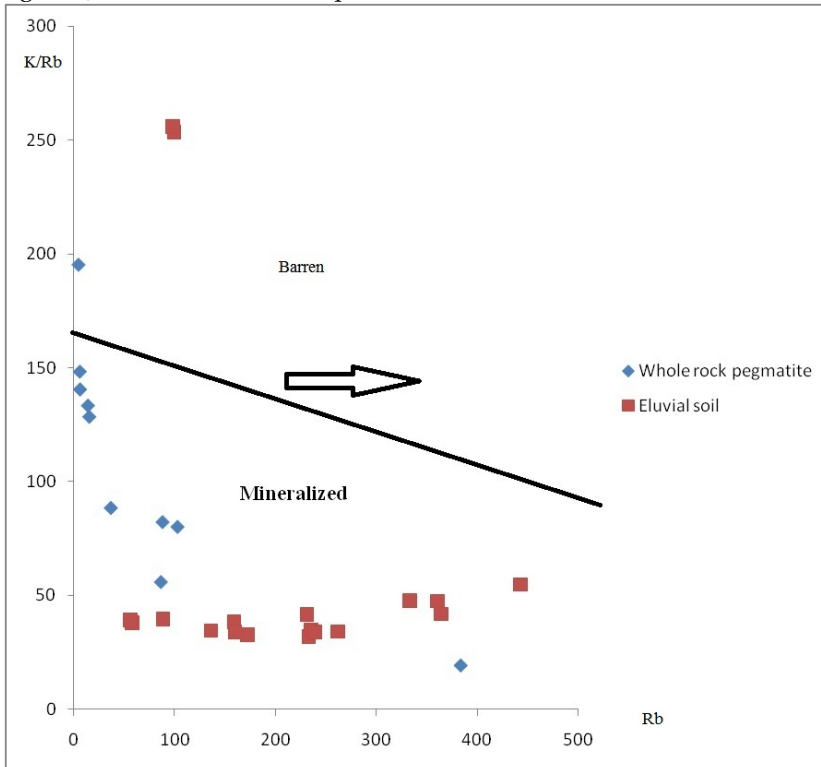
Elemental ratios	RS1	RS2	RS3	RS4	RS5	RS6	RS7	RS8	RS9	RS10
Ba/Rb	9.30	1.30	4.30	4.70	0.07	0.60	0.18	0.26	3.95	15.79
K/Ce	7.18	5.24	30.74	23.81	389.47	76.92	1640	397.79	39.56	3.92
K/Cs	8000	2666.7	1583.3	1636.4	1042.3	1090.9	1366.7	1309.1	1142.9	1600
K/Nb	695.7	439.6	114.1	118.6	74.3	134.1	184.1	201.3	79.2	404.0
K/Rb	195.1	148.2	128.4	133.3	19.3	55.9	80.1	82.2	88.4	140.4
K ₂ O/Na ₂ O	4.5	4.5	11.5	11	5.9	0.12	0.15	0.15	0.12	4.5
Mg/Li	3.16	6.32	15.79	15.79	15.79	169.52	22.11	18.95	185.12	9.47
Na/K	0.25	0.25	0.11	0.11	0.15	7.46	6.17	6.04	7.34	0.25
Nb/Ta	5.48	8.67	13.22	12.05	0.50	3.49	8.50	7.42	3.71	4.71
Rb/Ce	0.04	0.04	0.24	0.18	20.19	1.38	20.48	4.84	0.45	0.03
Rb/Cs	41	18	12.3	12.3	54.0	19.5	17.1	15.9	12.9	11.4
Rb/Sr	0.46	0.23	36.10	3.55	24.59	1.43	17.36	14.10	0.23	0.22
Sr/Rb	2.17	4.37	0.28	0.28	0.04	0.70	0.06	0.07	4.32	4.54
Ta/W	0.53	0.53	3.15	3.15	222.50	12.84	10.48	8.03	12.11	1.05
Zr/Hf	15.67	33.33	38.38	36.49	20.73	40.58	18.06	21.86	38.26	47.00
Zr/Sn	1.47	9.52	369.34	138.78	1.53	11.45	3.06	1.60	53.95	17.91
Na ₂ O/Al ₂ O ₃	0.03	0.02	0.01	0.01	0.03	0.36	0.45	0.44	0.24	0.02
K ₂ O/Al ₂ O ₃	0.12	0.08	0.11	0.11	0.16	0.04	0.07	0.07	0.03	0.07
(Y+Nb)	1.85	3.22	35.56	27.28	102.25	42.8	57.24	40.46	55.92	3.48
Ta/(Ta+Nb)	0.15	0.10	0.07	0.08	0.67	0.22	0.11	0.12	0.21	0.18
Mn/(Mn+Fe)	0.06	0.03	0.02	0.02	0	0.01	0.04	0.04	0.01	0.04
A/CNK	6.64	9.83	7.96	7.73	5.43	2.29	1.80	1.82	3.39	9.69

Table 9: Elemental ratios of some selected elements of eluvial soils of Oro

Elemental ratios	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10
Ba/Rb	0.89	0.97	1.80	1.14	0.68	1.08	0.78	2.11	1.10	1.12
K/Ce	58.59	108.11	121.31	74.79	84.53	98.21	72.91	103.20	54.52	100.00
K/Cs	393.81	378.38	212.89	454.55	328.67	423.08	362.75	218.95	340.25	440.00
K/Nb	96.33	40.46	118.88	87.28	4.84	81.82	104.80	293.61	116.68	51.09
K/Rb	34.01	32.54	41.74	39.46	34.51	37.94	31.75	47.41	34.85	39.22
K ₂ O/Na ₂ O	21.40	33.50	26.14	0.42	0.56	0.26	22.25	34.33	24.75	0.26
Mg/Li	23.53	30.44	176.14	21.05	26.32	47.37	21.57	229.63	41.51	34.62
Na/K	0.05	0.04	0.03	0	0	0	0.04	0.03	0.04	0
Nb/Ta	1.95	2.63	2.29	1.53	2.71	1.26	2.93	0.33	3.02	1.03
Rb/Ce	1.72	3.30	2.91	1.90	2.45	2.60	2.30	2.18	1.57	2.55
Rb/Cs	11.58	11.63	5.10	11.52	9.52	11.21	11.43	4.62	9.76	11.22
Rb/Sr	3.66	4.01	12.14	2.24	1.47	3.22	5.11	11.90	3.41	3.02
Sr/Rb	0.27	0.25	0.08	0.45	0.68	0.30	0.20	0.08	0.29	0.33
Ta/W	27.87	26.31	34.86	26.21	78.07	8.22	8.93	145.71	12.25	17.47
Zr/Hf	28.90	37.57	31.03	36.12	16.85	22.14	31.70	29.69	33.82	23.15
Zr/Sn	32.80	32.67	36.75	69.53	125.71	3.15	27.14	34.61	40.60	18.87
Na ₂ O/Al ₂ O ₃	0.002	0.001	0.003	0	0	0	0.002	0.003	0.002	0
K ₂ O/Al ₂ O ₃	0.04	0.03	0.08	0.02	0.02	0.01	0.03	0.09	0.04	0.01
(Y+Nb)	120.49	151.72	171.26	49.8	986.45	34.69	90.11	113.54	96.78	50.96
Ta/(Ta+Nb)	0.34	0.28	0.31	0.40	0.27	0.44	0.26	0.75	0.25	0.49
Mn/(Mn+Fe)	0.02	0.003	0.01	0.01	0.01	0	0.01	0.01	0.01	0

Considering the K/Rb versus Rb variation plot for the Oro whole rock pegmatites samples and the eluvial soil samples reveals a consistent trend (Fig.5), indicating the mineralization in the pegmatite of this study area to be high (Staurov et al., 1969). These plots also show a conspicuous distribution pattern of separation in the Oro pegmatite along the differentiation trend of the pegmatite in the study area. The pegmatites show a high differentiation and plot within the field of mineralization (Staurov et al., 1969).

Fig.4: K/Rb vs Rb distribution pattern in the whole rock and eluvial soils of Oro pegmatite



Arrow indicate normal differentiation trend after Staurov et al., (1969)

Also considering the variation plots of Ta versus Ga, Ta versus Cs, Ta versus Rb, Ta versus (Cs + Rb), Ta versus Nb, Ta versus K/Cs and Ta/W versus Cs (Fig. 6,7,8,9,10,11 and 12), these plots also show the whole rock samples plot below the Beus line of mineralization, (1966) while the eluvial soil samples of the Oro pegmatites plotting above the mineralized line of Beus, (1966) and Gordiyenko, (1971), this is an indicative that the rare metals have broken down in the whole rock samples due to in situ weathering and have also migrated to the soils thereby making the soils more enriched in the rare metals than the whole rock samples itself.

The overall trends invariably indicate the relative enrichment of Ta in the soil samples. Ta concentration values in the pegmatite samples of the area of study fall below Egbe pegmatite (Matheis, 1987) as well as Ijero pegmatite (Okunlola and Jimba, 2006) and much below the highly productive Tanco, Homestead and Withrope Ta-pegmatites (Cerny, 1989; Beus, 1966).

Fig.5: Plot of Ta vs Ga for the Oro Pegmatite.

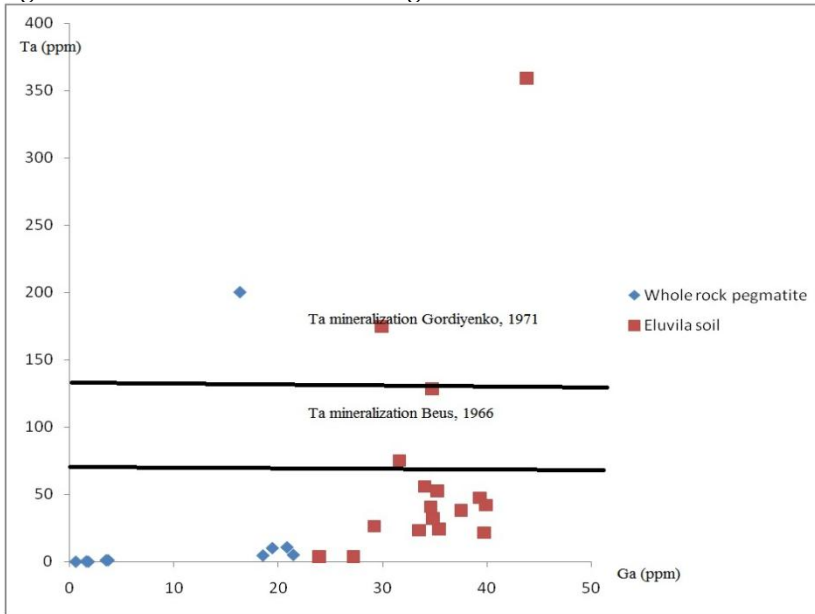
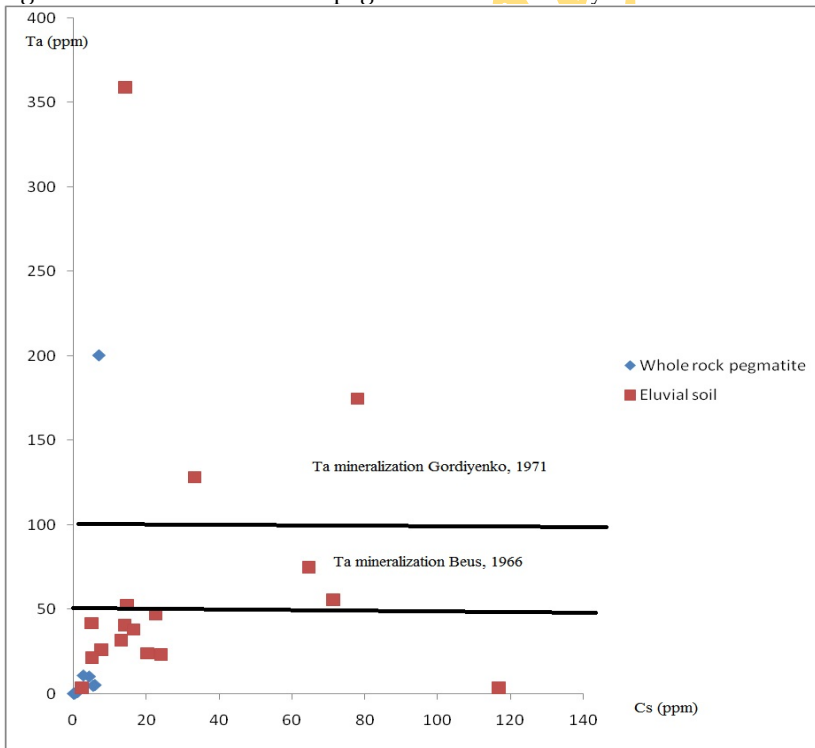
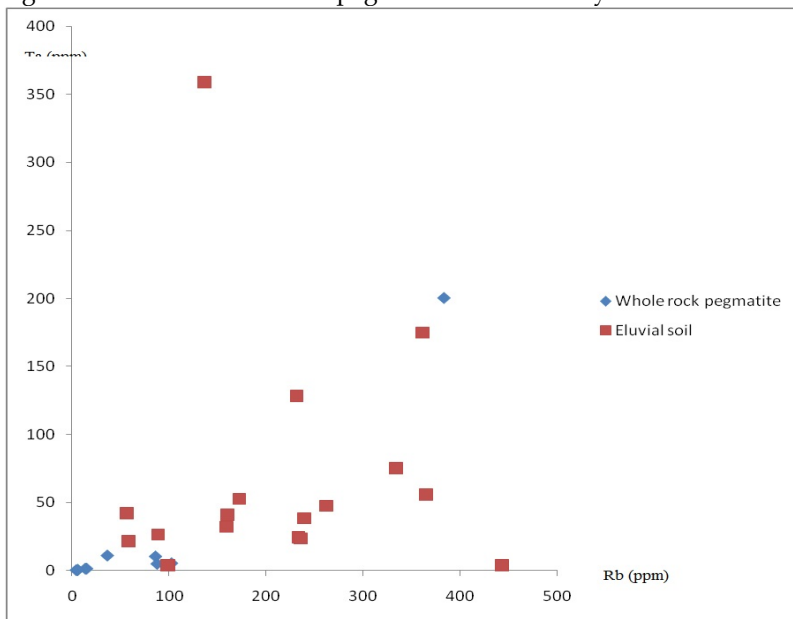


Fig.6: Plot of Ta vs Cs for the pegmatites of Oro study area



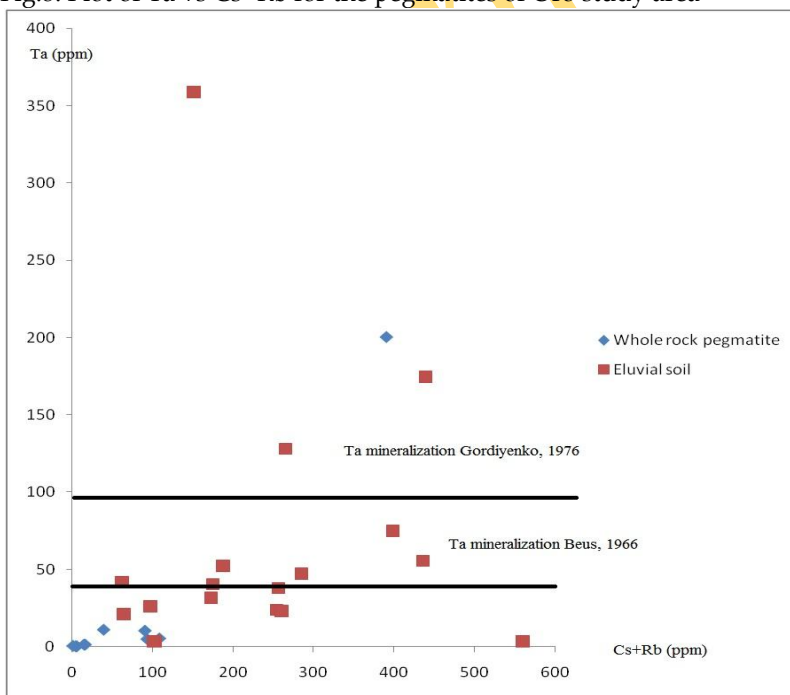
(after Moller and Morteani, 1987).

Fig.7: Plot of Ta vs Rb for the pegmatites of Oro study area



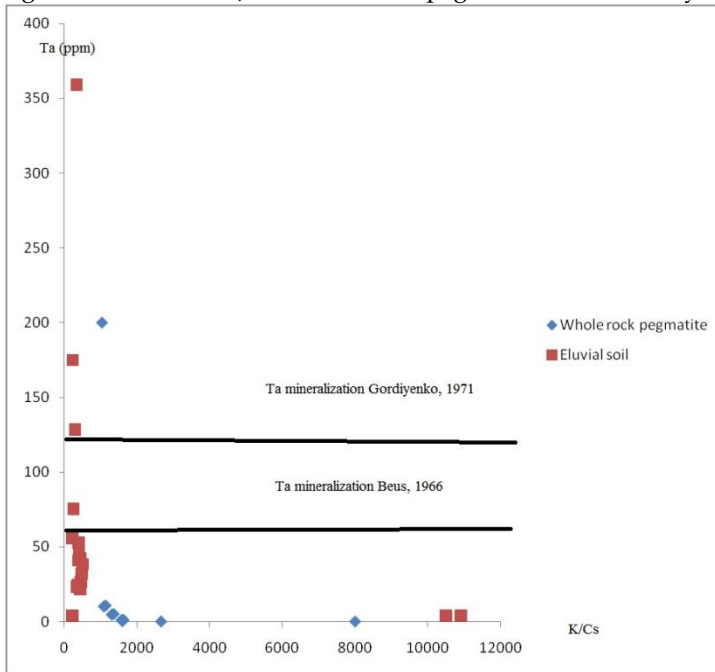
(after Moller and Morteani, 1987).

Fig.8: Plot of Ta vs Cs+Rb for the pegmatites of Oro study area



(after Gaupp *et al.*, 1984).

Fig.9: Plot of Ta vs K/Cs ratio for the pegmatites of Oro study area

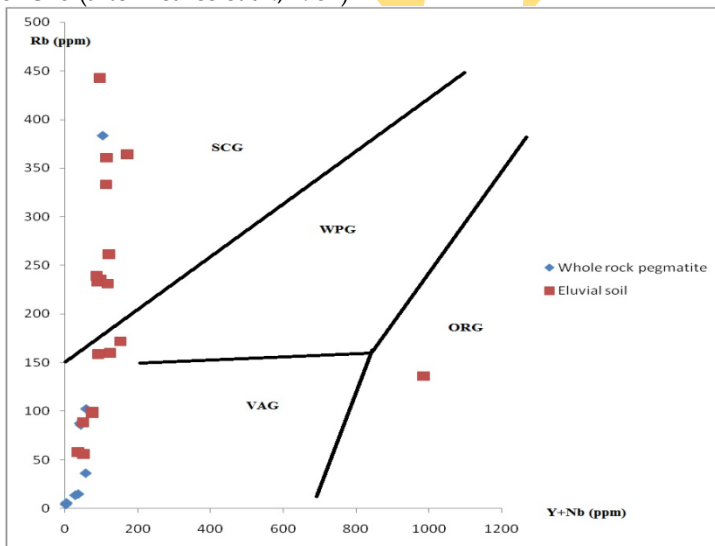


(after Gordiyenko, 1971 and Beus, 1966).

The trend of compositional variation in the columbite-tantalite quadrilateral has direct relationship with degree of fractionation. Pegmatites whose values plot in the field ferro-columbite have been generally interpreted as primitive and not good sources of Ta ores (Breaks et al., 1999). Most data here plot in the field of ferro-columbite and only one

plot in the field of ferro-tantalite. This indicates that the pegmatites of Oro area are moderately promising for tantalite and other rare metals. These Rb/ Y+Nb plot (Fig.10) shows that the pegmatites plot in the field of the volcanic arc granite with few of the samples plotting clearly within plate granite.

Fig 10: Rb vs (Y+Nb) discriminant diagram for the whole rock pegmatites and eluvial soils of Oro (after Pearce et al., 1984)



VAG-Volcanic Arc Granite
 SCG- Syn-Collisional Granite
 WPG- Within Plate Granite
 ORG- Oceanic Ridge Granite

The variation plot of Rb versus Sr (ppm) reveals the crustal thickness during emplacement of these pegmatite bodies (Fig.13) which reached about 30km as shown from the Rb/Sr plot of Condie, (1976).

Fig.11: Plot of Rb-Sr for the pegmatites of Oro study area. (after Condie, 1976).

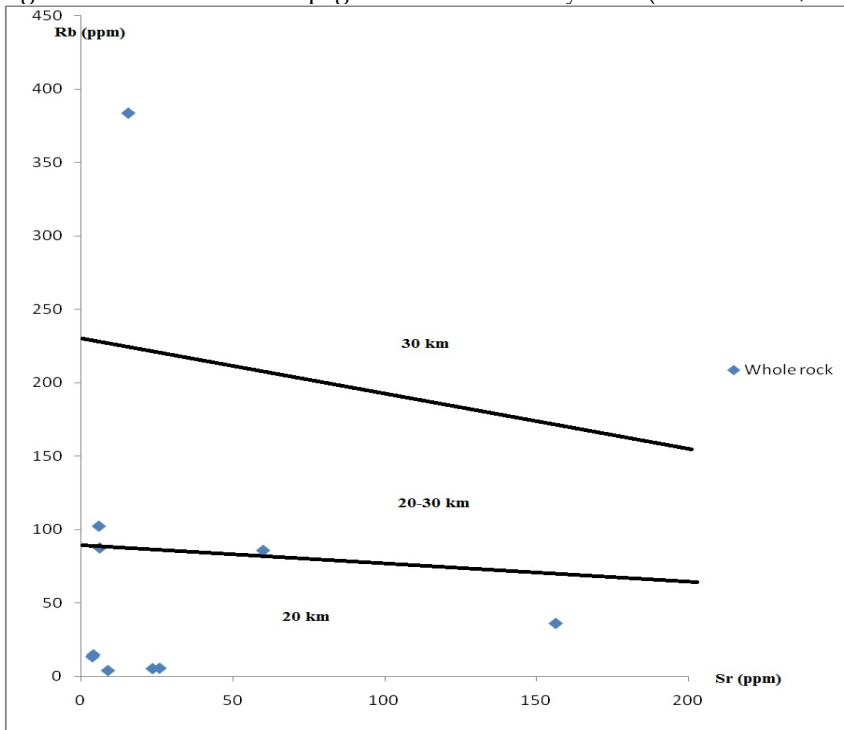
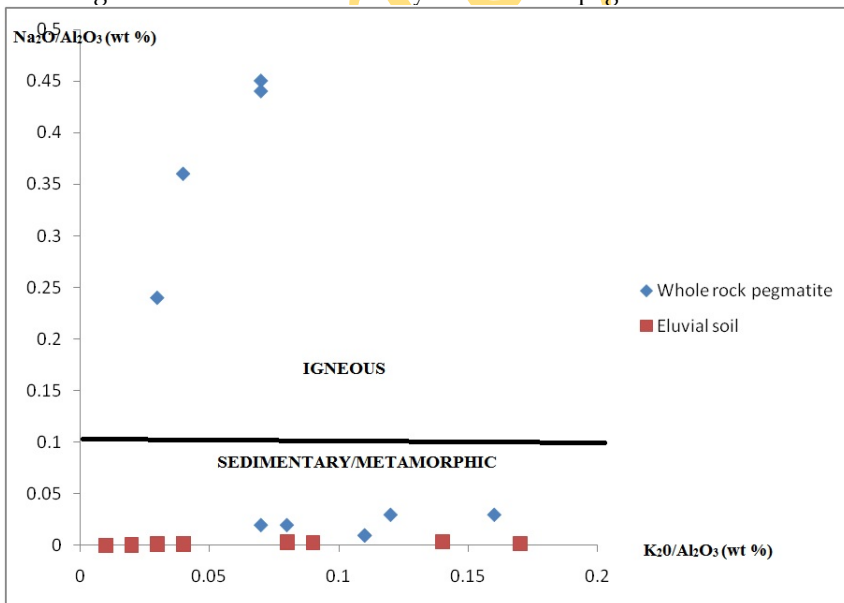
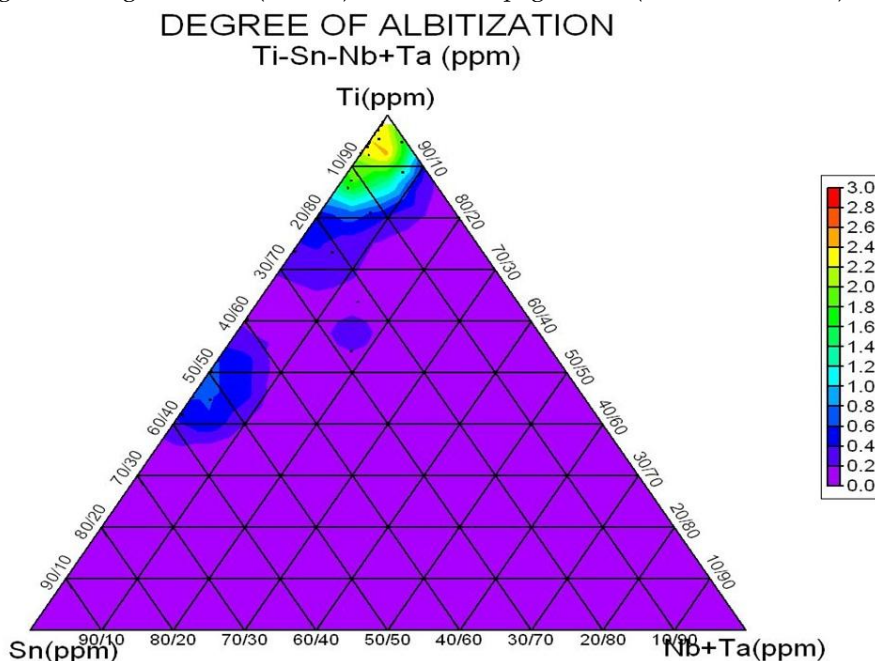


Fig.12: Plot of $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ vs $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ (Wt %) showing variation diagram for the field of Igneous and Metasedimentary rocks of Oro pegmatites.



The degree of albitization is revealed by the triangular Ti-Sn-(Nb+Ta) discriminant plot which plots in the zone of albitization (Fig. 12) for the Oro pegmatites. This plot also reveals a high degree of albitization and it indicates a significant difference between the mineralized and unmineralized pegmatite samples (Matheis and Emofurieta, 1990; Okunlola and King, 2003; Okunlola and Somorin, 2005; Jacobson and Webb, 1946), however these values are still low compared to those of the economically viable bodies like Tanco Canada (Moller and Morteani, 1987), but there are indications that the pegmatites of Oro area compare favorably with those of other mineralized pegmatite areas like Egbe and Igbeti areas southwestern Nigeria (Matheis and Emofurieta, 1987; Okunlola and Oyedokun, 2009). This is also indicative of the degree of fractionation.

Fig. 13: Triangular Ti-Sn-(Nb+Ta) Plot for Oro pegmatites (after Kuster, 1990)

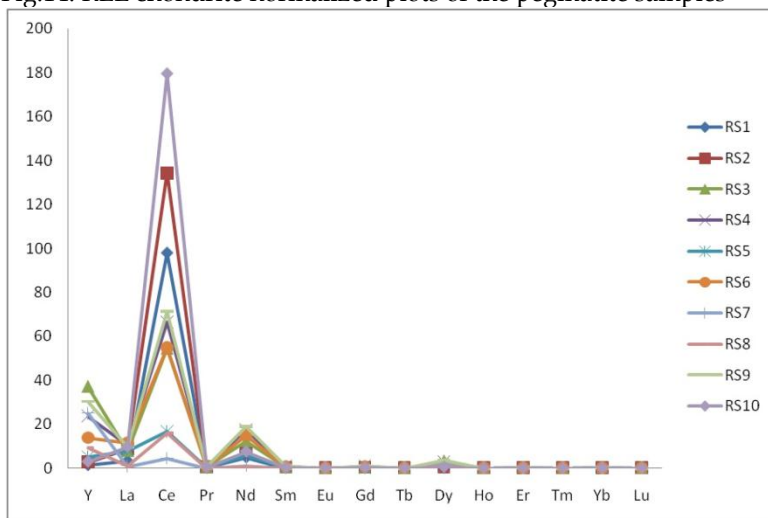


The Chondrite normalized plot (Fig.13) of the rare earth elements shows high light REE (LREE) (Ce, Nd) values and low heavy (HREE) (Tb, Dy, Ho, Er, Tm, Lu and Yb). There is a weak negative Europium (Eu) anomaly and a strong positive Ce anomaly. This is especially characteristic of LCT pegmatites with attendant high fractionation. (Cerny, 1991b) However, Taylor et al., (1986) had suggested earlier that where there is a weak negative Ce signature and a strong negative Eu signature as in this case of Oro pegmatite samples it is an evidence of considerable fractionation and metasomatism. Also, Piper, (1974) and Garba, (2003) believe that Negative Ce signature of rare metal pegmatite is taken to indicate oxidizing condition during mineralization and interaction between magmatic, melt fluids and host rocks over long distance sometimes.

Table 12: REE/Chondrite normalized data for Oro pegmatite

REE	RS1	RS2	RS3	RS4	RS5	RS6	RS7	RS8	RS9	RS10
Y	1.372	2.74	37.04	23.72	5.10	13.72	24.89	9.21	30.38	2.94
La	3.20	8.81	7.82	10.40	7.72	11.45	0.86	1.02	9.54	9.67
Ce	98.03	134.38	54.38	66.53	16.72	54.91	4.4	15.93	71.19	179.52
Pr	0.19	0.44	0.62	0.83	0.36	0.77	0.05	0.06	0.83	0.48
Nd	4.92	7.2	12.42	17.4	6.06	14.94	1.02	0.84	19.02	7.56
Sm	0.12	0.26	0.66	0.86	0.21	0.66	0.14	0.10	1.08	0.30
Eu	0.007	0.02	0.03	0.03	0.02	0.04	0.002	0.002	0.09	0.02
Gd	0.16	0.26	0.72	0.80	0.17	0.59	0.31	0.15	1.13	0.25
Tb	0.002	0.0005	0.02	0.02	0.006	0.02	0.02	0.009	0.03	0.005
Dy	0.17	0.45	3.17	2.63	0.67	1.80	2.44	1.01	3.86	0.50
Ho	0.002	0.005	0.05	0.04	0.007	0.02	0.03	0.009	0.05	0.004
Er	0.01	0.03	0.42	0.30	0.04	0.13	0.20	0.08	0.37	0.02
Tm	0	0.0006	0.011	0.008	0.002	0.003	0.006	0.002	0.008	0.0006
Yb	0.02	0.024	0.47	0.28	0.05	0.14	0.204	0.09	0.35	0.02
Lu	0	0.0007	0.014	0.010	0.002	0.003	0.005	0.002	0.010	0.001

Fig.14: REE chondrite normalized plots of the pegmatite samples



CONCLUSIONS

The pegmatites occur as vertically dipping and low-lying dykes, intruding the older quartz mica schist and granite gneiss. The pegmatites are observed to be rich in gem beryl, tourmaline, quartz and feldspar. Optical studies show the dominance of microcline, quartz, albite, biotite and muscovite with other opaques and accessory minerals.

Chemical data show that the pegmatites are highly siliceous, with silica contents ranging from 71.49-97.77%. The alumina contents of the whole rock pegmatite range from 0.73-15.20%. The K/Rb ratios, in the range of 19.3-195.1ppm were obtained from the whole rock pegmatite samples of the area, while the Ba/Rb ratio (0.07-15.79ppm) of the samples are comparable with other pegmatites from the southwestern Nigeria (Okunlola and Jimba, 2006). The relatively low average of K/Rb (107.13ppm) with Rb/Sr (9.83ppm) ratios of the pegmatites indicate a low to moderate degree of fractionation.

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