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## Geochemistry and Origin of Talc Mineralization in Kagara Area (Sheet 142 SE and Part of Sheet 142 SW) North Central, Nigeria

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### Abstract:

*This paper discusses the geochemistry and origin of talcose rocks in Kagara area, North central Nigeria. The study area is part of the Kushaka schist belt of the Northern Nigeria Basement Complex. It lies within latitudes 10° 00'N and 10°15'N and longitudes 6°10'E and 6°30'E, sheet 142 SE and part of Sheet 142 SW.*

*The major rock units in the area are migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolite, talcose rock, phyllite, granodiorite, porphyritic granite, fine-medium grained granite, and pegmatite. Petrographical studies revealed that quartz, microcline, plagioclase and biotite constitute the major minerals present in the migmatitic gneiss, porphyritic granite, fine-medium grained granite, meta-arkosic rocks and pegmatite with epidote as the dominant accessory mineral. The talcose rock contains in addition to talc, appreciable amount of chlorite, magnesite, anthophyllite with magnesite and quartz forming the accessory minerals.*

*Geochemical characterization of the talcose rock shows SiO<sub>2</sub> (28.63-34.99) wt %, MgO (29.21- 35.13) wt %, Fe<sub>2</sub>O<sub>3</sub> (6.36 - 13.20) wt %, and variable proportion of CaO (0.02-0.18) wt % and Al<sub>2</sub>O<sub>3</sub> (0.58-13.20) wt % are characteristic of the rock. The talcose rock also shows negative Eu anomaly and therefore paucity of plagioclase. High Ni (210-1850 ppm), Co (82-91 ppm), and Cr (170-1930 ppm) values indicate that the talcose rock was derived from an ultramafic protolith which has undergone moderate degree of metamorphism.*

**Keywords:** Talc, petrogenesis, mineralization, protoliths, Kagara, North central Nigeria

### 1. Introduction

Talc is a hydrated silicate of magnesium Mg<sub>3</sub>Si<sub>4</sub>O<sub>10</sub>(OH)<sub>2</sub>. It is an alteration product of original or secondary magnesian minerals or rocks resulting from mild hydrothermal processes, aided by simple dynamic metamorphism but never from weathering (Huston *et al.* 1993). The occurrences of talcose rock in ultramafic rocks in Kagara area have previously been reported by Elueze, (1982); Elueze and Dosunmu (1987); Elueze (1983) were speculated on tectonic affinity of the amphibolites in the area. Other works done in the past were related to the geochemistry and general geology of the area without special preference to deposits like talcose occurring within the Kushaka schist belt (Ajibade, (1982). Recently, geochemical studies by Ihaza *et al.*, (2014) focused on appraisal of talcose bodies in the area with emphasis on its industrial application while Amoka (2000); Ogunbanjo and Amoka (2005, 2006) worked on decolourization of talcose rock from Kagara using magnetic separation and acid bleaching as route for colour enhancement; Since strong colours are objectionable in most industrial applications, most of the talc deposits require bleaching before usage. From the available literature no account of the origin was done. The geochemical attributes of the talcose rocks from Kagara area will be examined so as to bring out more details relating to the origin and mineralization potential of the rocks.

### 2. Geological Setting

The study area belongs to the Nigerian Basemen Complex, which forms part of the mobile belt (Figure 1) that lies between the Archean to Early Proterozoic West African and Congo Cratons where talcose rocks are also known to occur (Olobaniyi and Annor, 2003). The dominant N-S trending structures and extensive areas of igneous rejuvenation of this basement are attributed to the Pan-African Orogenic events (Van Breeman *et al.* 1977). The lithological framework, deformation and metamorphism of the study area are established in the work of Ajibade (1980) and Elueze (1981). Olade and

Elueze (1979) consider the part of the study area to be fault-controlled rift-like structures. Grant (1978) and Turner (1983), based on structural and lithological associations, suggest that there are different ages of sediments. The geochemistry of the amphibolite within the schist belts has generated much controversy. Klemm *et al.*, (1984) confirmed the sedimentary sourced through enisimatic process. Ogezi (1977) and Ajibade (1980) have favoured dominantly ensialic processes in the evolution of the schist belts while Egbuniwe (1982) stressed that some include oceanic materials with tholeiitic affinities. The Kushaka belt occupies a belt of about 50 Km wide and stretches from Minna area up to Tsohon Birnin Gwari area in northwestern Nigeria. Kagara is located about 15 km northeast of Tegina along Tegina – Pandogari – Birnin Gwari road (Figure 1).

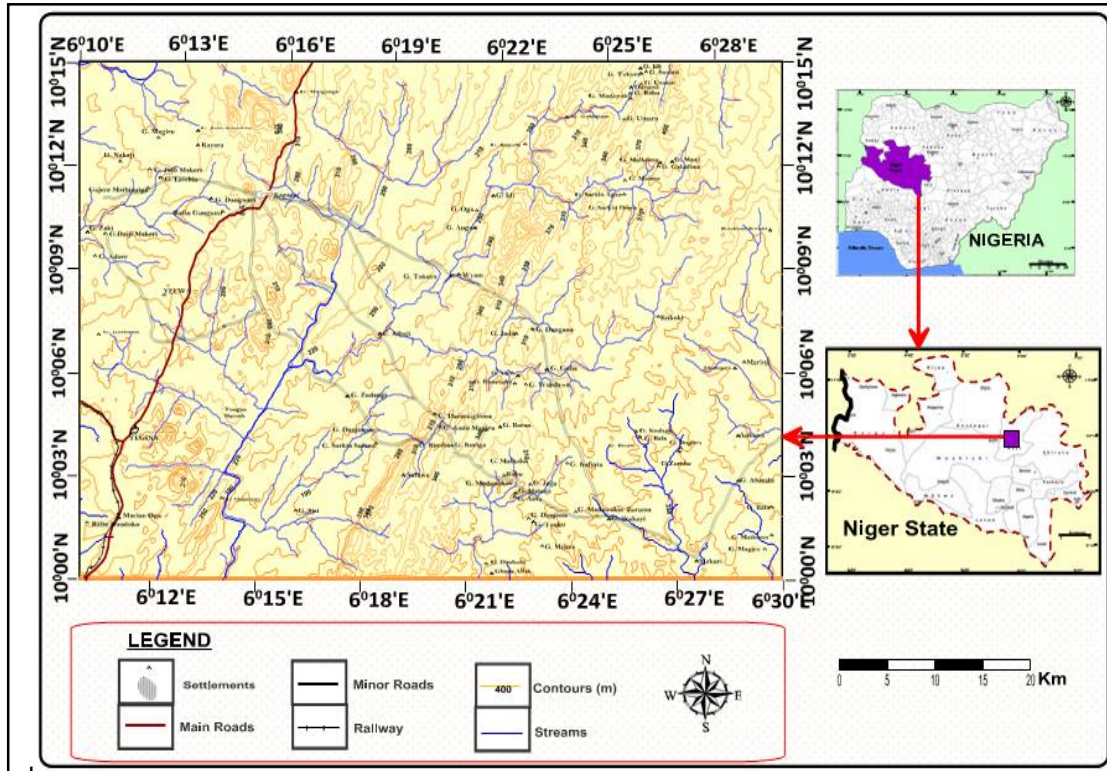


Figure 1: Location map of the study area.

### 3. Aim of the Study

The aim of this study is to undertake detailed field mapping and geochemical investigations of the talcose rock and host rocks in Kagara area in order to determine the origin of talcose rock.

### 4. Materials and Methods

The methodology adopted in the execution of this research work consists of field study and laboratory analyses. The field study involved geological mapping on a scale of 1:50 000 which was undertaken with topographic map, geologic hammer, compass - clinometers and Global positioning system (GPS). The laboratory work involved sample preparation, petrographic study and geochemical analysis. The petrographic study was undertaken with the petrological microscope at petrographic laboratory, Department of Geology, Ahmadu Bello University, Zaria. Thirteen (13) samples of talcose rock and associated rocks were prepared for petrographic study. Four (4) selected samples consist of two (2) representative's samples of talcose rock and two (2) samples of amphibolites were analysed for x-ray diffraction (XRD) at Activation Laboratories Limited (ACTLAB), Ancaster, Ontario, Canada. These consist of two (2) representative's samples of talcose rock, three (3) samples of amphibolites, two (2) granites and seven (6) others rock types. The analytical techniques for the whole rock geochemical analysis were performed on the powdered samples. The major elements were analysed using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). As a means of dissolving the mineral constituents, the analytical procedure involved addition of 5 ml each of perchloric acid (HClO<sub>4</sub>) and trioxonitrate (V) HNO<sub>3</sub> acid and 15 ml Hydrofluoric acid (HF) to 0.5 g of sample. The solution was stirred and allowed to evaporate to dryness after it was warmed at a low temperature for some hours. Four (4) ml of hydrochloric acid (HCL) was added to the cooled solution and warmed to dissolve the salts. The solution was cooled; then diluted to 50 ml with distilled water. The solution was then introduced into the ICP torch as aqueous – aerosol. The emitted light by the ions in the ICP was converted to an electrical signal by a photo multiplier in the spectrometer. The intensity of the electrical signal produced by emitted light from the ions were compared to a standard (a previously measured intensity of a known concentration of the elements) and the concentration were then computed. Analytical precisions vary from 0.1 % to 0.04 % for the major elements.

Trace elements were analyzed by inductively- coupled Plasma Mass Spectrometry (ICP - MS) from pulps after 0.2 g of rock powder was fused with 1.5 g LiBO<sub>2</sub> and then dissolved in 0.1 ml of trioxonitrate (V) (HNO<sub>3</sub>) acid. Analytical precisions vary from 0.1 to 0.5 ppm for trace elements. The rare–earth elements (REE) contents were determined by Inductively - Coupled Plasma Mass Spectrometry (ICP - MS) from pulps after 0.25 g rock- powder was dissolved with 5 ml of perchloric acid (HClO<sub>4</sub>) and trioxonitrate (V) (HNO<sub>3</sub>) acid, and 15 ml of hydrofluoric acid (HF). Analytical precisions vary from 0.01 to 0.5 ppm for rare earth elements.

## 5.Results and Discussion

### 5.1. Geology of the Study Area

The major rock units in the area are migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolites, talcose rock, phyllite, granodiorite, porphyritic granite, fine-medium grained granite, and pegmatite. Migmatitic–gneisses are extensive in the area, intruded by the Older Granites at the northern part truncating its massive extension from the western part of the area to the eastern. It constitutes well over 52% of the rock types in the study area. The Older Granites in the study area are porphyritic and fine-medium grained granites. The porphyritic granites intruded the other rocks in the area especially in the southwestern axis and central part northwards, covering about 30% of the entire area while fine-medium grained granites covers 4% of the area notably in the northeast and toward the central part of the study area. The amphibolites and phyllites constitute about 8% of the rock types in the area. Outcrops of the amphibolites in are lenticular, texturally distinctive and well oriented sub - parallel to the N-S foliated trend. The talcose rocks constitute about 6% of the rocks in the study area and occur in the northwestern part close to Kagara in Tsaunin Agwaru area in a ridge surrounded by amphibolites and the Older Granites. Outcrop of the talc occurs as lensoid bodies of moderate size and length. It extends to the southwestern part having contacts with the migmatitic–gneisses and the Older Granites in an oval shaped outcrop of about 15 m above the surrounding ground surface. In the southern part of Kagara, talcose rocks occurs as large inselbergs and massive exposures, and are bounded by the Older Granites and migmatitic gneiss in the western and eastern sides. The talcose rock truncates the linearly elongated north - south amphibolites bodies (Figure 2). The talcose bodies are largely extensive in Kagara area with different grade, colours, sizes, and textures. The colour of talc varies from grey, white to pale brown colour with a soapy feel when handled.

There are metamorphosed arkosic rocks mainly of sandstone containing at least 25 % of feldspar. This unit runs in N-S direction in the south-eastern part of the study area and also occurs in the north towards the east, though not as massive as in south-eastern part of the study area. The geological map of the study area is presented as (Figure 2)

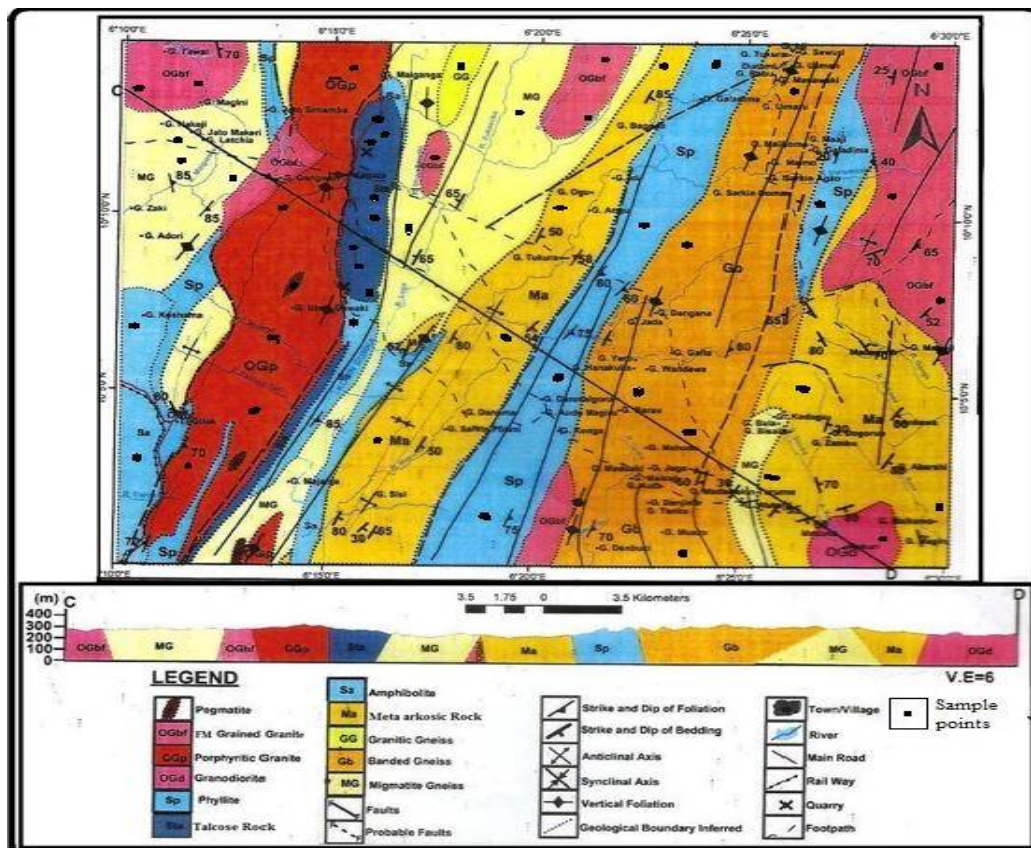


Figure 2: Geological map of the Kagara area

**6. Geochemical Results and Discussion**

Tables 1, 2 and 3 show the results of major, trace and rare earth element compositions of the study area.

The SiO<sub>2</sub> concentration range from 28.63 - 74.28 wt %, Al<sub>2</sub>O<sub>3</sub> range from 0.58 - 18.27 wt %, Fe<sub>2</sub>O<sub>3</sub> range from 0.98 - 8.88 wt %, MgO range from 0.19 - 35.15 wt %, L.O.I range from 0.40 - 22.60 wt %, from the rocks in the study area. In addition, the concentration of CaO, Na<sub>2</sub>O, K<sub>2</sub>O, MnO, TiO and P<sub>2</sub>O<sub>5</sub> from the study area also varies from 0.02-5.38 wt %, 0.33 - 8.14 wt %, < 0.01 - 3.49 wt %, 0.033 - 0.155 wt %, 0.02 - 1.213 wt %, < 0.01 - 0.25 wt % respectively.

Major elements versus SiO<sub>2</sub> plots were used to evaluate trends of the rocks (Figure 3)

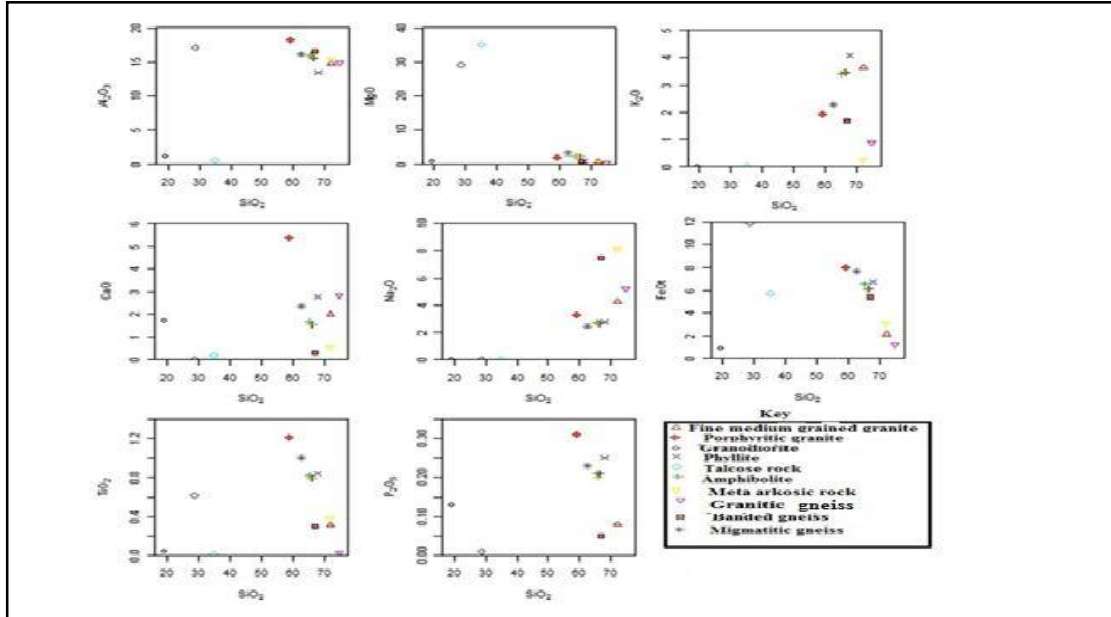


Figure 3: Harkers varaiton diagrams (SiO<sub>2</sub> Versus Al<sub>2</sub>O<sub>3</sub>, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, TiO<sub>2</sub>, P<sub>2</sub>O<sub>5</sub>, FeO<sub>t</sub>)

SiO<sub>2</sub> content is greatly high in migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolite, phyllite, granodiorite, porphyritic granite, and fine-medium grained granite from the study area but poor in talcose rock. Al<sub>2</sub>O<sub>3</sub> concentration in the host rocks does not show a strong variation as they relatively close to each other indicating a close relationship between the rocks whereas talcose rock show a strong variation of Al<sub>2</sub>O<sub>3</sub> that range from 0.58 - 17.11 wt %.

The chemical composition of talcose rock from Kagara area shows that talcose rock is rich in MgO and L.O.I but poor in migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolite, phyllite, granodiorite, porphyritic granite, and fine- medium grained granite from the study area (Table 3). Concentration of Fe<sub>2</sub>O<sub>3</sub> is higher in talcose rock than other rocks from the study area. The stability of iron - bearing minerals is dependent on the oxygen fugacity f(O<sub>2</sub>) in a system.

The compositions of CaO, Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub> and TiO<sub>2</sub> are generally low in talcose rock compared to values obtained in other rocks from the study area (Table 1). This petrogenetic affinity of talcose rock were also demonstrated on bivariate plots of FeO + TiO<sub>2</sub> versus Al<sub>2</sub>O<sub>3</sub>, MgO after Jensen 1976) (Figure 4).

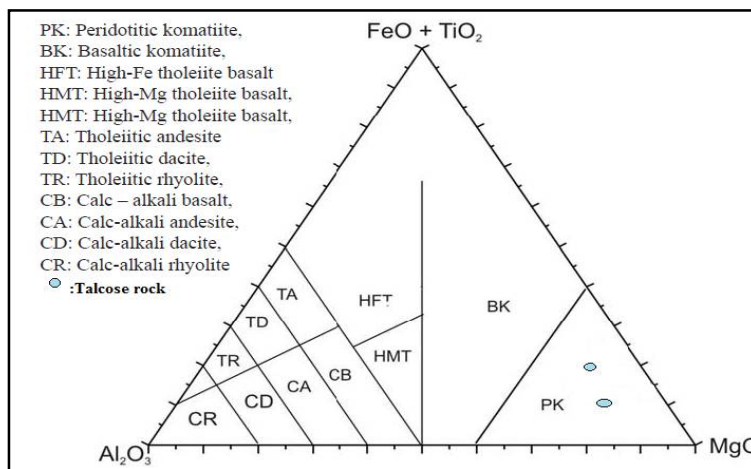


Figure 4: Classification of volcanic rocks after Jensen (1976)

Bivariate plots of Rb versus Y+Nb, and Rb versus Ta+Yb (after Pearce et al., 1984) were used to distinguish the granites based on their intrusive setting into four groups namely: Oceanic Ridge Granite (ORG), Volcanic Arc Granite (VAG), Within Plate Granite (WPG) and Collision Granite (COLG) Figure (5). The granitic rocks were plotted within Volcanic Arc Granite. The rare earth elements (REE) are usually sub-divided into the light rare earth elements (LREE) and heavy earth elements (HREE) classes. The LREE consist of La to Sm (atomic numbers 57- 62) and the HREE are Gd (atomic numbers 64 - 71). The rare earth elements (REE) data from the Kagara area is presented in Table 3

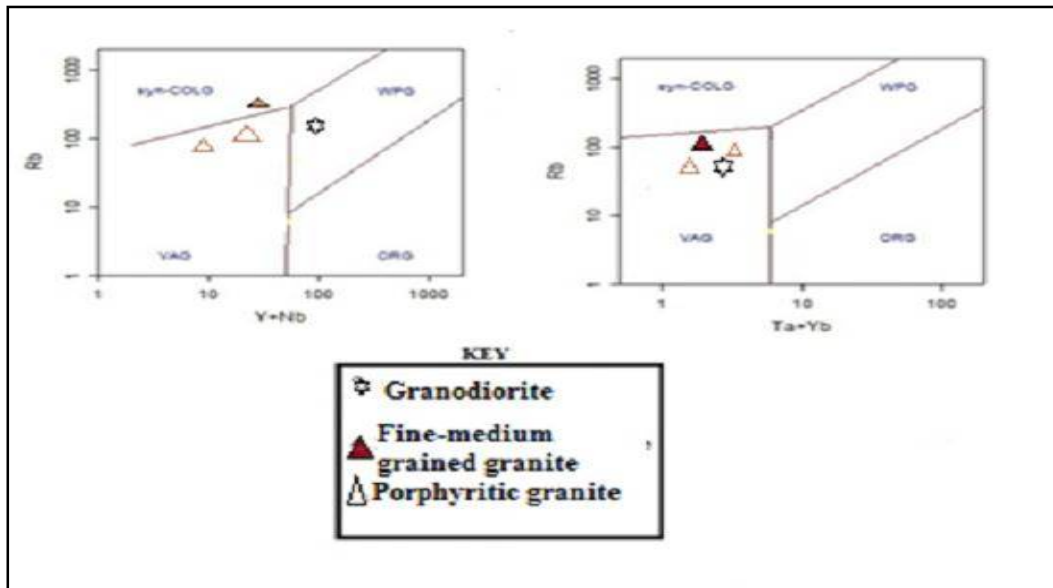


Figure 5: Rb versus Y+Nb and Rb versus Ta+Yb discrimination diagrams for granitic rocks in the area (after Pearce et al., (1984).

The trace elements composition of the rock samples obtained from the study area is presented in Table (2). Trace element compositions were normalized to average upper continental crust (UCC) values of Weaver and Tarney (1984). Trace elements composition in phyllite is very similar to those of the average upper continental crust though with depletion in Zr and Nb Figure (6). Ti and K are strongly enriched in talcose rock but depleted in amphibolite, fine - medium grained granite and granitic gneiss. Trace elements Ni, Co, Cr, and V, concentrations show enrichment in talcose rock followed by the amphibolite while Be, Sr, Cu and Zn are generally lower than average upper continental crust. There is a significant variation in trace elements concentration among the rock units. The variation in Ba, Sr, and Rb content is very useful in determining whether magmatic evolution was controlled dominantly by fractional crystallization, partial melting or more complex processes (Dall *et al.*, 1999). The Ba (<2 - 5ppm), Zr (4-8ppm), Sr (< 2 ppm) and Rb (< 2ppm) concentrations in the talcose rocks are generally low compared with other rocks within the study area (Table 3).

The  $\Sigma$ REE varies from 2.15 to 265.1ppm. The talcose rock from Kagara area has the lowest  $\Sigma$ REE of 2.15 whereas the highest  $\Sigma$ REE value was recorded in phyllite (265.1ppm). The rare earth elements data are normalized to chondrite values of Nakamura (1974). The REE pattern of talcose rock and its host rocks displays a steep slope from LREE to the HREE and a negative Eu anomaly (Figure 6). Specifically, the Negative europium anomaly ( $Eu/Eu^*$ ) relative to chondrite in talcose rock ranges from 0.10 - 0.65. The similarity in REE patterns suggests that the rocks were derived from a common source.

The normalized  $(La/Yb)_n$  range from 1.5 - 32.76. The talcose rock from Kagara area has the lowest  $(La/Yb)_n$  (1.5) with the highest value  $(La/Yb)_n$  recorded in fine - medium grained granite (32.76) Table (3).

Petrochemical trends of the rare earth elements of talcose rock reflected some subtle relationships to the amphibolites in the Kagara areas (Figure 6). The analysis of the different distribution patterns is presented in figures (7 to 9)

Table 3: Major elements composition of major rock types in the study area (all values in wt %).

	Granodionite	Fine-Medium grained granite	Porphyritic granite	Porphyritic granite	Amphibolite	Amphibolite	Phyllite	Talose rock	Talose rock	Granitic gneiss	Banded gneiss	Migmatitic gneiss	Meta-arkosic rock
Code	L27	L16	L12	L8	L10	L11	L22	L13a	L15	L6	L24	L25	L18
<b>Oxides</b>													
SiO <sub>2</sub>	69.20	72.11	66.39	65.42	59.01	62.57	67.89	34.99	28.63	74.28	71.93	65.95	66.97
Al <sub>2</sub> O <sub>3</sub>	14.13	14.82	15.62	15.9	18.27	16.08	13.4	0.58	17.11	14.85	15.42	15.69	16.52
Fe <sub>2</sub> O <sub>3T</sub>	0.98	2.38	6.84	7.24	8.88	8.51	7.46	6.36	13.2	1.39	3.48	6.76	6.01
MnO	0.04	0.148	0.09	0.136	0.151	0.155	0.103	0.077	0.062	0.017	0.033	0.09	0.064
MgO	0.80	0.78	2.03	2.05	1.78	3.17	0.76	35.13	29.21	0.19	0.33	2.09	0.73
CaO	1.72	2.01	1.53	1.69	5.38	2.34	2.77	0.18	0.02	2.84	0.55	1.56	0.32
Na <sub>2</sub> O	7.02	4.26	2.65	2.69	3.31	2.47	2.78	0.03	0.01	5.24	8.14	2.66	7.44
K <sub>2</sub> O	0.02	3.46	3.45	3.43	1.92	2.77	4.1	0.02	<0.01	0.86	0.25	3.49	1.68
TiO <sub>2</sub>	0.039	0.313	0.791	0.84	1.213	1.004	0.843	0.014	0.614	0.022	0.381	0.795	0.295
P <sub>2</sub> O <sub>5</sub>	0.13	0.08	0.21	0.21	0.31	0.23	0.25	<0.01	0.01	<0.01	0.05	0.20	0.05
L.O.I	3.57	0.40	1.46	1.38	0.69	2.15	0.38	22.6	10.98	0.41	0.36	1.51	0.55
<b>Total</b>	<b>99.6</b>	<b>100.9</b>	<b>101.0</b>	<b>101.0</b>	<b>100.9</b>	<b>100.9</b>	<b>100.8</b>	<b>99.99</b>	<b>99.86</b>	<b>100.6</b>	<b>100.9</b>	<b>100.8</b>	<b>100.6</b>
CaO/Al <sub>2</sub> O <sub>3</sub>	1.52	0.85	0.10	0.11	0.30	0.15	0.21	0.31	<0.01	0.19	0.04	0.10	0.02
**FeO	0.88	2.14	6.15	6.51	7.99	7.65	6.71	5.72	11.87	1.25	3.13	6.08	5.41

\*\* FeO = Fe<sub>2</sub>O<sub>3</sub> / 1.112

Table 1: Trace Elements composition of Major rock types in the study area (all values in ppm)

	Granodionite	fine-medium grained granite	Porphyritic Granite	Porphyritic granite	Amphibolite	Amphibolite	Phyllite	Talose rock	Talose rock	Granitic gneiss	Banded gneiss	Migmatitic gneiss	Meta-arkosic rock
CODE	L27	L16	L12	L8	L10	L11	L22	L13a	L15	L6	L24	L25	L18
Sc	1	4	18	13	13	13	12	4	63	<1	7	21	17
Be	<1	3	2	3	3	3	3	<1	<1	6	1	1	2
V	<5	26	82	97	101	101	51	17	353	5	7	150	150
Ba	7494	1172	577	837	832	842	973	5	<2	121	249	668	463
Sr	383	461	671	196	172	175	217	<2	<2	443	154	192	58
Y	9	8	17	24	24	24	46	<1	5	5	41	26	58
Zr	7	133	623	219	195	194	390	4	8	66	295	191	371
Cr	30	180	140	9	350	320	<2	1930	170	260	<20	360	<20
Co	32	56	46	31	32	31	42	82	91	33	24	37	27
Ni	30	<20	20	40	50	50	<20	1850	210	20	<20	60	20
Cu	130	10	40	40	50	40	10	<10	20	30	<10	50	10
Zn	200	60	130	80	80	90	100	40	70	<30	60	90	130
Ga	45	31	29	24	23	22	23	2	10	27	14	20	25
Ge	2	1	2	2	2	2	2	1	<1	1	1	2	1
As	355	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	6
Rb	<2	107	69	120	124	123	152	<2	<2	30	6	68	52
Nb	1	6	22	14	14	14	21	<1	<1	<1	7	10	9
Mo	7	<2	4	<2	7	6	<2	<2	<2	8	<2	6	<2
Ag	<0.5	<0.5	1.6	0.5	<0.5	<0.5	<0.5	1	<0.5	<0.5	0.6	<0.5	0.9
In	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sn	<1	1	2	3	3	3	5	<1	<1	2	2	2	3
Sb	15.3	0.6	0.6	0.6	0.5	0.6	0.5	<0.7	0.5	0.5	0.6	0.7	1.3
Cs	<0.5	2.6	3.4	9.3	9.5	9.7	4.7	<0.5	<0.5	1.2	<0.5	3.4	1.3

Table 2

Table 5: Rare earth elements concentration of major rock types in the study area (all values in ppm)

	Granodiorite	Fine-Medium-grained granite	Porphyritic granite	Porphyritic granite	Amphibolite	Amphibolite	Phyllite	Talcose rock	Talcose rock	Granitic gneiss	Banded gneiss	Migmatitic gneiss	Meta-arkose rock
Code Symbol	L27	L16	L12	L8	L10	L11	L22	L13,	L15	L6	L24	L25	L18
La	7.1	34.4	22.7	35.2	37.9	36.2	50.2	0.5	0.6	0.9	45.7	30.3	31.5
Ce	44.3	57.5	47.6	73	78.6	74.8	105	1.0	0.9	1.6	85	60.2	69.9
Pr	1.42	6.4	5.91	8.32	8.79	8.28	12.3	0.1	0.09	0.17	10.4	6.97	8.84
Nd	6.2	21.7	25.2	31.8	33.6	31.5	49.4	<0.4	0.4	0.8	39.3	27.4	37.7
Sm	1.6	3.1	6.2	6.5	6.6	6.3	11	0.1	0.3	0.2	8.1	5.7	9.5
Eu	0.42	0.88	3.17	1.51	1.55	1.5	2.31	0.05	0.05	0.23	1.7	1.53	2.37
Cd	1.7	2	5.9	5.4	5.8	5.4	11	0.1	0.6	0.3	7.4	5.3	9.6
Tb	0.3	0.3	0.9	0.8	0.9	0.8	1.7	0.1	0.2	<0.1	1.2	0.8	1.7
Dy	2.1	1.2	4	4.6	5	4.5	9.9	0.1	1.1	0.6	7.4	5	10.9
Ho	0.4	0.2	0.9	0.9	0.9	0.9	1.9	<0.1	0.3	0.1	1.5	1	2.3
Er	1.3	0.8	1.5	2.5	2.6	2.4	4.9	<0.1	0.7	0.4	4.6	3	6.7
Tm	0.18	0.11	0.21	0.38	0.38	0.35	0.7	<0.5	0.11	0.07	0.69	0.43	1.01
Yb	1.1	0.7	1.2	2.2	2.3	2.4	4.2	0.1	0.7	0.4	4.7	3	7
Lu	0.15	0.1	0.18	0.36	0.38	0.36	0.59	0.01	0.11	0.06	0.77	0.45	1.13
Hf	0.3	3.2	14.1	5.3	4.8	4.7	8.7	<0.2	<0.2	3.3	6.8	4.4	8.4
Ta	0.5	1.2	1.7	1.4	1.5	1.3	2.3	0.1	0.1	0.4	0.9	1	0.9
W	5	361	223	96	99	93	230	9	4	219	139	106	156
Ti	<0.2	0.5	0.3	0.5	0.5	0.5	0.7	<0.1	<1	<0.1	<0.1	0.2	0.9
Pb	<5	39	17	22	23	22	26	<5	38	38	13	12	14
Bi	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Th	0.3	7.7	3.9	10.4	11.2	10.8	14.7	0.1	<0.1	0.6	10.4	7.50	5.60
U	4	2.7	3.3	5	4.9	3.1	4.5	0.1	<0.1	9.1	6.3	1.9	2.30
ΣREE	68.27	129.39	125.57	173.7	185.30	175.6	265.0	2.15	6.16	5.83	218.4	151.1	200.15
ΣLREE	60.6	123.1	107.61	154.82	155.49	157.8	222.9	2.1	2.29	3.67	188.5	130.6	157.44
ΣHREE	7.65	6.29	17.96	18.65	28.22	18.61	2.2	0.05	3.87	2.16	29.96	20.51	42.71

Table 3: The REE chondrite-normalised value of talcose rock from Kagara and the host rocks (chondrite values obtained from Nakamura, (1974))

	Granodiorite	Fine-Medium-grained granite	porphyritic granite	Porphyritic granite	Amphibolite	Amphibolite	Phyllite	Talcose rock	Talcose rock	Granitic gneiss	Banded gneiss	Migmatitic gneiss	Meta-arkose rock
Symbol	L27	L16	L12	L8	L10	L11	L22	L13,	L15	L6	L24	L25	L18
La <sub>N</sub>	21.52	104.24	68.79	106.67	114.85	109.70	152.12	8.0	1.82	2.73	138.48	91.82	95.45
Ce <sub>N</sub>	51.21	66.47	55.03	84.39	90.87	86.47	121.39	1.52	1.04	1.85	98.27	69.60	80.81
Pr <sub>N</sub>	12.68	57.14	52.77	74.29	78.48	73.93	109.82	1.16	0.80	1.52	92.86	62.23	78.93
Nd <sub>N</sub>	9.84	34.44	40.00	50.48	53.33	50.00	78.41	0.89	0.63	1.27	62.38	43.49	59.84
Sm <sub>N</sub>	7.88	15.27	30.54	32.02	32.51	31.03	54.19	0.63	1.48	0.99	39.90	28.08	46.80
Eu <sub>N</sub>	5.45	11.43	41.17	19.61	20.13	19.48	30.00	0.13	0.65	2.99	22.08	19.87	30.78
Cd <sub>N</sub>	6.16	7.25	21.38	19.57	21.01	19.57	39.86	2.11	2.17	1.09	26.81	19.20	36.17
Tb <sub>N</sub>	6.38	6.38	19.15	17.02	19.15	17.02	36.17	3.51	4.26	-	25.53	17.02	31.78
Dy <sub>N</sub>	6.12	3.50	12.24	3.41	14.58	13.12	28.86	2.68	3.21	1.75	21.57	14.58	32.86
Ho <sub>N</sub>	5.71	2.86	10.00	12.86	12.86	12.86	27.14	3.16	4.29	1.43	21.43	14.29	29.78
Er <sub>N</sub>	5.78	3.56	6.67	11.11	11.56	10.67	21.78	3.26	3.11	1.78	20.44	13.33	33.67
Tm <sub>N</sub>	6.00	3.67	7.00	12.67	12.67	11.67	23.33	3.08	3.67	2.33	23.00	14.33	31.82
Yb <sub>N</sub>	5.00	3.18	5.45	10.00	10.45	10.91	19.09	2.94	3.18	1.82	21.36	13.64	33.24
Lu <sub>N</sub>	4.41	2.94	5.29	10.59	11.18	10.59	17.35	0.63	3.24	1.76	22.65	13.24	6.73
Total	154.14	322.33	375.48	474.69	503.63	477.02	759.51	33.7	33.55	23.31	636.76	434.72	628.66
La <sub>N</sub> /Yb <sub>N</sub>	4.30	32.76	12.66	0.67	10.99	10.06	7.97	0.12	0.57	1.5	6.48	6.73	3.00
Ce <sub>N</sub> /Sm <sub>N</sub>	6.50	4.35	1.80	2.64	2.79	2.79	2.24	0.01	0.70	1.88	2.46	2.48	1.73
Ce <sub>N</sub> /Yb <sub>N</sub>	10.24	20.89	0.09	8.44	8.69	7.93	6.36	0.02	0.33	1.02	4.60	5.10	2.54
La <sub>N</sub> /Sm <sub>N</sub>	2.73	6.83	2.25	3.33	3.53	3.53	2.81	0.14	1.23	2.77	3.47	3.27	2.04
Eu/Eu*	0.78	1.09	1.61	0.78	0.77	0.79	0.65	0.10	0.36	2.89	0.67	0.89	0.79

Table 4

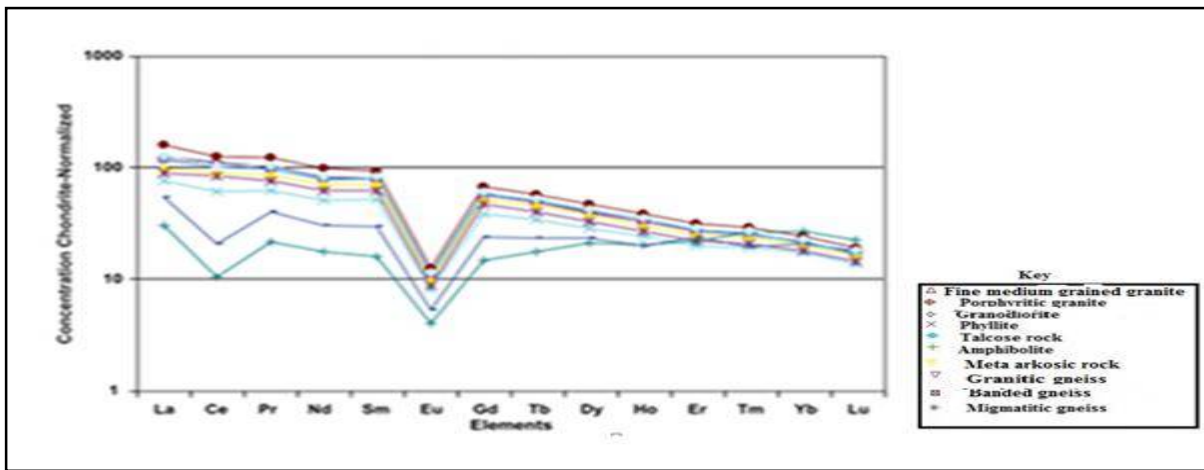


Figure 6: Rare earth elements distribution pattern of the rock from the study area normalized to the average crust. Normalizing value are those of Nakamura, (1974)

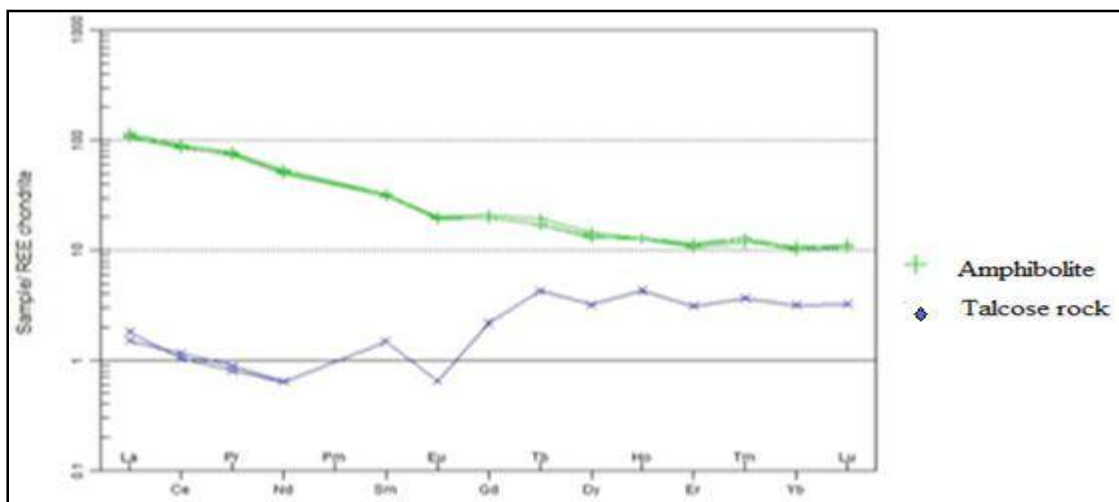


Figure 7: REE distribution pattern of amphibolite and talcose rock from the study area. Normalizing values are those of Nakamura, (1974)

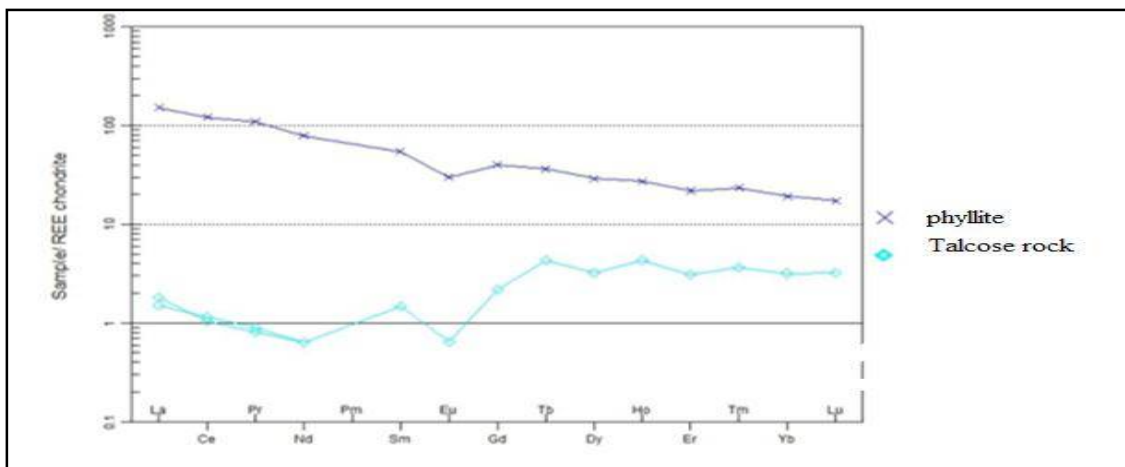


Figure 8: The distribution pattern of REE in phyllite and talcose rock. Normalizing value is those of Nakamura (1974)



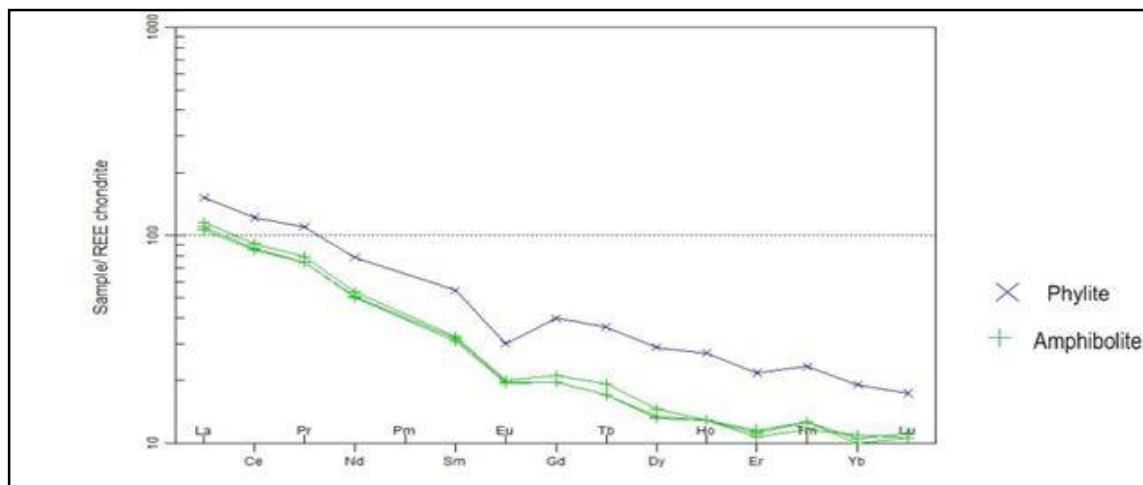


Figure 9: The distribution pattern of REE in phyllite and amphibolite. Normalizing value are those of Nakamura (1974)

**7. Geochemistry**

Major element data presented in Table 1 reveals that all rock samples have variable proportion of SiO<sub>2</sub> that range from (28.63 - 74.28) %, with the highest value recorded in granitic gneiss (L6) while talcose rock have the lowest SiO<sub>2</sub> content (L15a). The values of SiO<sub>2</sub> content in the talcose rock is the lower limit for ultra-mafic rocks. Alumina (Al<sub>2</sub>O<sub>3</sub>) content ranges from (0.58 - 18.27) % with the highest value recorded in amphibolites (L10) while talcose rock has the lowest (L13a). There is a wide range of concentration (0.58 - 17.11) % in the talcose rock. This may be attributed to the presence of chlorite.

Arndt (1976) has attributed the source of liquidus phase of melt with MgO > 20% to olivine and chromite source; He reported that MgO in the range of 2.0 to 12 % connotes Olivine + pyroxene source; and whereas MgO < 12 % represents pyroxene + plagioclase source. In the talcose rock concentration of MgO ranges from 29.21 % to

35.13 %, thus that talcose rock suggesting from Kagara area belong to olivine and chromite source. The L.O.I of the talcose rock is particularly high, (10.98 - 22.60) % which may be attributed to expulsion of carbon (iv) oxide from carbonate (magnesite) Segnit (1963) details in Table (7).

The Harkers diagrams (Figure 3) show that SiO<sub>2</sub> is positively correlated with Na<sub>2</sub>O and negatively correlation with Al<sub>2</sub>O<sub>3</sub>, MgO, P<sub>2</sub>O<sub>5</sub> and TiO<sub>2</sub>. The SiO<sub>2</sub> is positively and negatively correlated with FeO<sub>t</sub> and K<sub>2</sub>O.

The classification of volcanic rocks after Jenson (1976), the variation of FeO + TiO<sub>2</sub> with Al<sub>2</sub>O<sub>3</sub> and MgO, the talcose rock from Kagara area were plotted predominantly in the fields of peridotitic – komatiite. The overall chemical composition of the major element is similar to rocks of komatiitic series and peridotitic affinity (Brooks and Hart, 1974; Elueze, 1982; Olorunfemi *et al.*; 2010). Figures (7).

Location		Composition					
		SiO <sub>2</sub>	MgO	CaO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3T</sub>	L.O.I
<b>Kagara i</b>	This study	34.99	35.13	0.18	0.58	6.36	22.60
<b>Kagara ii</b>	This study	28.63	29.21	0.02	17.11	13.20	10.98
<b>Vermont</b>	A	35.98	32.95	-	0.43	5.67	23.18
<b>Luzenac</b>	B	47.50	26.05	1.05	13.25	2.68	9.00
<b>Norway</b>	C	39.80	34.50	0.40	1.30	2.67	23.60
<b>Finland</b>	D	3.61	25.32	6.86	7.71	10.45	6.15
<b>Asegbon-Nigeria</b>	E	53.99	31.73	0.09	1.83	-	5.40

Table 7: Chemical composition of talcose rock from Kagara area compared with some commercial talcs: A = Harben, (1995); B = Luzenac mine, (2003); C= Norwegian talc mine, (1995); D = Jahn *et al.*, 1980); E = Durotoye and Ige, (1991)

Trace elements composition of the rocks normalized to the average crustal values for all the rock samples (after Weaver and Terney, 1984) is plotted on a spider diagrams (Figure 7).

The migmatitic gneiss, amphibolites and the granodiorite show similar patterns, these rocks are all characterized by negative anomaly of some the field strength elements (HFSE): Nb, Th, Hf, Zr; and positive anomaly of some heavy rare earth elements (HREE): Tb, Yb, and Y. The granodiorite is characterized by negative anomaly of some large ion lithophile elements (LILE) namely Sr and Ba, while the migmatitic gneiss show positive anomaly of Ba and negative anomaly of Sr. The granites on the other hand is characterized by negative anomaly of some LILE (Ba and Sr) and some HFSE (Zr and Nb). Unlike the amphibolites and granodiorite that show positive Hf anomaly. The negative anomaly reinforces the calc-alkaline character suggested by the major element composition. Furthermore, the granites show positive U and La anomalies.

On the Rb versus Y + Nb and Rb versus Ta + Yb discrimination diagram (Figure 5) the granitic rocks plot in the syn-

collisional and volcanic arc granite fields of Pearce *et al.*, (1984). This is in agreement with the arc or syn- collisional origin of the Older Granites of Nigeria as proposed by Fitches *et al.*, (1985), Odewumi and Olarewaju (2013). Similar granitic rocks with volcanic arc and syn- collisional affinity emplaced during the Pan - African orogeny has also been reported in various parts of northern Nigeria by Olarewaju and Rahaman (1982), southwestern Nigeria, by Okonkwo and Winchester (2004), Okonkwo and Folorunso, (2013) and in south-eastern Nigeria by Ukwang and Ekwueme (2009); Obiora, (2012). These granitic rocks termed the " Older Granites" have been dated at 750 - 500 Ma by Rahaman *et al.*, (1983); Fitches *et al.*, (1985); and Ekwueme and Kroner, (1998).

The negative Eu anomalies in the talcose rock (Figure 6) indicate mineral fractionation and contamination within the basement rocks. The low Rb, Sr, Y, K, Ba and Zr contents of the rocks cannot be reconciled with the hydrothermal alteration, but point to depleted peridotites and pyroxenite as source rock. The concentration of Ni (210-1850) ppm and Cr (170-1930) ppm in talcose rock are similar to those of peridotites (Divakara Rao *et al.*, 1975). (Table: 4) which indicate the parental magma was formed from the mantle peridotite (Rollinson, 1975). The host rocks of talcose rock from Kagara deposit is of high concentrations of mobile elements, such as Rb, Ba, U, K and Sr (Table 5); these elements are relatively mobile during metamorphism (Schandl *et al.*, 1999), which reflects the composition of the original rocks. The concentration of these elements in the talcose rock can be ascribed to their chemical mobility under the influence of hydrothermal alteration, which commonly produces talc and chlorite from mafic and ultramafic rocks. This showed distinctive chemical enrichment trends in the talcose rock, rocks from the ore zone have variable and very low concentrations of Trace Elements Table (2). The incompatible trace elements such as Ta, Hf, and Zr which are inert under most geological conditions (Schandl *et al.* 1999, Gorton *et al.*; 1999), the low concentrations cannot be due to mobilization during metamorphism.

The REE abundances and the Chondrite-normalized patterns of the rocks studied using normalizing constants of Nakamura (1974) are broadly similar. The REE patterns for all rocks in Kagara area are characteristically skewed to the right except the talcose rock (Figure 6). This is also supported by (Ce/Yb)<sub>N</sub> ratios that range from (0.02 to 0.33). Moreover, (La/Sm)<sub>N</sub> ratio > 1 (0.14 - 1.23) also reveal a source related LREE enriched nature of these rocks (Hart and Blusztajn, 2006). (La/Yb)<sub>N</sub> ratios range from (0.12 - 0.57) suggesting a partial fractionated REE pattern (Table 3).

Talcose rock indicates absence of plagioclase as a negative Eu anomaly occurs in its chondrite normalized pattern (Figure 8). This is also supported by Eu/Eu\* values which are remarkably < 1 (0.10 - 0.36) for rock with negative Eu anomaly. The depletion in Ti content recorded in the granitic rocks suggests ilmenite fractionation.

## 8. Petrogenesis

The high Ni (210-1541ppm); Cr (170-1711ppm) and MgO (28.63 - 34.99) wt % concentration in talcose rock samples in the study area suggests original magmatic partitioning and points to the existence of a high Ni - phase presumably olivine in the parent rocks (Hawkesworth and O'Nious, 1977). Nickel (Ni) and Co are normally concentrated in olivine minerals and Cr in spinel, clinopyroxene. The Low Ni, Co, Cr values in the granitic rocks suggests that the calc- alkaline rocks are well fractionated while as high concentrations of Ni, Co, Cr in the talcose rock indicate a mantle source and limited fractionation.

REE patterns of Ce in talcose rock exhibit negative anomaly. Sample of the talcose rock with significant quantity of anthophyllite blasts / grains show least modification. The pattern shows enriched LREE and almost flat HREE Figures (7 to 9).

However, the investigations of basaltic rock samples by some workers (Ludden and Humphris, 1978) have shown that in certain situations, especially during rock alterations, the REE are mobile. Hellman *et al.*, (1979) identified the principal types of REE enrichment and discovered that to an extent, the most important problem is LREE or HREE group mobility or selective mobility, mainly of La, Ce and most likely Eu especially during rock alteration. The talcose rock from Kagara areas show extensive enrichment (La/Sm)<sub>n</sub> = 0.14 - 1.23, (La/Yb)<sub>n</sub> = 0.12 - 0.57 relative to chondrite (Arth *et al.*, 1977) formulated a unified petrogenetic model where the tholeiitic and the komatiitic series were thought to be genetically related simply because of their intimate spatial relationship. They believe that the tholeiitic melts, having (La/Sm)<sub>n</sub> and (Gd/Yb)<sub>n</sub> ratios > 1.0, might be the early melts extracted from a mantle source, characterized by a flat chondritic REE pattern. The extraction leads to LREE-depleted nature in the residue which in turn serves as the source for some LREE-depleted komatiites. This could be a plausible mechanism for LREE depletion, at least in talcose rock from Kagara area. The extent of LREE mobility can also be shown by the ratios of (La/Sm)<sub>n</sub>, (Ce/Sm)<sub>n</sub>, (Ce/Yb)<sub>n</sub> and (La/Yb)<sub>n</sub> (Table 6). The (Ce/Sm)<sub>n</sub> ratios vary widely, indicating that Ce is relatively mobile. The (La/Sm)<sub>n</sub> ratios are fairly constant, regardless of the different states of the talcose rock, whether altered or not. From a closer look, apart from Ce, metamorphism itself has not thoroughly altered the REE patterns of the rocks. Similarities in (La /Sm)<sub>n</sub> ratios and the fact that the bodies are within the same area, could suggest that various talcose rock bodies originate from the same magmatic chamber and that possibly the LREE character is inherited from the parent rocks.

The SiO<sub>2</sub> concentration below 41% of the bulk composition confirmed ultramafic but preclude mafic igneous protoliths whereas their very low Zr, Hf, Th, Ta and REE concentrations coupled with the low - high Al<sub>2</sub>O<sub>3</sub> content also preclude a felsic igneous protolith.

Logically, silica-rich fluid from surrounding granitoids has some amounts of Na, Rb, Ca, Sr, K, Ce and Ba. In an ultramafic medium, they may increase the concentrations of the aforementioned elements by contamination or metasomatism that result to crystallisation.

The talcose rocks from Kagara have high Ni, Cr, Co and low Rb, Sr, Y and Zr contents (Table 2). These low concentrations of Rb, Sr, Y and Zr well as the negative anomaly displayed by Th, Nb, K, Ta, Sr, and Zr, Hf on the spider diagram (Figures 5) likely reflect the nature of the protolith. The low concentration of Hf, Ta, Th and Zr in talcose rock from Kagara area are inconsistent with felsic igneous protoliths but high MgO concentrations with low Al<sub>2</sub>O<sub>3</sub> in the talcose rock would be consistent with the geochemistry of ultramafic rocks.

The MgO concentration in the talcose rock is consistent with the geochemistry of ultramafic rocks, while the extremely high Cr, Ni and Co content of these rocks confirmed mafic or ultramafic igneous protoliths. The concentration of SiO<sub>2</sub> in talcose rocks which is below 41% of the bulk composition confirms its ultramafic character but preclude mafic igneous protoliths as the source rock. Also, the very low Zr, Hf, Th, Ta and REE content (Tables) confirms that it is not formed from a felsic igneous protolith. Furthermore, the compositional spectrum suggests that the rocks consist of iron materials diluted by trace-elements and silica. The relatively low level of Hf (<0.02 ppm), coupled with high concentrations of Ni, Cr and Co in the rock simply means that the iron component is likely to have been derived from mafic rocks during differentiation from upper mantle.

The very high concentration of trace and rare-earth elements and the low- high concentration of Al<sub>2</sub>O<sub>3</sub> in talcose rock from the Kagara deposit suggest that the talcose rocks are product of metamorphism. The discriminant plots of Al<sub>2</sub>O<sub>3</sub> versus with (FeO / (FeO + MgO)), Al<sub>2</sub>O<sub>3</sub> versus MgO and FeO + TiO<sub>2</sub> further confirms the peridotitic - komatiitic petrogenetic affinity of the talcose rock in the study area.

Metamorphism in the study area has been effective with slow hydrothermal activity as the solution derived from associated rocks are not rich in some elements like Na, Rb, K, Ba, U, and Th.

In support of this is the regional deformation and faulting which produced fractures that served as conduit for easy ingress of solutions during the process of metamorphism in the study area. The deformational textures of the study area were preserved in the talcose rock as most of the tectonism must have taken place at the time of the mineralization. The high Ni (210-1541 ppm), Co (82 - 91ppm), and Cr (170-1930 ppm) values indicate that talcose rocks from Kagara area were derived from an ultramafic protoliths which have undergone moderate degree of metamorphism.

## 9. Conclusions

Mineralogically, the talcose rock contains in addition to talc, appreciable amounts of chlorite, magnesite, and anthophyllites with quartz and magnetite forming the accessory minerals.

In the study area, the effects of metamorphism on clinocllore at low pressure proceed to the right as crystallization of the tremolite was contemporaneous with reactions as successive event. During metamorphism some of all primary minerals in the study area were replaced or altered the presence of carbon (iv) oxide that produced magnesite. Mineral paragenesis obtained from metamorphosed mafic/ultramafic host rock including talc occurrences in the study area are: magnesite + clinocllore + ferroan+ magnetite + talc; carbonate + tremolite + talc; quartz + albite + biotite + clinocllore + muscovite + malc; serpentine + chlorite + talc; quartz+ albite+ muscovite + biotite + clinocllore; and quartz + chlorite + magnetite.

Geochemically, talcose rock has high SiO<sub>2</sub>, MgO, Fe<sub>2</sub>O<sub>3</sub>, L.O.I contents and low CaO, Na<sub>2</sub>O, K<sub>2</sub>O contents with variable proportions of Al<sub>2</sub>O<sub>3</sub>. Silica-rich solutions derived from granites became rich in some elements like Na, Rb, Sr, K, Ba, U, and Th). In an ultramafic medium, these increased the concentrations of the aforementioned elements by contamination or metasomatism that resulted to crystallisation. Talcose rocks have lower amounts of Ba, Sr, Th, U, Zr, and Y contents. These low concentrations as well as the negative anomalies displayed by Th, Nb-K-Ta, Sr, and Zr, Hf on the spider diagram likely reflect the character of the protolith. The Ni, Cr and Co concentrations can be assigned to high olivine and chromite contents of the original rocks. The high Ni (210- 1541 ppm), Co (82-91 ppm), and Cr (170-1711 ppm) content indicate that talcose rock was derived from a mafic or ultramafic rock in terms of parental affinity. Furthermore, the (La/Sm)<sub>N</sub> ratio > 1 (0.14 -1.23) also reveals a source related LREE enriched nature of these rocks while the (La/Yb)<sub>N</sub> ratio which ranges from 0.12 to 0.57 suggests a partial fractionated REE pattern. The talcose rock show negative Eu anomaly and therefore paucity of plagioclase. This is also supported by Eu/Eu\* values which is remarkably low < 1(0.10- 0.36) for the talcose rock. This paper has shown that the amphibolite in the study area has undergone alteration as a result of metamorphic process. This reaction has led to formation of talcose rock which were hitherto regarded as distinct and separate rock units.

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