Petrochemistry and genetic indicators of talcose rock of Esie area, southwestern Nigeria

Petrokemija in pokazatelji geneze lojevčevih kamnin (skrilavcev) območja Esie, jugozahodna Nigerija

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Abstract: Field, petrographic and geochemical data have been employed in appraising the compositional and the petrogenetic nature of the talc schist of Esie and environs, southwestern Nigeria. The rock unit occurs as low-lying lensoidal outcrops and in some places as massive or weakly foliated exposures. The main mineral assemblage of the rock is talc + anthophyllite and talc + chlorite + anthophyllite. Accessory minerals are ilmenite, hematite and spinel.

The variation plots of major oxides MgO, Al_2O_3, TiO_2 and SiO_2 on one hand and trace elements Ni, and Sc on the other, confirm komatiitic nature of the rock. Also, Petrogenetic inferences based on the rare earth elements (REE) and transition trace elements abundances, notably Ni and Cr, reveal almost flat heavy REE and enriched light REE (LREE) [$(La : Sm)_n$ = 1.53–5.06 and $(Ce : Yb)_n$ = 3.62–124.91] patterns. Ni (637–1870 μg/g) and Cr contents (1330–3440 μg/g) are consistent with the ultramafic parentage and komatiitic character of the rock.

A partial melting of upper mantle with variable post magmatic alteration/modification evolutionary model is proposed for the rock unit.

Original scientific paper

Povzetek: Za oceno sestave in petrogenetskih lastnosti lojevčevih skrilavcev širšega območja Esie v jugovzhodni Nigeriji smo uporabili podatke terenskih, petrografskih in geokemičnih raziskav. Litološka enota se pojavlja kot lečasti in ponekod masivni ali šibko foliirani izdanki. Glavna mineralna parageneza kamnine so lojevec + antofilit in lojevec + klorit + antofilit. Akcesorni minerali so ilmenit, hematit in spinel. Variacijski diagrami glavnih oksidov MgO, Al_2O_3, TiO_2 in SiO_2 na eni strani in slednih prvin Ni in Sc na drugi potrjujejo komatiitno naravo kamnine. Z geokemičnimi raziskavami elementov redkih zemelj (REE) smo dobili skoraj raven vzorec težkih REE in obogatene lahke REE (LREE) [$(La : Sm)_n$ = 1.53–5.06 in $(Ce : Yb)_n$ = 3.62–124.91]. Vsebnosti prehodnih slednih prvin, predvsem Ni in Cr [Ni (637–1870 μg/g) in Cr (1330–3440 μg/g)], se ujemajo z ultramafičnim poreklom in komatiitnim značajem kamnine.

Na tej osnovi je predlagan model nastanka litološke enote z delnim taljenjem zgornjega plašča, ki je bila postmagmatsko izpostavljena različni stopnji sprememb.

Key words: komatiite, petrogenesis, talcose rocks, trace elements, REE, Esie, Nigeria

Ključne besede: komatiit, petrogeneza, lojevčeve kamnine (skrilavci), sledne prvine, REE, Esie, Nigerija

INTRODUCTION

The Nigerian basement complex (Figure 1) consists of Precambrian gneisses and migmatitic rocks into which belts of N-S trending low to medium grade supracrustal rocks are infolded (AJIBADE et al., 1987). This supracrustal rocks, otherwise called the schists, consist of low to medium-grade metasediments of pelitic to semi-pelitic compositions, belonging to carbonates, psammitic rocks as well as mafic and ultramafic (talcose) rocks.These occur as lenticular to ovoid shaped bodies intercalated within the metasediments. Both basement and supracrustal cover sequence have suffered polyphase deformation and metamorphism and are Intruded in some places by Pan-African granitoids.

The schist belts include those of Ilesha, Kusheriki, Maru, Wonaka and Anka. (OLADE & ELUEZE, 1979; AJAYI, 1981; Kayode, 1981; Elueze, 1982; Klemm et al, 1984; Ige & Asubiojo, 1991;Truswell & Cope, 1963; Elueze, 1982; Ogezi, 1977) (Figure 1). Previous researchers attributed pre-metamorphic parent rocks to peridotite (Elueze, 1982), to magmatic origin (Ige & Asubiojo, 1991) or to tectonically emplaced slices of upper mantle material (Ogezi, 1977). The rocks in these areas are hardly preserved in their original state. Many bodies have suffered varying degrees of alteration and are extensively steatitized. Meta-utramafites are minor components of the Nigerian schist belts.

The Esie schistose rocks have been considered by some workers in the past to lie within the Egbe-Isanlu schist belt exposed in southwestern Nigeria (Annor, 1981, Ige & Onabajo, 2005). However, the Esie talcose rock actually is a northern extension of Ife-Ilesha schist belt. It lies within latitudes of $4^0 45'–5^0 00'$ North and longitudes $8^0 00'–8^0 15'$ East (Figure 1). The previous studies on the Ife Ilesha schistose rocks have generally focused on tectonic modeling (Rahaman, 1976; Olade & Elueze, 1979; Ajayi, 1981) and stratigraphic correlation (Klemm et al, 1983) with interpretations being based on major and trace element data. The Esie talcose rock have been studied mainly for their economic potential (Olorunfemi, 2007; Olorunfemi et al., 2009) and archaeological features (Olabanji et al., 1989; Ige & Onabajo, 2005).

The present study therefore, focuses on elucidating the origin and petrochemical characteristics of the talcose rock of Esie area in the northern part of Ife-Ilesha schist belt, and is expected to contribute to the knowledge of the geodynamic evolution of the schist belt in Nigeria.

Materials and Methods

For this purpose a systematic geological mapping was undertaken on a scale of 1 : 25,000. Optical (thin section) and X Ray Diffraction studies were carried out in order to understand the mineralogical composition. For the XRD determinations, powders of representative samples of six of the talc bodies were examined using a Philips–PW1011 model diffractometer. The diffractograms were recorded using a scanning rate 2^o $min^{-1}cm^{-1}$ with a Ni-filtered Fe K-alpha radiation.

Twelve pulverized samples of the rock unit were also chemically analyzed for major, trace and rare earth element composition by inductively coupled plasma–mass spectrometry (ICP-MS) instrumentation method at the Activation Laboratory Ontario, Canada. The detailed analytical procedure is described in Olorunfemi (2007).

Geological Setting and Petrography

The study area belongs to the Nigerian Basement Complex, which forms part of the mobile belt (Figure 1) that lies between the Archean to Early Proterozoic West African and Congo Cratons (KENNEDY, 1964). The dominant N-S trending structures and extensive areas of igneous rejuvenation of this basement are attributed to the Pan African Orogenic events (MCCURRY 1976, VAN BREEMAN et.al 1977).

In Esie, this unit occurs as low-lying boulders, massive or weakly foliated outcrops and also as lensoid bodies within country rocks (Figure 2). The low lying nature of the outcrops imposes a kind of flat to gently undulating terrain in some areas. Most outcrops of the talc deposits body are located around the southwestern end of the area. The boulder like and the massive varieties are whitish to grey in colour. However, some masses are brownish in colour probably due to iron

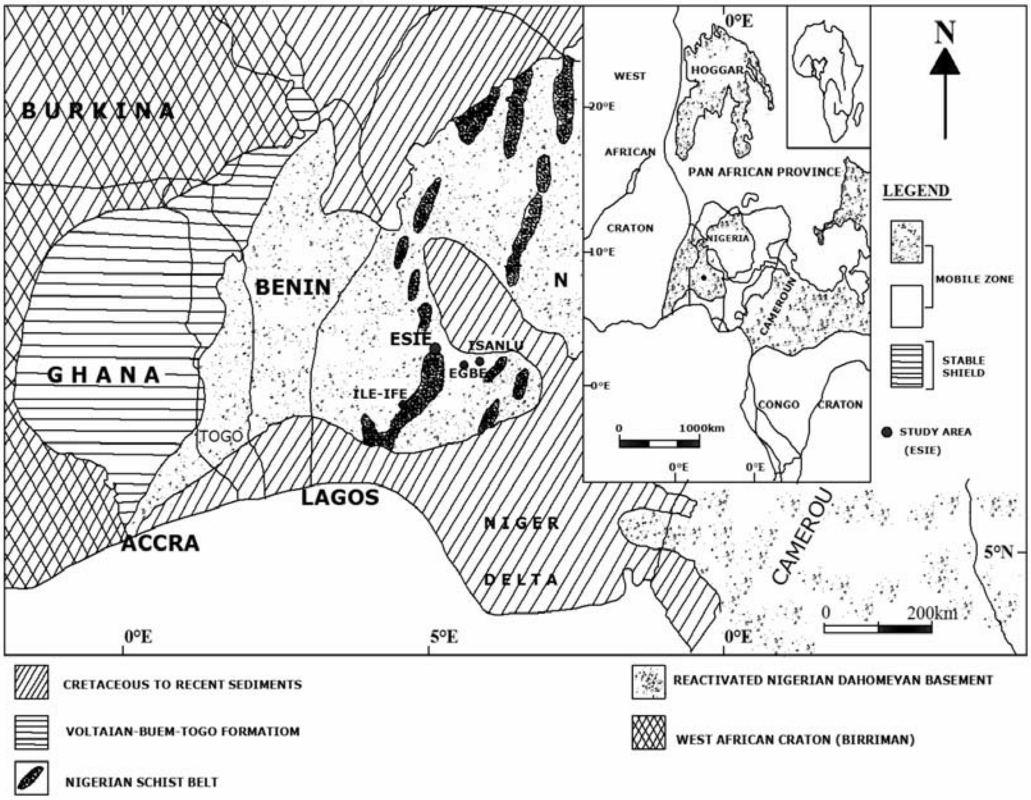

Figure 1. Map of Nigeria showing the location of Esie in the northern part of Ife-Ilesa schist belt. Inset: Map showing the location of the Nigerian basement within the Pan-African

percolation and pigmentation. Most of the samples are medium to fine-grained in texture with a characteristic soapy touch. The total extent along a NNE-SSW strike is about 10 km although the outcrops are not continuous.

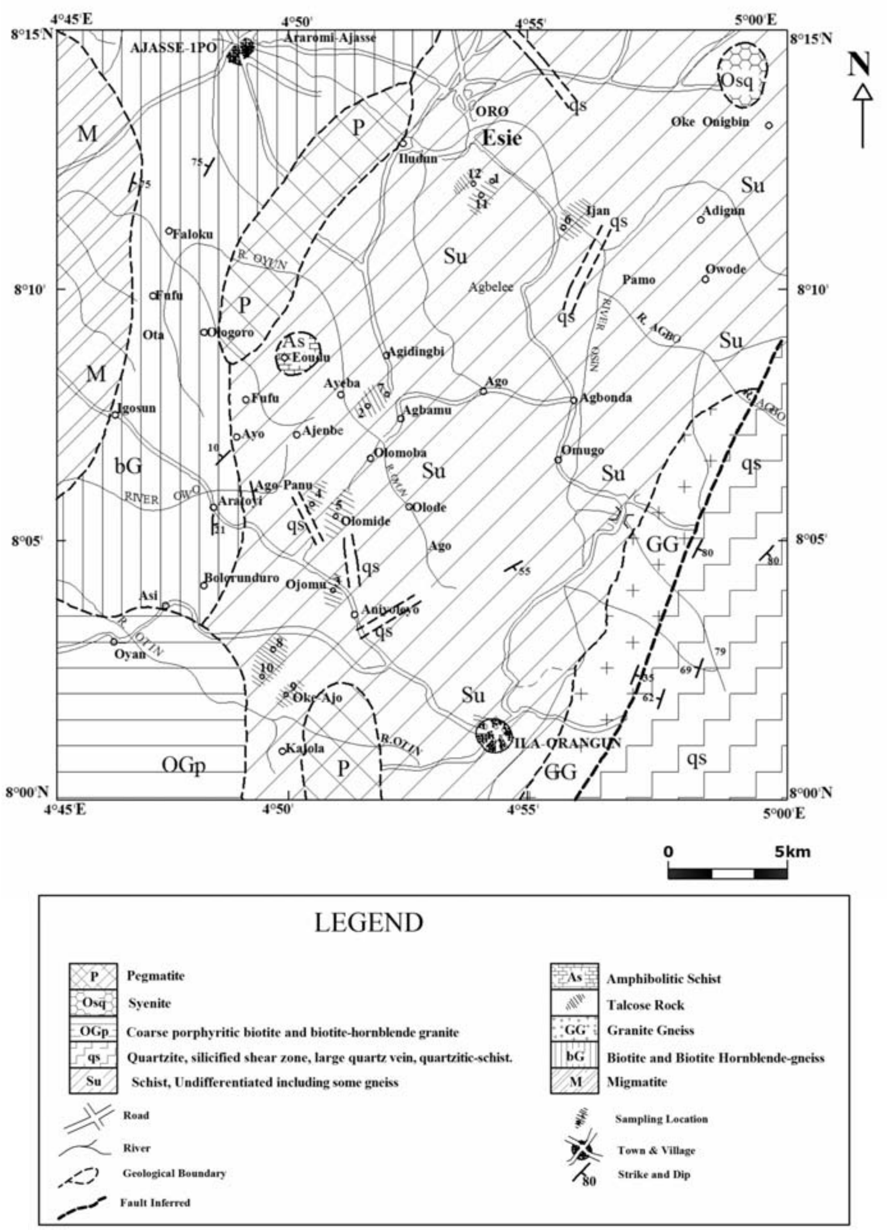

Figure 2. (Modified geological map from Geological Survey of Nigeria, 2004 and Olorunfemi, 2007)

The Esie talcose rock consists of talc as the most common mineral. This occurs together with varying amounts of chlorite, anthophyllite, and or tremolite. Primary silicate minerals are not preserved in this assemblage. The results of the X-ray diffraction analysis of powdered samples of the rock show conspicuous peaks of talc, anthophyllite and chlorite. Other minor peaks include mainly those of spinel, (Figures 3 and 4). Two petrographic varieties of this rock unit were distinguished being different in colour: talc-anthophyllite-schist and talc-chlorite-anthophyllite-schist.

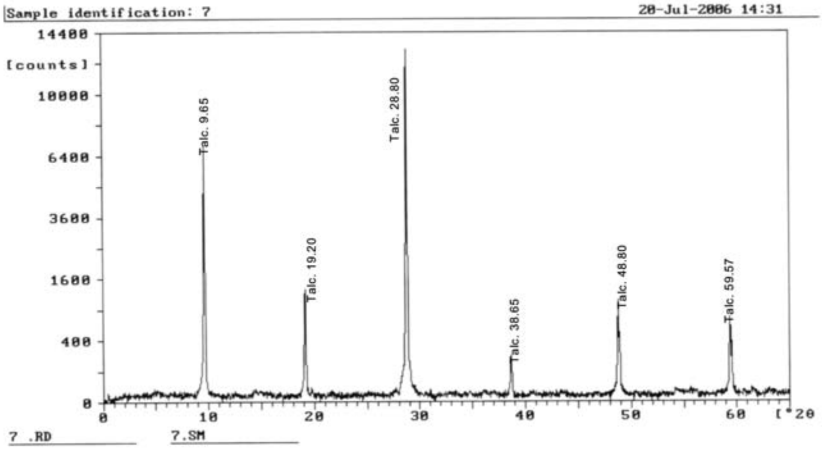

Figure 3. X-ray diffraction chart of talcose rock sample

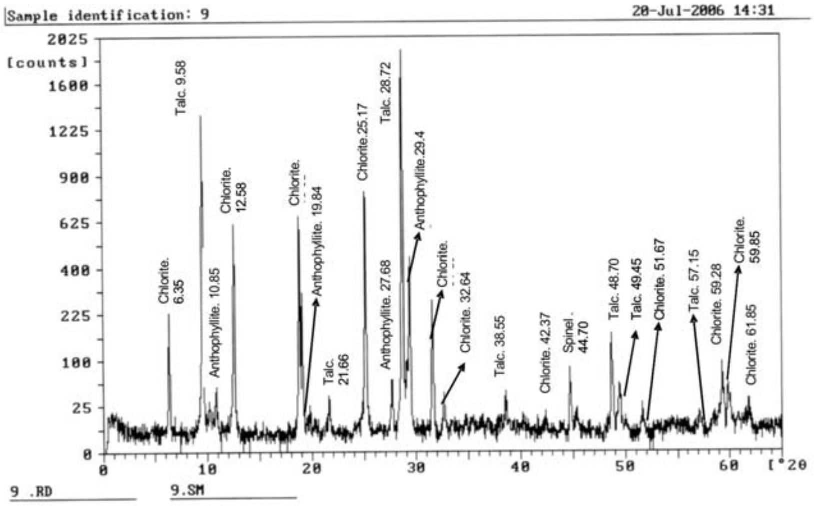

Figure 4. X-ray diffraction chart of the talcose rock sample with chlorite and anthophyllite

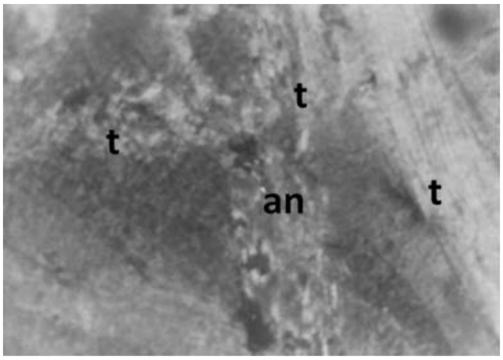

Figure 5a. Photomicrograph of Esie talcose rocks showing alteration of anthophyllite (an) within talc (t) matrix (x100). XPL= crossed polarized light

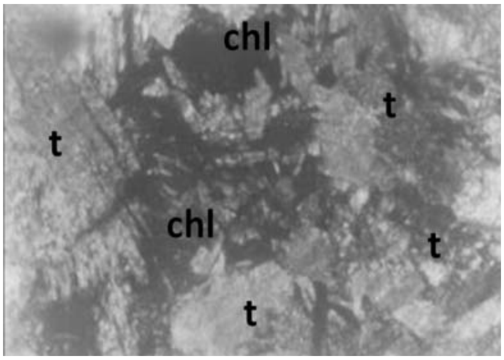

Figure 5b. Photomicrograph of Esie talcose rocks showing chlorite (chl) filling the interstices of the platy talc (t) (×100). XPL= crossed polarized light.

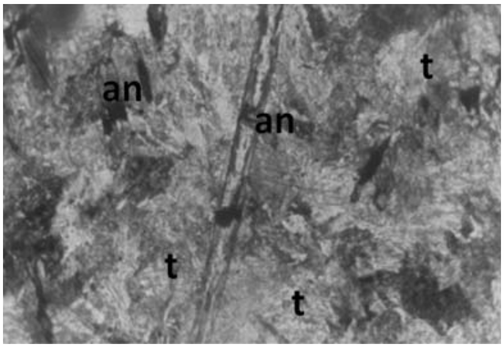

Figure 5c. Photomicrograph of Esie talcose rocks showing decussate arrangement of short and a long prismatic anthophyllite (an) within talc (t) matrix (×100). XPL= crossed polarized ligh

Talc-anthophyllite-schist consists of a large foliated mass of fine platy to fibrous aggregate of talc and traces of altered anthophyllite (Figure 5a). The rock varies in colour from buff white to light greyish green. Talc-chlorite-anthophyllite-schist consists of fine platy or fibrous aggregates of talc as well. Besides, radiating crystals of chlorites cluster in the talc matrix (Figure 5b), while anthophyllite forms long and short prismatic crystals. Some of them exhibit decussate arrangement and show spinifex texture (Figure 5c). The rock colour varies from buff-white to green depending on the relative proportion of the constituent minerals. When anthophyllite is dominant, the rock has a buff-white colour and a greenish one when chlorite prevails. Talc has been assessed to be between 70 % and 80 % (Figures, 3, 4, and 5). The proportion of anthophyllite and chlorite vary considerably while tremolite and opaque occurs in trace amounts.

For figs 5a-c, lower edge of the photo is 2mm

Talc in thin sections occurs as foliated mass, coarse to fine platy or fibrous aggregates with parallel arrangement (Figure 5a). Anthophyllite is found as long or short prismatic crystals and exhibits a parallel extinction. It forms a radiating texture with decussate like arrangement radiating within the matrix of talc (Figure 5). Alteration of anthophyllite to talc is visible in some samples (Figure 5a). Chlorite is seen as net-like crystals within talc matrix (Figure 5b). It is greenish in colour and is strongly pleochroic in shades of green and brown.

Geochemical results and discussion

Tables 1a, 1b and 1c show the results of major, trace and rare earth element compositions of the Esie talcose rocks. All the samples from Esie show high MgO with mass fractions *w*/% (26.09–31.35 %) and low Al_2O_3 (0.50–5.54 %), K_2O (0.01–0.12 %), P_2O_5 (0.01–0.03 %), MnO (0.03–0.178 %) and TiO_2 (0.008–0.126 %) (Table 1a). The SiO_2 content of all the samples is generally in excess of 50 %. Values of SiO_2 greater than 45 % are generally regarded as upper limit for ultramafic igneous rocks. Considering the above, and in comparison with rocks of similar compositional characteristics, the overall major element chemical composition of the rocks is distinctly similar to rocks of komatiitic series and peridotitic affinity (Brooks & Hart, 1974; Arndt et al., 1977; Elueze, 1982). However, the seemingly high SiO_2 content may suggest possible syntectonic metamorphic silicification of the rock.

The concentrations of the transitional trace elements Ni (637–1870 μg/g) and Cr (1330–3440 μg/g) in the rock samples are also similar to those of peridotites (Divakara Rao et al., 1975). This feature indicates a parental magma derived from a mantle peridotite source (Rollinson, 1993). High Ni, Cr and MgO content in the samples coupled with a seemingly positive relationship (Table 1a, b). Suggests original magmatic partitioning and points to the existence of a high Ni-phase, presumably olivine in the parent rocks (Hawkesworth & O'nion 1977). Co and Ni are often thought to have similar geochemical behavior, although the distribution coefficient of Co in olivine/liquid is in general lower than of Ni (Duke, 1976; Leeman, 1974). By the same argument, the high Cr-phase may be spinel or Cr-rich orthopyroxene. Arndt (1976) has shown that the liquidus phases in a melt with MgO > 20 % are olivine and chromite; if MgO is between 2.0 % to 12 %, olivine + pyroxene; and with MgO < 12 %, pyroxene + plagioclase.

The talcose rock samples have variable contents of V, Cu and Zn. The low V and Cu contents compared to all other elements possibly reflects the primitive nature of these rocks. The Cu and Zn contents are highly variable in the samples with the sample being generally poorer in Cu but elevated values of Zn (Table 1b). This behavior may be as a result of the high mobility of Zn during weathering processes. The Rb and Hf contents of

Table 1a. Major elements data (*w*/%) of Esie talcose rocks and data from typical examples of ultramafic rocks of komatiitic affinity (*w*/%)

Oxides	1	2	3	4	5	6	7	8	9	10	11	12	Mean 13	S834	Gt
SiO_2	55.41	58.18	57.99	52.87	58.30	57.97	58.19	57.10	50.48	55.32	55.38	57.38	56.21	43.61	50.16
Al_2O_3	2.45	0.64	0.55	2.76	0.95	0.85	0.53	1.12	5.54	1.77	2.11	0.5	1.66	7.71	4.46
Fe_2O_3T	6.93	5.74	6.73	7.51	5.23	6.49	5.61	7.6	7.09	7.31	10.63	6.03	6.90	10.45	2.54
MnO	0.072	0.069	0.121	0.178	0.088	0.106	0.072	0.139	0.096	0.134	0.206	0.03	0.10	0.16	0.22
MgO	28.68	30.56	29.81	31.35	30.44	29.76	30.08	29.18	29.91	30.26	26.09	30.47	29.71	25.32	23.86
CaO	0.04	0.01	0.12	0.31	0.04	0.01	0.01	0.03	0.17	0.21	0.37	0.01	0.16	6.86	4.79
Na_2O	0.17	0.16	0.16	0.16	0.25	0.18	0.15	0.15	0.12	0.18	0.20	0.09	0.16	0.20	0.3
K_2O	0.03	0.01	0.01	0.04	0.01	0.01	0.01	0.01	0.05	0.07	0.12	0.01	0.03	0.10	0.01
TiO_2	0.053	0.017	0.008	0.073	0.034	0.028	0.008	0.038	0.126	0.044	0.061	0.056	0.05	0.33	0.45
P_2O_5	0.02	0.01	0.03	0.03	0.01	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.06	0.1
LOI	5.16	4.6	3.9	4.23	4.49	4.24	4.68	4.67	6.07	4.22	4.57	4.76	4.63	6.15	2.03
Total	99.01	99.96	99.59	99.73	99.79	99.75	99.36	99.78	99.65	99.53	99.75	99.91	99.65	100.41	99.97
CaO/Al_2O_3	0.02	0.02	0.21	0.11	0.04	0.01	0.01	0.03	0.03	0.19	0.18	0.02	0.10		
**FeO	6.23	5.16	6.05	6.75	4.70	5.84	5.04	6.83	6.38	6.57	9.56	5.42			

- = not detected

1–12 = Samples from Esie (talc-anthophyllite-chlorite) (This Study)

13 = Mean values of samples 1–12

S834 = Komatiite from Suomussalmi, Finland (Jahn et.al., 1980)

Gt = Ife meta-ultramafite: anthophyllite- talc/tremolite-chlorite (trace) - magnetite-(trace). Ige & Asubiojo, 1991.

** FeO = Fe_2O_3/1.112

Table 1b. Trace elements data (μg/g) of Esie talcose rock and data from typical examples of ultramafic rocks of komatiitic affinity (μg/g)

Elements	1	2	3	4	5	6	7	8	9	10	11	12	Mean	S834	Gt
Sc	6	4	3	7	3	2	3	2	4	4	26	2	5.5	-	10
V	5	9	<5	16	<5	<5	<5	<5	18	16	32	27	10.7	150	-
Cr	2690	1450	3440	1520	1330	1880	1520	2130	1780	1490	2760	1640	1969	3004	1978
Co	67	57	70	70	76	79	75	78	81	72	76	42	70.25	100	57
Ni	1100	1380	1290	1460	1590	1870	1620	1620	1480	1510	637	888	1370.4	1171	4465
Zn	161	123	182	95	125	140	11	140	71	86	145	66	120.4	-	159
Cu	14	29	3	3	5	6	8	3	4	4	4	4.2	10.4	-	-
As	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-	-
Rb	6	<2	2	2	<2	<2	<2	<2	<2	<2	<3	<2	<2	1	1.4
Sr	2	<2	5	2	2	<2	<2	<2	2	,2	.3	<2	<2	29	-
Zr	<4	<4	<4	7	<4	<4	<4	<4	4	<4	8	<4	<4	7	-
Ba	14	<3	170	49	42	17	63	110	10	50	32	3	46.7	-	92

- = not detected

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S834 = Komatiite from Suomussalmi, Finland (Jahn et.al., 1980)

Gt = Ife meta-ultramafite: anthophyllite- talc/tremolite-chlorite (trace)-magnetite-(trace). Ige & Asubiojo, 1991.

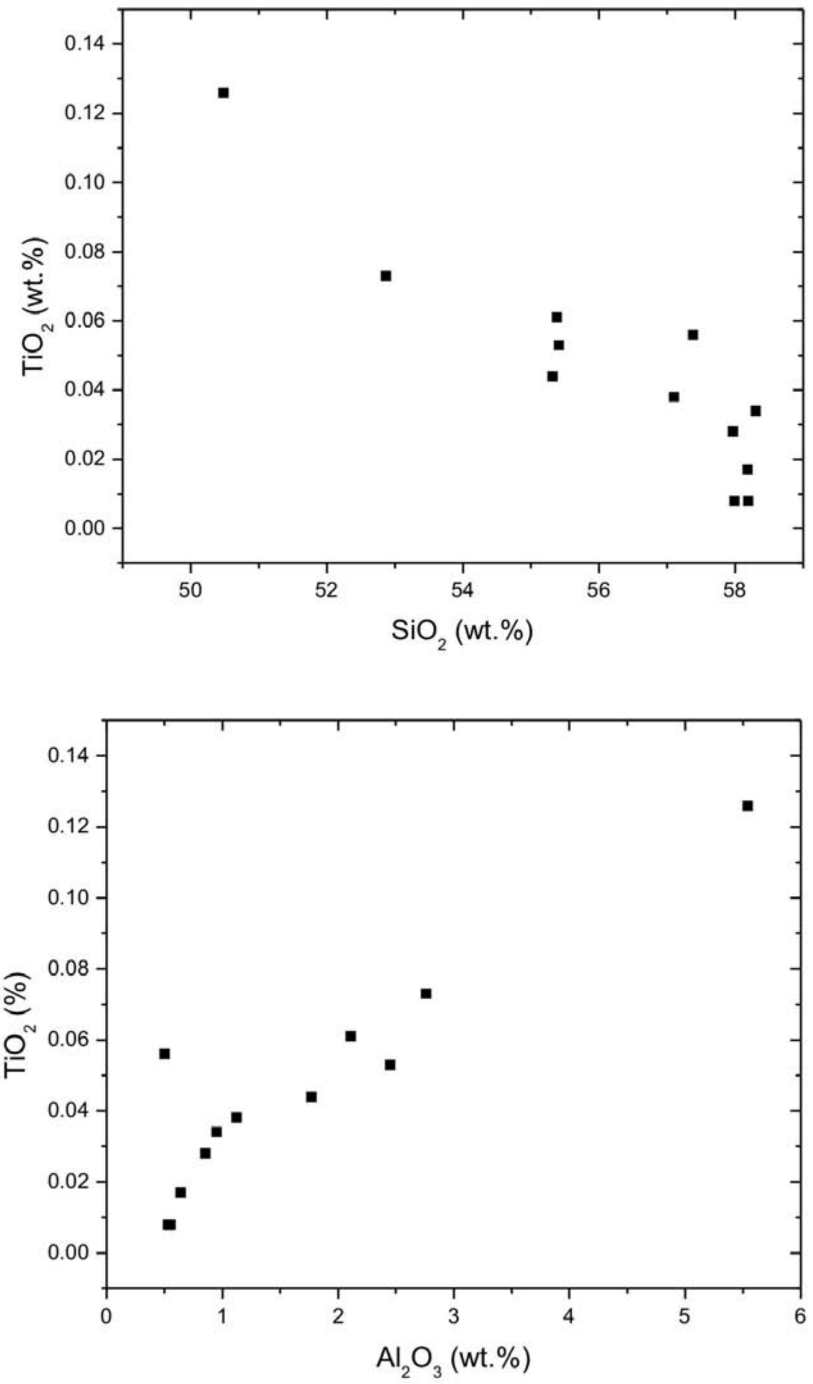
Table 1c. Rare earth elements data (μg/g) of Esie talcose rocks and data from typical examples of ultramafic rocks of komatiitic affinity (μg/g)

Elements	1	2	3	4	5	6	7	8	9	10	11	12	Mean	S834	Gt
La	1.4	0.5	6.5	3.6	1.7	1.6	1.6	1.8	1.4	1.0	2.0	2.5	2.13	0.634	3.0
Ce	4.7	0.7	9.4	17	39.8	48.6	70.3	46.9	30.3	2.8	17.7	3.6	24.31	2.292	7.9
Pr	0.37	0.16	1.48	1.04	0.66	0.48	0.6	0.53	0.34	0.26	0.69	0.86	0.62		
Nd	1.4	0.6	5.2	3.6	2.7	1.7	2.2	1.8	1.1	1.0	2.6	3.1	2.25	2.11	1.8
Sm	0.3	0.2	0.8	0.7	0.7	0.3	0.5	0.5	0.2	0.2	0.7	0.6	0.48	0.742	0.7
Eu	0.06	<0.05	0.17	0.14	0.18	0.08	0.12	0.07	0.05	0.06	0.15	0.13	0.10	0.266	0.5
Gd	0.2	0.1	0.6	0.7	<0.7	<0.1	<0.1	<0.1	<0.1	0.3	0.5	0.7	0.32	1.026	
Tb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		0.3
Dy	0.2	0.2	0.4	0.9	0.6	0.2	0.3	0.3	0.2	0.2	0.5	0.3	0.36	1.271	
Ho	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		0.2
Er	0.1	<0.1	0.2	0.7	0.3	0.1	0.2	0.2	0.1	0.2	0.3	0.2	0.23	0.823	
Tm	<0.05	<0.05	<0.05	0.11	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		
Yb	0.01	<0.1	0.2	0.7	0.3	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.23	0.862	0.7
Lu	<0.04	<0.04	<0.04	0.12	0.05	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.135	0.3
Total	9.03	3.00	25.25	29.51	47.94	53.25	76.41	52.69	34.28	6.51	25.73	12.48	31.23		

1–12 = Samples from Esie (talc-anthophyllite-chlorite) (This Study)
13 = Mean values of samples 1–12
S834 = Komatiite from Suomussalmi, Finland (Jahn et.al., 1980)
Gt = Ife- meta-ultramafite: anthophyllite-talc/tremolite-chlorite (trace)-magnetite-(trace). IGE & ASUBIOJO, 1991.

the talcose rocks are generally within the range of values for the ultramafic rocks of komatiitic affinity. The large ionic radii of these elements results in their exclusion from almost all mineral phases crystallizing during metamorphism. The Esie rocks are however depleted in Zr and Sr content relative to the ultramafic rock of komatiitic affinity.This may be due to the absence of a mineralogical phase to carry this element in the rock as a result of polymetamorphic reconstitution and alteration.

This petrogenetic affinity is also demonstrated in the plots of TiO_2 against Al_2O_3 and TiO_2 versus SiO_2. The talcose rock samples plot below 1.0 % TiO_2 value in both cases (Figure 6a & 6b), which is similar to the samples of Munro Township, Canada (ARNDT et.al, 1977). The plots of Al_2O_3 vs. FeO/(FeO + MgO) and Al_2O_3, MgO and FeO+TiO_2 further confirms the komatiitic petrogenetic affinity of this rock unit (Figure 7a & 7b). On the tholeiitic-komatiite classification scheme of NALDRETT & CABRI (1976) and the classification of volcanic rocks after JENSON (1976), the Esie rock samples plot predominantly in the fields of komatiite and peridotitic komatiite respectively.



Figures 6a, b. Variation of TiO_2 with SiO_2 and Al_2O_3 (*w*/%)

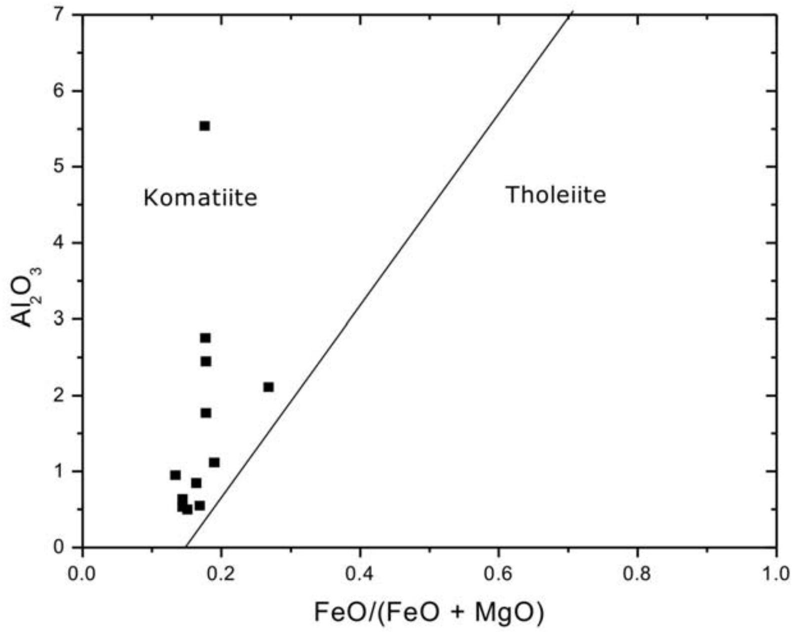


Figure 7a. Variation of Al_2O_3 with w(FeO/(FeO + MgO))/% ratio in Esie talcose rocks (NALDRETT & CABRI, 1976). Samples plot in the komatiite field.

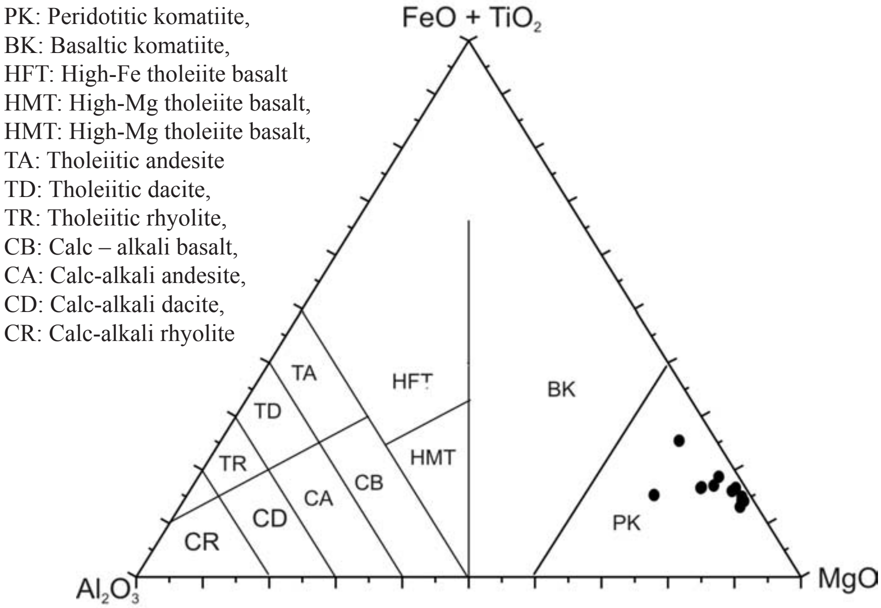


Figure 7b. Classification of volcanic rocks after JENSON (1976). On the diagram, Esie talcose rocks plot in the field of peridotitic komatiite.

Due to their coherent geochemical behaviour, REE are considered as resistant to post magmatic alterations and metamorphism. Therefore, they have been used in this study to present petrogenetic and petrotectonic interpretations. Although, ambiguity may sometimes emerge when a detailed comparison is made between different rock units, yet, they are still fairly good indicators (Jahn & Sun, 1979). Rare earth elements features as shown in the chondrite-normalized REE patterns for these rocks (Figure 8a and 8b) reveal that almost all the samples are high in total REE abundance. The values range from about 3.00 to 76.41 μg/g with an average value of 31.23 μg/g (Tables 1c, and 2).This indicates that this rock unit is distinctly different from those of ophhiolite from an orogen, but rather close to those of the ultramafic melanocratic rock series.(Wang Yuwang et. al., 2004) The talcose rock is enriched in LREE with $(Ce/Sm)_n$ ranging from 0.83 to 39.07 and moderate fractionation of source magma as shown by $(La/Yb)_n$ ratios (3.37–21.96).

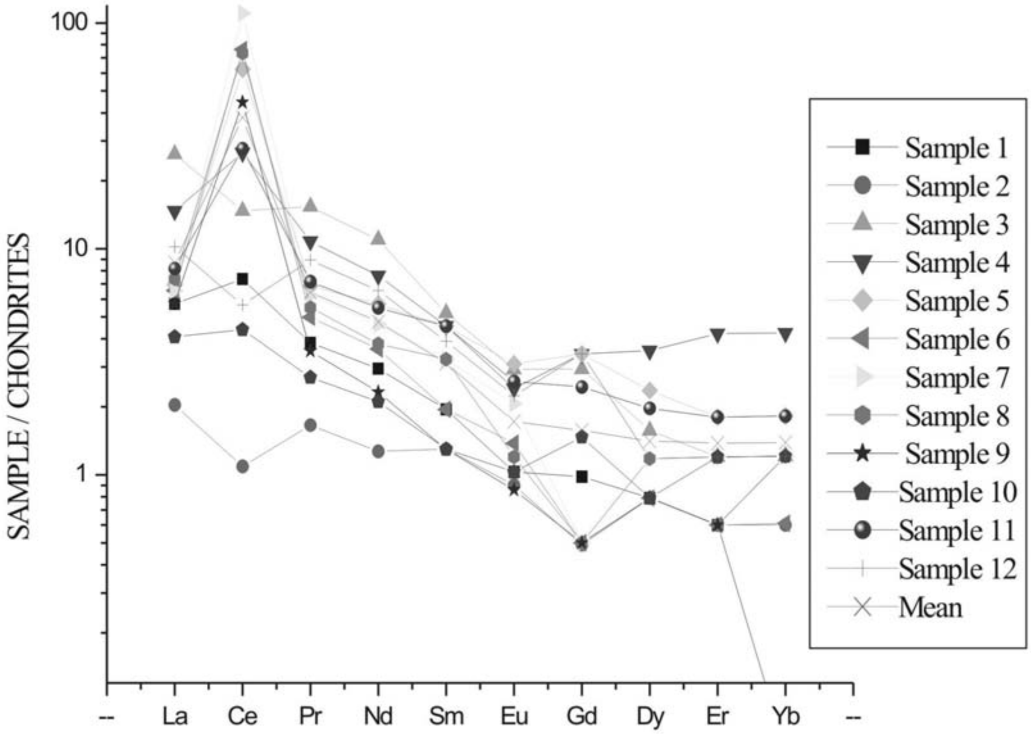
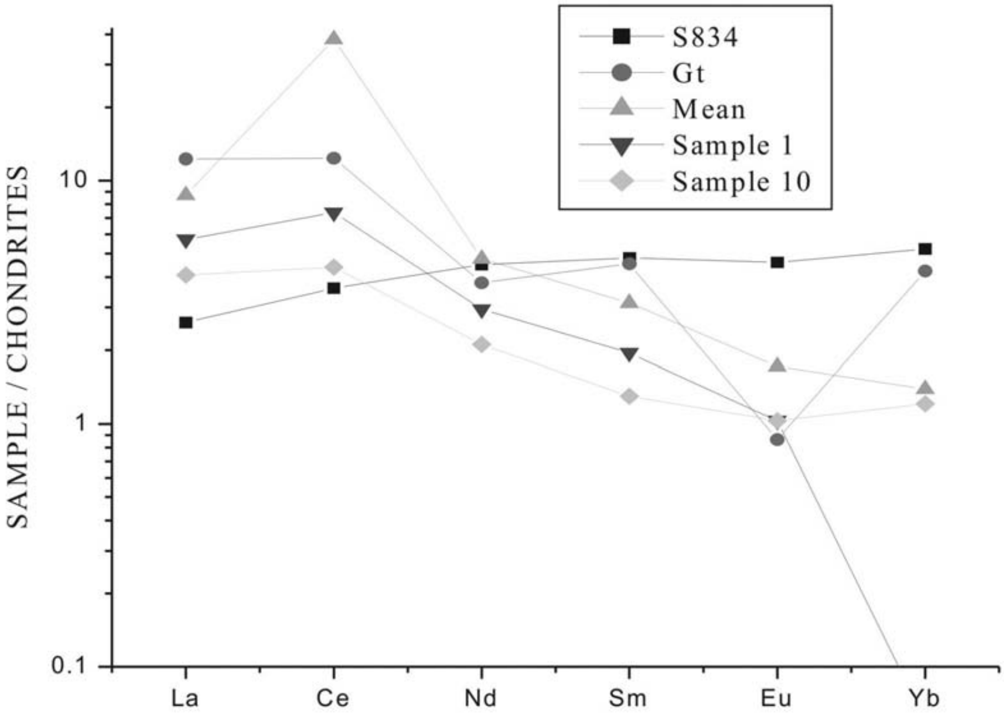


Figure 8a. Chondrite-normalised REE patterns for Esie talcose rocks



S834= Komatiite from Suomussalmi, Finland (Jahn et.al., 1980).
Gt = Ife meta-ultramafite: anthophyllite- talc/tremolite-chlorite (trace) - magnetite-(trace) (IGE & ASUBIOJO, 1991).

Figure 8b. Chondrite-normalised REE patterns of the Esie talcose rocks in comparison with data from typical ultramafic rocks of komatiitic affinity.

Most of the REE patterns have no significant detectable Eu anomalies but show significantly positive Ce anomalies. In contrast, a few samples show detectable Ce depletion. This may be due to the change in oxidation state of the Ce ion from trivalent to tetravalent as a consequence of metamorphic redistribution. (IGE & ASUBIOJO 1991) Positive anomalous Ce abundances have been known to occur in komatiitic rocks that have undergone weathering and burial metamorphism (FRYER, 1977).

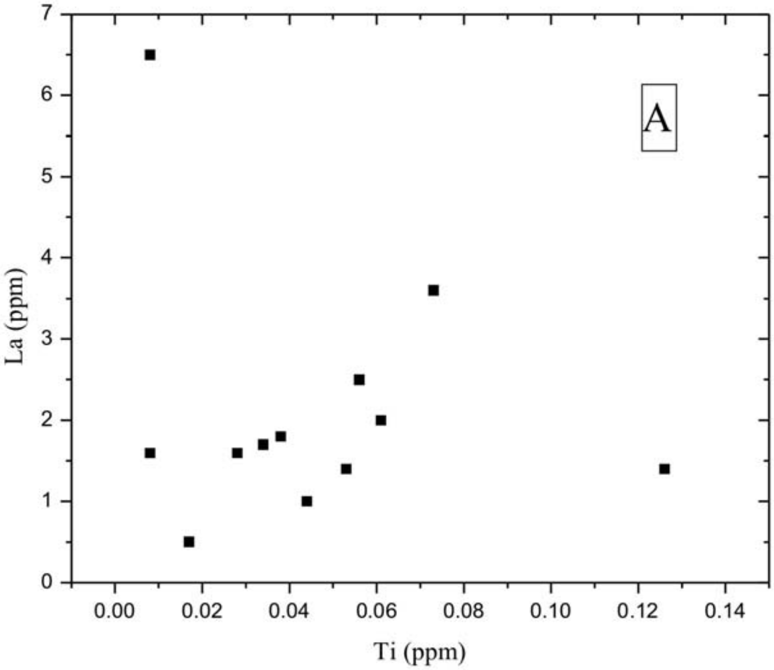
Samples of the talcose rock with significant quantity of anthophyllite blasts/grains show least modification, while the most evolved samples are enriched in talc (OLORUNFEMI, 2007). Their patterns show enriched LREE and almost flat HREE (Figure 8a & 8b). Judging from the complex REE patterns in Ar-

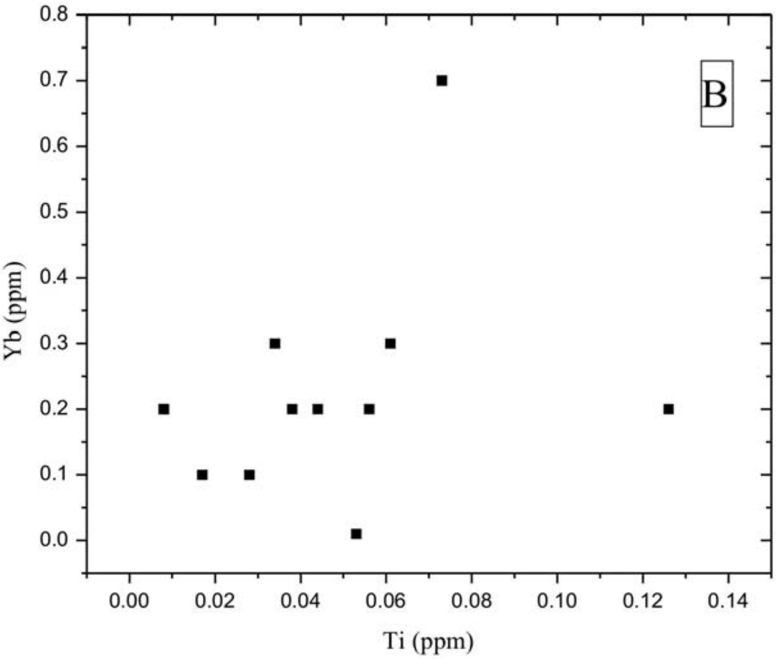
Table 2. The REE chondrite-normalised value of the Esie talcose rocks
** Chondrite values obtained from Evensen et. al (1978)

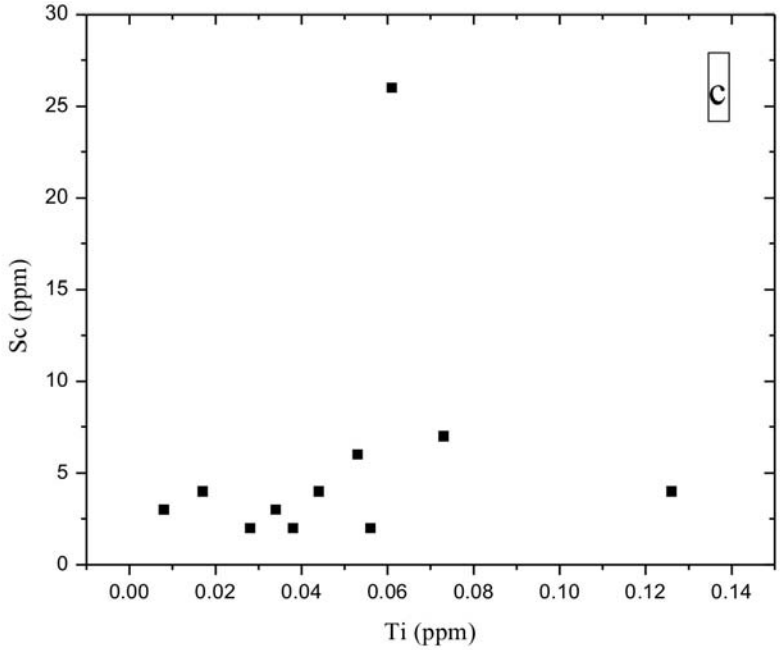
	1	2	3	4	5	6	7	8	9	10	11	12	Mean	S834	Gt	**
La	5.72	2.04	26.27	14.71	6.95	6.54	6.54	7.36	5.72	4.08	8.18	10.22	8.7	2.5919	12.26	0.2446
Ce	7.37	1.09	14.74	26.64	62.39	76.19	110.2	73.52	44.5	4.39	27.75	5.64	38.11	3.593	12.36	0.6379
Pr	3.84	1.66	15.36	10.79	6.85	4.98	6.23	5.5	3.53	2.7	7.16	8.92	6.43	--	--	0.09637
Nd	2.95	1.27	10.98	7.6	5.7	3.6	4.64	3.8	2.32	2.11	5.49	6.54	4.75	4.453	3.79	0.4738
Sm	1.95	1.3	5.19	4.55	4.55	1.95	3.25	3.25	1.3	1.3	4.55	3.9	3.12	4.818	4.54	0.154
Eu	1.03	0.9	2.93	2.41	3.1	1.38	2.06	1.2	0.86	1.03	2.59	2.24	1.72	4.584	0.8617	0.05802
Gd	0.98	0.49	2.94	3.43	3.43	0.5	0.5	0.5	0.5	1.47	2.45	3.43	1.57	--	--	0.2043
Dy	0.79	0.79	1.57	3.54	2.36	0.79	1.18	1.18	0.79	0.79	1.97	1.18	1.41	--	--	0.2541
Er	0.6	0.6	1.2	4.22	1.8	0.6	1.2	1.2	0.6	1.2	1.8	1.2	1.38	--	--	0.166
Yb	0.06	0.6	1.21	4.24	1.82	0.61	1.21	1.21	1.21	1.21	1.82	1.21	1.39	5.221	4.239	0.1651
Total	**25.29**	**10.74**	**82.39**	**82.13**	**98.95**	**97.14**	**137.01**	**98.72**	**61.33**	**20.28**	**63.76**	**44.48**				
La/Yb_n	95.3	3.4	21.96	3.46	3.82	10.72	5.4	6.08	4.72	3.37	4.49	8.45	6.26			
Ce/Sm_n	3.78	0.83	2.84	5.85	13.71	39.07	33.9	22.62	34.23	3.38	6.09	1.45	12.21			
Ce/Yb_n	122.83	1.817	12.18	6.28	34.28	124.91	91.07	6.56	36.78	3.62	8.38	4.66	27.42			
La/Sm_n	2.93	1.57	5.06	3.23	1.53	3.35	2.01	2.26	4.4	3.1	1.8	2.62	2.79			

chean komatiitic rocks, SUN & NESBITT (1978) proposed that the sources of spinifex textured komatiite must have originated from a depth greater than 400 km in the mantle. Early melts of low degree of partial melting may have concentrated more LREE and LIL. When these melts are separated, the residual mantle source would probably be depleted in LREE. There is no discernible trend in the variation of LREE and HFSE elements such as Ti and Sc, in the Esie talcose rocks. For example, when Ti is plotted against La, Sc and Yb (Figure 9a, 9b & 9c) there is no consistency in all the variations. Thus, if La, Ti, Yb, and Sc abundances are controlled by partial melting or simple fractional crystallization process, a consistent co-variation or conformity should be observed in the three elements. However, if the LREE results from a complex melting process no consistent variation would be observed. The REE have been known to be immobile elements and are expected to reflect the primary petrogenetic characteristics of fresh and unaltered igneous rocks. Some certain trace elements like Ti, Y, Nb, Zr (MENZIES, 1976) are in general considered to be immobile during rock alteration. However, the investigations of basaltic rock samples by some workers (WOOD et al., 1976, LUDDEN & HUMPHRIS, 1978; LUDDEN & THOMPSON, 1978, 1979) have shown that in certain situations, especially during rock alterations, the REE are mobile. HELLMAN & HENDERSON (1977) have also suggested that the LREE may be mobile also during rock alteration. 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 or fractionation. The Esie talcose rocks in almost all cases show extensive enrichment $(La : Sm)_n = 1.53–5.06$, $(La : Yb)_n = 3.37–21.96$ 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 $(La/Sm)_n$ and $(Gd/Yb)_n$ 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 some of the Esie rock samples.

The extent of LREE mobility can also be shown by the ratios of $(La : Sm)_n$, $(Ce : Sm)_n$, $(Ce : Yb)_n$ and $(La : Yb)_n$. The ratios are given in Table 4. The $(Ce : Sm)_n$ ratios vary widely, indicating the Ce mobility. The $(La : Sm)_n$ ratios are fairly constant, regardless of the differ-


A
La (ppm)
Ti (ppm)
0
1
2
3
4
5
6
7
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14


B
Yb (ppm)
Ti (ppm)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14



Figures 9a, b&c. Ti, La, Yb and Sc variation for the Esie talcose rocks

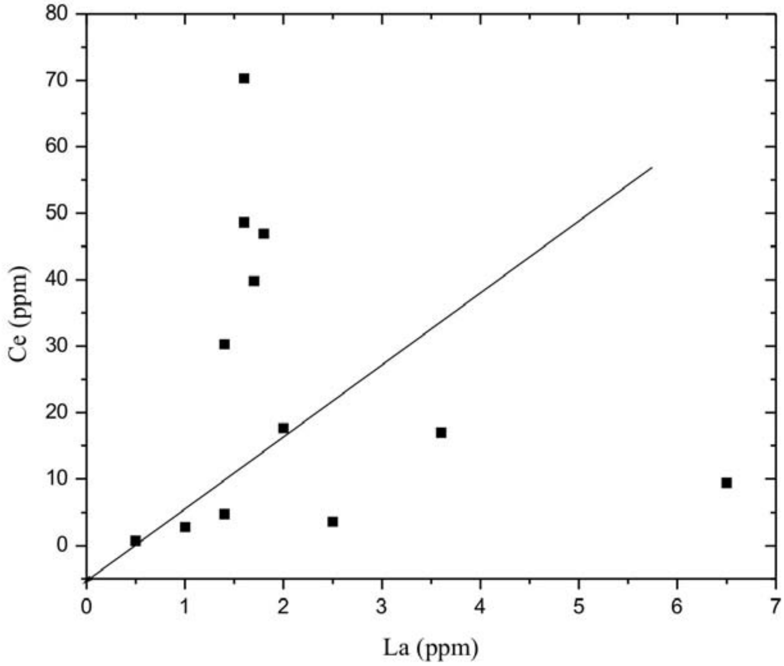


Figure 10. Ce-La variation in Esie talcose rocks

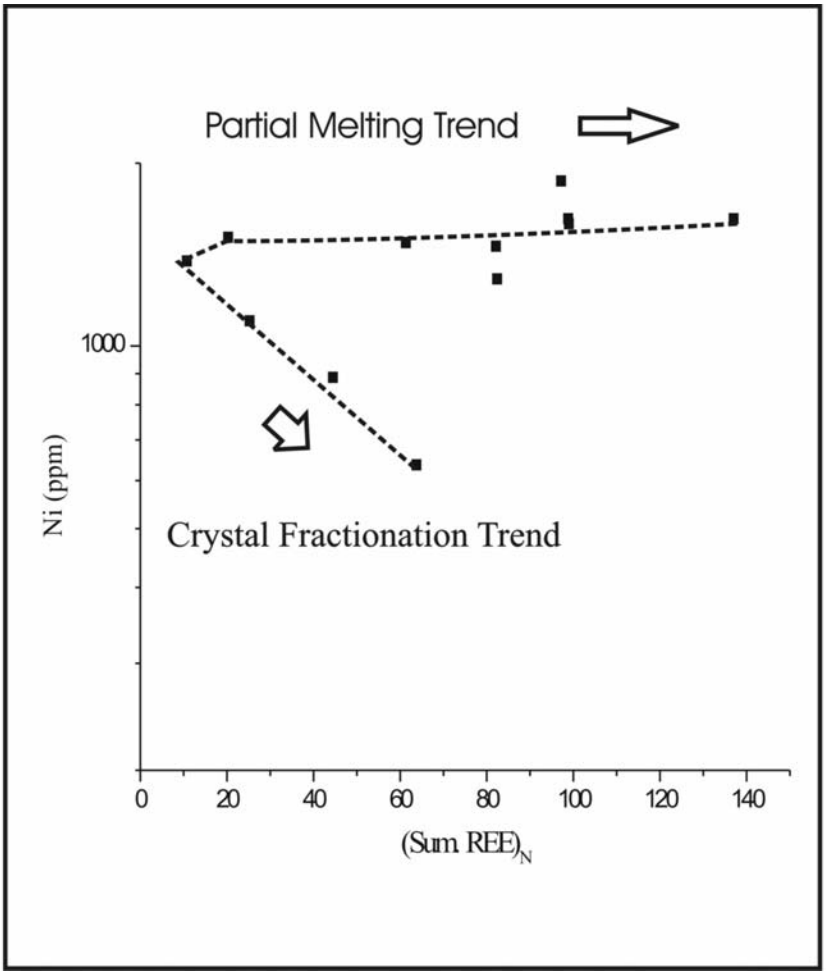


Figure 11. Experiment by Ringwood (1975) on the evolutionary trends of Ni against REE abundances. On the diagram, Esie talcose rocks plot in both trends

ent states of the talcose rock, whether altered or not. From a closer look, the data may imply that, apart from Ce, metamorphism itself has not thoroughly altered the REE patterns of the rocks. Similarities in $(La : Sm)_n$ ratios and the fact that the bodies are within the same area, could suggest that various talcose bodies originate from the same magmatic chamber and that possibly the LREE character is inherited from the parent rocks.

Although there is evidence of extensive modification, still some samples that are enriched in talc have suffered the least alteration effect and their patterns move closer to those recorded for well known ultramafic komatiites (Figure 8b).

Apart from the weathering processes, the Esie talcose rocks must have undergone polymetamorphic reconstitution. This can be shown by the plot of La against Ce (Figure 10). If the La enrichment is a primary petrogenetic effect, La and Ce should show a consistent variation. (since La is known to be slightly more compatible than Ce in the mafic system) As shown in Figure 10, there is no real consistent relationship between the two elements. This inconsistency may suggest the komatiitic nature of the source of the parent magma and also some Ce mobility.

CONCLUSIONS

Mineralogical and geochemical evidence show the Esie talcose rock is ultramafic and have undergone series of alteration in which the original mineralogy has not been preserved. Intensive weathering and poly metamorphic reconstitution are evident.

Chemical data of the rock indicate peridotitic komatiitic composition of its parental melt. The MgO content of the rock is in conformity with similar greenstone rock units from Isanlu-Egbe and parts of the ife Ilesha schist belt, central Nigeria. The high MgO content of the Esie rocks is attributed to both olivine and orthopyroxene. The highly enriched REE could pertain to the same minerals.

Most probably, the rock evolved from a complex and partial melting of upper mantle. Evidence of minor crustal contamination and fractional crystallization are evidently noticeable.

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