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Petrogenesis and functional applications of talcose rocks in Wonu-Apomu and Ilesa areas, southwestern Nigeria

Petrogeneza in uporabna vrednost lojevčevih kamnin na območjih Wonu-Apomu in Ilesa v jugozahodni Nigeriji

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Abstract

Petrogenesis and functional applications of the talcose rocks in Wonu-Apomu and Ilesa areas, southwestern Nigeria, were undertaken. Petrographic studies of the talcose rocks showed talc with variable amounts of anthophyllite, and chlorite. X-ray diffraction studies of the talcose rocks further revealed the presence of Al-bearing pyrophyllite (19.0 %) and Cr-bearing clinochlore (14.5 %), which have similar physical characteristics and diffraction peaks with talc and chlorite, respectively thus increasing the intensity of talc and chlorite on the x-ray diffraction charts.

Chemical data of the talcose rocks showed that the Wonu-Apomu samples are more siliceous (ca. 55.62 % SiO_2) than the Ilesa samples with ca. 52.35 %. Trace element data showed higher Cr (> 3 600 µg/g), Ni (> 1 620 µg/g) and Zn (> 160 µg/g) contents in the Ilesa talcose rocks. Petrogenetic indices, including low K, Rb, Rb/Sr (< 0.29), K/Rb (< 49.55), Ni/Co (< 1.05), Ga/Y (< 1.05) and CaO/Al_2O_3 (< 0.72) suggested tholeiitic basalt precursor for the talc bodies. The composition, physical and industrial characteristics of the talc bodies supported functional applications as fillers, filters and absorbents in ceramics, paints, rubber, paper, plastic, roofing materials and textiles.

Key words: talcose rock, mineralogy, geochemistry, petrogenesis, functional applications

Izvleček

Predmet preiskave sta bili določitev petrogenetskih značilnosti in ocena uporabne vrednosti lojevec vsebujočih kamnin s področij Wonu-Apomu in Ilesa v jugozahodni Nigeriji. S petrografskimi preiskavami kamnin so ugotovili razen lojevca še različne deleže antofilita in klorita. Rentgenske difrakcijske preiskave kažejo na prisotnost Al-vsebujočega pirofilita (19,0 %) in Cr-vsebujočega klinoklora (14,5 %), ki imata podobne fizikalne lastnosti in difrakcijske vrhove kot lojevec, iz česar izhaja zvečana intenziteta lojevca in klorita na rentgenskih difrakcijskih diagramih.

Iz podatkov kemijske analize je mogoče sklepati, da vsebujejo vzorci iz Wonu-Apomuja več kremena (povpr. 55,62 % SiO_2) od vzorcev iz Ilese, ki ga imajo povprečno 52,35 %. Analize slednih prvin kažejo v prvih več Cr (> 3 600 µg/g), Ni (> 1 620 µg/g) in Zn (> 160 µg/g) kakor v vzorcih lojevčevih kamnin iz Ilese. Petrogenetski kazalci, med drugim nizek K, Rb, Rb/Sr (< 0,29), K/Rb (< 49,55), Ni/Co (< 1,05), Ga/Y (< 1,05) in CaO/Al_2O_3 (< 0,72), nakazujejo, da je bila izvirna kamnina lojevca tholeiitni bazalt. Glede na sestavo lojevčevih teles in njihove fizikalne ter industrijske značilnosti ugotavljajo, da je mogoče kamnino uporabljati kot polnilo, material za filtre in kot absorbent, v keramiki, izdelavi barvil, gume, papirja, plastičnih snovi, kritine in v tekstilni industriji.

Ključne besede: lojevčeva kamnina, mineralogija, geokemija, petrogeneza, uporabna vrednost

Introduction

Talc bearing rocks and their protolithic amphibolites are common features of the Precambrian schist belts, which are largely confined to the western part of Nigeria (Figure 1). In the Ilesa schist belt of southwestern Nigeria, they occur in localities such as Wonu-Apomu, Ile-Ife, Isaobi near Ilesa, Ikirun and Esa-Oke. Within the Ilesa schist belt, talc bodies are closely associated with mafic and ultramafic bodies, mostly amphibolites and metasedimentary units such as quartzites and pelitic schists [1–7]. Various mineralogical and textural varieties of the talcose rocks have been identified by workers such as [8–10]. The four major mineralogical types according to Elueze and Akin-Ojo [10] are the talcose, tremolitic, chloritic and anthophyllitic varieties. Furthermore, studies on the regional occurrences and comparative industrial applications of various talc occurrences in southwestern Nigeria have also been carried out [10, 11].
Industrial appraisals of various talc bodies from southwestern Nigeria have also been inferred from their textural, mineralogical, chemical and geotechnical attributes [11–18]. Most of these investigations on the amphibolites and various talcose occurrences within the Precambrian basement complex tend to emphasize their field relations, petrological descriptions, mineralogical attributes and aspects of industrial applications, with little effort on the petrogenetic affinity. Mineralogical and chemical data were generated in the present investigation to unravel the petrogenetic affinity and petrochemical trends of the talcose rocks in Wonu-Apomu and Ilesa areas. The functional applications were also evaluated based on physical and thermal characteristics of the talcose bodies.

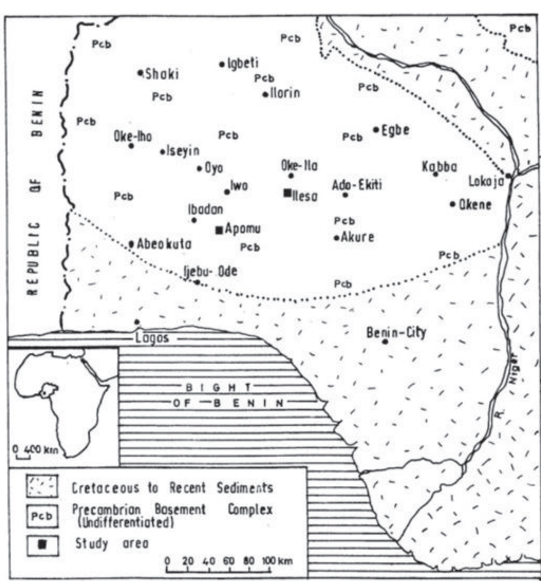

Figure 1: *Map of southwestern Nigeria showing the location of Apomu and Ilesha areas.*

Location and Geology of study areas

The Wonu-Apomu area is delineated by latitude 7° 15′ and 7° 19′ N and longitude 4° 3′ and 4° 6′ E (Figure 2); while the Ilesa area is defined by latitude 7° 31′ and 7° 38′ N and longitude 4° 38′ and 4° 45′ E (Figure 3). The Precambrian basement complex rocks in Nigeria have been classified into three major groups. These are the ancient migmatite-gneiss-quartzite com-

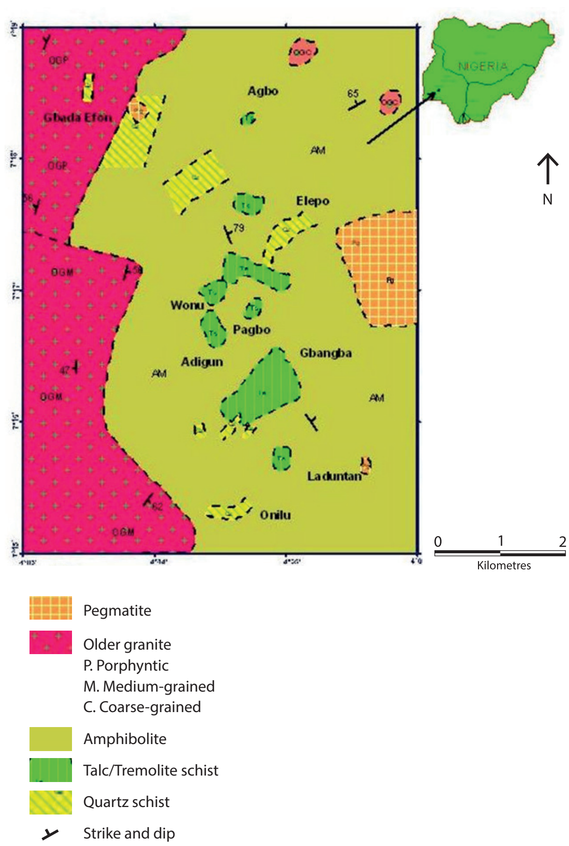

Figure 2: *Geological map of Wonu-Apomu area (modified after Akin-Ojo [9]).*

plex, the schist belts and the Pan African intrusive series (Older Granites). Others minor rocks include unmetamorphosed felsic and mafic intrusives [19].

The Wonu-Apomu and Ilesa areas lie within the schist belts of the basement complex of southwestern Nigeria characterized by migmatites and granitic gneiss, low to medium grade metasedimentary and metavolcanics rocks, notably quartzite and quartz schist, amphibolites and talc schist. Others are porphyritic granite and pegmatites (Figures 2 and 3). Talc schist occurs as narrow, northerly trending, and lens-shaped discontinuous bodies within the amphibolite at Pagbo, Wonu, Baale and Laduntan in the Wonu-Apomu area (Figure 4). In Ilesa area, the talc schists occur within biotite schist and amphibolitic rocks. They contain essentially talc with subordinate amounts of anthophyllite, pyrophyllite and chlorite. Chalcopyrite, pyrite, pyrrhotite and chromite, though intensively altered, are also present in some samples [20]. The mineralogy, feel, colour, texture, area extent, and the degree of weathering of the talcose rocks vary with location. The chlorite content of the talc-schist is reflected in its greenish colour, while the weathering effect is indicated by brownish colouration due to iron oxidation.

Figure 4: *Talc schist outcrop in Wonu-Apomu area.*

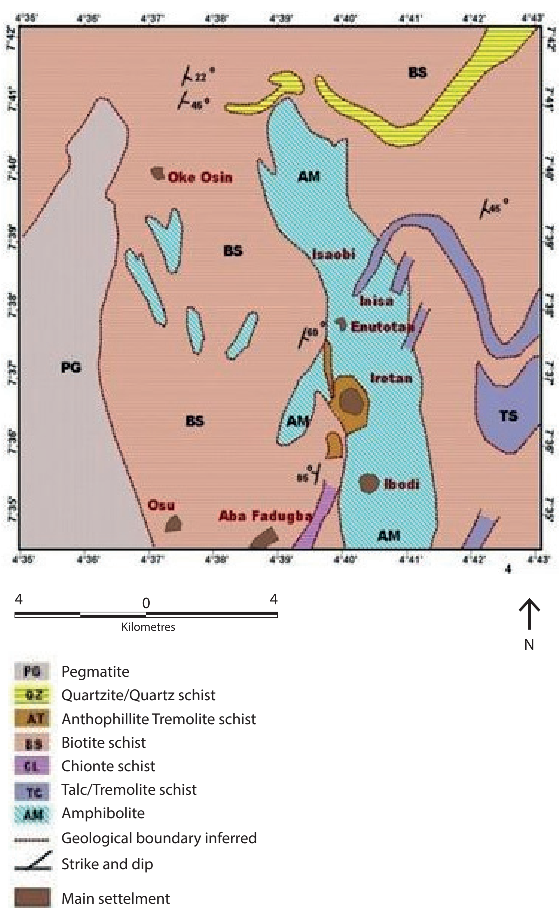

Figure 3: *Geological map of Ilesa area (modified after Kehinde-Phillips [7]).*

Materials and Methods

Forty samples of talc schist were collected from outcrops in Wonu-Apomu and Ilesa areas. The samples were selected for thin sectioning, X-ray diffraction studies and chemical analysis. Thin section of talc-schist and amphibolite samples were prepared and examined under petrographic microscope. X-ray diffraction (XRD) study of the talc schist samples were carried out in order to identify mineral phases that could not be identified with optical characteristics. Ten representative samples were selected from Wonu-Apomu and Ilesa areas. The samples were pulverized, pressed into an aluminium sample holder and analysed using Panalytical X' pert Pro diffractometer. Diffraction peaks obtained in 2θ degrees and nm-values were compared with established standards and interpreted with reference to the Joint Committee on Powder Diffraction Standards, Tables of X-ray powder diffraction patterns [21].

Twenty (20) talc samples were pulverized into fine powder and analysed at the Activation Laboratory in Ontario, Canada using the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The ICP-MS technique was used for the determination of major and trace element composition of the talc bodies, which include SiO_2, Al_2O_3, Fe_2O_3(T), MnO, MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5, Ba, Sr, Y, Zr, Zn, Rb, Co, Cu, V, Ga, Cr and Ni.

Pellets of raw pulverized talc were produced using a mechanical press. The pellets were dried in an oven set at 105 °C and the natural moisture content (NMC) determined. The pellets were fired in a kiln to temperatures of (950, 1 000, 1 050 and 1 100) °C for 2 h. The loss on ignition (LOI) was determined from the weight difference of the dried and fired samples. The linear shrinkage (LSK) was measured and calculated from the percentage decrease in diameter of the pellets after firing. The water absorption capacity was estimated from percentage weight increase after immersion in water for 24 h. Bleaching test for colour improvement was carried out on 10 samples by soaking 2 g in 5 ml of 1.0 M and 2.0 M HCl for 24 h.

Results and Discussion

Petrography

Thin sections of the talcose rock show flaky aggregates and plates of talc (Figures 5–7). Laths of anthophyllite and chlorite are also observed (Figure 5). Aggregates of prismatic needles and radiating fibres of anthophyllites and pyrophyllite were observed in the thin section of the talc schist. The talc-pyrophyllite-chlorite Wonu-Apomu samples are generally greyish to cream white in colour while the anthophyllite-pyrophyllite-chlorite rich types are brownish to grey. Anthophyllite is pleochroic from colourless to yellowish and green in thin section. Pyrophyllite, anthophyllite, chlorite and clinochlore are commonly present in both talcose bodies. A greenish or brownish tint in colour is observed with increase in chlorite and/or anthophyllite content. The pyrophyllite rich varieties are schistose in texture and cream-white in colour. The talc sample has a strong soapy feel. In thin sections, the talc schists are observed as flaky aggregates and platelets of talc (Figures 5–7). Pyrophyllite ($Al_2Si_4O_{10}\{OH\}_2$) occurs as fibrous aggregates and rosettes around fine-grained matrix of flaky talc. The pyrophyllite crystals have properties similar to those of talc and are observed as foliated masses in the talc schist. Laths of anthophyllite are also present with subordinate chlorite and clinochlore.

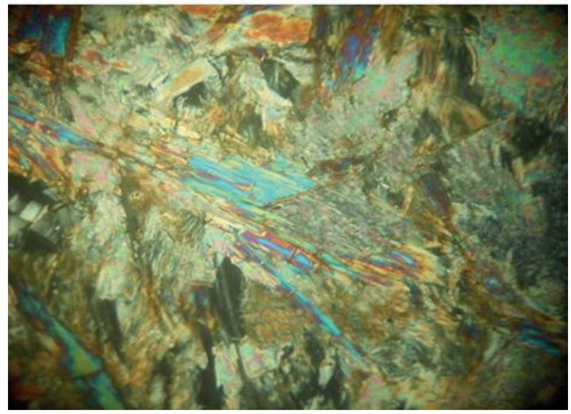

Figure 5: *Photomicrograph of Wonu-Apomu talcose rock showing talc and anthophyllite crystals (40-times, crossed polars).*

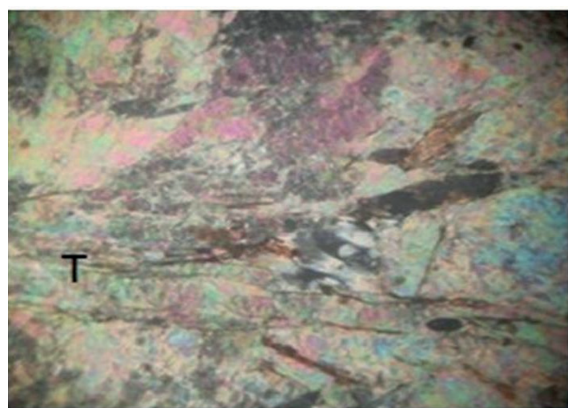

Figure 6: *Photomicrograph of Wonu-Apomu talcose rock showing plates of talc (T) (40-times, crossed polars).*

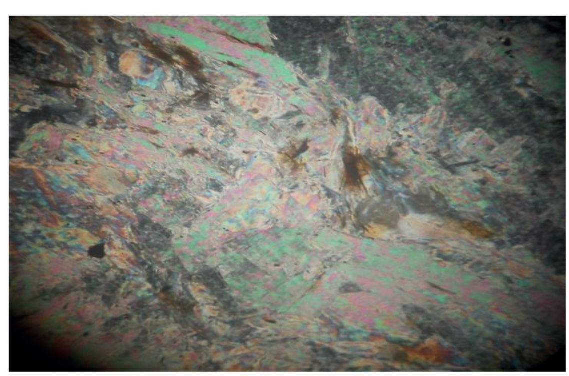

Figure 7: *Photomicrograph showing plates of talc in the Ilesa talcose rock (40-times, crossed polars).*

X-ray diffraction

X-ray diffraction studies revealed the presence of talc, anthophylite and substantial quantity of pyrophyllite and clinochlore (Table 1). Strong peak of pyrophyllite is close to those of talc and anthophyllite. The chromium bearing clinochlore has similar reflection peaks with chlorite. Talc was identified at (9.5, 28.6, 48.8, and 59.4) 2θ values (Figs. 8 and 9). Peaks of pyrophyllite occur closely with those of talc and anthophyllite at (9.5, 19.4 28.9, 29.4) 2θ values. Anthophyllite peaks are recorded at values of 2θ (9.6, 10.7, 19.8, 27.6, 29.1 and 31.2).

Table 1: *Mineral composition (%) of talc schist from Wonu-Apomu and Ilesa areas*

Minerals	1	2	3	4	Mean
Talc	30	32	21	24	26.75
Pyrophyllite	20	20	18	18	19.0
Anthophyllite	21	18	28	22	22.25
Chlorite	14	15	16	20	16.25
Clinochlore	14	14	16	14	14.5
Others	1	1	1	2	1.25
Total	100	100	100	100	100

1–2: Wonu-Apomu Talc-chlorite-anthophyllite schist
3–4: Ilesa Talc-anthophyllite-chlorite schist

Chlorite in association with clinochlore, a chromium-bearing monoclinic chlorite was identified at 2θ values of (6.2, 12.4, 18.6, 25.0 and 31.2). Chlorite is a hydrous silicate of aluminiun, iron and magnesium $(Mg, Fe)_5Al(AlSi_3)\ O_{10}(OH)_9$ while clinochlore with the chemical composition $(Mg, Fe, Al)_6\,(Si,Cr)\ O_{10}\ (OH)_8$ is a monoclinic crystal that is distinctly biaxial and optically positive as observed under the petrological microscope. The average clinochlore composition was about 14 % in each of the ten samples analysed. The total chlorite content (including clinochlore) of the talc schist samples was about 30 %, which was responsible for the greenish colour of most of the samples. The mineralogical data of the whole rock samples, using the peak height ratio showed that they are composed of about 30 % talc, 20 % pyrophyllite, 21 % anthophyllite, 28 % chlorite and 1% unidentified minerals.

Comparative studies of the Ilesa and Wonu-Apomu talc-schist with those of Oke-Ila, Iseyin, Baba-Ode and Erin-Omu (Table 2) showed that the Ilesa and Wonu-Apomu samples are higher in pyrophyllite and anthophyllite but lower in talc and tremolite/actinolite contents. The range values of talc for Ilesa and Wonu-Apomu samples is 21–32 % while those of Oke-Ila is about (58–81 %) and Iseyin (48–59 %) [15].

Table 2: *Comparison of mineral composition (%) of the Ilesa and Apomu talc schist with some other talc bodies in southwestern Nigeria*

Minerals	This study				Oke-Ila			Iseyin (TTSC)			Baba-Ode		Erin-Omu
	1	2	3	4	2 m	3 m	4 m						
Talc	30	32	21	24	58	66	81	59	52	48	24	74	59
Pyrophyllite	20	20	18	18	–	–	–	–	–	–	–	–	–
Anthophyllite	21	18	28	22	–	–	–	–	–	–	9	3	6
Tremolite/ Actinolite	–	–	–	–	18	20	10	28	26	33	48	7	24
Muscovite	–	–	–	–	–	–	–	–	–	–	–	6	2
Chlorite	14	15	16	20	22	12	8	12	21	17	16	–	7
Clinochlore	14	14	16	14	–	–	–	–	–	–	–	–	–
Others	1	1	1	2	2	2	1	1	1	2	1	1	2
Total	100	100	100	100	100	100	100	100	100	100			

1–2: Wonu-Apomu talc-chlorite-anthophyllite schist
3–4: Ilesa talc-anthophyllite-chlorite schist
Oke-Ila: talc-tremolite chlorite schist [15]
TTSC: talc-tremolite schist, Iseyin [14]
Baba-Ode: talc-tremolite chlorite anthophyllite schist [16]
Erin-Omu: talc-tremolite chlorite anthophyllite schist [18]

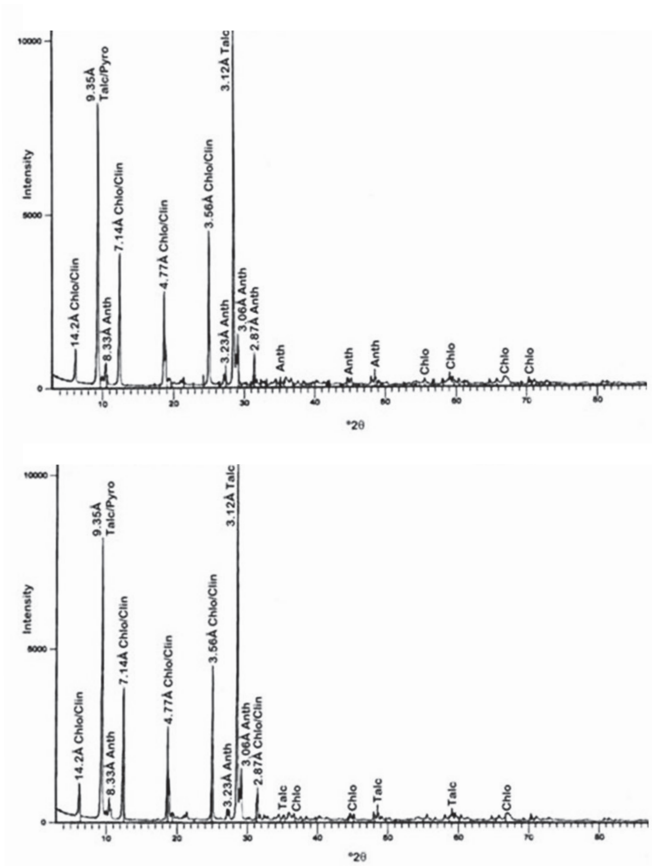

Figure 8: *X-ray diffraction charts of Wonu-Apomu talc - chlorite schists.*
(Anth – Anthophyllite, Chlo – Chlorite, Clin – Clinochlore, Pyro – Pyrophyllite)

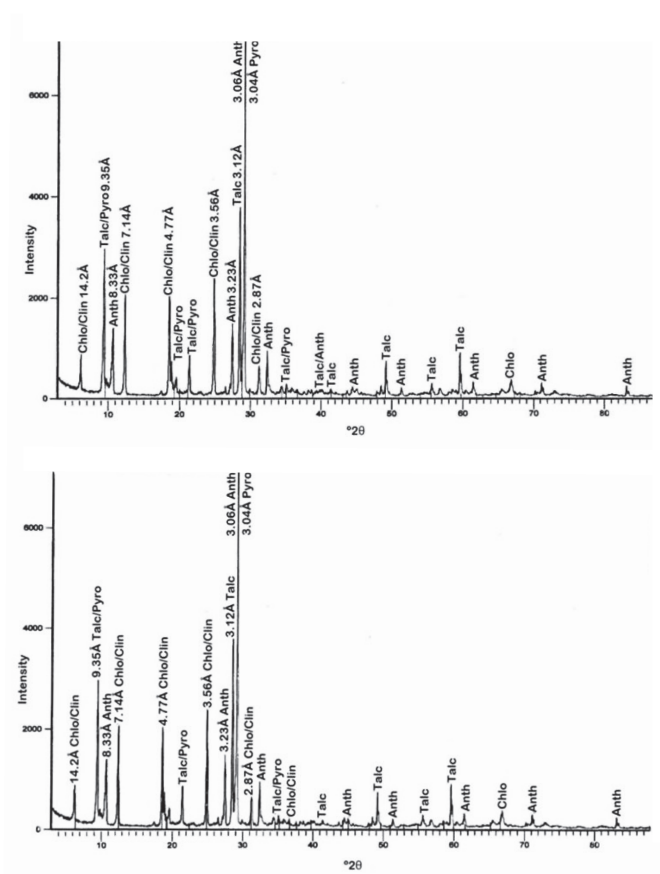

Figure 9: *X-ray diffraction chart of Ilesa talc - pyrophyllite schists.*
(Anth – Anthophyllite, Chlo – Chlorite, Clin – Clinochlore, Pyro – Pyrophyllite)

Table 3: *Major (%) and trace element composition of talc schist of Wonu-Apomu and Ilesa areas*

	1	2	3	4	5	6	7	8	9	10
SiO_2	52.29	51.43	52.23	61.15	61.01	52.42	52.82	52.1	52.24	52.15
Al_2O_3	4.16	4.3	3.62	0.84	0.77	5.2	4.99	5.22	5.3	5.14
$Fe_2O_{3(t)}$	8.34	7.83	8.27	3.94	3.75	9.54	9.26	9.38	9.42	9.33
MnO	0.14	0.13	0.15	0.48	0.05	0.15	0.14	0.14	0.14	0.14
MgO	28.59	27.89	29.18	30.04	30.06	26.54	26.67	26.03	26.46	26.02
CaO	2.7	3.17	2.59	0.06	0.05	1.39	1.34	1.38	1.31	1.38
Na_2O	0.04	0.01	0.11	0.03	0.03	0.08	0.07	0.01	0.01	0.01
K_2O	0.06	0.05	0.11	0.01	0.02	0.03	0.01	0.08	0.06	0.01
TiO_2	0.19	0.20	0.187	0.2	0.02	0.09	0.1	0.1	0.11	0.11
P_2O_5	0.03	0.03	0.03	0.01	0.01	0.03	0.02	0.03	0.03	0.03
LOI	4.42	4.65	4.21	4.81	4.79	5.22	5.24	5.33	5.27	5.1
Total	100.96	99.7	100.59	101.57	100.56	100.69	100.66	99.8	100.41	99.42
Trace element (µg/g)										
Ba	32	30	37	9	10	15	14	18	15	15
Co	69	69	70	71	73	72	70	69	70	69
Cr	1880	1820	1870	1030	1190	3770	3720	3640	3670	3610
Cu	70	60	70	10	10	20	10	10	10	10
Ga	7	6	5	2	2	8	8	8	8	8
Ni	1110	1080	1150	1670	1750	1710	1650	1620	1650	1640
Rb	29	6	4	3	2	2	3	2	2	2
Sr	10	12	9	2	2	4	3	4	4	4
V	78	80	67	5	5	48	46	45	48	45
Y	34	25	33	2	2	10	10	11	11	11
Zr	17	14	13	8	8	20	11	15	17	18
Zn	50	60	60	40	70	220	170	160	170	190
K/Rb	0.002	0.007	0.0021	0.003	0.008	0.013	0.003	0.033	0.025	0.004
Rb/Sr	2.9	0.5	0.44	1.5	1	0.5	1	0.5	0.5	0.5
K/Ba	0.002	0.001	0.0002	0.001	0.002	0.002	0.001	0.004	0.003	0.001
Ga/Y	0.2	0.24	0.152	1	1	0.8	0.8	0.727	0.727	0.727
Rb/Y	0.85	0.24	0.12	1.5	1	0.2	0.3	0.182	0.182	0.182
Na/K	0.6	0.178	9.83	2.675	1.337	2.38	6.25	0.111	1.042	0.892
Ba/Rb	1.1	5.0	9.25	3.0	5.0	7.5	4.66	9.0	7.5	7.5

1–5: Wonu-Apomu samples
6–10: Ilesa samples

Baba-Ode and Erin-Omu talc contents are ca. 49 % and 59 % respectively. Chlorite, on the other hand, is 14–20 % for Ilesa and Wonu-Apomu, while those of Oke-Ila and Iseyin are (18–22 %) and (12–22 %) respectively. It must be noted that pyrophyllite and anthophyllite, which occur prominently in the Ilesa and Wonu-Apomu samples are absent in the Iseyin and Oke-Ila samples.

Anthophyllite, an orthorhombic amphibole is a major constituent in the Ilesa and the Apomu talc-schist while tremolite, a monoclinic amphibole, which is one of the major constituents in the Oke-Ila, Iseyin, Baba-Ode and Erin-Omu talc-schist are absent in the Wonu-Apomu and Ilesa samples (Table 2). Anthophyllite is stable only at low temperatures. When heated to about 400 °C, it may alter to a monoclinic amphibole, such as, tremolite. The heat for the conversion of the anthophyllite to tremolite in the areas where they occur could have been provided by the granitic intrusives around the talc bodies.

Geochemistry

Chemical data show that the talcose rocks of the study areas are highly siliceous with an average value of 55.62 % and 52.35 % SiO_2 for Wonu-Apomu and Ilesa samples, respectively (Table 3). Also magnesia contents ranges between 27.89–30.06 % and 26.02–26.67 % for the Wonu-Apomu and Ilesa talcose samples. Alumina (0.77–4.3 %), Fe_2O_3 (3.75–8.345 %) and CaO (0.05–3.17 %) contents of Wonu-Apomu talcose rock show lower values and a wider range within samples when compared to the Ilesa samples with 4.99–5.55 %, 9.26–9.54 % and 1.31–1.39 % for Al_2O_3, Fe_2O_3 and CaO contents, respectively. Some samples from Wonu-Apomu, however, exhibit high silica (> 61 %) and magnesia contents (> 30 %), but correspondingly low Al_2O_3 (< 2 %), $Fe_2O_{3(t)}$ (< 4 %), CaO (0.05 %) and MnO contents (Table 4). These samples are higher in talc content than others (Tables 2, 3 and 4). The abundances of SiO_2, MgO, Al_2O_3, $Fe_2O_{3(t)}$ and CaO between Wonu-Apomu and Ilesa samples invariably reflect subtle mineralogical differences between samples. The MnO, Na_2O, K_2O, TiO_2 and P_2O_5 concentrations are generally low (< 0.05 %) and are not strikingly varied within samples. The loss on ignition (LOI) does not generally exceed 5.4 %.

As observed from Tables 3 and 4, Ilesa talcose samples are enhanced in Cr (> 3 600 µg/g), Ni (> 1 620 µg/g) and Zn(> 160 µg/g), while Wonu-Apomu indicated an average concentrations of 1 558 µg/g, 1 353 µg/g and 56 µg/g for Cr, Ni and Zn, respectively. Other trace elements such as Ba, Co, Cu, Ga, Rb, Sr, V, Y and Zr are generally low and do not show any marked trend. The talcose rock showed SiO_2 enrichment, probably due to the effect of chemical weathering. Hydrothermal alteration accompanied by serpentinization of the tholeiitic protoliths was reflected in high MgO (26.34–29.15 %) and $Fe_2O_{3(t)}$ (6.43–9.39 %) contents of the talcose rocks. The relative chemical mobility of Na, Ca and K during secondary alteration processes is largely displayed by strong depletions of these Na, Ca and K oxides in the talcose samples relative to the protolith amphibolites (Table 5) [22].

The Ba (24 µg/g), Sr (7 µg/g) and Rb (9 µg/g) concentrations in the talcose rocks are generally low compared to the amphibolites within the area (Table 5). This trend is also due to their chemical instability during secondary alteration processes. On the other hand, Cr (3 684 µg/g) and Ni (1 654 µg/g) contents, as a result of their chemical immobility even under hydrothermal alteration, which commonly produce talc, serpentine and chlorite from mafic and ultramafic rocks showed distinctive chemical enrichment trends in the talcose rocks. The values for Co (ca. 70 µg/g) remain unchanged in both the talcose rock and the amphibolites (Table 4). These could serve as exploration guide for basemetals and platinum group elements (PGE) in the area.

Functional potentials of the talc bodies

The physical and industrial properties of the talcose body include determination of natural moisture content (NMC), loss on ignition (LOI), linear shrinkage (LSK), water absorption capacity (WAC), firing colour and pH. Results obtained from these tests (Table 6) served as basis for the evaluation of functional potentials of the talc bodies. The results showed that the NMC ranged from 5.00 % to 6.55 %.

Table 4: *Average chemical composition of Wonu-Apomu and Ilesa talcose rocks compared with other talcose rocks elsewhere in Nigeria*

	Wonu-Apomu		Ilesa		Iseyin (TTCS)		SW Nigeria (TTAS)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
SiO_2	55.62	51.23–61.15	52.35	52.15–52.82	54.70	53.61–55.35	55.01	46.82–55.37
Al_2O_3	2.74	0.77–4.3	5.17	4.99–5.3	3.54	1.86–4.84	2.52	1.19–2.86
$Fe_2O_{3(t)}$	6.43	3.75–8.34	9.39	9.26–9.54	6.50	5.75–7.25	4.50	3.20–4.50
MnO	0.19	0.05–0.48	0.14	0.14–0.15	0.16	0.10–0.25	0.05	0.004–0.13
MgO	29.15	27.89–30.06	26.34	26.02–26.67	27.20	22.06–30.38	30.04	29.13–32.04
CaO	1.71	0.05–3.17	1.36	1.31–1.39	4.43	2.76–5.32	1.50	0.41–4.47
Na_2O	0.04	0.01–0.11	0.05	0.01–0.08	0.22	0.16–0.32	0.01	0.01–0.02
K_2O	0.03	0.01–0.11	0.04	0.01–0.08	0.03	0.01–0.06	0.02	0.01–0.02
TiO_2	0.16	0.02–0.2	0.10	0.09–0.11	Nd	Nd	Nd	Nd
P_2O_5	0.02	0.01–0.03	0.03	0.02–0.03	0.02	0.02–0.3	0.06	0.05–0.13
LOI	4.58	4.21–4.81	5.23	5.1–5.33	2.99	1.82–4.88	6.00	3.60–5.41
Total	100.68		100.2		99.86		99.71	
Trace element (μg/g)								
Ba	24	9–37	15	14–18	Nd	Nd	Nd	Nd
Co	70	69–73	70	69–70	71	52–80	Nd	Nd
Cr	1558	1030–1880	3684	3610–3770	826	806–897	2000	Nd
Cu	44	10–70	12	10–20	Nd	Nd	Nd	Nd
Ga	4	2–7	8	8	Nd	Nd	Nd	Nd
Ni	1352	1080–1750	1654	1620–1710	1278	1034–1702	1500	Nd
Rb	9	2–29	2	2–3	Nd	Nd	Nd	Nd
Sr	7	2–12	4	3–4	Nd	Nd	Nd	Nd
V	47	5–80	46	45–48	Nd	Nd	Nd	Nd
Y	19	2–34	11	10–11	Nd	Nd	Nd	Nd
Zr	12	8–17	16	11–20	Nd	Nd	Nd	Nd
Zn	56	40–70	182	160–220	69	58–82	Nd	Nd
K/Rb	0.004	0.001–0.008	0.0155	0.003–0.033	Nd	Nd	Nd	Nd
Rb/Sr	1.27	0.44–2.9	0.6	0.5–1.0	Nd	Nd	Nd	Nd
K/Ba	0.011	0.001–0.002	0.002	0.004–0.006	Nd	Nd	Nd	Nd
Ga/Y	0.52	0.15–1.0	0.756	0.727–0.8	Nd	Nd	Nd	Nd
Rb/Y	0.74	0.24–1.5	0.21	0.182–0.3	Nd	Nd	Nd	Nd
Na/K	2.92	0.18–9.83	2.136	0.111–6.25	Nd	Nd	Nd	Nd
Ba/Rb	4.67	1.10–9.25	7.23	4.66–9.00	Nd	Nd	Nd	Nd

Nd: Not determined
TTCS: Talc-tremolite schist, Iseyin [14]
TTAS: Talc-tremolite/actinolite schist, SW Nigeria [13]

Table 5: *Comparison of the major (%) and trace element (%) composition of the amphibolites and the talcose rocks in Wonu-Apomu and Ilesa areas*

	*Amphibolite				Talcose rocks			
	Wonu-Apomu		Ilesa		Wonu-Apomu		Ilesa	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
SiO_2	48.91	44.79–50.62	47.27	44.86–49.10	55.62	51.23–61.15	52.35	52.15–52.82
Al_2O_3	15.11	14.01–16.41	17.29	15.20–20.22	2.74	0.77–4.3	5.17	4.99–5.3
$Fe_2O_{3(t)}$	13.31	12.27–14.62	12.44	11.56–13.34	6.43	3.75–8.34	9.39	9.26–9.54
MnO	0.13	0.07–0.23	0.11	0.08–0.14	0.19	0.05–0.48	0.14	0.14–0.15
MgO	9.84	8.08–12.15	9.52	7.85–11.16	29.15	27.89–30.06	26.34	26.02–26.67
CaO	9.33	8.72–10.00	9.50	8.11–10.55	1.71	0.05–3.17	1.36	1.31–1.39
Na_2O	1.52	1.13–1.88	1.87	1.28–2.72	0.04	0.01–0.11	0.05	0.01–0.08
K_2O	0.73	0.46–0.99	0.732	0.55–0.85	0.03	0.01–0.11	0.04	0.01–0.08
TiO_2	0.05	0.25–0.88	0.61	0.39–0.86	0.16	0.02–0.2	0.10	0.09–0.11
P_2O_5	0.03	0.01–0.05	0.03	0.02–0.05	0.02	0.01–0.03	0.03	0.02–0.03
LOI	0.31	0.25–0.35	1.46	0.24–0.35	4.58	4.21–4.81	5.23	5.1–5.33
Total	99.69		99.86		100.68		100.20	
Trace elements (µg/g)								
Ba	184	86–350	137	88–231	24	9–37	15	14–18
Sr	123	106–143	122	106–145	7	2–12	4	3–4
Rb	33	26–40	34	27–46	9	2–29	2	2–3
Cr	79	58–92	63	45–94	1 558	1 030–1 880	3 684	3 610–3 770
Co	71	40–85	62	48–82	70	69–73	70	69–70
Ni	64	24–98	57	25–85	1 352	1 080–175	1 654	1 620–1 710
Zr	55	48–62	56	46–66	12	8–17	16	11–20
Y	37	26–45	37	25–45	19	2–34	11	10–11

* Wonu-Apomu and Ilesa amphibolites [29]

The LOI ranged between 4.21 % and 5.27 %. The LSK values are generally low (2.33–4.40 %). The WAC ranged from 8.05 % to 10.00 % while the pH of the slurry produced from the talcose rock ranged between 8.00 and 8.35 indicating alkalinity (Tables 6 and 7). The pH values and the LOI compare favourably with those of talc bodies from Erin-Omu, Iseyin, Oke-Ila and Baba-Ode (Table 7) all in southwestern Nigeria [15, 16, 18]. On the other hand the WAC is lower than those of the Erin-Omu and Baba-Ode samples and comparable to that of Oke-Ila but higher than that of Iseyin (Table 7). The variation in the mineralogical compositions and textures of the talcose rocks from one area to the other is reflected in the results of the firing tests presented. Generally, the results are comparable to other similar talc bodies within the schist belts of south-western Nigeria as reported by Durotoye and Ige [11]. The colour of the raw talcose pellets changes from green, brown, grey or cream to shades of red, yellow and cream after firing (Table 6). Bleaching of the talcose rocks yielded white to off-white coloured samples with increasing concentration of the HCl acid used.

Based on the foregoing the talc bodies of Wonu-Apomu and Ilesha areas are assessed as viable industrial raw materials in coloured ceramics including insulation ceramics [23]. They could also function as filler and extender in paints [24], paper, roofing materials and textiles after screening to remove gritty particles, which are mainly quartz [25–27]. The talc bodies could be used to improve the stability and rigidity of plastic goods at high temperatures based on the specifications of Noble [28]. It must be noted that pyrophyllite is commonly used for the same purpose as talc. The high content of trace elements in the talc bodies, notably Cr, Ni, Co, Cu, V and Zn would not permit utilization for pharmaceutical purposes. Also, chemical data are not within the specifications of the American Society for Testing of Materials [29] for the manufacture of powder, creams and soaps. However, the bleaching test suggested that they could serve as absorbents for oil, grease and other chemicals.

Conclusions

Talcose rocks from Wonu-Apomu and Ilesa areas contain talc, pyrophyllite, anthophyllite and chlorite (clinochlore). Comparative studies of these talc bodies with those of Erin-Omu, Iseyin, Oke-Ila and Baba-Ode showed that the former is higher in pyrophyllite, anthophyllite and chlorite (clinochlore) but lower in talc and lack tremolite/actinolite contents.

Chemical data for the talcose rock showed that they are siliceous. Petrochemical trends of the major and trace element data of the talcose rocks reflected some subtle relationships to the amphibolites in the areas. Trace elements concentrations of the talcose rocks indicated enrichments in Cr, Ni, Cu, V and Zn relative to the amphibolites within the area. Petrogenetic indices suggest tholeiitic basalt precursor for the talc bodies [29].

Table 6: *Industrial properties of Wonu-Apomu and Ilesa talcose rocks*

	1	2	3	4	5	6	7	8	9	10
NMC	5.20	5.35	5.20	6.20	6.55	5.00	5.26	5.10	5.44	5.00
LOI	4.42	4.65	4.21	4.81	4.79	5.22	5.24	5.33	5.27	5.10
LSK	4.40	3.83	4.27	2.40	2.33	2.54	3.60	3.38	3.42	3.33
WAC	8.54	8.33	8.05	9.48	10.00	8.05	8.40	8.55	8.40	8.35
Raw colour	Brown	Brown	Green	Cream	Cream	Brown	Green	Brown	Brown	Brown
Fired colour	Red	Red	Yellow	White	White	Red	Yellow	Red	Red	Red
pH	8.35	8.30	8.33	8.00	8.10	8.30	8.26	8.34	8.30	8.25

NMC – Natural moisture content (%)
LOI – Loss on ignition (%)
LSK – Linear shrinkage (%)
WAC – Water absorption capacity (%)

Table 7: *Result of physical and industrial test on Wonu-Apomu and Ilesha talcose rocks compared to similar rock types in SW Nigeria*

	This study	Erin-Omu	Iseyin	Oke-Ila	Baba-Ode
NMC	5.00–6.55	Nd	Nd	7.50–8.90	Nd
LOI	4.21–5.27	2.87–4.11	1.45–6.03	3.75–5.28	4.25–4.41
LSK	2.33–4.40	1.01–1.81	0.25–2.0	2.45–3.50	1.01–1.52
WAC	8.05–10.00	13.25–16.25	6.96–11.65	4.21–5.80	15.14–18.25
pH	8.00–8.35	8.01–8.21	Nd	7.5–9.5	8.01–8.21

This study – Wonu-Apomu and Ilesa areas
NMC – Natural moisture content (%)
LOI – Loss on ignition (%)
LSK – Linear shrinkage (%)
WAC – Water absorption capacity (%)

The Wonu-Apomu and Ilesa talc bodies possess requisite mineralogical, chemical and industrial specifications for use as raw materials in the manufacture of ceramics, paints, rubber, paper, textile, plastic, roofing materials and textiles. They can also be used as absorbent. However, they might not be appropriate for use in the pharmaceutical, powder, creams and soaps manufacturing industries without rigorous beneficiation, which might not be economical.

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References

[1] De Swardt, A. M. J. (1953): The geology of the county around Ilesa. *Geological Survey of Nigeria. Bulletin,* 23, 54 p.

[2] Olade, M. A., Elueze, A. A. (1979): Petrochemistry of the Ilesa amphibolites and Precambrian crustal evolution in the Pan-African domain of southwestern Nigeria. *Precambrian Research*, 8, pp. 303–318.

[3] Ajayi, T. R. (1980): On the geochemistry and origin of amphibolites in Ife-Ilesa area, southwestern Nigeria. *Journal of Mining and Geology,* 17(2), pp. 177–196.

[4] Elueze, A. A. (1982): Mineralogy and chemical nature of meta-ultamafites in Nigerian schist belt. *Journal of Mining and Geology,* 19(2), pp. 21–29.

[5] Elueze, A. A. (1988): Geology of the Precambrian schist belt of Ilesa area, southwestern Nigeria. In: Oluyide, P.O. (Ed); *Precambrian Geology of Nigeria*, Geological Survey of Nigeria, pp. 77–82.

[6] Ige, O. A., Asubiojo, O. I. (1991): Trace element geochemistry and petrogenesis of some metaultramafites in Apomu and Ife-Ilesha area of southwestern Nigeria. *Chemical Geology*, 91, pp. 19–32.

[7] Kehinde-Phillips, O. O. (1991): *Compositional variations in lateritic profiles over mafic and ultramafic rock units of Ilesa schist belt, southwestern Nigeria.* Unpublished Ph.D. Thesis, University of Ibadan, Ibadan, Nigeria. 201 p.

[8] Elueze, A. A. (1981): Petrographic studies of metabasic rocks and meta-ultramafites in relations to mineralization in Nigerian schist belt. *Journal of Mining and Geology,* 18(1), pp. 31–36.

[9] Akin-Ojo, O. A. (1992): *Compositional and industrial studies of talc bodies in the Precambrian domain of southwestern Nigeria*. Unpublished Ph.D. Thesis, University of Ibadan, Ibadan, Nigeria, 215 p.

[10] Elueze, A. A., Akin-Ojo, O. A. (1993): Functional characteristis of talc bodies in southwestern Nigeria. *Mineral Wealth*, 85, pp. 7–14.

[11] Durotoye, M. A., Ige, O. A. (1991): An inventory of talc deposits in Nigeria and its industrial application potentials. *Journal of Mining and Geology,* 27(2), pp. 27–31.

[12] Ige, O. A. (1985): Mineralogical and industrial properties of some Wonu Apomu talcs, western Nigeria. *Nigerian Journal of Science,* 19, pp. 121–130.

[13] Elueze, A. A., Ogunniyi, S. O. (1985): Appraisal of talc bodies of the Ilesa district, southwestern Nigeria, and their potential for industrial applications. *Natural Resources and Development,* 21, pp. 26–34.

[14] Elueze, A. A., Awonaiya, F. A. (1989): Investigation of talc bodies in Iseyin area, southwestern Nigeria, in relation to their application as industrial raw materials. *Journal of Mining and Geology,* 25(1&2), pp. 217–225.

[15] Bolarinwa, A. T. (2001): Compositional and industrial evaluation of talc bodies of Oke-Ila area, Ilesa schist belt, southwestern Nigeria. *Mineral Wealth,* 118, pp. 48–52.

[16] Okunlola, O. A., Ogedengbe, O., Ojutalayo, A. (2002): Compositional features and industrial appraisal of the Baba-Ode talc occurrence, southwestern Nigeria. *Global Journal of Geological Sciences,* 1(1), pp. 63–72.

[17] Adeola, A. J. (2006): *Compositional and industrial characteristics of talc bodies and associated rocks in Odogbe-Okolom area, Egbe-Isanlu schist belt, southwestern Nigeria.* Unpublished M. Sc. Project, Department of Geology, University of Ibadan, Ibadan, Nigeria, 88 p.

[18] Okunlola, O. A., Anikulapo, F. A. (2006): Compositional characteristics and industrial qualities of talcose rock in Erin Omu area, southwestern Nigeria. *Journal of Mining and Geology,* 42(2), pp. 105–112.

[19] Oyawoye, M. O. (1984): The geology of the Nigerian basement complex. *Journal of Mining and Geology,* 1, pp. 87–102.

[20] Adeleye, M. A. (2009): *Petrogenetic studies of talc and amphibolites in Wonu-Apomu and Ilesa areas, southwestern Nigeria.* Unpublished M.Sc. Project, Department of Geology, University of Ibadan, 87 p.

[21] JCPDS, (1974): Selected powder diffraction data for minerals 1st edition, (Ed. L.G. Berry), Joint Committee on Powder Diffraction Standards, Philadelphia, 833 p.

[22] Mitchel, L. (1975). Ceramic raw materials. In Leford J. (ed). *Industrial minerals and rocks,* American institute of mining and Metallurgical and Petroleum Engineers, New York, 33 p.

[23] National Paint and Coating Association (1975): *Industrial specification for the paint industry*, New York, 25 p.

[24] Payne, H. F. (1954): *Organic coating technology*. John Wiley, New York, 2, 725 p.

[25] Severinghus, N. (1975): Fillers, filters and absorbents. In: Letond, J.S (ed) *Industrial minerals and rocks,* New York, 125 p.

[26] American Textile Manufacturer Institute (1975): *Industrial specification for raw materials in the textile industry*, 54 p.

[27] Noble, P. (1988): *Marketing guide to the paper and pulp industry*. Fairfteld, N. J, 148 p.

[28] American Society For Testing of Materials (1988): *Handbook of construction materials*, 45 p.

[29] Bolarinwa, A. T., Adeleye, M. A. (2015): Nature and origin of the Amphibolites in the Precambrian Basement Complex of Iseyin and Ilesha schist belts southwestern Nigeria. *Journal of Geography and Geology*, 7(2) pp. 6–17.