Ife Journal of Science vol. 8, no. 2 (2006)

PETROLOGY AND ECONOMIC POTENTIAL OF OLOJUORO SILLIMANITE DEPOSIT, IBADAN SOUTHWESTERN NIGERIA.

O.A. Phillips[+] and A.O. Falana
Department of Geology, The Polytechnic, Ibadan, Nigeria.

(*Submitted*: 20 October 2005; *Accepted*: 15 November 2006)

Abstract

The petrographic, chemical studies and determinations of physical characteristics like specific gravity and firing properties were undertaken for sillimanite quartzite samples taken from different borehole locations within Olojuoro area, Ibadan. The aim was to assess the potential for industrial application of the sillimanite deposit. Two chains of sillimanite quartzite ridges were recognized. There was a general increase in quartz content and a corresponding decrease in sillimanite content from northern part of the study area (Olarinde) to the southern part (Apata). Similarly, the Atomic Absorption Spectrometric analysis carried out on these samples showed that aluminium contents in the sillimanite samples range between 40.40% to 57.69% (except samples from Apata with average of 33.44%). This allows sillimanite investigated for use in making refractory bricks. At temperature of 1450 °C, the samples showed no fusion which is expected of a high alumina refractory, hence its use for mortars, castables, plastic and ramming mixes which are refractories' products sold as non-formed products classified as "refractory specialities".

The change in the specific gravity due to firing could be attributed to the production of fine microscopic or submicroscopic cracks caused by the natural thermal expansion with increasing temperature or perhaps to volume change in the associated minerals. The least change in specific gravity observed in the sample at Olarinde, may indicate its industrial superiority over others.

Keywords: sillimanite, firing properties, industrial applications, sub-microscopic cracks, refractory bricks.

1. Introduction

Olojuoro is situated 25 km southeast of Ibadan in southwestern Nigeria which is part of the Precambrian Basement Complex of Nigeria (Iseyin-Ona-Ara Schist belt). It lies between latitude 7°072 and 7°152 N; longitude 3°552 and 4°002 E within Ibadan, Sheet 261 SE (Fig. 1). It occupies an area of about 175 square kilometers. The sillimanite deposit investigated occurs as a lensoid body on the Olojuoro ridge.

There are two chains of sillimanite bearing quartzite ridges close to River Omi within the study area. Owing to the growing commercial importance of sillimanite in the manufacture of refractories, porcelain and the importation of mullite bricks into the country, there is the need for its proper exploration and economic assessment. Sillimanite finds its application both in calcined and raw forms in the manufacture of mullite bricks, refractory mortars, cement, castables, plastic and plastic ramming mixes (Budmikov, 1964).

It is expected that at high temperatures (1400-1650 °C) this mineral changes over to mullite ($3Al_2O_3.2SiO_3$) and vitreous silica-cristobalite (Anon, 1961). Mullite is rare in nature, remains stable up to 1810 °C (Bateman, 1950). Raw sillimanite is used to offset the shrinking of the clay binder while the calcined sillimanite is used in the coarser sizes to give strength to the body (Peck, 1925). Klin furniture is composed chiefly of graded sizes of calcined sillimanite banded with a little ball clay (Bateman, 1950).

The objective of this study is to determine the mineralogical and chemical compositions and the refractory characteristics of the sillimanite quartzite in order to assess the potential for industrial application of the sillimanite deposit.

2. Petrology

Geological mapping of the area on the scale of 1:25,000 around the reported sillimanite quartzite ridges in Olojuoro was undertaken. The area is underlain by quartzite, migmatitic gneiss, amphibolite, porphyritic granites and pegmatites (Fig. 2).

The quartzite forms a chain of low lying ridges, trending North-South in the eastern half of the area. Sillimanite occurs as fibres interlayered with quartz crystals which are transparent or milky. The dominant minerals are quartz and sillimanite. Muscovite, magnetite and corundum are accessories (Table 2).

The first of the two ridges, which is Olarinde-Olojuoro, and Apata sillimanite quartzite ridge, has the concentration of sillimanite varying widely

+ *corresponding author* (email: oluphills2004@yahoo.com)

between 65-85% and a decrease in sillimanite content is noticed southwards from Olarinde through Olojuoro to Apata village. Three types of sillimanite rocks were identified on this ridge. Each of these samples is described below based on the location.

At Olarinde, the quartz crystals are dotted with tiny black tints of biotite and occasional brown iron oxides stains (Plate 1). The Olarinde sample consists of jumbled mass of sillimanite fibres. The mineralogical composition is sillimanite 85%, quartz 10%, magnetite 3% and corundum 1% (Table 2). The magnetite might have been formed from illmenite present in the original sediments, which was altered, to haematite and finally magnetite. Sillimanite is used as an index mineral indicating high-medium pressure and high temperature metamorphic regime. The corundum occurs as blue and pink crystals and might have formed from cordierite. This is indicated by the reduction in quartz contents of 23% from Olojuoro sample to 10% in the sample from Olarinde.

The Olojuoro type is similar to Olarinde but lighter in colour. It shows intense foliation (Plate 2). The mineralogical composition of Olojuoro type sillimanite quartzite is 75 % sillimanite, 23 % quartz, and 2 % magnetite (Table 2). The quartz crystals are crushed, fractured and elongated parallel to foliation direction (Plate 2). The Apata type is not well foliated though not devoid of inclusions. The crystals are also crushed and unaligned. The modal analysis of the rock gives sillimanite 65%, quartz 30 %, magnetite and other accessories including muscovite 5 %.

The Pabiku-Oloya sillimanite quartzite ridge represents the second chain of ridges. This is about 1.5 Km east of Olarinde-Olojuoro-Apata chain and stretches for about 4.4 Km North-South and about 300 m wide. Some of the hand specimens show strong enrichment of sillimanite fibres alternating with quartz crystals (Plate 3). The sample is greyish in colour, foliated and thinly bedded, with iron oxide stains. The decrease in sillimanite content southwards towards Owoade and Adeosun is also evident as in Olojuoro ridge.

Pabiku sample has 73 % sillimanite, 23 % quartz, 2 % magnetite and 1 % accessory minerals while Oloya type has 70 % sillimanite, 26 % quartz and 4 % opaque/accessory minerals.

3. Materials and Methods

Seventeen core samples were collected from five boreholes drilled within the chains of ridges. At Olarinde, Olojuoro and Apata three samples each were collected for analysis while four samples each were collected from Pabiku and Oloya representing the second chain of ridges.

For petrographic study, samples were selected at various sites for thin sections. Photomicrographs were taken from some sections. Both chemical analysis and physical characteristics determination were carried out.

Determination of the major elemental abundance was done using Atomic Absorption Spectrometry (AAS), after total decomposition with mixture of HF-$HClO_4$-HNO_3. The Perkin Elmer model 305B was used.

In order to determine heat capacity and firing shrinkage value, firing tests were carried on sillimanite quartzite samples. Samples were crushed and pulverized (-100mesh). The samples were then made into bricks and subjected to a temperature of 1450 °C each for a period of four hours, and allowed to cool in a dessicator.

Specific gravity determination for fired and unfired samples was done using the pyconometer method. Empty specific gravity bottle B (g) was weighed and then filled with sample BS (g), making it up with water represented by mass BSW (g) . The contents were thereafter emptied and filled with only water for mass determination (BWg). Specific gravity was then determined using the formula

$$S.G = \frac{(BS\ B)\,g}{\{(BS + BW)\ (B + BSW)\}\,g}$$

The balance used was Metler balance, model P1210.

4. Results and Discussion

There is a general increase in SiO_2, from Olarinde through Olojuoro to Apata (between 35.32 % to 59.78 %) while there is an increase from 47.10% to 48.97 % considering the second chain of ridges i.e. from Pabiku to Oloya (Table 1). TiO_2 is highest for Olarinde (0.08 %), which is the same value for the other locations (0.05 %) except at Pabiku (0.03%). Al_2O_3 is highest for Olarinde (57.69%) and lowest at Apata (33.44 %) on the first chain of ridges, while there is a decrease in Al_2O_3 from Pabiku to Oloya (43.88 %-40.40 %). It is evident from these results that increase in SiO_2 contents is marked with a corresponding decrease in Al_2O_3 contents establishing an inverse proportionality between these contents of sillimanite. The first chain of sillimanite ridges has total Fe_2O_3 content ranging between 0.96 and 2.24 %. The highest value of Fe_2O_3 is recorded as 5.59 % at Oloya on the second chain of ridges.

The chemical distinctions between the sillimanite quartzites are shown in MnO, CaO, MgO, Na_2O, K_2O and P_2O_5 concentrations (Table 1). The TiO_2, Na_2O and K_2O contents are very low. This may be due to physico-chemical reactions which have taken place changing the mineralogy into a simple one, mostly sillimanite, quartz and little opaque minerals. The variation in the mineralogical and chemical compositions from North to South (Pabiku-Oloya) is not different from the first chain of ridges. The trends observed from the results are:

Table 1: Result of chemical analysis of Olojuoro Sillimanite quartzite samples.

Major oxides (wt. %)	LS10 (1,2,3) Average	LS9 (1,2,3) Average	LS4 (1,2,3) Average	LS8 (1,2,3,4) Average	LS12(1,2,3,4) Average	Typical sillimanite Industrial Specifications % Crookston and Fitzpatrick, 1983)
SiO_2	35.32	38.20	59.78	47.10	48.97	42.00
TiO_2	0.08	0.05	0.05	0.05	0.03	1.0-2.0
Al_2O_3	57.69	55.92	33.44	43.88	40.40	56.00
Fe_2O_3	1.62	0.96	2.24	1.60	5.59	1.00
MnO	0.05	0.04	0.07	0.01	0.02	-
CaO	1.12	0.55	0.56	0.70	0.56	0.1max
MgO	0.40	0.80	0.20	1.70	0.40	0.1max
Na_2O	0.01	0.03	0.01	0.50	0.48	0.03 for combined alkali
K_2O	0.01	0.05	0.05	0.80	0.78	-
P_2O_5	0.40	3.20	3.00	0.90	1.60	-
LOI	0.39	0.48	0.49	0.47	0.59	-
S.G	3.21	3.2	3.15	3.08	3.18	3.23

LOI - Loss on Ignition; S.G. - Specific Gravity; LS 10 - Samples from Olarinde; LS 9 - Samples from Olojuoro; LS 4 - Samples from Apata; LS 8 -Samples from Pabiku; LS12 - Sample from Oloya

Table 2: Average modal analysis of Olojuoro sillimanite quartzite.

Mineral	LS 10	LS 9	LS 4	LS 8	LS 12
Quartz	10	23	30	23	26
Sillimanite	85	75	65	73	70
Magnetite	3	2	2	3	-
Corundum	1	-	-	-	-
Opaque/ accessories	1	-	2	1	4
Total	100	100	99	100	100

Table 3: Changes in specific gravity of sillimanite quartzite of Olojuoro as a result of firing

Sillimanite type	Unfired S.G	Fired to 1,450 °C S.G
LS 10 (Average)	3.21	3.01
LS 9 (Average)	3.20	2.98
LS 4 (Average)	3.20	2.98
LS 12 (Average)	3.18	2.96
LS 8 (Average)	3.08	2.87

Fig 1: Accessibility map

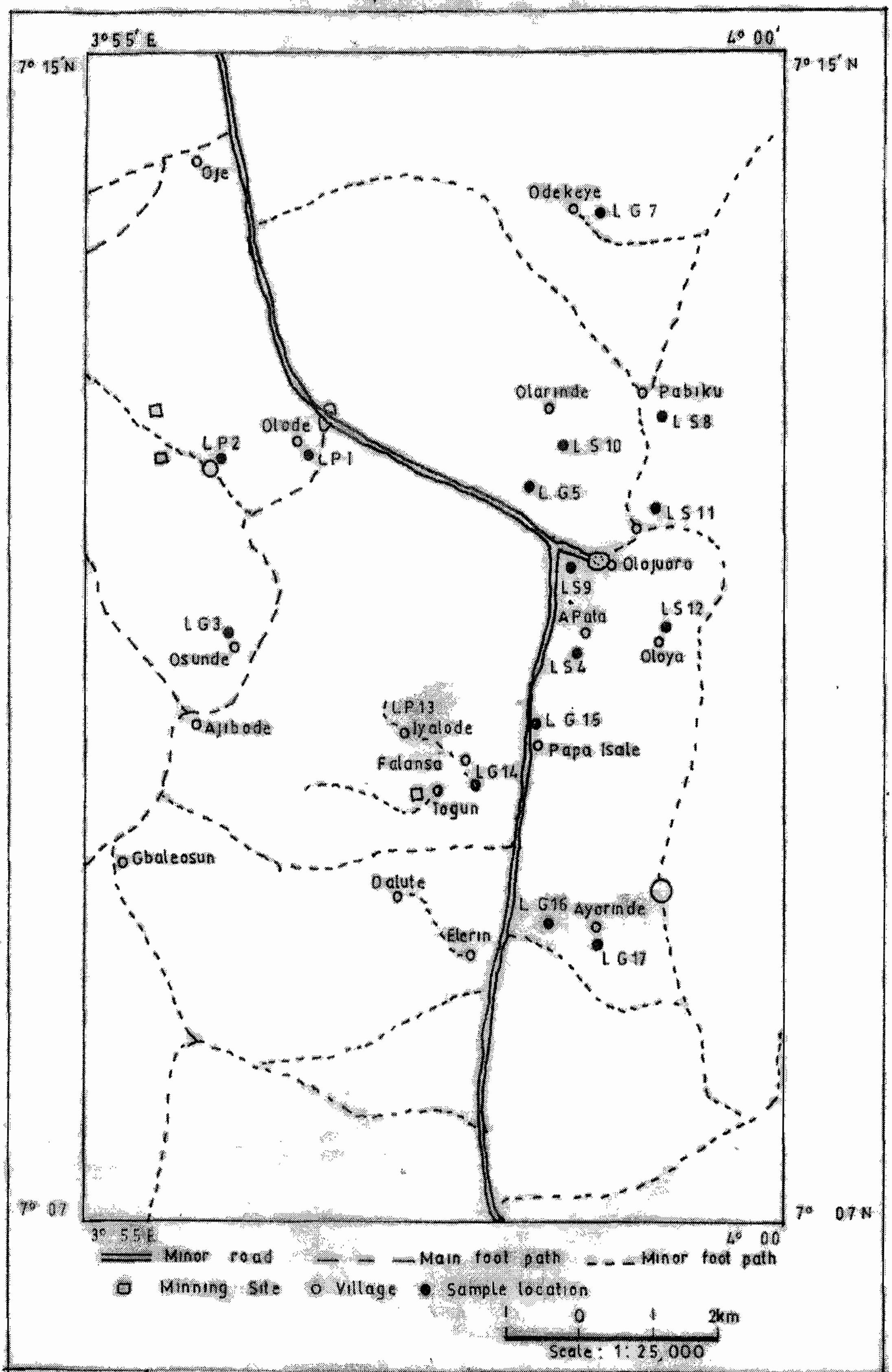


FIG 1 ACCESSIBILITY MAP

FIG. 2: Geological map of Olode area (Phillips, 1998)

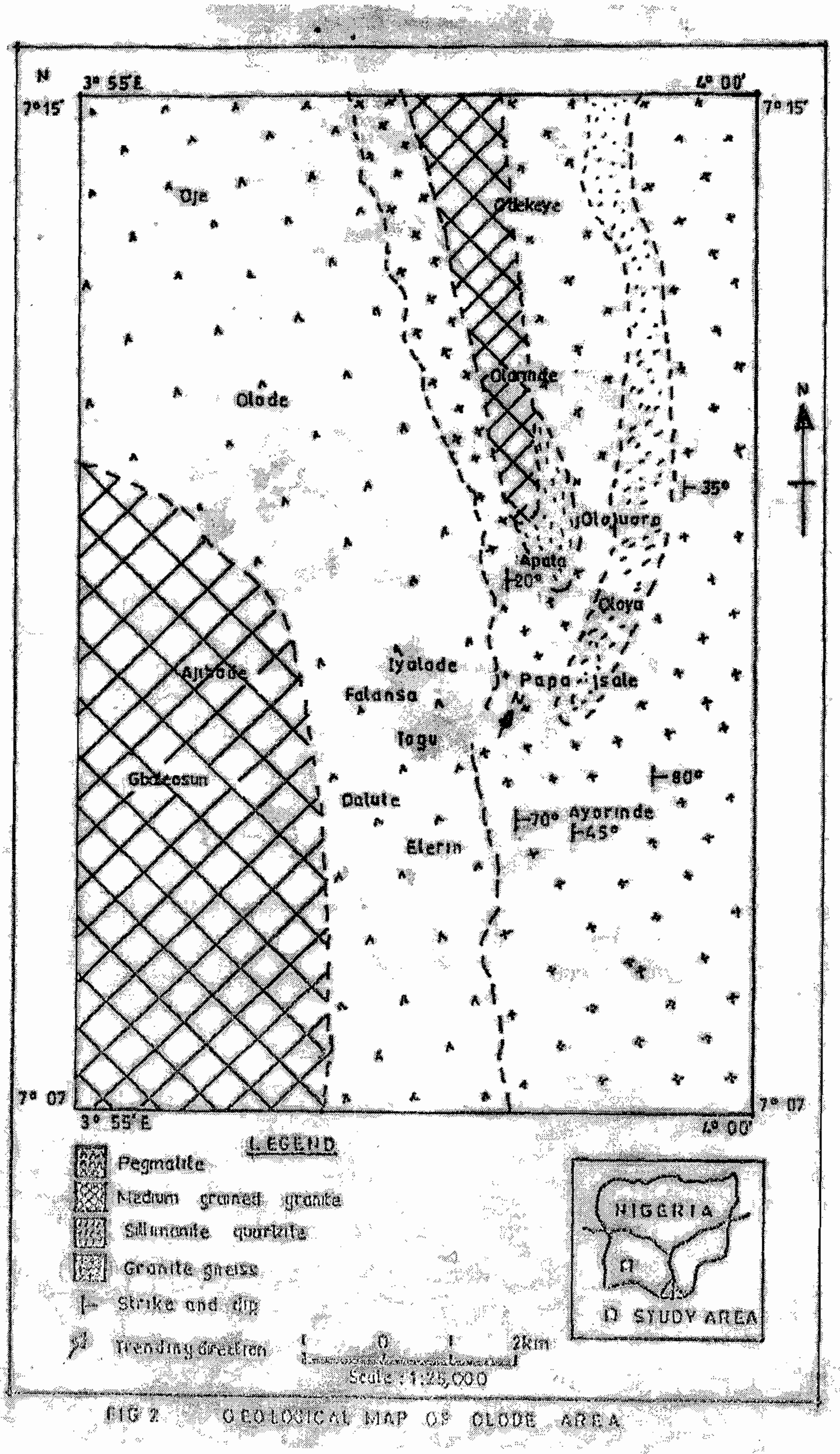
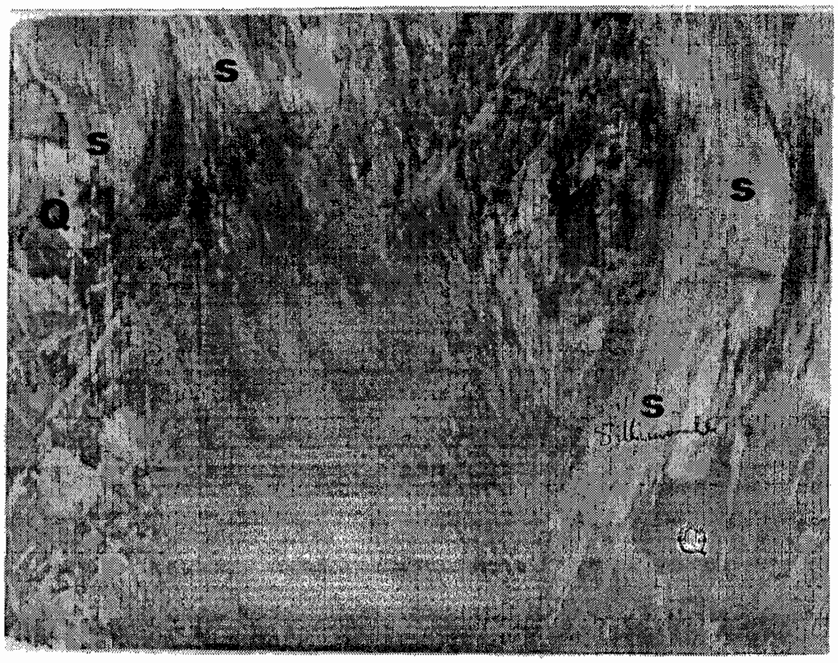


FIG 2 GEOLOGICAL MAP OF OLODE AREA

DESCRIPTION OF PLATES



Q = Quartz
S = Sillimanite
M = Muscovite

Plate 1: Sillimanite quartzite from Olarinde showing extensive sillimanite mineralization
Cross-polars. Magnification- 2.28 x 3.10 mm

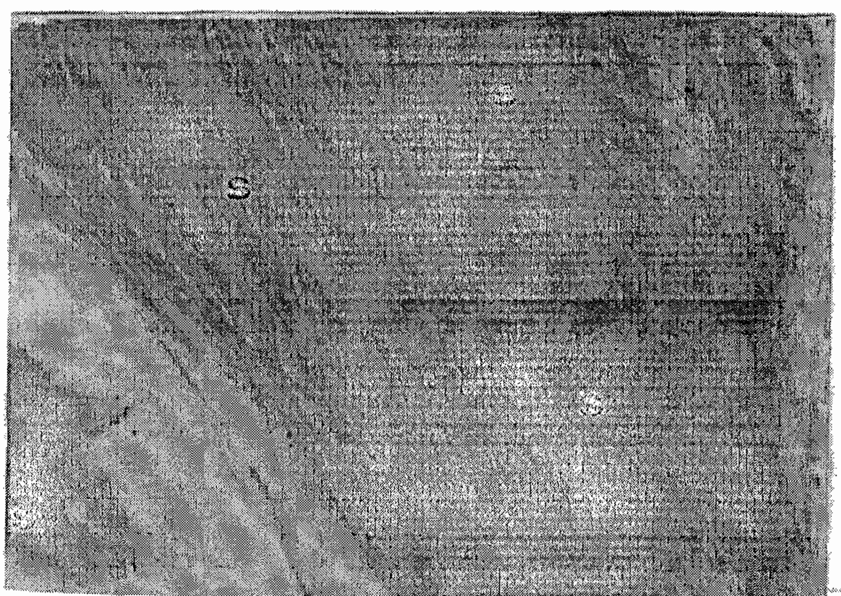


Plate 2: Sillimanite quartzite from Olojuoro showing its acicular nature as observed under plain polarized light
Magnification- 2.28 x 3.10 mm

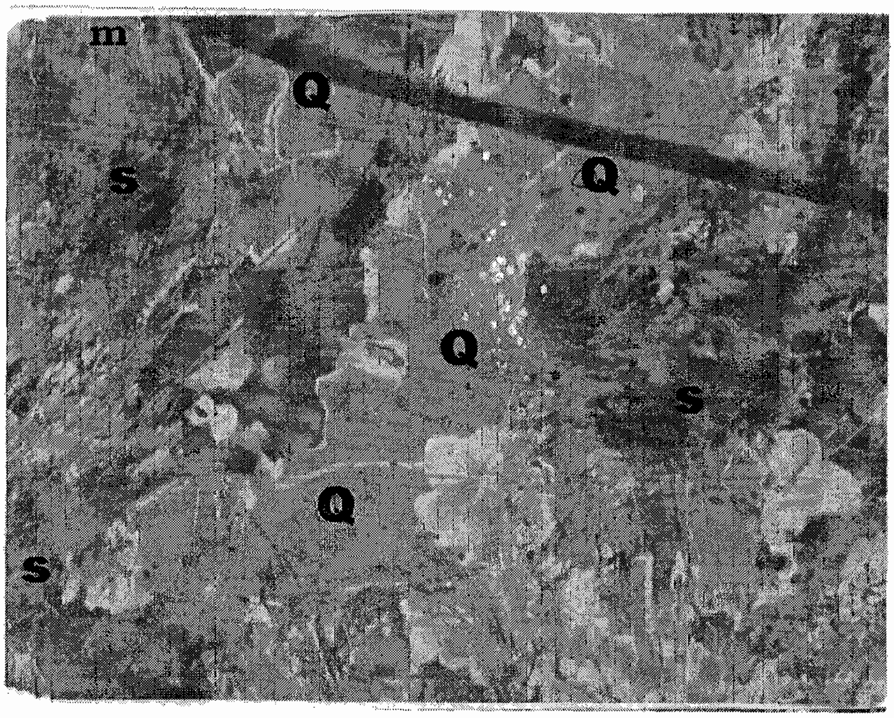


Plate 3: Sillimanite quartzite from Apata showing quartz in preferred orientation
with few flakes of muscovite
Cross-polars Magnification- 2.28 x 3.10 mm

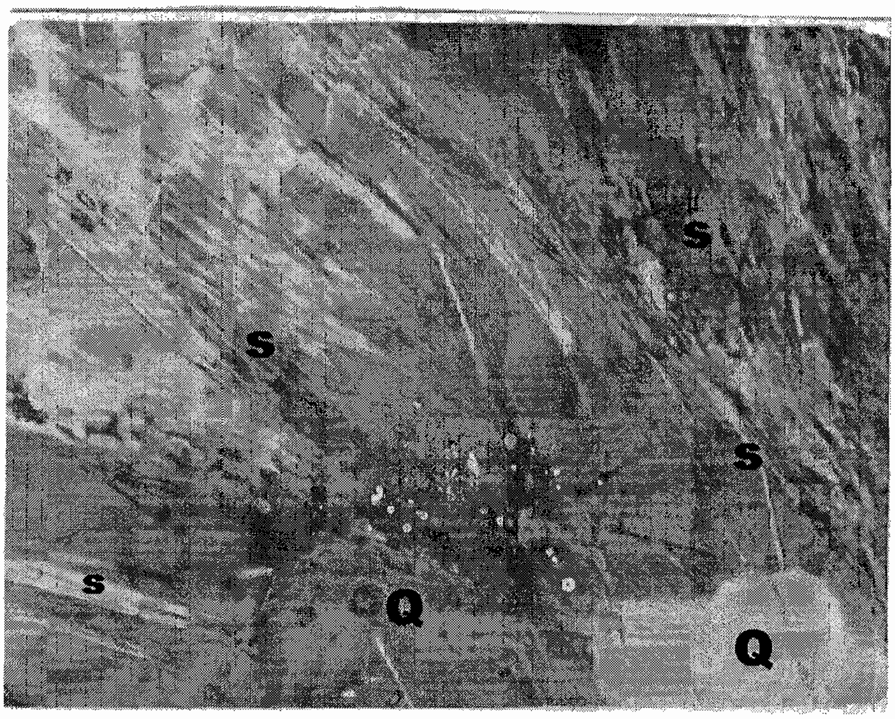


Plate 4: Sillimanite quartzite from Oloya
Cross-polars Magnification- 2.28 x 3.10 mm

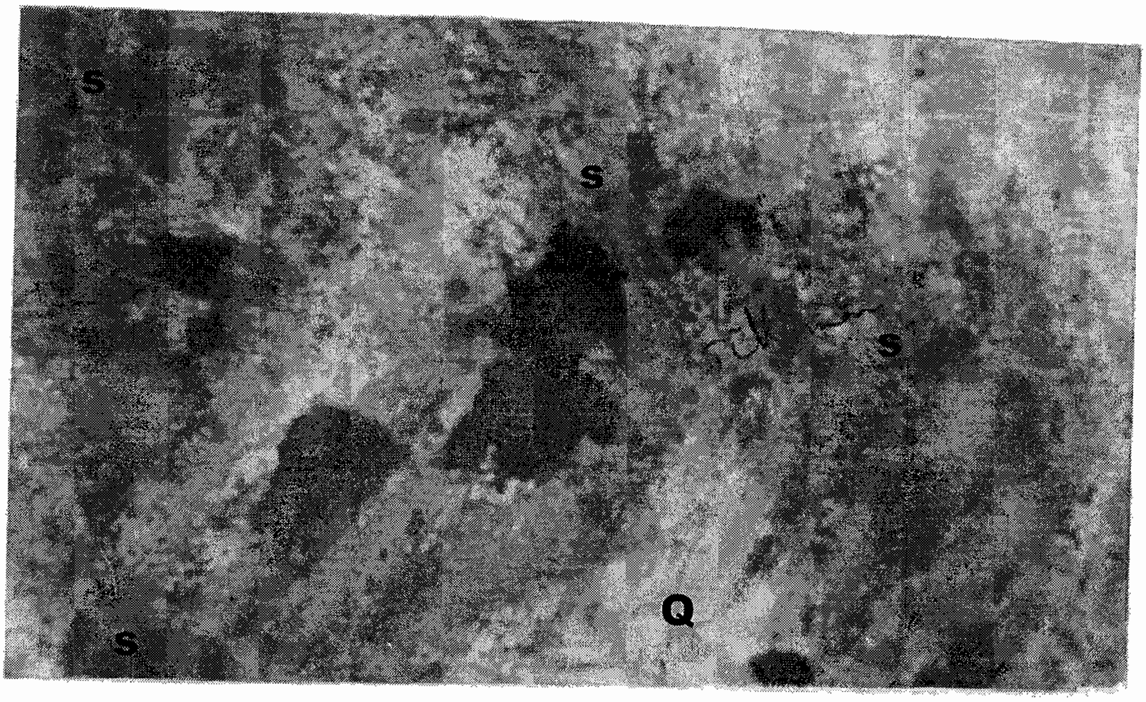


Plate 5: Sillimanite quartzite from Pabiku
Cross-polars. Magnification- 2.28 x 3.10 mm

a. A general decrease of sillimanite content from Olarinde-Olojuoro to Apata i.e. southwards. Also there is increase in free quartz in the same order.
b. A decrease of magnetite and corundum contents and a preferred alignment of sillimanite fibres southwards.
c. An increase in the Al_2O_3 from 33.44% to 55.92% while there is a decrease in the total SiO_2 from 59.78% to 35.32%. This is not unexpected since the total silica is the combined free silica and the silica of the individual sillimanite crystals (See the equation below)

$$\underset{}{KAl_2[Si_3AlO_{10}](OH)_2} + \underset{\text{Quartz}}{SiO_2} \longrightarrow \underset{\text{K-Feldspar}}{KAlSi_3O_8} + \underset{\text{Sillimanite}}{Al_2SiO_5} + \underset{\text{Water}}{H_2O}$$

The higher the sillimanite the more the alumina percentage and there is a corresponding decrease in the silica percentage. The equation above could imply that the silica content was reduced during the formation of sillimanite from mica since quartz is consumed during the transformation. The specific gravity values determined fall within the ranges for standard values. The individual values for sillimanite quartzites range from 3.08 to 3.2 for the unfired samples. After been subjected to firing at 1,450 °C the values decreased from 3.01 to 2.87 (Table 3). Microscopically, sillimanite shows no dissociation when subjected to firing test. The change in the specific gravity due to firing, therefore would seem to be due to the production of fine microscopic or submicroscopic cracks caused by the natural thermal expansion with increasing temperature or perhaps more likely still, to volume changes in the associated minerals which were present in small amounts (Anon, 1961). The least change in specific gravity is recognized in sample from Olarinde (LS10), which may give indication of its industrial superiority over others.

5. Conclusion and Recommendations

The sillimanite group of minerals in general belong to high alumina refractories, which are alumina-silica refractories containing close to 50% or more of alumina. When they are used as refractory bricks, they are classified in accordance with their alumina contents. The typical industrial specifications *(Table 1)* from the chemical analysis show that the sillimanite from these chains of ridges have industrial application. The firing temperature for the sillimanite samples is 1450 °C. At this point there was no fusion. The sillimanite quartzite will likely withstand the high temperatures required for a high alumina refractory. Plastic and ramming mixes used to repair refractory installations also have sillimanite constituting 10-40% of the mixtures while the rest is refractory clays and coarser grog material (Chesters, 1963).

Increasingly, users of refractories have been more willing to accept higher first costs provided that the refractory item gives increased life or otherwise contributes to lower refractory cost per unit of products being produced (Anon, 1961). Thus for example, high alumina refractories (sillimanite, kyanite, andalusite, and product mullite) are gradually replacing fire clay refractories in some applications. Infact, sillimanite is often of high chemical purity although may be expensive but the cost will be made-up for considering the cost per unit products being produced.
Considering the typical industrial specification of sillimanite, it can be said that the sillimanite quartzite at Olojuoro can be exploited economically with little beneficiation. Olojuoro is easily accessible but short roads will have to be constructed to the ridges. It is believed that if appropriate/adequate attention is channelled towards the production of sillimanite, it will serve as a great booster to the Nigerian economy as some of the ridges stretch for as long as 2.5 km and as wide as 500 m.

Acknowledgement

The moral encouragement and viable criticism received from Dr. Olugbenga Okunlola of the University of Ibadan is greatly acknowledged.

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