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Geometallurgical Evaluation of Itapa Ekiti Feldspathic-Biotite Ore Deposit for Effective Processing and Extraction

Ajibola Olawale Olarewaju[1,*], Boluwade Edward Ayodele[2], Borisade Sunday Gbenga[1]

[1]Department of Materials and Metallurgical Engineering, Federal University Oye Ekiti, Oye Ekiti, Nigeria
[2]Department of Minerals and Petroleum Resources Engineering Tech., Federal Polytechnic, Ado Ekiti, Nigeria

Abstract This work reports the result of a mineralogical investigation of the Itapa Ekiti rock samples. Samples were collected from six locations within the town. The physical properties (colour, streak, and hardness) of their mineral contents were evaluated. The crushing strength was determined and the chemical analysis by Atomic absorption spectrometry techniques was used. The petrologic analysis shows that the rock is highly mineralised. The results revealed about seventeen metals are present in the rock samples which are mostly dominated by alkali and alkali earth metals such as 7.4% Na, 5.8% K, 7.6% Mg and 6.5% Ca with other heavy metal associates like 5.1% Zn, 5.4% Fe, 5.1% Cu and 2.7% Ni. This provides useful information on the Itapa Ekiti rocks for the exploration and exploitation of these vast industrial minerals.

Keywords Mineralogy, Itapa Ekiti, Feldspathic-Biotite Rock, Mineral Processing

1. Introduction

The availability of sufficient information of the geology, mineralogy of ore and ore texture assist in the effective design of concentration flow-sheet. More importantly, these characteristics facilitate setting the proper grinding size to get required liberation and reduce over-grinding, and help out in discovering correct concentration (flotation) constraints to achieve the optimum mineral separation [1].

A vast number of reports of research work had been published over the years on the geological exploration [2, 3], mining survey [4, 5] and metallurgical exploitation (mineral processing and extraction) [6-11] of numerous mineral deposits discovered across the boundaries of Nigeria. The major focuses of such reports were to develop theses mineral for economic applications [12].

Ekiti being one of the developing states among the 36 states in Nigeria, presently involved and striving in the establishment of various manufacturing and construction industries some of which may require the use of very large quantity of many industrial minerals and rocks present in the geographic area. Ekiti state is covered with vegetation and rocks that has been formed through the cooling solidification of magma which might have under gone the processes of metamorphic rock formation [13].

* Corresponding author:
olawale.ajibola@fuoye.edu.ng (Ajibola Olawale Olarewaju)
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Itapa Ekiti is one of the many towns located in Oye Local Government of the Ekiti state on the Lat 7°, 48'N and Long 5°, 23'E (Figure 1). It is surrounded by rocks that are predominantly granite and believed to have been exposed through several years of erosion activities. Geographically, the terrain of Itapa Ekiti and its environs belong to complex basement that are characteristically metaigneous [14]. Literatures are scarcely available on the record of research works done on the economic minerals present in Itapa Ekiti. Also the quest to search for more industrial minerals in Ekiti state have daily motivated the industrial mineral engineers and geoscientist in finding out some of the economic minerals present in Itapa Ekiti rocks.

Intrusive igneous rocks form very good engineering materials, possessing high crushing strength and shearing strength especially when they are fresh and un-weathered, unless they are minutely fractured. They make a good source of concrete aggregate and typical construction materials. Paying much attention to jointing and possible faulting, weathering along fractures, some tests may be necessary before using it for engineering construction. On the other hand, the engineering properties of sedimentary rocks depend largely on the degree of compaction, consolidation and cementation, these, which determine the hardness, crushing strength and shearing resistance (Strength) of the rocks. Metamorphic rocks share structural complexity in both physical and chemical properties and hence, make it impossible to generalize their engineering properties.

It is necessary to assess the suitability of the Itapa rock through geochemical and petrographic study for the abundance of the Precambrian ore in Ekiti State, Nigeria and for their economic potential in building construction and extractive industry.

2. Methodology

2.1. Materials Sampling

A total of 36 rock samples were collected from six (6) different locations within Itapa Ekiti and the samples were labelled A11-A16, B11-B16, C11-C16, D21-D26, E11-E16 and F11-F16.

Sample designations	Locations of Sampling	Mineralogy
A11-A16	Ikole road area	Plate 1
B11-B16	Oba palace area	Plate 2
C11-C16	Methodist church area	Plate 3
D21-D26	Itapa town extreme	Plate 4
E11-E16	Oye road area	Plate 5
F11-F16	Itapa town center	Plate 6

2.2. Equipment and Materials

Some of the equipment used for the experiment include: Denver jaw crusher, pulverizer, (vibrating mill), sieve shaker, streak plate and hardness test (durometer), hydraulic compressive strength tester, Petrologic photo-microscope and Atomic Absorption spectrometer (AAS). Standard grades of HCl, HF, HNO_3 Boric acid and lanthanium chloride were all purchased from the chemical store.

2.3. Experimental Procedure

(A) Physical Properties Determination

The following physical examinations were carried out on the six (6) samples (A, B, C, D, E and F) of Itapa-Ekiti rocks. Each of the properties carried out include: colour, lustre, streak hardness, crushing strength, cleavage, texture, and the results were presented in Table 1.

(i.) Colour: Some mineral can be easily identified just from their colour. The variation of colour in most minerals is due to atomic substitution or presence of impurities. Colour alone is not usually sufficient to identify and distinguish a mineral.

(ii.) Lustre: This is the behaviour of the minerals to reflection or absorption of light incident on them which gives it a characteristic appearance. The mineral which will allow the passage of light through it or the edges are said to have non-metallic lustre and are further described as: vitreous or glassy, resinous, silky, pearly, adamonite and waxy or greasy

(iii.) Streak: This is the colour that is obtained when a mineral is grinded to powder. It is different from the initial and usual colour of the mineral itself. The mineral is rubbed across a streak plate, and will leave a trail of powder on the plate.

(iv.) Hardness test: The hardness tests of samples are determined using Brinell Hardness Testing Machine and the values are calculated from equation (1)

$$BHN = F/[(\pi D/2)(D-\sqrt{(D^2-D_i^2)})] \quad (1)$$

where BHN = the Brinell hardness number
F = imposed load in kg
D = diameter of the spherical indenter in mm
Di = diameter of the resulting indenter impression in mm

(v.) Crushing strength: It is carried out by placing the specimen on a flat surface followed by application of a uniform load to it through a bearing block in a standard mechanical or hydraulic compression testing machine. The load at which cracks appear in the refractory specimen represents the CCS of the specimen. It is determined as (2)

$$CCS = F/A^2 \quad (2)$$

where F = Applied load, A= Cross sectional area of specimen

(vi.) Cleavage: Mineral shows cleavage when it breaks along smooth surfaces in definite directions. The surfaces can be easily seen due to the reflection of light. Cleavage is usually described as perfect, good, fair or poor together with the direction of cleavage.

(B) Leaching of Rock Samples

Each of the six rock samples were crushed and milled to fine particles using the laboratory size jaw crusher and the vibrating mill. The grinded samples were sieved to obtain -63μm particle size. 1.0g of each of the samples A, B, C, D, E and F were weighed into a 100 ml plastic container in which 5 ml HF was added. 10 ml of aqua-regia (HNO_3) was also added. The containers and their contents were heated up on a stream boiler for 45 minutes. 5 ml saturated solution of boric acid was then added to each of the boiled rock solutions. After, the samples were made up to the mark with distilled water (100 ml) and lanthanum chloride solution was added to prevent interferences during AAS analysis. The AAS analysis calibration stock standard was taken to be 10 ppm for each of metals analyzed. For the instrumentation, a bulk model 200AA flame system was used, air – acetylene were used for all metals. Normal instrumental parameters were employed for all the analysis. Equation (3) was used to determine the AAS parameters of the rock samples and the results were presented in Table 2.

$$\text{Metal content (ppm)} = (R*V*D_f) / Wt_{sample} \quad (3)$$

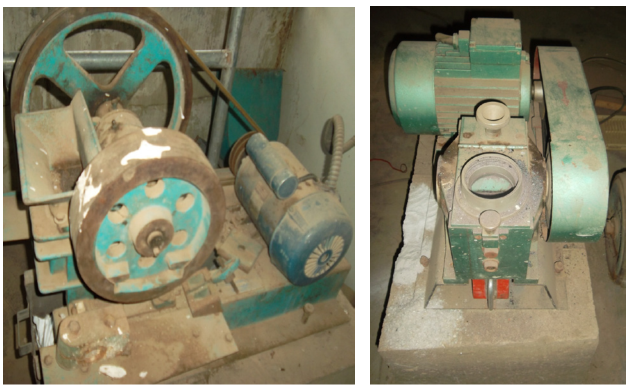
where R= Sample reading /Standard reading,
V = Vol. of solution = 100 ml,
D_f = Dilution factor = 10.
Wt_{sample} = Weight of sample

2.4. Particle Size Analysis

About 500g of the sample was weighed, crushed and grinded using the Denver jaw crusher and vibrating mill (Figure 2 a, b). This test involves passing a (500g) representative crushed sample through a set of sieves (4750 to 63 μm aperture) arranged in descending order with the largest sieve size at the top. The sieves were clamped on the sieve shaker for about 15 minutes. The sieves were later removed and reweighed with their corresponding contents. The undersize crushed particle size range was selected between (-212 to -63) while the oversize (+425 to +212 µm) was take for secondary reduction (grinding). In each of the comminution stage the he quantity of weight retained (% R) in each screen is determined as in (4):

$$\text{Percentage of weight retained (\%R)} = \frac{w_3 - w_2}{w_1} \times 100 \quad (4)$$

where W_1 = weight of sample used
W_2 = weight of empty sieve
W_3 = weight of sieve + sample
$W_3 - W_2$ = weight of sample retained.



(a) (b)

Figure 2. Crushing (a) and (b) grinding equipments

3. Results and Discussion

The results of the physical properties of the Itapa Ekiti rock samples revealed the six rock samples have very close physical characteristics.

Table 1 shows that the samples collected from different locations within deposit in the township have an average hardness value of 6.75 on the Rockwell scale. This value is very close to a generally accepted hardness value for quartz (7.0) and olivine (6.5-7.0) as reported by Burchefield [15]. The colour varies from brownish red to dark brown. A typical rock may contain alternating lighter layer (leuocosome) such as feldspar and quartz in combination of dark layer (melanosome) such as biotite [3, 16]. The mineral lustre is glassy while the streak varies from whitish to buff colour. A fairly high crushing strength (kN/mm^2) ranging from 49.32 to 50.19 (kN/mm^2). The cleavage varies from low faint to faint while the texture varies from fine to medium. The fracture patterns observed are defined by parallel and sheets characteristics.

The investigated rock specimens in Table 1 could be relatively compared with any known igneous rock or rather an hybrid metamorphic igneous rock [17, 18] It is known and established that igneous rocks are made up of silicate minerals, and often in crystalline forms of coarse or medium grain size like quartz and feldspar [3]. Quartz identified as greyish glassy looking, harder than steel while feldspar present in igneous rocks are orthoclase, having pink to white crystals. According to Carlos et al, [19], rich occurrences of quartz and feldspar may indicate that leucosome is present in such selected rock. The plagioclase is greyish white both are harder than steel and show low faint cleavage planes according to Raymond [20]. It has been established that plagioclase are common in granitic pegmatite and the granite stuffs according to Berry, [21].

The geochemical analysis some selected outcrop of Itapa Ekiti rock samples are presented in Table 2. The average values (%) of seventeen major metals identified in the samples signify the richness of metallic minerals present in the samples. Large scale rich deposits of Pb-Zn sulphide complex ore and Iron ore have been for long discovered and explored in the country [11, 12]. In the same vein, the Itapa Ekiti rocks is containing very high amount of Pb, Zn, Fe, Cr, Cu, Al and Ni containing minerals beside the alkali metals (Mg, Ca, K, Na) in the sample.

Apart from the available information on mineralogy of ore, the ore texture helps out in the effective design of separation flow-sheet. For an efficient metallurgical exploitation of any mineral proper particle sizing are required in the liberation and in reducing over-grinding.

Table 1. Mineral Physical Identification Properties (MPIP) of Itapa rock samples

Mineral properties	A	B	C	D	E	F
Colour	Dark brown	Brown	Dark brown	Dark brown	Brownish red	Very dark brown
Lustre	Glassy	Glassy	Glassy	Glassy	Glassy	Glassy
Streak	Grey	Whitish	Smoky grey	Greyish -white	Pink white	Buff colour
Hardness	6.75	6.7	6.75	6.74	6.68	6.73
Crushing strength (kN/mm^2)	50.07	49.32	50.01	50.06	49.47	50.19
Cleavage	Low faint	Low faint	Faint	Faint	Low faint	Faint
Texture	Fine	Fine	Medium	Fine	Fine	Fine
Fracture	Parallel	Sheets	parallel	Parallel	Sheets	parallel

These as well help out in discovering correct concentration (flotation) control parameters required to optimise the mineral separation. The particle size distribution of crushed rock sample is presented in Table 3. It is obvious that the liberation posed no difficulty despite the average hardness value of 6.75 and fairly high crushing strength (49.32 - 50.19 kN/mm^2).

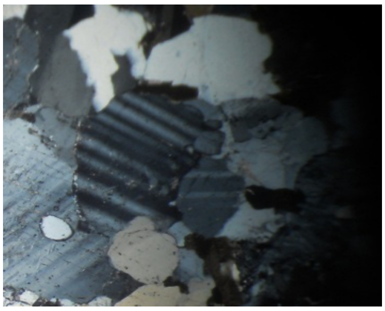
The sieve analysis in Table 3 shows that not less than 45% (225.05 g) of the crushed rock particles reported as undersize (-212 to -63 µm) in a single stream of size reduction using a laboratory size Denver jaw crusher.

From about 32.55% (162.75 g) of the size -600 to +212 µm returned for grinding in the vibrating mill, 61.11% (99.46 g) was reported as undersize (-212 to -63 µm) in a single stream of size reduction (grinding). Egunlae and Oluwaseyi [22] as well as Ajibola et al. [11] had earlier reported the successful flotation of -212 ~ +75 µm PbS/Zns particles. Hence there is much prospect in the comminution of these minerals for flotation and extraction purposes.

3.1. Analyses of Rock Sample

The petrographs and the mineral contents of selected rock samples are reflected in Plates 1-6 and in Table 4. The photo-petrologic of the mineral thin sections are examined as the cross polar and plane polar views.

Cross polar



Plane polar

Plate 1. Petrography of Itapa Ekiti rock (Sample A12) x80 mag

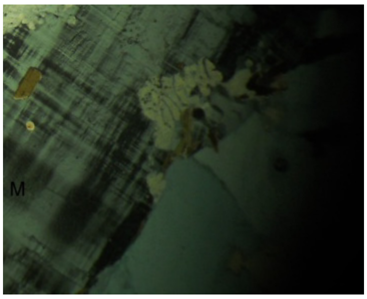
Table 2. Geochemical analysis of Itapa Ekiti rock samples

Metals	A (x10%)	B (x10%)	C (x10%)	D (x10%)	E (x10%)	Average
Si	0.15	0.18	0.15	0.16	0.13	0.154
Zn	0.51	0.51	0.49	0.45	0.49	0.49
Pb	0.17	0.14	0.11	0.18	0.11	0.142
Ba	0.09	0.05	0.11	0.07	0.11	0.086
Fe	0.52	0.54	0.41	0.46	0.53	0.492
Mg	0.71	0.68	0.72	0.67	0.76	0.708
Ca	0.63	0.57	0.65	0.54	0.63	0.604
Na	0.65	0.71	0.63	0.48	0.74	0.642
K	0.58	0.52	0.57	0.61	0.50	0.556
Mn	0.10	0.13	0.14	0.09	0.07	0.106
Ti	0.11	0.17	0.14	0.19	0.22	0.166
Zr	0.08	0.06	0.03	0.08	0.02	0.054
Cr	0.13	0.11	0.08	0.15	0.15	0.124
Cu	0.46	0.21	0.33	0.51	0.27	0.356
Al	0.19	0.22	0.22	0.18	0.14	0.190
Ni	0.21	0.27	0.18	0.20	0.17	0.206
Li	0.07	0.06	0.09	0.01	0.03	0.052

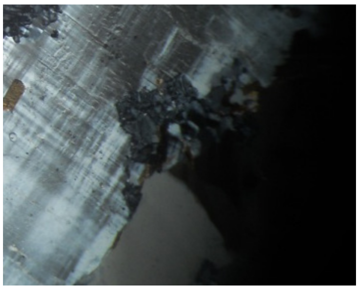
Table 3. Particle size (µm) distribution of crushed rock sample

Sieve range (µm)	+4750 +1180	-1180 +850	-850 +600	-600 +425	-425 +300	-300 +212	-212 +180	-180 +150	-150 +75	-75 +63	-63
Wt. (%R)j$_c$	5.78	7.15	9.51	10.03	11.71	10.81	16.21	14.86	9.08	3.72	1.14
Wt. (%R)$_g$	-	-	-	13.71	11.02	14.16	11.72	10.34	16.81	15.21	7.03

c- crushing, g-grinding

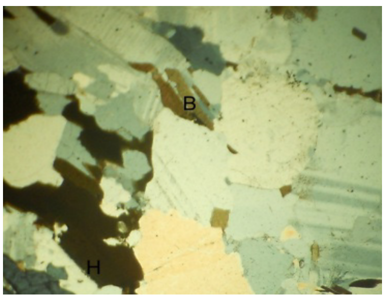


Cross polar

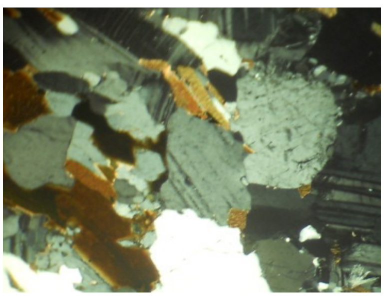


Plane polar

Plate 2. Petrography of Itapa Ekiti rock (Sample B16) x80 mag

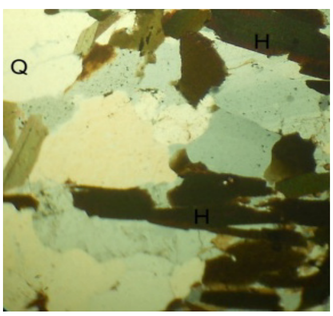


Cross polar

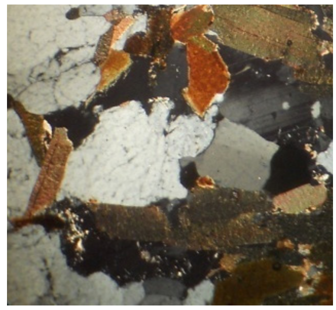


Plane polar

Plate 3. Petrography of Itapa Ekiti rock (Sample C11) x80 mag

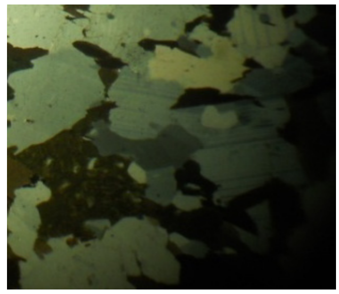


Cross polar

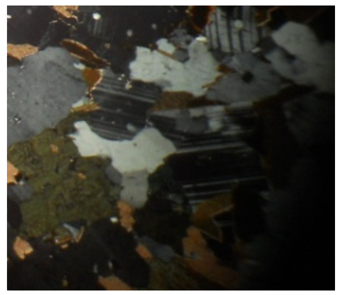


Plane polar

Plate 4. Petrography of Itapa Ekiti rock (Sample D24) x80 mag

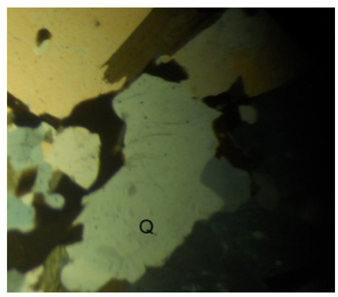


Cross polar

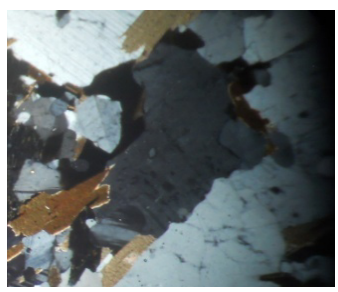


Plane polar

Plate 5. Petrography of Itapa Ekiti rock (Sample E13) x80 mag



Cross polar



Plane polar

Plate 6. Petrography of Itapa Ekiti rock (Sample F12) x80 mag

The combination of the petrographs and the geochemical analysis show that the rock is highly mineralised. Different types of minerals such as quartz, plagioclase, microcline, biotite, hornblende and opaque minerals are found in the deposit. As observed in the petrographs (Plates 1-6) and in the mineral contents of selected rock samples in Table 4, the presence of opaque minerals suggests the presence of metallic minerals in the deposit.

From Table 2, the results of geochemical analysis revealed that about seventeen metals were identified to be present in large quantities within the ore body. The ore is primarily dominated by the alkali and alkali earth metals such as Na, K, Mg and Ca with about 0.65%, 0.58%, 0.71% and 0.63% content respectively. Apart from the alkali metals, the ore (rocks) could be assessed to be rich in-other metals having 0.51% Zn, 0.52% Fe, 0.46% Cu and 0.21% Ni. The vast number and occurrences of other metals in smaller quantities within the rocks samples could be explained from the understanding of rock metamorphism. For metamorphic rocks, heat and pressure may cause the chemical elements in the original rock to react and reform into new minerals. In this process, no elements are added to or taken away from the original elements simply re-arranged to suit new conditions [3, 19, 21].

Table 4. Mineral contents of selected rock samples

Plates	Designations	Mineral contents
Plate 1	A12	quartz (28.2%), plagioclase (26.5%), microcline (18.6%), biotite (16%), hornblende (9.4%), opaque (1.3%),
Plate 2	B16	quartz (30.1%), plagioclase (24.5%), microcline (17.4), biotite (17.2%), hornblende (8.2%), opaque (2.6%),
Plate 3	C11	quartz (31.4%), plagioclase (27.6%), microcline (19.2%), biotite (10.2%), hornblende (9.8%), opaque (1.8%),
Plate 4	D24	quartz (31.4%), plagioclase (30.6%), microcline (19.8%), biotite (12.2%), hornblende (5.1%), opaque (0.9%),
Plate 5	E13	quartz (24.6%), plagioclase (33.4%), microcline (20.2%), biotite (13.5%), hornblende (6.2%), opaque (2.1%),
Plate 6:	F12	quartz (22.4%),plagioclase (40.6%), microcline (21.4%), biotite (10.4%), hornblende (4.6%), opaque (0.6%),

Although metamorphism may involve great heat, the rock does not melt as it changes [15]. Hence, the high percentage of alkali and alkali earth metals like Na, K, Mg, Ca, Ba, Si, Fe and Li present in the ore (Table 2) points to the fact that such igneous rock is composed largely of quartz and alkali feldspar.

Apart from using the rocks in engineering constructions works, the occurrence of a large number of heavy and transition metals such as Ti, Cr, Mn, Fe, Ni, Cu, Zn, and Al shows that the rocks samples are rich in other economic minerals from which these valuable metals could be won for industrial use.

Lead is found as Galena PbS, (regularly with sphalerite, chalcopyrite, pyrite, tetrahedrite, and gangue minerals such as calcite, quartz. It is also in pegmatites, and in the company of garnets, rhodonite, feldspar, diopside and biotite. Copper in most cases occurs as Chalcopyrite CuFeS, Bornite Cu_5FeS_4, Chalcocite Cu_2S, Covellite CuS, (but most often in veins in the midst of other sulphides, such as galena, sphalerite, pyrrhotite, pyrite, and also cassiterite, common gangue minerals quartz, calcite, dolomite. disseminated amid bornite and pyrite in porphyry copper deposits).

Table 5. Some Engineering Applications of the Metal Values

Metals	Applications
Zn	galvanizing, electrodes in dry cell, alloying
Pb	plumber glue, accumulators, lead shot, bullet proof
Fe	steel and alloyed steels
Ba	coating electrical conductors, filler for rubber products, in fireworks, and in rat poisons.
Mg	Alloying element
Ca	Food supplements
Zr	Refractory
Cr	alloying, coating
Cu	electric cable, alloying, bronze & brass
Ni	alloying, coating
Li	light weight batteries, brazing alloys, Potline
Al	electric cable, automotive engines
Si	alloying
Mn	alloying,
Ti	paint pigments, welding-rod, coatings

Some principal minerals of Nickel are pentlandite (FeNi)S, garnierite (hydrated Ni-Mg silicate) and millerite NiS with other nickel minerals and sulphides. Zinc minerals occur as Sphalerite ZnS, (associated with pyrrhotite, pyrite and magnetite), Hemimorphite (Calamine) $Zn_4Si_2O_7.(OH)_2.H_2O$ (the sulphides of zinc, iron, and lead), Smithsonite $ZnCO_3$ (sphalerite, galena, and calcite) Marmatite (Zn, Fe)S (associate with galena). Some engineering applications of some of the metal values that could be explored economically are shown in Table 5.

4. Conclusions

Petrologic analysis shows that the rock is highly mineralised. The geochemical mineral analysis revealed that seventeen metals were identified. This work provides useful and meaningful information on the presence of valuable metals in Itapa Ekiti rocks. It also draws the awareness of the government and other investors to this locality for the commencement of exploration and exploitation of these vast industrial minerals and metals available in Ekiti State, Nigeria. The rocks are granitic, useful for construction materials such as crushed rock, polished rocks and aggregates. Since the recycling of metals from discarded scraps cannot meet the demand for metals and alloys needed in Nigeria, more efforts should be drawn toward boosting the production preferably by hydrometallurgical route and electrometallurgical processes. Studies are still on going on the process design for the cost effectiveness of the whole metallurgical processes in order to validate the economic profitability of the processing for free enterprise development.

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