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Geology and Economic Evaluation of Odobola, Ogodo Feldspar Mineral Deposit, Ajaokuta Local Government Area, Kogi State, Nigeria

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Abstract

The Odobola, Ogodo area is part of the basement complex of Nigeria and is underlain mainly by schists and intrusive granitic and pegmatitic rocks along with sediments weathered from these rocks. The granitic and pegmatitic intrusives are source of feldspar with a significant K_2O component (k-feldspar). A study of the area reveals the occurrence of feldspar deposit hosted by granitic and pegmatitic intrusives. Geochemical data for the feldspar samples show average Si_2O, Al_2O, K_2O, Na_2O, CaO, Fe_2O_3, MgO and TiO_2 contents of 65.81wt%, 16.67wt%, 10.67wt%, 5.83wt%, 0.02wt%, 0.26wt%, 0.5wt% and < 0.001wt% respectively while mineralogical results reveals average anorthite, orthoclase and albite contents of 0.42%, 85.40% and 14.06% respectively. The results of the analyses compared with those of the British international Standard (BIS) shows that the feldspar deposit can be used in industries such as glass, ceramic tiles, sanitary wares and insulators. Field and petrographic evidence show that the area is a potential source of gemstones such as tourmaline and tantalite. Mineral Resource and Reserve Estimation classify the feldspar resource as an estimated proven feldspar-bearing Reserve of about 119Million tons. Apart from feldspar, inferred Minerals Resource of quartz, tantalite and tourmaline can also be obtained from this area.

Keywords: Odobola, Ogodo, K-feldspar, pegmatitic intrusives, mineral resource, reserve estimation

1. Introduction

The Nigerian basement complex consists of Eburnean granite and metamorphic rocks into which are folded Upper Proterozoic supra-crustal low grade metasediments and metavolcanic rocks forming N-S elongated belts. Pan-African granitoids mark the last major event and they have intrusive and/or tectonic relationships with the earlier units (Woakes et al., 1989). The Pan-African granitoids and pegmatites which intrude these rocks are a paucity of industrial materials occurrences. The Nigerian Geological Survey Agency has been responsible for the regional mapping and surveys which provide an invaluable base for more detailed surveys and exploration of industrial minerals in the country.

It is suggested that Nigeria's relatively low industrial minerals production from the basement rocks is as a result of lack of comprehensive and reliable data about these deposits. Also, depending on oil as its main source of revenue, solid mineral sector which can complement revenue generation has been neglected. In order to provide comprehensive and reliable data on industrial minerals potential of parts of the country, the Odobola, Ogodo feldspar mineral deposits hosted by granites and pegmatites was chosen for this study.

Apart from containing rare earth elements and gemstones such as tourmaline, tantalite, topaz and aquamarine, pegmatites usually contain crystals of quartz, feldspar and mica in quantities of economic value. The feldspar, quartz and mica usually occur in different varieties and with different physical and chemical properties suitable for different industrial purposes (Scott, 1983). This work therefore evaluates the feldspars and related minerals associated with the granitic and pegmatitic intrusive rocks of Odobola, Ogodo in order to classify and quantify them and to decide whether the data produced from the study justify any investment in the deposits.

It is very important to point out here that, commercial feldspar product as defined by Harben (1995) is a soda spar, soda feldspar, sodium feldspar, or K-feldspar with Na_2O weight percent greater than 7 ($Na_2O > 7\%$). However, Browne (2006) lists K-feldspar products, especially those advertised by companies operating in Mitchell country, North Carolina, which is the classic location for soda spar Mining in the USA, that have Na_2O

< 7 %, but where $Na_2O > K_2O$. Harben 1995, also defined a commercial feldspar product with $K_2O > 10$ % as potassium feldspar, potash spar, or K-feldspar.

The information used in the preparation of this report is mainly from intensive field work on the site since no documented information is presently available on the feldspar deposits. However, review and study of similar works by some authors were consulted and equally cited in the list of references (Browne, 2006; Alimon & Ahmad, 2011). The method by Shekwolo (1995) was used to review resources estimates and classifications.

2. Regional Geological Setting

The geology of Kogi State is part and parcel of the geology of Nigeria and the rocks that occur there are similar to what has been described in the other parts of the country. Coincidentally, Kogi State has two main rock types, namely, the basement complex rocks of the Precambrian age in the western half extending slightly eastwards beyond the lower Niger Valley and the sedimentary rocks in the eastern half. The various sedimentary rock groups extend along the banks of River Niger and Benue and Southeast wards through Enugu and Anambra States, to join the Udi Plateau.

Generally, the Precambrian rocks of Nigeria are grouped into three principal subdivisions. These are the ancient magmatite complex, the low grade schists and the plutonic series together with affiliated minor rocks which bear imprints of Liberian (in 2700 Ma), Eburnean (in 2000 Ma), and Pan African (in 650 Ma) tectonic events. The latter being the most widespread. However, older ages> 3.0 Ga have recently been reported in some areas such as the Kaduna Migmatites (Dada & Briqueu, 1996) and this reinforces the view that this migmatite-gneiss complex may belong to an Archean Protoshield subjected to the Proterozoic thermotectonic process (Elueze, 1992) and subsequent evolvement of the Phanerozoic basins. Overlying the older assemblages are sedimentary sequences of Cretaceous to Tertiary ages deposited in five basins notably Mid-Niger basin, Benue Trough, Anambra Basin all of Cretaceous ages and the Sokoto, Chad and the Niger- Delta basin of Tertiary and Tertiary to Recent ages respectively.

3. Accessibility, Physiography, Climate, Vegetation and Infrastructure

3.1 Accessibility

The Odobola, Ogodo Feldspar Mineral deposit is easily accessible from Abuja-Lokoja-Anyigba highway and a network of secondary roads that provide good access to most parts of the property. The Ajaokuta-Itakpe-Aladja railway line that was to supply raw materials and finished products to and from the Ajaokuta Steel Complex is also an alternative access to the property. The property located not more than five (5) kilometers from River Niger that flows from Lokoja-Ajaokuta-Onitsha, provides another possible access to the property.

3.2 Physiography

The property is located within the boundaries of Odobola, Ogodo, in Ajaokuta Local Government Area. The terrain heightening of most of the areas under study ranges from a lower elevation of 50-215 m. However, on the northern boundary, some isolated areas rise up to 400 m. The area hosting the feldspar deposit is flat-lying and is mainly associated with schist and granite complexes intruded by the pegmatite-bearing feldspar. They area is equally characterized by sharp concave breaks of slope around their margins. In some areas, the terrain is strongly dissected with a high proportion of bare rocks (plate 1).The valleys have irregular drains usually with fine to coarse textured sand and large amounts of rock outcrops (Obaje, 2009). The sides of the drains are eroded and exposed during the dry season (plate 2). The area is largely covered with soil but old working (pits) of illegal miners sourcing for gemstones and stream channels permit access to the underlying geology. Also, large exposures of pegmatites and granite-bearing feldspars and other rock types also exposed the geology.

The flood plains of the River Niger valleys have the hydromorphic soils which contain mixture of coarse alluvial and colluvial deposits (Ileoeje, 1979). The soils contain a lot of quartz rubbles, being products of weathering of the pegmatitic and granitic rocks hosting the feldspar.

The ecological problems in the area are not necessarily peculiar to it. Some of these include leaching, erosion and general impoverishment of the soil. These problems are compounded by the annual bush burning and grazing of the savannah that further exposes the top soil to more erosion. Floods pose a problem on the flood plains during the rainy season, while aridity is a problem to several areas at short distances from the rivers during the dry season. The property is located on the right-hand side of the Lokoja-Anyigba road, a few kilometers from the River Niger Bridge.

Plate 1. Photograph of bare rocks (schists) strongly dissecting the terrain in the study area

Plate 2. Photograph of a feldspar- bearing rock exposed by Oguro River (the main drainage in the study area)

3.3 Climate and Vegetation

The area has an annual rainfall of between 1,100 mm and 1,300 mm. The rainy season lasts from April to October. The dry season, which lasts from November to March, is very dusty and cold as a result of the north-easterly winds. The proposed property area is within the savannah zone associated with high temperatures, low humidity and cloudless sky for most parts of the year. The climate of the area is tropical which is under the influence of the Inter-Tropical Convergence Zone (ITCZ) or Inter-Tropical Discontinuity Zone (ITDZ). The meteorological conditions of the study area greatly influenced by the seasonal alteration (Abah, 2004).

The vegetation is guinea savannah with tall grasses and some trees. These are green in the rainy season with fresh leaves and tall grasses, but the land open during the dry season, showing charred trees and remains of burnt grasses. The trees which grow in clusters are up to six meters tall, interspersed with grasses which grow up to about three meters.

These trees include locust bean, Shear butter, and oil bean and isoberlinia trees. The savannah vegetation is, however, not in its natural luxuriant state owing to the careless human use of its resources.

3.4 Infrastructure

The nearest communities to the deposit are Ohunene, Oguro (Niger Bridge), Ajaokuta village and Ogodo village, all lying 5 km on average from the study area. The Ajaokuta-Obajana Gas Pipeline Project and the Ajaokuta-Itapke Railway line are located more than 500 m away from the property site. The area has a history of steel production and presently due to availability of power and energy from hydroelectric power, and natural gas pipeline from Niger Delta, the West African Ceramic Limited and the Chinese Milling Industry have now located their companies within localities close to the property site. These would equally be available for mining and processing requirements. The presence of the industries also offers a large labour force skilled in quarrying, processing and transporting the feldspar products. Also, many areas within the property would be suitable for the construction of a plant, waste dumps and tailings ponds.

4. Property Description and Location

The Odobola, Ogodo Feldspar deposit falls within Ajaokuta Local Government Area and is located within the following co-ordinates- latitudes 07°24.97′- 07°25.24′N and longitudes 006°39.20′ 006°39.46′E. Settlements are not found within the proposed project site, except the Fulani cattle rearers who have their temporary settlements in the area. However, the surrounding settlements is inhabited mainly by Ebiras, Igalas, Bassas and in some cases the Hausa, Ibo, Tivs and Yoruba migrants. The main occupations are crop farming, animal husbandry, fishing and petty trading. The area under study is almost 8 km^2 and the study stretch is mainly savannah woodland with fringing forest along some of the river banks. The terrain is flat and undulating with occasional outcrops. The major river is River Oguro and its tributaries which always dry up during the dry season.

5. Property Geology

Investigation into the Odobola, Ogodo area reveals an area having high potential to host economic deposits of feldspar, quartz, tourmaline and tantalite (Figure 1). The mineral commodities are found in three modes of occurrence, each of which contains two or more of the economic minerals listed above.

1) The unweathered granitic rock is favorable for the occurrence of primary deposit of sodium feldspar, potassium feldspar and quartz.

2) The unweathered pegmatites that intrude the granitic and schistose rocks of the study areas are the most favorable for the occurrence of these economic minerals.

3) The weathered granitic and pegmatitic rocks are favorable for residual deposit of clay that contains feldspar, quartz, tourmaline and tantalite.

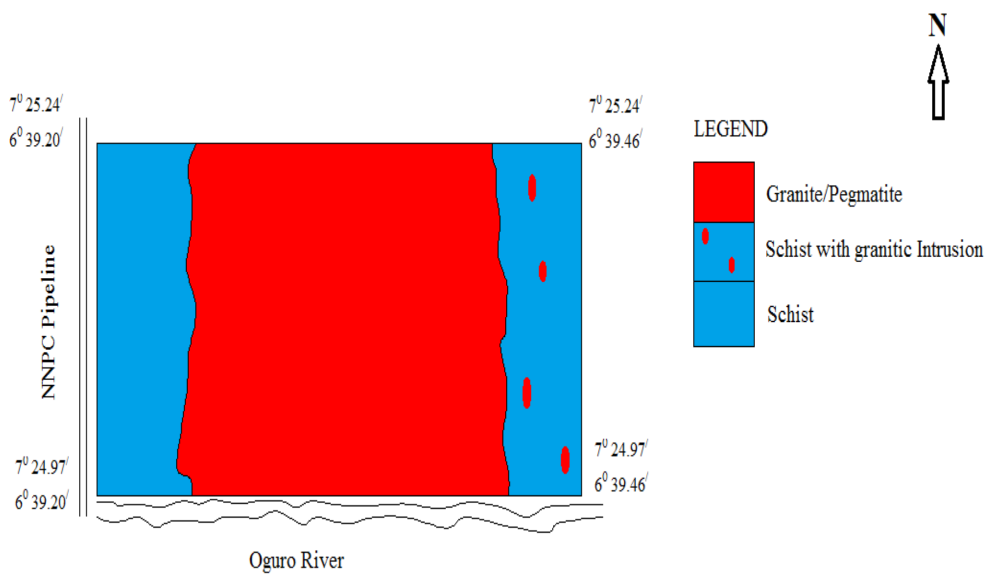

Figure 1. Geological sketch map of the study area

5.1 Lithologies

5.1.1 Granitic Rocks

The granitoid intrusive rocks of Pan-African age, occupy a large portion of the Odobola, Ogodo area and is believed to form part of a body referred to as the Older Granites in Nigeria(Obaje,2009). The granitic lithologies in the area consist predominantly of granodiorite with subordinate adamellite, tonalite, and granite. The principal mineral constituents are quartz, K-feldspar, and muscovite with trace to minor amounts of muscovite, garnet and epidote. Occurring as batholiths, these rocks display medium-to coarse-grained and porphyritic textures. Erosion has seriously exposed the batholiths resulting in a mature topography where they are exposed.

Field evidence shows the granitic intrusions (batholiths) to be a border zone of the intrusion that occurs along interface between the main-stage, coarse-grained, and porphyritic Ogodo batholiths and the Precambrian rocks. Intrusion into the cooler roof rocks resulted in a distinctive and texturally diverse unit characterized by dominant granular medium-grained and subordinate coarse-grained and presence of well-developed porphyritic textures. The unaltered intrusive rocks contain a primary assemblage of plagioclase, K-feldspar, quartz, muscovite and biotite (plate 3) and are predominantly granodioritic to granitic composition. Owing to physiochemical conditions of crystallization within the hydrous pods of granitic liquid, the resultant solidified rocks show a stronger tendency towards higher proportions of K-feldspar relative to plagioclase and higher K_2O/Na_2O ratios. The main orientation is NNE-SSW, sub vertical dipping (40^o-60^o) or with NW-SE orientation, steeply dipping NE.

Plate 3. Photograph of a granitic rock showing quartz (white), orthoclase, (pink), muscovite (white) and tourmaline (black)

5.1.2 Pegmatites

The pegmatites are extremely coarse grained igneous rocks, usually of granitic or granodioritic composition. In the study area, they are intrusive to the granites and schist and due to intensive erosion; they have been extensively exposed (plates 4a and 4b). In some areas they measure more than 100 m long, 10 m wide and 5 m high. At the pits where illegal miners had been mining gemstones, very large crystals of K-feldspar (pink in colour), quartz (white) and muscovite (white) are seen (plate 5). Where the intrusions have been weathered, the pegmatites occur as ridges outcropping for very long distances that can be traced without any difficulties.

Plate 4a. Photograph of pegmatite with large crystals of feldspar (orthoclase, pink) exposed in the field

Plate 4b. Photograph of pegmatite showing large crystals of quartz, orthoclase, muscovite and tourmaline (black)

Plate 5. Photograph of large crystals of K- feldspar from pit where illegal miners are looking for gemstones and where samples were collected for analyses

Granitic and granodioritic pegmatites consist largely of quartz, alkali feldspars, biotite, and muscovite and perhaps of crystallization, when the remaining magma is enriched in volatiles and elements that do not easily enter into common rock-forming minerals. Such elements include: boron, cesium, beryllium, zirconium, niobium, uranium, thorium, tantalum, tin, rare elements, etc. The presence of abundant fluids uncommon elements often results in the formation of large, unusual, and sometimes valuable minerals. Apart from these valuable minerals, gemstones such as tourmaline, beryl and topaz are also common in pegmatites (Perkins, 2006).

5.1.3 The Weathered Granitic and Pegmatitic Rocks

The exposed Ogodo granitic and pegmatitic rocks have been subjected to intense weathering in a tropical or near-tropical climate. In response to strong weathering, much of the feldspar and at least some of the mica in these rocks have been altered to one or more varieties of clay minerals. The waste material is primarily quartz and K-feldspar, with Na-feldspar (Plagioclase) accounting for only a minor proportion of the total feldspar. Large crystals of orthoclase, quartz and mica books are scattered all over the place. Residual clay deposits in the Ogodo area reflect this mineral distribution, and targeted commodities from strongly-weathered granitic and pegmatitic rocks are clay (kaolin), quartz and feldspar.

5.1.4 Schists

The study area consists of rocks of the basement complex which is represented by schists. The schists are the oldest rocks in the area and have been intruded by the Pan-African granites and the pegmatites. The schists are highly foliated and banded. The foliations are characterized by the development of dark coloured bands alternating with white coloured bands. The dark coloured bands are represented by the ferromagnesian minerals while the white coloured bands represent quartz and feldspar (quartzo-feldspathetic mineralss). The general trend of the shcists is NE-SW and a general dip of between 35-60^{o}W. Minerlogically, the schists contain quartz, feldspar and mica but none of these attracts any interest because they don't occur in any economic concentration in the rocks (schists), thus, limiting the search for any economic feldspar concentration within the intruded granites and pegmatites.

Plate 6. Photograph of schist with a NE-SW trending direction (with a dip of 30^{o}) showing the ferromagnesian minerals (dark colour) and the quartzo-feldsparthic minerals (white band)

6. Methods of Investigation

The methods of investigation of this work consist of the following:

(i) Geological method

(ii) Laboratory method.

(iii) Geophysical method

6.1 Geological Method

In the geological method, rock and mineral samples were collected from the granitic and pegmatitic rock outcrops and the coordinated of the location where the samples were collected was recorded on a field notebook using a Global Positioning Systems (GPS). Samples were collected mainly from the rocks that show the presence of the targeted mineral (feldspar). In the field, the general direction of trending of the host rocks was recorded and strike and dip values taken from schists (using Geological Compass Clinometer) were noted and recorded. Three types of sample set were collected from the field. (1) Rock samples from outcrop, (2) pit samples for feldspar, and (3) feldspar samples from the weathered granitic and pegmatitic rocks. The sampling was done randomly and each sample was labeled and assigned a location number. The pits were dug between 1- 4 m and a total of six pits were dug. The geochemical samples collected were sent to the laboratory for whole-rock geochemical analysis while some were kept as back-up samples for further reference.

6.2 Laboratory Method

The laboratory method consists of thin section preparation and whole-rock geochemical analysis of the mineral and rock samples collected in the field. The thin sections were prepared in the workshop of Department of Geology, Federal University of Technology, Minna, according to the method described by Roland (1953). Observation and description of the thin section was done in the laboratory of the same organization. For the chemical analyses, the concentrations of major elements (SiO_2, Al_2O_3,TiO_2, Fe_2O_3t, MnO, K_2O, CaO, Na_2O) were determined in the laboratory of Nigeria Geological Survey Agency in Kaduna according to method of Browne, 2006. Results of analyses are presented in table below.

Table 1. Analytical data for the Ogodo Feldspar samples

Major Elements (wt. %)	OOF 1	OOF 2	OOF 3	OOF 4	OOF 5	OOF 6
SiO_2	65.38	67.15	67.35	65.12	66.35	65.29
Al_2O_3	18	17	16	17	16	16
K_2O	11	9	10	12	10	12
Na_2O	5	6	6	5	7	6
MgO	0.5	0.6	0.5	0.5	0.4	0.5
CaO	0.02	0.02	0.02	0.02	0.02	0.02
Fe_2O_3t	0.15	0.25	0.25	0.19	0.39	0.31
TiO_2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mineralogy (mole %)						
An	0.40	0.38	0.43	0.41	0.44	0.46
Or	80.61	90.12	85.75	90.05	87.25	78.56
Ab	19.32	9.65	13.94	9.58	12.06	19.89

6.3 Geophysical Method

A resistivity profile (Werner electrode configuration) was run across the E–W direction of the area. This is because the rocks that host hosting the deposit run N - S. The Resistivity profile result shows that the deposit is not laterally continuous throughout the entire area. Therefore, the deposit is suspected to be present on the profile 105 m; and between 165 m and 195 m from the start point which is the reference point. Consequently, Vertical Electrical Sounding (Hummel electrode configuration) was carried out at some selected points and results were initially obtained by curve matching with standard master curves. These were improved upon using *Interpex 1xD resounding software* and interpreted results.

The results of the vertical electrical sounding (VES) data show basically four geoelectric or lithologic units; the top silty-sand, weathered feldspar; poorly weathered feldspar zone and fresh basement.

This investigation has afforded the opportunity to geophysically delineate the area into feldspar and non-feldspar mineralized zones.

Overburden is estimated at 2-13 m at VES 1; 3-12 m at VES2 and 2-13 m at VES 2. The thickness of the feldspar deposit is estimated to be between 20-35 m thick. Fractures were also observed in all vertical electrical soundings between 10-15 m and 30-60 m. The thickness of the deposit as shown from this investigation varies from 15-35 m throughout the area.

7. Mineralogy

7.1 Feldspar: Occurrence and Geology

Feldspars are one of the most abundant rock-forming minerals in the earth crust, comprising a complex series of aluminosilicates with varying amounts of potassium, sodium and calcium and rarely barium. Common amongst those are the potash feldspar called orthoclase and microcline ($K_2O{\cdot}Al_2O_3{\cdot}6SiO_3$), sodium feldspar called albite ($Na_2O{\cdot}Al_2O_3{\cdot}6SiO_3$) and calcium feldspar called anorhite ($CaO{\cdot}Al_2O_3{\cdot}2SiO_3$), though feldspar occurs in various colours, pink, brown and grey feldspar are common.

The main lithologies in the Odobola, Ogodo feldspar deposit are schists, granites and pegmatites. The feldspars are hosted exclusively by the granites and pegmatites. The granitic lithologies are batholithic plutons and consist primarily of granodiorite, adamellite and granite. Total feldspar content in these intrusive rocks is reported to range from 78.56-90.12 %, with an average of about 85.39 % total feldspar. Thus, the unweathered Ogodo granites represent a source carrying a high total feldspar abundance of which a higher and, significant proportion is sodium-bearing (orthoclase, sodic plagioclase). Much of these feldspars in the granite occur in the red and pink granite especially at the north boarder of the investigated site. The red and pink colour is as a result of the presence of significant amount of feldspar in the rocks. A much higher and significant amount of feldspar occurs in the pegmatites. Large crystals as long as 10 cm and above can be seen on fresh surfaces of the pegmatite intrusions. Mineralogically, the pegmatite contains larger crystals of feldspar, quartz and muscovite than the granite and the proportion of feldspar in the pegmatites is equally larger than that of granites. The fieldwork was later supported by petrographic analyses of thin sections which also indicate that the intrusive rocks range from granodioritic to adamallite to granite, with true granites being the most common (plate 7). Estimated total feldspar abundances in the rock samples range from 78.5-90.12 % and an average of about 85.39 %.

Plate 7. Photograph of a true granite showing crystals of K-feldspar, quartz and muscovite much smaller than they occur in pegmatite. Note the presence of tourmaline (black) in the rock, an indication of occurrence of gemstones in the area

Representative samples of the unweathered granites and pegmatites are illustrated by the photomicrographs in plates 8-11. The photomicrographs were taken using transmitted light under plane polarized (PPL) and crossed polarized lights respectively and show the distribution of feldspar and quartz.

In the photomicrographs, orthoclase has yellow green colour that is overprinted by weak reddish brown colour in areas of incipient clay alteration while in some areas it shows light blue colour, while quartz and the micas are non-luminescent. The granitic rock samples are estimated to contain 60% K-feldspar, 15% quartz, 15% muscovite and 10% plagioclase. Fresh samples of the granitic rocks show interlocking crystals of K-feldspar, quartz, muscovite and plagioclase. The K-feldspar includes microcline and orthoclase and crystals measure as long as 5-12 cm with average diameter of 5-10 mm.

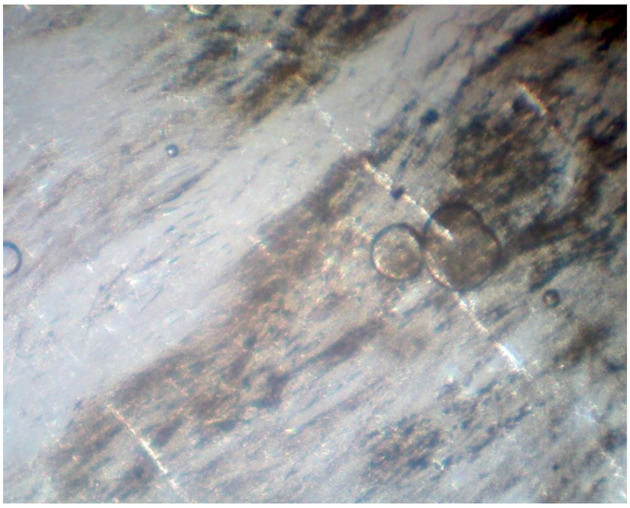

Plate 8. Photomicrograph of feldspar showing tourmaline mineralization

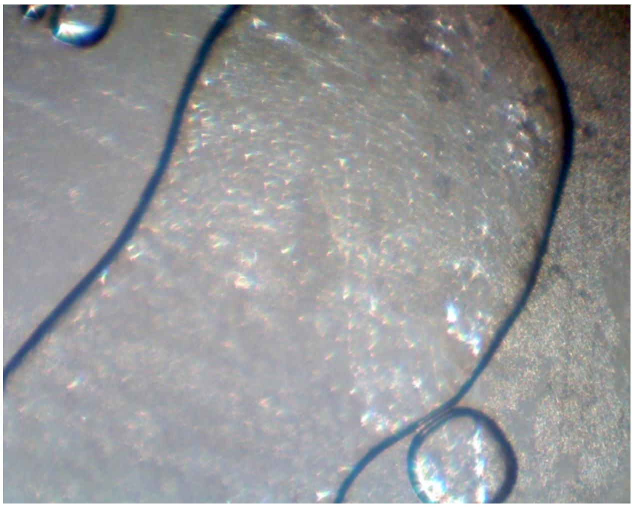

Plate 9. Photomicrograph of tourmaline-rich host rock

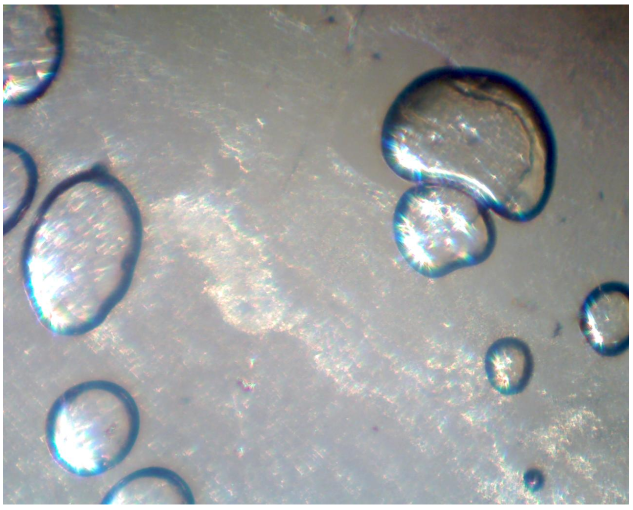

Plate 10. Photomicrograph of feldspar with tourmaline inclusions

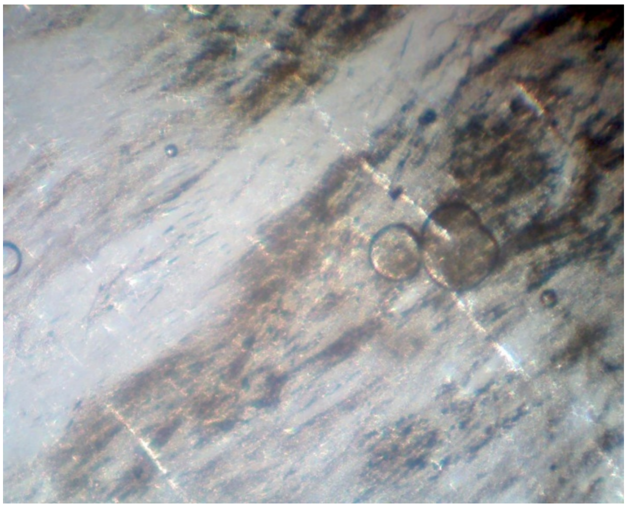

Plate 11. Photomicrograph of feldspar showing two directions of cleavage and Carlsbad twinning

Field evidence shows that, two generations of feldspar occur in the proposed project area. These two generations are associated with the two main types of intrusions in the area. The first generation is associated with the granitic rocks that intruded the schists of the basement complex. The second is associated with the pegmatites which later intruded the granitic rocks. This development resulted in the pegmatites having much more and larger crystals of feldspar than the granites (plate 12).

Plate 12. Photograph showing two generations of K-feldspar: the first generation with smaller mineral grains (below) and the second with larger grains (above)

They occur as pink-red anhedral or euhdral grains commonly elongated with a tabular appearance. Crystals show good direction of cleavage which under the microscope were seen to intersect at 90°. Twinning is Carlsbad but microcline shows crossed-hatch twinning.

Based on the petrographic and whole rock geochemistry studies of the feldspar and quartz, representative samples were further studied in order to quantify feldspar compositions and determine potential product quality in terms of alkali, abundances and suitably low Fe_2O_3 contents based on the method by Clark (2003a, 2003b). Petrographic analyses on both samples from the granites and pegmatites revealed that the feldspars rarely have inclusions of Fe-bearing minerals (biotite, muscovite or FeOx). Clark (2003a) has suggested that a hypothetical feldspar product composition calculated from estimated feldspar abundances and the whole-rock geochemistry data might show good correspondence with the chemistry of an actual feldspar concentrate after beneficiation. The calculated feldspar product was based on the average feldspar abundance, distribution and compositions for all the samples examined petrographically in order that the hypothetical product might closely approximate that of a representative feldspar concentrate. Potassium feldspar obtained from the pegmatites and granites from the area can be used traditionally as a source for alumina and alkali in ceramic and glass industries which account for more than 90% consumption. It may also find use as functional fillers in paint, plastic, rubber and adhesive; as a bonding ingredient in abrasives; and in the manufacture of artificial teeth, fertilizer and white cement. The BIS specifications of potassium feldspar for use in various products are given below (Table 2).

Table 2. Specifications of potassium feldspar for use in various industries

Characteristics(% by mass)	1	2	3	4	5	6	7	8
Al_2O_3	67	67.5	62-68	64.5-68	-	60-70	65	63-67
SiO_2	17-20	17-21	16-20	17-21	$18_{min.}$	20-24	18	17-20
K_2O	9	8	11-14	11-12.5	9	-	-	12-14
Na_2O	4	5	2-7	2-3	4	-	-	1-3
MgO	-	-	-	-	-	-	0.5	-
CaO	-	-	-	-	-	-	0.6	-
$K_2O + Na_2O$	13	11.3	-	-	$14_{max.}$	-	$10_{max.}$	-
CaO + MgO	0.75	1.0	-	-	-	11-12	-	-
$SiO_2 : Al_2O_3$	3:4	3.4:4.0	-	-	-	-	-	-
Fe_2O_3	0.20	0.42	0.25	0.48	$1_{max.}$	1.5	0.45	$0.3_{min.}$
LOI	0.6	0.7	-	-	-	0.8	2	-

1. Glass industry. 2. Sanitary ware industry. 3. Insulators industry. 4. Ceramic tiles industry. 5. Refractory industry. 6. Abrasive industry. 7. Electrode industry.

Source: BIS (1990)

The results of chemical analyses of feldspar samples (Table 1) compared to those of the British International Standard (BIS) presented in Table 2 show that the Ogodo feldspar deposit can be put into almost all the uses of feldspar mentioned above.

7.2 Quartz

Significant amounts of quartz occurs in the granitic and pegmatitic rocks of the proposed project site and it makes good sense to investigate the mineral as a possible co-product of the granitic and pegmatitic source feldspar mining operation. Petrographic examination of granitic and pegmatitic rock samples from the Ogodo area show that the quartz in the rocks is relatively free from Fe-bearing mica or oxide inclusions. This lack of deleterious constituents (such as TiO, MgO, Fe_2O_3) therefore, makes the mineral a good by-product of the mining of feldspar.

7.3 Accessory Minerals

Accessory minerals in the granitic and pegmatitic rocks include muscovite, tantalite, tourmaline, zircon and apatite. The rare-metal pegmatites of the area also contain economic concentrations of tantalite and tourmaline. Obaje (2004) reported the occurrence of these minerals in a NE-SW trending belt in the pegmatites which have sharp contacts with their hosts but wall rock alteration (of mostly tourmalinisation) is a common phenomenon. Mineralization of these minerals is in the form of veins and dissemination. Traces of these minerals are seen on the surface of rock material excavated by artisanal miners and as surfaces of rock outcrops.

8. Mineral Resource and Reserve Estimation

In this study, mineral resources are categorized as either inferred, indicated or measured resources. It is worth to note that mineral resources that are not mineral reserve do not demonstrate economic viability. Mineral reserves are defined at the completion of this study of which the work in this report is part of it. This report is a comprehensive study of the viability of a mineral project that has advanced to a stage where the mining method, pit configuration, in the case of an open pit (as the case with this project) has been established. It also involves determination of exploration information such as geological, geophysical, sampling, pitting and trenching, analytical testing, mineralogy and other similar information concerning the property that is derived from activities undertaken to locate, investigate, define and delineate the mineral prospect or mineral deposit.

8.1 Resource Estimation

A mineral resource is a concentration or occurrence of a particular mineral (in this case, feldspar) in or on the earth's crust in such from and quantity and of such a grade or quality that it has reasonable prospects for economic extraction. The location, quantity, grade, geological characteristics and continuity of the mineral resource are known, estimated or interpreted from specific geological evidence and knowledge.

Mineral resources are sub-divided in order of increasing geological confidence, in to Inferred, Indicated and Measured Categories. An inferred mineral resource has a lower level of confidence than that applied to an indicated mineral resource. An indicated mineral resource has a higher level of confidence that an inferred mineral resource but has a lower level of confidence than a measured mineral resource.

Field and laboratory evidence so far show that the feldspar resource in the proposed project site can be classified as a Measured Mineral Resource. This is because its quantity, quality, density, shape and physical characteristics are so well established that they can be estimated with confidence sufficient to allow the appropriate application of economic viability of the deposit. The estimate is based on detailed and reliable exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits that are spaced closely enough to confirm both geological and grade continuity. It is advisable to carry out more detailed studies to confirm the viability of the resource and therefore ascertain the reliability of this report.

8.2 Reserve Estimation

In this report, mineral reserves are described as either probable or proven based on order of increasing confidence. A probable Mineral Reserve has a lower level of confidence than a proven Mineral Reserve. The primary objective of this study is the delineation of K-feldspar reserves in order to accommodate the various feldspar product required by various manufacturers. In the Ogodo area the primary targets for source rocks with a significant k-feldspar (orthoclase) component are areas underlain by the least weathered granitic and pegmatitic rocks. Orthoclase abundances tend to be much higher in the least-weathered rocks, because feldspar alters quickly to clay minerals relative to other minerals in the rocks undersurface weathering conditions. Results from geological and geophysical mappings indicate that the ridges in the area of generally underlain by significant thickness of slightly weathered granites and pegmatites. The intensity of the weathering declines with depth and relatively fresh rock carrying abundant primary orthoclase are seen as from the surface where these rocks are exposed. Field evidence shows that topographic lows and mature stream valleys offer the highest potential for low soil and weathered rock cover over relatively unweathered, orthoclase-bearing rocks. Six pits dug in the area indicated very shallow overburden of 1-3 m and the whole rock geochemistry of samples from the pits together with the estimated thickness, average length, width and specific gravity of the feldspar were used to estimate the feldspar reserve in the proposed project area as follows:

Thickness of Overburden = Negligible

Assumed average thickness of Outcrops = 53m

Length of outcrops (granite + pegmatite) = 2150m (2,150m)

Average width of outcrops = 510m

$$Volume\ of\ outcrop = 53m \times 2150m \times 510m = 58{,}111{,}500m^3$$

$$Probable\ volume\ of\ feldspar = 80\%\ of\ total\ outcrop = 46{,}489{,}200m^3$$

Specific gravity of feldspar (Orthoclase) = 2.55gm/cc

$$Tonnage = 46{,}489{,}200m^3 \times 2.55 = 118{,}547{,}460\ metric\ tons$$

Therefore, feldspar can be extracted from a proven feldspar-bearing reserve of about 119 million tons.

However, more detailed intergraded work and drilling could prove a larger reserve.

9. Conclusions

The Ogodo feldspar mineral deposit is hosted primarily by schists, large granitic and pegmatitic intrusive bodies and soil and sediments derived from the weathering and erosion of these schists rocks. These rocks have been subjected to saprolitic weathering, resulting in the development of soils of variable thickness given rise to average overburdens of 1-3 m. Based on field evidence from geological mapping the Ogodo feldspar covers more than 109.65ha (270.96 acres) underlain by granitic and pegmatitic rocks favorable for the hosting of primary feldspar, quartz, tantalite and tourmaline. Also pitting within the proposed lease that contains the granitic and pegmatitic intrusives, together with geological, geophysical and geochemical evidence gives a Measured Mineral Resource, as defined by 119 million tons feldspar and quartz that can be categorized as on inferred Mineral Resource. Also, geochemical results demonstrate that the feldspar (K-feldspar) is of high quality and warrants further exploration and research into the potential for the property to produce feldspar (and other minerals) products according to the specifications of the manufacturers.

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