Determination of Physicochemical Characteristics of Feldspar Deposits in Zango Daji, Kogi State Using Geophysical and Geochemical Methods.

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Received: 26-APRIL-2024; Reviewed: 21-SEP-2024; Accepted: 10-OCT-2024
https://dx.doi.org/10.4314/fuoyejet.v9i4.22

ORIGINAL RESEARCH

Abstract - To determine the physicochemical characteristics of feldspar in the study area, eighteen fresh rock samples were randomly collected. The photographs and locational coordinates of sample points were taken using a sledgehammer, geologist's hammer, camera, and global positioning system device. Thin sections of freshly prepared samples were observed under hand lenses and microscope. The remaining samples were subjected to geochemical and mineralogical analysis. The chemical analysis of the collected feldspar samples showed its type and quality. It meets the British International Standard specification for the production of various products of the feldspar family. Furthermore, the electrical resistivity tomography survey was conducted by the Vertical Electrical Sounding technique in a Schlumberger Electrode Array to determine the significant resistivity contrast between the feldspar and the compact bedrock in the profile. The resistivity data were processed into Resists curves and subjected to inversion with WinResist software to obtain a 1 - D modeling of Iso – resistivity and Isopach maps of overburden and target minerals. Furthermore, the percentage composition of Oxide of K_2O, using X-ray fluorescent Spectrometry showed it contained 17.1958 mass %. These figures are far greater than Calcium and Sodium contents. The study also revealed the occurrence of feldspar deposits hosted by granitic and pegmatitic intrusives. Geochemical results showed average Si_2O, Al_2O_3, K_2O, Na_2O, CaO, and Fe_2O_3, contents of 59.54 mass %, 17.83 mass %, 17.19 mass %, 2.33 mass %, 0.08 mass %, and 1.60 mass % respectively while mineralogical results revealed it is orthoclase in view of its high alumina content of 17.83 percent. Field and petrographic evidence showed a potential source of gemstones and niobium.

Keywords - K-feldspar, Pegmatitic-intrusives. Spectrometry, Unweathered-granitics, Unweathered- pegmatites

1 INTRODUCTION

The demand for feldspar as raw material for ceramics and other uses is continuously increasing. In Tunisia, the traditional sources of feldspar, pegmatite and neptheline syenite ore does not exist. This implies a massive importation of this raw material (26 million dinars at 2007) (Gaied and Gallala, 2015). Nigeria is blessed with solid minerals widely distributed across the different geographical belts of the country and was experiencing a booming economy that even made her to give out loan and aid to poor countries (Orji *et al.*, 2018). Prior to the early crude oil boom era of the 1970s and the 1980s, solid minerals such as Coal, Tin and Columbite to mention but a few, contributed immensely to the economy of Nigeria (Olumide *et al.*, 2013). Coal was the major source of power generation as well as the main source of power for the railway transportation systems. Nigeria was the largest producer of Columbite at one point. In the prevailing times, the earnings from solid minerals were used to develop roads, education, hospitals and in fact develop the petroleum industry (Olumide *et al.*, 2013). 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 (Ako and Onoduku, 2013).

Feldspar is a rock forming mineral that is industrially important in glass and ceramic industries, and as a bonding agent in the manufacture of bonded abrasives.

To some extent, feldspar is used as a filler and extender in paint, cements and concretes, fertilizer, insulating compositions, tarred roofing materials, used in medications like anticonstipation drugs and as a welding rod coating.

Commercial feldspar product defined by Harben (1995) is soda spar, soda feldspar, sodium feldspar with Na_2O weight percent greater than 7% as sodium feldspar and feldspar product with K_2O weight percent > 10 % as potassium feldspar, potash spar, or K-feldspar. Browne (2006) lists K-feldspar products to have Na_2O less than 7% but where $Na_2O > K_2O$. Alkali feldspar granites represents rocks with highest quartz content in granitoid family. Silicates are extremely important materials, both naturally and artificially, for the development of science and technology. Although there is no known way of accurately ascertaining the abundance of every mineral within the earth's crust, based on a rough estimate, silicates comprise most of the earth's crust (Klein and Philpotts, 2017). In addition, silicates are the main component of ceramics, Portland cement, and glass. Silicate-based materials as amendments such as zeolites, clays, and cementitious materials show increasing

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Section F- GENERAL SCIENCES

Can be cited as:
Omoijuanfo I.S., Opafunso Z.O., Saliu M.A. and Lajide L (2024). Determination of Physicochemical Characteristics of Feldspar Deposits in Zango Daji, Kogi State Using Geophysical and Geochemical Methods. FUOYE Journal of Engineering and Technology (FUOYE**JET), 9(4), 711-724.**
https://dx.doi.org/10.4314/fuoyejet.v9i4.22

interest in the stabilization/solidification of heavy-metal contaminated soils or environments (Xu *et al.*, 2017). Therefore, research efforts to improve the geotechnical characteristics of soil is centred on local product development and material such as fly ash and rice husk ash. (Ogunsanya *et al.*, 2022).

The proportion of mafic minerals in alkali feldspar granites is generally below 5% and represents product crystalized from residual silicon (Si) and potassium (K) rich melts in the last stages of the magma (Haldar, 2020). Mineralogical and mechanical properties of granites (rocks) have been identified as two main properties that influence its suitability for dimension stone production (Saliu, 2018). Feldspar, its uses and application are as diverse as the mineral itself, from glass making to ceramics to fillers. It is important to note that feldspars can be split into two primary groups, which are potassium feldspar (orthoclase) and plagioclase feldspars. The mineral of which composition is based primarily on the solid solution range between albrite and anorthite is what is known as plagioclase feldspars while those between albrite and orthoclase or mono line are what is collectively known as alkali feldspar. They are referred to alkali feldspars due to the presence of potassium and sodium (African Pegmatite, 2023). Among the most copious group of minerals found on the earth's crust are feldspars, formed as a result of magna crystallize veins in igneous and metamorphic rock. Feldspars are group of hard crystalline minerals that consist of aluminum silicate of potassium, sodium, calcium or barium having the requisite qualities for glaze composition. Mostly, feldspars progressively contained higher degree of silica under saturation. Feldspars show broad range of compositional and structural characteristics that present rich information of their origin (Balic *et al.*, 2013). Feldspathic materials are transparent gems of different properties which are typically classified into potassium feldspars (sanidine, orthoclase, and microcline) and plagioclase feldspars (albite, bytownite, moonstone, oligoclase, andesine, labradorite and anorthite) (Dietrich, 2020). Pliability tendency of some of these feldspathic materials revealed array of new innovations in ceramic products. Ceramics have moved beyond traditional clay materials to high substances that transmute to objects of permanent, utility and beauty after vitrification which is the way to stabilizing inorganic raw materials. The process of becoming vitreous is manifested in high technology materials of refractory, glass and glaze Abiodun *et al.*, 2013).

The industrial use of feldspar minerals is restricted to the most common varieties and those with low melting points, such as alkali feldspars (orthoclase and microcline) and Na-rich plagioclase (albite). Major consumers are the glassmaking and ceramic industries. In glassmaking, it is crucial because its alkali components reduce the melting temperature of quartz and help to control the viscosity of glass (Jan *et al.*, 2020). The need to determine the physicochemical characteristics of the rock samples forms the basis of its industrial and commercial applications or uses. Ogundare and Lajide, (2013) determined the difference in the physicochemical properties and mineral contents in the unfortified compost and the fortified com- posts samples and also compared with that of the chemical fertilizer NPK (15:15:15).

Feldspar has immense economic potential and is a key ingredient in the ceramics, glass industry, construction material and in abrasives, playing vital roles in the production of ceramic tiles, sanitary ware, tableware, and porcelain products. Despite the abundance of mineral resources in the country, Nigeria remains underdeveloped. The problem, partly lies in the inability to attract investments into the sector due to several factors, some of which are economic, social, environmental, geological and mineral resources development factors. Geological exploration is a process of finding commercially viable mineral resource and the objective is to locate it in the shortest possible time and at the lowest possible cost (Gandhi and Sarkar 2016). Mining, as an economic sector should contribute significantly to gross domestic product, to national employment and to export. This has not been so as statistics released by the National Bureau of Statistics (NBS, 2022) reported that contributions of mining and quarrying sector declined and it only contributed 5.25% in quarter four of 2021 compared to same period in 2020, contributed 25, 618 to the employment sector, with 596 expatriates in 2021 and its contribution to export value was a mere 0.24% in 2021. The lack of adequate geological and mining data on deposits has hindered the economic development of the deposits. This research is concerned with closing these gaps by conducting geological and mineral resources evaluation to attract investment to the sector based on a favorable economic analysis.

2. LITERATURE REVIEW

2.1. STRATEGIC DEVELOPMENT OF MINERAL RESOURCES IN NIGERIA

In Nigeria, mineral resources, including feldspar are available in large quantities and distributed across the country but the strategies for exploration and development have been the major obstacles to its success in Nigeria (Micah and Ibitomi 2020a). The world is continuously looking for alternative to oil and reasonable discoveries have been made to that effect. The deposit of

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bitumen in Igbokoda, Ondo State of Nigeria is unarguably the second largest deposit of bitumen in the world, yet it remains untapped among other huge solid mineral deposits found all over the country (Aniobi *et al*., 2021). The strategies and goals for the development of mineral resources formed the basis of profit maximization, poverty eradication, revenue generation and job creation. Based on these findings, the problems of solid minerals development in Nigeria are, amongst others, inadequate basic infrastructure, illegal mining, unfavorable laws in the sector, high capital outlay, inadequate professional in the sector, governance issues and many more. Furthermore, it was pointed that the strategies that can be used for exploration of solid mineral in Nigeria should include resource control policy, exploration of mineral resources should be private sector driven, the tenure of the private miners should be secured and the establishment of fund to protect the environment should be provided (Micah and Ibitomi, 2020b). It is customary, though not mandatory, for the evaluation of the technical feasibility and economic viability of production for a given mineral deposit to proceed through three stages of progressively more rigorous analysis (William, 2019). These are preliminary economic assessment, preliminary feasibility study and feasibility study. Edeme and Nkalu, (2019) citing Hlavová (2015), stated that many of the developing countries are rich in minerals and at the same time one of the least developed due to over dependence on one sector as major source of revenue. For rapid development in Nigeria, there is the need to move from the mono-economic based approach and tap into the huge opportunities available in solid mineral development.

In the laboratory, it is relatively easy to identify feldspar by determining their chemical compositions, their structure, or their optical properties. In some cases, staining techniques are employed. Fortunately, most feldspar grains can also be identified easily on the basis of microscopic examination in the field, using properties such as those described. Hazen (2004) revealed that on the basis of similar chemical compositions and structures, all rock-forming feldspars have several similar properties. As indicated by the fact that they lack inherent colours, feldspars can be colourless, white, or nearly any colour if impure. In general, however, orthoclase and microcline have a reddish tinge that ranges from pale, fresh like pink to brick-red, whereas, typical rock forming plagioclase are white to grey. As a group, they range from transparent to nearly opaque, have nonmetallic lusters, typically vitreous to sub vitreous on fractures and pearly or porcelaneous on cleavage surfaces, exhibit two cleavages – one perfect and the other good, at or near 90^0 to each other, and have a Mohs hardness of approximately 6. The presence of two cleavages, at or near 90^0 distinguishes the feldspar from all other common rock-forming minerals except halite and the pyroxenes. The hardness, 2.5 and the salty taste of halite make that distinction clear. The grey to black streak of the common rock-forming pyroxenes, which contrasts markedly with the white or slightly tinted hues of the streak of feldspar, including those that are dark-coloured, affords a simple way to distinguish between these minerals, even those that are similar in appearance (Naturenews, 2022).

Approximately 19,500 metric tons of feldspar was produced in Nigeria in 2020, a sharp decline from figures obtained from between 2015 and 2019 (Statista Research Department, 2023). In a 2023 report by Volza Grow Global, there are approximately 6200 import shipments of Feldspar into Nigeria by 628 Nigerian importers and 315 suppliers from India, Germany and China. According to the United Nations COMTRADE database on International trade, Nigeria's import of feldspar, leucite, nepheline, syenite and fluorspar from Spain in 2021 stood at US$753.

2.2. CLASSIFICATION OF FELDSPAR FOR INDUSTRIAL APPLICATION

It is important to distinguish the feldspar mineral group from other rock-forming minerals and from one another. This is because their presence or absence, alongside their relative quantities, serves as the basis for classifying and naming many rocks, especially those of igneous origin. In the laboratory, it is relatively easy to identify feldspar by determining their chemical compositions, their structure, or their optical properties. In some cases, staining techniques are employed. Fortunately, most feldspar grains can also be identified easily based on microscopic examination in the field, using properties such as those described. Hazen (2004) revealed that on the basis of similar chemical compositions and structures, all rock-forming feldspars have several similar properties. As indicated by the fact that they lack inherent colours, feldspars can be colourless, white, or nearly any colour if impure. In general, however, orthoclase and microcline have a reddish tinge that ranges from pale, fresh like pink to brick-red, whereas, typical rock forming plagioclase are white to grey. As a group, they range from transparent to nearly opaque, have nonmetallic lusters, typically vitreous to sub vitreous on fractures and pearly or porcelaneous on cleavage surfaces, exhibit two cleavages

– one perfect and the other good, at or near 900 to each other, and have a Mohs hardness of approximately 6. The presence of two cleavages, at or near 900 distinguishes the feldspar from all other common rock-forming minerals except halite and the pyroxenes. The hardness, 2.5 and the salty taste of halite make that distinction clear. The grey to black streak of the common rock-forming pyroxenes, which contrasts markedly with the white or slightly tinted hues of the streak of feldspar, including those that are dark-coloured, affords a simple way to distinguish between these minerals, even those that are similar in appearance (Naturenews, 2022).

Physical properties of rocks have been used to devise geophysical methods that are essential in search for minerals, oil and gas and other geological and environmental problems. The methods are Gravity method, Seismic method, Electromagnetic method and Geothermal method. Others are Magnetic method, Electrical method and Radiometric method (GNI, 2021). Geophysical methods respond to the physical properties of the subsurface media (rocks, sediments, water, voids, etc) and can be used successfully when one region differs sufficiently from another in some physical property (Reynolds, 2011). With other physical parameters, geoelectrical properties are utilized in both applied and general geophysics. They are exploited commercially in the search for valuable orebodies, which may be located by their anomalous electrical conductivities (Lowrie 2007a). The resistivity of rocks is strongly influenced by the presence of groundwater, which acts as an electrolyte. This is especially important in porous sediments and sedimentary rocks. The minerals that form the matrix of a rock are generally poorer conductors than groundwater, so the conductivity of a sediment increases with the amount of groundwater it contains (Lowrie, 2007b). These observations are summarized in an empirical formula, called Archie's law, for the resistivity ρ *of* the rock in Equation 1.

$$\rho = \frac{a}{\theta^m S^n} \rho_w \quad (1)$$

Where, θ and S are fractions between 0 and 1, ϱw is the

resistivity of the groundwater, and the parameters *a*, *m* and *n* are empirical constants that have to be determined for each case.

There are several classifications of feldspar for industrial and commercial uses. The British International Standard (BIS) classification for Potassium feldspar for use in various products are given in Table 1.

Table 1: British International Standard (BIS) Specification for Potassium Feldspar for Use in Various Industries (BIS,1990)

Classification By (%)	**Glass Ware**	**Sanitary**	**Insulators**	**Ceramic**	**Refractory**
SiO_2	67	67.5	62 - 68	64.5 - 68	-
Al_2O_3	17 – 20	17 – 21	16 - 20	17 – 21	18_{min}
K_2O	9	8	11-	11 -	9
Na_2O	4	5	2 – 7	2 – 3	4
MgO	-	-	-	-	-
CaO	-	-	-	-	-
$K_2O + Na_2O$	13	11.3	-	-	14_{max}
CaO + MgO	0.75	1.0	-	-	-
$SiO_2 + Al_2O_3$	3:4	3.4:4	-	-	-
Fe_2O_3	0.20	0.42	0.25	0.48	1_{max}
LOI	0.6	0.7	-	-	-

Although the quartz, which is one of the major minerals of the alkali feldspar granite rocks, does not form any problem in terms of color and brightness, it can increase the fragility due to their hardness. Therefore, the quartz ratio is also important in the prescriptions produced. Apart from these, there are also other studies on the effects of feldspar on ceramics or frit (Deniz and Kadioglu, 2019)).

3. MATERIALS AND METHODS

This section with the materials and methods used for sample collection, preparation and for the analysis of the mineral compositions. The samples collected during reconnaissance and exploration with geologist tools were analyzed to obtain the characteristics and reserve estimates of the feldspar deposit.

3.1. STUDY AREA DESCRIPTION

The study area is located in Zango Daji forest in Adavi and Ajaokuta Local Government Areas in Kogi State, North Central Nigeria. Figure 1 shows the geological and mineral resource map of the study area. The area is surrounded by hills that drains into the tributaries of River Niger and comprises of ore rich deposits of feldspar and quartz, and significant massive granite gneiss rock were observed.

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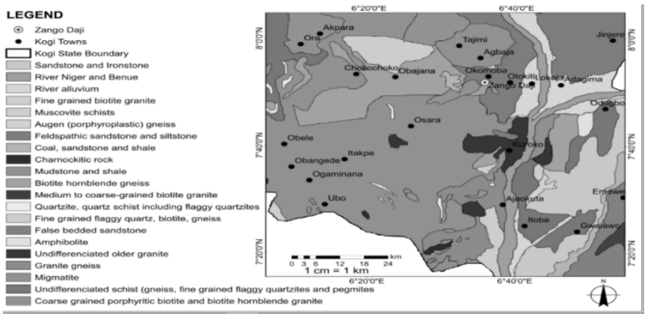

Figure 1: Geological and Mineral Resources Map of Kogi State

Global Positioning System (GPS) was used to take coordinates and camera to take photographs. The location coordinates of the study area are shown in Table 2.

Table 2: The Geographical Coordinates of Corners of Block A

S/No.	Longitude	Latitude
1.	06° 36^{I} 00^{II}	007° 48^{I} 45^{II}
2.	06° 36^{I} 15^{II}	007° 48^{I} 45^{II}
3.	06° 36^{I} 15^{II}	007° 48^{I} 30^{II}
4.	06° 36^{I} 30^{II}	007° 48^{I} 30^{II}
5.	06° 36^{I} 30^{II}	007° 48^{I} 00^{II}
6.	06° 35^{I} 45^{II}	007° 48^{I} 00^{II}
7.	06° 35^{I} 45^{II}	007° 48^{I} 30^{II}
8.	06° 36^{I} 00^{II}	007° 48^{I} 30^{II}

The study area was further mapped into three adjoining blocks, namely A, B and C based data collected during the reconnaissance survey carried out. Figure 2 shows the thematicmap of the three mapped out blocks located in the study area.

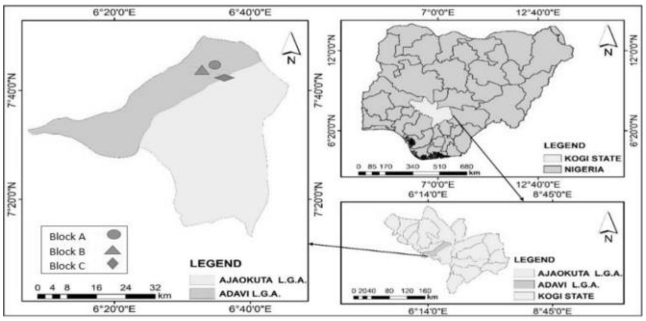

Figure 2: Map of the Study Area showing the three mapped out Blocks

A total of eighteen (18) fresh representative rock samples of the feldspar deposits were randomly collected with spades, digger and geologist hammer, stored in sample bags and carefully labelled. Six (6) rock samples obtained from the field were shared into two portions. One portion was prepared into thin sections and the other powdered into 50 µm at the Federal University of Technology, Akure (FUTA) Geology and Chemistry Laboratories and subjected to X- ray spectrometer and X-ray diffusion to determine various percentages of elemental compositions of each sample. The results of analyzed rock samples were computed. The X-ray fluorescence and X-ray diffusion methods were conducted at the National Geosciences Laboratory Centre (NGSLC), Kaduna, according to Brown method and University of Johannesburg, South Africa using EZS991XNV scanner. The physical properties such as the density, colour, cleavage, lustre and hardness of the rock samples were determined in the Geology and Chemistry Laboratories of the Federal University of Technology, Akure by observing under the microscope, using a set of mineral hardness picks and hand lens. The remaining twelve (12) samples in a ratio of 4:4:4 from the three blocks were used to obtain the physical properties stated.

The density of the feldspar sample was determined by using the Density bottle method (Densometer) while the hardness test was determined using the Mohs hardness test method. Forty (40) grams each of the feldspar rock prepared from samples collected from the three blocks were immersed separately into the density bottle of known weight and when water added, the weight of density bottle increased. obtain a volume increase in the water. The difference in volume was calculated and divided with the known weight of solid. The average density of the feldspar from the three blocks was

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determined The density of the feldspar rock was determined by using the density bottle method and calculated as summarized by Equation 2.

$$S = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)} \times D_r \; (Kg/m^3) \qquad (2)$$

Where, Dr is Density of fluid used, M_1 is Weight of empty bottle + stopper, M_2 is Weight of bottle + stopper + dry sample, M_3 is Weight of bottle + stopper + dry sample + water, M_4 is Weight of bottle filled with water only, and S is Density of feldspar sample. The other physical properties were determined by observation under a high powered microscope.

3.2. OVERBURDEN QUANTIFICATION AND FELDSPAR DEPOSITS THICKNESS ESTIMATION USING GEOPHYSICAL SURVEYING METHOD

Electrical resistivity survey was carried out across the ore rich deposit of feldspar and quartz pegmatite **within** blocks A, B and C mapped out of the entire study area by reading their resistance values from the Omega Resistivity Meter using the Schlumberger electrode array with maximum $\frac{AB}{2}$ spacing ranging between 100 – 150 m, where AB is the current electrode separation. A total of thirty – one (31) vertical electrical sounding (VES) points were conducted across the investigated area. The data obtained were used to produce resist graphs, geo electric sections, iso resistivity maps and isopach maps which gave some geological information about the deposits needed for this research.

The resistance values obtained in blocks A, B and C within the study area by using the schlumberger array were calculated using Equation 3.

$$\rho_a = \pi \frac{\left(\frac{s^2 - a^2}{4}\right)}{a} \frac{\Delta v}{I} \qquad (3)$$

Where, π is a constant, s is distance between the two outer electrodes and the two inner electrodes, a is the distance between the two inner electrodes, Δv is the voltage change across the potentials and I is the current,

and ρ_a is the resistance measured across the two inner electrodes.

The resistance values obtained from the three blocks were further filtered using WinResist GIS software to eliminate or reduce errors due to instrument mal-function, weather condition or recording. The values obtained from block A are presented in Table 3. They were converted into thickness values in metre using the WinResist GIS application.

Table 3: The Measured Resistance (VES) Data Taken from Block A

Peg	VES 1	VES 2	VES 3	VES 4	VES 5	VES 6	VES 7
VES 8 Distances (m)							
1.	146	46	115	481	1341	644	91
513	2.	31	55	80	858	595	64
373	414	3.	30	44	49	632	505
60	366	330	4.	28	62	53	419
474	65	338	254	6.	24	62	91
874	490	76	310	234	6.	25	44
114	1137	491	72	401	211	8.	27
76	48	136	494	86	310	223	
12	28	114	60	69	556	109	200
243	15	31	114	23	73	512	141
162	125	15	28	165	83	72	524
134	202	244	25	43	135	64	83
613	157	225	275	32	53	142	162
117	719	188	234	268	40	68	147
179	114	833	212	237	278	40	74
158	172	104	874	236	214	314	
65	114	225	283	180	847	378	324
394							
100	192	201	202	239	919	613	476
517	100	206	293	207	222	897	664
386	610	150	337	441	1379	991	1099
884	620	699					

A total number of eight (8) VES points were taken across the investigated area in block A along a distance of 150 metres of peg line. A total number of nine (9) VES points were taken across the investigated area in block C along a distance of 150 metres of peg line. The measured VES points located within block A are presented in Figure 3.

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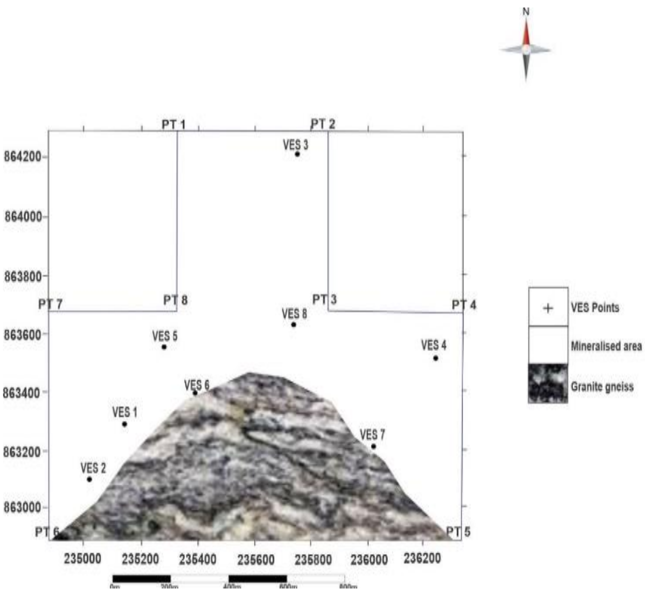

Figure 3: Eight (8) VES Points Taken Within Block A Conducted During the Exercise.

Statistical analysis validity tests of data using the goodness of fit test were conducted on the exploratory data obtained from VES values in the blocks within the study area. The Wiener-Kolmogorov prediction for interpolating requires that the VES data obtained should be normally distributed before they can be suitable for Kriging or Gaussian process regression line technique which is governed by prior covariance (Christianson *et al.,* 2022). The method is widely used in the domain of spatial analysis and computer experiments. To achieve this, the data were subjected to statistical testing at 0.05% significance level, using the goodness of fit method, and if not normally distributed, are transformed into standard normal to produce the Q-Q plots using the ggplot2 software. Kriging or Gaussian process gives the best linear unbiased prediction of the intermediate values (Christianson *et al*., 2022). The general formula used for Kriging prediction is given in Equation 4

$$\hat{Z}(S_0) = \sum_{i=1}^{N} \lambda_i Z(S_i) \qquad (4)$$

Where Z(Si) is the measured value of the i^th location, λ_i is the unknown weight for the measured value of the i^th location, S_0 is the prediction location and N is the number of measured values.

3.3.1. Data testing and validation result

The data testing and validation using goodness of fit are presented. The resistivity data for both overburden layers and target mineral layers tested at 0.05 significance level for blocks A, B and C were linearly normal as presented in Q-Q plots shown in Figures 4 - 5 for the block A.

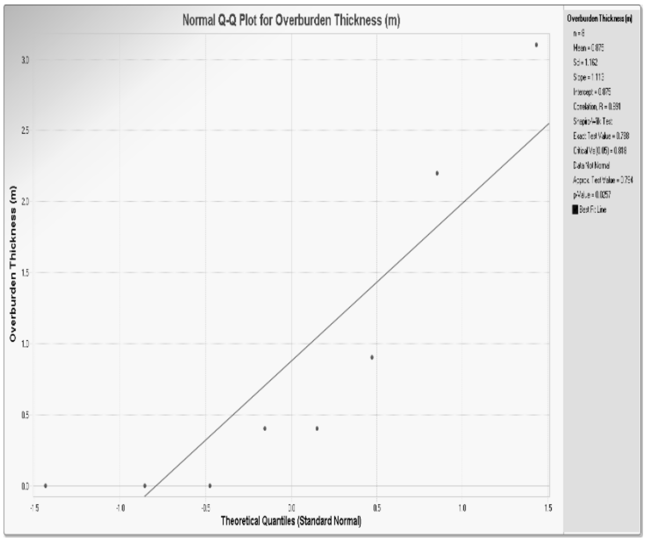

Figure 4: Normal Q-Q plot for Overburden Thickness for Block A

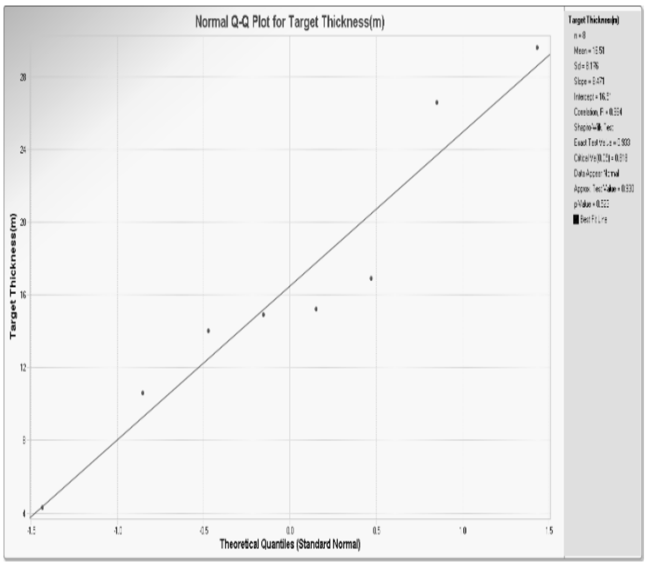

Figure 5: Normal Q-Q plot for Target Mineral Thickness for Block A

From Figures 4 and 5, most of the data points for overburden layer and target mineral thickness in block A tested are linearly normal along the regression line when they were plotted on the Q-Q plot. The significance of these Q-Q plots are to show that the data are in conformity with the Wiener-Kolmogorov prediction for interpolating which requires that the VES data obtained should be normally distributed.

4 RESULTS AND DISCUSSIONS

4.1. SITE MAPPING USING GEOGRAPHICAL INFORMATION SYSTEM (GIS) AND OTHER SCIENTIFIC TOOLS.

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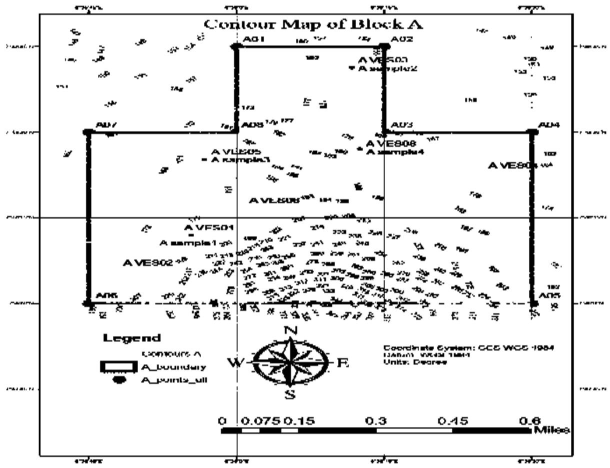
The coordinates and elevations data collected were used to produce the contour map of the mining project of block A. This is shown in Figure 6. The contour maps of blocks B and C were similarly produced. These maps provide some information for calculation of reserve estimation and volume of overburden of the feldspar deposit.

Figure 6: Contour Map for Block A Showing Sample Contour Lines



4.2 LABORATORY RESULTS OF PHYSICAL AND CHEMICAL ANALYSIS TESTS OF ROCKS SAMPLES

The laboratory results of physical and chemical analysis of rock samples are presented in the subsequent subsections.

4.2.1. Chemical analysis test

The results of chemical composition of four (4) rock samples each taken from blocks A, B and C, using laboratory methods are presented in Table 4.

Table 4: Mineralogical Composition of Feldspar Samples from Block A

% Oxide Composition	Sample 1 @ 235180E 863308N @ 186m Elevation	Sample 2 @ 235686E 864208 @ 167m Elevation	Sample 3 @ 235225E 863717N @ 179m Elevation	Sample 4 @ 235708E 863770N @ 182m Elevation
SiO_2	65.89	65.55	66.82	
Al_2O_3	17.66	17.63	17.65	
PbO	0.001	0.001	<0.001	
K_2O	14.15	14.17	14.13	
Na_2O	0.57	0.60	0.62	
CaO	0.18	0.20	0.29	
MgO	0.02	0.015	0.03	
TiO_2	0.018	0.022	0.02	
MnO	0.019	0.019	0.019	
Fe_2O_3	0.03	0.041	0.064	
CuO	0.004	0.004	0.004	
ZnO	0.004	0.004	0.004	
NiO	0.004	0.004	0.005	
Cr_2O_3	0.01	0.01	0.01	
V_2O_5	ND	ND	ND	
Cr	0.062	0.063	0.065	
Cu	0.031	0.035	0.033	
Zn	0.033	0.034	0.031	
Pb	0.014	0.011	0.009	
Ni	0.033	0.035	0.040	
Mn	0.144	0.144	0.147	
LOI	1.40	0.70	0.3	

From Table 4, the percentage composition of Oxides of Potassium, Aluminum, Sodium, Calcium, Silicon and Magnesium in the feldspar sample taken from the three blocks are presented. The ratio of Si: Al is within the range of 3:1 and the percentage composition of Potassium oxide is greater than 10%. The oxide composition of Potassium and Aluminum ranges from 14.13 to 15.63 for K_2O and 17.63 to 17.66 for Al_2O_3 for block A. Similarly, values of 15.70 to 15.80 for K_2O and 16.90 to 16.99 for Al_2O_3 for block B and 15.43 to 15.81 for K_2O and 16.96 to 16.99 for Al_2O_3 for block C also ranges. The interpretation of these results shows that the composition of the values of K_2O and Al_2O_3 from the four samples taken are within the required standard.

4.2.2 X-ray fluorescence spectrometry result

Similarly, the results of three (3) whole rock samples from the three blocks, pulverized, sieved and analyzed using X - ray fluorescence spectrometer is presented in Table 5.

Table 5: Result of X – Ray Fluorescence and X – Ray Diffusion Analysis of Feldspar Sample Showing the Oxide Composition of Sample in Blocks A, B and C

BLOCKS	A	B	C
Component		Value %	
Na_2O	2.2196	4.4095	2.2708
MgO	0.0465	0.7126	0.0328
Al_2O_3	18.0177	16.7249	15.8666
SiO_2	59.4385	66.4371	64.4877
P_2O_5	0.0145	0.1484	0.1000
SO_3	0.0163	0.0157	0.0179
Cl	ND	0.0317	ND
K_2O	18.7658	2.5157	14.9741
CaO	0.2966	4.8416	0.3150
TiO_2	ND	0.4012	ND
Cr_2O_3	0.0165	0.0212	0.0328
MnO	0.0371	0.0457	0.0688
Fe_2O_3	0.9710	3.4044	1.6092
NiO	0.0088	0.0121	0.0112
CuO	0.0093	0.0146	0.0186
ZnO	ND	0.0060	ND
Ga_2O_3	ND	0.0077	0.0075
As_2O_3	ND	0.0039	ND
Rb_2O	0.1040	0.0100	0.1380
SrO	0.0068	0.0832	0.0040
ZrO_2	ND	0.0498	0.0026
Nb205	ND	ND	0.0189
BaO	ND	0.1030	ND
PbO	0.0308	ND	0.0236

From Table 5, the X – ray fluorescent spectrometry and X – ray diffusion employed in the analysis is presented. The table shows the percentage composition of Oxides of Potassium, Aluminum, Sodium, Calcium, Silicon and Magnesium in the feldspar sample taken from blocks A, B and C. The ratio of Si: Al is within the range of 3:1 and the percentage composition of Potassium is greater than 10%. The table shows that the result of the oxide composition by value percentage of Potassium Oxide (K_2O) and Aluminum Oxide (Al_2O_3) in the feldspar deposit from the study area and analyzed through X- ray fluorescence spectrometry is 18.7658 and 18.0177, 18.5157 and 16.7249 and 17.1958 and 17.8291 respectively. Therefore, they meet the required standard, as the value of a feldspar deposit is determined by the presence of Potassium Oxide (K_2O) and the presence of Aluminum Oxide (Al_2O_3) in the sample.

Also, Table 5, shows that the oxide composition of Potassium Oxide is far greater than the oxide composition of Calcium Oxide (CaO) and Sodium Oxide (Na_2O) in samples from the three blocks are 0.2966, 4.8416, 0.0837 by value percentage for Calcium Oxide and 2.2196, 4.4095, 2.3332, by value percentage for Sodium Oxide respectively. The low elemental composition of CaO and Na_2O shows also that the feldspar deposit in the study area is orthoclase and not plagioclase in accordance with Harben, (1995) definition of commercial and K- Feldspar.

Also, Table 5, shows that the oxide composition of Potassium Oxide is far greater than the oxide composition of Calcium Oxide (CaO) and Sodium Oxide (Na_2O) in samples from the three blocks are 0.2966, 4.8416, 0.0837 by value percentage for Calcium Oxide and 2.2196, 4.4095, 2.3332, by value percentage for Sodium Oxide respectively. The low elemental composition of CaO and Na_2O shows also that the feldspar deposit in the study area is orthoclase and not plagioclase in accordance with Harben, (1995) definition of commercial and K- Feldspar.

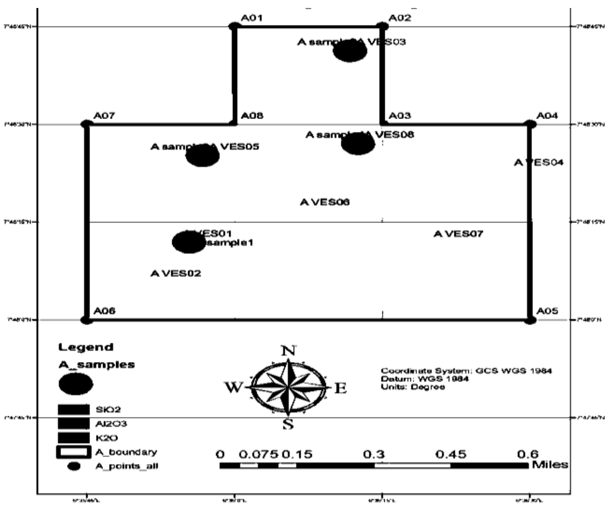


Figure 7: Design of Mineral Composition Location Map of Block A

The maps show the geographical positions where VES was carried out and the composition of minerals in the samples taken from those positions.

4.2.3. Physical analysis test

The results of rock samples taken from all three blocks, prepared into thin sections in the laboratory and analyzed for physical characteristics were processed. The summary of results is presented in Table 6. The average density of the feldspar from the three blocks was determined to be 2.56 g/cm^3 and a hardness of 6 was obtained, using the Mohs scale.

Table 6: Results of Physical Characteristics of Feldspar Samples Taken from three Blocks

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Physical Characteristics	Result Obtained
Mohs Hardness Test	6
Density	2.55 g/cm³
Diagnostic Properties	Feldspar sample has a perfect
cleavage.	
	Cleavage faces intersecting at or cl
to 90˚.	
	Consistent hardness, specific gravi
pearly	
	lustre on cleavage faces, showing
flakes of quartz	
	(white) and muscovite (white). It i:
granitic and	
	granodiorite composition.

4.3. ELECTRICAL RESISTIVITY DATA PRESENTATION AND DISCUSSION

The measured electrical resistivity data taken from blocks A, B
and C within the study area are displaced in several formats as depth sounding curves, tables, plans and 2-D or plain maps. All plans or contour maps are registered to the WGS 84, Zone 32N UTM grid coordinate system. The profiles of the inverted models show the presence of a predominance feldspar, mica, granitic intrusive and gemstones.

4.3.1 Electrical resistivity data for block A

Thirty-one (31) VES data were obtained for blocks A, B and C. All VES data in ohms were processed into depths in metres. The eight (8) vertical electrical sounding (VES) data for block A which measured the resistivity in ohms were as well processed into depths. The interpreted depths in metres, registered to the local grid coordinates were processed into depth sounding curves and presented as Resist graphs for VES 1 and VES 2 are shown Figure 8 and 9.

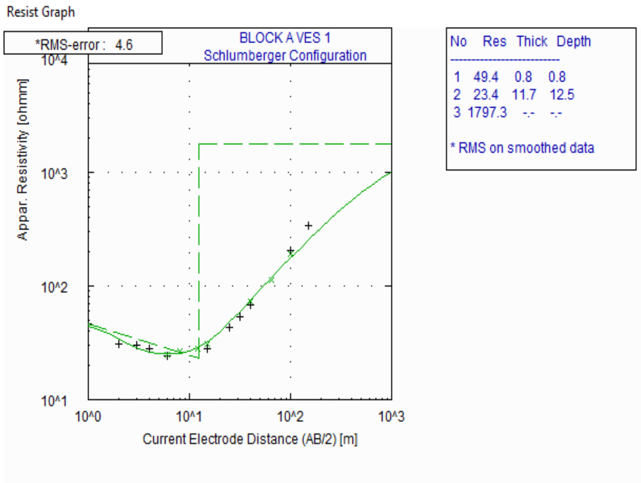

Figure 8: Resist Graph Shows the VES Curve for VES 1 in Block A

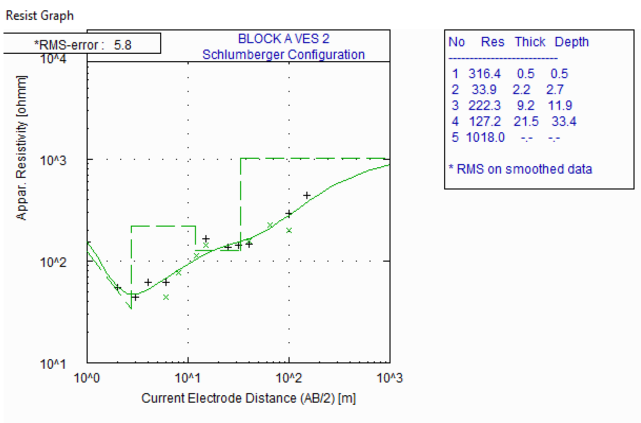

Figure 9: Resist Graph Shows the VES Curve for VES 2 in Block A

VES 1 in the figure shows a resistance of 49.4 ohms and 23.4 ohms respectively, indicating the top soil and weathered feldspar profile at the given depths of 0.8 m and 12.5 m. At these depths, the top soil and weathered feldspar thicknesses are 0.8 m and 11.7 m. at depth number, there is no occurrence of feldspar. VES 2 in Figure 9 indicates a resistance of 316.4 ohms, 33.9 ohms and 222.3 ohms with thicknesses of 0.5 m, 2.2 m and 9.2 m respectively. This shows that only at depth of 33.4 m the feldspar occurrence began with a thickness of 21.5 m. Beyond this, no feldspar occurrence was indicated.

4.3.2 Inverted VES data of results of overburden layer and target mineral thickness of the blocks

To obtain the curves, the results of VES values were subjected to inversion with WinResist program in order to obtain the 2-D modeling of overburden layer and target mineral thickness. The
Summary is presented in Table 7.

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Table 7: Vertical Electrical Sounding Curves after Inversion for Block A

VES Location	Easting (m)	Northing (m)	Elevation (m)	Overburden Resistivity (Ωm)	Overburden Thickness (m)	Target Resistivity (Ωm)	Target Thickness (m)
VES 1	235140	863308	186	49.4	0.8	23.4	11.7
VES 2	235040	863119	191	316.4	0.5	127.8	10.9
VES 3	235686	864208	167	2633.3	0.3	120.4	5.5
VES 4	236174	863637	167	2191.3	0.4	146.3	5.3
VES 5	235225	863717	179	664.7	1.0	555.2	10.3
VES 6	235506	863453	196	112.9	0.6	370.1	11.5
VES 7	235922	863302	188	502.2	0.7	365.6	15.6
VES 8	235708	863770	182	710.3	0.9	660.3	31.5

4.3.3 Overburden layer iso-resistivity and isopach maps of block A

The iso-resistivity map of the overburden layer material of block A is presented in Figure 10.

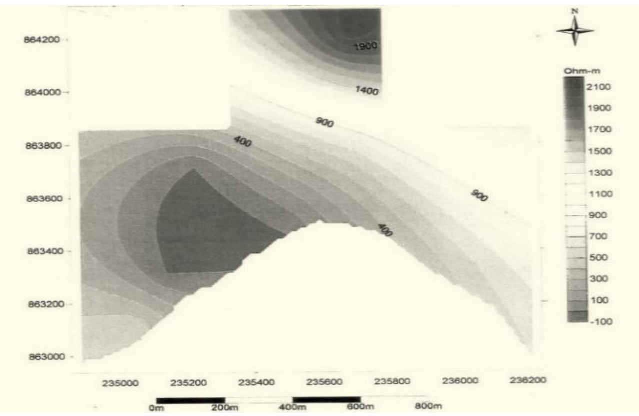

Figure 10: Overburden Layer Iso-Resistivity Map of Block A

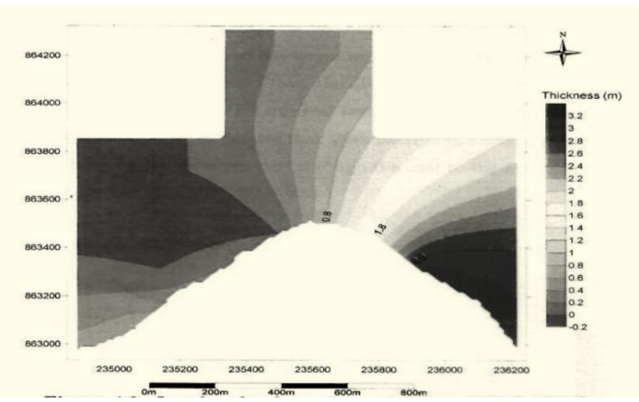

Figure 11: Overburden Layer Isopach Map of Block A

It shows the distribution of the resistivity of the overburden layer within the mineralized portion of block A. It ranges between 316.4 Ωm and 502.2 Ωm. In Figure 11, it shows the overburden layer isopach map within the mineralized portion of block A. It indicates the distribution of the overburden layer thickness. The overburden layer thickness in the isopach map ranges from 0.5 m to 1.0 m where predomination of thickness greater than 0.5m exist in the southern part of the map. The net part of this area is characterized by thickness less than 1m with major concentration of this value in the north and western axis.

4.3.4. Target mineral layer iso-resistivity and isopach maps of block A

The iso-resistivity map of the target mineral (feldspar) layer of the mineralized portion of block A is presented in Figure 12.

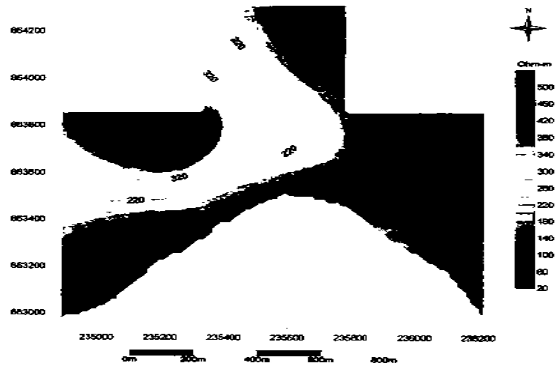

Figure 12: Target Mineral Layer Iso-Resistivity Map of Block A

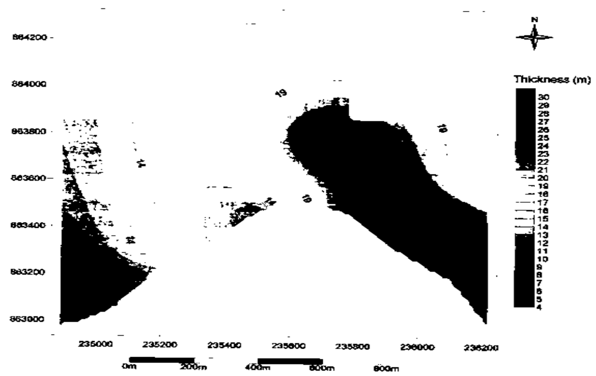

Figure 13: Target Mineral Layer Isopach Map of Block A

It shows the distribution of the resistivity which ranges between 127.2 Ωm and 290.7 Ωm across this portion. Figure 13 is the isopach map of the target mineral (feldspar) layer within the mineralized portion of block A. The map shows the distribution of the feldspar thickness

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within block A at given depths. The target mineral layer thickness ranges between 14.9 m – 33.4 m where the predominant thickness greater than 20m exist in the south eastern part of block A. It is observed that the south eastern part through the east to the northern part is characterized by thickness greater than 20m.

4.3.5. Geo – Electric Section Models

The geo – electric section maps illustrates the mineral occurrence profile and thickness in metres of the feldspar deposit and overburden materials in each block. The geo – electric section models for VES points 4 and 8 in block A are presented in Figures 14 - 15.

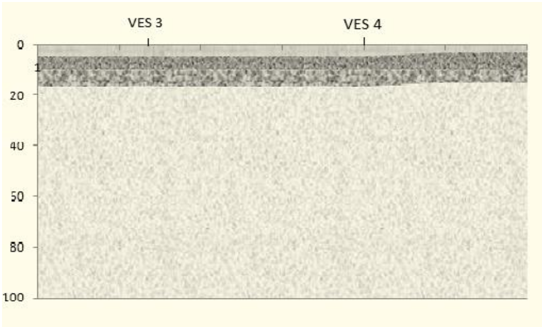


Figure 14: Geo – Electric Section of VES 3 to VES 4

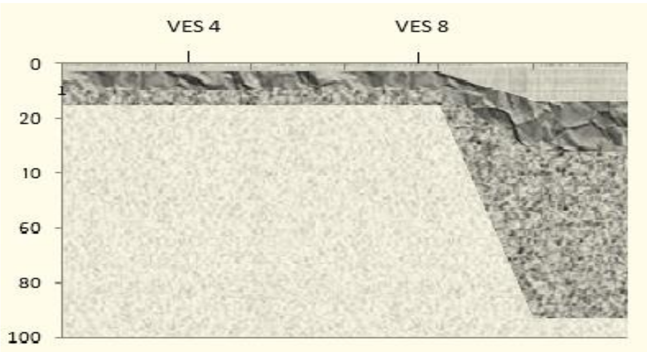
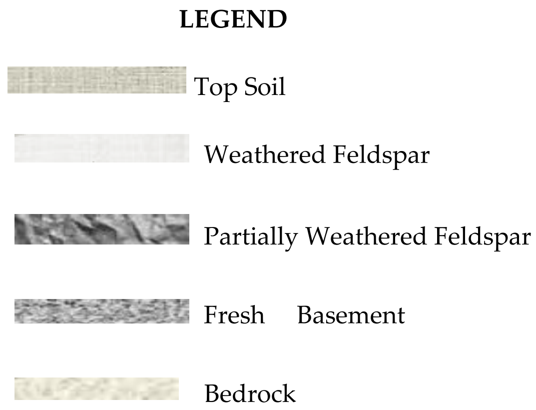


Figure 15: Geo – Electric Section of VES 4 to VES 8

From Figure 14, the distribution of weathered and partially weathered feldspar is slightly even across VES 3 to VES 4. The thickness of deposit ranges from 2m to 3m for weathered feldspar and 2.5m to 3m for partially weathered feldspar. Top soil ranges from 0m to 1.5m. From Figure 15, the distribution of weathered and partially weathered feldspar is uniform at VES point 4 and tabular at VES 8. The thickness of deposit ranges from 2m to 20m for weathered feldspar and 2m to 60m for partially weathered feldspar. Top soil ranges from 0m to 10m.

The geo-electric sections presented in Figures 14 – 15 are indications of the thickness of deposit spread across the feldspar deposit. They provide information of the profile of the deposit such as the various depths or layers of sub surface and under surface occurrences. From the analysis of the results, the average depths and thicknesses obtained could be virtually assessed and evaluated for planning. The ratio of average of depths and thicknesses of overburden and target minerals from observation and measurement is 5 m- for overburden and 50 m for target mineral.



4.4. RESERVE ESTIMATE AND OVERBURDEN MATERIAL VOLUME QUANTIFICATION OF FELDSPAR DEPOSIT IN BLOCKS A, B AND C.

The method applied for reserve estimate and overburden material volume quantification for the feldspar deposit in the three blocks were determined by adopting contouring using the thickness values obtained from the interpreted VES results.

4.4.1. Estimation of the volume of feldspar in blocks.

The estimation of the volume of feldspar deposit over the mineralized portion of blocks i.e. 0.96 km², 0.61km² and 2.8km² were each divided into different sizes of five, six and five portions respectively for easier computation. Results of reserve estimation of volume of feldspar and overburden volume estimates are hereby presented:

Table 8: Estimation of Volume of Feldspar Per Portion of Block A

Portion	Number of Sample Contour Lines	Thickness of Contour Lines (m) Block A (Overburden Layer Thickness)	Mean Thickness (m)	Standard Deviation of Thickness (m)	Standard Error of Thickness (m)	Area of Portion (m^2)	Volume of Overburden Material (m^3)
1.	4	0.8,0.6,0.4,0.2	0.5	0.26	0.13	195,136.77	97,568.39 ± 25,192.05
2.	3	0.4,0.2,0	0.2	0.2	0.12	255,215.40	51,043.08 ± 29,469.74
3.	10	0.6,0.8,1.0,1.2,1.4,1.6,1.8,2.0,2.2,2.4	1.53	0.61	0.19	204,819.33	312,814.98 ± 39,407.46
4.	5	0.2,0,0,0.2,0.4	0.16	0.17	0.08	187,045.35	29,927.26 ± 13,997.19
5.	12	1.0,1.2,1.4,1.6,1.8,2.0,2.2,2.4,2.6,2.8,3.0,3.0	2.08	0.70	0.20	120,277.91	250,578.98 ± 24,138.96

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Total Volume of Target Mineral = 17,292,213.44 m^3
Total Volume of Uncertainty of Target Mineral = ± 849,855.48 m^3
Target Mineral Reserve = 44,268,066 ± 2,175,630kg ie 44.3 ± 2.18 million metric tons
Error Mass = 2,175,630 kg

The product of the volume and the measured density puts the target mineral (feldspar) reserve in block A at 44,268,066 ± 2,175,630 kg ie 44.3 ± 2.18 million metric tons, 22,053,189 ± 1,765,188kg ie 22.1 ± 1.77 million metric tons in block B and 47,910,236 ± 2,590,634kg ie 47.9 ± 2.59 million metric tons in block C respectively. Total reserve estimate for the three blocks is 113.3 million metric tons ± 2.59 million metric tons.

Table 9: Estimation of Overburden Volume Material Per Portion of Block A.

Portion	Number of Sample Contour Lines	Thickness of Contour Lines (m) Block A (Target Layer Thickness)	Mean Thickness (m)	Standard Deviation of Thickness (m)	Standard Error of Thickness (m)	Area of Portion (m^2)	Volume of Target Mineral (m^3)
1.	11	14,15,16,17,18,19,20,21,22,23,24	19	3.32	1	195,136.77	3,707,598.63± 195,136.77
2.	12	11,12,13,14,15,16,17,18,19,20,21,22	16.5	3.61	1.040346	255,215.40	4,211,054.10± 65,512.32
3.	14	18,19,20,21,22,23,24,25,26,26,25,24,23,22	22.5	2.47	0.660428	204,819.33	4,608,434.93± 135,268.42
4.	13	5,6,7,8,9,10,11,12,13,14,14,13,12	10.3	3.07	0.850416	187,045.35	1,926,567.11± 159,066.36
5.	14	29,28,27,26,25,24,23,22,21,20,23,22,21,20	23.6	2.95	0.79977	120,277.91	2,838,558.68± 94,871.61

Total Volume of Overburden Materials = 741,932.68 m^3
Total Volume of Uncertainty of Overburden Materials = ± 132,205.40 m^3
The same procedure was followed in calculating the volume of overburden material for all three blocks. This was estimated as 741,932.68 m^3 ± 132,205.40 $m^3$for block A, 724,515.33 m^3 ± 87,798.94 m^3 for block B and 2,324,533.90 m^3 ± 232,363.05 m^3 for block C, bringing the total of removable overburden material to 3.79 ± 0. 452 million cubic metres.

5 CONCLUSIONS

The physicochemical properties of the feldspar deposit in the study area mentioned using geophysical and geochemical methods were determined after mapping the area into three blocks using GIS. The following findings and conclusion were drawn from the study.
The average specific gravity of 2.56 g/cm^3, hardness of 6 on the Mohs scale were obtained and the chemical composition showed a deposit of rich feldspar and Quartz pegmatite with low iron content.
Geophysical survey, which gave the resistivity of the ore body with respect to the bedrock conducted using electrical resistivity method was used to determine the reserve estimate of the three mapped out blocks within the ore rich deposits of feldspar in a quartz pegmatite zone located in Zango Daji forest in Adavi and Ajaokuta local government areas of Kogi state, Nigeria.
The results of geochemical and geophysical analysis carried out showed that the feldspar deposit possesses the characteristics of Potassium Feldspar or K-Feldspar. It also possesses the properties of an orthoclase feldspar and those listed in the British International Standard condition for various uses of feldspar in terms of suitability and applicability.
Quantitatively, both the ore rich deposit of feldspar and the volume of removable overburden material were estimated i.e. for block A, the results are 44.3 ± 2.18 million metric tons and 741,933 ± 132,205 m^3 respectively; for block B, the results are 22.1 ± 1.77 million metric tons and 724,515.33 m^3 ± 87,798.94 m^3 respectively and for block C, the results are 47.9 ± 2.59 million metric tons and 2,324,532 m^3 ± 232,363 m^3 respectively.
The preference for the development of the three mapped out blocks of feldspar based on the level of geoscientific information obtained would be made upon the information obtained from the economic evaluation of the deposit.

6. RECOMMENDATIONS

Feldspar's unique properties, which are contained in its physicochemical characteristics, such as its high alkali content, low iron content, and excellent thermal stability, make it an indispensable mineral for a wide range of applications. As Nigeria continues to explore and harness its mineral resources, the utilization of feldspar is expected to play a crucial role in the country's industrial growth and economic development.

Based on the physicochemical characteristic of the feldspar deposit, it is recommended that:

i. An economic evaluation be carried out to determine the economic and financial viability of the project. The economic evaluation would determine the capacity of the project to generate profit without any liability after the loan payback period.
ii. In addition to determining the economic and financial viability of the project, an economic mining model should be developed through a cash flow analysis to evaluate the economic feasibility of

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the project and its viability given the technical and managerial skills of the mangers of the project.

AVAILABILITY OF DATA AND MATERIALS

The data used in the study were the laboratory analysis results from intensive geophysical and geochemical methods carried out at the study area.

COMPETING INTEREST

The authors declare that they have no competing interests

AUTHORS CONTRIBUTIONS

All sections of the manuscript including data collection, analysis and interpretation were carried out by the authors

REFERENCES

Abiodun, S.M. Akintonde, M. and Akinde, T. (2013) Small Scale Ceramics Industry in Oyo State: Challenges and Prospects. *Journal of Economic and Sustainable Development* (4): 56 – 65.

African Pegmatite, 2023) Feldspar: Uses and Application. Available at https://mineralmilling.com

Ako, T. A. and Onoduku, U. S. (2013) Geology and Economic Evaluation of Odobola, Ogodo Feldspar Mineral Deposit, Ajaokuta Local Government Area, Kogi State, Nigeria. *Journal of Earth Science Research.* 2(1): 52.http://dx.doi.org/10.5539/esr

Aniobi, S.C. Olusegun, J. A. and Godwin, N.N. (2021) Economy beyond Oil: Harnessing Nigerian Solid-Mineral Deposits for Sustainable Development. Available at: www.researchgate.com

Balic-Zunic, T. Piazolo, S. Katerinipoulov, A. and Schmith, J.H. (2013): Full Analysis of Feldspar Texture and Crystal Structure by Combing X-Ray and Electron Techniques. *American Mineralogist*. (98):41 – 52

Baloyi V.D. and Meyer L.D. (2020) The Development of a Mining Method Selection Model through a Detailed Assessment of Multi Criteria Decision Methods. *Results in Engineering Journal*. 8(1). www.sciencedirect.com

Browne, L.B. (2006) Helmer – Boviee Feldspar, Quartz and Kaolin Mineral Leases. Latarh Country, Idaho. pp. 52 -53.

Deniz, K and Kadioglu, Y.K (2019) Investigation of Feldspar Raw Material Potentials of Alkali Feldspar Granites and Alkali Feldspar Syenites Within Central Anatolia. *Bulletin of Mineral Research and Exploration.* (158): 265 - 289. http://bulletin.mta.gov.tr.

Dietrich, R.V. (2020) Feldspar Mineral, Encyclopaedia Britannica.

Edeme, R.K. and Nkalu, N.C. (2019 Predicting the Effects of Economic Diversification on Solid Mineral Development in Nigeria. *Journal of Contemporary Research in Business, Economics and Finance.* 1(4): 6

Gandhi, S.M. and Sarkar B.C. (2016) Reconnaissance and Prospecting in Essentials of Mineral Exploration and Evaluation. *Elsevier Journals and Books*. pp. 53-79

Gandhi, S.M. and Sarkar B.C. (2016) Geological Exploration. In Essentials of Mineral Exploration and Evaluation. *Elsevier Journals and Books.* pp. 159-198

Gaied M.E. and Gallala W. (2015) Beneficiation of Feldspar Ore for Application in the Ceramic Industry: Influence of Composition on the Physical Characteristics. *Journal of Arabian Chemistry*. 8(2):186 - 190GNI, (2021) Geoscience News and Information. Available at https://geology.com

Haldar, S.K (2018) Reconnaissance: An Overview in Mineral Exploration. (Second Edition). From Principles and Application. *Elsevier Journals and Books*. www.sciencedirect.com. 1-23Haldar, S.K (2020) Basic Mineralogy. Introduction to Mineralogy and Petrology. (Second Edition). *Elsevier Journals and Books*. www.sciencedirect.com. 349 -376

Harben, P.W. (1995) The Industrial Minerals Handy Book. Second Edition. A Guide to Markets, Specification and Prices. Ontario. pp. 36-43

Jan, Z. Jakub, J. Jaromír, S and Martin, S. (2020) Production, Reserves and Processing of Feldspar and Feldspathoid Rocks in the Czech Republic from 2005 to 2019.
- An Overview. pp. 14-16

Klein, C. and Philpotts, A.R. (2017) Chapter 7 Igneous rock-forming minerals. In *Earth Materials:* Introduction to Mineralogy and Petrology, 2nd ed. Cambridge University Press: New York, NY, USA. 161.

Lowrie, W. (2007) Fundamentals of Geophysics. Second Edition. Cambridge University Press. p. 256. www.cambridge.org/

Micah, E.E.M. and Ibitomi, T. (2020) Problems and Strategies for Exploration of Solid Mineral Resources in Nigeria. Available at: http://www.researchgate.com

National Bureau of Statistics, NBS (2021) Mineral Production Report for 2019 – 2020.

National Bureau of Statistics, NBS (2022) Mineral Production Report for 2021

Naturenews. (2022) Nature News. Feldspar. The Environment First. Available at: www.naturenews.africa/feldspar

Ogundare, M.O and Lajide, L. (2013): Physicochemical and Mineral Analysis of Composts Fortified with NPK Fertilizer, Ammonium Chloride and Kaolin. *Journal of Agriculture, Chemistry and Environment*. 2(2): 27-33. http://dx.doi.org/10.4236/jacen.2013.22005

Ogunsanya O.A., Aluko O.O. and Ogundipe O.M. (2022): Performance of Glass and Steel Slag Mixtures as a Partial Replacement for Fine Aggregate in Asphalt Concrete, FUOYE Journal of Engineering and Technology (FUOYEJET), 7(2), 257-263. http://doi.org/10.46792/fuoyejet.v7i2.752

Olumide, S. A. Akongwale, S. and Udefuna, P.N. (2013) Economic Diversification in Nigeria. Any Role for Solid Mineral Development? *Mediterranean Journal of Social Sciences*. 4(3):691

Orji, M.C. Eleanya, E. E. Mohammed, D. A, Yahaya, A. B. Williams, O. E and Chukwu, C. U. (2018) The Solid Mineral Sector and Economic Diversification in Nigeria. *Lapal Journal of Economics*. 2(2):2

Reynolds, J. M. (2011) An Introduction to Applied and Environmental Geophysics. Second Edition. John Wiley & Sons, Limited. p. 14.

Saliu, M.A. (2018) Investigation into Factor Controlling Potential for Dimension Stone Production of Selected Granites from South West Nigeria. Ph.D. Thesis submitted to University of Exeter. p.317.

Statista Research Department, (2023): Volume of Feldspar Produced in Nigeria, 2015 – 2020. Available Online at https://www.statista.com

William, B. L. (2019) Technical and Economic Evaluation of Mineral Deposits. Micon International Limited. Mineral Industry Consultants. p. 1.

Xu, Y. Liang, X. Xu, Y. Qin, X. Huang, Q. Wang, L and Sun, Y. (2017) Remediation of Heavy Metal-Polluted Agricultural Soils using Clay Minerals: A review. Pedosphere, (27): 193–204.