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Physicochemical Characteristics of Feldspar Deposits in Zango Daji, Kogi State Using Geological Methods

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ABSTRACT: *Six rock samples were randomly collected and photographs, locational coordinates and elevation points were taken with appropriate tools and devices. Portions of samples were prepared into thin sections and observed under hand lenses, microscope, tested for hardness and other diagnostic properties. Specific density was also determined. The remaining samples were subjected to geochemical and mineralogical analysis. An average percentage composition of 17.1958 mass % of K_2O was obtained which is far greater than its Calcium and Sodium contents, indicating it is a K-feldspar. Geochemical result showed averages of 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. The results showed that the sample specification meets the British International Standard specification. Furthermore, electrical resistivity tomography survey was conducted by setting up Schlumberger Electrode Array to determine the significant resistivity contrast between the feldspar and the compact bedrock in the profile. The resistivity data of eight points were processed into Resists curves after conversion and subjecting the data by inversion with WinResist software to obtain 1 - D and 2 – D maps. Together with results of chemical analyses and vertical electrical sounding, the location map of mineralogical composition of the Oxides were determined. Field and petrographic evidence showed a potential source of gemstones and niobium. The study also revealed the occurrence of feldspar deposit are hosted by granitic and pegmatitic intrusive. The quantum and reserve estimates of both overburden layer and target mineral thickness were determined to be 44.3 ± 2.18 million metric tons and 741,933 ± 132,205 m^3 respectively.*

Keywords: K-feldspar, pegmatitic-intrusives. spectrometry, unweathered-granitics, unweathered-pegmatites

INTRODUCTION

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. The demand for feldspar as raw material for ceramics and other uses is continuously increasing worldwide. In Tunisia, the traditional sources of feldspar, pegmatite and neptheline syenite ore does not exist, implying a massive importation of this raw material. In 2007, the sum of 26 million dinars was spent to import this raw material for ceramic production and other uses (Gaied and Gallala, 2015). 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. 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 unfortified and fortified composts samples and also compared with that of the chemical fertilizer NPK (15:15:15).

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 interest in the stabilization/solidification of heavy-metal contaminated soils or environments (Xu *et al.*, 2017). 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 albite and anorthite is what is known as plagioclase feldspars while those between albite and orthoclase or monocline 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).

Significance of the Study

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 in Nigeria 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. This research is concerned with closing these gaps by conducting geological and mineral resources evaluation and carrying out economic analysis to attract investment to the sector.

LITERATURE REVIEW

Strategies and Goals for Development of Mineral Resources

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 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).

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 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). The general properties of feldspar minerals are given in Table 1.

Table 1: Generalized Properties of Feldspar Minerals. **Source**: Geology.com, (2022)

Property	Description
Chemical Classification	Silicates
Mohs Hardness	6 to 6.5
Specific Gravity	2.5 to 2.8
Diagnostic Properties	Perfect cleavage with cleavage faces usually intersecting at or close to 90^0. Consistent hardness, specific gravity and pearly lustre on cleavage faces

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.

$$\rho = \frac{a}{\theta^m S^n} \rho_w \tag{1}$$

Where, θ and S are fractions between 0 and 1, ρ_w 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 international standard specifications of feldspar for industrial and commercial uses such as the American standard specification, the Indian standard specification, the Canadian standard specification etc. The British International Standard (BIS) classification for Potassium feldspar for use in various products are given in Table 2.

Table 2: British International Standard (BIS) Specification for Potassium Feldspar for Use in Various Industries

Classification By (%)	Glass	Sanitary Ware	Insulators	Ceramic	Refractory	Abrasive	Electrode	Others
SiO_2	67	67.5	62 - 68	64.5 - 68	-	60 - 70	65	63 – 67
Al_2O_3	17 – 20	17 – 21	16 - 20	17 – 21	18_{min}	20 - 24	18	17 – 20
K_2O	9	8	11-	11 -	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 -	-	-
$SiO_2 + Al_2O_3$	3:4	3.4:4	-	-	-	-	-	-
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	-

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)).

MATERIALS AND METHODS

Description of the Study Area

The study area is located in Zango Daji in Kogi State. It is about 20 kilometres from Lokoja, the Kogi state capital and less than five kilometres away from Okene and Ajaokuta towns, in Kogi state. Figure 1 shows the map of the study area.

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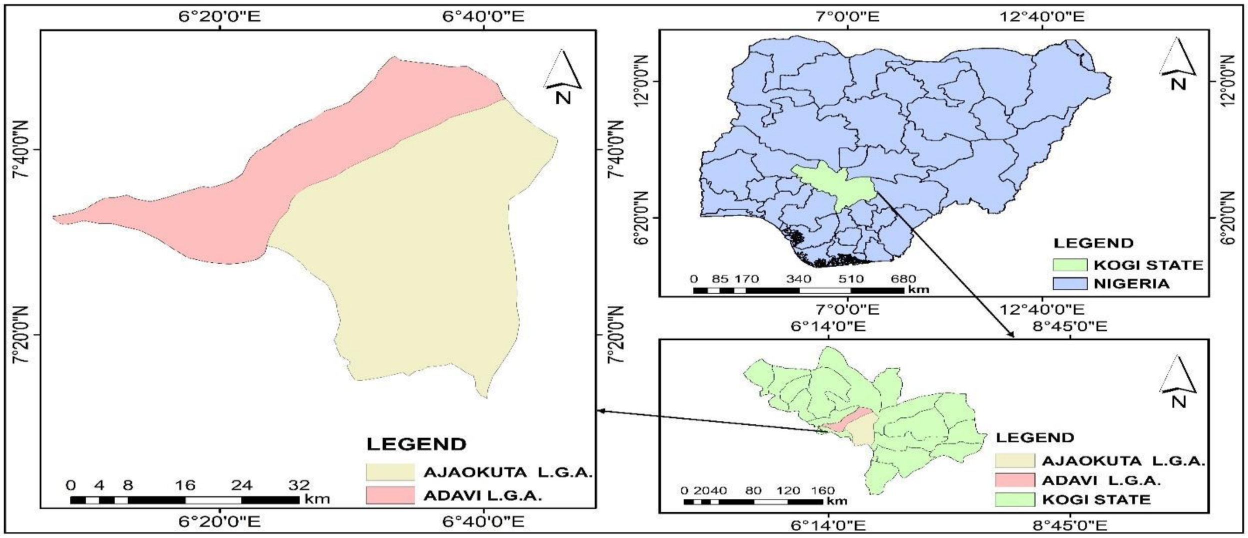

Figure 1: Map of the Study Area

Method of Data Collection

Samples were collected from the study area based on the reconnaissance survey carried out Coordinates elevation points and photographs were taken to produce drawings and thematic maps. The area comprises of ore rich deposits of feldspar and quartz and significant massive granite gneiss rock. Figure 2 is the geological and mineral resources map of Kogi State showing the study area.

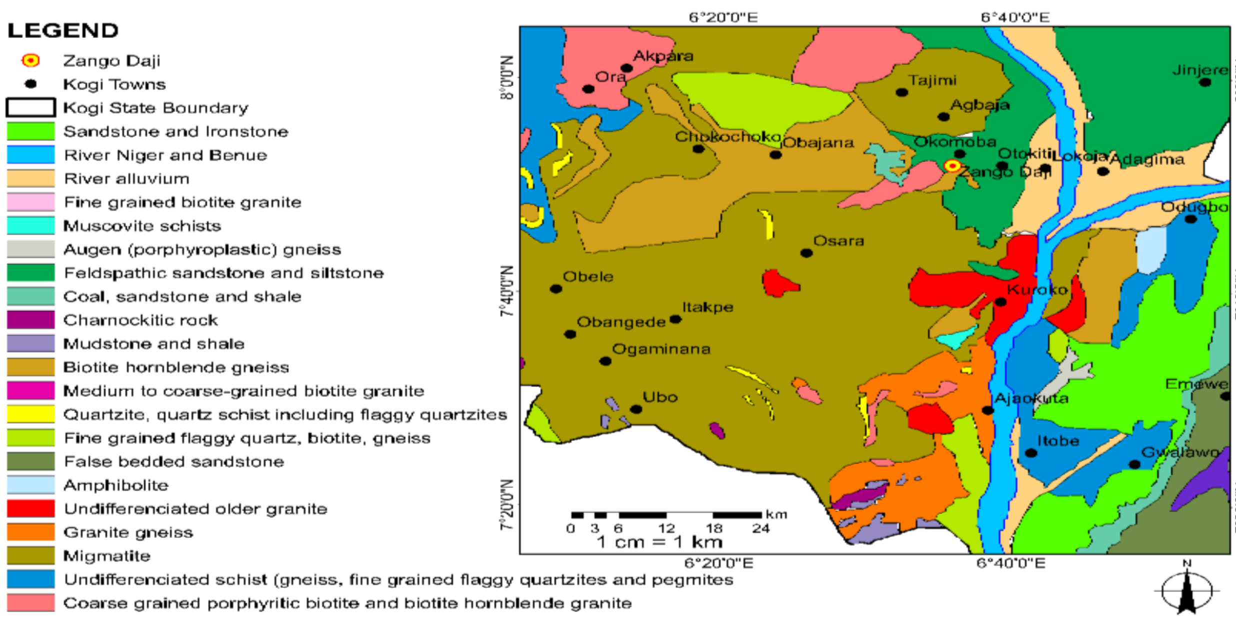

Figure 1: Geological and Mineral Resources Map of Adavi and Ajaokuta Local Government Areas

A total of six (6) rock samples were randomly collected from the study area with spades, digger and geologist hammer for studies, observations, testing, description and identification. They were shared into two portions in the ratio of 2:4 to determine their physical and chemical characteristics. The photograph of outcrop of Feldspar rock found in the study area is shown in Plate 1.

Plate 1: Feldspar Outcrop found in the Study Area

Furthermore, the resistivity data of the ore body with respect to the bedrock were collected using the omega resistivity meter. Plate 2 shows the laying of surveying cable across the inferred structures in N-S direction.

Plate 2: Laying of Surveying Cable in N-S Direction Across Inferred Structures in the Study Area

Determination of Chemical Properties of the Rock

The portion comprising of four (4) rock samples were further shared into three (3) equal parts of four (4) samples each. One part was pulverized into powdered form for homogeneity. It was then sieved using a 50 μm mesh and digested at the Federal University of Technology, Akure (FUTA) Geology and Chemistry Laboratories to determine its chemical characteristics in accordance with the British Chemical Standard Certified Reference Materials, BCS-CRM Number 376/1. The second and third parts were separately subjected to X- ray fluorescence spectrometer and X- ray diffraction to determine both the oxides and elemental compositions of each sample respectively. The average of results of the analyzed samples were computed and recorded accordingly. The X-ray fluorescence spectrometer and X-ray diffraction was conducted at the National Geosciences Laboratory Centre (NGSLC), Kaduna, according to Brown method and University of Johannesburg, South Africa using EZS991XNV scanner.

Determination of Physical Properties of the Rock

The portion comprising of two (2) rock samples were prepared into thin sections to determine its physical properties of the rock sample. The analysis was conducted at the Geology and Chemistry Laboratories of the Federal University of Technology, Akure. 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.

Eight (8) grams each of the feldspar rock prepared from samples collected from the study area were immersed separately into 90 cm^3 of water to 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 study area was determined from the results of the two rock samples used. Equation 2 shows the summary of the method of determining the density of the rock by using the density bottle method.

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

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.

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 the mapped out block in the study area. The readings of the resistance values were obtained from Omega meter arranged in a Schlumberger electrode array with maximum $\frac{AB}{2}$ spacing ranging between 100 – 150 m, where AB is the current electrode separation. A total of eight (8) vertical electrical sounding (VES) points were sounded across the investigated area shown in Plate 2. 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 within the study area were calculated by 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 measured values obtained in ohms are presented in Table 3.

Table 3: The Measured Resistance (VES) Data

Peg Distances (m)	VES 1	VES 2	VES 3	VES 4 (ohms)	VES 5	VES 6	VES 7	VES 8
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

The eight (8) VES points taken across the investigated area along a distance of 150 metres of peg line are presented in Figure 3.

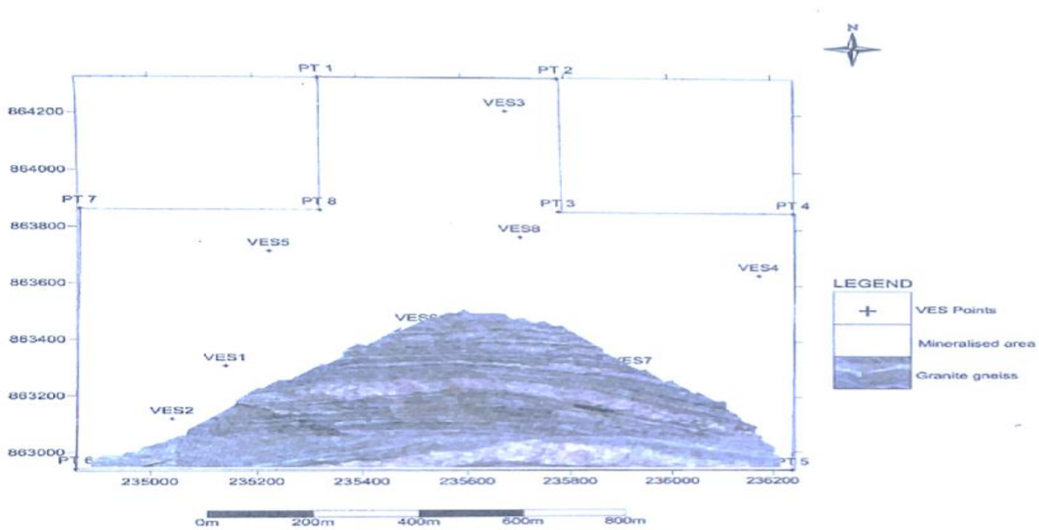

Figure 3: Eight (8) VES Points Taken Within the Study Area

Data Testing and Validation Using the Goodness of Fit (GOF) Method

In accordance with the Wiener-Kolmogorov prediction for interpolating goodness of fit regression line, it is required that the VES data obtained should be normally distributed before they can be suitable for Kriging or Gaussian process 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. The result of the normal distribution obtained is used 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.

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

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.

RESULTS AND DISCUSSIONS

Site Mapping Using Geographical Information System (GIS) and Other Scientific Tools

The coordinates and elevations points data collected were used to produce the linear dimension and thematic maps such as the likelihood activity impact circumference map, contour map, digital terrain map, digital elevation, map of various landscape for virtual assessment of the mining project in the study area. The linear dimension of the study is shown in Figure 6 while the likelihood activity impact circumference map is shown in Figure 7. From the map in Figure 6, the size of the study area is estimated to be 1.48 Km^2.

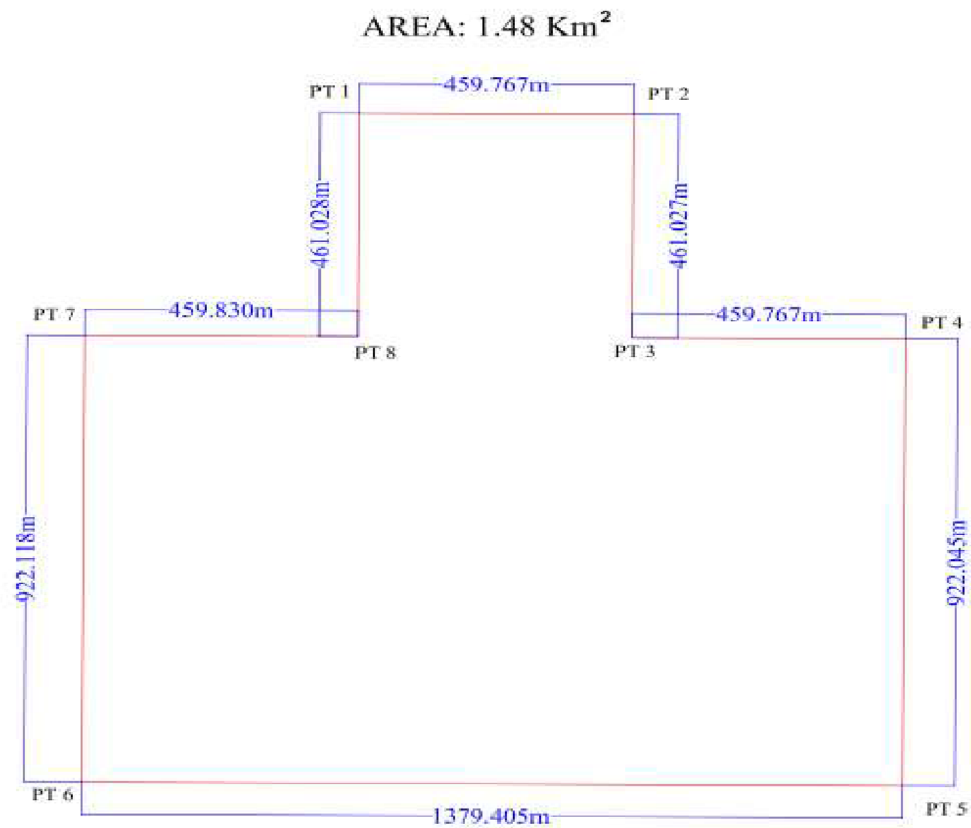

Figure 6: Linear Dimension of the Study Area

From the map in Figure 7, it is estimated that the mining project if embarked upon will be a distance of about 0.81 km radius away from the sparsely occupied area.

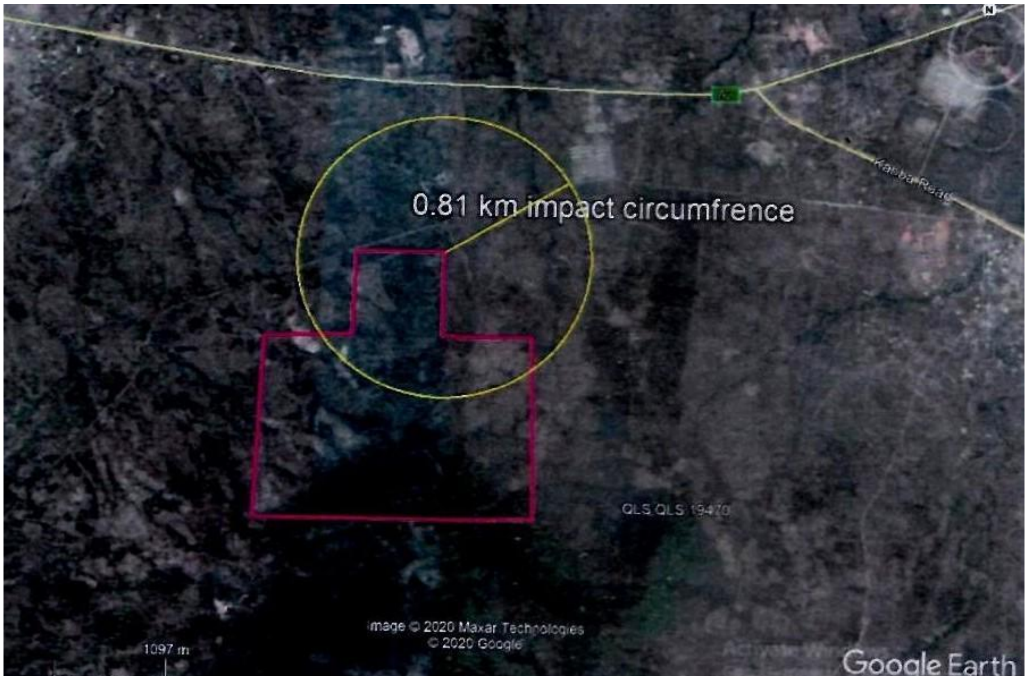

Figure 7: Estimated Minimal Distance of Likelihood Activity. Source: (Google Earth, 2020)
Likewise, the contour map of the study area was similarly produced. The map provides the number of contour lines and the thickness of contour which are required for calculating of reserve estimation and volume of overburden. The contour map obtained for the study is shown in Figure 8.

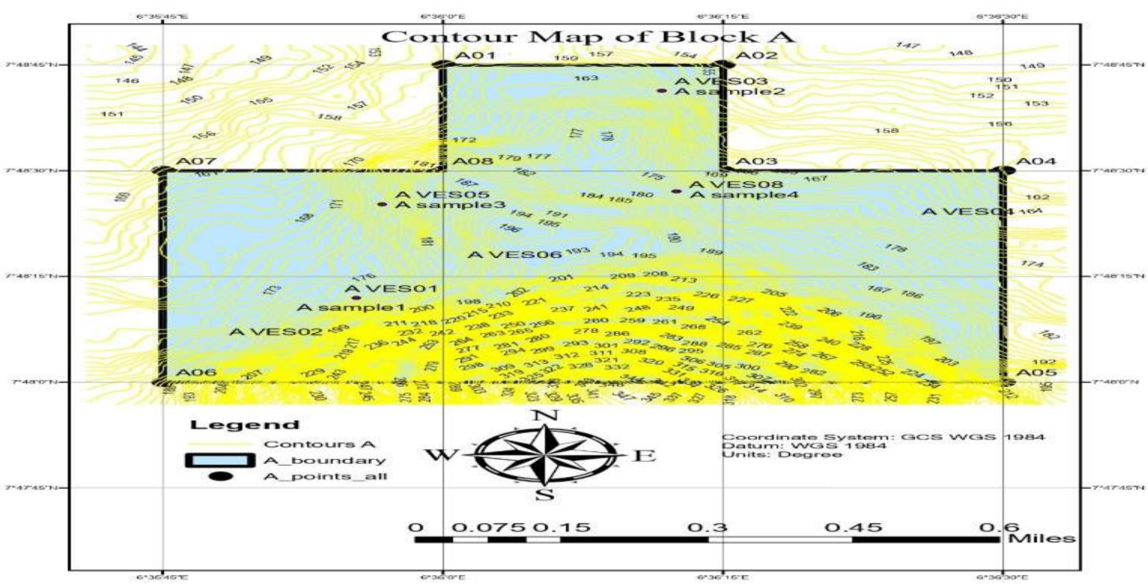

Figure 8: Contour Map of Study Area Showing Sample Contour Lines

The digital surface maps provide information for drainage flow pattern and showed natural or man-made features in the study area for mine planning and development of the feldspar deposit. Figure 9 is the digital elevation model for the study area. It shows an elevation of between 160 m and 340 m.

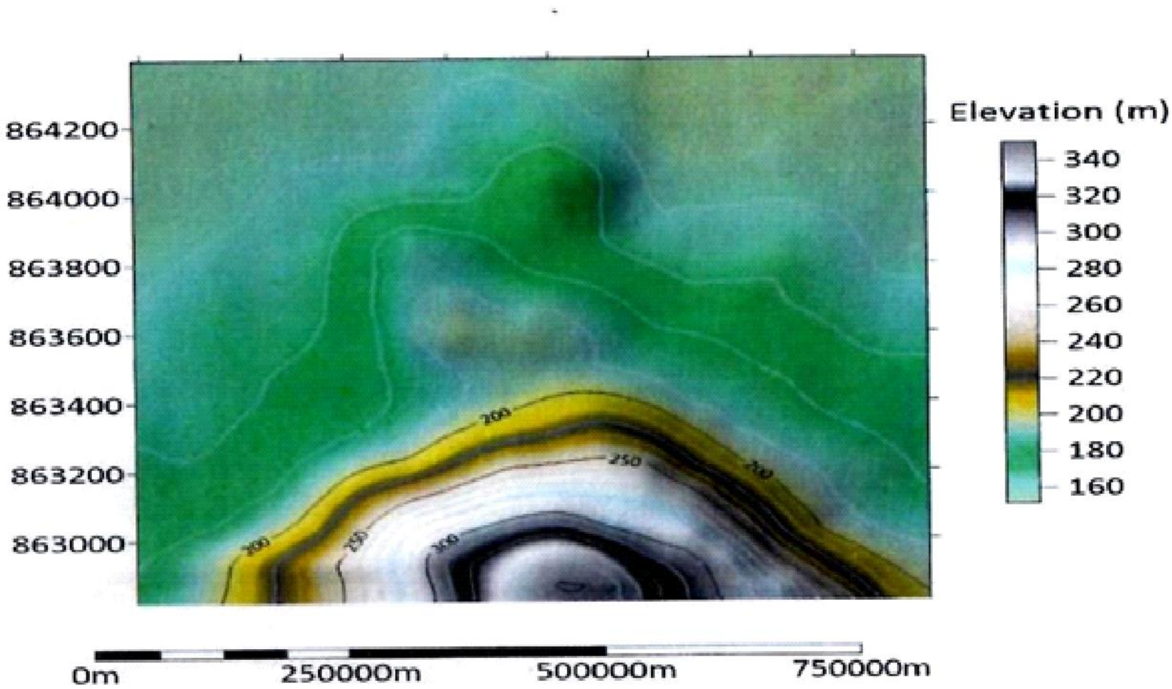

Figure 9: Digital Elevation Model (DEM) of Study Area

Laboratory Results of Physical and Chemical Analysis Tests on Rock Samples

Chemical analysis test

The results of chemical composition of four (4) rock samples each taken from study area using three laboratory methods are presented. Table 4 show the results of average percentage (%) composition of elements and oxides in the sample.

Table 4: Laboratory Results of Average Percentage (%) Composition of Element and Oxides of Feldspar Samples in the Study Area

Elements/Oxides Composition Composition	Sample No 1	2 (%)	3	4	Average (%)
SiO_2	65.89	65.55	66.82	64.79	65.76
Al_2O_3	17.66	17.63	17.65	17.64	17.65
PbO	0.001	0.001	<0.001	<0.001	<0.001
K_2O	14.15	14.17	14.13	15.63	14.52
Na_2O	0.57	0.60	0.62	0.64	0.61
CaO	0.18	0.20	0.29	0.30	0.24
MgO	0.02	0.015	0.03	0.03	0.02
TiO_2	0.018	0.022	0.02	0.019	0,020
MnO	0.019	0.019	0.019	0.019	0.019
Fe_2O_3	0.03	0.041	0.064	0.07	0.051
CuO	0.004	0.004	0.004	0.004	0.004
ZnO	0.004	0.004	0.004	0.004	0.004
NiO	0.004	0.004	0.005	0.005	0.0045
Cr_2O_3	0.01	0.01	0.01	0.01	0.01
V_2O_5	ND,	ND,	ND,	ND	ND
Cr	0.062	0.063	0.065	0.085	0.069
Cu	0.031	0.035	0.033	0.035	0.034
Zn	0.033	0.034	0.031	0.033	0.033
Pb	0.014	0.011	0.009	0.006	0.01
Ni	0.033	0.035	0.040	0.039	0.037
Mn	0.144	0.144	0.147	0.145	0.145
LOI	1.40	0.70	0.30	0.80	0.8

From Table 4, the average percentage composition of Oxides of Potassium, Aluminum, Sodium, Calcium, Silicon and Magnesium in the feldspar sample from the study area are presented. The ratio of Si: Al is within the range of 3:1 and the average percentage composition of Potassium oxide is greater than 10%. The average oxide composition of Potassium and Aluminum is 14. 52 for K_2O and 17.65 for Al_2O_3. 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.

X-ray fluorescence spectrometry and X-ray diffraction results

Similarly, the results of the whole rock samples from the study area pulverized, sieved and analyzed using X-ray fluorescence spectrometer and X-ray diffraction is presented in Table 5.

Table 5: Result of X-Ray Fluorescence and X-Ray Diffraction Analysis of Feldspar Sample Showing the Average Elemental and Oxides Composition of Sample in the Study Area

Elemental/Oxides Composition	Value %
Na_2O	2.2196
MgO	0.0465
Al_2O_3	18.0177
SiO_2	59.4385
P_2O_5	0.0145
SO_3	0.0163
Cl	ND
K_2O	18.7658
CaO	0.2966
TiO_2	ND
Cr_2O_3	0.0165
MnO	0.0371
Fe_2O_3	0.9710
NiO	0.0088
CuO	0.0093
ZnO	ND
Ga_20_3	ND
As_2O_3	ND
Rb_2O	0.1040
SrO	0.0068
ZrO_2	ND
Nb205	N D
BaO	ND
PbO	0.0308

From the results in Table 5, the X-ray fluorescent spectrometry and the X-ray diffraction analysis are presented. These results show presence of some rare earth elements not detected in the chemical analysis method used earlier. The table shows the average percentage composition of Oxides of Potassium, Aluminum, Sodium, Calcium, Silicon and Magnesium in the feldspar sample taken from the study area. The ratio of Si: Al is within the range of 3:1 and the average percentage composition of Potassium is greater than 10%. The table also shows that the result of the values of oxides percentage composition 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 and X-ray diffraction methods are 18.7658 and 18.0177 respectively. Therefore, they met the required standard, as the presence of feldspar in any deposit is determined by the presence of Potassium Oxide (K_2O) and 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 study area. It is 2966 by average percentage value for Calcium Oxide and 2.2196, by average percentage value 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.

The coordinates and VES points where samples taken were used to produce thematic map of the mineralogical composition of feldspar in the study area was designed to show the location. Figure 10 shows the designed mineral composition map and the location of sample grades in the study area.

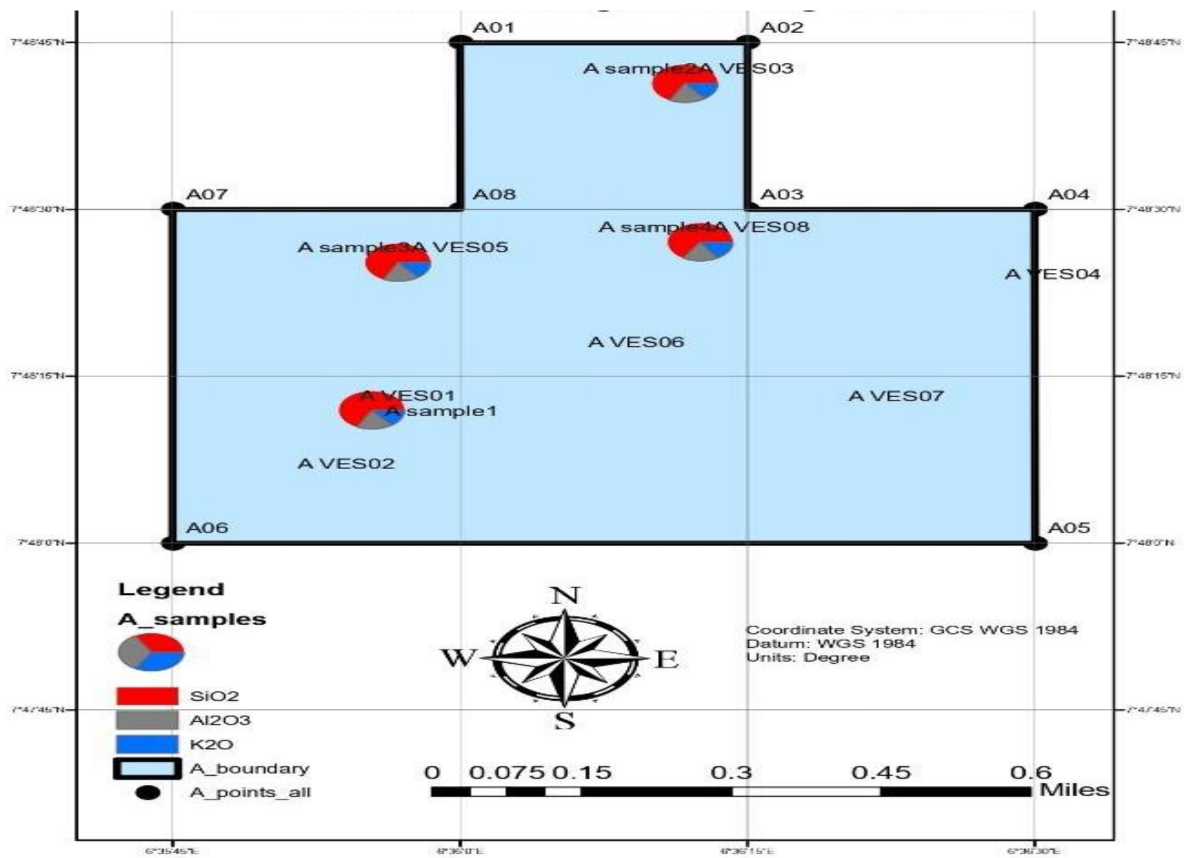

Figure 10: Designed Mineral Composition Location Map of Study Area

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

Physical analysis test

The results of rock samples taken from study area which were prepared into thin sections in the laboratory and analyzed for physical characteristics were tested. The summary of results is presented in Table 6. The average density of the feldspar from the samples wase 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 the Study Area

Physical Characteristics	Description of Result Obtained
Mohs Hardness Test	6
Density	2.55 g/cm^3
Diagnostic Properties	Feldspar sample has a perfect cleavage. Cleavage faces intersecting at or close to 90°. Consistent hardness, specific gravity, pearly lustre on cleavage faces, showing flakes of quartz (white) and muscovite (white). It is granitic and granodiorite composition.

Electrical Resistivity Data Presentation and Discussion

The measured electrical resistivity data taken from the study area are displayed in several formats in tables, as depth sounding curves, as plans and in 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.

Electrical resistivity data

Eight (8) VES data were obtained for the study area. All VES data in ohms were processed into depths in metres after filtering to eliminate errors as shown in Table 7.

Table 7: Presentation of Result of 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

The vertical electrical sounding (VES) data for the study area after converting them into depths in metres, registered to the local grid coordinates and processed using the WinRESIST software are presented as Resist graphs showing two VES curves for VES points 1 and 2 shown Figures 11 and 12.

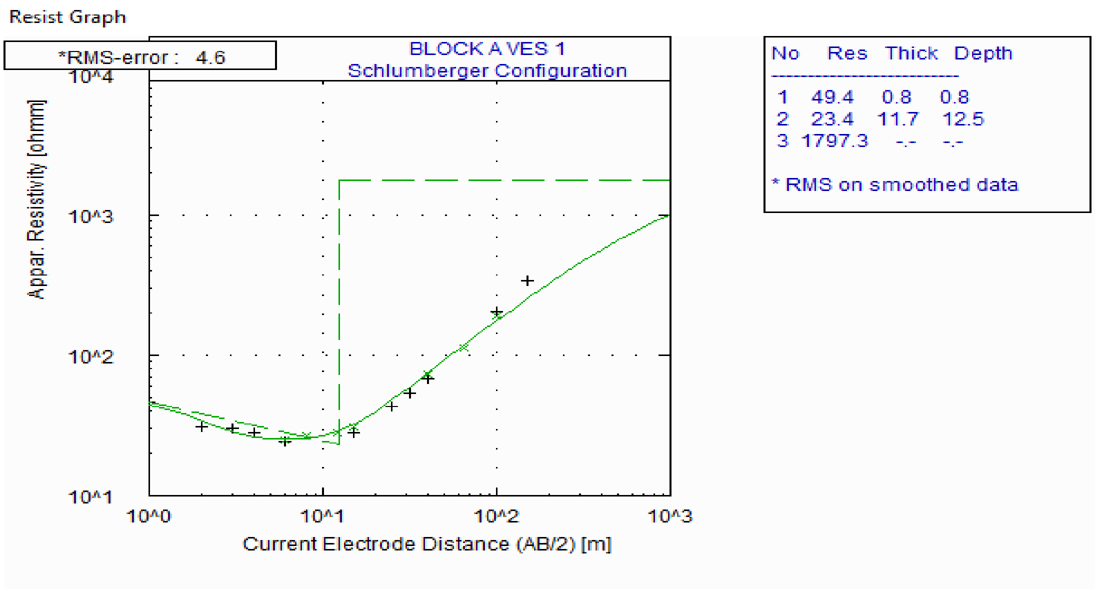

Figure 11: Resist Graph Shows the VES Curve for VES 1

Figure 11 shows resistivity of deposit with respect to the bed rock. 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.

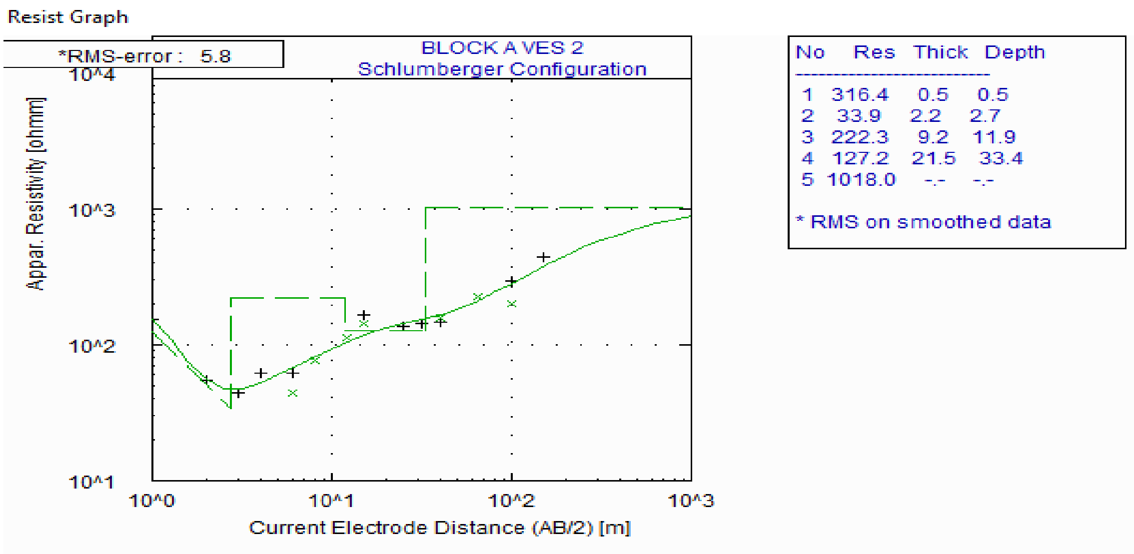

Figure 12: Resist Graph Shows the VES Curve for VES 2

Figure 12 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.

Overburden layer iso-resistivity and isopach maps of study area

The iso-resistivity map of the overburden layer material of the study area is presented in Figure 13 and isopach map of overburden thickness layer in Figure 14,

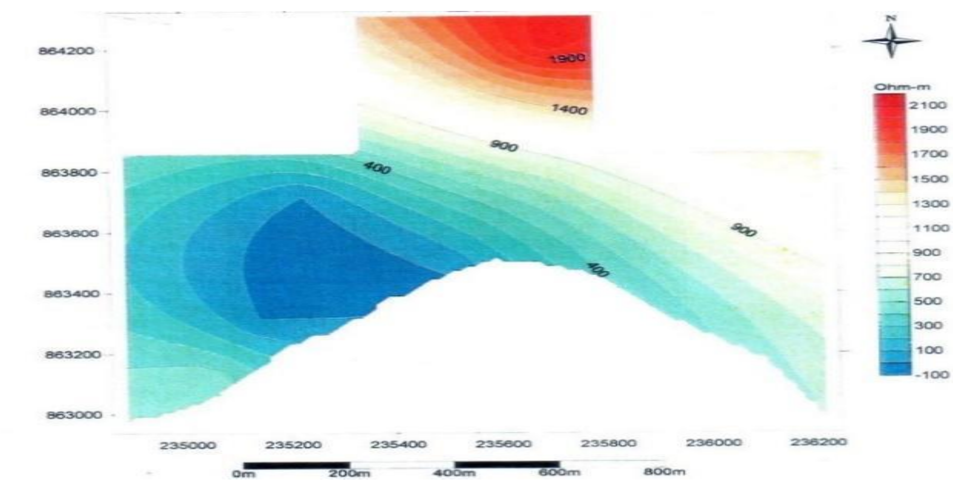

Figure 13: Overburden Layer Iso-Resistivity Map

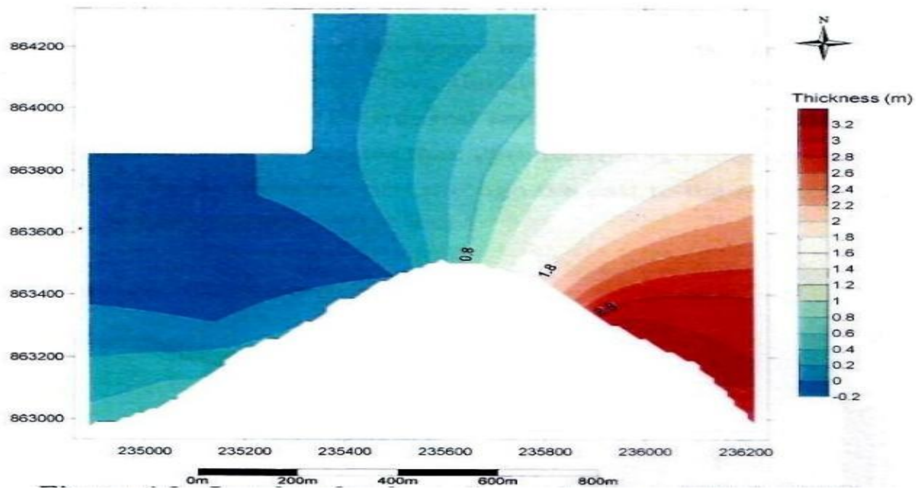

Figure 14: Overburden Layer Isopach Map of Block A

In Figure 13, the iso-resistivity map shows the distribution of the resistivity of the overburden layer within the mineralized portion. It ranges between 316.4 Ωm and 502.2 Ωm.
In Figure 14, the isopach map shows the distribution of the overburden thickness layer within the mineralized portion of study area. It indicates the distribution of the overburden thickness layer. The overburden layer thickness in the isopach map ranges from 0.5 m – 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.

Target mineral layer iso-resistivity and isopach maps of block A
The iso-resistivity map of the target mineral (feldspar) layer and the isopach map of the target mineral (feldspar) thickness of the mineralized portion of the study area are presented in Figures 15 and 16.

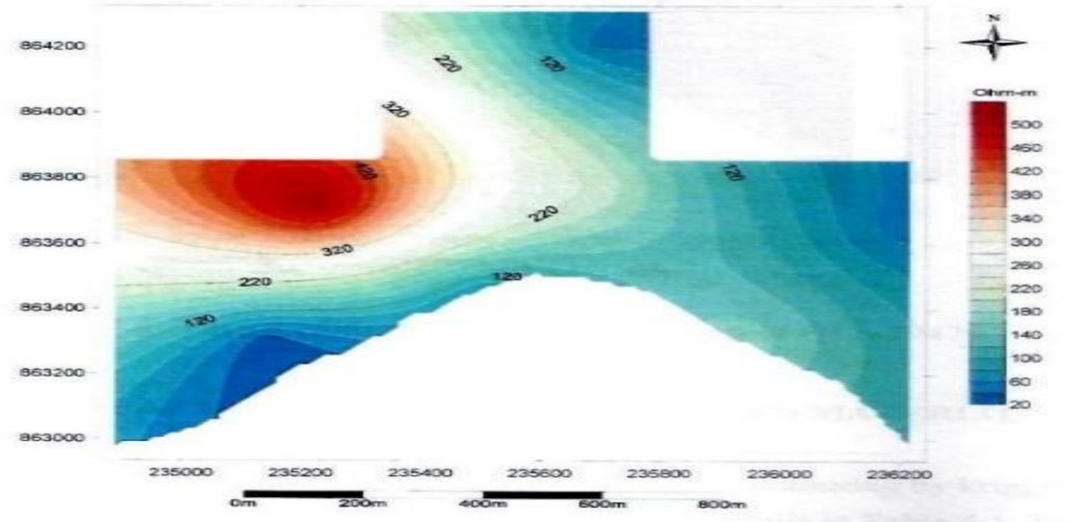

Figure 14: Target Mineral Layer Iso-Resistivity Map

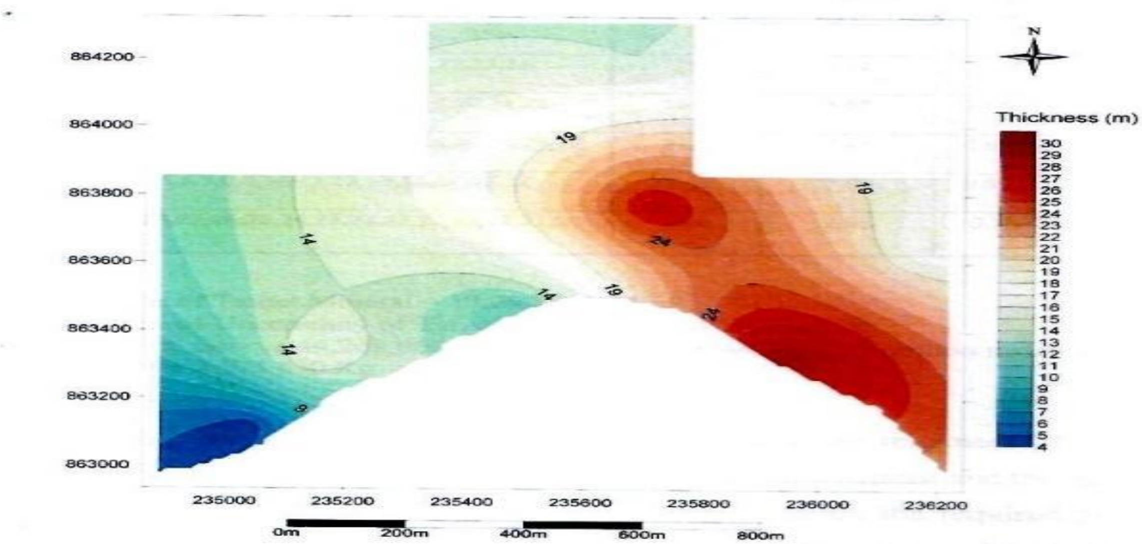

Figure 15: Target Mineral Layer Isopach Map

Figure 14 shows the distribution of the resistivity target mineral which ranges between 127.2 Ωm and 290.7 Ωm across this portion.

Figure 15 shows the distribution of the isopach map of the target mineral (feldspar) layer within the mineralized portion of study area. The map shows the distribution of the feldspar thickness within the portion in metres. 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. It is observed that the south eastern part through the east to the northern part is characterized by thickness greater than 20m.

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 3 and 4 and VES points 4 and 8 in the study area are presented in Figures 16 - 17.

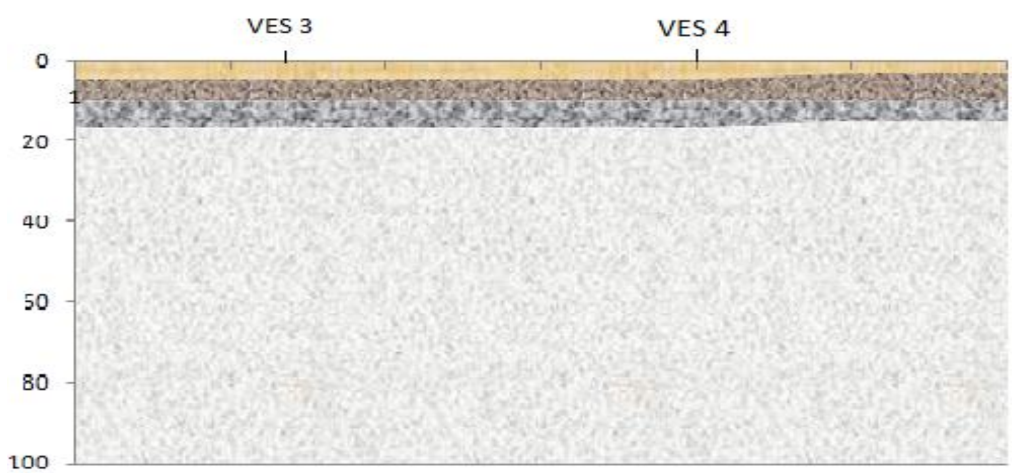

Figure 16: Geo – Electric Section of VES 3 to VES 4

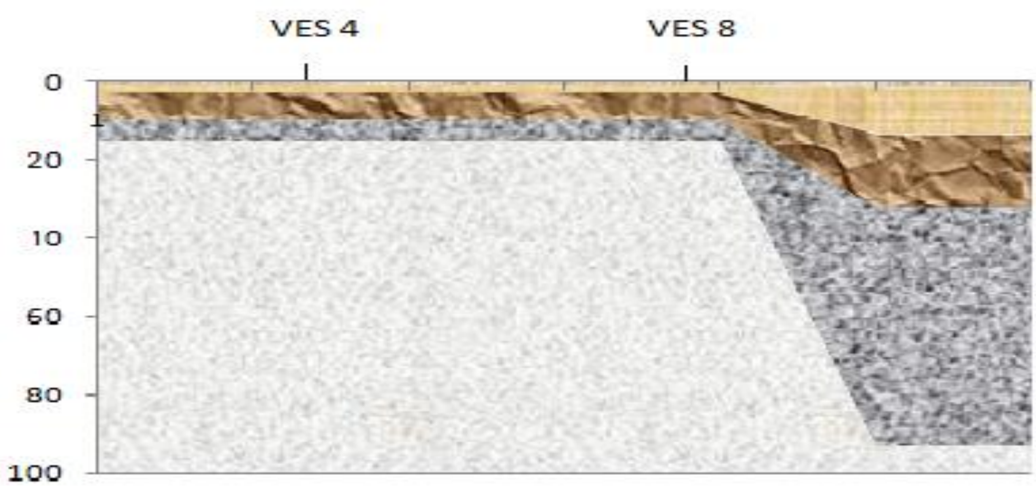

Figure 17: Geo – Electric Section of VES 4 to VES 8

From Figure 16, 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.

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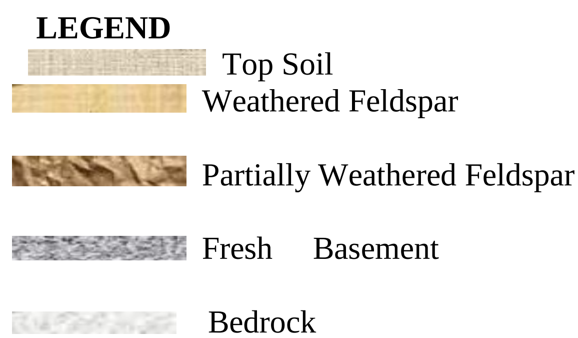
From Figure 17, the distribution of weathered and partially weathered feldspar is uniform at VES point 4 and tabular at VES 8. The thickness of deposit ranges from 2m to 20m for weathered feldspar and 2m to 60m for partially weathered feldspar. Top soil ranges from 0m to 10m.
The geo-electric sections presented in Figures 16 – 17 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.



Reserve Estimate and Overburden Material Volume Quantification of Feldspar Deposit in the Study Area.
The method applied for reserve estimate and overburden material volume quantification for the feldspar deposit in the study area were determined by adopting contouring using the number contour lines, thickness of contour and feldspar thickness values obtained from the interpreted VES results.

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 km^2 was divided into different sizes of five portions for easy computation. Results of reserve estimation of volume of feldspar and overburden volume estimates are presented in Tables 8 – 9.

Table 8: Estimation of Volume of Feldspar Per Portion of Study Area.

Portion	Number of Sample Contour Lines	Thickness of Contour Lines (Target Layer) (m)	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	55,215.40	4,211,054.10± 265,512.32
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 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 the study at 44,268,066 ± 2,175,630 kg ie 44.3 ± 2.18 million metric tons.

Table 9: Estimation of Overburden Volume Material Per Portion of Study Area.

Portion of Overburden	Number of Sample Contour Lines	Thickness of Contour Lines (Overburden Layer) (m)	Mean Thickness (m)	Standard Deviation of Thickness (m)	Standard Error of Thickness (m)	Area of Portion (m^2)	Volume 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

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 the study area. This was estimated as 741,932.68 m^3 ± 132,205.40 m^3

Model Testing and Validation

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 were found to be normally distributed linearly as shown in the regression lines plotted as Q-Q plots shown in Figures 18 – 19.

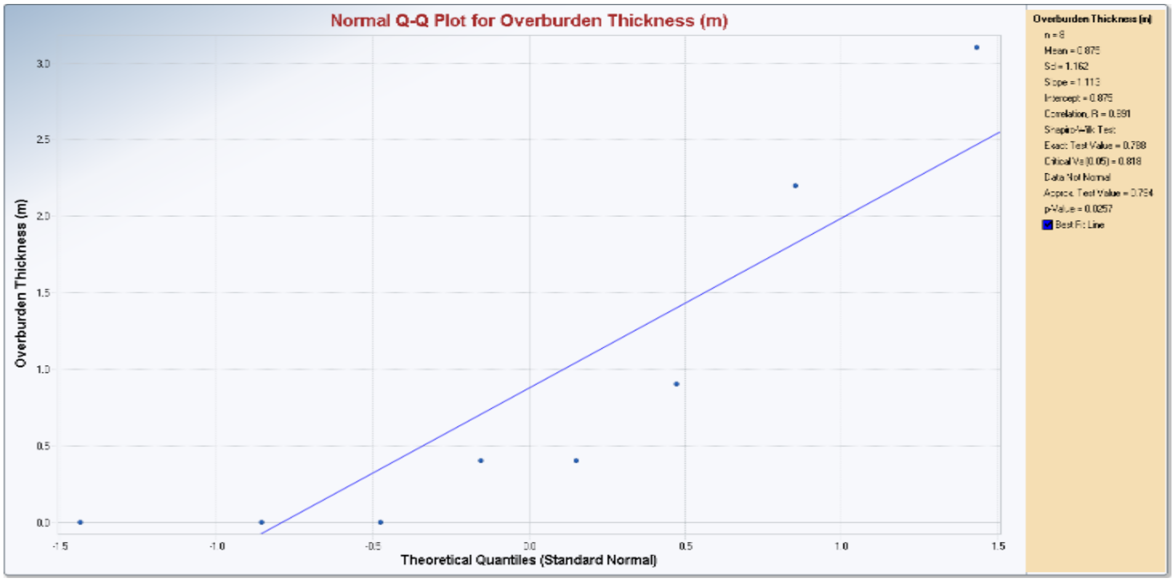


Figure 18: Normal Q-Q plot for Overburden Thickness

Figure 19: Normal Q-Q plot for Target Mineral Thickness

From Figures 18 and 19 it is observed that most of the data points for overburden layer and target mineral thickness in the study area are normally distributed along the linear 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.

CONCLUSIONS

The physicochemical properties of the feldspar deposit in the study area mentioned using geological methods were determined using GIS. The following findings and conclusion were drawn from the study;

i. 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.
ii. 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 ore rich deposits of feldspar in a quartz pegmatite zone located in Zango Daji forest in Kogi state, Nigeria.
iii. 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 compares with those listed in the British International Standard condition for various uses of feldspar in terms of suitability and applicability.
iv. Quantitatively, both the ore rich deposit of feldspar and the volume of removable overburden material was estimated to be 44.3 ± 2.18 million metric tons and 741,933 ± 132,205 m^3 respectively.
v. The preference for the development of the feldspar deposit based on the level of geoscientific information obtained would be made upon the information obtained from the economic evaluation of the deposit.

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, an economic evaluation is recommended to be carried out to determine the economic analysis and economic feasibility of the project. The economic evaluation would determine the capacity of the project to generate profit without any liability after the loan payback period. Through an economic analysis, a mining model would be developed and cash flow analysis would be carried out to evaluate the economic feasibility of the project and its viability given the technical and managerial skills of the mangers of the project.

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