Volume 4 No. 1, January 2014 ISSN 2224-3577

International Journal of Science and Technology

http://www.ejournalofsciences.org

Determination of type of Underground Mineral Deposit in Gongola basin, Nigeria, using Gravimetric Technique

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ABSTRACT

Determination of type of underground mineral deposit is usually done by drilling several boreholes to extract the underground material in order to know the type. In this research residual gravity anomalies were used in the determination of type of the underground minerals. Residual gravity anomalies measured along profile for 300 stations were used. The data was interpolation at grid points using the method of Kriging which makes it possible for the application of a two dimensional Fourier analysis and Gauss theorem to determine the quantity and excess mass of the mineral deposit respectively. The density of the underground mineral deposit was subsequently computed using the computed excess mass and quantity of the underground mineral deposit. The density was used to identify the possible type of mineral body buried in that area. The results obtained revealed that the possible mineral body buried underground responsible for the gravity anomalies has density of $0.85gcm^3$ which suggest that, petroleum is suspected to be deposited in that area. The residual gravity anomalies at the area of suspected mineral deposit used for the computation of excess mass and quantity of mineral deposit was analyzed at five percent level of significance and found that the data represent the normal population, that is, the data used was derived from the one used for the investigation. The result of the type of mineral deposit at that area agrees with the result obtained by Shell Nigerian Exploration and Production Company (SNEPCO). The method used in this research is therefore recommended for investigation of type of mineral deposit in area where the gravity data is known.

Keywords: *Gravimetry, Fourier analysis, Kriging, Gongola basin*

I. INTRODUCTION

Underground mineral deposit can be described as sub-surface bodies whose natural habitat is the earth and whose beneficial exploration requires the use of various methods e.g. drilling, mining, etc. (Opeloye and Dio, 1999). The techniques of drilling were initially used to search for sub-surface mineral deposits and to produce minerals from shallow wells. Improved techniques and instrumentations allowed for the abstraction of minerals especially oil from wells. Robinson and Coruh (1988), observed that in 1946, 106 wells were drilled to depth in excess of 1219m while the deepest production during that year was obtained from Louisians well at 1400m. The risks in exploratory drilling techniques were later expose and also, it was uneconomical since decision as to where to drill was taken like a gamble because there was no prior information about the actual location of the mineral resources before drilling. This had led to drilling many places but with success (if any) in few areas. For instance, The Federal Government of Nigeria stopped drilling for oil on the Nigerian side of Chad Basin because a huge sum of money had been spent on drilling twenty two wells out of which only two showed existence of oil and gas as contained in (Mustapha, 2000). As a result of the low rate of success in the discovery of mineral resources in the Chad basin, the early resumption of mineral exploration in this basin by the Federal Government of Nigeria is unlikely (Bego, 2005). In Egypt, over forty wells were drilled with oil found in only thirteen and gas in three while in Chad Republic, mineral exploration started in 1952 and it was in 1974, twenty two years after exploration activities began, that the first mineral deposit was discovered (Mustapha, 2000).

The search for mineral deposits and hence the art of mineral exploration continued to advance because of the economic benefits of different mineral deposits to man. This advancement, from the early years of twentieth century, provided a good opportunity for explorers to look for more effective, less risky and more economical methods of sub-surface mineral exploration. This led to the discovery of different methods of mineral exploration often referred to as geophysical surveying or geophysical exploration techniques. The method is concerned with the investigation of the interior of the earth. It essentially involves taking measurements on or near the earth's surface that are influenced by the distribution of the earth's underground masses. Analysis of the measurements will reveal various properties of the earth's surface (Kearey and Brooks, 1988). Geophysical surveying is broadly divided into: natural source method also referred to as gravimetric method and artificial source methods. Gumert (1992), Robin (1995) and Kearsley et al. (1975), observed that the natural-source method can play a complimentary role to the artificial-source method

Volume 4 No. 1, January 2014 ISSN 2224-3577

International Journal of Science and Technology

http://www.ejournalofsciences.org

Before any exploration work, it is paramount to determine the type of the underground mineral deposit. Several methods of determining the type of these minerals exist. Determining the density of the underground mineral deposit can aid in the determination of the type as observed by Meurig and Jones (1987). It is therefore the objective of this research to determine the density of the underground mineral deposit in order to discern the type of mineral deposit.

II. METHODOLOGY

The method used includes the application of kriging to predict residual gravity anomalies at grid points in the study area. Newton's Gauss theorem was applied to determine the excess mass and there after the application of two dimensional Fourier analysis was used to determine the quantity of the mineral deposit which is also known as the actual mass of the buried substance. The two masses computed (Excess mass and Actual mass) were used to determine the density of the buried mineral body.

Data Acquisition

The data used for the study includes rectangular coordinates, residual gravity anomalies of points in the study area presented in profile as abstracted from Idowu (2005). The distance between two successive gravity stations (i.e. gravity station interval) for the residual gravity anomalies was averagely 500m. The gravity survey covers parts of Bauchi, Gombe and Plateau States of Nigeria which form part of the Gongola basin. The extract of the data is hereby presented in table 1 below, columns 1,2,3, and 4 of the table shows the serial number, X-coordinates , Y-coordinates and the residual gravity anomalies respectively.

Table 1: Extract of Data (Residual Gravity Anomalies) used for the Research

S/N no	X(m)	Y(m)	R(mgal)
1.	658742.200	1122860.600	-0.094731
2.	658730.900	1122362.300	00.377338
3.	659104.000	1122152.800	01.665155
4.	659539.000	1121931.800	01.441542
5.	659972.300	1121694.100	01.906113
6.	660276.400	1121309.800	02.528534
7.	660496.900	1120872.000	02.924877
8.	660872.400	1120544.500	02.783191
9.	661165.200	1120164.800	02.627027
10.	661634.900	1120015.800	02.009606
11.	662037.200	1119720.900	01.223088
12.	662376.20 0	1119355.800	00.688359
13.	662698.600	1118979.600	00.009444
14.	662865.600	1118525.800	-0.049030
15.	663045.100	1118080.900	-0.415414
16.	663246.400	1117626.000	-0.757984

International Journal of Science and Technology

http://www.ejournalofsciences.org

17.	663460.200	1117175.600	-1.288014
18.	663561.500	1116695.800	-1.986381
19.	663800.800	1116320.300	-2.745139

Data Processing

This includes the prediction of residual gravity anomalies at grid points using kriging method and subsequent utilization of these predicted data to determine the excess and actual mass of the mineral deposit using a method base on Gauss theorem and two dimensional Fourier analysis respectively.

Gridding

Gridding of the residual gravity anomalies at grid points of 563 meters interval was performed by the method of kriging. Kriging is a group of geostatistical techniques that interpolate the value $Z(x_0)$ of a random field $Z(x)$ (e. g. the elevation Z of the landscape as a function of the geographic location x) at unobserved location x_0 from observations $Z_i=Z(x_i), i = 1, \dots \dots, n$ of the random field at nearby location $x_i, \dots \dots . x_n$. Kriging computes the best linear unbiased estimator $\hat{Z}(x_0)$ of $Z(x_0)$ based on a stochastic model of the spatial dependence quantified either by the variogram y(x,y) or by expectation $\mu(x) = E\,[Z(x)]$ and the covariance function $c(x,y)$ of the random field. The kriging estimator is given by a linear combination as shown below:

$\hat{Z}(x_0) = \sum_{k=0}^{n} \omega_i(x_0) Z(x_i)$ of the observed values $Z_i = z(x_i)$ with weights $w_i(x_0)$,

$i = 1, \dots\dots, n$ chosen such that the variance (also called kriging variance or kriging error)

$$\sigma_k^2(x_0) = Var[Z(x_0) - (Z(x)] = \sum_{i-1}^{n} \sum_{i-1}^{n} \omega_i(x_0)\omega_j(x_0)c(x_i x_j) + Var[Z(x)] - 2\sum_{i-1}^{n} \omega_j(x_0)c(x_i x_j)$$

The kriging variance must not be confused with the variance:

$Var\hat{Z}(x_0) = Var\left(\sum_{i-1}^{n} \omega_i Z(x_i)\right) = \sum_{i-1}^{n} \sum_{i-1}^{n} \omega_i \omega_j c(x_i x_j)$ of the kriging predictor $\hat{Z}(x_0)$ itself. A more detailed explanation of the method is shown in Goovaerts (1997) and Chiles and Delfiner (1999).

Determination of Excess Mass

Determination of the excess mass (M_e) as presented in Reynolds (1998) which is base on Gauss theorem was utilize, this is presented as:

$M_e = 23.9\Sigma^{u}_{i=1}(\Delta g_i \Delta a_i)$ (M_e in tonnes)

(1)

Where: Δg_i = is the residual gravity anomalies representing a grid square

Δa_i = is the area of each grid square

Determination of actual Mass of the Mineral deposit by two dimensional Fourier analysis

Determination of the actual mass was achieved by utilizing two dimensional Fourier analysis as discussed in Tsuboi (1983):

$$f(xy) = \Sigma_m \Sigma_n \alpha_{mn} {}^{\cos}_{\sin} mx {}^{\cos}_{\sin} ny$$

(2)

Suppose a distribution of a certain quantity $f(xy)$ is given within a square,

Volume 4 No. 1, January 2014 ISSN 2224-3577

International Journal of Science and Technology

http://www.ejournalofsciences.org

$0 \le x \le 2\pi$, $0 \le y \le 2\pi$. The distribution of the value of $f(xy)$ in the direction of *x* along a certain value of *y* can be expressed by a single Fourier series of *x* such as:

$$f(xy) = \sum_m \beta_n(y) {}^{\cos}_{\sin} mx.$$

(3)

The coefficient β_m changes according to υ, so that it can be expressed by a single Fourier series of υ such as:

$$\beta_m(y) = \sum_n \gamma_n {}^{\cos}_{\sin} ny.$$

(4)

Then as a whole, $f(xy)$ is given as:

$$f(xy) = \sum_m \sum_n \beta_n \gamma_n {}^{\cos}_{\sin} mx. {}^{\cos}_{\sin} ny.$$

(5)

If $\beta_n \gamma_n$ is written as α_{mn} then

$$f(xy) = \sum_m \sum_n \alpha_{mn} {}^{\cos}_{\sin} mx {}^{\cos}_{\sin} ny$$

(6)

Therefore, using the double Fourier series, if a distribution of gravity anomaly

($R(xy)$) is given by:

$$R(xy) = \sum_m \sum_n B_{mn} {}^{\cos}_{\sin} mx {}^{\cos}_{\sin} ny$$

(7)

Then, the underground mass (M) at a depth (d) that will produce this $R(xy)$ can be given by:

$$M(xy) = (1/2\pi K) \sum_m \sum_n B_{mn} \exp\left\{\sqrt{(m^2 + n^2)}d\right\} {}^{\cos}_{\sin} mx {}^{\cos}_{\sin} ny$$

(8)

Detailed explanation of the process can be found in Abubakar T. and Idowu T.O.(2013)

Determination of the Density of Mineral Resources

Using Newton's Gravitational Method of computing actual mass, the formula for the computation of density of anomalous body can be deduced. This is presented in Telford et al., (1990) as:

$M = \rho_1 M_e / \rho_1 - \rho_2$

(14)

From the above formula, ρ_1 can be derived as:

$\rho_1 = M\rho_2 / M - M_e$

(15)

where: ρ_1 = density of the anomalous body

ρ_2 = density of the host rock.

But $\rho_2 > \rho_1$ therefore,

$\rho_1 = M\rho_2 / M + M_e$

(16)

Presentation of Results

The extract of result of the interpolated residual gravity anomalies at grid points are presented in table 2. Column one of the table is the grid number, columns two and three are the X and Y coordinates respectively while column four is the residual gravity anomalies.

Table 2: Extract of interpolated residual gravity anomalies at grid points

Grid no.	X(m)	Y(m)	R(mgal)
001	656649.700	1104887.100	00.842308
002	656649.700	1105450.059	00.836793
003	656649.700	1106013.018	00.376764

International Journal of Science and Technology

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004	656649.700	1106575.977	00.448133
005	656649.700	1107138.936	00.517463
006	656649.700	1107701.895	00.576390
007	656649.700	1108264.854	00.658272
008	656649.700	1108827.813	00.744601
009	656649.700	1109390.772	00.066292
010	656649.700	1109953.731	-0.166433
011	656649.700	1110516.691	00.501225
012	656649.700	1111079.650	01.408544
013	656649.700	1111642.609	02.389070
014	656649.700	1112205.568	02.581767
015	656649.700	1112768.527	02.253498
016	656649.700	1113331.486	01.986430
017	656649.700	1113894.445	02.187140
018	656649.700	1114457.405	02.707387
019	656649.700	1115020.364	02.718768
020	656649.700	1115583.323	03.584070
021	656649.700	1116146.282	03.062530
022	656649.700	1116709.241	03.381362
023	656649.700	1117272.200	02.876759
024	656649.700	1117835.159	02.642403
025	656649.700	1118398.118	02.613720

Table 3 shows the extract of residual gravity anomalies at the area of suspected mineral accumulation. Column one of the table is the grid number, columns two and three are the coordinates X and Y respectively while column four is the residual gravity anomalies.

Table 3: Extract of residual gravity anomalies at the area of underground mineral accumulation

S/N no	X(m)	Y(m)	R(mgal)
1.	673546.9500	1114457.4045	0.129999900
2.	673546.9500	1115020.3600	0.242259900
3.	673546.9500	1115583.3200	0.146722020
4.	673546.9500	1116146.2800	0.525574800
5.	673546.9500	1116709.2400	0.788450800
6.	673546.9500	1117272.2000	0.991356000
7.	673546.9500	1117835.1590	1.253334000
8.	673546.9500	1118398.1181	1.414522000
9.	673546.9500	1118961.0772	1.411378900
10.	681995.5750	1114457.4045	0.715512600
11.	681995.5750	1115020.3600	0.012709700
12.	681995.5750	1115583.3200	1.016062004
13.	681995.5750	1116146.2800	0.926954030
14.	681995.5750	1116709.2400	0.924087980
15.	681995.5750	1117272.2000	1.097611990
16.	681995.5750	1117835.1590	1.454454050
17.	681995.5750	1118398.1181	1.824401100
18.	681995.5750	1118961.0772	2.208005100
19.	681995.5750	1119524.0363	2.420137400

An extract of the data used for the computation of excess mass is presented in table 4 below. Column one of the table is the grid number, columns two and three are the coordinates X and Y respectively. Columns four and five are the residual gravity anomalies and area representing each grid square.

International Journal of Science and Technology

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Table 4: Extract of the data used for the computation of excess mass

Grid squ no	X(m)	Y(m)	R(mgal)	Area(m^2)
1.	673828.450	1114738.905	0.288470	316969.000
2.	673828.450	1115301.860	0.338505	316969.000
3.	673828.450	1115864.820	0.474348	316969.000
4.	673828.450	1116427.780	0.704350	316969.000
5.	673828.450	1116990.740	0.922218	316969.000
6.	673828.450	1117553.700	1.137103	316969.000
7.	673828.450	1118116.659	1.272847	316969.000
8.	673828.450	1118679.618	1.313054	316969.000
9.	673828.450	1119242.577	1.307706	316969.000
10.	673828.450	1119805.536	1.249431	316969.000
11.	673828.450	1120368.495	1.127604	316969.000
12.	673828.450	1120931.455	0.998521	316969.000
13.	673828.450	1121494.414	0.864796	316969.000
14.	673828.450	1122057.373	0.722546	316969.000
15.	673828.450	1122620.332	0.533514	316969.000
16.	674391.692	1114738.905	0.452019	316969.000
17.	674391.692	1115301.860	0.540622	316969.000
18.	674391.692	1115864.820	0.665563	316969.000
19.	674391.692	1116427.780	0.803722	316969.000
20.	674391.692	1116990.740	0.978468	316969.000

Fig 1A 1B are contour maps and digital elevation model of the study area respectively showing the area of suspected mineral accumulation.

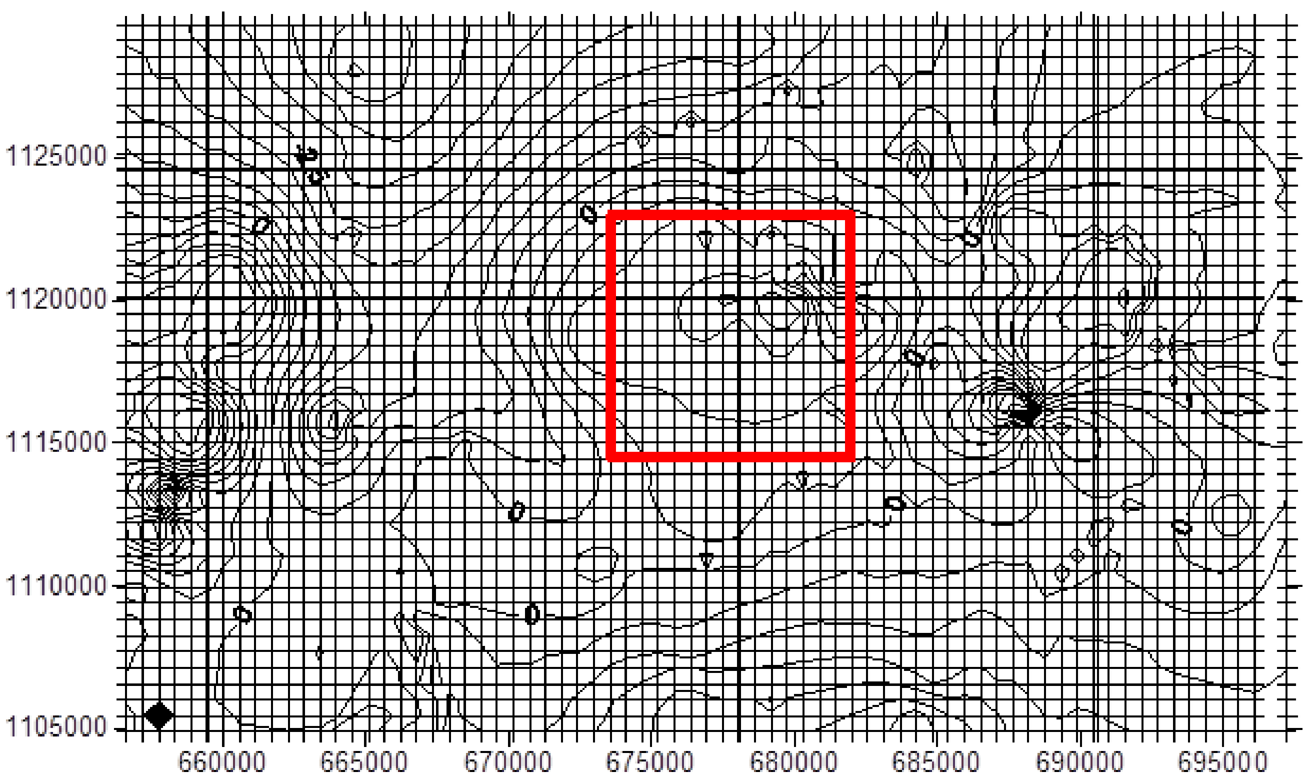

Fig 1A: Contour map of study area showing area of mineral accumulation

ISSN 2224-3577

International Journal of Science and Technology

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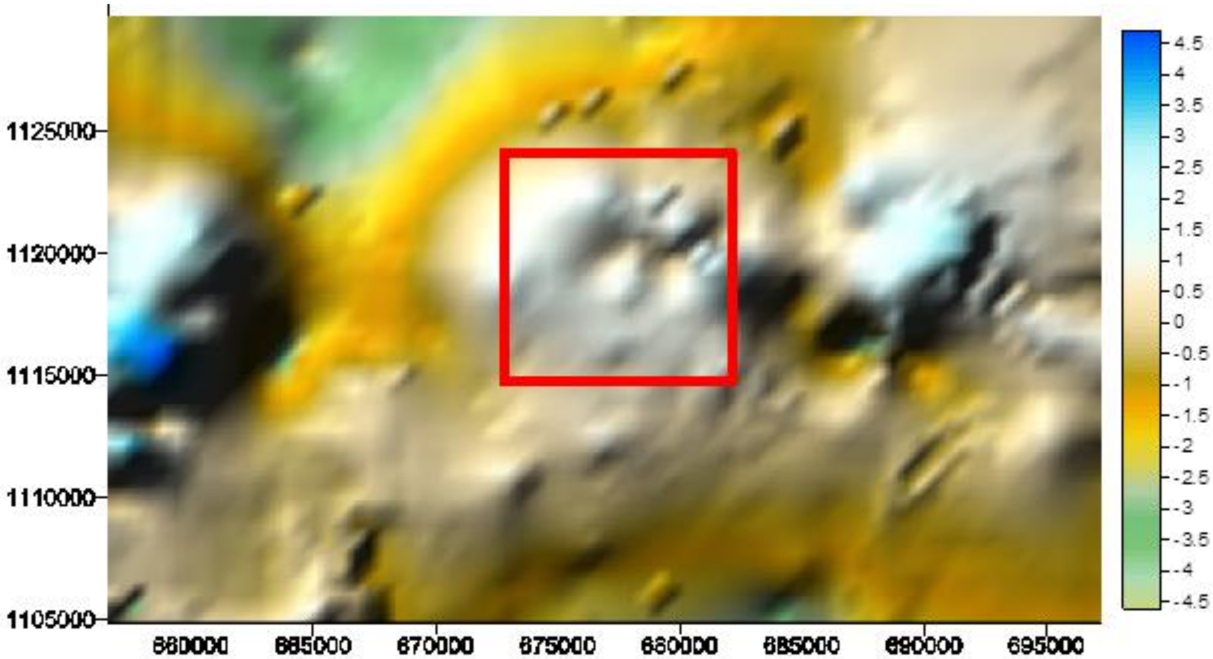

Fig.1B: Digital Elevation Model of study area showing area of mineral Accumulation

Table 5 contains the computed quantities, these quantities comprises of excess mass in row 1, quantity of the underground mass in raw 2 and density of the buried mass in raw 3.

Table 5: computed quantity, excess mass and density

S/N	Computed parameters	Quantity
1	Computed Excess mass	9.60 x10^{-8}tones
2	Computed quantity by two dimensional Fourier analysis	7.19 x10^{-8} tones
3	Density of the mineral body	0.85gcm^{-3}

Table 6: computed and table statistics for data used in gridding at 0.05 level of significance

Level of significance	0.05
Degree of freedom	143
Table Statistics	177.998
Computed statistics	15.842

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III. DISCUSSION OF RESULT

Gridding of the residual gravity anomalies was done at interval 563m apart. The spacing is within the range that allows for a good interpretation of gravity data in especially places with suspected oil reserve. The variance of the population from the statistics report was 1.9036340 and the variance of the sample population (area suspected to have mineral accumulation) that was used in the computation of the mineral deposit was computed as 0.2108308. From table 6 above, it can be seen that value of computed statistic at 0.05 levels of significance is less than the table statistics $\chi^2_{1-\alpha/2}$ at (n-1), therefore we accept the null hypothesis (H_o) that $\sigma^2 = \sigma_0^2$. This suggests that the null hypothesis, that the residual gravity anomalies at the area of suspected mineral accumulation used for the computation of the quantity of mineral deposit are extracted from the normal population (residual gravity anomalies representing the study area) is accepted.

The density of the mineral deposit computed was found to be $0.85gcm^{-3}$. Therefore since the density is known, the type of mineral can be obtained. From the range of densities of different minerals presented in Telford et al (1990), the type of mineral that its density corresponds to this computed density is petroleum ($0.60\ gcm^{-3}$ to $0.90\ gcm^{-3}$). Consequently, it can be assumed that the possible type of mineral that exit in that area can be said to be petroleum. Similarly Shell Nigeria exploration and production company (SNEPCO) in 1995, carried out a similar investigation on the same site using a different method. Their investigation reveals that petroleum exit in that area.

IV. CONCLUSIONS AND RECOMMENDATIONS

In this research, residual gravity anomalies where used to determine the excess mass, actual mass and density of the underground mineral deposit which subsequently leads to the determination of the type of mineral deposit. The residual gravity anomalies used in the research were measured in profile. One of the preconditions of determining the excess mass is to have the residual gravity anomalies measured at grid points, this precondition was made possible by prediction. The prediction was carried out using Kriging, were residual gravity anomalies were predicted at grid points of 563m interval. The result of the prediction shows that at 0.05 level of significance, the residual gravity anomalies used in the computation of the parameters in this research are true representation of the normal population. The density of the underground mineral computed suggested that the suspected mineral can be petroleum. It is therefore recommended that gravimetric technique can also be used to determine the density and subsequently the type of mineral deposit.

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