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Investigation of Solid Mineral Deposit in Gubio, Nigerian Sector of Chad Basin Using Aeromagnetic and Aerogravity Forward and Inverse Modelling

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Authors' contributions

This work was carried out in collaboration between both authors. Author MA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MA and GOA managed the analyses of the study. Author GOA managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The issue of diversification of economy in Nigeria has become a necessity, following the drop in the price of crude oil, which is the major source of revenue, as a result of closure of many industries/companies worldwide, due to the effect of Covid-19. Therefore there is need for an alternative source of revenue generation such as revenue generation from the sale of mineral deposits, which is commonly found in the Nigeria territory. Hence, this research work used some geophysical approach and investigated economy mineral deposits in Gubio area, which is part of the Nigerian sector of Chad basin, which falls within latitudes 12°00′ to 13°00′ North and longitudes 12°30′ to 14°00′ East. Qualitatively and quantitatively interpretations of aeromagnetic and aerogravity data had been carried out. Regional and residual anomalies were separated using polynomial fitting (first order), which was fitted by least square method. The residual values of both magnetic and Bouguer anomalies obtained were used to produce the residual magnetic intensity and residual gravity maps respectively. Forward and inverse modeling was carried out using aeromagnetic data and it estimated the basement depth for P1-P6 as 877, 1836, 4365, 2052, 722

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and 709 m respectively with corresponding magnetic susceptibility values of 0.001, 0.0250, 0.0002, 0.0400,0.0170, 0.0003,which indicate economy mineral deposits such as: Kaolinite, Marble, Clay, Granite, Sandstone and Limestone could be found in the area. Similarly, the aerogravity forward and inverse modeling estimated basement depth for P1 and P2 as 3460 and 1250 m, with respective density values of 2.700 and 2.630 ug/cm^3. This shows that Marble and Granite could also be located in the area. These economy mineral deposits, when properly harnessed could be commercialized and thus could improve the economic statue of the nation. With the availability of these solid mineral deposits, it is recommended that industries such as cement and ceramic should be sited in this area this could provide employment opportunity and hence reduce the unemployment rate in the country.

Keywords: Mineral deposits; forward and inverse modeling; aeromagnetic and aerogravity.

1. INTRODUCTION

Increase in Nigerian population demands for increase in revenue generation sources, which could provide enough funds that could be used for providing quality education service, construction of roads, renovation of infrastructures, payments of workers salary and so on. Over 80% of Nigerian revenue is generated from the sale of hydrocarbon [1,2], which is mostly explored in the Niger-Delta area, where kidnapping and communal crises are on the increase. In addition, if the hydrocarbon of this area is depleted then they may be low or no exploration of hydrocarbon. Similarly, the global pandemic known as corona virus (COVID 19) has lead to the closure of many industries in some countries. Consequently, this led to reduction in the price of crude oil. These situations if not controlled could lead to low generation of revenue. This may affect the economy of the country; hence the country may suffer set back in development. In order to do away with this negative situation there is need to search for other sources of revenue generation such as the revenue generation from the sale of mineral deposit. It has been observed that Nigeria has a lot of on tap mineral deposits, which if harnessed could improve the financial statue of the country. Therefore, this work investigates part of the Nigerian sector of Chad basin, where evidence had been shown by other researchers [3,4,5,6], that the area has high prospect for mineral deposit. Many research works had been carried out in this area though they were centered on exploration of hydrocarbon and water resources. Few works on mineral deposits were carried out; in addition most of these works were carried out using magnetic methods but this might have failed to exposé other mineral deposit that do not have magnetic response. Hence, this work combines magnetic and gravity methods and explore the mineral deposit in the area, which could have been abandoned using only the magnetic method.

1.1 Location and Geology of the Study Area

Gubio, the study area is found in Nigerian sector of Chad Basin, which lies within latitude 1200' to 1300' North and longitude 12 30' to 1400' East (Fig. 1). Nigerian sector of Chad basin is part of Chad basin that is within the vast area of central and west Africa at an elevation between 200 and 500 m above sea level and covers an area approximately 230,000 km^2 [7]. It is the largest area of inland drainage in Africa [8,9,10] and extends into parts of the republic of Niger, Chad, Cameroon, Nigeria and Central Africa. The Nigerian sector of Chad Basin is about one tenth of the Chad basin and has a broad sediment-filled depression spanning north eastern Nigeria and adjoining parts of the Republic of Chad.

1.2 Source of Data

Airborne magnetic data adopted in this research work were gotten from Nigerian geological survey agency (NGSA) Abuja. These airborne magnetic data were measured using a 3 × Scintrex CS2 cesium vapor magnetometer belonging to Fugro Airborne Surveys. This magnetic survey was flown at 80 m elevation along flight lines spacing of 500 m apart. The flight line direction was 135°, while the tie line direction was 225°. The airborne magnetic data were recorded in digital format (X, Y and Z file). X and Y represent the longitude and latitude of the study area, while the Z represents the magnetic field intensity measured in nano Tesla. The Earth's main field, which constitutes about 99% of the recorded value of the magnetic field, was removed by applying international geomagnetic reference field (IGRF 2010). Similarly, temporal and spatial variations

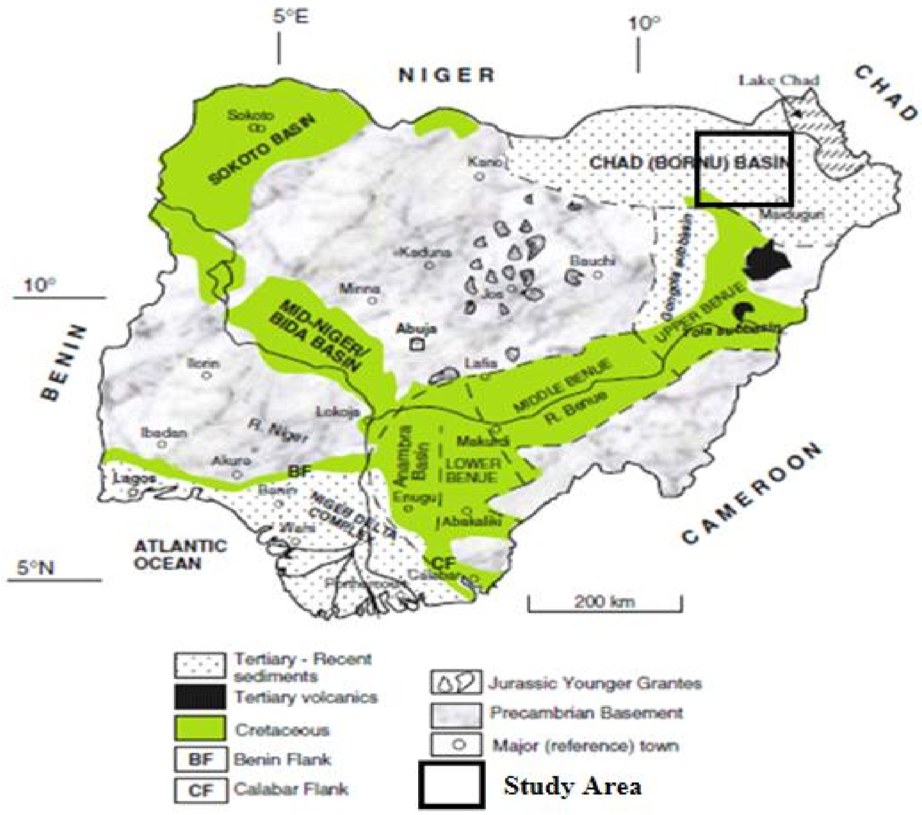


Fig. 1. The map of Nigeria showing the location of Chad Basin [11]

corrections were applied on the air borne magnetic data. On the other hand, the airborne gravity data used in this research work were measured by national aeronautics and space administration (NASA) together with German aerospace center using satellites. The airborne gravity data were recorded in digital format (X, Y and Z file). X and Y represent the longitude and latitude of the study area, while the Z represents the Bouguer anomaly of the study area. Corrections such Drift, Earth-tide, elevation and terrain, latitude and eotovos were applied on the gravity data. These corrections however were carried out by the Nigerian geological survey agency Abuja. The measurements of these data were carried out between 2008 and 2013.

2. METHODS

2.1 Qualitative Interpretation

The total magnetic intensity data were imported into Oasis Montaj 6.4 software and gridded using minimum curvature. These gridded data were further used to produce the total magnetic intensity maps. The regional - residual separation was carried out by first order polynomial fitting. The residual magnetic intensity map was produced using the residual values of magnetic anomalies. Similar processes were carried out using the Bouguer data; hence the Bouguer anomaly and residual Bouguer maps were separately produced [5,6].

2.2 Quantitative Interpretations

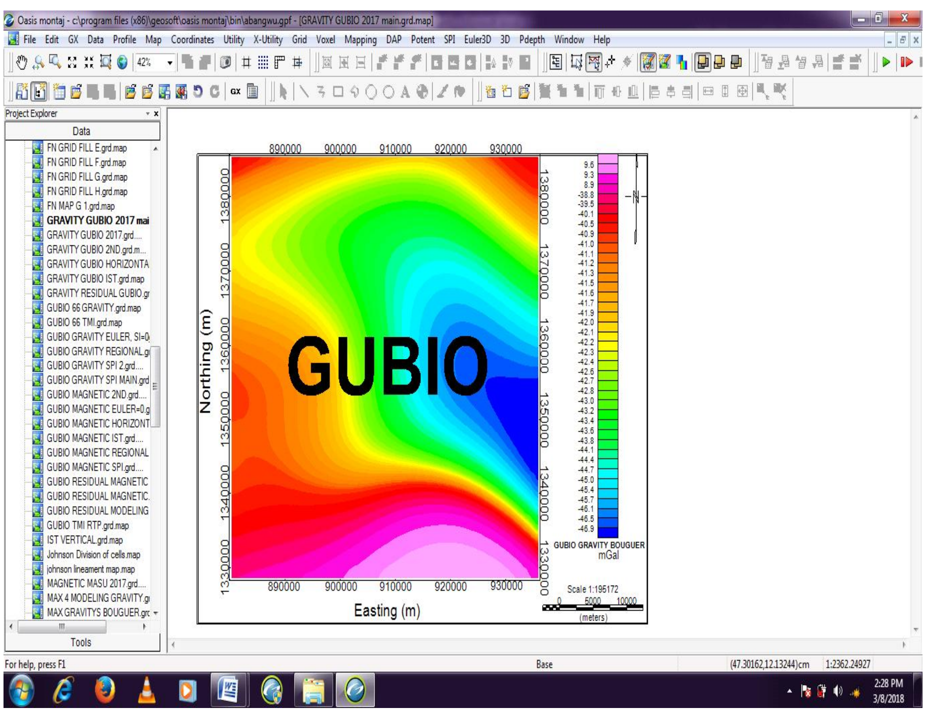
Inversion procedure was performed on residual magnetic and gravity data. The calculated field and the observed field values were produced using the potent Q software and were further compared. Root means square (RMS) between the observed and calculated values was minimized by the inversion algorithm. At the end of each inversion, the root means square value was displayed. This root means square value decreases as the fit between the observed and calculated field continues to improve until a reasonable inversion result was reached. Less than 5% of root means square was set as an acceptable error margin. The residual magnetic and gravity maps were converted to residual magnetic contour grid map and residual gravity contour grid maps (Fig. 3 a & b). This is to showcase locations that might likely be suitable for modeling. The profiles in each model show the variation of the field values with distance at the area or points modeled. Six points, P1-P6 were taken on the residual magnetic contour grid map and modeled with an ellipsoid and rectangular shapes respectively. Similarly, two points, PI and P2 were taken around the western and northeastern parts of the residual gravity contour grid map and modeled with an ellipsoid shapes. Forward modeling being a trial and error method, the shape, position and physical properties of the models were adjusted so as to get a good correlation between the calculated fields [5,6].

2.3 Research Findings

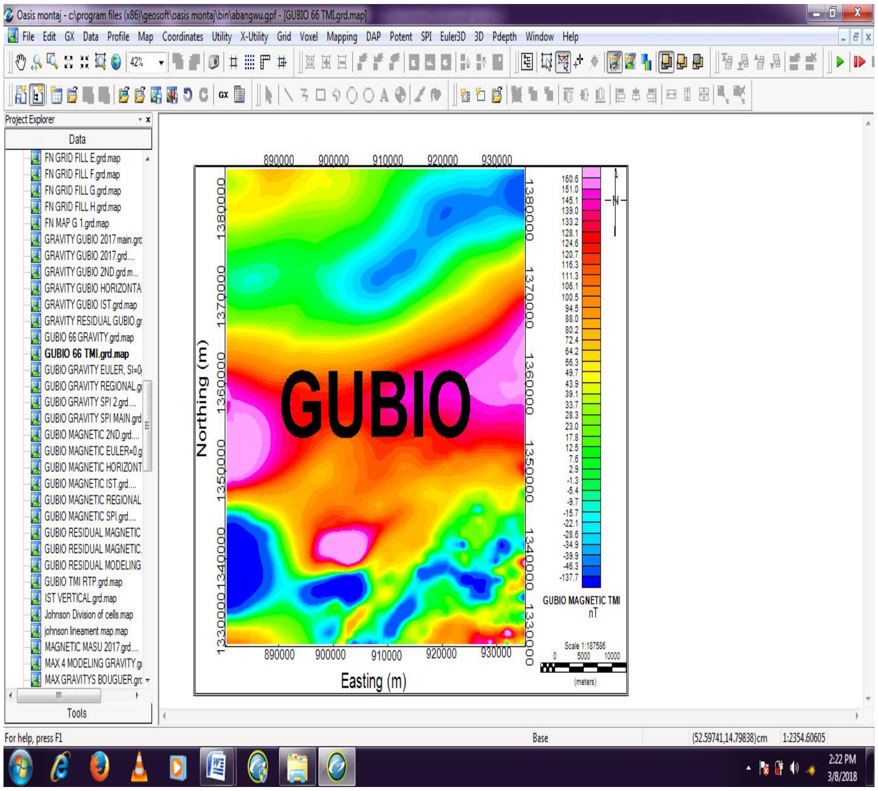
Fig. 2 indicates the total magnetic intensity, Bouguer anomaly, residual magnetic anomaly and residual Bouguer anomaly maps, while Fig. 3 presents residual aeromagnetic contour map, residual aerogravity contour map and magnetic profile models 1 - 4 respectively. Magnetic Profile 5 (P5), Magnetic Profile 6 (P6), Gravity Profile 1 (P1) and Gravity Profile 2 (P2) are shown in Fig. 4.

Table 1. Summary of aeromagnetic forward and inverse modeling results of Gubio

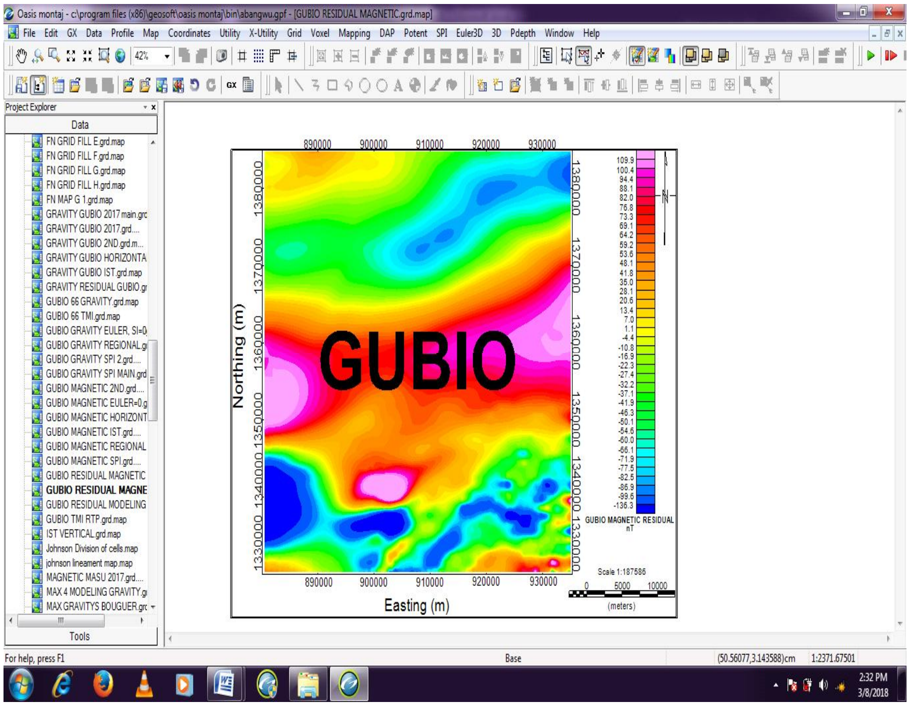
Model	Model shape	X(m)	Y(m)	Depth to anomalous body (m)	Plunge (deg)	Dip (deg)	Strike (deg)	Magnetic susceptibility (SI)	Possible cause of anomaly
P1	Ellipsoid	926548	1336244	877	-43.2	95.5	51.0	0.0001	Kaolinite
P2	Rectangular Prism	901032	1340314	1836	5.1	-48.7	-57.9	0.0250	Marble
P3	Rectangular Prism	882794	1337029	4365	-6.9	-105.6	-70.8	0.0002	Clay
P4	Ellipsoid	882871	1350161	2052	156.1	74.2	-127.4	0.0400	Granite
P5	Ellipsoid	885478	1372407	722	0.6	-11.7	-97.0	0.0170	Sandstone
P6	Rectangular Prism	921361	1380475	709	-24.5	75.8	-78.0	0.0003	Limestone



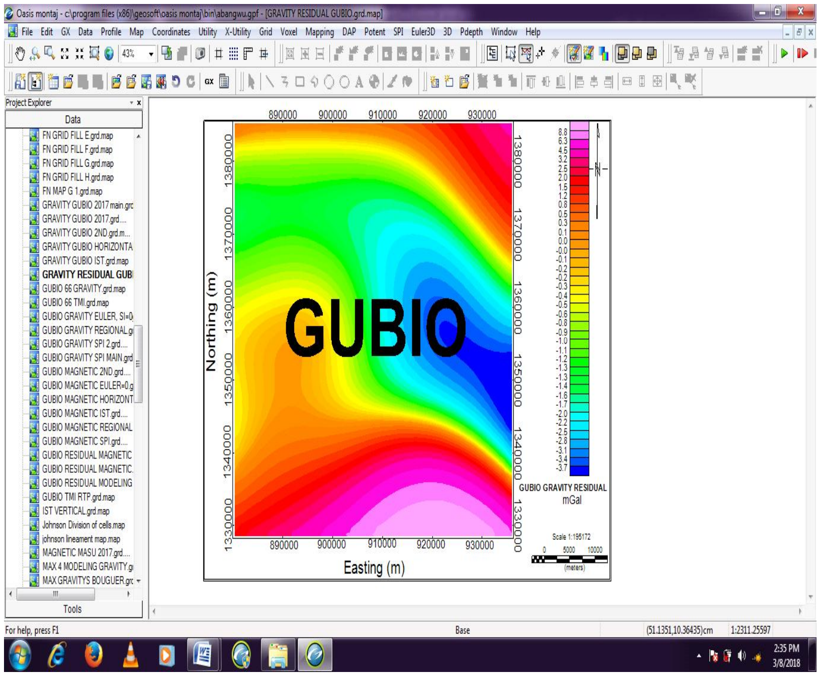
(a)


GUBIO
Northing (m)
Easting (m)
GUBIO MAGNETIC TMI
nT

(b)

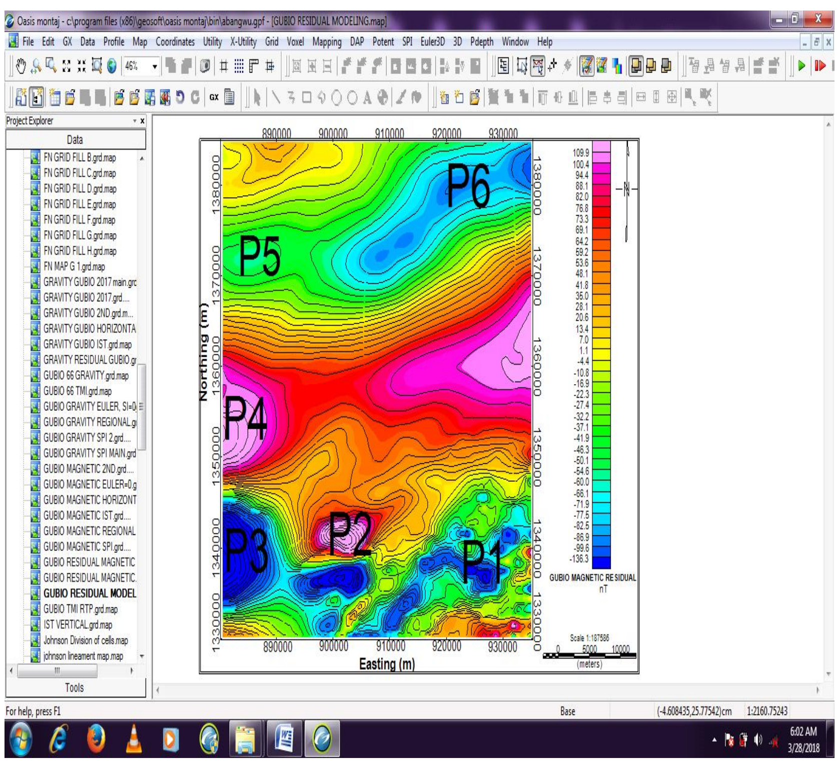

GUBIO
Northing (m)
Easting (m)
GUBIO MAGNETIC RESIDUAL
nT

(c)

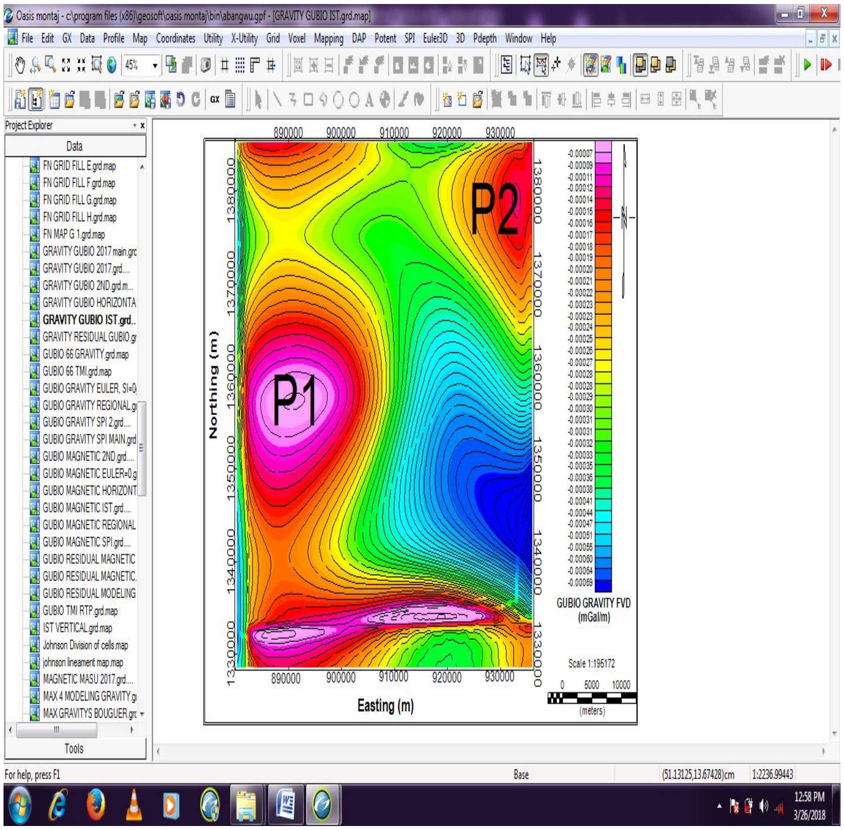


(d)

Fig. 2. (a) Total magnetic intensity map, (b) Bouguer anomaly map, (c) Residual magnetic anomaly map, (d) Residual Bouguer anomaly map



(a)



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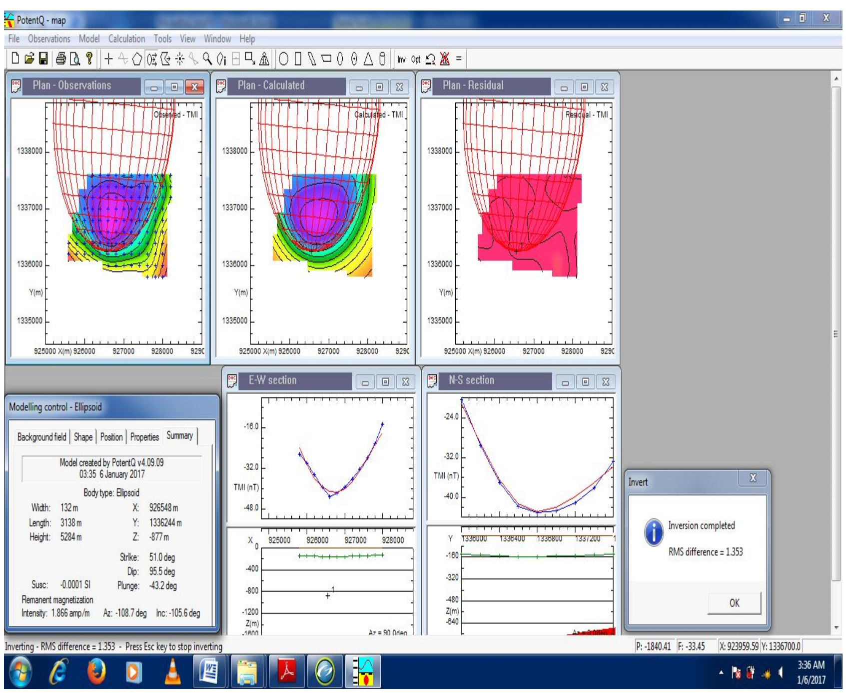

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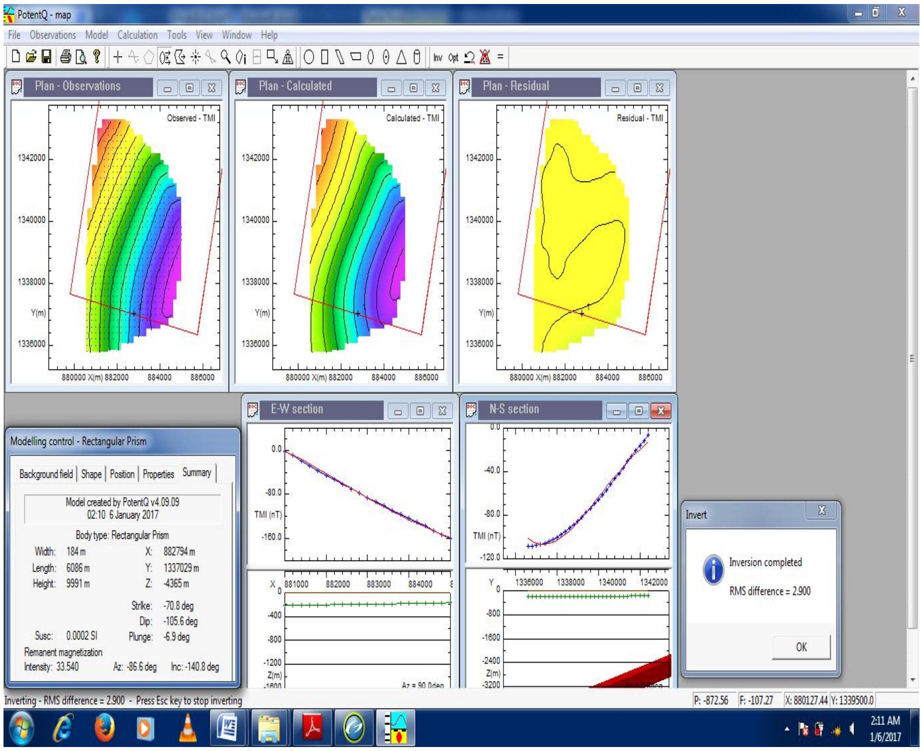
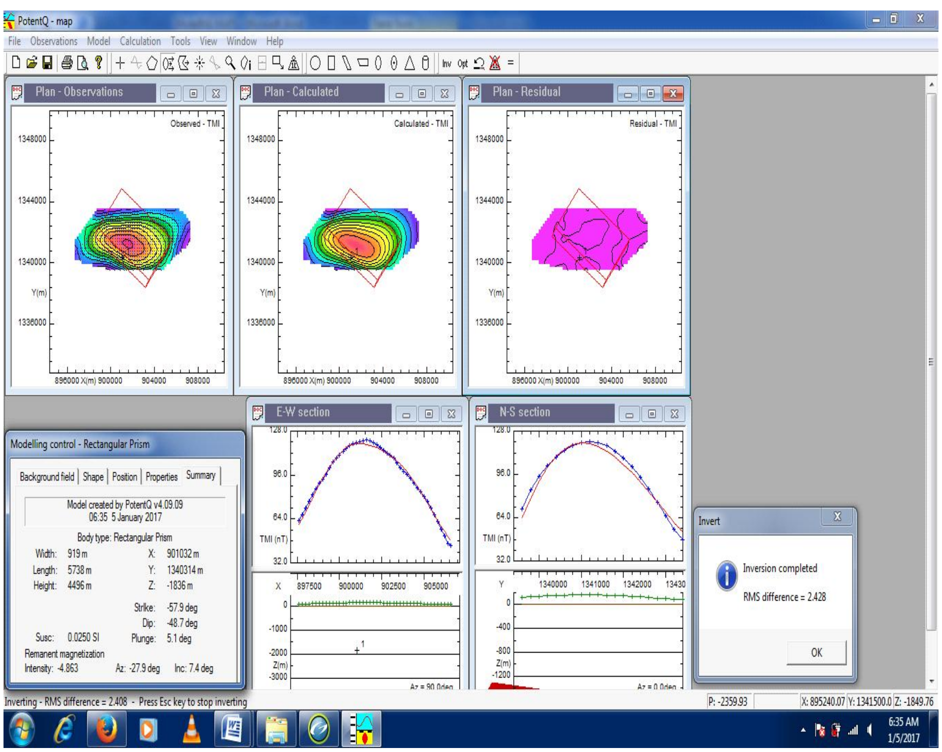

PotentQ - map
File Observations Model Calculation Tools View Window Help
Plan - Observations
Observed - TMI
Plan - Calculated
Calculated - TMI
Plan - Residual
Residual - TMI
E-W section
N-S section
Modelling control - Rectangular Prism
Background field | Shape | Position | Properties | Summary
Model created by PotentQ v4.09.09
02:10 6 January 2017
Body type: Rectangular Prism
Width: 184 m X: 882794 m
Length: 6086 m Y: 1337029 m
Height: 9991 m Z: -4365 m
Strike: -70.8 deg
Dip: -105.6 deg
Susc: 0.0002 SI Plunge: -6.9 deg
Remanent magnetization
Intensity: 33.540 Az: -86.6 deg Inc: -140.8 deg
Invert
Inversion completed
RMS difference = 2.900
OK
Inverting - RMS difference = 2.900 - Press Esc key to stop inverting

(d)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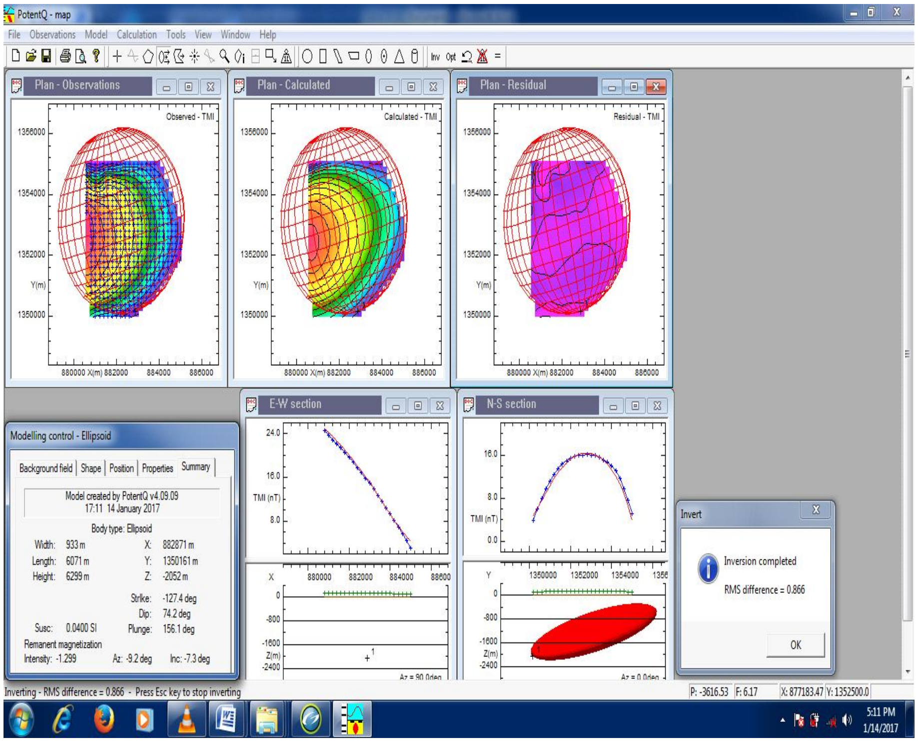
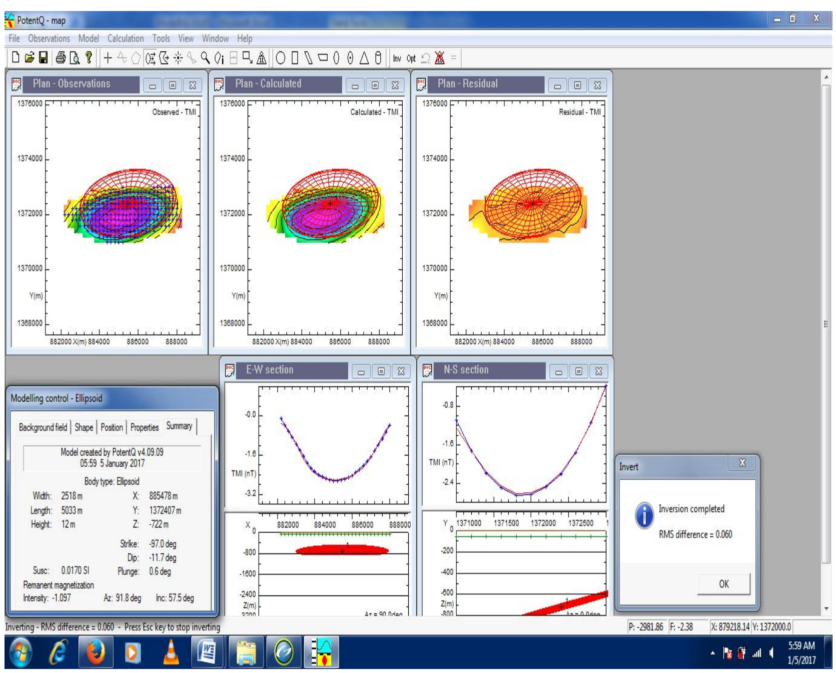
File Observations Model Calculation Tools View Window Help
Plan - Observations
Observed - TMI
Plan - Calculated
Calculated - TMI
Plan - Residual
Residual - TMI
E-W section
N-S section
Modelling control - Rectangular Prism
Background field | Shape | Position | Properties | Summary
Model created by PotentQ v4.09.09
06:35 5 January 2017
Body type: Rectangular Prism
Width: 919 m X: 901032 m
Length: 5738 m Y: 1340314 m
Height: 4496 m Z: -1836 m
Strike: -57.9 deg
Dip: -48.7 deg
Susc: 0.0250 SI Plunge: 5.1 deg
Remanent magnetization
Intensity: -4.863 Az: -27.9 deg Inc: 7.4 deg
Invert
Inversion completed
RMS difference = 2.428
OK
Inverting - RMS difference = 2.408 - Press Esc key to stop inverting

(e)

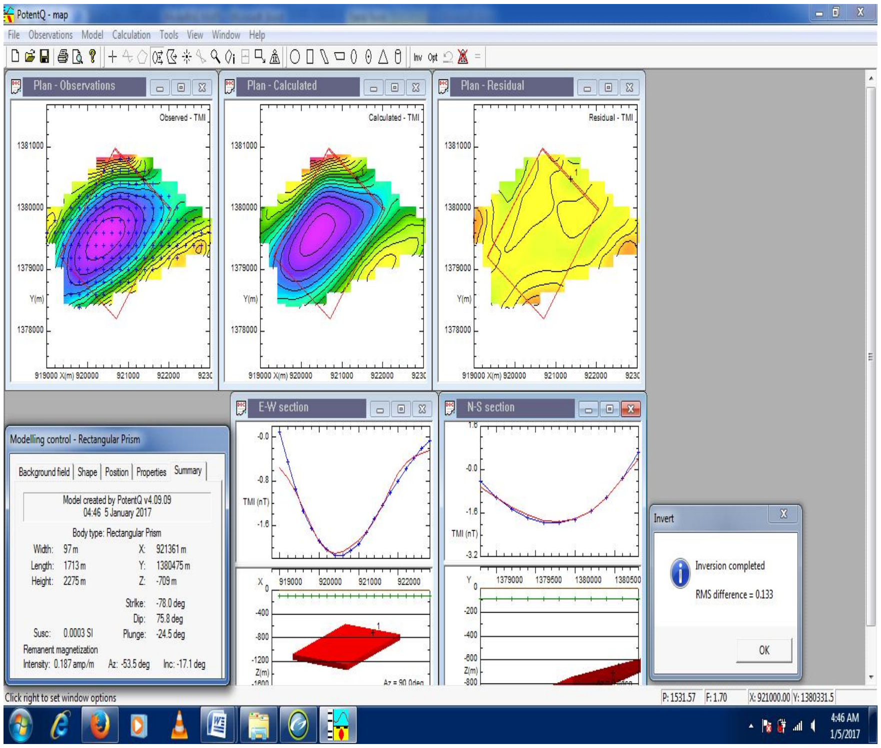


(f)

Fig. 3. (a) Residual aeromagnetic contour map, (b) Residual aerogravity contour map (c) Magnetic profile 1(P1), (d) Magnetic profile 2 (P2), (e) Magnetic profile 3(P3), (f) Magnetic profile 4(P4)



(g)


PotentQ - map
Plan - Observations
Plan - Calculated
Plan - Residual
E-W section
N-S section
Modelling control - Rectangular Prism
Invert
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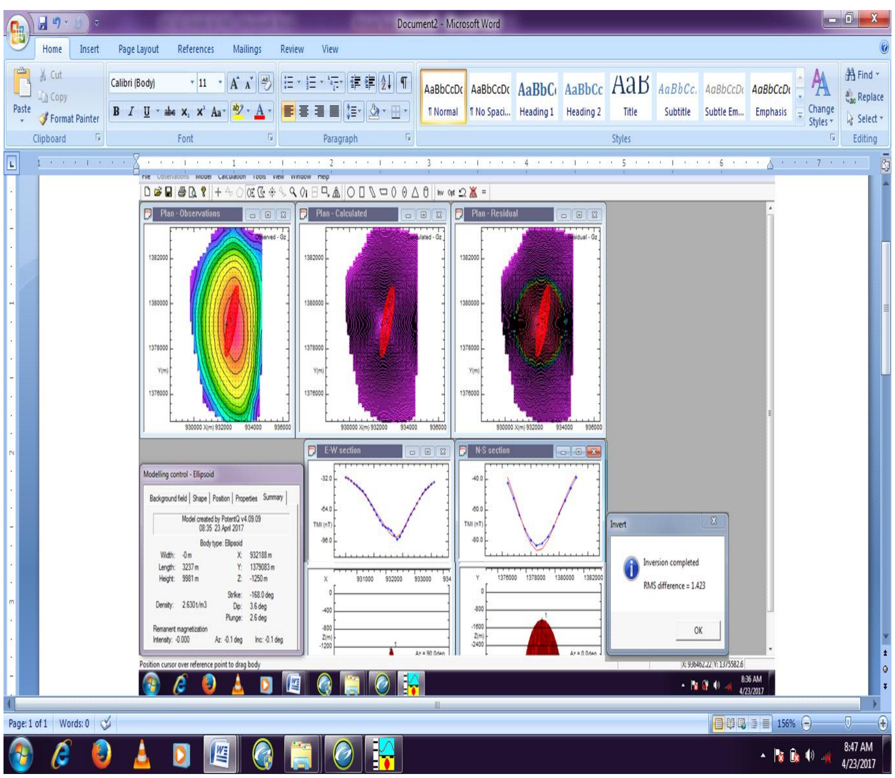
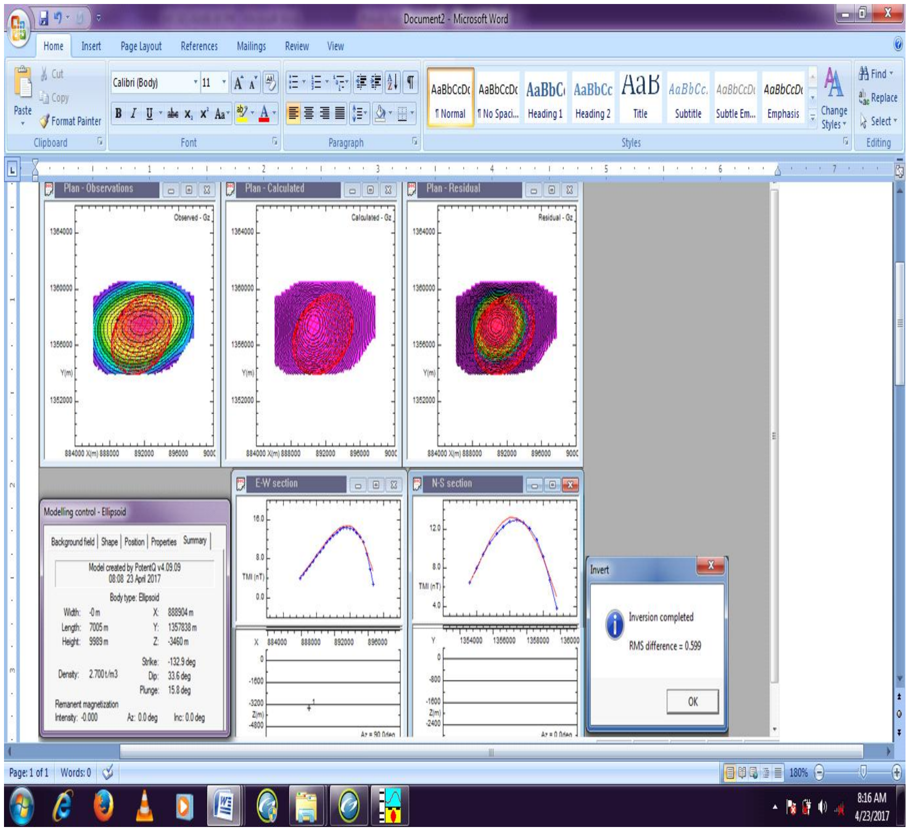
OK

(h)


Document2 - Microsoft Word
Plan - Observations
Plan - Calculated
Plan - Residual
E-W section
N-S section
Modelling control - Ellipsoid
Invert
Inversion completed
RMS difference = 1.423
OK

(i)



(j)

Fig. 4. (g) Magnetic profile 5 (P5), (h) Magnetic profile 6 (P6), (i) Gravity PROFILE 1 (P1), (J) Gravity profile 2 (2)

Table 2. Summary of aerogravity forward and inverse modeling results of Gubio

Model	Model shape	X(m)	Y(m)	Depth to anomalous body (m)	Plunge (deg)	Dip (deg)	Strike (deg)	Density value (g/cm^3)	Possible cause of anomaly
P1	Ellipsoid	888904	1357838	3460	15.8	33.6	-132.9	2.700	Marble
P2	Ellipsoid	932188	1379083	1250	2.6	3.6	-168.0	2.630	Granite

3. DISCUSSION OF FINDINGS

The total magnetic intensity (TMI) of Gubio vary from -137.7 to 160.6 nT (Fig. 2a). This implies that the area is magnetically heterogeneous. Meanwhile, high magnetic anomalies are identified mainly in the central region of the map. Low magnetic anomalies are observed in the south and northern parts of the map. The high and low magnetic intensity in the area may be attributed to variations in the depth, differences in magnetic susceptibility, differences in lithology and degree of strike [1]. On the other hand, the Bouguer anomaly values, of this area vary from -46.9 to 9.6 mGal (Fig. 2b). This shows that the area has high and low gravity of variable amplitudes. Hence, the Bouguer anomalies of the area trend from east to west directions. Low Bouguer anomaly is observed in the east and increases towards the north and southern parts of the map, thereby making the north and south to dominate with high Bouguer gravity anomalies. The low Bouguer anomaly in the area could be attributed to deep seated structures, while the high Bouguer anomaly could be due to intrusion or basement up lift. This variability of the anomalies indicates that the basement rocks of Gubio sink eastward and uprising in the south and north under the sedimentary sequence of the basin. This agrees with [12] who observed that the Bouguer anomaly of Ouled Abdoun basin in Morocco sinks and has uprising nature.

The residual magnetic intensity (RMI) of Gubio (Fig. 2c) shows a similar trend to that of the total magnetic intensity (Fig. 2a) despite the fact that it only highlighted local or residual structures. Meanwhile high and centrally located residual magnetic intensity is bounded by low residual magnetic intensity in the north and south. This shows that the central region of the area is occupied by intrusive magnetic rocks. Further observations reveal that the residual magnetic intensity of the area ranges between -136.3 and 109.9 nT. This indicates the area is predominantly area of low residual magnetic anomalies and few areas of high residual magnetic anomalies. It further implies that Gubio area is mostly occupied by sedimentary rocks. The low residual magnetic anomalies occurring in the north and southern parts of the area reflect zones of low magnetization. This could be attributed to low concentration of magnetic bodies or mineral. Meanwhile high residual magnetic anomaly observed in the map, reflects high concentration of magnetically susceptible minerals, which could be attributed to intrusion (suspected to be granite). This agrees with the work of [4] who observed that high residual magnetic intensity in most part of Chad Basin area are caused by near surface rocks.

Observations from Fig. 2d identify high residual gravity anomalies in the south and parts of northeast, while the low residual gravity anomaly is seen in the northwest and spread towards the east. The high and low residual gravity anomalies depict features of variable densities in the areas.

The results of the aeromagnetic forward and inverse modeling as shown in Fig. 3 (a - f) and 4 (g - h) and summarized in Table 1 indicate that the estimated depths from the forward and inverse modeling are 877, 1836, 4365, 2052, 722 and 709 m with susceptibility values of 0.0001, 0.025, 0.0002, 0.04, 0.017 and 0.0003 for P1 – P6 respectively. These indicate dominance of minerals like Kaolinite, Marble, Clay, Granite Sandstone and limestone as could be ascertained from standard values of magnetic susceptibilities and densities of some rocks and minerals (Thompson and Oldfield, 1986 and Telford *et al*., 1990). Similarly, the estimated depths from the forward and inverse modeling of aerogravity data as shown in Figs. 4 (i- j) and summarized on Table 2 show that the depth estimated from aerogravity forward and inverse modeling are 3460 and 1250 m with density values of 2.700 and 2.630 (g/cm^3) for P1 and P2 respectively. These indicate the presence of Marble and Granite as could be ascertained from standard values of magnetic susceptibilities and densities of some rocks and minerals [13,14].

4. CONCLUSION AND RECOMMENDATIONS

The 2D total magnetic intensity (TMI) map of Gubio shows magnetic anomalies, which vary from -137.7 to 160.6 nT. This implies that the area is magnetically heterogeneous. On the other hand, Bouguer anomaly map of Gubio reveals Bouguer anomaly values, which vary from -46.9 to 9.6 mGal. This shows that Gubio area has high and low gravity of variable amplitudes. Hence, the Bouguer anomalies of the area trend from east to west directions. From the modeling results, it is therefore concluded that Gubio area has the following mineral deposits: kaolinite, marble, clay, granite, sandstone and limestone. Ceramic and cement industries could be sited in this area, this could further provide employment opportunity and also boast the economics of the nation. It is recommended that the Federal Government of Nigeria should give adequate consideration to the development and harnessing of mineral deposits in its efforts of diversing the economy.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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