

Subsurface Characterization Based on Densities, Heat Sources and Thickness of Sediments Obtained From Inverse Modelling of Gravity Data

Anyadiiegwu F. C¹, Aigbogun C. O², and Eze, M. O³

³Department of Physics, Michael Okpara University of Agriculture Umudike

^{1&2}Department of Physics, University of Benin, Benin City

Received Date: 02 July 2021
Revised Date: 03 August 2021
Accepted Date: 14 August 2021

Abstract

The gravity data over the Nsukka area, Igumale area, Ejekwe area, Udi area, Nkalagu area, and Abakaliki, was obtained from Nigerian Geological Survey Agency, NGSA. These sheets covered areas within latitude 6°00'N to 7°00'N and longitude 7°00'E to 8°30'E. The data were merged and modeled using Glabox and Bloxer software. The Gravity model result of the study area revealed thick sedimentation, in areas with a thickness of 8 Km, sedimentation uncovered in the region is likely a shale interspersed with sandstone with a medium density range of 2.30 - 2.75 g/cm³. In the areas with sedimentary thickness range of 10 Km to 15 Km, existing rocks are changed into rocks with a high density of 2.92 - 3.12 g/cm³ where the possibility of rocks uncovered is granite rocks that become reservoir cover rocks. Reservoirs revealed are, 2 large reservoirs located in the west and east with a high density of about 3.47 - 3.65 g/cm³ are interpreted as heat sources in the study area. Based on these results, the study area has high heat reservoir potential, which can be harnessed as geothermal energy. There is also a possibility of high temperature and pressure hydrocarbon reservoir potential due to areas interpreted as heat sources and density, which suggested shale intercalation.

Keywords - Gravity Data, Inverse Modelling, Densities.

I. INTRODUCTION

The gravity method has been employed widely for detecting the subsurface density variations and geological structures; this geophysical method measures the spatial variations in the strength of the gravitational field of the earth and uses this physical property to precisely define the Earth's composition, structure, and probable origin. It is an important geophysical tool used in the subsurface mapping of density distributions. Result interpretation based on gravity data can be used for mineral and oil exploration, underground water exploration, engineering, and construction sites investigation.

The gravity data is used to estimate the depth of the sedimentary basin and detect sub-sea basalt, which is mostly associated with reservoirs (Hongzhu *et al.*, 2017). For effective and successful application of gravity methods, fast forward modeling and stable inversion tools are employed on gravity data sets to create images of the subsurface density structures.

Two different strategies are employed in data interpretation, imaging, and modeling. In imaging, the measured waveform themselves are presented in a form in which they simulate an image of the subsurface. The most obvious are gravity surveys for shallow engineering investigations processed to produce shaded colored or contour maps where the shading or color correlates with the structures been sort. Imaging is a very powerful tool as it provides a way of summarizing huge volumes of data in a format that can be readily comprehended. Its disadvantage is the inability to quantify data from it. In modeling, the geophysicist predicts the form of the actual waveform recorded by choosing a particular type of structural model of the surface. This model is adjusted to give the closest fit between the calculated and the observed field. The accuracy of the match obtained is dependent on the model used.

Thanks to advances made in the mineral exploration sector, (Writer *et al.*, 2016), potential field techniques are available to independently test geological conceptual models in three dimensions without drilling (Fullagar *et al.* 2008). These techniques utilize gravity and/or magnetic data, rock property data (density and magnetic susceptibility), and a 3D geologic model.

The study area covers part of Southeastern Nigeria and parts of the Northcentral or middle belt; it lies between latitude 6°00'N to 7°00'N and longitude 7°00'E to 8°30'E. It covers a total surface area of about 18,150 square kilometers, and is within the Lower or southern Benue Trough. Fig. 1, shows the major locations within the study area.



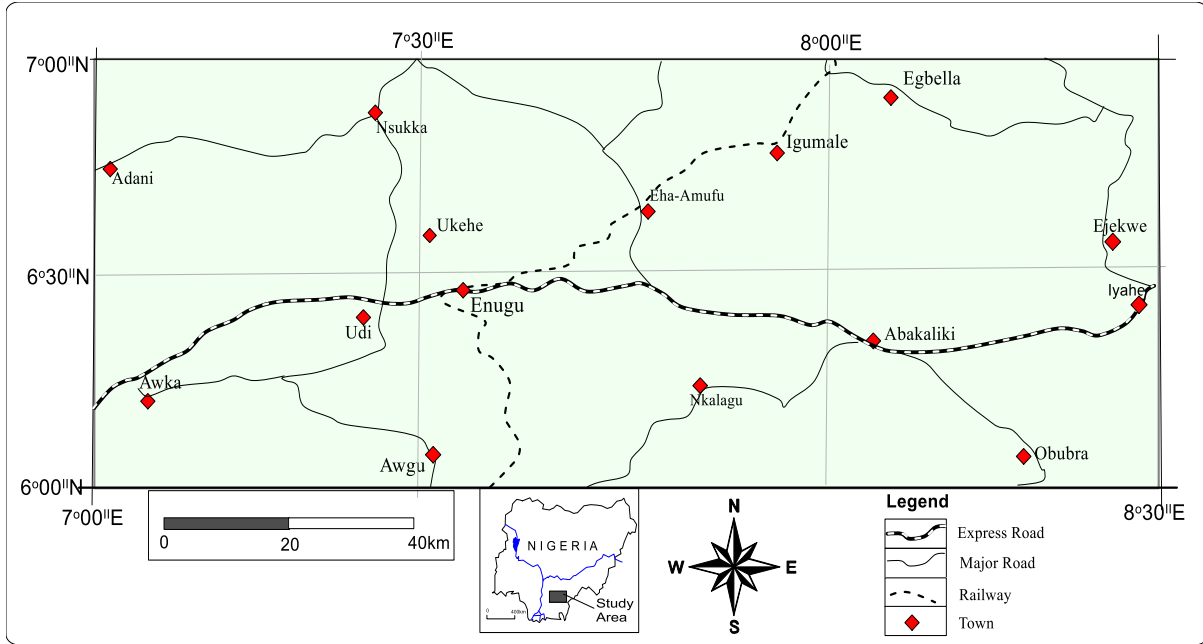


Figure 1: location map of the study area. (Redrawn after Encarta 2008).

II. MATERIALS AND METHODS

Six sheets of gravity data over Nsukka area, Igumale area, Ejekwe area, Udi area, Nkalagu area, and Abakaliki, with sheet numbers 287, 288, 289, 301, 302, and 303, respectively, were obtained from the Nigerian Geological Survey Agency, NGSA. The agency did some pre-processing on the acquired data; these include some reductions or corrections such as the effects of terrain removal. The maps covered areas with latitude 6°00'N to 7°00'N and longitude 7°00'E to 8°30'E. The six (6) gravity sheets were obtained in Geosoft file format and were merged to produce the complete Total gravity map of the whole study area depicted in figure 2.

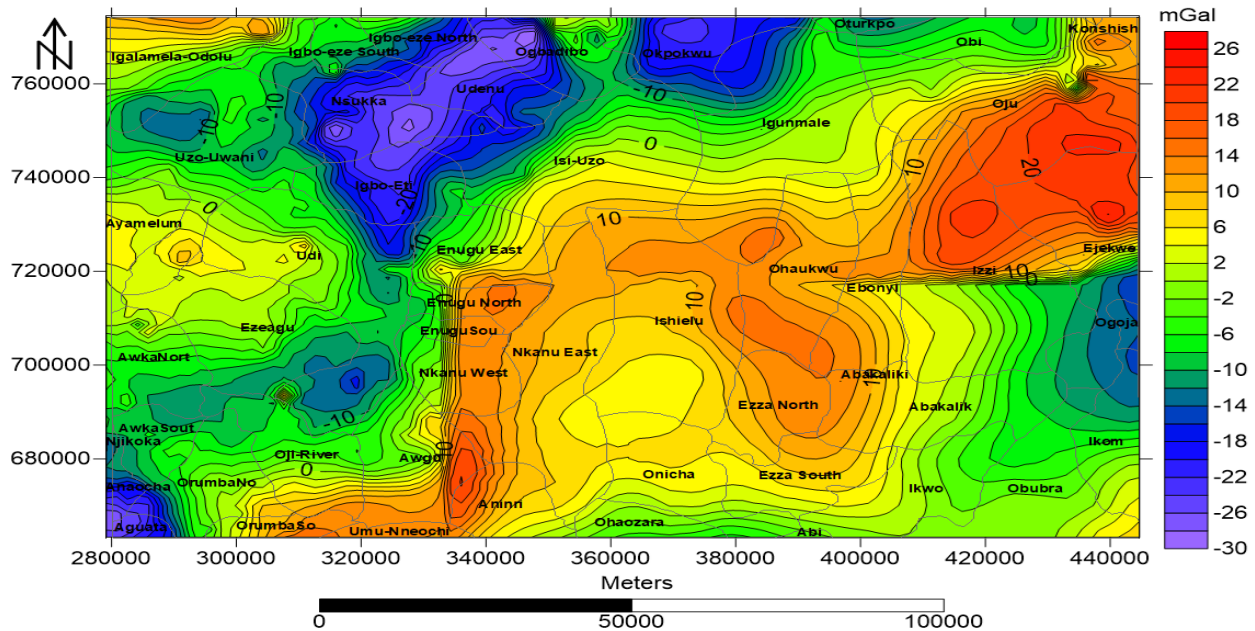


Figure 2: The merged Total gravity map of the study area, comprising of the 6 sheets.

Grablox 1.6 and Bloxer 1.6 software was used in quantitative analysis to model the Bouguer gravity data, which was obtained from the regional residual separation of the total gravity data; the model generated the density of the subsurface material, their burial depth, as well as the dimensions and the positions of the bodies causing the anomalies.

The merged six-sheet Bouguer gravity data was modeled to obtain densities using Grablox 1.6 and Bloxer 1.6 software.

The GRABLOX computer program computes the synthetic gravity anomaly of a 3-D block model.

Figure 3 illustrates the model; a large rectangular block is divided into smaller brick-like volume elements. Each minor block is assigned an individual, constant density value.

The Grablox computer program can be used for forward and inverse modeling. The inverse or inversion method optimizes either the density or the height of the individual blocks so that the difference between the measured and the computed gravity data is minimized. The height inversion allows interpretation of thickness variations of the overburden layer (depth to the basement) using constant density contrast (Pirttijärvi, 2008). The resulting density or thickness variations distribution inside the block model can then be used in geological interpretation.

BLOXER program can be used for model editing and visualization.

The optimization method is based on linearized inversion, while the original inversion method uses singular value decomposition (SVD) with adaptive damping. The alternative inversion method utilizes Occam's principle, where the roughness of the model is reduced together with the data misfit. The parameters of a base anomaly represented by a second-degree polynomial can also be optimized. Density and the interface position of the blocks can be fixed (weighted) based on a priori information (e.g., petrophysical or drill-hole data).

BLOXER program, which can be used to visualize and to edit the 3-D block models.

Bloxer is a computer program used for interactive visualization, construction, and maintenance of three-dimensional block models. Block models are used in the Grablox (Pirttijärvi, 2009) program build for the geophysical modeling and interpretation of gravity data. The 3-D block model consists of a large super-block which comprises of smaller brick-like elements or minor blocks. The minor-blocks are assigned one or more characteristic parameter values or values, respectively. The model is assigned a rectangular xyz coordinate system. The spatial distribution of a petrophysical parameter, such as density, magnetic susceptibility, or electrical conductivity, is described by the volume of the model. Figure 6 shows an example of a regular block model, with all the minor blocks having equal size and shape. Note that the block model must be fully filled, therefore, cells cannot overlap or have empty space between them.

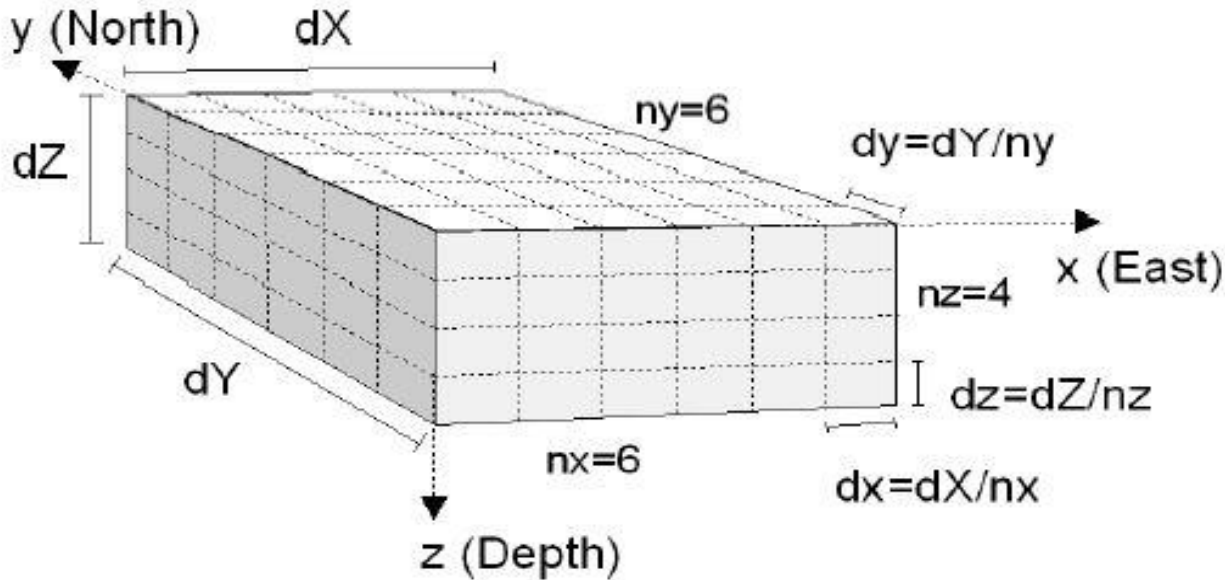


Figure 3: Block model of size $dX.dY.dZ$ divided into $nx.ny.nz$ minor-blocks of size $dx.dy.dz$. The model is aligned with the rectangular coordinate system (Pirttijärvi, 2009; Pirttijärvi, 2012).

RESULTS AND DISCUSSION

Initial model (figure 4) used in this study has 13680 minor blocks, which made one major block, which is, 13 blocks for all nx layers, 20 blocks for all ny layer, and 38 blocks for all nz layers. The model that is made refers to the density value of Bouguer in regional research so that a model will be obtained that corresponds to the subsurface state. The initial

model initiation was done in the Grablox 1.6 software. The model size for Pasuruan is about 165 km to the east (X-axis) and 45 km to the north (Y-axis), while the depth of the model is 40 km towards the vertical (Z-axis). The value on the Z-axis is determined from the spectrum analysis results. More details will be visualized in Figures 5, 6, and 7.

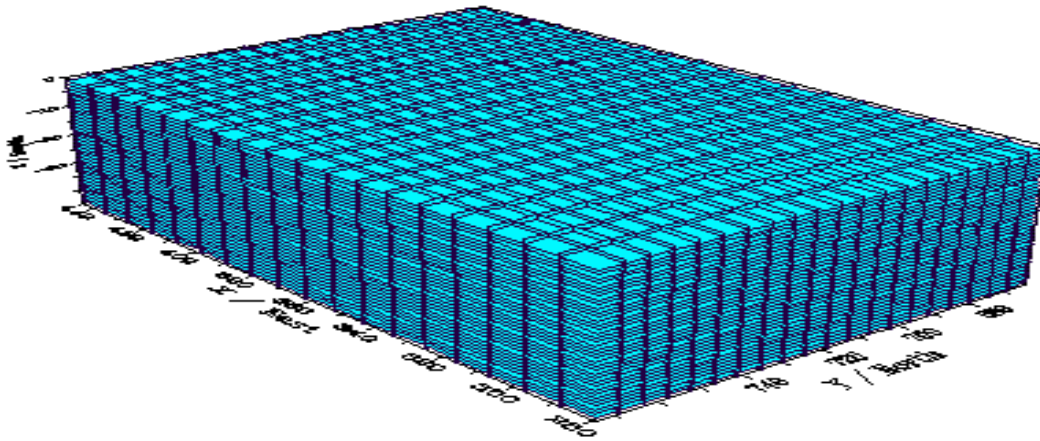


Figure 4: Initial Model

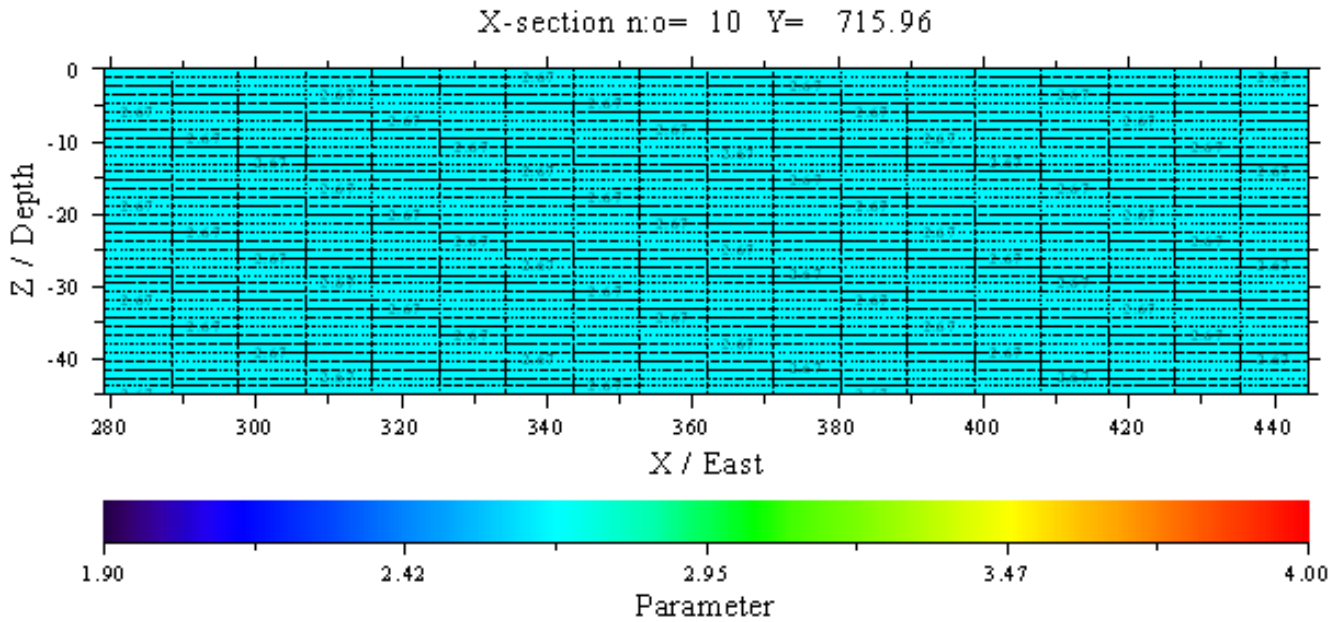


Figure 5: X Section

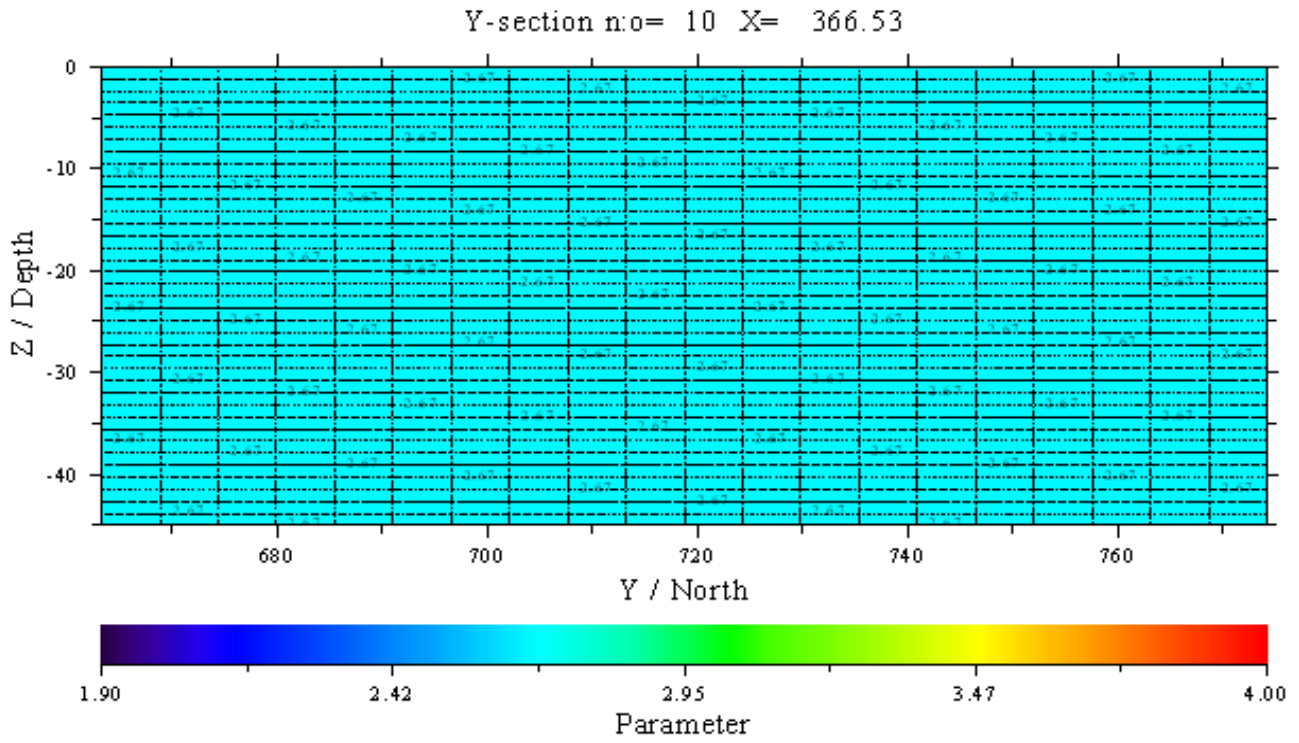


Figure 6: Y Section

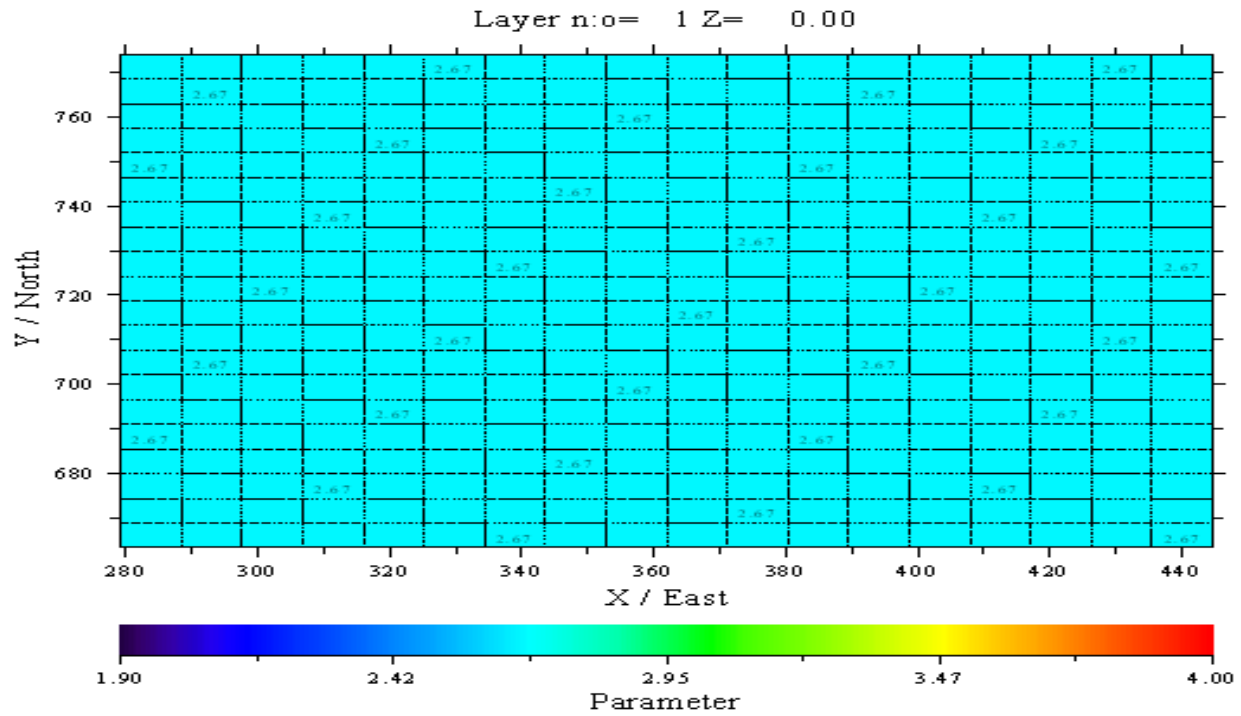


Figure 7: Z Section

3-dimensional inversion modeling using the Grablox 1.6 app uses initial model data and residual data for each region. The data will be used in the input of the initial model (.inp) and residual data (.dat). Then, after the data reading process is complete, the model will be shaped like Figure 8a. Furthermore, base optimization is performed to optimize the base value of anomalous parameters (figures 8b and 8c). In

the study area, rms was obtained by 15%. The value is still calculated large, so repeated optimization must be done until it gets a stable RMS result. After repeated optimization, the RMS value in the study area is 3%; this value is quite small because it is < 10%. The result of data seems to need to be fit again, so we decide to use svd inversion for fitting the data.

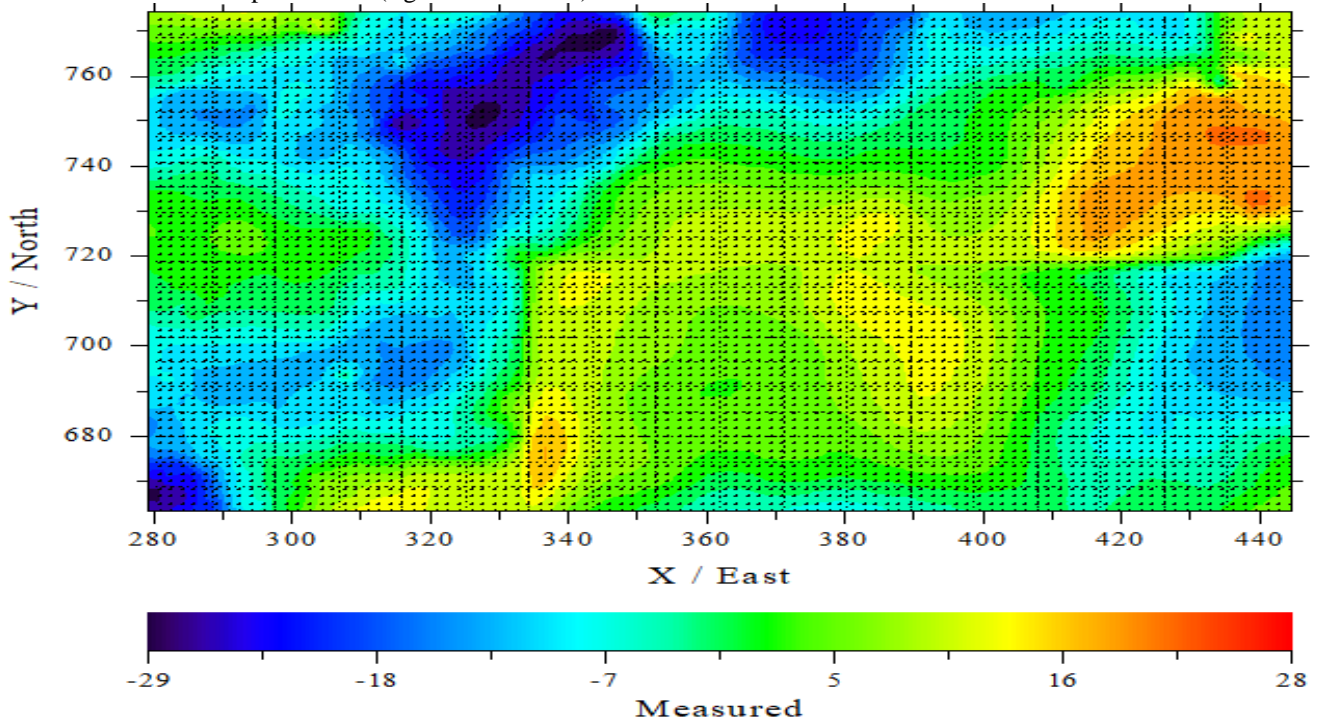


Figure 8a: Measured Base Optimization

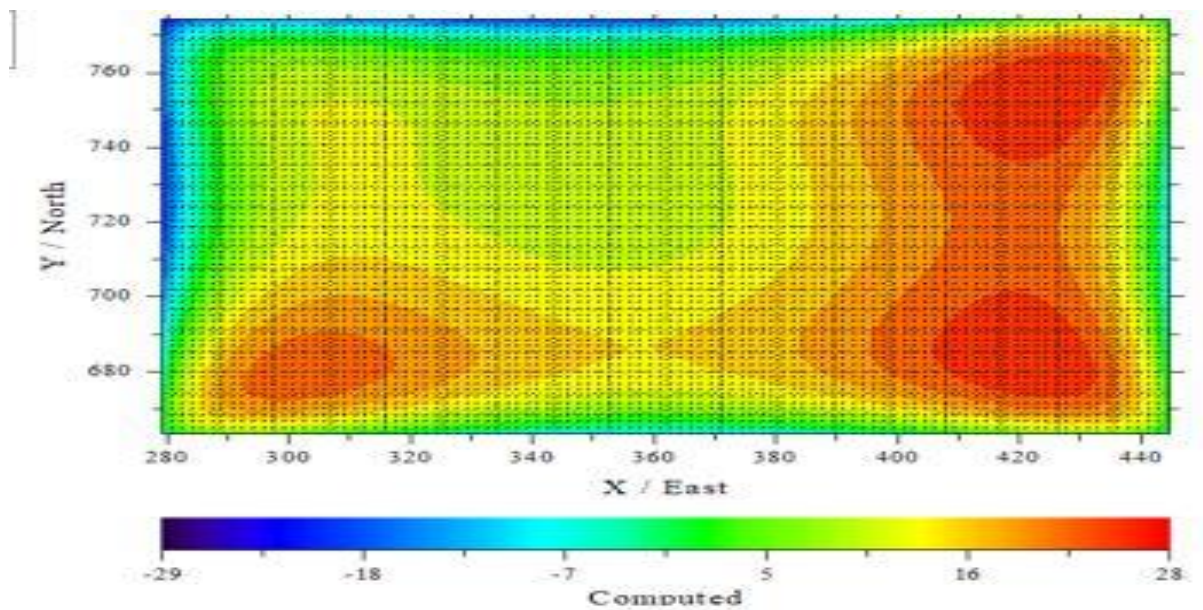


Figure 8b: Computed Base Optimization

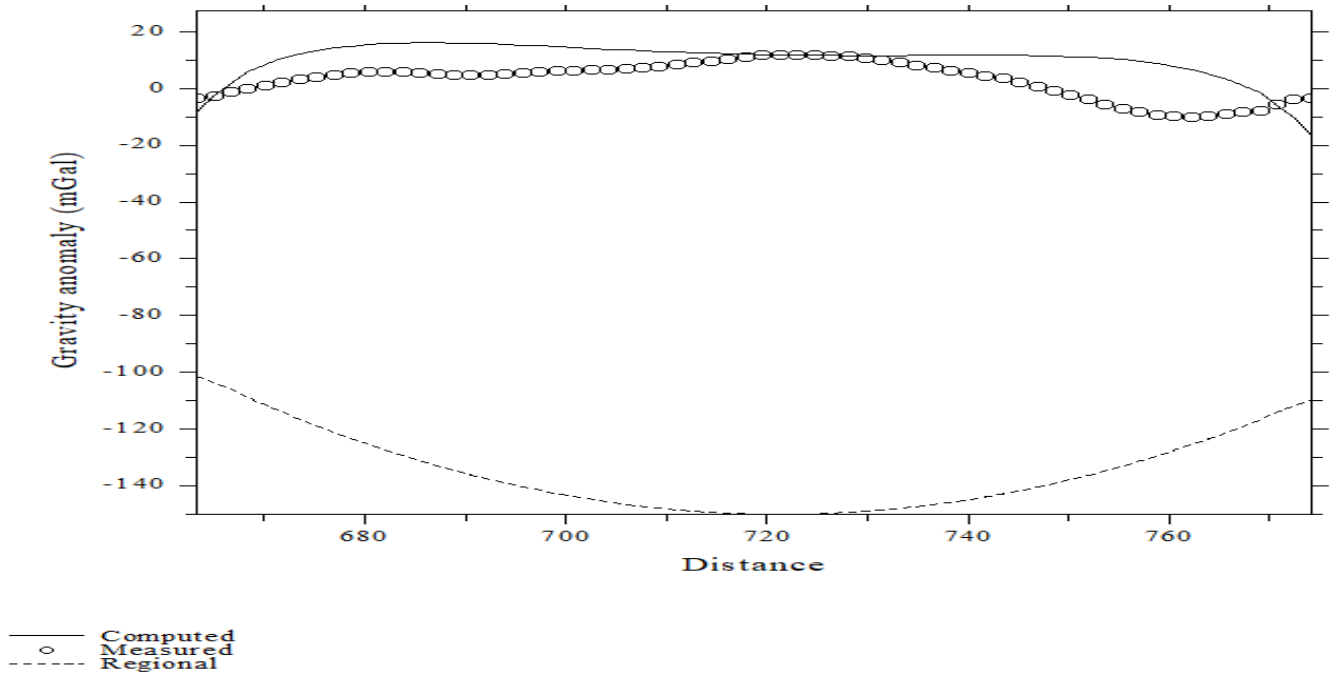


Figure 8c: Profile of Base Optimization

In short, Density Optimization uses inverse second vertical derivative. The purpose of density optimization is to optimize the density value so that the density value between the measurement and calculation data is close (figures 9a, 9b, and 9c). Iterations/repetitions performed on this optimization are 1 time. The RMS error rate in the study area was 1%, with a processing time of 10 hours and 30 minutes.

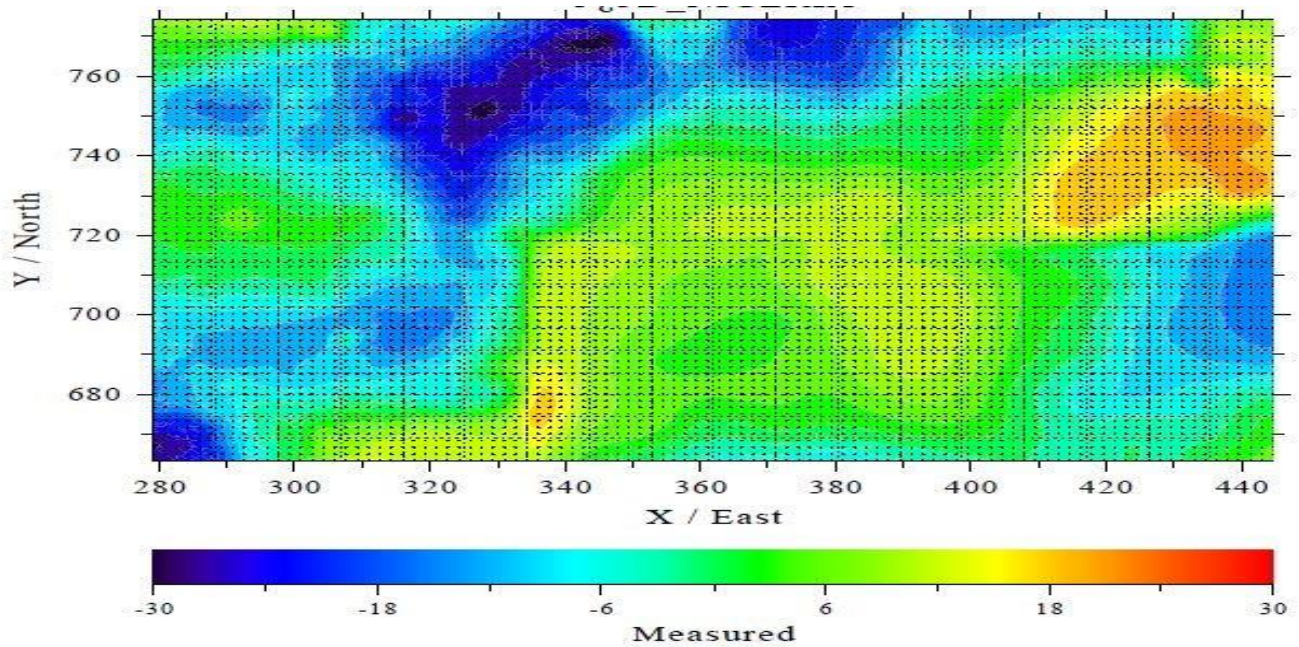


Figure 9a: Measured Density Optimization

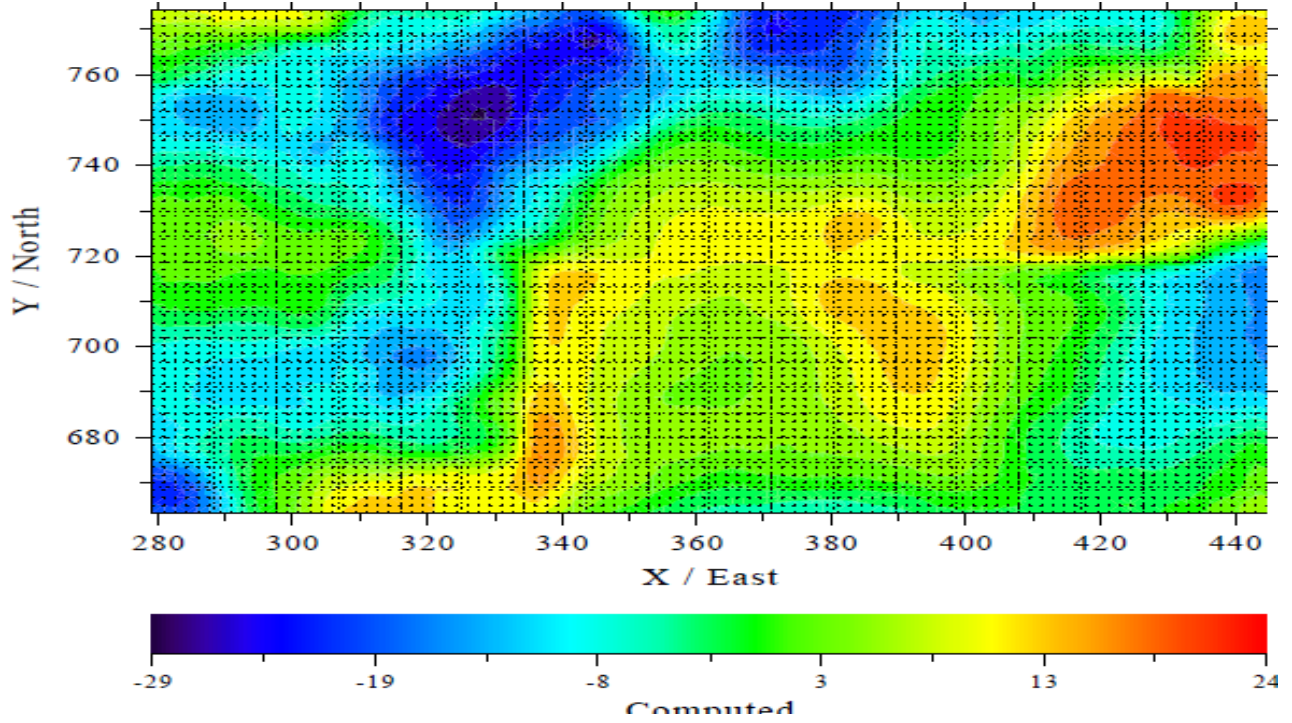


Figure 9b: Computed Density Optimization

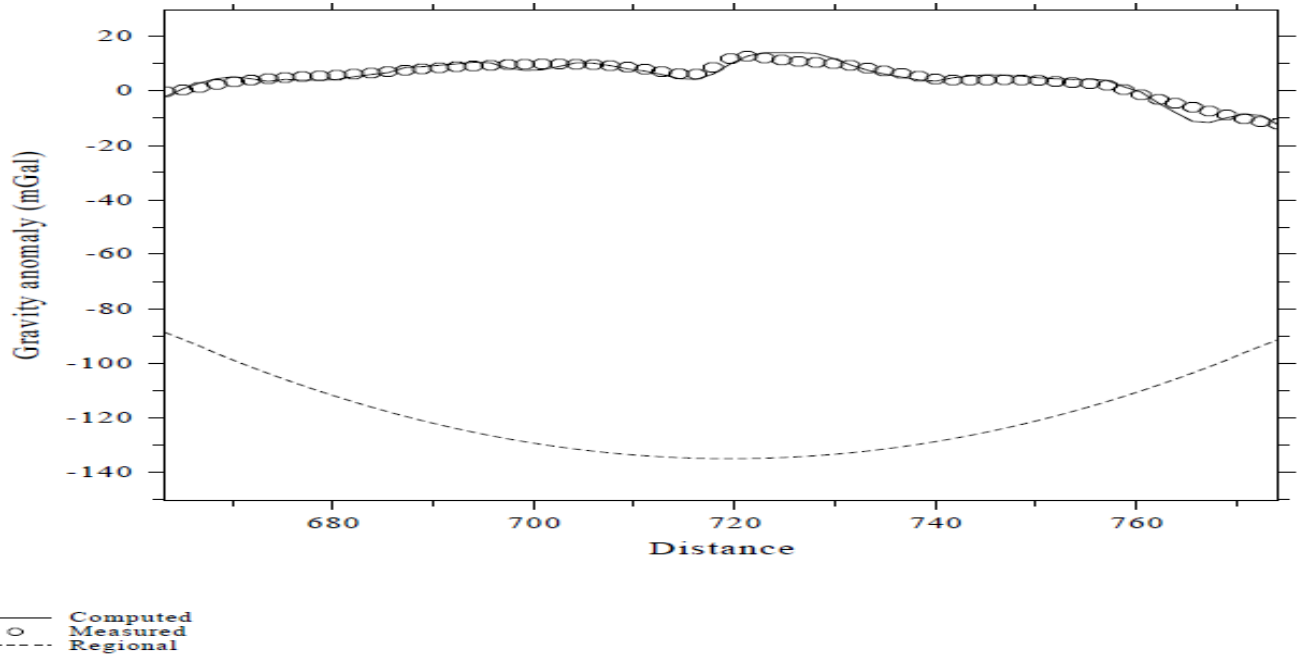


Figure 9c: Profile of Density Optimization

Occam d is an inversion that helps match measured and calculated density values (figures 10a, 10b, and 10c). The study area has a value of RMS 1% with a processing time of 30 minutes. After this, save the inversion data in the format (.inp) for readability in Bloxer 1.6 software which depicts the final model (figure 11).

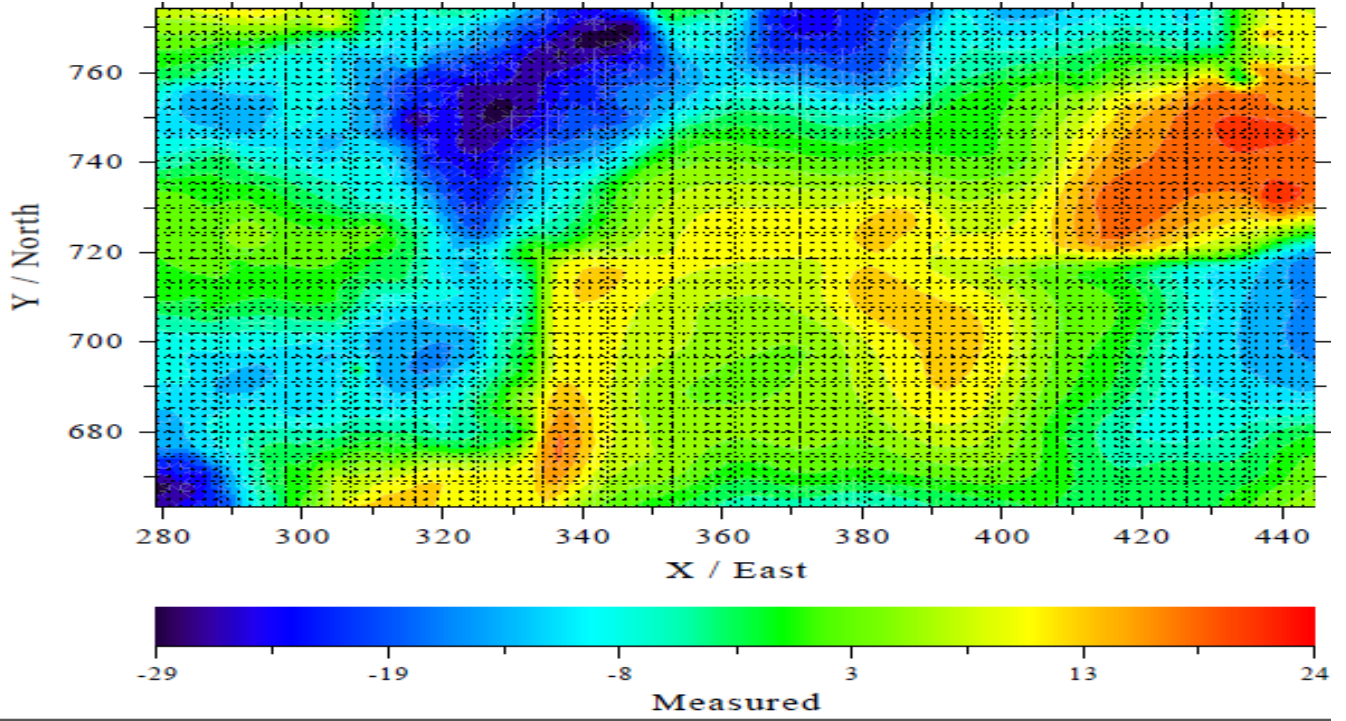


Figure 10a: Measured Occam d

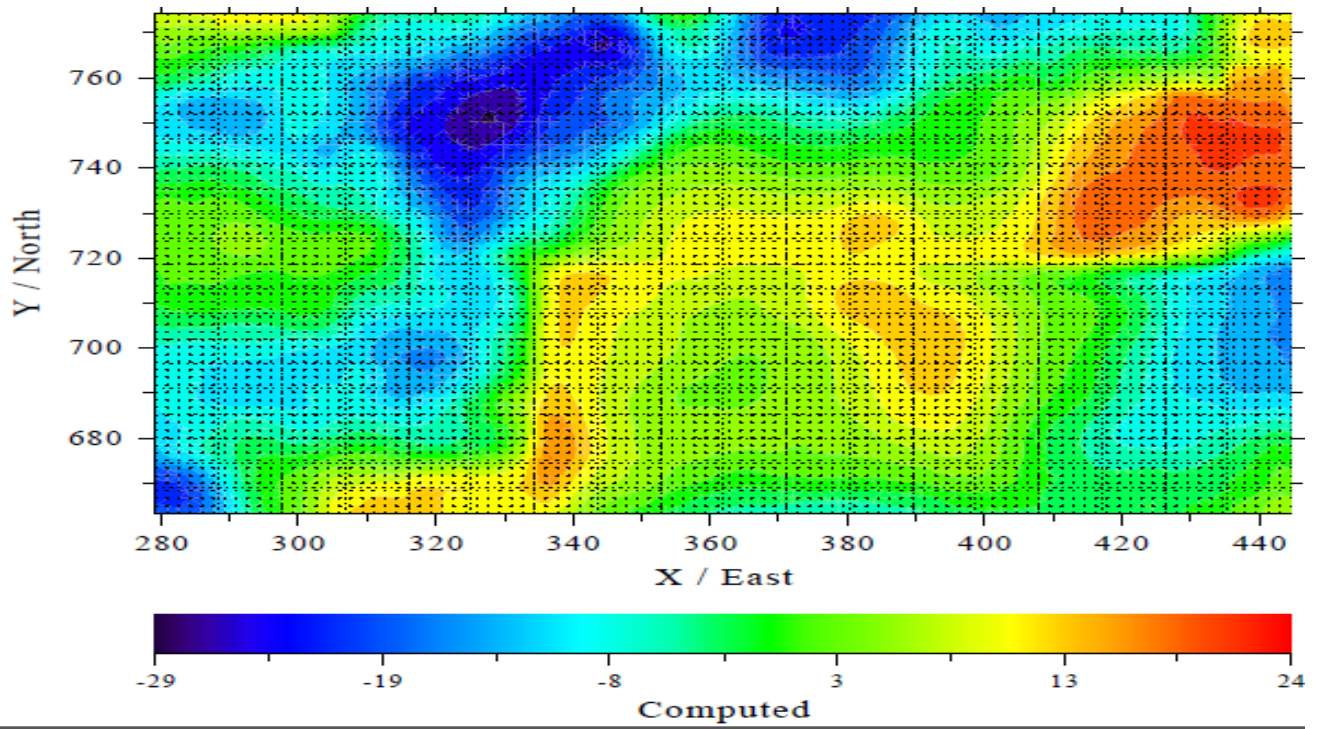


Figure 10b: Computed Occam d

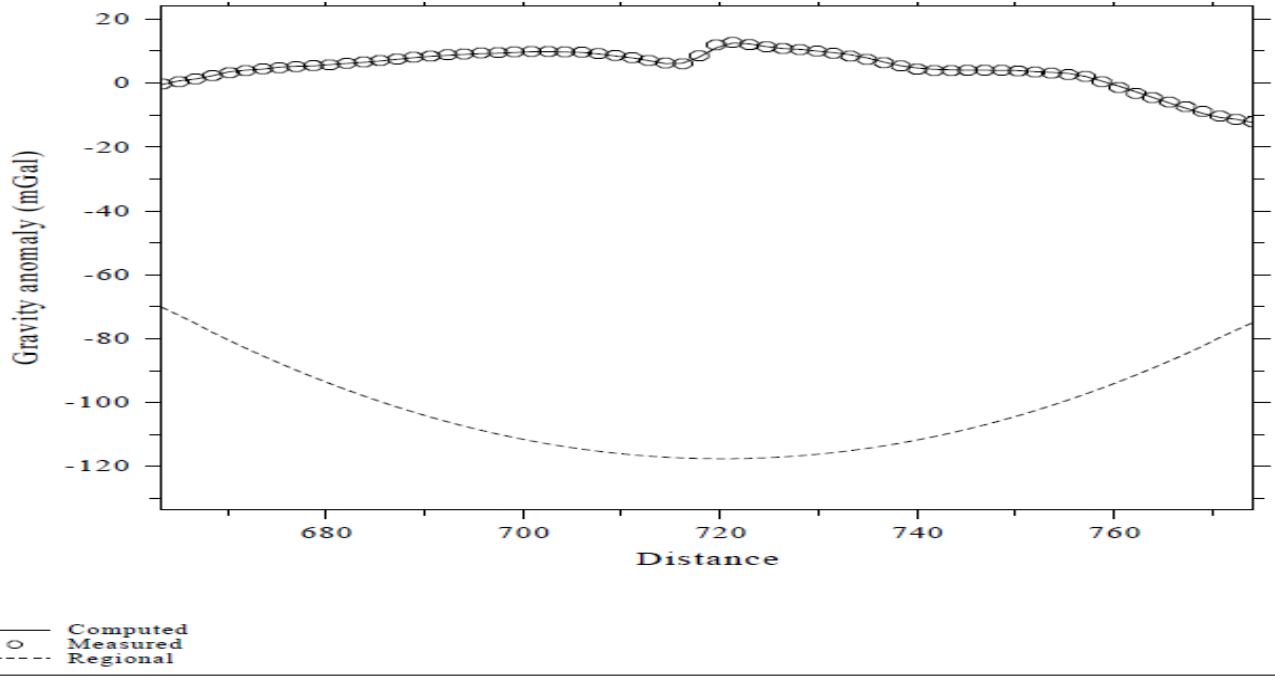


Figure 10c: Profile for Occam d

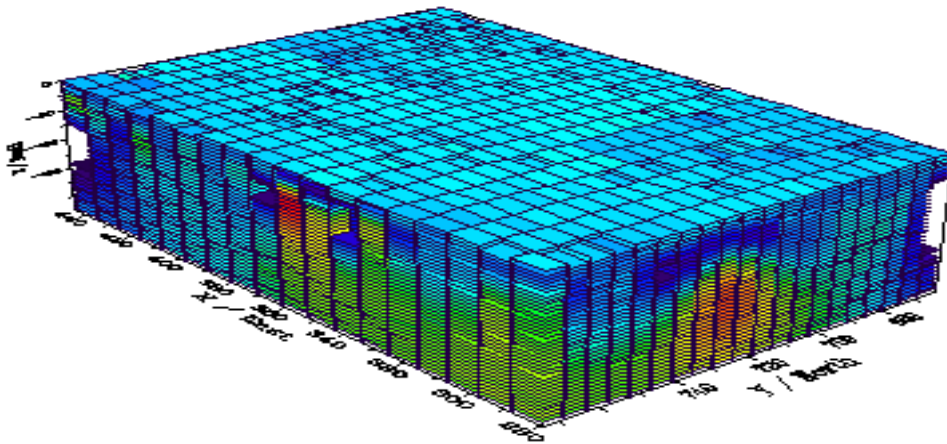


Figure 11: Result Model

The study area is an area with thick sedimentation; in areas with a thickness of 8 Km (figure 12), sedimentation uncovered in the region is likely a shale interspersed with sandstone with a medium density range of 2.30 - 2.75 g/cm³. In the areas with sedimentary thickness range of 10 Km to 15 Km (figure 13), existing rocks are changed into rocks with a high density of 2.92 - 3.12 g/cm³, where the possibility of rocks uncovered is granite rocks that serve as reservoir cover rocks. Reservoirs are revealed in this study; 2 large reservoirs located in the west and east with a high density of about 3.47 - 3.65 g/cm³, which is interpreted as a source of heat in the study area (figure 14). The heat source that can show the factors of sudden temperature changes.

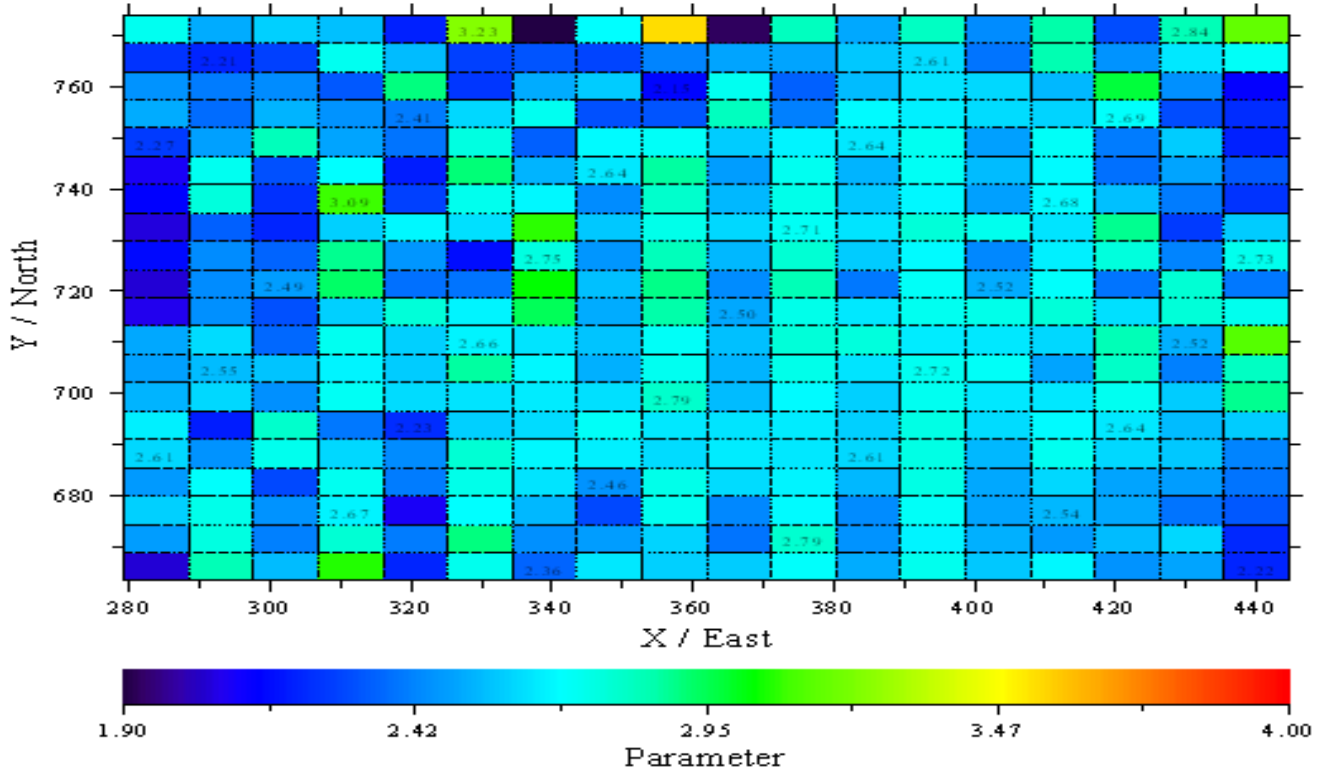


Figure 12: Slicing Z at a depth of 8 Km

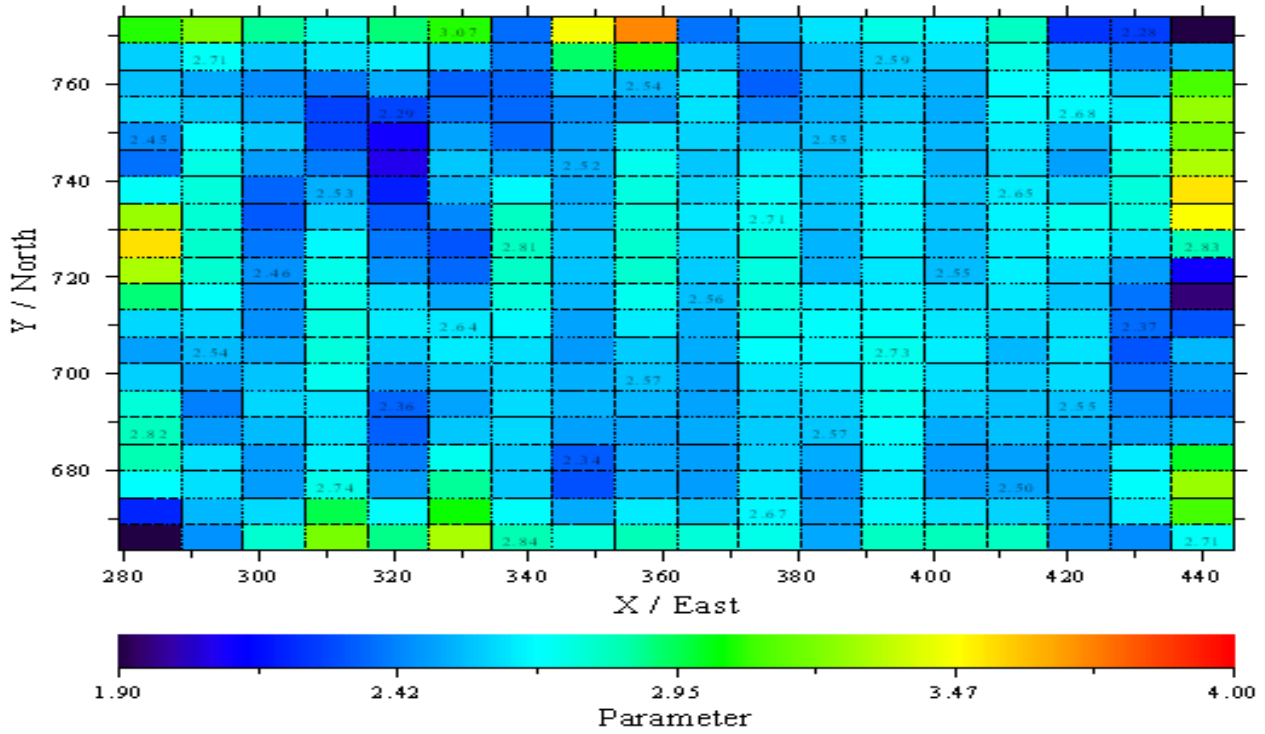


Figure 13: Slicing Z at a depth of 17 Km

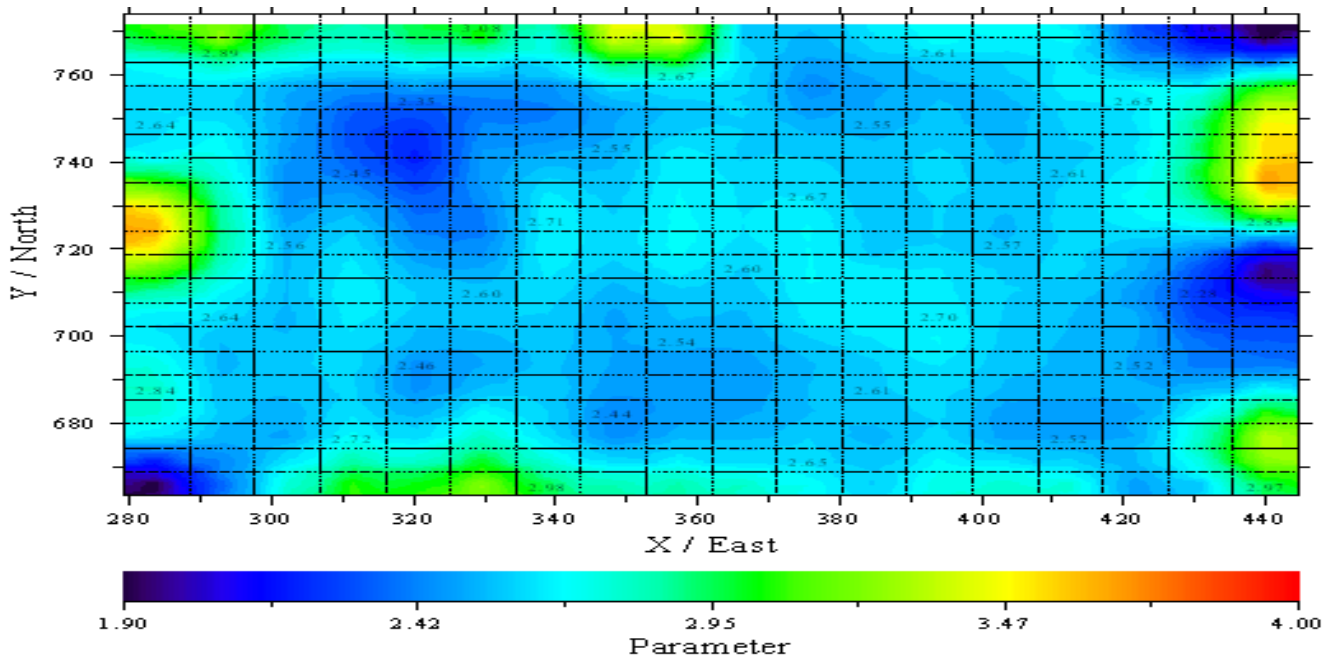


Figure 14: Slicing Z at a depth of 21 Km

On the east side, we can see a high anomaly covered with layers of granite and shale rocks. This high anomaly allows the presence of reservoirs in this section, the possibility of having two reservoirs (figure 15).

In the western region, we can see a reservoir zone larger than the east. This reservoir has a thicker portion of granite and shale cover than the eastern region. More details can be seen in figure 16.

Shifting to the north, it turns out that the reservoir in the west is associated with the reservoir in the northern region, and it can be concluded that the western to northern reservoirs have a very large reservoir coverage area in that part. It can be seen in figure 17, depicting the northern region of the model.

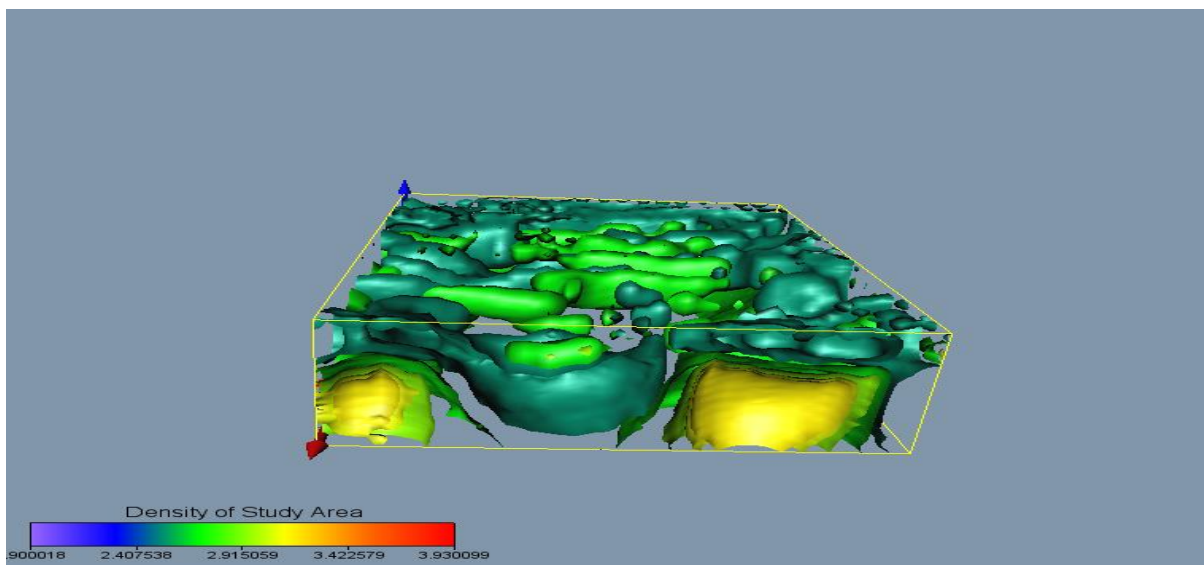


Figure 15: 3D Gravity Model (East Area)

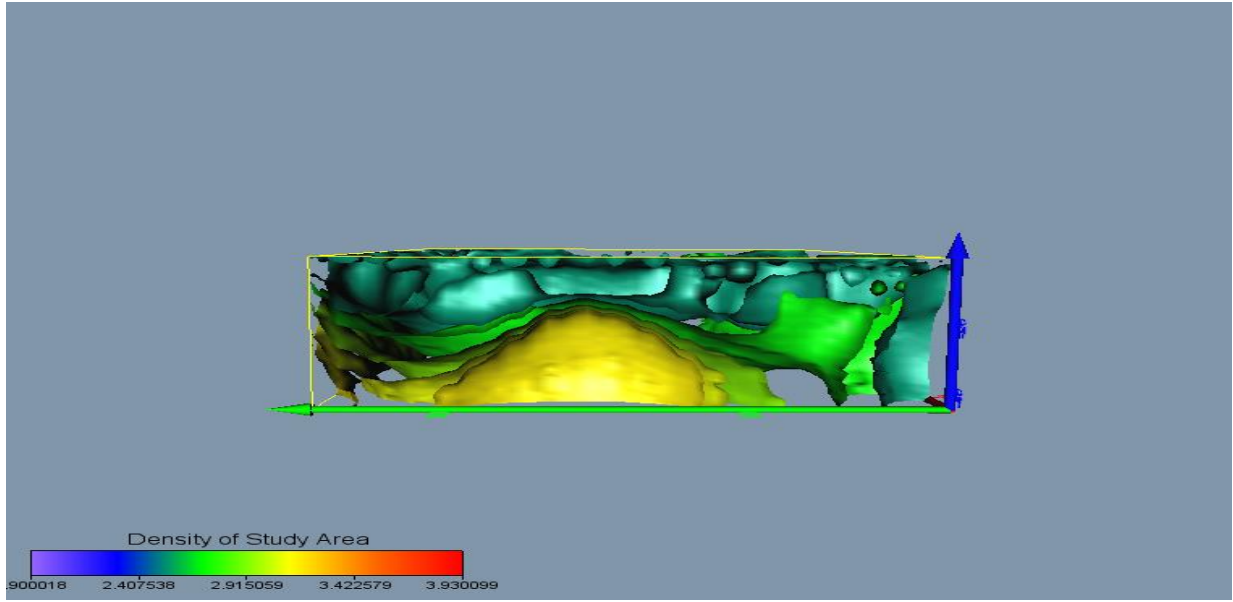


Figure 16: 3D Gravity Model (Westward)

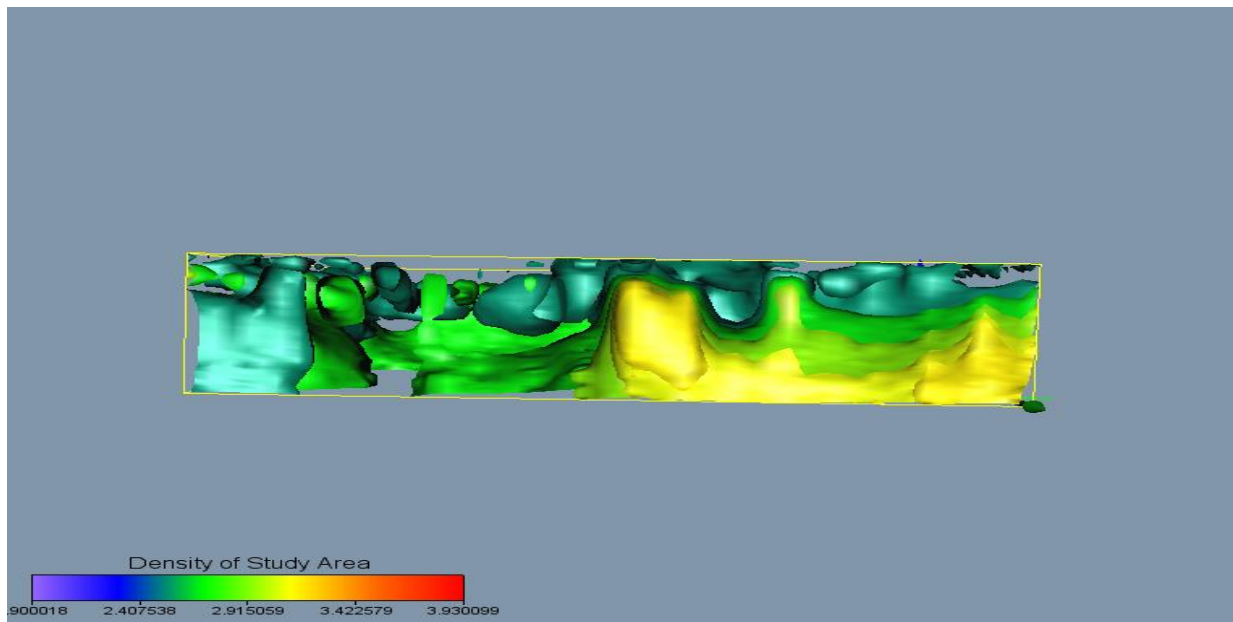


Figure 17: 3D Gravity Model (North Area)

CONCLUSION

The Model of gravity data revealed that areas with a sedimentary thickness of 8 Km, are likely a shale interspersed with sandstone with a medium density range of 2.30 - 2.75 g/cm³. In the areas with sedimentary thickness range of 10 Km to 15 Km, existing rocks are changed into rocks with a high density between 2.92 - 3.12 g/cm³, where the possibility of rocks uncovered is granite rocks that serve as reservoir cover rocks. Geothermal Reservoirs are revealed

in this study, 2 large reservoirs located in the west and east with a high density range from 3.47 - 3.65 g/cm³ are interpreted as sources of heat in the study area. The high density of about 3.47 - 3.65 g/cm³, which is interpreted as a source of heat, correlates with the areas with the highest gravity anomaly revealed around Igunamle, Abakaliki, and Ejekwe area predominantly as shown in figure 2.

REFERENCES

- [1] Encarta., Microsoft Encarta Student (2008). World Atlas.
- [2] Fullagar PK, Pears GA, and McMonnies B (2008). Constrained inversion of geologic surfaces—pushing the boundaries. *Lead Edge*. 1:98–105.
- [3] Hongzhu Cai, Bin Xiong, and Yue Zhu., 3D Modeling and Inversion of Gravity Data in Exploration Scale, *Gravity - Geoscience Applications, Industrial Technology, and Quantum Aspect*, Taher Zouaghi, IntechOpen, DOI: 10.5772/intechopen.70961.. (2017).
- [4] Pirttijärvi, M., GRABLOX 1.6, Gravity interpretation and modeling software based on a 3-D block model, User's guide to version 1.6, University of Oulu, Department of Physics, 60., (2008).
- [5] Pirttijärvi, M., GRABLOX2, Gravity interpretation and modeling software based on a 3-D block model, User's guide to version 2.0, University of Oulu, Department of Physics, 62 (2009).
- [6] Pirttijärvi, M., BLOXER, Gravity interpretation and modeling software based on a 3-D block models, User's guide to version 1.6, University of Oulu, Department of Physics, 54(2012).
- [7] Witter, J.B., Siler, D.L., Faults, J.E. and Hinz, N. H., 3D geophysical inversion modeling of gravity data to test the 3D geologic model of the Bradys geothermal area, Nevada, USA. *Geothermal Energy* 4: 14., (2016).