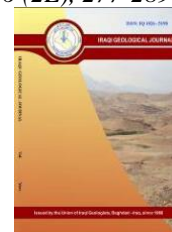




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Inverting Gravity Data to Density and Velocity Models for Selected Area in Southwestern Iraq

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Abstract

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The gravity method is a measurement of relatively noticeable variations in the Earth's gravitational field caused by lateral variations in rock's density. In the current research, a new technique is applied on the previous Bouguer map of gravity surveys (conducted from 1940–1950) of the last century, by selecting certain areas in the South-Western desert of Iraqi-territory within the provinces' administrative boundary of Najaf and Anbar. Depending on the theory of gravity inversion where gravity values could be reflected to density-contrast variations with the depths; so, gravity data inversion can be utilized to calculate the models of density and velocity from four selected depth-slices 9.63 Km, 1.1 Km, 0.682 Km and 0.407 Km. The depths were selected using the power spectrum analysis technique of gravity data. Gravity data are inverted based on gravitational anomalies for each depth slice or level and the extracted equivalent depth data from available wells using a connection curve between densities and velocities, which were mostly compatible with Nafe and Drake's standard curve. The inverted gravity data images highlight the behavior of anomalies/structures in the model and domain of density/velocity, which can be utilized in the processing of the recorded seismic data and time to depth conversion, in parallel with available well's data information within the intended study area of South-Western Iraq.

Keywords: Gravity data Inversion; Power Spectrum analysis; Density-Velocity Models; SW Iraq

1. Introduction

Many of the theories and notions proposed by geophysicists in the field of earth sciences were primarily intended to understand what is happening to the Earth's interior and surface related to processes and deformations (Sjöberg and Bagherbandi, 2017). The current study is dependent on the related potential topic, i.e., gravity data of the selected area in the southwest of Iraq within the provinces' administrative boundary of Najaf and Anbar. Several exploratory geological/ geophysical studies in several areas of central and south-central Iraq lack to provide a true/proper velocity model, due to the lack of velocity data and oil-wells drilled within these areas (Mazeel, 2010).

Due to the less clarity (blurry) in the background of structural and stratigraphic subsurface models, utilizing specific geophysical surveys and available well data/info, which is used as a control point will to assist a large extent in resolving various geologic problems (Bornatici, 2011). The gravitational method, which theoretically relies on variations in the densities of subterranean rocks, has usually provided (in several situations) important details about the geometry of fault systems, subsurface structures, basement rock's depth and sedimentary basins spread (Abdulrahim et al., 2022; Al-Khalidi

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et al., 2023; Carigali, 2004). In general, the residual procedure/analysis should be avoided in the Bouguer gravity network process, since the data is suitable for processing without external control (Blakely, 1996). Instead, the processing of gravity data using the analysis of Power Spectrum (PSA), will highlight the low and high amplitudes with the depth of the earth layers via behavior energy-decay curves (Chamoli and Dimiri, 2010). The regional-residual gravity of the Southern desert of Iraq (i.e., southern the current study area) has been studied and analyzed using the Empirical Mode Decomposition (EMD) of the multi-dimensional technique (Al-Bahadily and Al-Rahim, 2023), they referred that the regional structure of gravity anomaly was related to the deep-seated gravitational sources, while the residual anomalies separated to three residual maps according to the depths of these positive and negative gravity anomalies.

The current research is depending on inverting Bouguer gravity data to the density and velocity models for a selected area in the South-Western Iraq within the provinces' administrative boundary of Najaf and Anbar, i.e., to exploit the relationship between the density of rocks and the velocity for model of the gravity, i.e., values density model at first, afterwards invert the density data-model to the velocity model, in order to characterize subsurface features of the study area.

2. Location of the Study Area

The location of the area of interest is within the administrative borders of two governorates Najaf and Anbar, in South-western Iraq with a total area of 3554 Km², as shown in Fig.1. The study area location coordinates in the U.T.M. system are shown in Table 1.

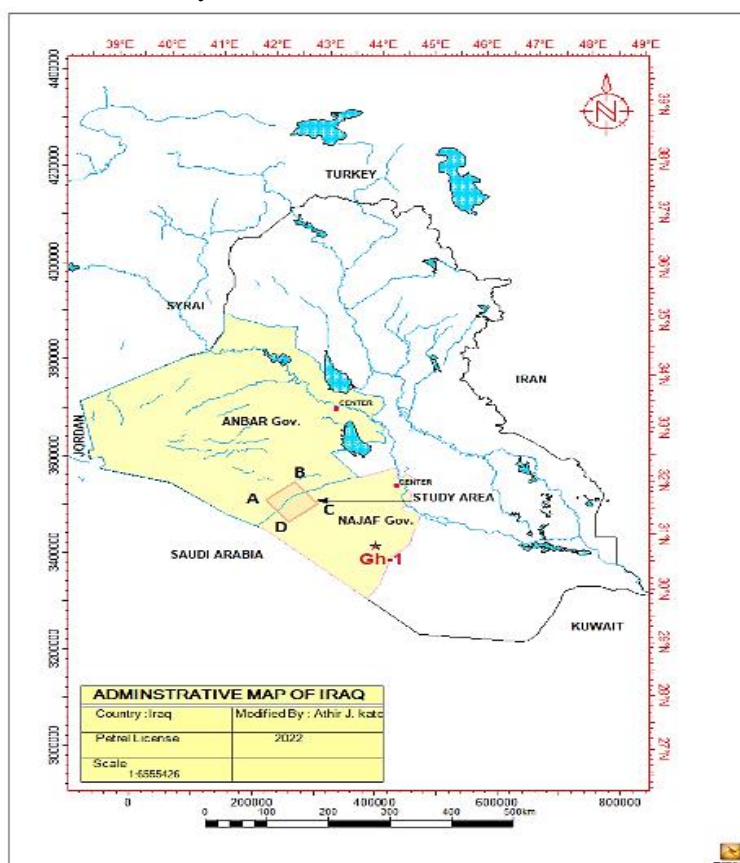


Fig. 1. The Map of Iraq with the site of the study area highlighted by the red square

3. Basement Rock Setting and the Stratigraphic Units of the Study Area

The basement rocks of the study area are completely dominated by low-density metamorphic rocks, i.e., phyllite-type rocks, as shown (green-colored rocks) in Fig. 2, according to Jassim and Goff (2006). To illustrate the stratigraphic unit's sequence within the southwestern desert area, the drilled oil well of Ghalaisan-1 (Table 2) was used to explain the relationship between velocity and density within the selected area of the south-western desert of Iraq (Al-Karadaghi, 2018).

4. Materials and Methods

4.1. Gravity Stations Base Map of the Study Area

The Bouguer gravity survey was conducted during the 1940 and 1950's according to the base map of measurement stations with different interval spaces between measurements (Fig.3). Following the area conditions, the study area was surveyed with 1 km space-interval between every two successive points (Getech, 2011). The main workflow chart of the current research is illustrated in Fig.4.

Table 1. The corner coordinates of the study area

| Point | East | North |
|-------|-----------|------------|
| A | 223598.48 | 3507588.42 |
| B | 270679.18 | 3545171.09 |
| C | 307688.70 | 3499318.59 |
| D | 260576.59 | 3461843.22 |

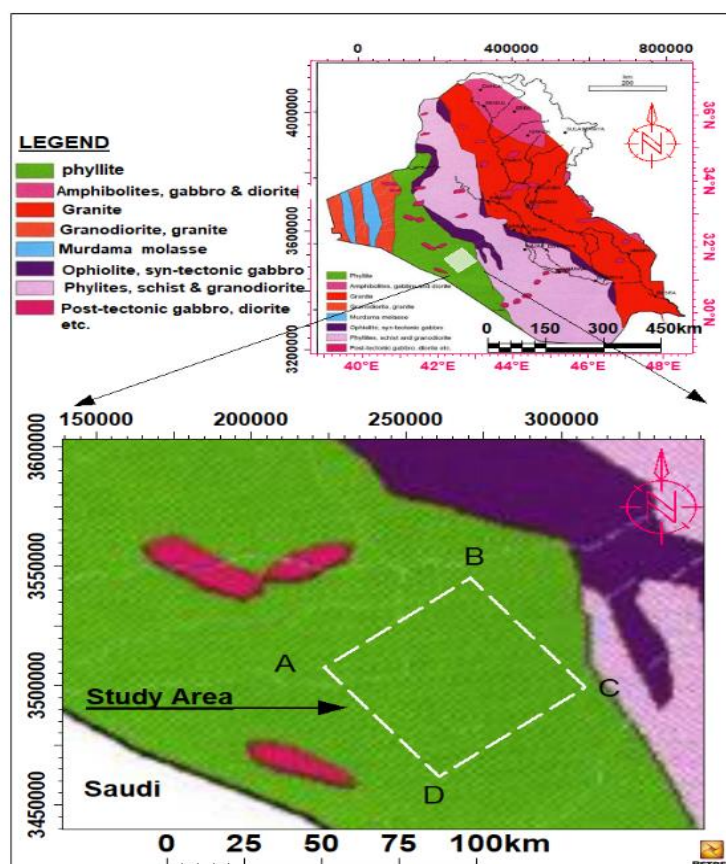


Fig. 2. The distribution basement rocks map of Iraq, the white-color square represents the study area, which is dominated by phyllite metamorphic rocks (after Jassim and Goff, 2006)

Table 2. The Stratigraphic units and their depths of the Ghanaian (Gh-1) oil well (Modified from Al-Karadaghi, 2018)

| Period | Epoch | Formation Name | Depth (m) |
|------------|----------------------|------------------|-----------|
| Tertiary | Eocene- Paleocene | Dammam | Surface |
| | | Umm Er- Radhumah | 114.5 |
| | Upper | Tayarat | 441.7 |
| | | Shiranish | 501.3 |
| | | Hartha | 641.5 |
| | | Saadi | 1010.5 |
| | | Tanuma | 1131 |
| | | Khasib | 1135.6 |
| | | Kifl | 1159 |
| | | Rumaila | 1169.4 |
| Cretaceous | Lower | Mauddud | 1317.5 |
| | | Nahr Umr | 1355.6 |
| | | Shuaiba | 1479 |
| | | Zubair | 1487.6 |
| | | Ratawi | 1727 |
| | | Yamama | 1793.6 |
| | | Sulaiy | 1815 |
| Jurassic | Upper | Gotnia | 1828 |
| | | Najmah | 1883 |

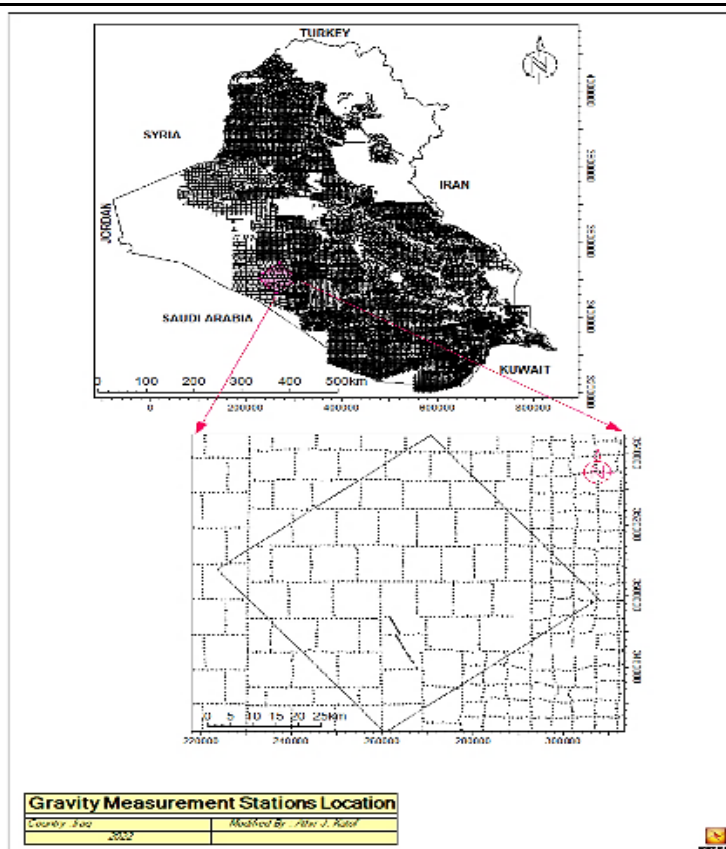


Fig. 3. The Map of gravity measurement stations of the study area (Getech, 2011)

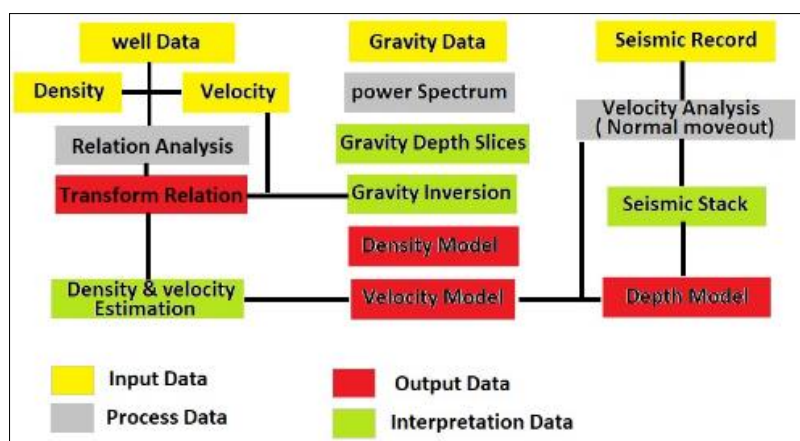


Fig.4. The Flow chart of current geophysics integration which is consisting of input data, processing, interpretation and output data

4.2. Analysis of Well Data and Estimate Density and Velocity Relation

There are several empirical relations illustrate the Seismic velocity (wave velocity) and Bulk density of subsurface rocks and materials (Brocher, 2005). Here are common relations and their equations which used the density (ρ) as a function of velocity (V_p):

Nafe and Drake's (1961) curve relation is:

$$V_p = A \times \rho^B \quad (1)$$

Gardner et al. (1974) relation is:

$$\rho \left(\frac{\text{g}}{\text{cm}^3} \right) = 1.74 V_p^{0.25}, \quad (2)$$

While Christensen and Mooney (1995) proposed relation is:

$$\rho \left(\frac{\text{g}}{\text{cm}^3} \right) = 0.541 + 0.3601 V_p, \quad (3)$$

And Godfrey et al. (1997) proposed relation is:

$$\rho \left(\frac{\text{g}}{\text{cm}^3} \right) = 2.4372 + 0.0761 V_p, \quad (4)$$

Where V_p in all mentioned equations represents the compressional wave velocity (km/s), ρ is the bulk density in g/cm^3 , and A and B in Eq.1 are the coefficients specific to the kind of rocks/materials being studied (Brocher, 2005).

Depending on a regional study area which has 24 wells, containing well velocity survey, and 14 wells containing density logs (e.g., Wk-1, Ak-1, Dn-1, Ek-1, Js-1, Rt-5, Ga-2, Kl-1, Me-1, Kf-4, Ad-1, Jr-1, Ns-1 and EB-1), as shown in Fig. 5. The curve of velocity data in wells represent the variants in velocities and density in intended well, the total relation curve between density and velocity in 8wells of total 14 well had highly matching with Nafe and Drake standard curve (red line) more than other curves, as shown in Fig. 6. By Adopting this relation for the 8 wells in the study area and using Nafe and Dark Equation (Nafe and Drake, 1961), we can calculate the estimated density and average velocity in the study area (Al-Banna and Al-Karadaghi, 2018).

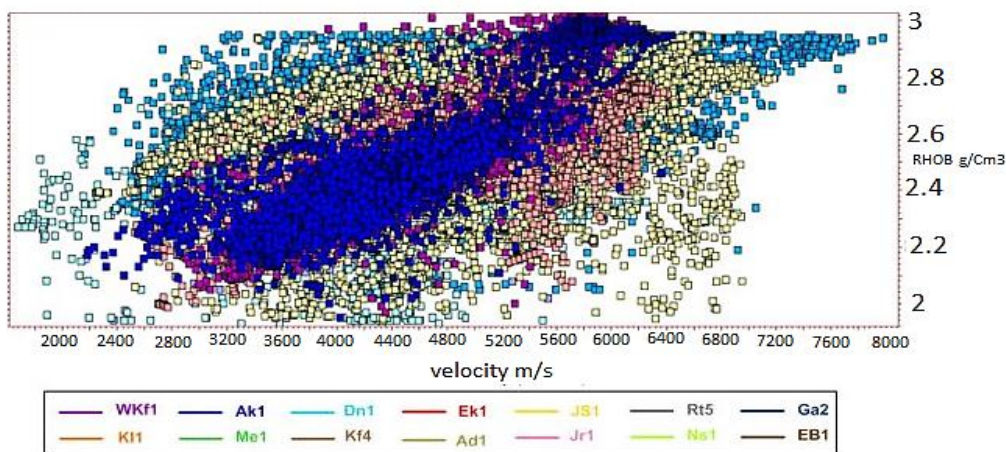


Fig. 5. The velocity values and the Density relationship within regional certain deep wells (Modified from Al-Banna and Al-Karadaghi, 2018), The colored dots represent scattering points showing the linear relationship between velocity and density within the fourteen wells used to derive the linear relationship in Fig. 7 (red color) to use the optimal equation (Nafe and Drake, 1961) in the conversion process

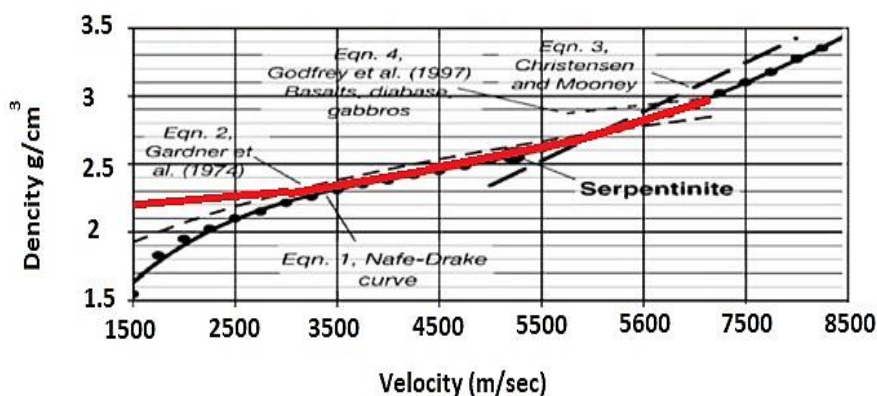


Fig. 6. The general behavior matching of Density and Velocity curves in eight regional deep-wells (In red) along the standard corresponding curve of Nafe and Drake (After Al-Banna & Al-Karadaghi, 2018)

4.3. Analysis of the Gravity Power Spectrum

In the power spectrum process, the high and low frequency and amplitude functions will be represented in relation to depths and distances and then will be reflected the details of anomaly distribution with the related depth (Maus and Dimiri, 1996). The procedure depends on using the gravity and magnetic software GETgrid (version 1.2), from GETECH (2003). In GETgrid software, we import the Bouguer gravity grid and analyze it into spectral gradients concerning amplitude and frequency values, as shown in Fig. 7. By taking the traces of a solid line for each component of the power curve; every line represents the variants of the frequency and amplitude (Barbour and Parker, 2015). Each one of the depth-slices will highlight anomalies with depth level, the deeper depth-level will reflect a high amplitude energy and low frequency, while the shallow depth-level is reflecting a low amplitude energy with high frequency (Jacoby et al., 2009). According to this process, the analyzed Bouguer gravity data will produce the dominant anomalies effects of four distinctive depth levels: 9630 m related to Basement Rock/beds, 1100 m represents the Saadi Formation (Upper Cretaceous), 682 m is the Hartha Formation (Upper Cretaceous) and 407 m depth represents the Tayarat Formation (Upper Cretaceous) (Fig. 8).

These mentioned depths are consistent with the subsurface geologic formations related to the stratigraphic depth units of the Ghalaisan-1 well (Al-Karadaghi, 2018) (Table 2).

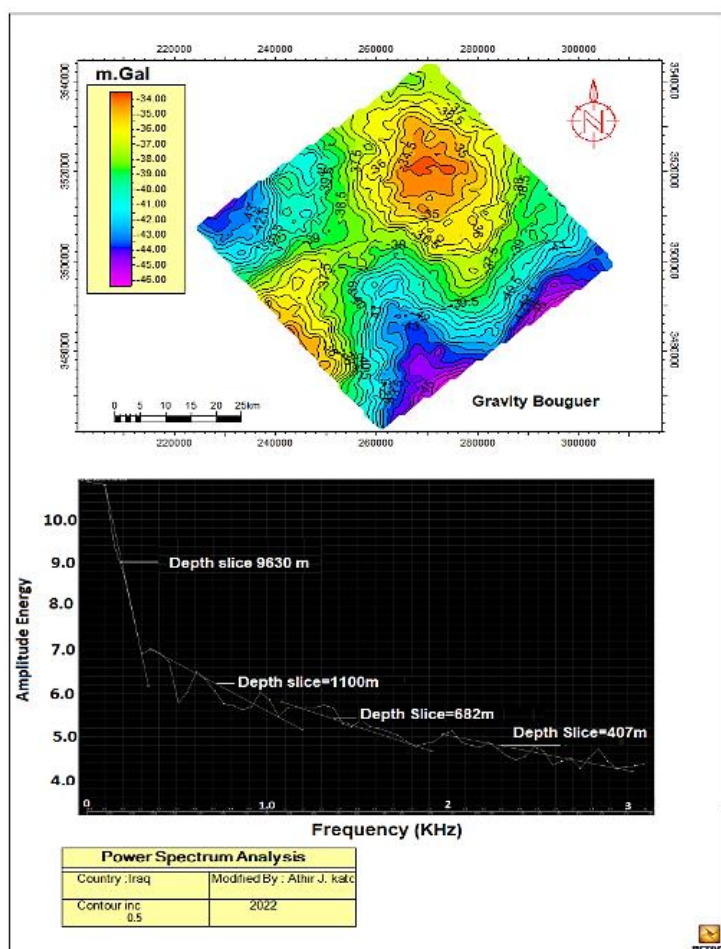


Fig. 7. The analysis of Power Spectrum of Bouguer data, the map shows the spectrum-curve of the high-low frequencies and amplitude variants

4.4. Modeling of the Density and Velocity

The Extraction or deducing of depth levels from Bouguer-gravity values even the depths and densities of subsurface Formations were estimated by using the curves of the relationship between density and velocity and their related depths, as mentioned before. The objective of modeling the density and velocity data construction is to put the slices effective for several functions' parameters, e.g., gravity, depth from slices, density in wells data at the relevant slice and the gross depth of model, the well info will use as a control point, to estimate an exact match of the true density at well sites (El-Khadragy et al., 2014).

In density deduced model, it can extract any depth surface/level, which is then displayed in the density domain. The process was conducted using the Fast Fourier Transform (FFT) method, the density model can be converted to a velocity model depending on the standard curve of Nafe and Drake (1961), as shown in Figs. 9 and 10.

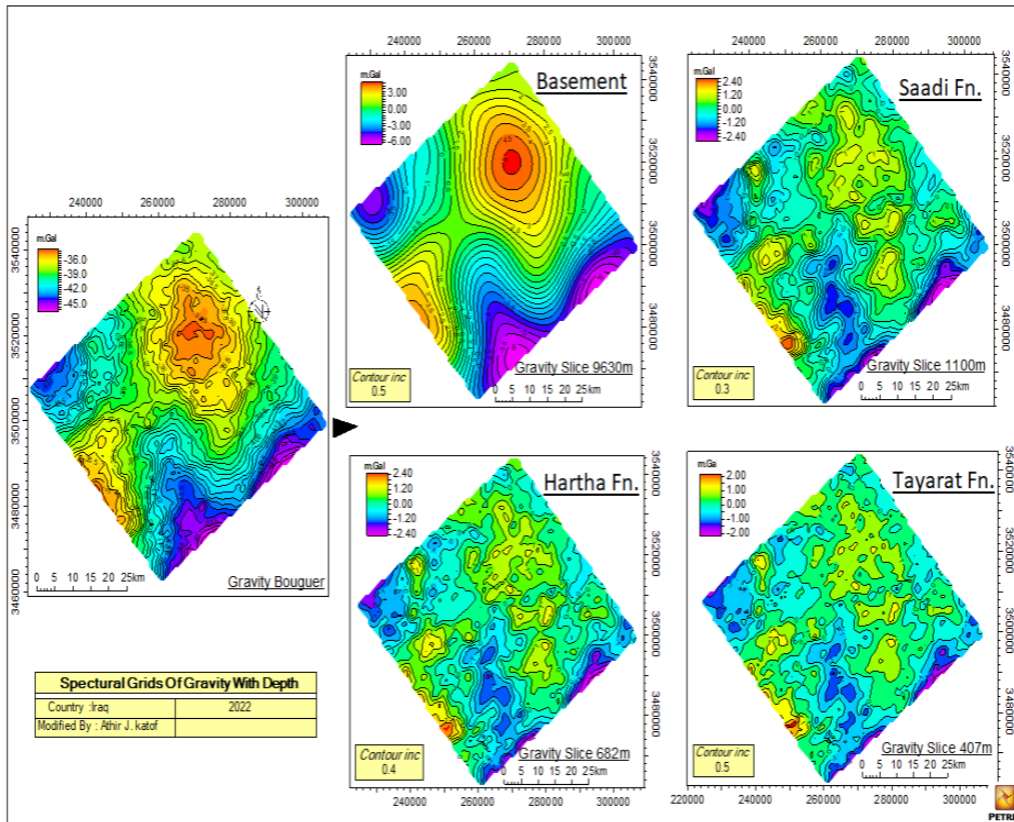


Fig. 8. The spectral grids of the effectively dominated gravity anomalies at different depth levels, i.e., Basement rocks at 9630 m, Saadi Formation. at 1100 m, Hartha Formation. at 682 m and Tayarat Formation. at 407 m depth, by applying the Power Spectrum Analysis to the gravity Bouguer data

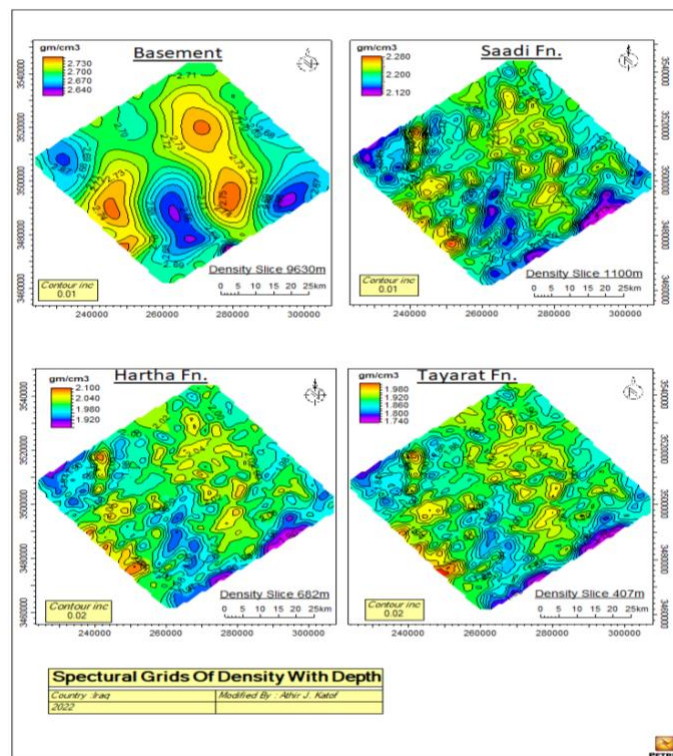


Fig. 9. The Spectral Density in a 2D surface-grid, built up using the Fast Fourier Transform method

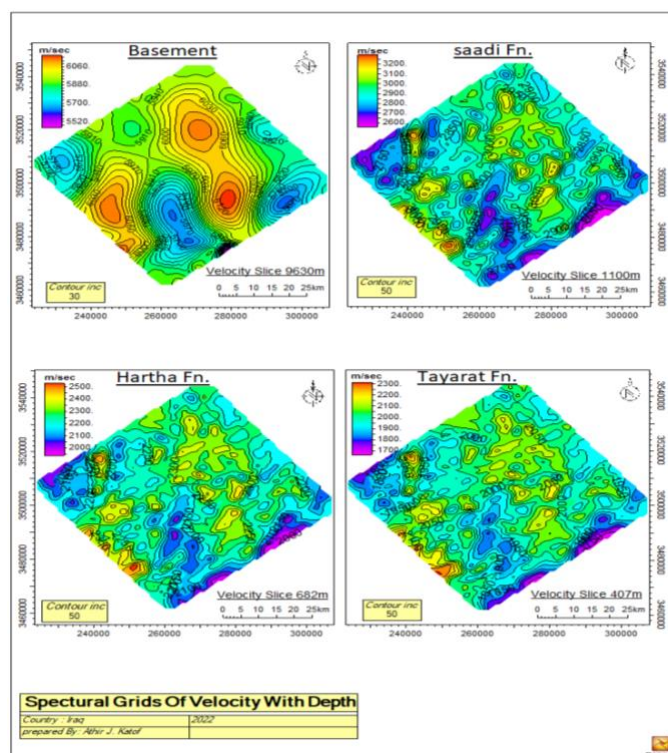


Fig. 10. The Spectral velocity in 2D depth-levels constructed using the curve of Nafe & Drake for data profile spectral of various depths

4.5. Geometrical 3D Modeling Conversion

The density and velocity values within the all-grid profiles have been interpolated to put available data over the entire 3D model. Determination and stochastic techniques are able for the deployment of continual properties, as a part of the geometric modeling processing, thus pre-set system variables may be used to create the estimated density and velocity models (Al-Banna and Al-Karadaghi, 2018). Every cell in the model will obtain a numeric value that fits the specific system variable. Depending on all resultant four subsurface-slices till 9630 m depth; the 3D cube of velocity in the Seg-y form will be generated.

The constructed 3D model of velocity can be utilized to process the measured seismic data/records, in addition, to use in the conversion of time to depth field (Fig. 11).

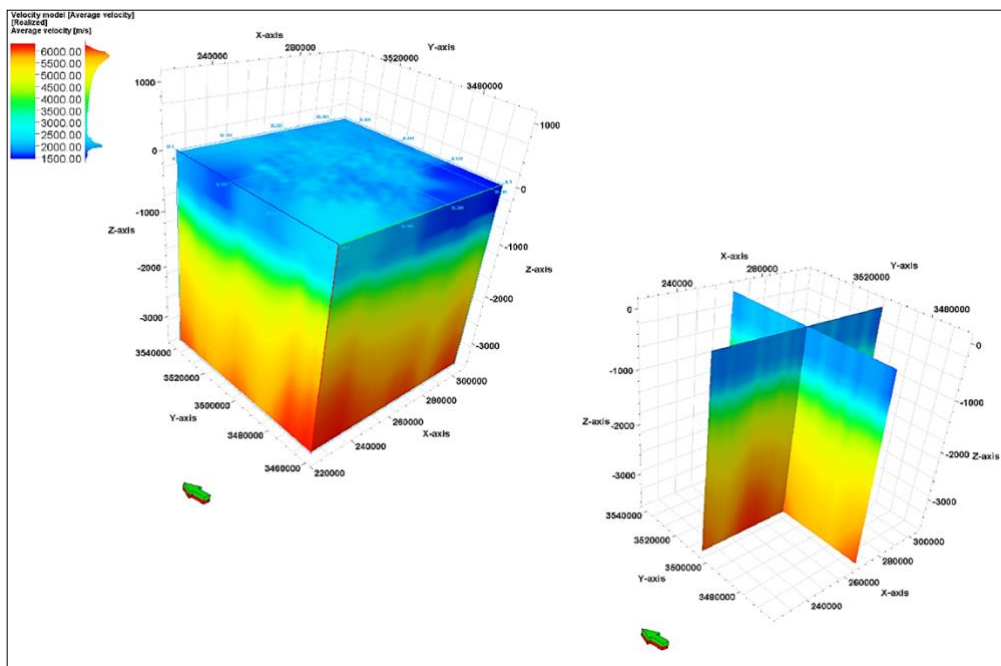


Fig.11. The 3D velocity cube (in Seg-y format) with the depth obtained after converting the model to the inverted velocity model derived from the gravity subsurface-slice

The 3D model of velocity was used to extract the velocity of 2D lines within the study area, which are matching with the supposed new seismic survey lines of the same selected area. The deduced 2D velocity (Seg-y) lines will be helpful in the processing of the 2D reflection seismic lines, as shown in Figs. 12 and 13.

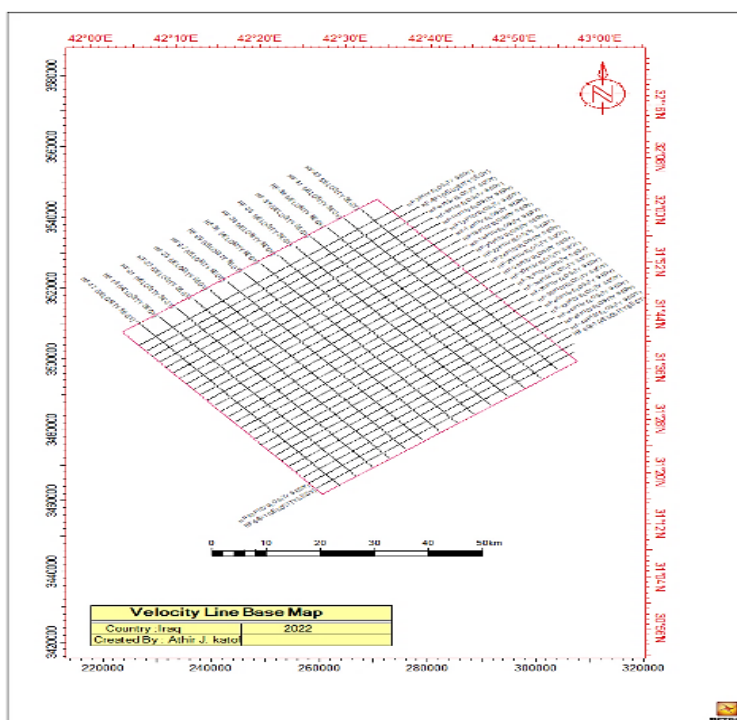


Fig. 12. The 2D velocity lines map which is extracted from the 3D estimated velocity cube according to the proposed 2D seismic survey lines

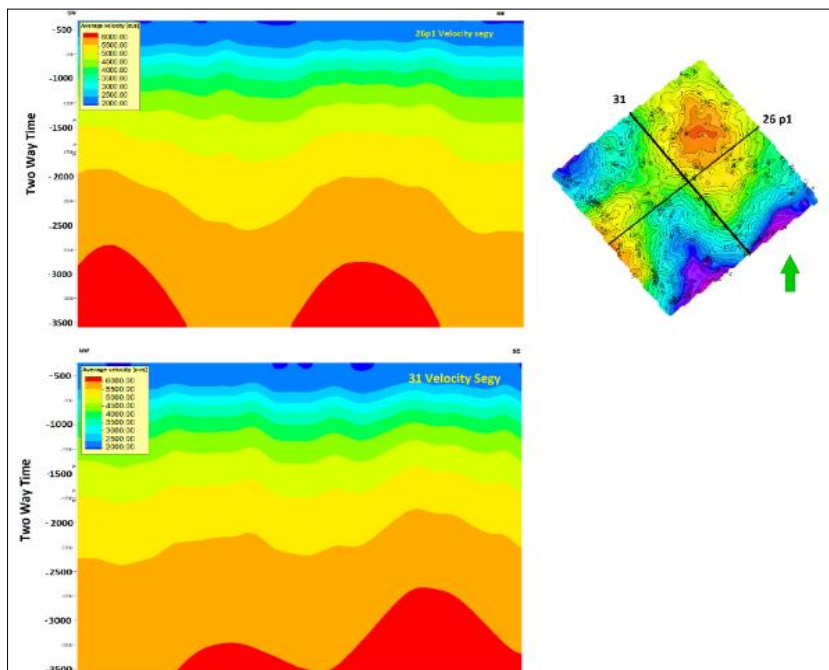


Fig.13. The 2D velocity line which is extracted from the 3D estimated velocity cube model with their location in the Bouguer map

It was applied with seismic velocity process as a Quality Control (Q.C) of velocity model which inverted from gravity (Horscroft and Bain, 2015). Through the processing works, the improvement was evident in the quality of the seismic signal of records after using the average velocities deduced from the gravitational data in the processing steps/process of seismic data, compared to the resulting quality after using the Root Mean Square (RMS) velocity process (Fig. 14A & B), which is illustrated that the technique is regarded as a preliminary procedure conducting by the Iraqi Oil Exploration Company (Al-Banna and Al-Karadaghi, 2018).

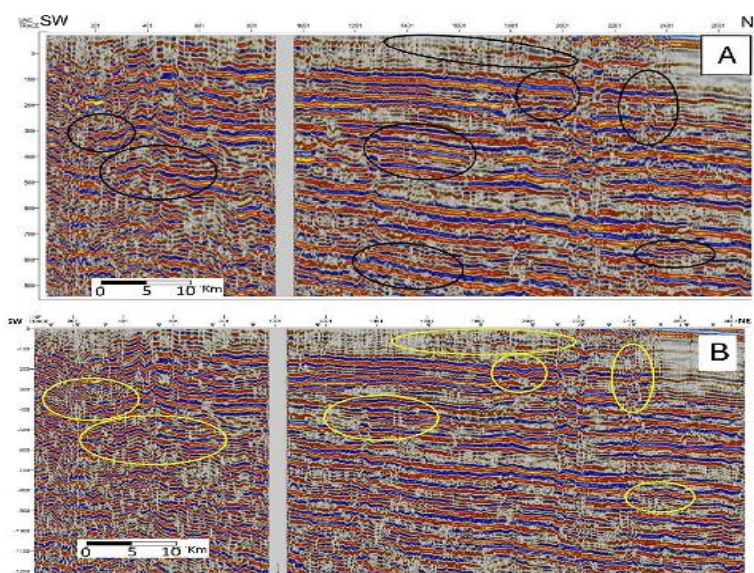


Fig. 14. The Seismic lines comparison of 7Gn – 16, concerning the results of the seismic processing section, using the velocity extract from gravity (Fig.14A), with a section of applying the RMS velocity (Fig.14B), the common improvements in the reflectors was highlighted by the black (a) and yellow circles (b) (after Al-Banna & Al-Karadaghi, 2018)

5. Conclusions

The current research which is dependent on the potential gravity data with the use of integrated geophysical applications, illustrated that:

Analysis of the power spectrum process is an analytical process to separate levels of gravity data with relevant depth in terms of amplitude and frequency changes, instead of estimating directly the depth-values.

The model of density estimation of gravity data illustrates an inverted gravity model depending on the data density of relevant wells as a preliminary model. In contrast, the Quality Standard (QS) factor of density distribution levels is dependent on the geometric model, i.e., overall model-depth, data-levels amount/density and the relevant corresponding depths.

This study illustrated the relationship transforms from the Density to Velocity covering the selected region of the southwestern Iraqi-territory, which corresponded generally with the standard curve of Nafe and Drake.

It is preferable to use velocity models resulting from gravitational data instead of RMS stack velocity models in processing the seismic records, due to the good results acquired on the seismic sections resulting after the processing. Furthermore, the Quality Standard (Q.S) was suitable for the proposed output velocity applied to seismic records, which reflected a clear improvement in record processing (e.g., the model extracted from the gravity data).

References

- Abdulrahim, H., Al-Naji, A.J., Sa'ad, R.Y., Al-Hussaini, B.S., 2022. Determining the tectonic implication derived from geophysical data of Bahr an-Najaf basin, SW Iraq. *Iraqi Geological Journal*, 55(1F), 40-46.
- Al-Bahadily, H.A., Al-Rahim, A.M., 2023. Analyzing the gravity field of the Southern Desert of Iraq with its possible geological implications using multi-bidimensional empirical mode decomposition technique. *Research Square*.
- Al-Banna, A.S. and Al-Karadaghi, S.S., 2018. Inversion to density and velocity model by integrated with wells data at regional area (central and Southwestern Iraq). *Iraqi Journal of Science*, 59(1A), 156-172.
- Alkhalidi, A.W., Al-Rahim, A.M., Mousa, A.S., 2023. Delineate the main structural trend in Anah and surrounding area, Western Iraq using Pie-slice technique on gravity data. *Iraqi Geological Journal*, 56(1B), 143-152.
- Al-Karadaghi, S.S.H., 2018. An Integrated Geophysical Study of the Najaf Region and Its Vicinity to Identify Hydrocarbon Reservoirs. Unpub. Msc., College of Science, University of Baghdad, Iraq.
- Barbour, A.J. and Parker, R.L., 2015. Normalization of Power Spectral Density Estimates. *Computers & Geosciences Research*, 34: 51-68.
- Blakely, R.J., 1996. *Potential Theory in Gravity & Magnetic Applications*. Cambridge University Press.
- Bornatici, L., 2011. Regional integrated interpretation, central north Gulf of Mexico. In *SEG Technical Program Expanded Abstracts 2011*, 2334-2338. Society of Exploration Geophysicists.
- Brocher, T.M., 2005. Empirical relations between elastic wave speeds and density in the Earth's crust. *Bulletin of the Seismological Society of America*, 95(6), 2081-2092.
- Carigali, G., 2004. *Geophysical Surveying Using Gravity*. Kursus ES304-Geophysical Prospecting.
- Chamoli, A., Dimri, V.P., 2010. April. Spectral analysis of gravity data of NW Himalaya. In *EGM 2010 International Workshop* (cp-165). EAGE Publications BV.
- El-Khadragy, A., Azab, A.A., EI-Khafeef, A. A., 2014. Contribution to the integrated interpretation of gravity, aeromagnetic and seismic data of the Northern and Central Parts of Sinai, Egypt. *World Applied Sciences Journal*. 31 (9), 1540-1551.
- Getech, G. plc. 2011. *Reprocessing, Compilation & Data Basing the Aeromagnetic and Gravity Data of Iraq*, Aeromagnetic and Gravity Data of Iraq. Kitson House, Elmete Hall, Elmete Lane, Leeds, LS8 2LJ, UK.
- Horscroft, T.R., Bain, J.E., 1996. Validation of seismic data processing and interpretation with integration of gravity & magnetic data. *Geological Society, London, Special Publications*, 99(1), 5-9.

- Jacoby, W., Smilde, P.L., 2009. Gravity interpretation: fundamentals and application of gravity inversion and geological interpretation. Springer Science & Business Media.
- Jassim, S.Z. and J.C. Goff., 2006. Geology of Iraq, Dolin, Prague and Monrovia Museum, Brno.
- Maus, S., Dimri, V., 1996. Depth estimation from the scaling power spectrum of potential fields. *Geophysical Journal International*, 124(1), 113-120.
- Mazeel, M.A., 2012. Hydrocarbon reservoir potential estimated for Iraq bid round blocks. *Oil and Gas Journal*, 110, 42-54.
- Nafe, J.E., Drake, C.L., 1961. Physical properties of marine sediments. Lamont Geological Observatory Palisadesny.
- Sjöberg, L.E., Bagherbandi, M., 2017. Gravity inversion and integration. Basel, Switzerland: Springer International Publishing AG.