Analysis of gravity and aeromagnetic data to determine structural trend and basement depth beneath the Ajdabiya Trough in northeastern Libya

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Abstract

In this study, we analyse both ground gravity and aeromagnetic data in order to delineate structural trends, fault systems and deduce sedimentary thicknesses within the Ajdabiya Trough in Libya's northeast. A high-pass filter and a reduced-to-the-pole (RTP) transformation are applied to the gravity and aeromagnetic data respectively. Different filters are used to enhance the structural signatures and fault trends within the study area. The Werner deconvolution and source parameter imaging (SPI) techniques are applied to the RTP magnetic data for source depth estimation. Four well-data within the area are used as constraints in the two-dimensional forward modelling process. The results show that the Ajdabiya Trough is characterised by gravity anomaly highs and magnetic anomaly lows. The analysis of gravity data shows predominant Northeast–Southwest structural trends, whereas the analysis of magnetic data shows predominant North–South magnetic lineaments within the Ajdabiya Trough. The Euler deconvolution depth estimates of faults depths range between 1500 and 9500 m. The SPI estimates of the magnetic basement range between 2500 and 11,500 m beneath the study area (deepest beneath the Ajdabiya Trough). Constrained by the well-data, six major layers characterize the four profiles that are taken within the area. One of the profiles shows a high-density intrusion (about 4 km from the surface) within the sedimentary sequence. The intrusion may be the result of the rifting Sirt Basin which caused a weakening of the crust to allow for mantle intrusion.

Keywords Ajdabiya Trough · Gravity and aeromagnetic · Structural trend · Basement

Mathematics Subject Classification 86A11

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1 Introduction

The Sirt Basin has been described as a triple-junction rift along the northern margin of the African crust in north-central Libya [1]. The structural features of the basin are largely due to tectonic interactions between the African and the Eurasian plates. The Ajdabiya Trough located northeast of the Sirt Basin is the youngest sedimentary

basin in Libya. The trough is believed to be the main depositor of the Oligocene and Miocene sediments [2] and expected to be one of the most promising areas for hydrocarbon exploration. According to [3], about 8500 km² due South of the Ajdabiya Trough is underexplored. This region is among the six underexplored basin centres with petroleum potential in Libya [3–5]. The structure and stratigraphy of central Ajdabiya Trough is poorly known because

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exploration activities around the trough focus mostly on the shallow basin flanks and adjacent platforms [6]. The complex geological setting, particularly to the North of the Ajdabiya Trough further complicates the present understanding of the structural trend. More so, there is little information about the deep structures which can play an important role in the geometry of potential hydrocarbon accumulation.

The study region spans latitudes 29.25°N–30.75°N and longitudes 19.55°E–20.75°E within which is the Ajdabiya Trough (Fig. 1). Integrating geological and geophysical data to determine nine facies of reservoir units southeast of the Ajdabiya Trough, Abdelnabi et al. [7] observed that faults mostly control the distribution and thickness of one of the reservoir units. A 3D (three-dimensional) seismic survey [8] showed a channel-like feature (of submarine origin) within the southern part of the trough (called the Intisar E field). Some pinnacle reefs in the Intisar complex contained hydrocarbon reservoirs while adjacent reefs are barren due to a cut in the channel that supplied carbonate debris in the late stages of the reefs' growth [8]. Submarine scouring caused turbidity currents through the channel that resulted in carbonate sedimentation in the hydrocarbon reservoirs [8].

That the accumulation of hydrocarbon can be controlled structurally (e.g. Abdelnabi et al. [7]) is an important justification to examine the structural trends by analysing

the available geophysical datasets. Hence, this study attempts to (1) obtain the structural trend and fault systems within the Ajdabiya Trough; (2) determine the depth to the magnetic basement beneath the trough. The depth of magnetic basement can help to calculate the shape of the sedimentary basin. Qualitatively, different filters will be applied to both the ground gravity and the aeromagnetic data over the study area to discern the structural trends, magnetic lineaments and to identify the fault systems. Also, quantitative analysis will be carried out to obtain a 2D (two-dimensional) model that best approximates the anomalies observed from the geophysical datasets.

Previously, numerous investigations, e.g. [1, 9–19] have provided information about the Sirt Basin but few published reports (based on the analysis of potential field data) focus on the Ajdabiya Trough. Recently in 2010, a qualitative subsurface investigation by Saheel et al. [20] concluded that different basement structure exists in opposite flanks of the trough. The study was however limited to the use of a few filters (only a high-pass filter at 150 km cut-off wavelength was applied to the gravity data while the total horizontal gradient was applied to both the gravity and aeromagnetic data). Later in 2011, using aeromagnetic data over the Sirt Basin, Saheel et al. [21] deduced different fault trends in the NE–SW, N–S and NW–SE directions within the trough and attributed the faults to different tectonic events within the basin. Using decompaction and back-stripping to quantify the tectonic subsidence of the trough, Ghanush et al. [6] reported that the subsidence brought a modification of a basin-style within the Cenozoic period in the form of convex-upward for a short and quick subsidence stage. Ghanush et al. [6] attributed the cause to the installation of Late to Early Eocene arrangements between 55 and 50 Ma. The basement subsidence curves for the Ajdabiya Trough [6] have a good correlation with the results of earlier studies e.g. [22–25]. More recently, [26] investigated the structure and stratigraphy of the Ajdabiya Trough using potential field and 2D seismic reflection data to identify predominant NW–SE fault trends (which penetrated the Cretaceous sediments) as well as NE–SW and E–W fault trends (that penetrated the Miocene and older strata). The faults [26] are several hundred meters apart with large throws on the Cretaceous and underlying horizons.

Fig. 1 Topography and bathymetry map of the study area showing the various troughs, platforms and the location of four oil wells (blue triangles)

2 Geological setting and basement structure of the study area

The Pan-African and Paleozoic structures (which make up the basement beneath Libya) trend in different directions and have a gentle to moderate dip to the southeast of Libya [10–27]. Although intrusive rocks have been

reported to form the widest segment of the crystalline basement series, e.g. [9, 27], the basement rocks of the Sirt Basin are considerably undifferentiated stratigraphy due to inadequate data. A simplified geological map of the Sirt Basin (Fig. 2) shows the different rock units within the region. From petrography related drilling and geochemical studies, pre-pan-African metamorphic rocks such as schists have been suggested to characterize the basement [28] due south of the study area. To the North of the Ajdabiya Trough, the basement contains mica-schists, graphite-mica-schist rocks [9, 29, 30]. These rocks were ranked lithostratigraphically to the Late Proterozoic and Cambrian [29]. The Ajdabiya Trough extends from the Kalanshiyu High in the South through the northern margin of onshore Sirt Basin to the Mediterranean Sea “off-shore Sirt Gulf” [31, 32]. Block faulting has been reported [10–27] along the NNW–SSE to NW–SE zone of weakness that cross-cut Paleozoic structures at a high angle but possibly parallel to some of the basement shear zones.

Discussing the four main phases (Late Jurassic to the Early Cretaceous, Late Cretaceous, Paleocene and Middle Eocene) of uplifting and subsidence within the Sirt Basin, Kassab et al. [33] reported active subsidence along

the NW trending structure within the Ajdabiya Trough which started in the Middle Eocene and continues till date. According to [26], variations in the sea level and/or sedimentation during Late Mesozoic and Cenozoic periods correlate with the seismic stratigraphy of the trough. Progradation of the Paleocene, Early and Middle Eocene sequences along the trough margin suggests rapid sedimentation with a slow increase in accommodation [26]. The 2D model [34] shows a major N–S trending strike-slip fault set, igneous intrusions and other structural elements beneath the Ajdabiya Trough. However, only a single profile was taken and with only one well data. More so, the model [34] did not explicitly discern the depth to basement around the trough which is part of the objective of this study.

3 Methodology

3.1 Data

Ground gravity survey data are obtained from the Libyan Petroleum Institute (LPI). The LPI collaborates with the

Fig. 2 A simplified geological map of the Sirt Basin showing the distribution of rock units and major structural elements (modified after [2]). The brown line shows the boundary of the Sirt Basin

Table 1 Formation tops of well data used in this study (Libyan National Oil Corporation)

Lithology	Well I1-6	Well A1-41	Well A1-119	Well E1-6
	Formation tops (m)			
Pliocene	100	–	–	100
Miocene	750	75	–	680
Oligocene	1800	1200	92	–
Eocene	2670	2840	1500	–
Palaeocene	3680	3920	2985	–
Mesozoic	4280	–	4000	–
Total Depth	4604	4179	4146	1200

Table 2 Rock densities used in 2D modelling [35, 36]

Unit	Density (g/cc)	Unit	Density (g/cc)
Pliocene	2.30	Mesozoic	2.50
Miocene	2.38	Paleozoic	2.54
Oligocene	2.40	Basement	2.67
Eocene	2.45	Intrusion	2.79
Palaeocene	2.48	–	–

Libyan Gravity Project (LGP) and the Libyan National Oil Corporation (NOC). The NOC obtains data from numerous oil and gas companies that operate in Libya. The gravity data consist of 74,520 data points taken at 1.0 km station separation across the study area. A reduction density of 2.67 g/cm³ based on the Geodetic Reference System 1980 (GRS 80) datum reference had been used to obtain the Free-air and Bouguer corrections. Latitude and terrain corrections had also been applied prior to obtaining the gravity data. The aeromagnetic data are obtained from the African Magnetic Mapping Project (AMMP). The AMMP is part of a worldwide collaboration between Peterson, Grant and Watson Limited (PGW, Canada), Getech (UK) and the International Institute for Geo-Information Science and Earth Observation (ITC, in the Netherlands). Flight lines and data points along each line are both 1.0 km apart. About 22,270 magnetic data points are obtained from 113 flight lines in the E–W direction. Well-data from four boreholes within the study area (Fig. 1) are used to constrain the 2D models. The NOC also provided the formation tops of the four wells—A1-119, A1-41, E1-6 and I1-6 (Table 1). The rock densities used in this study are estimated from both borehole data and rock densities (Table 2) that have been measured [35, 36]. A total of nine continuous density well logs and 781 core samples from 31 wells have been used to determine the rock densities for the whole of Libya [35, 36].

4 Data analysis

All applicable corrections had been applied to the gravity data from the LPI, such as Drift, Latitude, Free-Air, Bouguer and terrain corrections. The AMMP took aeromagnetic data points at 1.0 km grid and a constant 1.0 km terrain clearance with the appropriate corrections (e.g. diurnal, geomagnetic corrections). The raw data show Bouguer anomaly lows and highs as well as magnetic anomaly lows and highs with respect to their background values within the study area. The Oasis Montaj software provided by the LPI is used to analyse both the gravity and magnetic data. The “minimum curvature” gridding is applied to the data points. A high-pass filter is applied to the gravity data to obtain the residual gravity anomaly. In the process, cut-off wavelengths are gradually increased in multiples of 5 km. The 50-km cut-off wavelength produced the smoothest regional trend. To minimize polarity effects, a reduction-to-the-pole (RTP) filter is applied to the magnetic data. The RTP filter restores the spatial shift in the peak of anomalies caused by the vector nature of the magnetic field and centre them to be on top of the causative anomalies. The RTP process assumes uniformity in the direction of magnetisation throughout the causative body and a uniform geomagnetic field throughout the study region which may not be accurate for large areas [44]. The ambient magnetic field taken at coordinates 20.00°N and 30.25°E within the study area is calculated from the IGRF formula (2008) to have an inclination of 42.6°N and a declination of 1.46°E.

The flow chart (Fig. 3) illustrates the entire process in this study. Enhancement techniques such as the total horizontal gradient (THG), e.g. [37, 38], tilt angle derivative (TAD) [39] and the Centre for Exploration Targeting (CET) grid analysis [40] are applied to both the residual gravity and RTP grids. The THG method has low sensitivity to noise in datasets because only the two first-order horizontal derivatives of the field are required [41]. The TAD method normalises the ratio of vertical and the total horizontal derivatives of the grid. The CET grid analysis identifies the density discontinuity using a combination of texture analysis and bilateral symmetric feature detection. The CET operation calculates the standard deviation of the data values at each location in the grid. Compared with the background signal, a highly variable computational value suggests the presence of significant features.

Furthermore, the 3D Euler deconvolution (ED) method (applied to both the gravity and magnetic anomaly grids) is used to estimate fault depths. The ED uses the first vertical derivatives in three dimensions (*x*, *y*, and

Fig. 3 A flow chart of the methodology used in this work

z) to determine location and depths to anomalous targets. The ED technique estimates the source location of the causative anomalies by assuming the type of body which is defined by a specified Structural Index (SI) prior to computation. A window size of 8 by 8 cell units and a maximum depth tolerance of 18% is used for both grids. Following the recommendation of [42], the SI is set to 0 for gravity and 1 for the magnetic grids. The Werner deconvolution (WD) [43] and the Source Parameter Imaging (SPI) techniques [44] are applied to the RTP magnetic anomaly grid to estimate the depth to the magnetic basement. The WD is a 2D-based profile method which assumes that the magnetic source is also 2D. With this assumption, the horizontal derivative of the magnetic anomaly can be calculated for the observed profile. The SPI technique (sometimes referred to as the local wave number method) is based on the relationship between the source depth and the local wave number (K) of the analytic signal of the observed field [44]. The SPI method is independent of remanent magnetization or other magnetic parameters like inclination, declination, dip and strike. However, the SPI method requires the first- and second-order derivatives of the magnetic field (to obtain the first- and second-order wave numbers), which can amplify noise in the data and be affected by interference. After the application of the above stated techniques, the resulting grids are exported from the Oasis Montaj software and the Generic Mapping Tools (GMT) version 6.1 software [45] is used to visualize all but the ED grid which was difficult to extract from the Oasis

Montaj software as a comma-separated-value (csv) file. Instead, the Surfer v16 software is used to visualize the exportable ED grid file format.

For modelling purposes, four long profile lines are taken across sections of the study area. The profile lines are labelled from letter **A** through **D** (Fig. 4). Three of the profile lines (**A**, **B** and **C**) are taken across the Ajdabiya Trough in the E–W direction while profile **D** is taken in the SE–NW direction. The 2D forward modelling [46, 47] is applied to both the residual gravity anomaly and the RTP grids. Magnetic anomalies (Table 3) are obtained based on the formulation by [48]. The profile ends are extended to avoid edge effects. The geological models across the study area are created by the GM-SYS profile modelling extension of Oasis Montaj. The GM-SYS allows for the creation of a model and to perform validation test on the potential field responses to the observed measurements.

5 Results

5.1 Bouguer and total magnetic intensity anomaly maps

Bouguer gravity anomaly highs (GAH) trend mainly NW–SE (Fig. 4a) while magnetic anomaly lows (MAL) trend predominantly NE–SW and N–S in the central part of the study area (Fig. 4b). The Ajdabiya Trough is characterized by GAH and MAL (Fig. 4a, b) respectively. To the East of the Ajdabiya Trough, part of the Amal Platform shows both GAH and gravity anomaly lows (GAL), as well as MAL which gradually increase southwards. The Assumud Ridge which is due South of the Ajdabiya Trough also shows GAH and MAL. The Jahamah Platform and the Hugfa Trough to the west and southwest respectively of the Ajdabiya Trough show GAL and magnetic anomaly highs (MAH) with respect to the background values. GAH and MAL characterise the Zelten Platform, southwest of the Ajdabiya Trough. The highest and lowest gravity anomaly values are around the Ajdabiya and the Hugfa Troughs respectively. On the other hand, the highest and lowest magnetic intensity anomaly values are southeast of the Ajdabiya Trough.

5.2 Residual gravity and reduction to the magnetic pole anomaly maps

The residual Bouguer anomaly map (Fig. 5a) shows similar GAH as Fig. 4a, trending NW–SE around the Ajdabiya Trough, but GAL is observed in the eastern section of the trough. Southwest of the trough, the Assumud Ridge and Zelten Platform are also characterized by GAH. Meanwhile, GAL and GAH characterise the Jahamah Platform.

Fig. 4 **a** Bouguer anomaly map, **b** total magnetic intensity anomaly map. In both maps, brown and blue colours represent anomaly highs and lows respectively. (Green lines **A–D** are profile lines for 2D modelling purposes)

Table 3 Magnetic susceptibility values used in the study [38]

Unit	Susceptibility (cgs)	Unit	Susceptibility (cgs)
Pliocene	0.0000025	Mesozoic	0.0000543
Miocene	0.0000047	Paleozoic	0.0000628
Oligocene	0.00000513	Basement	0.00438
Eocene	0.0000212	Intrusion	0.003
Paleocene	0.0000218	–	–

The GAL appears to widen within the Amal Platform. The GAH with NW–SE orientations around Ajdabiya Trough (Fig. 5a) may be referred to the Early Cretaceous. The RTP map (Fig. 5b) shows a broader MAH within the Ajdabiya Trough and bounded by MAH around the Amal and Jahamah Platforms. This steep gradient of magnetic anomaly refers to a strong NNW–SSE structural trend truncated by a N–S trend between the Ajdabiya Trough and the Amal Platform. The Hugfa Trough is characterized by both MAL and MAH. The Ajdabiya Trough shows MAL.

5.3 Edge detection and fault depths

The steepest portion of the magnetic anomaly is usually the effect of abrupt lateral change in rock properties at dipping contacts. The THG (of residual Bouguer anomaly grid) map accentuates the NW–SE structural trends within the Ajdabiya Trough (Fig. 6a). The THG (of the RTP grid) map (Fig. 6b) did not discern the magnetic lineament clearly around the Ajdabiya Trough but shows discernable magnetic signatures southwest of the trough. The TAD value is about zero near the source edges. A positive TAD value indicates a positive contrast of the causative source while a negative value is outside the source limits. The TAD (of residual Bouguer anomaly grid) map shows dominant trends (with positive contrast) in the NE–SW and NNE–SSW directions (Fig. 7a). On the other hand, the TAD (of the RTP grid) map shows a dominant N–S trend (with positive contrast) within the Ajdabiya Trough (Fig. 7b). The CET grid analyses of the residual Bouguer anomaly grid (Fig. 8a) and the RTP grid (Fig. 8b) show predominant NW–SE and N–S trending faults respectively around the Ajdabiya Trough. The reason for this trend is unclear. The NW–SE trending faults

Fig. 5 **a** Residual Bouguer anomaly map at 50 km cut-off wavelength, **b** RTP magnetic anomaly map

may have contributed to the development of the basement beneath the Zelten Platform and Hugfa Trough.

The Euler solutions (Fig. 9) corroborate the trends from the application of CET grid. The Euler solution map for gravity anomaly (Fig. 9a) shows NW–SE trending faults with depths ranging between 1800 and 7500 m while the magnetic counterpart (Fig. 9b) shows a wider range of fault depths (between 1200 and 9500 m). At these depths, the faults are expected to permeate the Cenozoic and Mesozoic sedimentary sections. This indicates a thick sedimentary sequence beneath the region. Areas within the Ajdabiya Trough show a depth range between 3500 and 9500 m with NNW–SSE trends.

5.4 Source depth estimation

The SPI map (Fig. 10) shows that magnetic source is deepest (more than 10,500 m) beneath the Ajdabiya Trough. The application of Werner deconvolution (WD) indicates the existence of an intrusive body beneath one of the profile lines (profile line **D**). The WD result shows both GAH and MAH southwest of the Ajdabiya Trough (black oval, Fig. 11). The causative body is estimated to be around 4000 m below the surface. The existence of this body

(assumed to be a dyke) is the result of volcanic activities that occurred during the Cenozoic.

5.5 2D forward modelling

Figure 12a–d shows the results of 2D forward modelling of the four profile lines (**A** to **D**) respectively. The magnetic susceptibility values used are based on the formulation by Clark and Emerson [48]. In Fig. 12a, Well A1-119 (4146 m deep) stopped in the Paleocene strata. Crustal extension at different times is believed to cause faulting represented by the three normal faults (F_1 , F_2 and F_3). The inferred blind faults appear to penetrate the sedimentary sequence with F_1 and F_3 truncating in the basement while F_2 ends in the Paleozoic strata. The faults have been identified by the Euler deconvolution solution map (Fig. 9a). The basement appears shallower on the western flank when compared with the eastern side of the Ajdabiya Trough.

Moving northwards from profile **A** the 2D model constructed along profile line **B** (Fig. 12b) also shows three normal faults (F_4 , F_5 and F_6) which may be a continuation of faults F_1 , F_2 and F_3 respectively. However, only faults F_5 and F_6 appear to reach the basement. On the left of the figure is Well I1-6 (4604 m deep) which ends

Fig. 6 Total horizontal gradient (THG) map of **a** residual Bouguer anomaly, **b** RTP magnetic anomaly

in the Paleocene strata. The basement along this profile appears relatively horizontal.

Further north from profile line **B**, the 2D model constructed along profile line **C** (Fig. 12c) traverses the less steep northeastern magnetic anomaly gradient of the Ajdabiya Trough seen in the TMI map. Well A1-41 (4179 m deep) starts from the Miocene strata. This is due to irregular sedimentation during the Miocene. The area was later eroded. Sedimentation during the Pliocene continued around Wells I1-6 and E1-6 but not around the region surrounding Well A1-41. Two normal faults (*F7* and *F8*) are inferred and the basement appears deeper on the East when compared with the West of the profile.

The 2D model (Fig. 12d) constructed along profile line **D** shows two faults *F9* and *F10* that reflect the movements within the crust. Rifting of the Sirt Basin caused extensional forces that weakened the crust to cause mantle intrusion observed as both GAH and MAH in

their respective maps. However, the high-density intrusion includes some modelling uncertainties and may be further modified. The intrusion which may be basaltic is the result of local uplifting during the Cenozoic [2].

6 Discussion

The gravity and magnetic maps indicate that the Ajdabiya Trough is characterized by elongated GAH that trend NW–SE and MAL that trend N–S, showing a strong correlation with the structural highs (associated with platforms) and the structural lows (associated with sedimentary filled troughs) known from drilling. The Ajdabiya Trough is flanked by gravity and magnetic gradients. The RTP magnetic map shows MAH to the East and West of the trough. The MAL observed within the trough is due mainly to the presence of low susceptibility rocks.

Fig. 7 Tilt angle derivative (TAD) map of **a** residual Bouguer anomaly, **b** RTP magnetic anomaly

It is important to emphasize that the terrain clearance of the magnetic data used in this study is 1 km. At this constant terrain clearance, closely spaced magnetic units within rocks may exhibit anomalies as single features or a continuous pattern. The horizontal dimension of an anomaly over magnetic sources increases in direct proportion to the terrain clearance. However, the interesting anomaly falls within a factor of five times the source-sensor separation and due to a large terrain clearance, the resolution of geological detail may be compromised by the horizontal component of the anomaly over all other compact magnetic sources [49]. The magnetic signatures are extended more in an E-W direction due to magnetic sources in low latitudes [49]. Fortunately, the E-W flight lines (which is nearly normal to the principal geological strike) are best suited for the region of this study.

The various enhancement techniques (THG, TAD and CET grid analysis) accentuated the structural and magnetic lineaments. This study obtains structural trends similar to

those obtained previously [34] and identified more fault systems. The gravity data analysis shows predominant NW–SE trending structures and inferred faults, whereas the analysis of magnetic data delineated structures and fault systems that are N–S predominantly. That lithological boundaries often follow boundaries in magnetic properties allow the trend in magnetic anomaly observed in this study to be associated with structural trends. The study area is characterized by fault systems along with subordinate faults of variable trends and strikes. These trends represent the faults that occurred after the Pan-African Orogeny. It is unclear whether the faults are connected with the N–S extensions along the edge of the Neo-Tethys [30, 50–52]. The NW–SE trending faults may have been reactivated during the Late Permian–Triassic and developed along a marginal zone of extended crust, partitioned by major Pan African NW–SE trending crustal fracture zones, e.g. [10]. This trend could also be related to a reactivated Hercynian or older basement structure [53].

Fig. 8 CET grid analysis maps of **a** residual Bouguer anomaly, **b** RTP magnetic anomaly

Fig. 9 Euler deconvolution solution maps of **a** residual Bouguer anomaly, **b** RTP magnetic anomaly

Fig. 10 Source Parameter Imaging (SPI) of RTP magnetic anomaly map showing magnetic source depth distribution across the study area

Shell company has drilled some wells, but details of these wells are not yet public knowledge [36]. Previous studies usually include the trough as part of a wider area of study. Recent studies in close proximity to the study area focus on reservoir formation or hydrocarbon potential, e.g. [32, 33, 36, 54]. However, [34] focused on the structure and stratigraphy of the Ajdabiya Trough which is mostly related to this study. Whereas [34] performed modelling of a single profile in the NW–SE direction to infer three faults, the modelling result of this study (along four profile lines in the E–W and SE–NW directions) identified several different faults. In addition to their trends, the depths of faults are estimated by the 3D Euler deconvolution. The faults inferred from this study penetrated the Cenozoic,

Mesozoic and Paleozoic strata, while the result of previous studies shows that faults ended in the Mesozoic strata.

In the light of newer techniques to analyse data, the results of this study are corroborated by different analytical techniques. For example, the RTP magnetic anomalies are corroborated by the CET counterpart; faults identified by Euler deconvolution show largely similar distribution with the CET anomaly map; fault lines from 2D forward modelling (Fig. 12) align very closely with the Euler deconvolution solution maps (Fig. 9). Unlike studies hitherto, e.g. [34], this study explicitly determined the basement depth beneath the Ajdabiya Trough from both the SPI technique and 2D forward modelling (which are very comparable). This study also determined an intrusion and estimated its geometry, while the previous study suggested intrusions based on magnetic anomalies and previous geological studies which are not based on techniques to detect the geometry of the magnetic anomalies.

The recent development of petroleum exploration relies on the re-examination of known hydrocarbon provinces. Improvements in quality and scope of relevant data have led to the identification of specific areas as important targets for further drilling. Preexisting high structural formation affected the spatial distribution of a reservoir located Southeast of the Ajdabiya Trough and faults are believed to control the distribution and thickness of another reservoir in the same location [33]. While the result of this study has provided more insight into the structure and fault distribution around the Ajdabiya Trough, the result of this study may also inform further studies related to exploration of the trough.

7 Conclusion

In this study gravity and magnetic data have been used to obtain the structural trends, direction and depths of faults, as well as depth to the basement within the Ajdabiya Trough. Structural trends control the oil and gas accumulations within the study area. A reservoir located southeast of the Ajdabiya Trough is believed to be structurally controlled by faults. The result of applying different enhancement techniques has been represented in different maps. The gravity and magnetic maps indicate that the study area is marked with elongated gravity anomaly highs (trending NW–SE) and magnetic anomaly lows (trending N–S), showing a strong correlation with the structural

Fig. 11 Werner deconvolution solution across profile line **D** showing the RTP curve (red line) and THG curve (green line)

highs (associated with platforms) and the structural lows (associated with sedimentary filled troughs). The maps show that Ajdabiya Trough is marked by a long wavelength gravity anomaly lows and highs flanked by steep gravity gradients which delineate faults along the edges. The varying anomalies are the result of different features with varying densities and magnetic susceptibilities. Analysis of residual gravity anomaly shows a NW–SE trending anomalous structure which may be the result of crustal extensions that occurred in the Early Upper Triassic to Early Cretaceous during different phases that formed the Ajdabiya Trough. The analysis of magnetic residual anomaly shows a group of faults with varying trends. These trends represent the faults that occurred after the Pan-African Orogeny. Fault depths range between 1800 and 9500 m.

The result of the Werner deconvolution shows that a high-density causative body is about 4000 m in depth. The depth to basement beneath the Ajdabiya Trough is about 11,500 m. The basement depth is corroborated by the result of 2D forward modelling which ranges from 9700 to 11,000 m within the trough. The 2D forward modelling profiles also show different faults that have penetrated the Cenozoic, Mesozoic and Paleozoic strata beneath the trough. These faults may be the consequence of tectonic events at different times and may play significant roles in reservoir formation within the Ajdabiya Trough. One of the profiles shows an intrusion into the sedimentary section of the area. This is attributable to volcanic activities in the study area.

Fig. 12. 2D models from both gravity and magnetic anomalies across four profile lines: **a** A(E–W, 70 km), **b** B(E–W, 93 km), **c** C(E–W, 58 km) and **d** D(NW–SE, 136 km)

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Compliance with ethical standards

Conflict of interest The authors report no conflict of interest.

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