Gravity and Magnetic Profile along Seismic Intersect Ku – 89 – 04, Southern Kufra Basin - Libya

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Abstract

The present work is designed to study the sedimentary cover of part of the Kufra Basin by means of potential field analyses and modeling. The basin has been poorly explored (geologically) mainly due to its remoteness, being at least 450 km from the nearest existing oil infrastructure (Sarir Oilfield), and because of the existence of two discouraging dry exploration wells drilled in the northern part of the basin.
In this study, approximately 350 km length of gravity and magnetic profile along seismic intersect Ku–89–04 has been constructed from an existing gravity and magnetic data set. The profile trends NNW from Jabel Nuqay in the west and terminates towards the Jebal Aweinat Massif located at the eastern part of the basin. The observed Bouguer gravity and magnetic anomalies from the produced maps and the constructed profile are composites of several anomalies with varying wavelengths. First, a regional trend in the Bouguer gravity is present, with generally more negative values to the northwest. This regional trend is likely a reflection of gradually thickening crust from southeast to northwest, or a gradual reduction in average subsurface densities, or a combination of both. High density light basement blocks are interpreted to be the source of the magnetic anomalies, these reflect the effects of variable magnetized igneous bodies. The depths to the top of the igneous bodies range from 3 km to 4 km. The profile shows that the sedimentary cover at this part of the basin causes a large negative anomaly in the Bouguer anomaly map. It reflects the distribution of thick sequences of Paleozoic rocks, and moderately thick Mesozoic rocks. The gravity and magnetic data in this case provides some insights into the early history of the basin, while the seismic data shows that the geometries in this part of the Basin are much larger and thicker. The model has shown flat, gentle strata thickening at the middle and it coincides with the interpreted seismic section. The modeling results also show a high correlation between the residual gravity, (reduced to pole residual magnetic) and the basement geometry, which suggests that the density and the magnetic content of the basement rocks are homogeneous. Locally, gravity and magnetic observations help constrain the interpretations of low density anomalies located at the western and the eastern ends of the profile. They may be associated with sedimentary bodies composed of clastic sediments ranging in age from Infracambrian to Cambro – Ordovician. The Modeling interpretations of the magnetic field constrain the depths and geometry of heterogeneous basement structures, including Precambrian and Paleozoic formations of variable density. Locally, the interpreted low density bodies and these basement structures may control the locations of prospective hydrocarbon traps in the southern flank of the Kufra Basin.

General Overview & Geological Background

The Kufra basin is situated on the South Eastern part of Libya (Fig. 1). The basin extends along Chad and Libyan borders, occupying a small part of NW Sudan and SW Egypt. It mainly consists of Mesozoic to Paleozoic medium to high grade metamorphic rocks. The basin forms an elongate depression oriented northeast – southeast, with an area of about 400,000 km². It coincides with a zone of crustal weakness known as the trans – Africa lineament which defines a region of a strike sleep movements between two crustal plates (southeast Africa and Arabian plate and northwest Africa plate) at its North Eastern end (Neev,1975; Nagy et al., 1976). The basin has been poorly explored (geologically) mainly due to its remoteness, being at least 450 km from the nearest existing oil infrastructure (Sarir Oilfield), and because of the existence of two discouraging dry exploration wells drilled in the northern part of the basin.

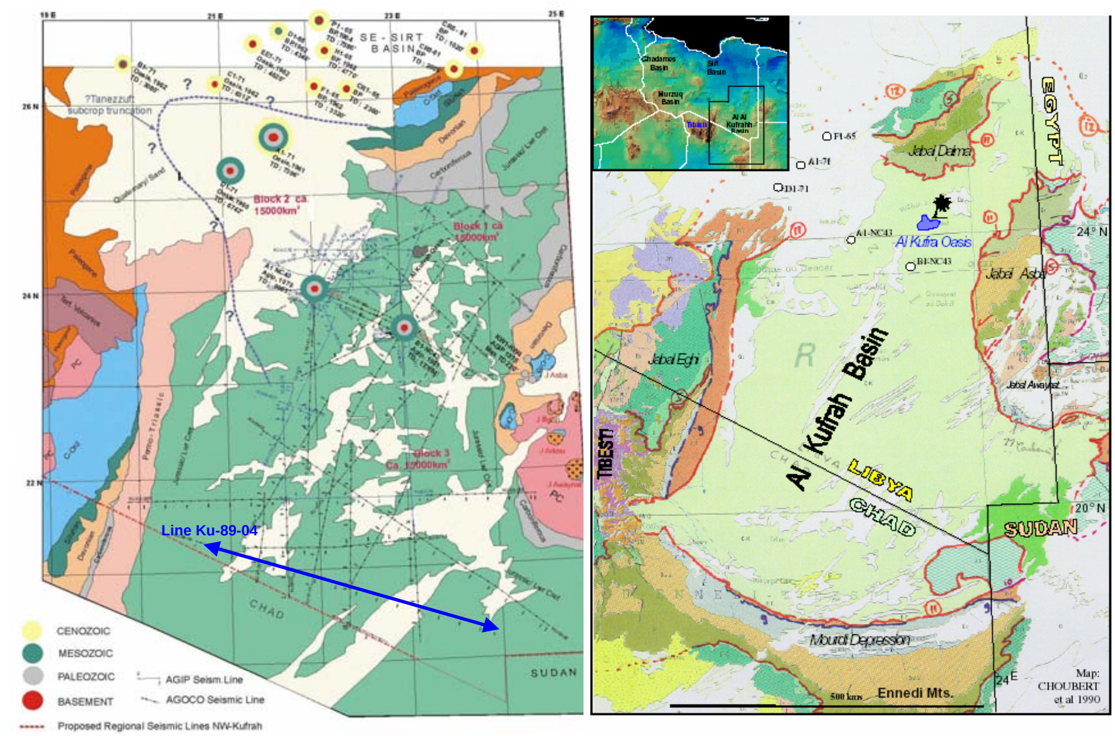

Figure (1) Simplified geological and location map of the Kufra Basin with its confining basement highs. Modified IRC Geologic Map 1:1000,000

The basin is bounded by four basement high structures, namely the Tibesti Massif (including Jebel Nuqay and Jebel Dohone) in the west, the Jebel Aweinat Massif (including Jebel Asba) in the east, the Ennedi and Borkou mountains in the south, and the Calancio Arch (Jebel Dalma) in the north. The basin filling attains a maximum thickness of 2600m (AGIP, 1976) and comprises a sequence of Paleozoic sediments uncomfortably overlain by Mesozoic strata. The center of the basin is covered with sand except for a few small isolated hills of Cretaceous Nubian Sandston outcrops which are limited to the north, southeast and the southwest of the Al kufra oasis. The base of the Paleozoic succession is exposed only in the southeast and the southwest where it rests uncomfortably on Precambrian basement. Sequence stratigraphic models have not been developed for the Kufra Basin. According to S. Luning et al. (1999), the sedimentary succession in the area can be subdivided in to eight major stratigraphic units, namely the infracamberian (upper Neoprotrozoice to Lowermost Cambrian), undifferentiated Cambro – Ordovician (Gargaf Group, consisting of Hassaouna, Melez Chogran and Memouniat formations), Lower Silurian Tanezuft Formation, Lower and Upper Silurian Akakus Formation, Lower Devonian Tadrart Formation, middle and upper Devonian Binem Formation, Carboniferous Dalma Formation and the post Hercynian Nubian Formation (Fig 2), mentioned by S. Luning et al., 1999 (modified after Bellini et al., 1991; Bezan, 1991). The continental shelf was characterized by low gradients which facilitated rapid flooding of wide areas during several sea level rises. In contrast to the Sirte Basin to the north, terrestrial depositional environments have prevailed in the Kufra Basin since the Late Carboniferous (Herycinian) interpolate uplift of the region.

Introduction

Previous interpretation work in the area was based on regional tying of overlying seismic horizons to Paleozoic outcrops with well – established ages (AGOCO, 1989 and LASMO plc, UK, 1999 – 2000). This work is aimed to study the nature of the sedimentary cover of part from the Basin by means of potential field analyses and modeling in particular by integrating three geophysical tools (gravity, magnetic and seismic) in order to predict geolpogical model and depth to the basement. However, it is precisely in this frontier and complex geologic environment where the gravity and magnetic fields often well have their greatest expression. The gravity data in the whole Basin were collected along a regional seismic lines and the coverage in this case is restricted to the limit of these lines by which no enough coverage, nor complete image by the gravity survey can be obtained. The simplified calculation in this study carried out to produce the Bouguer gravity and the magnetic anomalies implies that there may be considerable uncertainty in the accuracy of the produced anomalies. Therefore the details of the modelling in this case are very uncertain due to lack of any subsurface control since only two wells have been drilled in the northern part of the basin, (far distance from the profile location). The uncertainty of the modelling in this case has greatly depends on the formations densities, and the magnetic susceptibilities.

Data Used

Gravity data used in this study were extracted from the Libyan gravity data bank that Libyan Petroleum Institute (LPI) recently made available for research purposes. LPI staff recompiled the Libya gravity data base using the data of previous studies, augmented by the data of more recent industrial surveys and reduced to a local basement rocks density of 2.67 g/cc.

Magnetic data used in this study also obtained from the LPI, released by the Libyan Industrial Research Centre (IRC), this data is a combination of airborne and draped satellite data of 1km grid interval.

Seismic data obtained from AGOCO Company acquired in 1989.

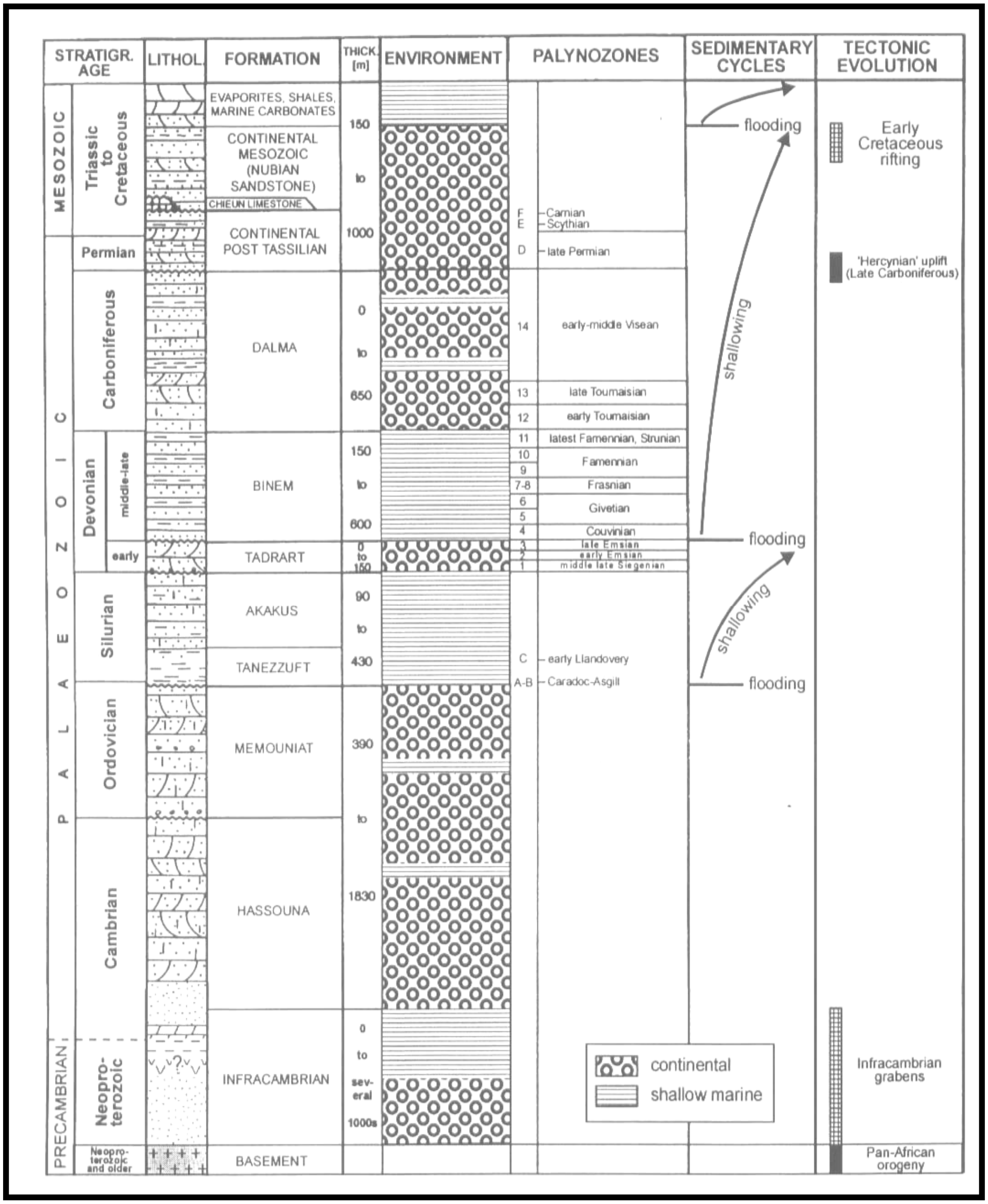

Figure (2) Stratigraphy of the Kufra Basin (modified after Bellini et al., 1991, and Grigari et al., 1991from (S. Luning etal., 1999)

Interpretation of the Anomalous Potential Fields

Gravity and magnetic profile, shown in (Fig 6) were extracted from the residual gravity anomaly map (Fig 3), and the reduced to the pole residual magnetic anomaly map (Fig 5), along the axis of seismic line Ku – 89 -04. This axis is about 350 km long. The profile passes over the basement uplift coincides with analogues from the Jabel Awanat Massif situated in the eastern part of the basin and terminated towards the Jebel Nuqay in the west. The gravity anomalies extracted from the data are in the range from –22 to 29 mGal and the magnetic anomalies are in the range from -216 to 163 nT. The data where inverted using GM - SYS software where 2D model was created. Local subsurface densities and magnetic susceptibilities were used to put constrains in the model parameters. The densities used were obtained from some regional studies and other geological reports while the magnetic susceptibilities were estimated based on world wide reports and charts. The observed Bouguer gravity anomalies along the profile are composites of several anomalies with varying wavelengths. First, a regional trend is present, with generally more negative values to the northwest (Fig 4). This regional trend is likely a reflection of gradually thickening crust from southeast to northwest, or a gradual reduction in average subsurface densities, or a combination of both. If we attribute this trend completely to a thickening of the crust, the amount of thickening required to explain the regional trend is probably more than 8 km over a distance exceeding 350 km. We attempt to remove this longest-wavelength regional trend in the current study and focus on modeling the shorter wavelength anomalies. The residual gravity anomalies along the profile show variations in the gravity gradients. The eastern and western ends of the profile show low gravity signatures with steeper gradient towards the eastern part, while the middle part shows high gravity signatures. The sedimentary cover in the middle is quite thicker compared with the other parts and has a thickness of about 4000 meters mainly coincides with the Kufra southern basin center. The high gravity signature along this part is probably attributed to the effect of a high density basement. The thickness of the sediments is decreased gradually towards the two ends of the profile with amount ranging from 800 to 1000 meters. They are marked near to the flanks of the basin. Then the low gravity signatures are not related to thick sediments but presumably due to a thinning crust or probably due to the existence of low density sedimentary bodies overlain by high density sediments. These characterized by strong chaotic seismic amplitude reflections as shown on the seismic line (Fig 7). Evidences of Infracamberian structures have been studied from rock unit at the north eastern flank of Jebel Arknu (IRC, 1985a). In addatiioon to that Infracaberian rift graben of several km of thickness have been interpreted on seismic lines acquired in 1989 by AGOCO. (S. Luning et al., 1999). Then the interpreted low density bodies in this case my composed of sediments of Infracamberian – to Cabmro - Ordovician age formed during basin evolution (movement of African plate etc….). The magnetic anomalies are very coincides with the gravity anomalies along the profile, these reflect a homogenous distribution of density and magnetization within the sediments and the basement. The modeling shows that the high positive anomaly up to 29 mGal accounted for by a combination of heterogeneous basement blocks with variable densities ranging from 2.67 to 3.0 gm/cc, these blocks represent a positive gravity anomalies that may attributed to an uplift at the Moho (crust/mantle interface) and letter commenced with crustal magmatism. The gravity and magnetic profile also show that the sedimentary cover is composed of thick sequences of Paleozoic and Mesozoic rocks, thickening at the middle and pinching out near the ends of the profile, these seems to be very conformable with that obtained by the seismic interpretation as shown on (Fig 7).

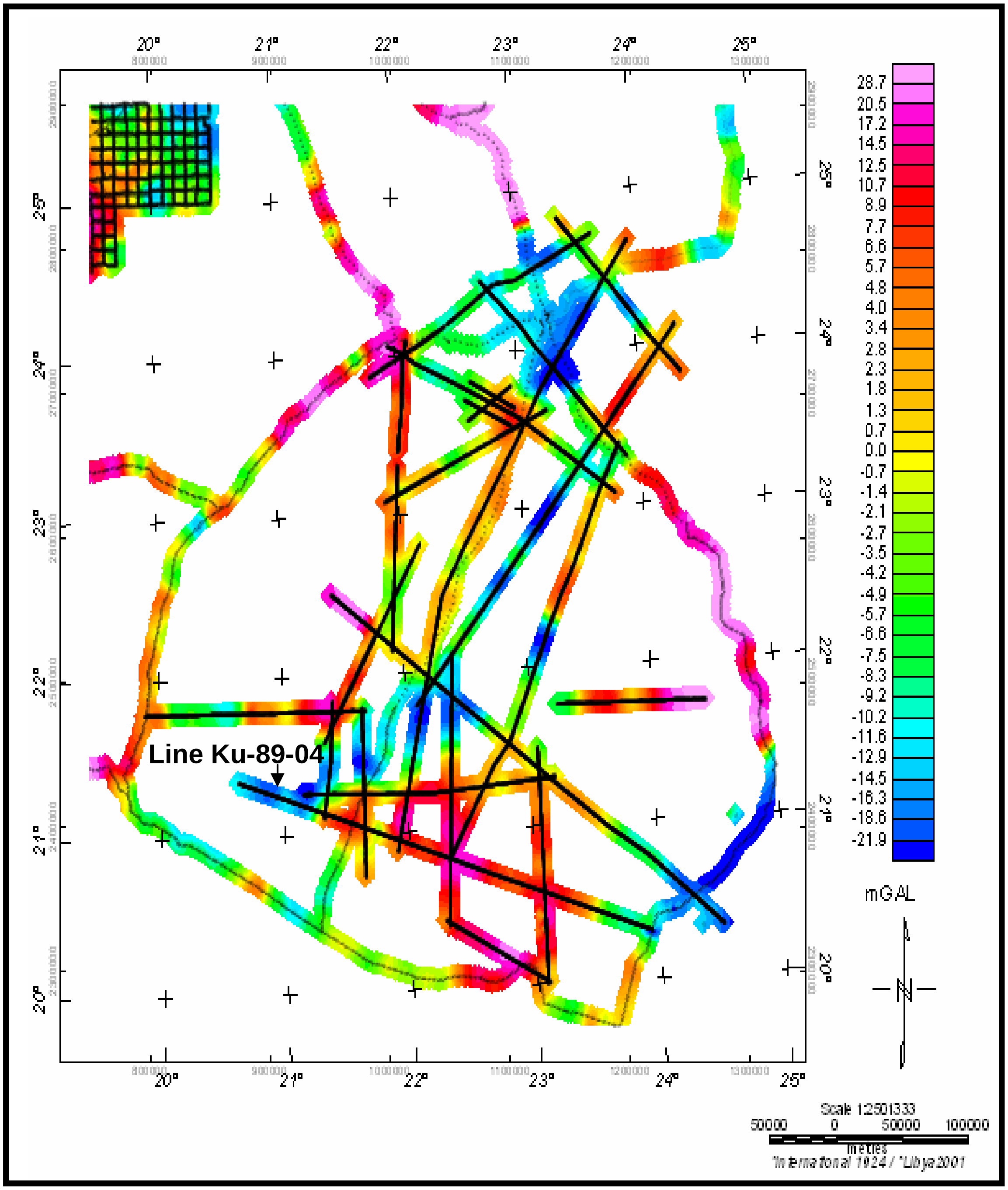

Figure (3) Depicting the residual Bouguer gravity map of the Kufra Basin, data acquired along seismic lines by AGOCO 1989 other data items have been acquired along main roads by Geodic Survey Institute.

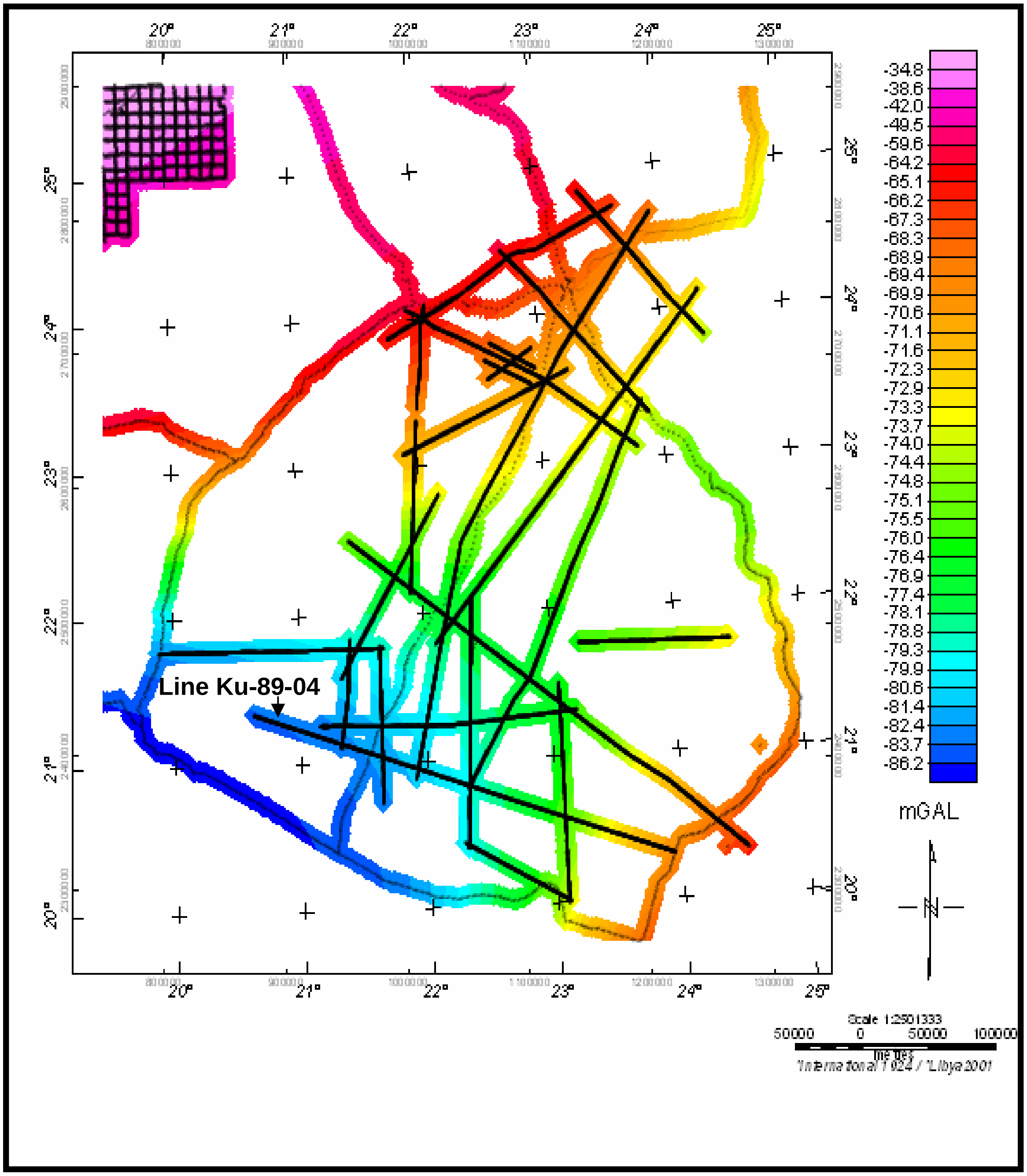

Figure (4) Depicting the regional gravity field in the Kufra Basin, data show thickening crust towards the north west part of the constructed profile (warm blue colour)

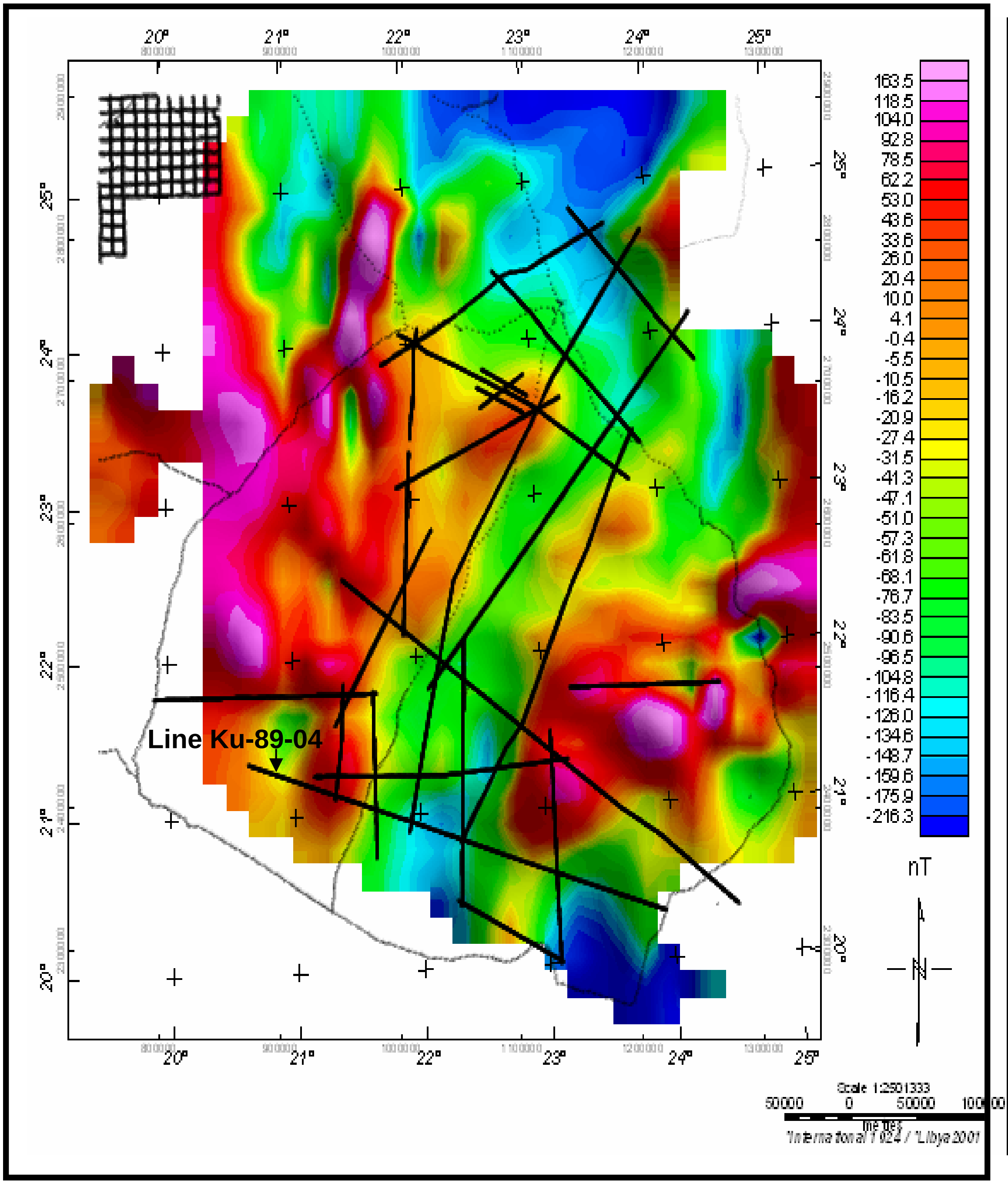

Figure (5) Reduced to the pole residual magnetic anomaly map of the Kufra Basin

Discussion

We discuss the viability of our first-order forward model and it's consistency with seismic observations, and suggests refinements that can improve our understanding about the structure of part of the Kufra Basin. In this study potential field data has been processed to produce residual anomalies. In general, residual field anomalies reflect lateral density and magnetic susceptibility variations in the upper crust. Thus, the gravity and magnetic anomalies can be used to infer the subsurface geometry of known or unknown geologic features. Despite the limitations of the gravity data coverage around the constructed profile, the modeling has shown considerable anomaly amplitudes. Southern Kufra Basin characterized by gravity anomalies that reflect the distribution of thick sequences of Paleozoic rocks, and moderately thick Mesozoic rocks. In addition, the magnetic data reveal the presence of linear features that may reflect basin and range faults whereas additional detailed gravity and magnetic data can indicate the presence of smaller-scale faults. Gravity highs reflect the effect of Pre-Paleozoic rocks along the south margin of the basin. Gravity highs also delineate other exposed or shallowly buried pre-Cenozoic rocks in the southeastern part of the basin. In general, gravity lows reflect moderately thick sedimentary basins. Thus gravity data along the constructed profile show gravity highs, which mainly attributed to the effect of high density basement blocks overlain by intermittently Paleozoic rocks which formed part of a continuous northwest – southeast trending ridge that extends towards the Jabel Aweinat Massif. The gravity highs overlies this part of the study area coincident with a magnetic highs associated with mapped granite basement rocks composed of variable magnetic content. The sedimentary cover in the study area is generally considered to be almost non-magnetic, and the anomalies are sourced overwhelmingly in the crystalline basement. Local intra-sedimentary anomaly sources may be related to depositional concentrations of magnetic minerals in some clastic rocks. We suggest that mafic and/or ultramafic rocks could be responsible for the strong magnetic and gravity anomalies. However, their dimensions and shape suggest that they cannot justify the amplitude and shape of the observed anomalies. Depth estimates inferred by the model analysis suggest that the depth to the top of the bodies causing the gravity and magnetic anomalies are ranges from 3 to 4 km. Bouguer gravity values decline gradually to the northwest as the Basin deepens. Because the depth to magnetic sources increases with basement depth, the shortest-wavelength magnetic anomalies must be found in the southeastern and northwestern parts of the profile, where the basement is at shallow or zero depths close to the Jebel Aweinat Massif and Jebel Nuqay respectively. .

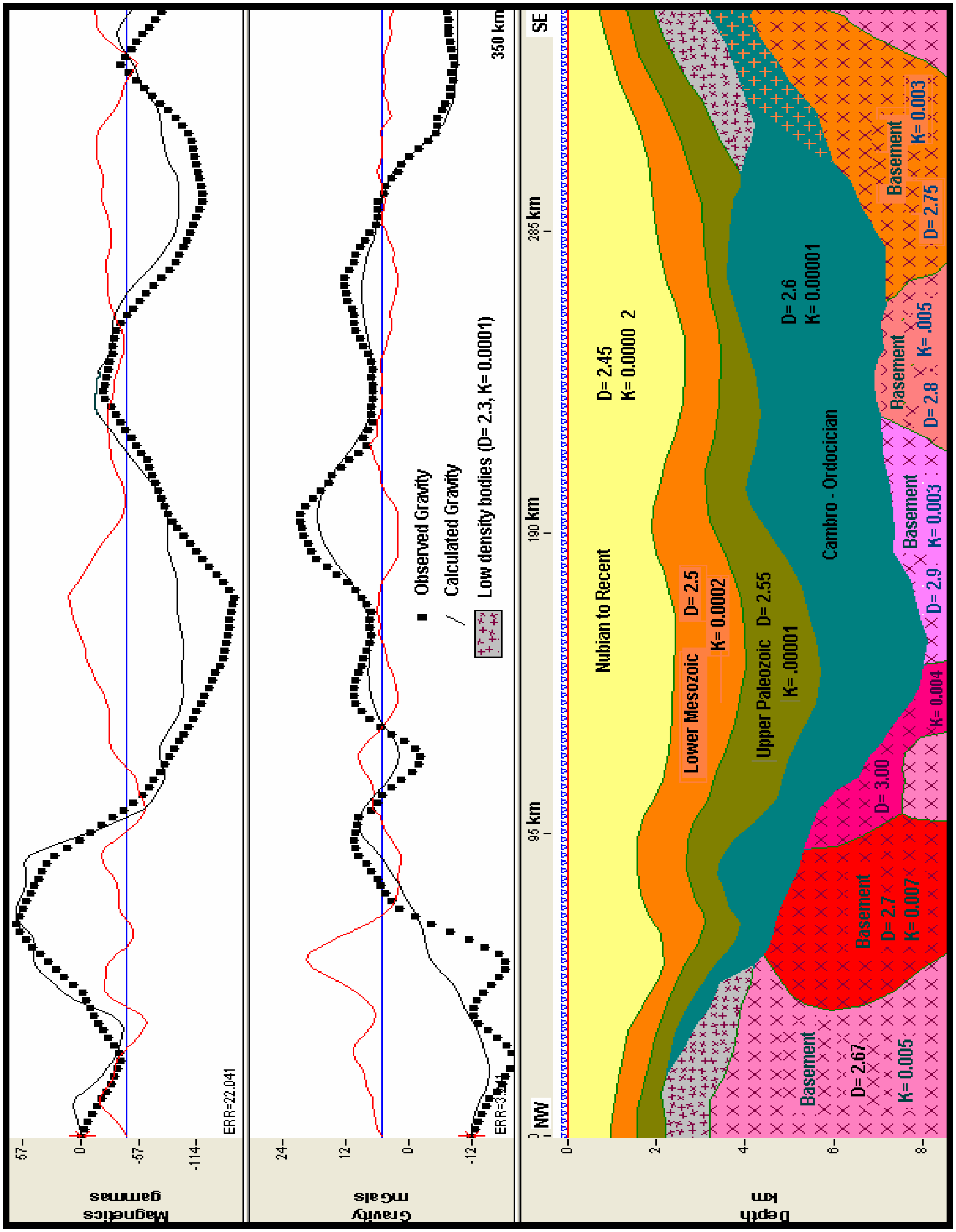

Figure (6) Subsurface geological model deduced from gravity and magnetic data along seismic intersect, **KU – 89 – 04**, Kufra Basin.

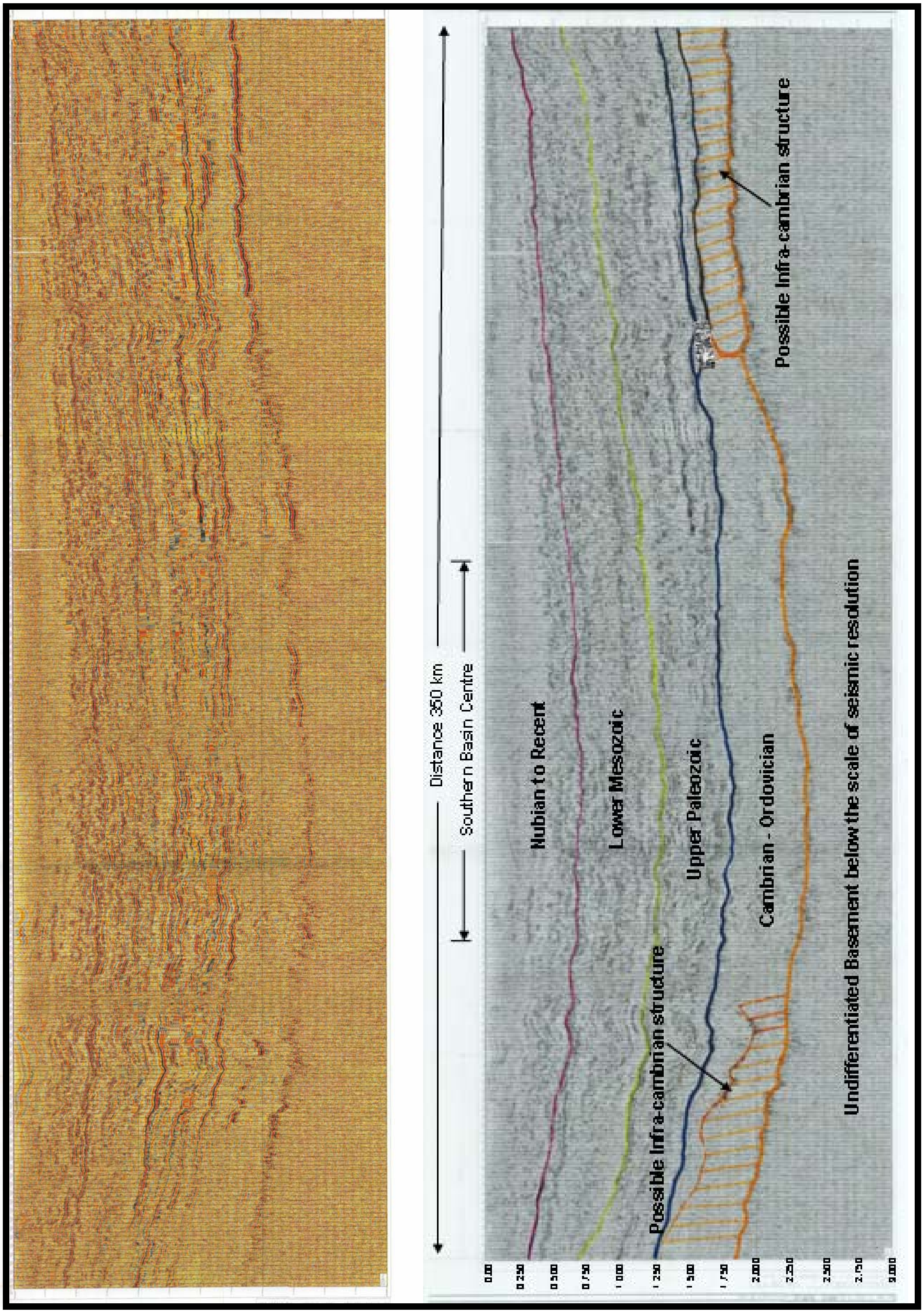

Figure (7) Seismic line **Ku-89-04** at the top with interpretation copy below. The definition of the main horizons has been made based on previous interpretation by LASMO plc, UK, 2000.

Conclusions

In this paper, gravity and magnetic anomalies and their relation to the surface geology in the area of southern Kufra Basin were studied. Two-dimensional model of gravity and magnetic data has been constructed. It was concluded from the model presented that the causative bodies were situated into the upper crust via the lower crust from the upper mantle. Their shapes suggest variable different products from the same location at different times. The second emplacement probably occurred with magma of high magnetite content. The Interpretation of the gravity and magnetic profile along the seismic intersect Ku – 89 – 04 is complicated by the highly 3-dimensional nature of the geologic structure in the area as well as changes in local azimuth of the profile relative to the geologic structure. The profile display high values associated with high density light basement blocks and low values associated with part of the Kufra southern basin centre. Steep gravity gradient from low to high is associated also with an influence from Jebel Aweinat Massif to the east**.** The highest gravity values towards the Jebel Aweinat Massif coincide with exposures of infra - Cambrian rocks that reported by early studies in the area. Locally, gravity and magnetic observations help constrain the interpretations of low density anomalies located at the western and the eastern ends of the profile. They may be associated with sedimentary bodies composed of clastic sediments ranging in age from Infracambrian to Cambro – Ordovician. Structural high trend is the dominant structural feature as evidenced on both regional gravity and magnetic data. High magnetic content basement is interpreted to be the source of the magnetic anomalies along the profile. The depth to the magnetized bodeis is in the range from 3 to 4 km. Variations in the basement depth caused by stratigraphical thickening may be concealed from surface geological investigations but are amenable to gravity investigation provided the changes in thickness are substantial and a density contrast exists between the sediments and the basement. The negative anomalies appear on the Bouguer gravity map are attributed to a thick sequence of sediments. These show that the sediments are of significantly lower density than the underlying basement rocks (granite ….etc). For the adopted density contrast, the maximum thickness of the sediments is about 2000 m for the Mesozoic sediments and about 2000 m for the Paleozoic sediments. The morphology and thickness of these sections are comparable with that obtained by the seismic observations. The modeling in this case allows the gravity and magnetic data to be used to augment seismic imaging and to eliminate or reduce ambiguities that arise from using one method alone. In addition, better resolution in seismic tomography models might help resolve the size and shape of the zone of low densities in the uppermost crust (e.g., resolve whether the body in the uppermost crust does change appreciably in thickness and/or density across the region).

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