The Gravity and Magnetic Study of Joya Mair Area, Potwar Sub-Basin, Pakistan

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ABSTRACT

The geophysical study based on gravity, magnetic and borehole data has been carried out in Joya Mair (Potwar Sub basin) area. The objective of the study was to delineate the subsurface structure and assess the remaining recoverable reserves of the Joya Mair Oilfield. The total estimated reserves of Joya Mair Oilfield are 23-25 million barrels (mmbbl), whereas, at present the recoverable reserves are only 10.45 mmbbl (Pakistan Energy Yearbook, 2003). To resolve this problem and delineate the subsurface structure of Joya Mair area, an integrated geophysical study has been done. The geological model based on gravity data constrained with magnetic and borehole data has been computed. This model demonstrates that the Joya Mair thrust (F1) dips 75° SE and penetrates up to the basement, whereas, the Mengan thrust (F2) dips 58° NW and penetrates in the sedimentary wedge up to the depth of 2.6 km. The thickness of sedimentary wedge is 5.8 km in the south and 5.4 km in the north. The estimated net slip computed from this model is 340 meters and 260 meters along F1 and F2, respectively. The model also indicates that the 38 km thick crystalline crust of Indian shield dips at an angle of 2.3° SE. The qualitative and quantitative interpretation of gravity and magnetic data suggests that F1 and F2 deformed the structural trap in the study area, which shows that the Joya Mair anticline is not a single structure, it is rather faulted into blocks. That is why Joya Mair well did not produce the expected reserves.

INTRODUCTION

The Himalayas represent the most extensive, active collision zone in the world, extending westward from Burma, through northern India, Nepal and southern Tibet, into northern Pakistan (Figure 1). The Himalayas is subdivided into Sub Himalayas, Lesser Himalayas and Higher Himalayas (Figure 2). The Potwar Plateau is a broad zone of Himalayan foreland thrusting in northern Pakistan. The study area lies in the southeastern part of the Potwar Plateau (Figure 3). The Potwar Plateau is the foreland fold-and-thrust belt, lies to the north of the Salt Range Thrust. The post collisional molasse deposits, the Kamlial, Chinji, Nagri and Dhok Pathan formations cover the project area. The area was initially mapped by Gee (1934) and the oil

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discovery was made by Attock Oil Company (AOC) in 1944. The anticlinal structure of Joya Mair was delineated by AOC purely on the basis of surface geology. Later on Pakistan Oilfields Ltd. (POL) conducted geological and seismic survey in the area and defined the structure on the basis of these studies. The total estimated reserves in Joya Mair Oilfield are 23-25 million barrels (mmbbl). The recoverable reserves are estimated 10.45 mmbbl (Pakistan Energy Yearbook, 2003).

As there are steep dips in the study area, the structure cannot be explained merely on the basis of geological and seismic data. In order to solve this problem it was planned to carry out an integrated gravity and magnetic survey for the modelling of Joya Mair structure. The station interval of gravity and magnetic survey have been taken at an interval of 100 meters and the data is plotted on the base map of scale 1:25000. The contour interval of magnetic map is 10 gammas, whereas the Bouguer anomaly map is 2 mgals. The density used for the calculation of Bouguer anomaly was 2.5gm/cc.

GEOLOGY

Joya Mair area lies in the southeastern part of Potwar Sub-basin where the structural trend is northeast-southwest as compared with the dominant east-west trend of northern Potwar. The rocks of Miocene – Pliocene age known as Nagri Formation and Chinji Formation are exposed in the core of the structure and its flanks. A prominent thrust cum tear fault Chak Naurang-Wari fault is passing through the study area (Shami., 1986). There is general disharmony between the younger molasses sequences and the lower older sequences due to thrust tectonics, which are playing a dominant role in the Potwar region. Thus Joya Mair is not an exception to this disharmony and the Chinji Formation in the core of the surface structure must have been brought up by thrusting. The lithologically territories are laying unconformably over Paleozoic and the whole Mesozoic section is absent in and around the area. The Sakesar Limestone and Chorgali Formation of Eocene age are the primary reservoir objective while Permian and Cambrian sandstone are secondary objectives. The Eocene, Paleocene and Permian shales are supposed to be the potential source and cap rocks.

Interpretation of Gravity and Magnetic Maps

The total magnetic anomaly map of Joya Mair (Figure 4) demarcated the area into four different zones. The anomaly variation ranges from -60 gammas in the north to +50 gammas in the south giving a magnetic relief of 110 gammas. The magnetic contours closure on this magnetic
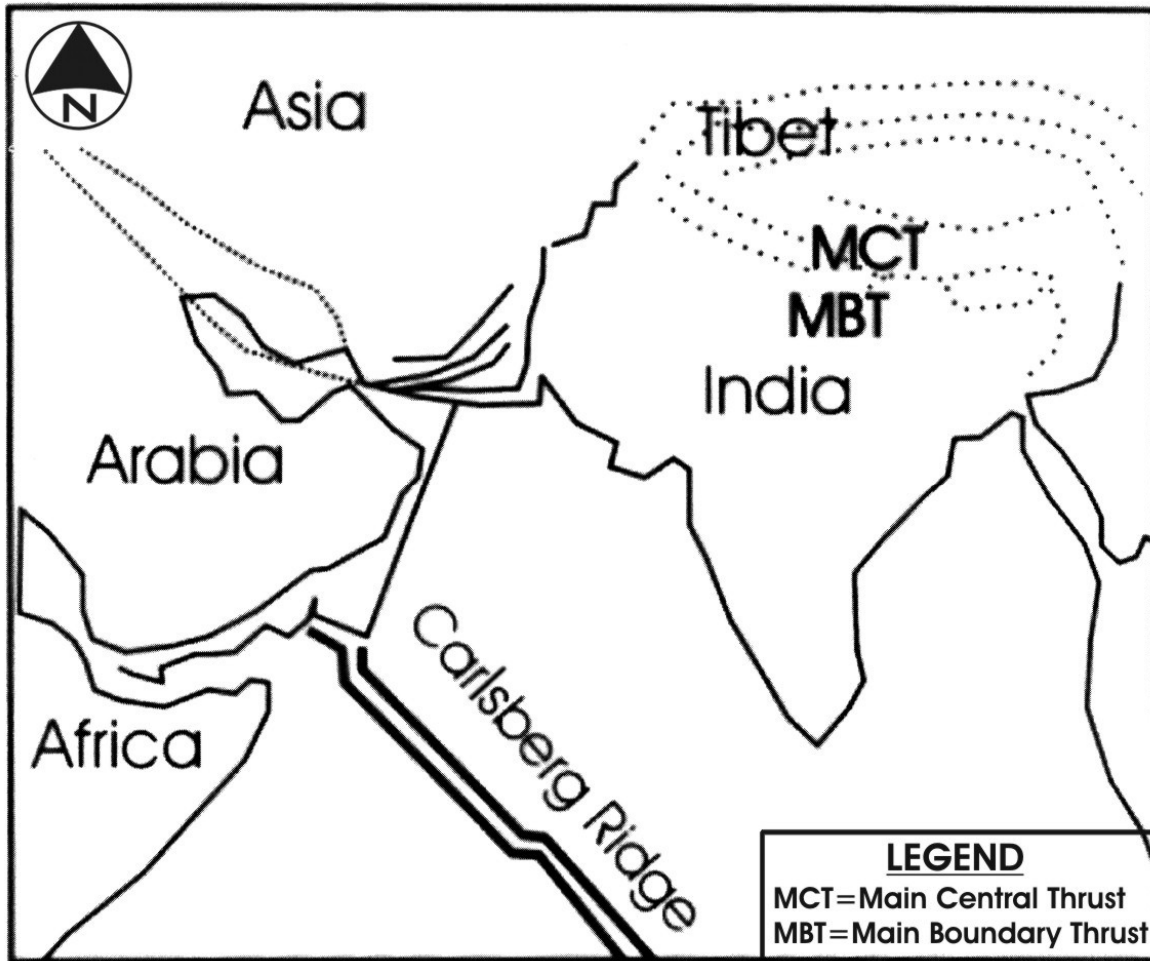
Figure 1- Generalized tectonic map of Himalayas and its associated regional tectonic elements compiled after Powell (1979).

anomaly map indicates the magnetic low in zone 1 and zone 3. These magnetic low may be an indication of thick salt layer. The magnetic contour trend in the NE-SW with magnetic gradient 2-3 gamma/100 meters and demarcated the fault F1 and F2 (Figure 4). The relatively positive magnetic contours closure at Thanil Fathui indicates that salt layer is at deeper depth.

The Bouguer anomaly variation ranges from −145 mgals in the north to −135 mgals in the south giving a gravity relief of −10 mgals (Figure 5). The trend and pattern of the Bouguer anomaly map dictates the total magnetic anomaly maps. The NE-SW trend with steep gradient in northern and central zone delineates the fault F1 and F2, which confirmed the total magnetic anomaly map. The low gravity in central and the southern zone indicate that the low density Salt Range Formation is present near the surface of the Joya Mair area, whereas, the comparatively high gravity values with steep gradient represent the lithostructural variation.

The current study concludes that the trend of gravity and magnetic contours demarcates the F1 and F2. The fault F1

is dipping southward and F2 into north. These faults deformed the structural trap in the study area and the central area between these faults moves downward.

GRAVITY MODELLING

Gravity modeling in Joya Mair, area has been attempted by using Talwani et al. (1959) technique using software of Malinconico (1986). Geological bodies in this case are approximated as horizontal prism with finite length and polygonal cross sections. Modeling is carried out to cover the buried features such as Joya Mair anticline and other expected basement and surface faults. For this purpose the profile A-A' is selected. This profile is extended from Ballo Kass to Thanil Fathui (Figure 6). For the construction of the geological model of Joya Mair area, gravity modeling is done incorporating grass density zoning of the subsurface lithological units of Joya Mair Well # 4 and previously known lithostructural information of Leather (1987), and Khan and Ali (1994). The litholog of Joya Mair Well # 4 is used for the gravity model. In gravity modeling the density contrasts
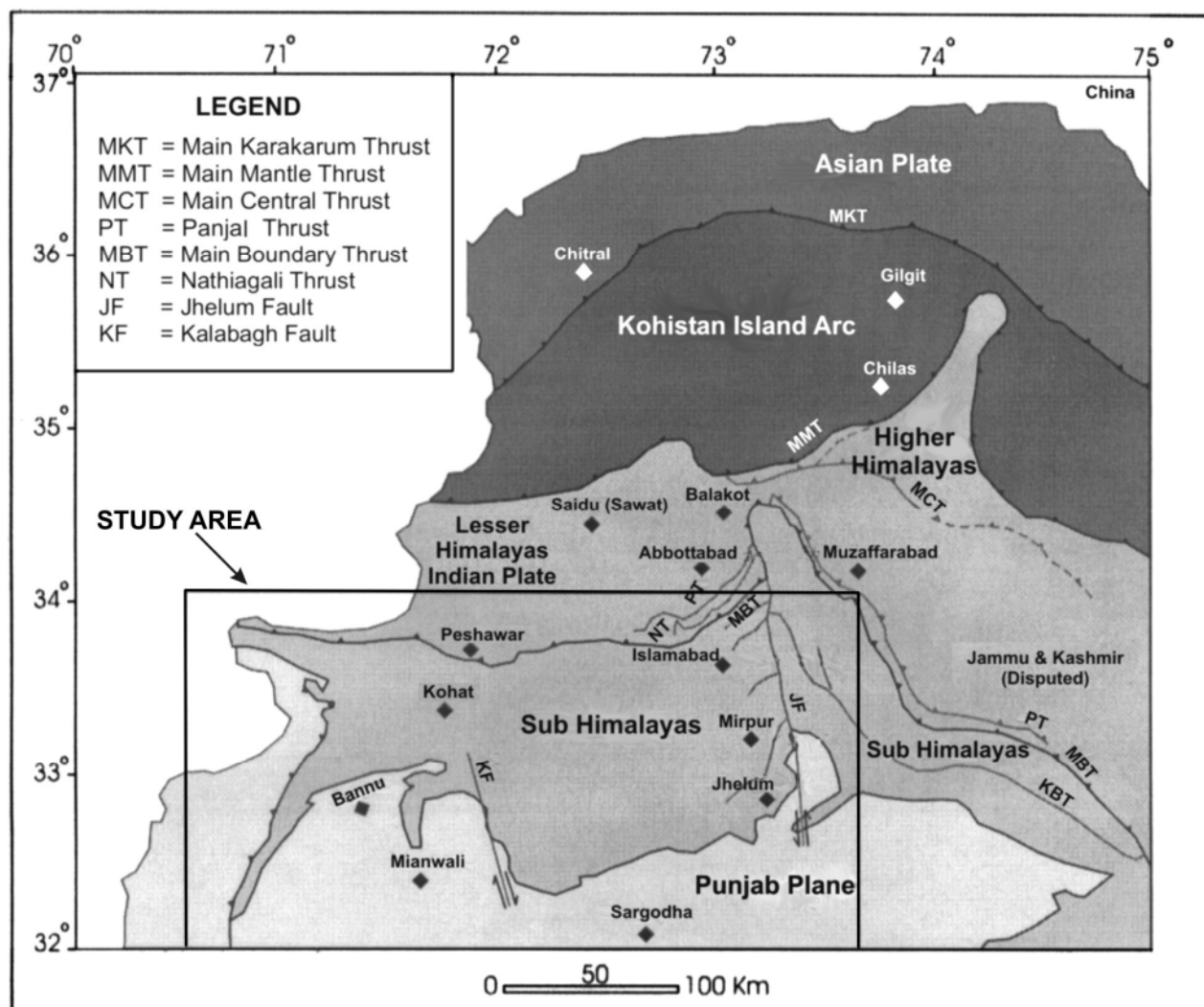
Figure 2- Tectonic map of Northern Pakistan, compiled after Kazmi and Rana (1982), Khan and Ali (1994).

assigned to geological prism of Joya Mair area are relative to the average density of the crystalline basement. The density of crystalline basement has been taken as 2.95 gm/cc after Leather (1987), Verma (1991) and Khan and Ali (1994). The density used for the Salt Range Formation is 2.25 gm/cc after Leather (1987) and Khan and Ali (1994). The lithological units of the area are classified on the basis of subsurface data of Joya Mair Well # 4. These units are Molasse sediments of Miocene through Pliocene age, carbonates rocks of Eocene to Cambrian age and Salt Range Formation of Precambrian age. The density contrast assigned to Moho with respect to crystalline crust is 0.30 gm/cc. This model is the outcome of the several attempts which were made to have a best fit among geology, observed gravity and the calculated gravity.

The gravity modeling (Figure 6) shows that the Joya Mair thrust (F1) is dipping at an angle of 75° SE and penetrates up to depth of basement in the study area, whereas,

Mengan thrust (F2) dips at an angle of 58° NW and penetrates upto the depth of 2.6 Km. The net slip computed from this model is 340 meter and 260 meter along F1 and F2, respectively. The thickness of the sedimentary wedge is 5.8 km towards Thanil Fatui, which decreases to 5.4 km towards Ballo Kass. The 2 to 3 Km thick Salt Range Formation (decollement) is present under the Joya Mair area, which increases towards NW direction. Along the profiled A-A' between Ballo Kass to Thanil Fatui the 38 Km thick crystalline crust dips at an angle of 2.3^{o} in the SE direction. The presence of the faults F1 and F2 deformed the structural trap in the study area. The central part of the structural moves downward as compared to the northern and southern blocks. The thickness of the carbonates of the central block is relatively more as compared to the northern and southern blocks. The thickness of the salt layer is less towards the southeast as compared to the northwest in the Joya Mair area.
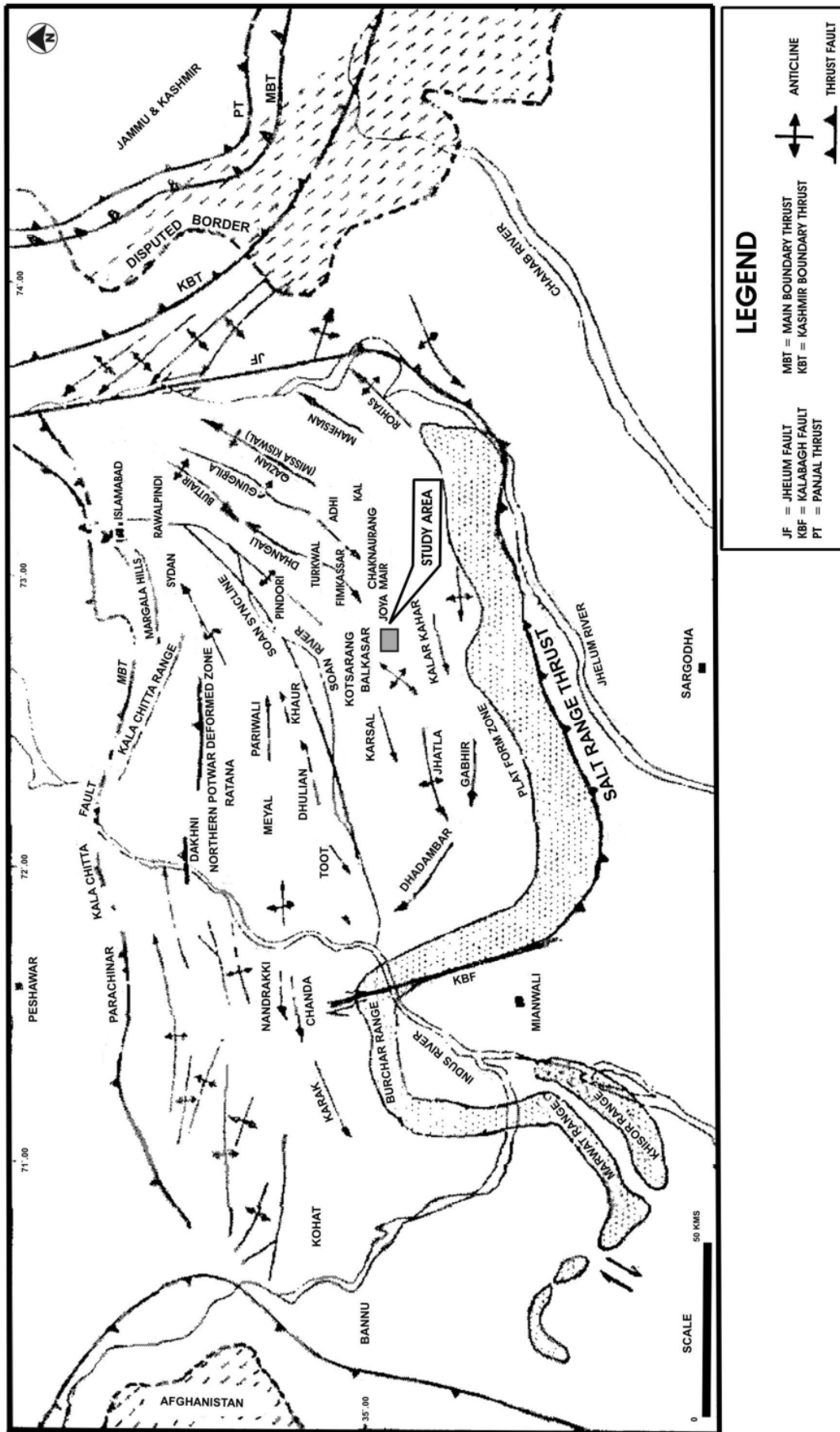
Figure 3- Generalized structural map of Salt Range – Potwar Foreland Basin showing location of oil and gas structures compiled after Khan and Hasany (1998), Kazmi and Rana (1982) and Shami (2002).
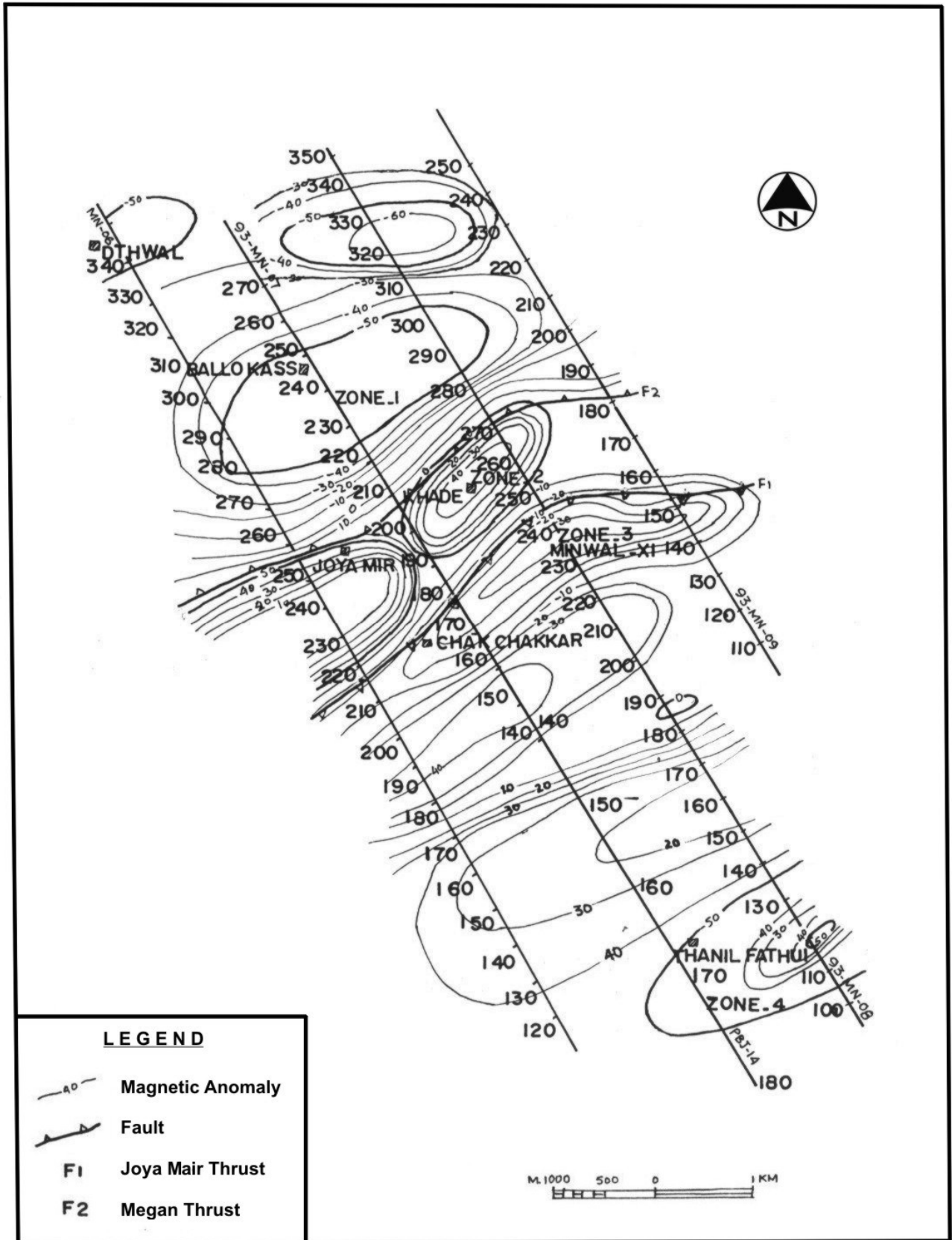
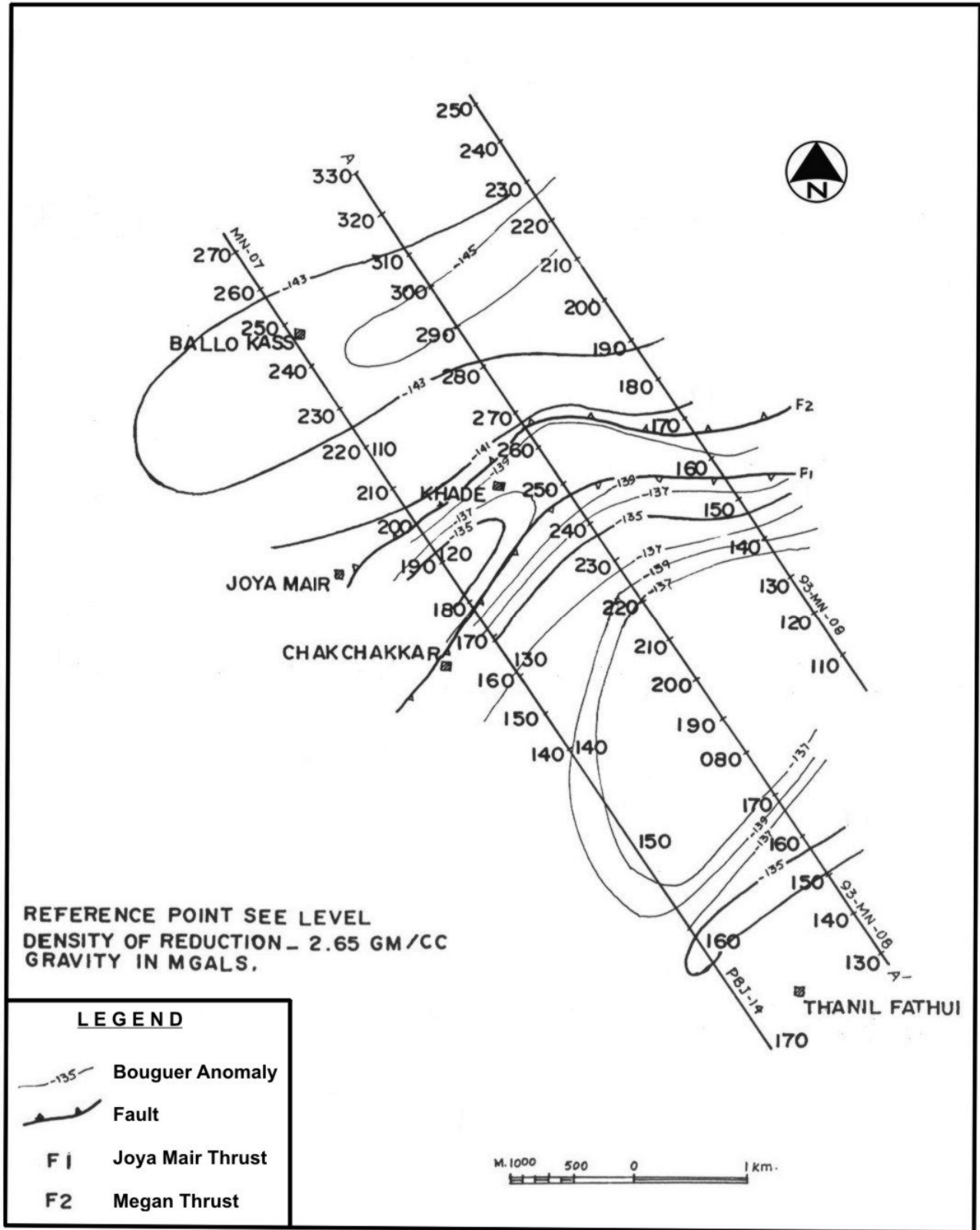**Figure 4 - Total magnetic anomaly map of Joya Mair Potwar Area.**

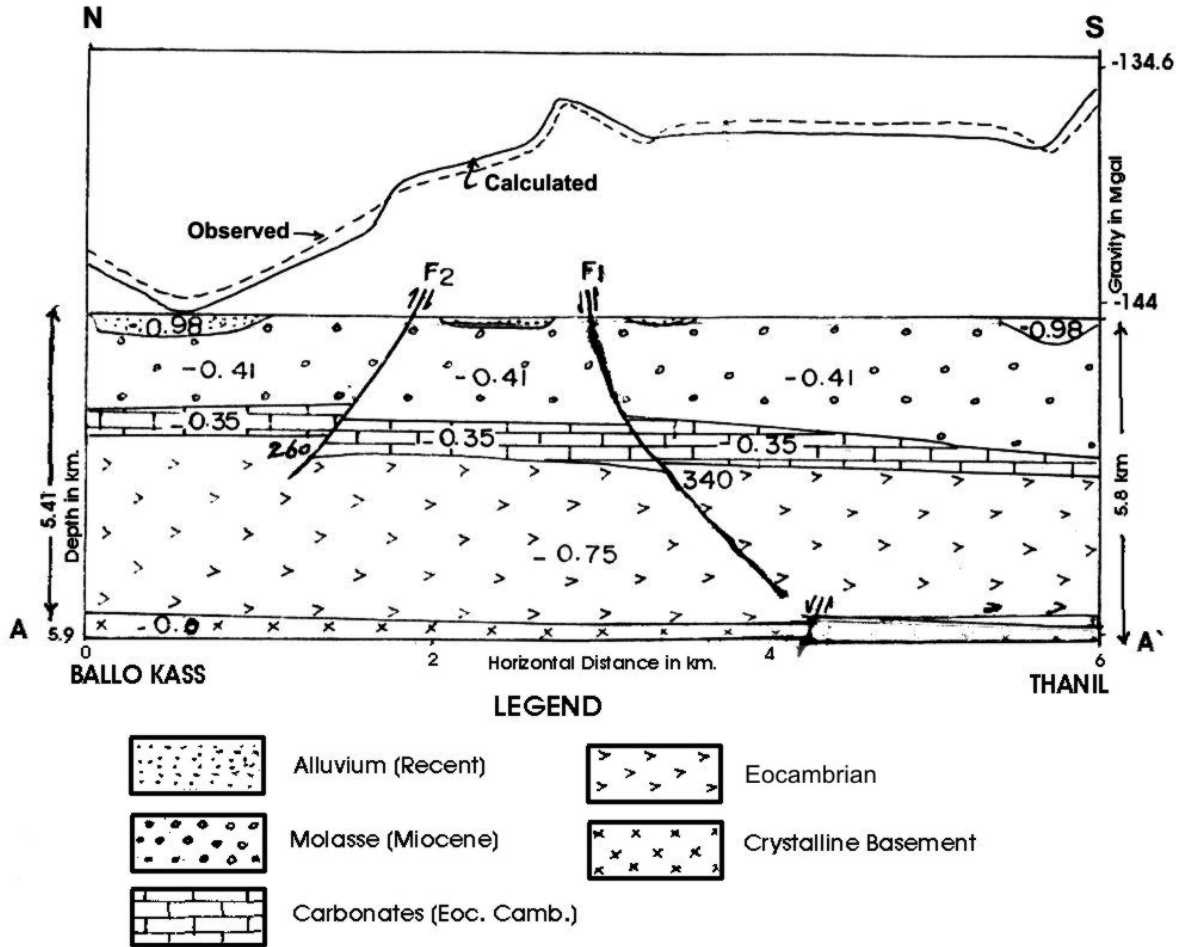**Figure 5 - Bouguer anomaly map of Joya Mair Potwar Area.**

Figure 6- Gravity model along the profile A-A' from Ballo Kass to Thanil Fatui.

DISCUSSION

The area under investigation lies in the Potwar Sub-basin in the foothills of western Himalayas in Pakistan. The structures of the Joya Mair area are very complex due to folding and faulting, resulted due to stresses caused by the collision of Indian and Eurasian plates. The Geological model of Joya Mair area has been computed on the basis of gravity data constrained with magnetic and borehole data, and previously known lithostructure information. This model demonstrated the F1 and F2 faults in the study area. The fault F1 is dipping at an angle of 75° SE and penetrates up to the basement, whereas, F2 is dipping at an angle of 58° NW and penetrates upto the depth of 2.6 Km in the sedimentary wedge. POL delineated the Joya Mair Oilfield as structural trap on the basis of surface geology and seismic data. According to POL, Joya Mair structure is a simple anticline. The current study based on geophysical techniques negates the POL findings and suggests that Joya Mair anticline is not a single structure but it is faulted into blocks. The thrust and back thrust in the study area have been developed due to the stresses which are caused by the collision of Indian and Eurasian plates and the presence of salt, incompetent strata and basement fault. Shami and Baig (2002) also suggest that Joya Mair structure is not a simple anticline, it is a triangle zone, which is formed by the combination of Mengan thrust and Joya Mair thrust resulting in the triangle geometry at subsurface and faulted anticline structure. Khan and Ali (1994) indicated similar structures in the northern Potwar near Rawalpindi, which are Rawat thrust and Kahutta backthrust. They suggested that Rawat thrust and Kahutta backthrust have been developed due to SSE ward stress, decollement and the extensional basement fault present in the upper crystalline basement. Pennock et al. (1989) reported that the Salt Range Formation thins out to 500 meter in the eastern Salt Range-Potwar Plateau. The model also demonstrated that the Eocambrian evaporites do not retain their thickness. All of the sedimentary strata above the basement are detached from basement along a decollement in the Eocambrian evaporites. The salt layer is at the deeper depth in the central part as compared to the northern and southern.

The interpretation of the current geophysical data shows that the Eocambrian Salt Range Formation is present under the sedimentary wedge in the study area and plays an important role in the geometry of Joya Mair structure. It overlies the basement and has a general thickness of about 2 to 3 km in the study area. The present study based on, gravity, magnetic and borehole data, suggest that the thrust and backthrust in the Joya Mair area developed due to the stresses, Salt Range Formation and the extensional basement fault. The F1 and F2 faults were produced during the deformation. The F1 is dipping towards southeastern side of the structure, while the F2 is dipping towards the northwestern side (Figure 4, 5 and 6). The present study also indicates that two types of deformation have been observed in this area, i.e. deformation in the sedimentary wedge and deformation in the crystalline basement. The compressional stresses caused by the collision of Indian and Eurasian plates are responsible for the deformation of the sedimentary wedge, whereas the extensional stresses caused by the bending of Indian Plate, developed the normal fault in the upper crystalline basement. The basement faults in the southern Potwar are also reported by Leather (1987) and Sultan (1988). The Geological Model (Figure 6) derived from gravity data describes that the 2 to 3 Km thick Salt Range Formation (decollement) is present under the Joya Mair area, which increases towards NW and the crystalline crust of 38 Km thick dips towards southeast at an angle of 2.3^{o} between Thanil Fathui to Ballo Kass. The presence of the faults (F1 and F2) deformed the structural trap in the study area.

CONCLUSION

This study concludes that faults F1 and F2 deformed the structural trap in Joya Mair area. It also indicates that Joya Mair anticline is not a single structure but it is faulted into blocks. That is why the expected reserves potential of Joya Mair Oilfield are not recovered so for.

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