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Subsurface Structural and Crustal Assessment on the Basis of Gravity Data Along Bagh, Dir Kot and Adjoining Areas of Azad Jammu and Kashmir, Pakistan

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Abstract: The research work is based on gravity data is taken from numerous parts of an active tectonic belt of Azad Kashmir to delineate the crustal thickness and demarcation of thin- skin and thick-skin structures in the study area. The study area includes Bagh, Dhirkot, Arja, Kohala, Sudhan Gali, Ghazi Abad, Chikkar and Chakoti. The study area bounded by the latitude 33°59′3″ and 34°9′22″ N and longitude 73°37′26″ and 73°40′16″ E. The proposed study area is a complex geological entity and is an active zone. This study has been focused to assess the subsurface lithology and structural geometry present in Bagh and surrounding areas. For this purpose the gravity data has been acquired with the help of CG-5 Auto-grav using multi-profile survey technique. Gravity model suggested that Riasi Thrust in the study zone is plunging at an angle of 42° NE and pierces to a depth of 7 km in the sub-surface. The model also suggested that Bagh Basement Fault in the study area is dipping at an angle of 75° NE in the crystalline basement up to Moho depth. Shaheed Galli Thrust has been delineated in Dhirkot area. The fault dips at 49° NE and penetrated up to a depth of 8 km in the sedimentary/meta-sedimentary wedge. The geological model demarcated, 11 km depth of sedimentary/meta-sedimentary wedge in the southwest and 13 km in the northeast area. The crustal thickness increases from 51 km in the southwest area to about 53.17 km in the northeast area.

Keywords: Gravity, Azad Kashmir, survey, crustal, subsurface.

Introduction

Geophysical surveys are appropriate for understanding the subsurface structure, composition, and layering of the earth surface for investigation of geomorphologic features (Kneisel, 2006).

The gravity method is one of the geophysical methods that measures differences in the earth's gravitational field at particular locations (Huang et al., 2001). Gravity technique plays an important role in locating the subsurface geological objects and structures. The success rate of the gravity depends on the subsurface materials having parameters like-bulk densities (mass) or magnetic significance that produce variations in measurement (Šumanovac, (2010). For determination of thickness and the deep structures of the earth's crust, gravity and geodetic measurements play a vital role (Ahmad et al., 2018). These methods provide the basis to measure the thickening or thinning of continental crust (Kono, 1974). The project work was carried out in the core of HKS and comprises of rocks of sub-Himalayas. The study area bounded by the latitude 33°59′3″ and 34°9′22″ and longitude 73°37′26″ and 73°40′16″. The purpose of this research work is to demarcate the thick-skinned and thin-skinned structures in the study area, the thickness of sedimentary/meta-sedimentary wedge and the total thickness of crust.

Geology and Tectonic Setting of the study area

Main tectonic components are exposed on the northern side of Pakistan as well as in Kashmir. The main thrusts are the Main Boundary Thrust (MBT), Main Central Thrust (MCT), Main Karakoram Thrust (MKT), and the Salt Range Thrust (SRT) (Hughes et al, 2019). The border between Kohistan Island Arc and Indian plate is called the Indus Tsangpo Suture zone or (MMT) shown in Figure 1 (Baig and Lawrence, 1987). The HKS is positioned to the southern side of Kohistan Island Arc. MBT cuts the Murree Formation from all directions of HKS. The Panjal Thrust moves parallel to MBT on the eastern side of HKS (Calkins, et al. 1975). The Jehlum fault is the left-lateral strike-slip fault which moves laterally towards the western boundary of the axial plane of HKS. Kashmir boundary thrust lies to the south of MBT settle the Cambrian Muzaffarabad Formation on the Miocene Murree Formation (Ghazi et al, 2015). In the south-east of Bagh and Kotli Main Boundary Fault (MBF) separating the hanging wall units from the footwall of Siwaliks knowns as Raisi thrust (RT), Pangal thrust (PJ), Nathiagali thrust (NT) and MBT lies on the eastern and western side of the study area (Rustam and Ali 1994) (Figure 1). The regional geology of Hazara Kashmir Syntaxis (HKS) ranges from Precambrian to Recent while the research work covers the sedimentary strata ranging from Miocene to Recent i.e. Murree Formation, Kamlial Formation, and Alluvium. (Bossart, et al., 1984).

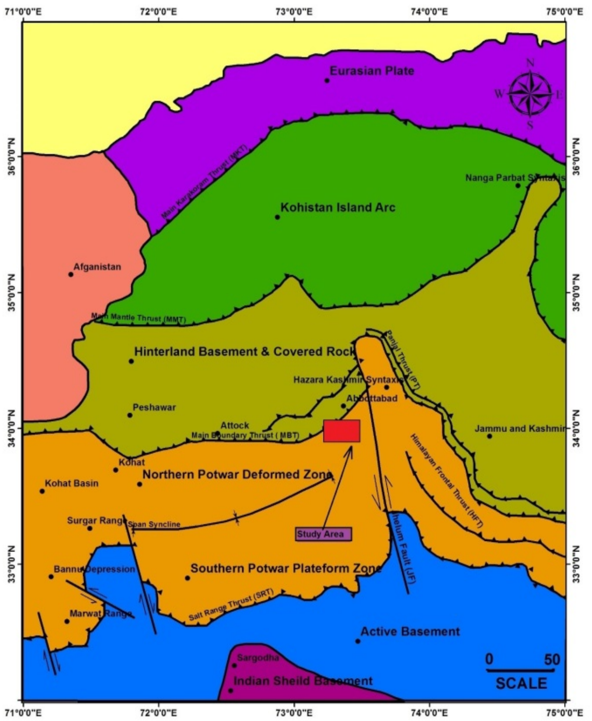

Fig. 1: The tectonic background of northern Pakistan displays the study area and different faults present in the study area. Figure represents Hazara Kashmir Syntaxis lies in the Northern Pakistan and the other faults i.e. Main boundary Thrust, Punjal Thrust, Himalayan Frontal Thrust, Main Mantle Thrust and Bagh basement faults compiled and modified after Wadia, (1982); Latif, (1973); Kazmi and Rana (1982) and Calkins, et al. (1975).

Materials and Methods

The instrument CG-5 Autograv was used for the measurements of gravity having a range of 1000 mGal, with long-term drift less than 0.01 mGal per day. Elevation measurements were made using a Global Positioning System (GPS). The selection of the base station is done with the main base station in the Rawalpindi. The main base station was precisely connected by the looping system with the international gravity station. The national base station has previously been tied to the Teddington and Washington Pendulum station. Changes in observed gravitational acceleration due to the response of the gravimeter over time are regarded as instrumental drift. Correction for instrumental drift is created on repeatedly at every base station at a time of recording. The formula used for drift correction is as follow.

$$D.C = \frac{gbase2 - gbase1}{tbase2 - tbase1} X\ (tos - tbase1)$$

Or

D.C = drift rate × elapsed time

The CG-5 Autograv meter tells us software-based, computerized results to regulate the drift constant and update the internal correction automatically.

Results and Discussion

The size, shape, and structure of the geological features have been estimated in qualitative interpretation. For this interpretation free air anomaly, Bouguer anomaly, regional and residual anomalies, as well as the elevation maps of the study area, have been prepared.

Bouguer Anomaly Map of the Area

Bouguer anomaly, is defined upon the datum level of gravity reduction of an arbitrary elevation (Hackney and Featherstone, 2003 Vaníček, 2001. For the research work, the map has been prepared with an interval of 2mGL (Figure 3). The density used for the calculation of Bouguer anomaly was 2.67 gm/cc. The Bouguer anomaly values ranges between -255 to -196 mGal with a total gravity relief of -59 mGal. The negative gravity anomaly indicates the thickening of the crust in the study area.

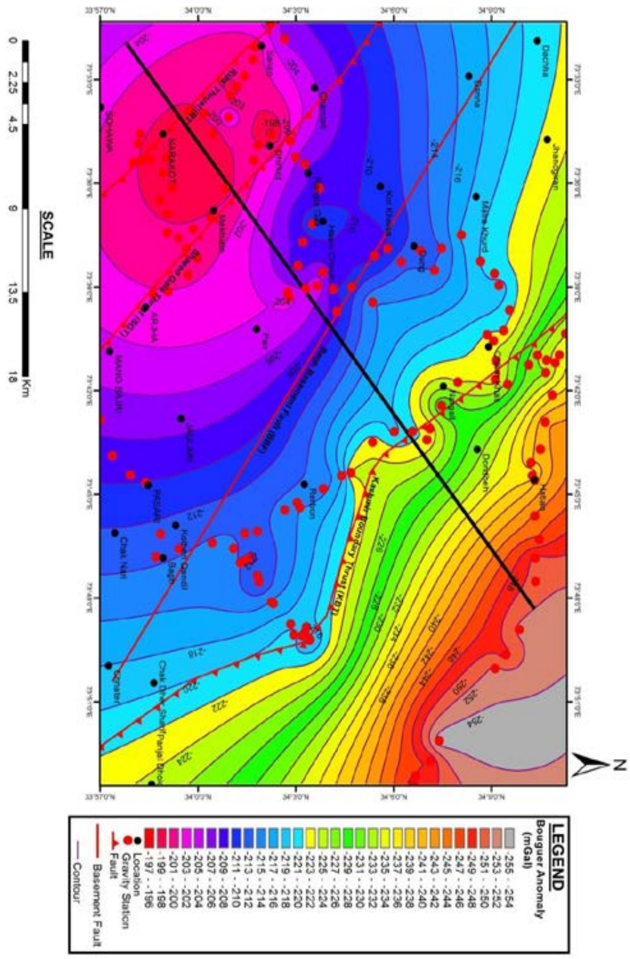

Fig. 2 Bouguer anomaly map of the project.

Fig 2 The contours of the area follows a common trend in NW-SE directions. Its value ranges between -204 to -208 mGal in the project area in the southwestern part. In the study area, the gravity gradient is -0.24 mGal/km that indicates the presence of Riasi Thrust and Shaheed Galla Thrust.

The figure also shows that in the central portion, the Bouguer anomaly values decrease from -208 to -220 mGal with a gravity relief of -12 mGal. The value of gravity gradient is -2.12 mGal/km that indicates a low gravity gradient and the presence of Bagh Basement Fault.

Further, in the northeastern part, the Bouguer anomaly abruptly decreases from -220 to -252 mGal with a gravity relief of -32 mGal. In this area the contour trend in NW-SE direction with a gravity gradient of -2.7 mGal/km. This low gravity gradient indicates the presence of KBT. The contours trend also confirms the trend of this fault.

FREE AIR ANOMALY AND ELEVATION MAPS OF THE AREA

The free air anomaly and elevation maps (Fig 3 and 4) have been prepared to have contour interval of 5 mGal and 50 meters respectively. The free air anomaly map is made to evaluate the effects of topography on gravity observations. The comparison of these maps reveals that the free air anomaly generally follows the elevation pattern with slightly discordant in the pattern in some areas due to density variation in some subsurface rocks (Fig 5). The increase in free air anomaly in the central portion of the free anomaly map is associated with the rise in the topography of the area. The negative free-air anomaly in this region is due to the isostatically over-compensated crust.

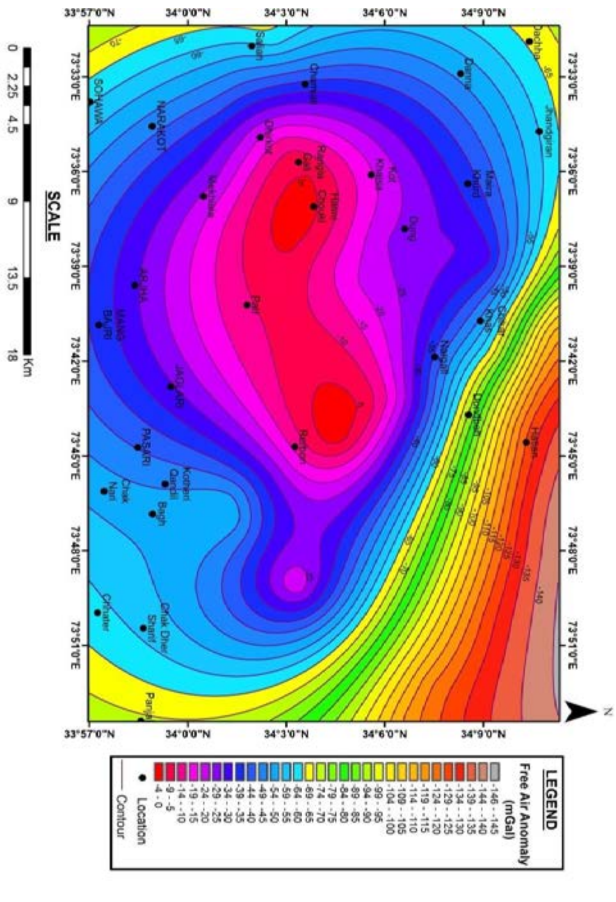

Fig. 3 Represents the free air anomaly map of the project.

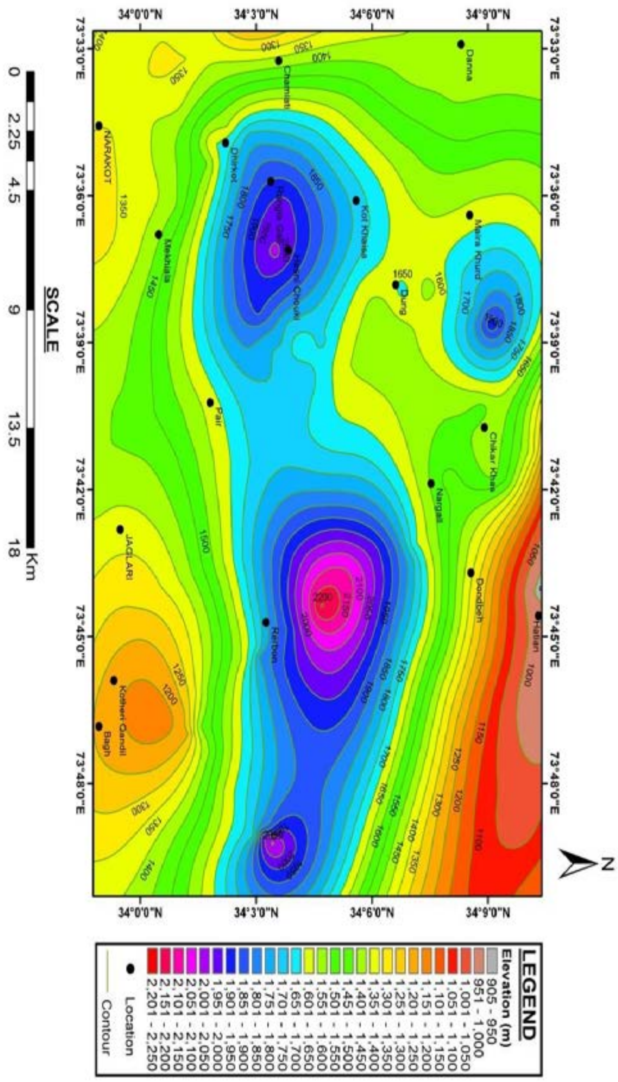

Fig. 4 Elevation map of the project

Regional Bouguer Anomaly Map

The map of the research work was prepared with a contour break of 5 mili Gal as shown in Figure 5. The map follows a normal movement in the NW-SE direction with a decrease in anomaly towards the northeast to southwest. The map also shows that the anomaly is low in the northeast portion which indicates that the crust is thin in this section. In the southwest portion of the map, the values of the regional Bouguer anomaly are very high which indicates the maximum crustal thickness in this region.

The map of the present work was prepared with a contour break of 2 mGal presented in Figure 6. The residual component has been acquired by subtracting the regional component from the measured Bouguer anomaly data. The map shows many closures in the shape of low gravity in the project area. The gravity low zones L1, L2, L3, L4, and L5 are marked on a map. The Figure also shows the low gravity zone L1, L2, L3, L4, and L5 is due to the occurrence of low-density material which is present in the subsurface.

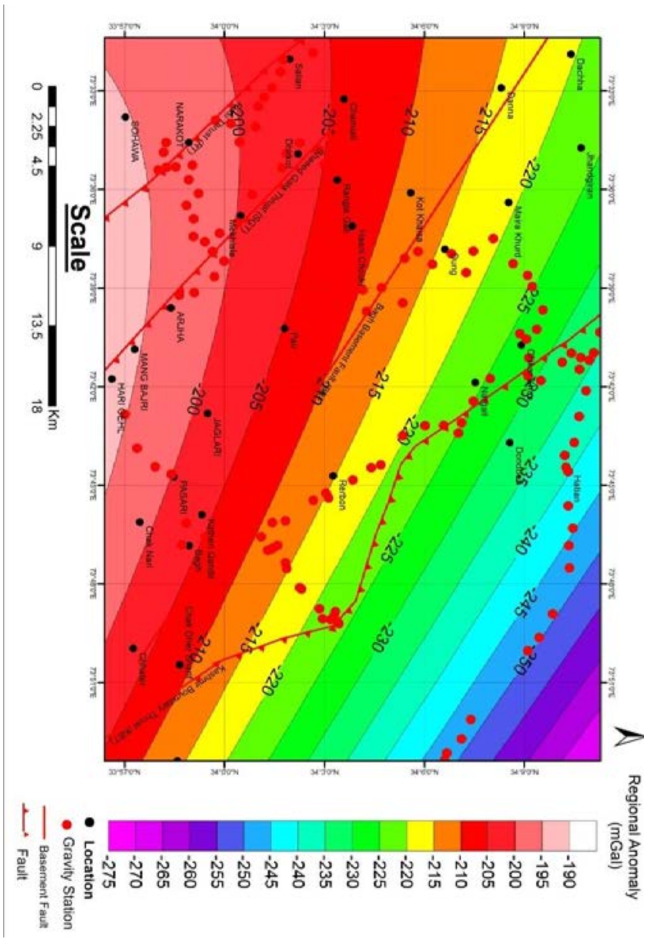

Fig. 5: Regional Bouguer anomaly map of the project.

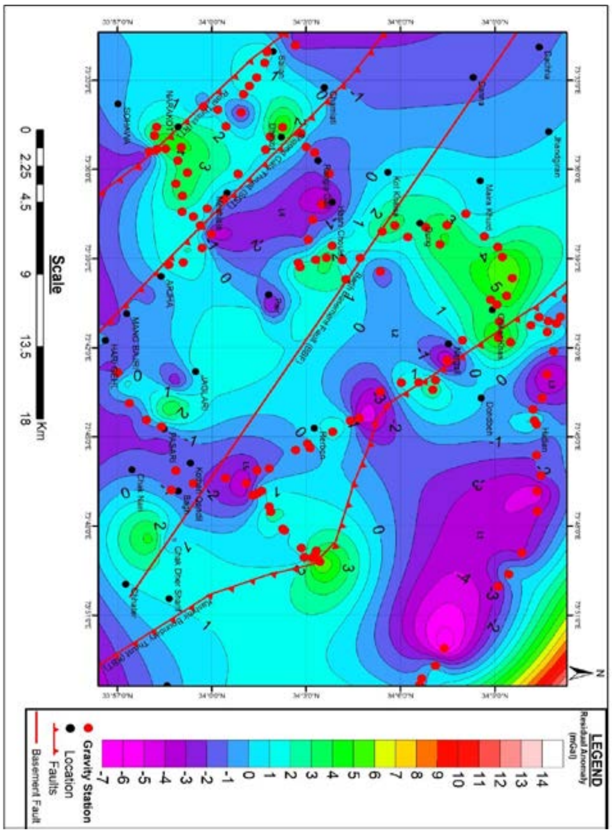

Fig. 6 Residual Bouguer anomaly map of the project.

Quantitative Interpretation

The study area has been extensively analyzed qualitatively in order to prepare the gravity model for the purpose of subsurface crust analysis, subsurface tectonic structures as well as to demarcate the surface faults. For the quantitative interpretation, the gravity modeling is used in the study area by using (Talwani et al., 1959) technique and also the software of Malinconico, (1986). Figure 7 shows the geological map of the area showing gravity stations.

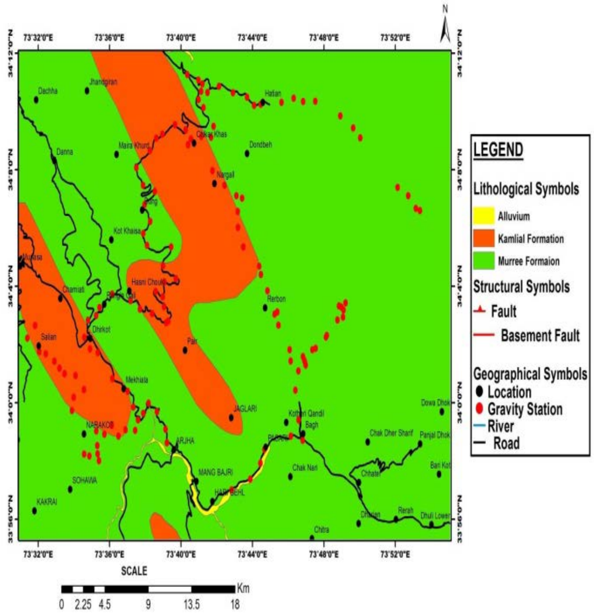

Fig. 7 Geological map of the project area displays the gravity station.

Gravity Modeling

Geophysical data modeling plays an important role in direct interpretation. Gravity modeling involves computing the gravity effects of a given density model (Huang et al., 2001). In this study the orientation of the profile B-B′ is southwest-northeast and has been selected across different lithological units for gravity modeling. The total length of profile BB′ was 31 km and the geographic coordinates are, B = 33°57′47″N, 73°31′55″E and B′ = 34°10′19″N, 73°51′54″E. In this gravity modeling, three steps modeling technique is used to calculate the adjustment and observed gravity data. The three-step model techniques are (1) the effect of sediments (2) effect of Moho (3) the combined effect of Moho and sediment with respect to 38km thick crystalline crust of Indian shield by Rustam and Ali (1994). The density difference that is used for the mantle and geological bodies is comparative to the average density of the crystalline basement used as 2.95 gm/cc by Rustam and Ali (1994). The density assigned for mantle is 3.30 gm/cc. The geological units of the study area are classified as Salt Range Formation and Meta-sediments of (Precambrian), Carbonate rocks of (Cambrian-Eocene), Kuldana Formation (Eocene), Murree Formation (Miocene) and Siwaliks are of (late Miocene- Pliocene). The densities assigned to these rocks units are given in Table 1. The designed gravity of this model shows the reasonably observed gravity effect. The gravity model computed by geophysical experiments is the abrupt change in Bouguer anomaly as well as low gravity gradient of -0.24 mGal/km in the southwestern portion of Bouguer anomaly map delineated Riasi and Shaheed Galla Thrust.

The Riasi thrust (RT) is demarcated in the study area between Murree Formation and Siwaliks. The model displays that the RT in the study area dips 42° NE and pierces up to a depth of 7 km in the sedimentary/meta-sedimentary wedge. The difference in density across this fault is 0.05 gm/cc. The Shaheed Galla Thrust (SGT) is determined within the Murree Formation and dip with an angle of 49° NE in the subsurface. Both RT and SGT intersect with the Bagh Basement Fault in the subsurface at a depth of 8.5 km towards north-east of SGT. BBF is demarcated in the Murree Formation. BBF dips 75° NE in the sedimentary/meta-sedimentary rocks and 85° in the crystalline basement in north-east directions and extends up to Moho depth. The gravity gradient in the modeled area is -2.12 mGal per km. Due to fault present in the basement crystalline crust of the Indian plate is broken into two blocks Figure 9. Further northeast of BBF, the gravity model represents high values of gravity gradient of -2.7 mGal/km demarcated the Kashmir Boundary Thrust (KBT) between Murree Formation and Kuldana Formation. KBT dips 30°NE and may go up to a depth of 4.2 km in the research work. The difference in the gravity values is 0.2 gm/cc.

From the study of model, it is recommended that the crustal thickness may increases from nearly 51 km in Sohawa to about 53.17 km in the northeast of Hatian area presented (Fig 8). The thickness of sedimentary/ meta-sedimentary wedge in southwest and northeast area is 11 km and 13.5 km respectively. The model clearly specifies the thickness of the crust layer that is increasing towards north-east direction because of the mounding of thrust along with the different reverse faults that are present in the study area.

Table 1 Density zones in project area, (Rustam and Ali 1994).

Formation	Lithology	Density (gm/cc)	Average density (gm/cc)
Siwaliks Group	Sandstone and shale	2.35-2.55	2.45 ± 0.1
Murree Formation	Sandstone and shale	2.44-2.66	2.55 ± 0.11
Kuldana Formation	Shale and marl	2.30-2.50	2.40±0.1
Carbonate Rocks	Limestone	2.60-2.75	2.67 ± 0.08
Meta sediments	Slates, phyllite and shale	2.48-2.55	2.53 ± 0.04
Salt range Formation	Marl, salt and gypsum	2.15-2.35	2.25±0.06

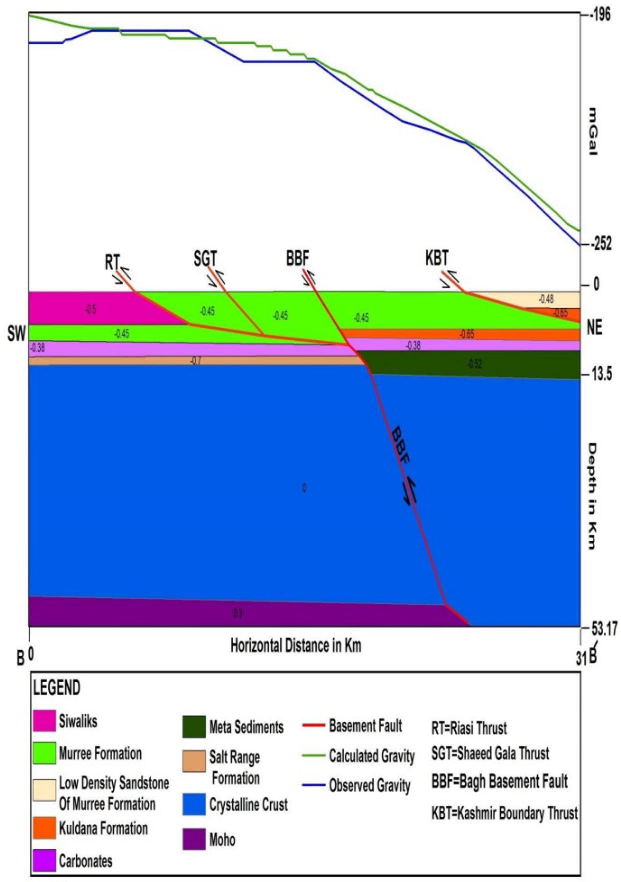

Fig. 8 Gravity model displays the sediments and Moho effects along profile B to B' from Sohawa to Hatians area.

Results and Discussion

From the study, it is confirmed that the model which we prepared tells us about the thickness of sedimentary/meta-sedimentary rocks is 11 km in SW of Sohawa and 13 km in NE of Hatian area. There will be contrast in the thickness of crust or Moho in different areas i.e. 49 km in SW of Sohawa to 53 km in NE of Hatian within a distance of 31 km. The computed gravity model also suggests that the crust thickness dips towards NE between Sohawa and Hatian.

Present study demarcates the Bagh Basement Fault in the study area which cuts throughout the sedimentary/ meta-sedimentary wedge and the basement up to Moho depth. The BBF dips at 75° north-east and stabbed up-to a depth of 53.17 km. The study showed that the Bagh Basement Fault is the boundary between salt and no salt zone in the subsurface.

Rustam and Khan, (2003) specified the presence of salt layer under the western portion of (HKS) Hazara Kashmir Syntaxes. They who suggested that the salt layer is pinching out at Jehlum fault and absent under the eastern limb of HKS. On this basis it was concluded that higher topography and high angle thrust faults that are present on the eastern portion of HKS are answerable for the absence of decollement.

According to Rustam and Khan, (2003), the Kashmir Boundary Thrust (KBT) is formed due to stresses produced by collision of Indian and Eurasian plates and this fault is a shallow thrust fault. It was determined that in NE of Muzaffarabad city, KBT links with (IKSZ) and penetrated up-to Moho- depth. The KBT is dynamic (active) tectonically and along with this fault, earthquakes of low and medium magnitude are expected.

The present study suggested that the KBT is passing between Murree and Kuldana formations and extends up-to a depth of 4.2 km in the area. The Raisi Thrust (RT) cuts through the sedimentary wedge between Siwaliks and Murree Formation and penetrates up to a depth of 7 km.

References

Ahmad, B., Akram, S., Ahmed, N., Jamil, S. (2018). Geological and geotechnical investigations at dam site for site characterization of 4320MW Dasu hydropower project, northern Pakistan. Journal of itallic *Himalayan Geology*, **39** (2), 171 – 187.

Baig, M. S., R. D. Lawrence, (1987). Precambrian to early Paleozoic orogenesis in the Himalaya. *Kashmir Journal of Geology*, **5**, 1-22.

Bossart, P., D. Dietrich, A. Greco, R. Ottiger J. G. Ramsay. (1984). A new structural interpretation of the Hazara-Kashmir Syntaxis (southern Himalaya) Pakistan. *Kashmir Journal of Geology*, **2**, 19-36.

Calkins, J. A., Offield, T. W., Abdullah, S. K. M. Ali, S.T., (1975). Geology of the southern Himalayan in Hazara Pakistan and adjacent area. *U.S Geological Survey*, **716**-C, 29.

Ghazi, S., Ali, S. H., Sahraeyan, M., Hanif, T. (2015). An overview of tectonosedimentary framework of the Salt Range, northwestern Himalayan fold and thrust belt, Pakistan. *Arabian Journal of Geosciences*, **8** (3), 1635-1651.

Hackney, R. I., Featherstone, W. E. (2003). Geodetic versus geophysical perspectives of the ‘gravity anomaly’. *Geophysical Journal International*, **154** (1), 35-43.

Huang J. Vaníček P. Pagiatakis S. Brink W. (2001). Effect of topographical mass density variation on gravity and the geoid in the Canadian Rocky mountains, *Journal of Geodynamic*, **74**, 805–815.

Hughes, N. C., Myrow, P. M., Ghazi, S., McKenzie, N. R., Stockli, D. F., DiPietro, J. A. (2019). Cambrian geology of the Salt Range of Pakistan: Linking the Himalayan margin to the Indian craton. *Bulletin*, **131** (7-8), 1095-1114.

Kazmi, A. H., Rana, R. A. (1982). Tectonic map of Pakistan 1: 2 000 000: Map showing structural features and tectonic stages in Pakistan. Geological Survey of Pakistan.

Khan, M. R., (1994). Tectonic study of the Hazara and its adjoining areas based on gravity study. *Unpublished Ph.D thesis*, 85 pages.

Kneisel, C. (2006). Assessment of subsurface lithology in mountain environments using 2D resistivity imaging. *Geomorphology*, **1**(2), 32-44.

Kono, M. (1974). Gravity anomalies in east Nepal and their implication to the crustal structure of the *Himalayan Journal of Geophysics Society*, **39**, 283- 300.

Latif, M. A. (1973). Partial extension of the evaporite facies of the Salt Range to Hazara Pakistan. *Nature*, **244**, 14- 125.

Malinconico, L. L. Jr. (1986). The structure of Khoistan-Arc terrain in northern Pakistan as inferred from gravity data. *Tectonophysics*, **124**, 297-300.

Rustam M.K., Ali, M. (1994). Preliminary gravity model of the Western Himalayas in Northern Pakistan. *Kashmir Journal of Geology*, **11**, 59-66.

Rustam, M. K., Khan, M. S. (2003). Study of shallow geological structures in the core of Hazara Kashmir syntaxis based on residual gravity data in Azad Jammu & Kashmir, Pakistan. *Geol. Bull. Punjab Univ*, **8**, 35-42.

Šumanovac, F. (2010). Lithosphere structure at the contact of the Adriatic microplate and the Pannonian segment based on the gravity modelling. *Tectonophysics*, **485** (1-4), 94-106.

Talwani, M., Worzel, J. L. Landisman, M. (1959). Rapid gravity computations for two dimensional bodies with application to the Mendocino submarine fracture zone. *Journal of Geophysical Research*, **64** (1), 49-59.

Wadia, D. N. (1982). The geology of Poonch State (Kasmir) and adjacent portion of the Punjab, *Memoir Geological survey* India, **51**, 185-370.

Vaníček, P., Novák, P., Martinec, Z. (2001). Geoid, topography and the Bouguer plate or shell, *Journal of Geodynamics*, **75**, 210–215.