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Tectonics of the Hazara and Adjoining Areas, Based on Gravity Data, Northwest Himalaya, Pakistan

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ABSTRACT: *Gravity data in the Hazara-Kashmir Syntaxis of northern Pakistan has been incorporated into interpretation of the gross crustal structure of the area. In this area, due to the continued northward migration of Indian plate, the Indian plate has been overridden by slices of its own northern margin and activity has caused the slight thickening of crust in the northeast and northwest of the Hazara-Kashmir Syntaxis. In the sedimentary wedge, the thinskin structures have been developed by the southward migration of the sedimentary wedge. In northern Pakistan, Late Precambrian to Early Cambrian strata constitutes the zone of decollement. It is absent in eastern side in Kashmir and India. In the eastern limb of the Hazara-Kashmir Syntaxis, the Main Boundary Thurst (MBT) and the Panjal Thrust (PT) are developed. Here the strong coupling between sediments and basement occured due to the absence of decollement which caused the high topography of the Hazara-Kashmir Syntaxis range front. In the western limb the MBT and the Nathiagali Thrust (NT) are developed. These thrust sheets moved southward over this decollement. The thrust system of eastern and western limbs are converging near the apex of Hazara-Kashmir Syntaxis. The differential movement resulted due to presence and absence of salt in the area developed the Jhelum fault. Jhelum fault cuts the PT, MBT and the Kashmir Boundary Thrust (KBT) in the Kashmir side and the MBT and NT in the western side in northern Pakistan. The sedimentary wedge of the western limb of the Hazara-Kashmir Syntaxis moves southward along this fault.*

INTRODUCTION

Northern Pakistan is characterized by two major structural arcuations. Northern one is the Nanga Parbat Syntaxis and southern one is called Hazara-Kashmir Syntaxis (HKS; Wadia, 1931). The Geology and tectonics of Himalaya east of the HKS are better understood than those towards west in northern Pakistan. The subdivision of Himalaya is well mapped in India, the major structure of the Hamalaya are the Indus Tsangpo suture, the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT). The MCT is less clear in Kashmir and yet is not traced satisfactorily towards west in Pakistan. This work mainly focuses on the Hazara and its adjoining areas of western Himalaya (Fig. 1).The tectonic evolution of the Himalayan-Tibtan system of thickened continental crust is the result of the Tertiary collision between India and Eurasia. Following break-up of Gondwana, India moved northward about 80 Ma ago at the rate of 15-20 cm/yr, which reduced to 5 cm/yr about 52 (Patriot and Achache, 1984) or 45 Ma ago (Dewey *et al.*, 1988). As a result of the commutative post collisional northward drift, the Himalaya-Tibetan system have accommodated over 2000 km of shortening through combined processes of subduction of India under Eurasia (Argand, 1924; Powel and Conaghan, 1973; Butler and Cowdard, 1989).

MODELLING

Gravity modelling in western Himalaya has been attempted by Khan (1994) using software of Malinconico (1989). Geological bodies in this case were approximated as horizontal prisms with finite length and polygonal cross-sections. In case of gravity modelling, the density contrasts assigned to mantle and geological bodies are relative to the average density of the crystalline basement taken as 2.95 gm/cc after Verma (1991). The lithological units crossed by the gravity sections are given in table-1. The density of these rock units is measured by Khan (1994) and the density assigned for the mantle is 3.29gm/cc after Leather (1987) and Khan (1994).

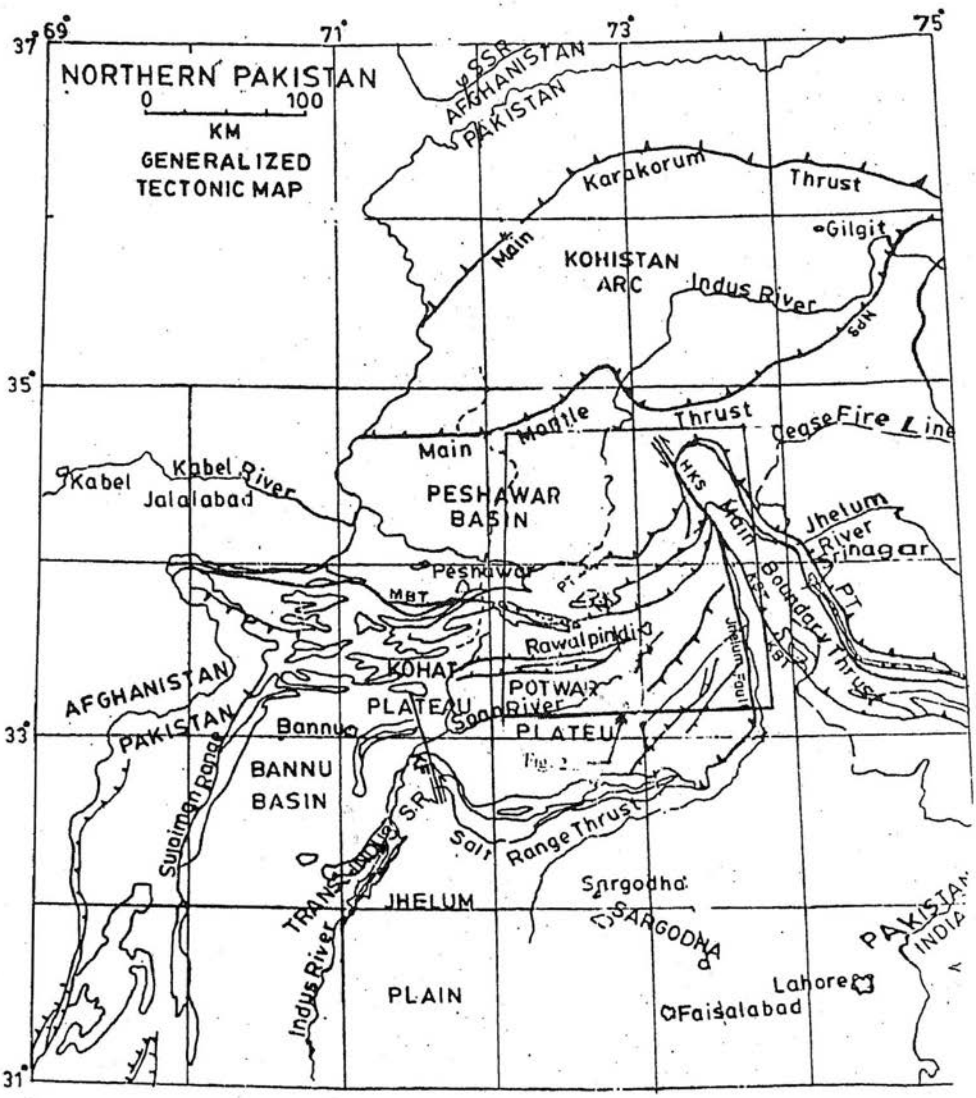

Fig. 1. Tectonic map of northern Pakistan. PT=Panjal Thrust, MBT=Main Boundary Thrust, KBT=Kashmir Boundary Thrust (Kazmi and Rana, 1982 and Chaudhary and Ghazanfar, 1993). Rectangle shows the study area of Fig. 2.

TABLE 1. DENSITY ZONES IN THE STUDY AREA (KHAN, 1994).

Formations	Major lithology	No.of Samples	Density (gm/cc)	Average Density (gm/cc)
Siwaliks	Sandstone and shale	20	2.35-2.55	2.45±0.1
Murree Fm.	Sandstone and shale	30	2.44-2.66	2.55±0.11
Carbonate Rocks	Limestones	66	2.60-2.75	2.67±0.08
Hazara Fm.	Slate and Shale	20	2.48-2.55	2.53±0.04
Panjal Fm.	Basic Volcanics and	10	2.75-2.80	2.72±0.11
	Agglomeratic Slates	10	2.59-2.71	
Tanol Fm.	Pelites/Psammites	20	2.43-2.60	2.51±0.08

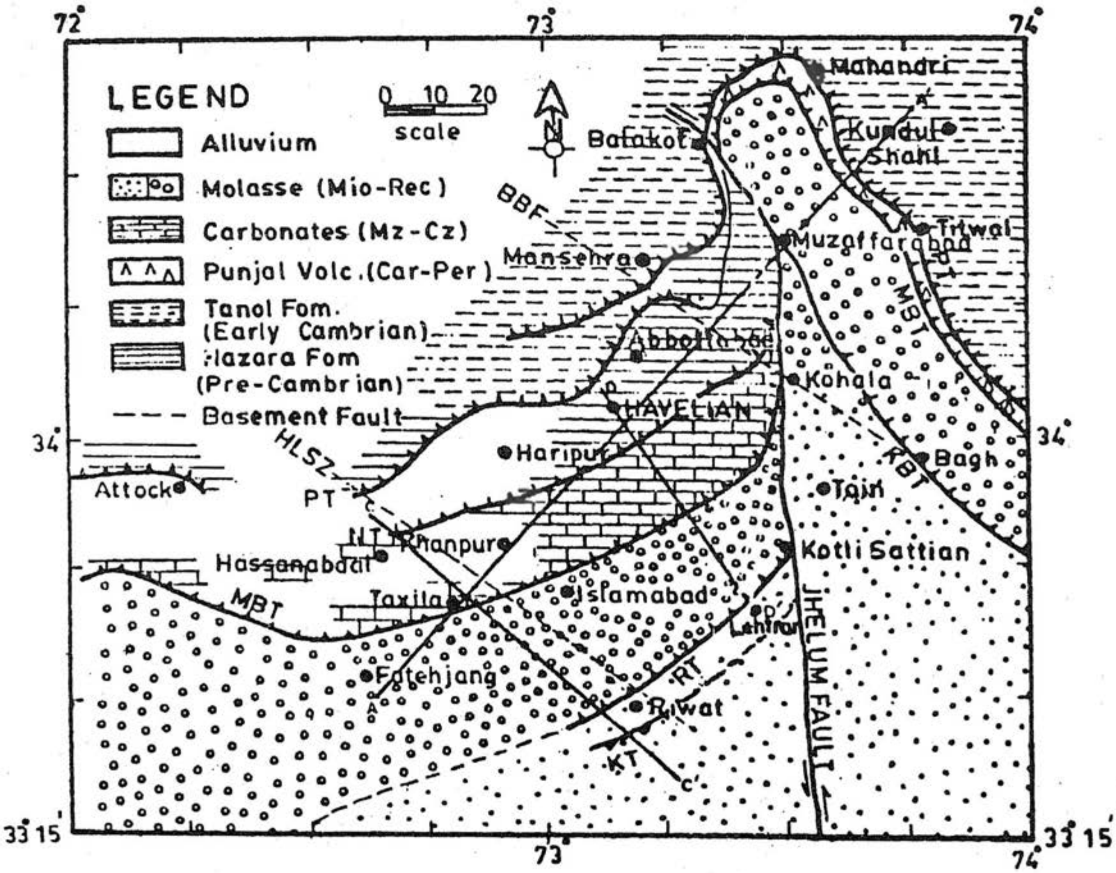

Fig. 2. Generalized tectonic map of Hazara-Kashmir Syntaxis in northern Pakistan. MT=Mansehra Thrust, PT=Panjal Thrust, MBT=Main Boundary Thrust, KBT=Kashmir Boundary Thrust, RT=Riwat Thrust, KT=Kahuta Thrust, HLSZ=Hazara Lower Seismic Zone and BBF=Bagh Basement Fault; (Waida, 1928; Latif, 1970, 1973; Calkins, et al. 1975; Kazmi and Rana, 1982; Baig and Lawrence, 1987; Greco, 1989; Chaudhry and Ghazanfar, 1993 and Khan and Ali, 1994. Section A-A′, C-C′ and D-D′ are selected for gravity modelling (Khan, 1994).

The modelling process was started from an initial geological model that was modified until the calculated gravity curve showed an acceptable agreement with the observed one. Modelling was carried out on three selected profiles which cross the HKS. One profile (A-A′) is trending SW-NE from the Fatehjang to Kundal Shahi in the Neelum Valley whereas the other two profiles (C-C′, D-D′) are SE-NW oriented from Riwat to Hassanabdal and from Lehtrar to Havelian, across the Hazara thrust system (Fig. 2) To cover the buried features such as Hazara Lower Seismic Zone (HLSZ) and Indus Kohistan Seismic Zone (IKSZ) of the Seebar and Armbruster (1979) and other expected basement and surface faults, the profile is selected. This profile in the western limb crosses the Hazara thrust system obliquely in the northeastern periphery of the area. In the eastern limb this profile crosses across the MBT and PT of Wadia (1931). The other two profiles C-C′ and D-D′ are selected across Hazara thrust system (MBT and NT).

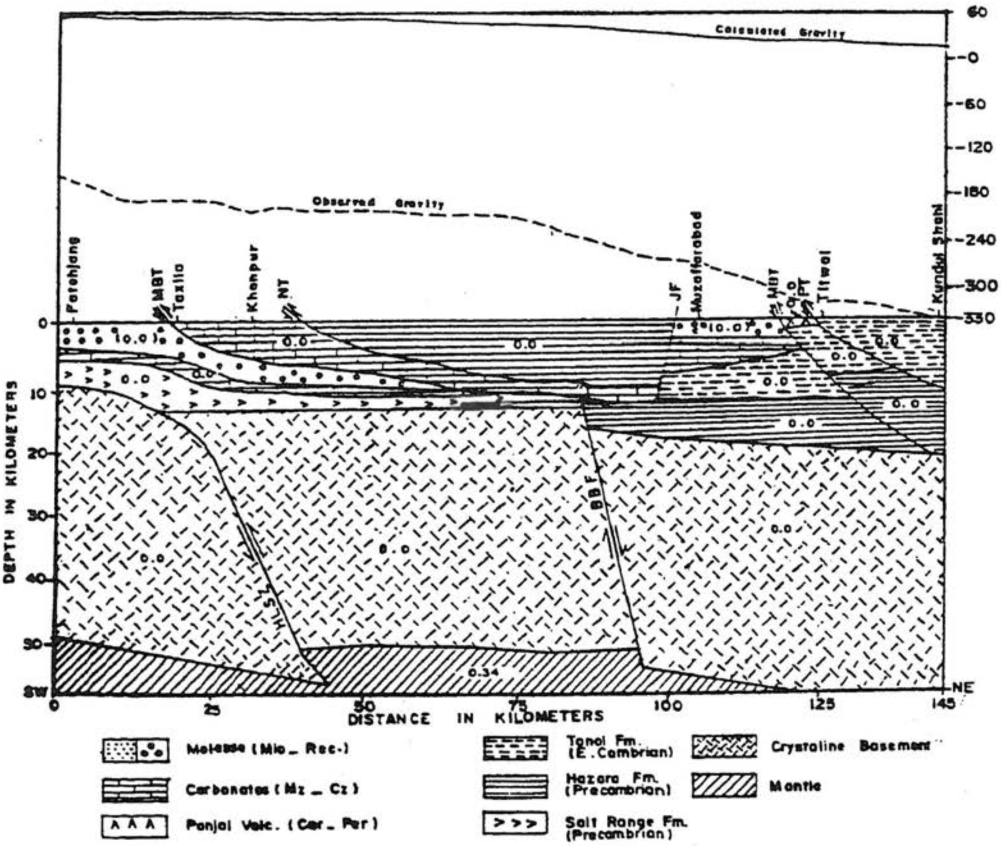

Fig. 3. Gravity model shows the Moho effect along the gravity profile A-A′. HLSZ=Hazara Lower Seismic Zone, BBF=Bagh Basement Fault.

Adjustment of calculated and observed gravity data is based on three step modelling i.e., contribution Moho, of sediments and then the combined effect of Moho and sediments with respect to 38 Km thick transitional crust of Seeber and Armbruster (1979). The Moho contribution if is separated from the adjusted model, then the calculated anomaly appears to give positive behaviour with relatively less deviation from the observed bouguer anomaly in the southwest. Corresponding to this calculated gravity effect along profile A-A′ (Fig. 3), the Moho shows a generalized dip of 4.73° towards northeast with major disruptions under Taxila to Khanpure and Mansehra areas (Khan, 1994). The sedimentary contribution in this model shows more negative behaviour of calculated gravity as compared to the observed bouguer anomaly (Fig. 4). In the southern side particularly south of MBT, the anomaly seems to be effected by low density post collisional molasse and the Salt Range Formation of Precambrian age. Whereas, from Khanpur to Kundal Shahi the anomaly is under the influence of thick and relatively denser sediments/metasediments and basic Panjal volcanics of Carboniferous to Permian age. The geological model derived from the combination of sediments, transitional crust and juxtaposition of the Moho is shown in Fig.5. The calculated gravity of this model shows reasonably the observed gravity effect. A similar approach has been followed in modelling the profile C-C′ and D-D′ oriented roughly NW-SE perpendicular to profile A-A′ (Fig.2).

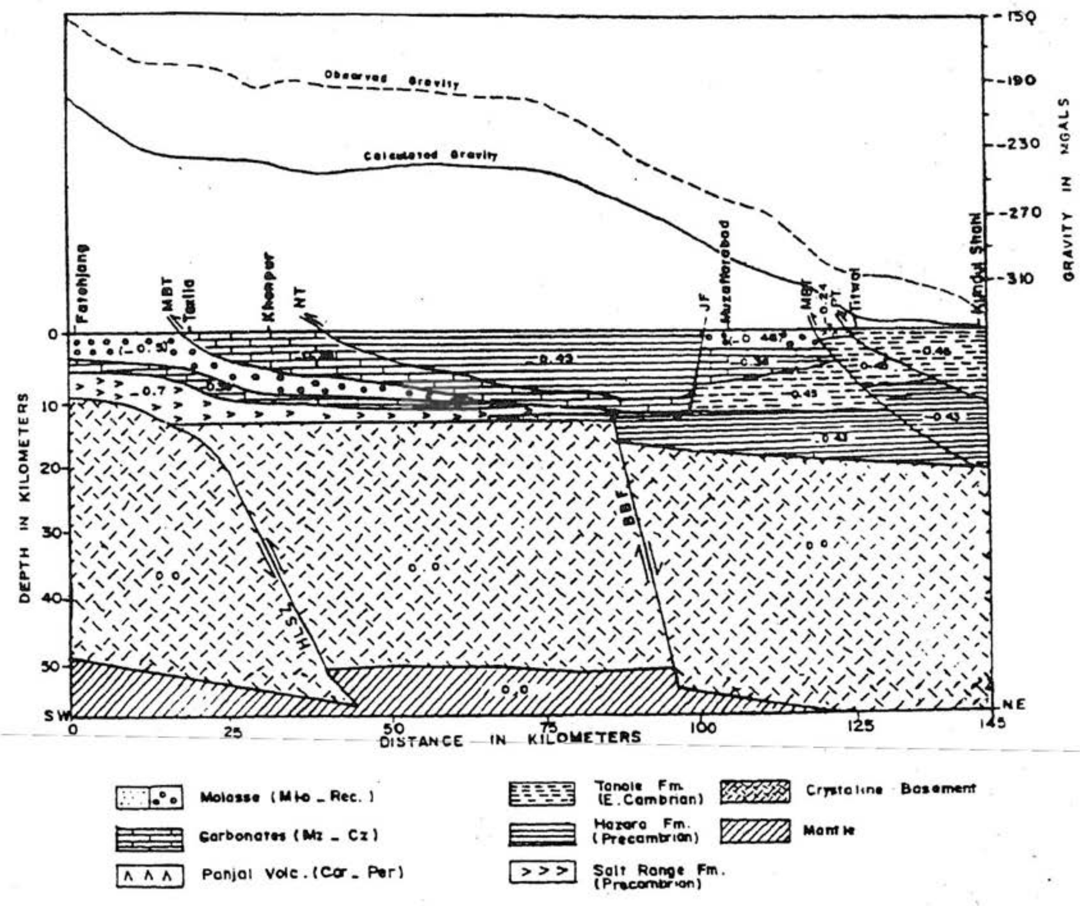

Fig. 4. Gravity model shows the sedimentary effect along the profile A-A′.

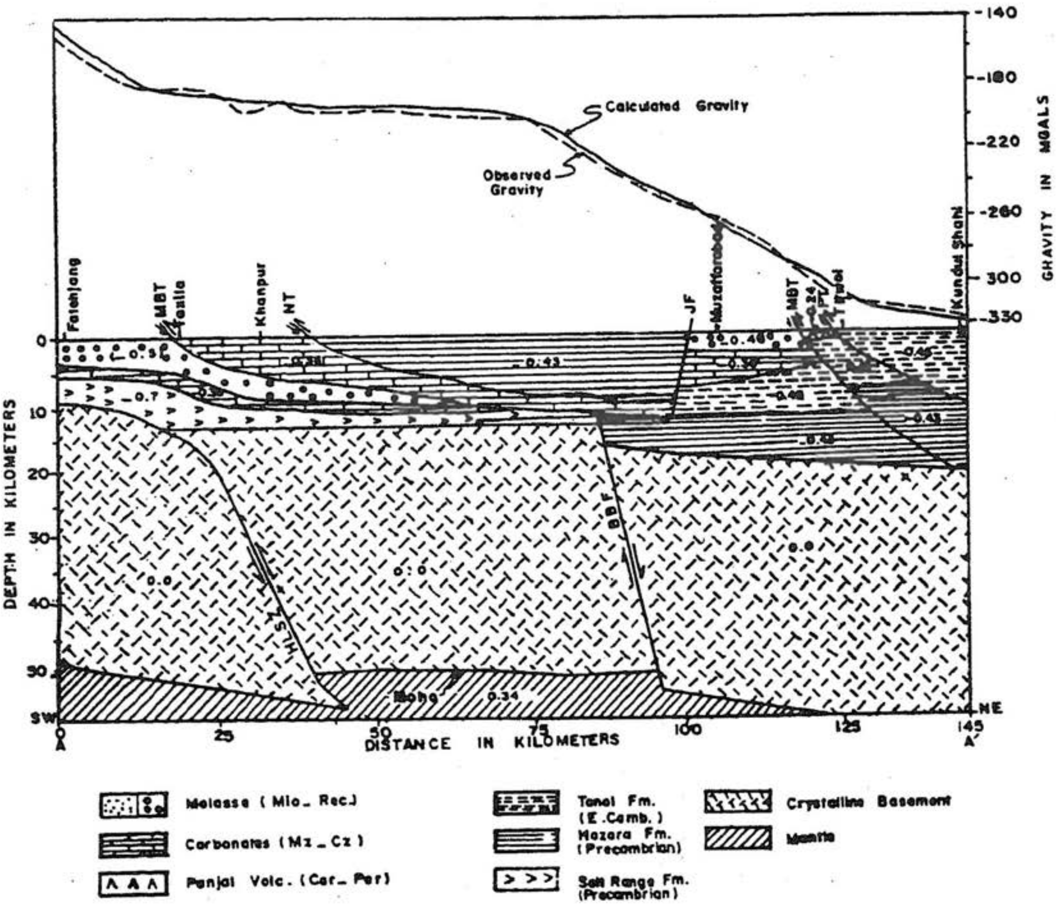

Fig. 5. Gravity model shows the combined sediments and Moho efects along the profile A-A′.

RESULTS

The gravity modelling along profile A-A′ (Fig.5) north of Taxila shows that the comparatively high density limestones of Eocene to Createaceous age thrust over the low density post collisional Murree and Siwaliks molasse along the MBT. In this area, the MBT dips 10° north. The Nathigali Thrust (NT) north of Khanpur, shows a dip of 14° north and brings the metasedimentary rocks of Precambrian Hazara Formation over the Eocene Cretacous limestones. In the eastern limb of the HKS near Titwal, MTB is a boundary between the basic Panjal volcanics and the molasse of Murree Formation. The gravity modelling (Fig.5) shows that the MBT in this region is dipping at an angle of 41° NE and penetrates to a depth of 20 Km (Khan, 1994). PT north of MBT separates the Permocarboniferous Panjal volcanic and Tanol Formation of Early Cambrian age and shows a dip of 30° NE. It is also observed in this modelling that the sedimentary wedge is thickening towards northeast (Khan, 1994). This modelling also indicates 2 Km thick Precambrian Salt Rang formation under Fatehjang, 3.75 Km under Taxila and pinches out near Jhelum fault. In contrast it is absent under the eastern limb near the apex of the HKS. The low angle faults of the western limb are the argument of southward thrusting on decollement. Whereas along the eastern limb the absence of decollement is responsible for high topography and high angle thrust faults. The modelling of profile C-C′ that extends from Riwat to Hassanabdal is given in fig.6. A sequence of low and high gravity observed in this case is due to rocks of different densities brought incontact by tectonic reasons. Steep gravity gradients near Hassanabdal, Taxila, Riwat and Kohuta are the indications of NT, MBT, Riwat Thrust (RT) and the Kohuta Thrust (KT) respectively. The Murree Formation molasse thrusts on the Siwaliks molasse along the Riwat Thrust. MBT in the northwest of RT bring the limestones of Eocene to Cretaceous age over the Murree Formation. In the northwest, the Hazara Formation of Precambrian thrust on the Eocene to Cetaceous limestones along NT. The gravity model (Fig.6) shows that the RT and MBT dip at 40° NW and 9° NW at Riwat and Taxila respectively. NT in the southwest of Khanpur dips at 12° NW. This model suggests that the Moho is deepening systematically towards north. Profile D-D′ represents the area between Lehtrar to Havelian about 40 Km northeast of profile C-C′. The model D-D′ is similar to model C-C′. In this model the MBT and the NT dip towards northwest at almost double the angle observed in C-C′. From these two models (C-C′, D-D′) it is evident that as we move towards northeast, the gradual increase in the dip of the thrust planes occur. This could be the result of thinning or pinching out of the decollement of the these sections. In the presence of decollement in the south, the rocks are thrusted southward, whereas in the area where decollema is absent, the rocks have been uplifted.

DISCUSSION

Indian crust dips northeast at 1 to 3° and is exposed near Kirana Hills Sargodha. It trends as ridge of the raised continental crust. Gravity anomaly is positive over the ridge and decreases to −330 m gals in the northeast. Farah *et al.*, (1977) attributed positive gravity signature to the horst like structure, whereas Duroy *et al.*, (1989) interpreted it interms of flexural model and attributed to the combined effect of Moho buldge and the excess of mass at lower crust or upper mantle levels. In the HKS between Fatehjang and Kundul Shahi, gravity gradient changes from −1 mgal/ Km in the southwest (Fatehang) to −0.4 mgal/Km in the central part (Taxila to Abbottabad) and −2.0 mgal/Km further northeast. Reduction in gravity gradient in the central part has been accounted in gravity modelling by Moho convexity and block displacement between crustal scale faults. Moho generally follows the dip of the overlying crust, if is warped or depressed anywhere corresponding to the configuration of the elastic crust, would generate tremendous stresses.

The geological models (Figs. 5-7) derived from gravity data describe lithostructural nature of the sedimentary/metasedimentary wedge and decollement. The decollement is a salt horizon between the overlying sediments and the underlying crystalline basement. The decollement under the western limb of the HKS thins out towards east and is terminated near Jhelum fault (Khan, 1994). The deformation front along the Salt Range Thrust Front is currently advancing into the foredeep progressively involving younger sediments. The folding, thrusting and shortening of the sedimentary wedge along its front are the most prominent surface expression of the ongoing southward slip of the decollement toward the foreland. The detachment beneath western limb of the KHS (Potwar plateau) coincides with the thick Precambrian Salt Range Formation that outcrops at the Salt Range area. A significant quantity of gypsum was found in the Hazara Formation outcropping in the uplifted block of the NT (Latif, 1973). Calkins *et al.* (1975), also reported gypsum in the Salkhala Formation of Cambrian age at the Tarbala dam site. On the western side of the syntaxis the presence of the salt on the detachment beneath the Potwar platean is well documented by petroleum exploration (OGDC).

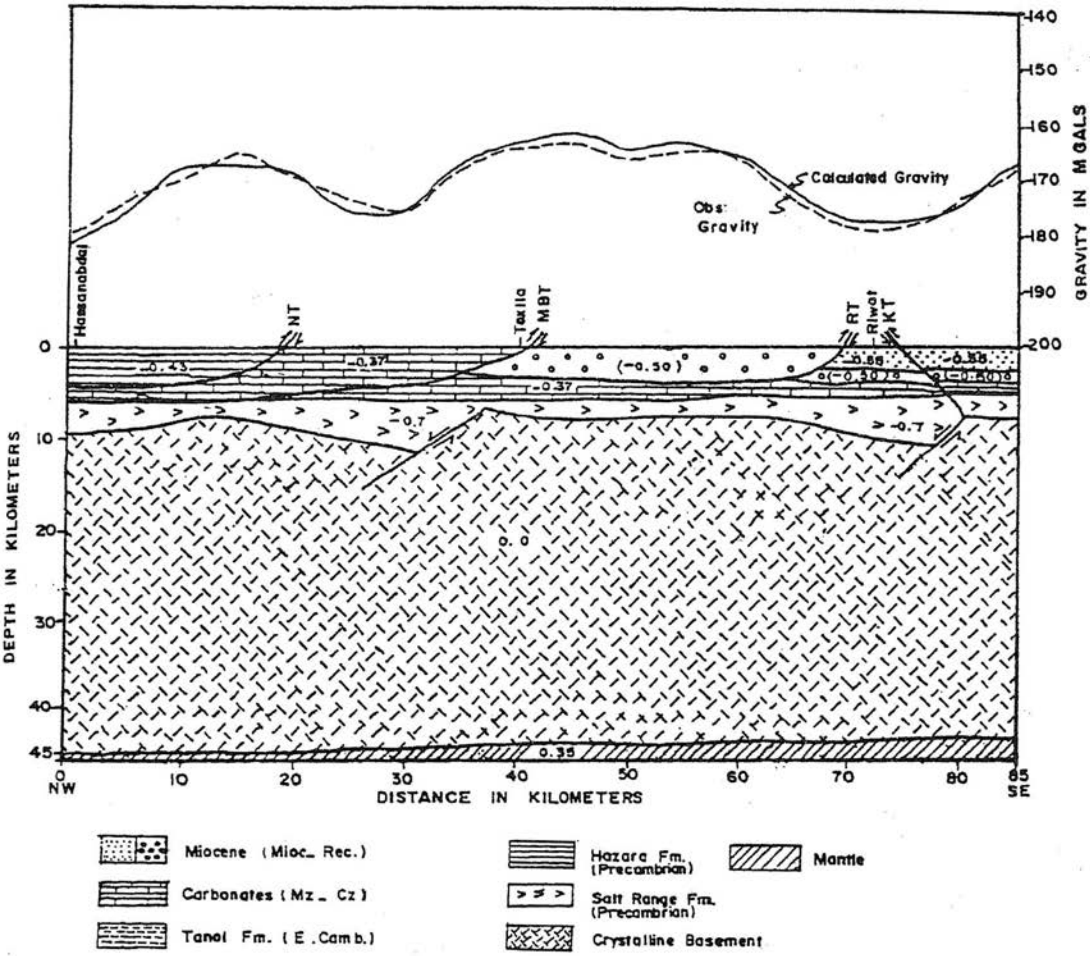

Fig. 6. Gravity model shows the combined effects of sediments and Moho along the profile C-C′.

In the sub-Himalaya east of the syntaxis no salt is reported on the up thrown side of the Riasi thrust or KashmirBoundary Thrust (KBT) as shown in fig. 2. Further east, in Kangra, exploration wells showed no salt at the base of the sediments (Mathur and Kohli, 1964). In the eastern limb the Panjal volcanics thrust on the Murree Formation along the MBT and the Tanol Formation thrusts on the Panjal volcanics along the PT near Titwal. Relatively high angle thrust faults (MBT and PT) in the eastern limb trend in the NW-SE and converge near the apex of HKS. Seismic activity along MBT and high topography are possibly related with the absence of salt under the eastern limb. This also seems responsible for an anomalous thickness (16-20 Km) of the thrust wedge through a process of stacking of thrust sheets. In contrast 10 to 13 Km thick thrust wedge of the western limb shows low angle thrust faults, low topography over the decollement and SSE tectonic transportation. The angle of these thrust faults increased from SW to NE where the thickness of the Salt Range Formation decreased.

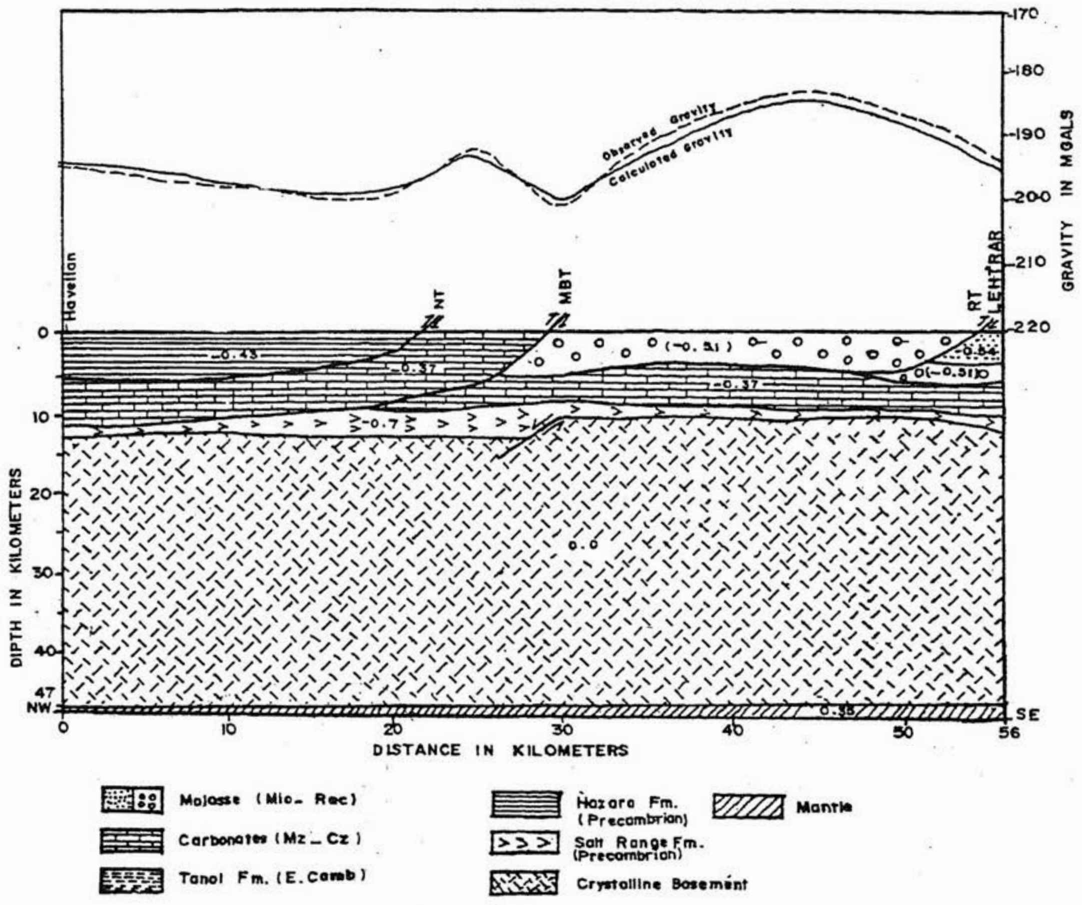

Fig. 7. Gravity model shows the combined effects of sediments and Moho along the profile D-D′.

Crustal shortening due to northward under thrusting of the Indian plate beneath Eurasian plate continued creating active tectonic features on the northern fringe of Indian craton since the major collision began in Eocene time (Fig. 2) The Kohistan Island arc overriding the Indian plate is pushing the rocks to the south and developed the thinskin structures in the sedimentary wedge. Due to this pushing SSE ward stresses developed on the western limb and SSW ward stresses on the eastern limb of HKS. The Hazara Formation of Precambrian age thrust on Eocene to Cretaceous limestones along the NT and these limestones are thrust over the Murree Formation in the western limb along the MBT. In the latest stage SSE ward stresses developed the Jhelum fault which cuts the Hazara thrust system in the west and Titwal thrust system (PT and MBT) and KBT in the east. The western limb of HKS moves southward along this fault whereas in the eastern limb thrust sheets are uplifted. The Kuldana shales are acting as a secondary decollement for the Riwat thrust in the southeast of the MBT.CONCLUSIONS

1. The style and deformation in the western limb of Hazara Kashmir Syntaxis differs from that of the eastern limb. The Salt

   Range Formation acts as a decollement under the western limb of Hazara Kashmir Syntaxis and is absent under the eastern limb.

2. Due to the presence of Salt Range Formation, the Hazara thrust system has low angle faults and low topography. The angle of these thrust faults gradually increases from SW to NE where the thickness of Salt Range Formation decreases.

3. In the eastern limb of the Hazara Kashmir Syntaxis the absence of Salt Range Formation developed the high angle thrust faults (MBT and PT) and high topography. There is strong coupling between sediments and basement as compared to the western limb of the Syntaxis.

4. Due to the collision of Indian and Eurasian plates crystalline basement has been overridden by slices of its own northern margin. The SSE stresses on the western limb and SSW stresses on the eastern limb developed the thinskin thrust faults in the sedimentary wedge. These thrust sheets have brought in contact the different lithological units which caused the 8 Km thick sedimentry/metasedimentry wedge at the Fatehjang in the southwest and 20 Km thick at the Kundul Shahi in the northeastern side of the area.

5. Kuldana shales are acting as a secondary decollement for the Riwat thrust in the southeast of the MBT.

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