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Deep Structure of Himalaya

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ABSTRACT

The Siwaliks of Himachal Pradesh are contained between the MBF on the east and the eastern margin fault of the Marwar Craton. Similarly the NE margin fault of the Aravalli Craton limits the Lr.Tertiary of UP from the MBF of the Kumaon region. This fault proceeds eastwards from Tanakpur as the southern boundary of the Siwalik outcrops of Nepal and Bhutan until it meets the northern promontory of the Shillong mass. Thereafter it proceeds eastwards as the Jorhat fault of Upper Assam. The combined fault from west to east is the northern limit of the Precambrian shield.

A composite NS seismic section from Samastipur in Bihar across Nepal, the Himalaya and S.Tibet upto Tsangpo suture is available (Indepth). Two major deep faults are mapped in this section. The first is near the MBF and the other is at the foot of the Himalayan peaks in Nepal. The former coincides with the northern limit of the Precambrian shield and has a throw of about 30 km. at Moho level. The other fault at the foot of the Himalaya also has a throw of about 30 km. at Moho level. On comparing with the gravity anomaly picture these faults are located in the regions of very high gravity gradients. The western and eastern extensions of the latter can be considered to be corresponding extension of the deep faults.

These faults lie in the subduction zone of the Indian subcontinent below the Himalayan thrusts. It is apparent that in the precollision period they are part of the Indian shield like the Gondwana grabens. Interestingly the Himalayan Gondwanas are located between these fault zones, whether in Kashmir,Nepal or Arunachal Pradesh. The conclusion is that, precollision, the faults form the boundaries of a long Gondwana graben extending from Kashmir to Arunachal Pradesh. This graben limits the Precambrian shield in the north.

INTRODUCTION

An effort to study the Himalayan foreland was initiated by the ONGC in connection with its programme of oil exploration. It consisted of gravity, magnetic and seismic surveys to delineate structures which could possibly entrap hydrocarbons. While the surveys were of high quality, subsequent drilling proved that the area was devoid of hydrocarbons, a situation that persists even today. However the surveys have proved to be of great academic value in understanding the structure of the foreland basins. One constraint in the effort was that a substantial portion of the northern foreland lay in Nepal and Bhutan, areas that were inaccessible to Indian explorers. As far as the Himalayas themselves are concerned, the data available was confined to the maps prepared by the geologists of the Geological Survey of India and by several foreign geologists. The best composite map available today is that published by A.Gansser. Geophysical data was until recently totally non-existent. At present two major seismic profiles across the Himalayas are available. The first extends from the Srinagar Valley northwards upto Pamir. The second extends from the southern border of Nepal northwards across the High Himalayas, Southern Tibet and upto the Tsangpo suture. The latter is recognized as the "Indepth Section". Gravity data in the Himalayas,Nepal and Bhutan is now available only on the basis of satellite measurements. These are however extremely useful in the study of the deep structure of the Himalayas. The present paper is an effort to put together all the currently available information to study the foreland and the Himalayas in an integrated form.

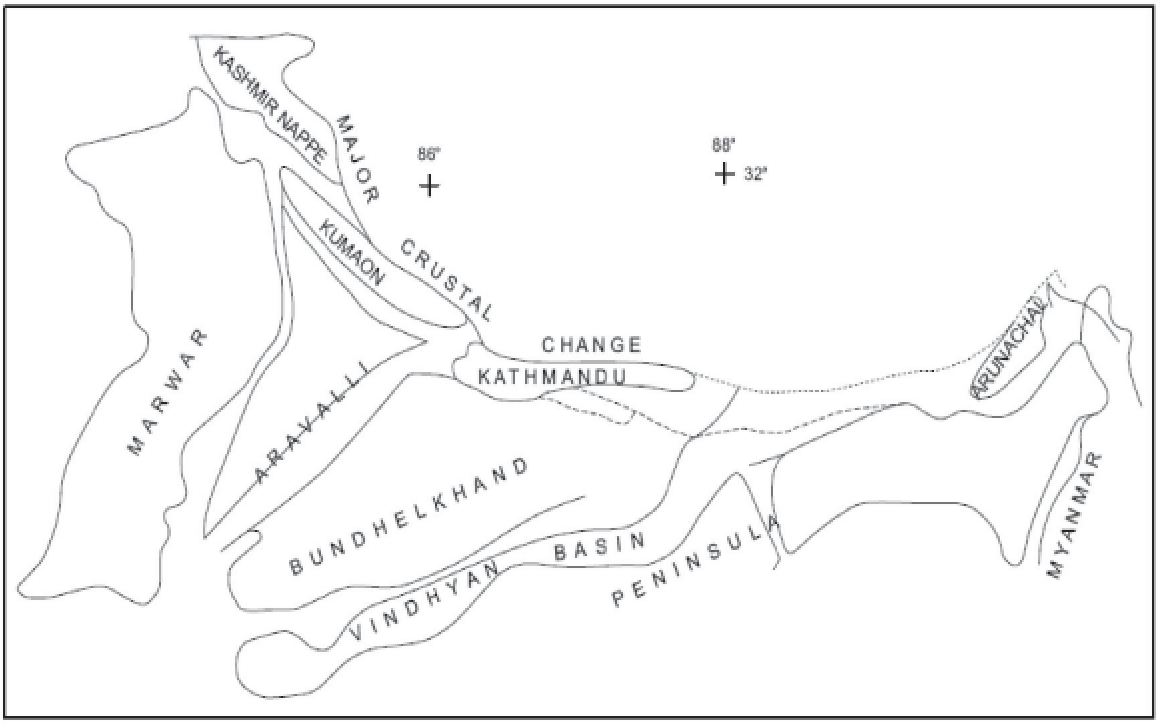

Figure 1. Cratons of North India.

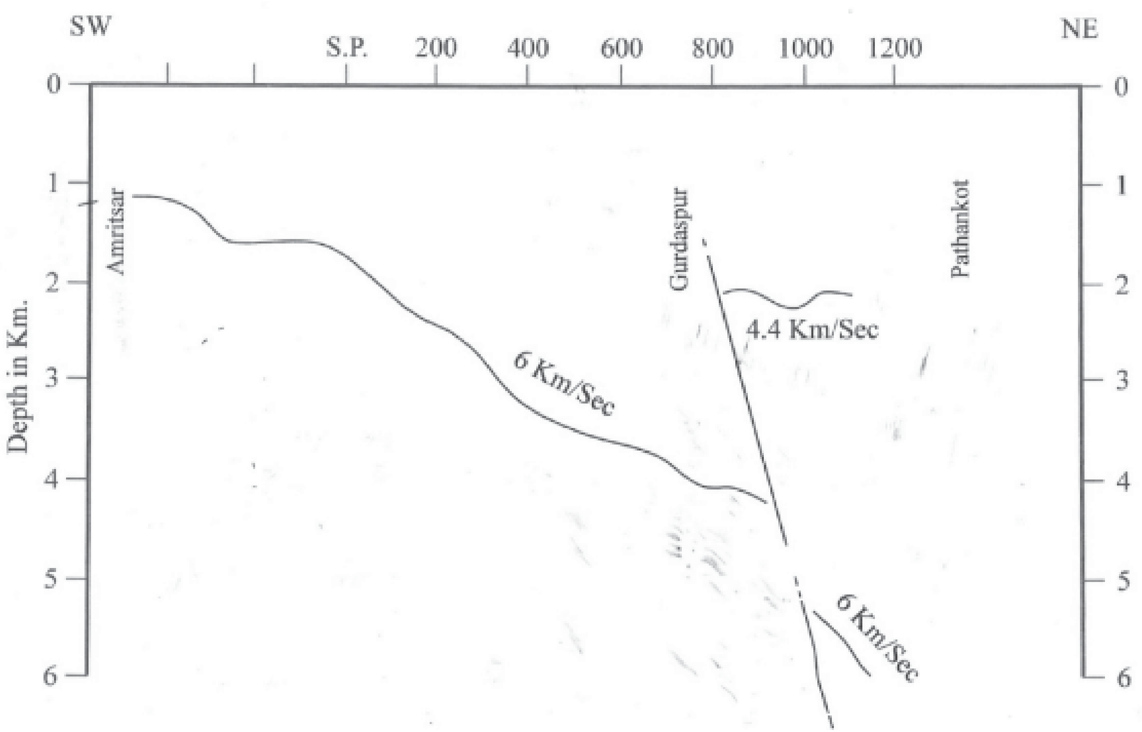

Figure 2. Amritsar-Pathankot Refraction Profile.

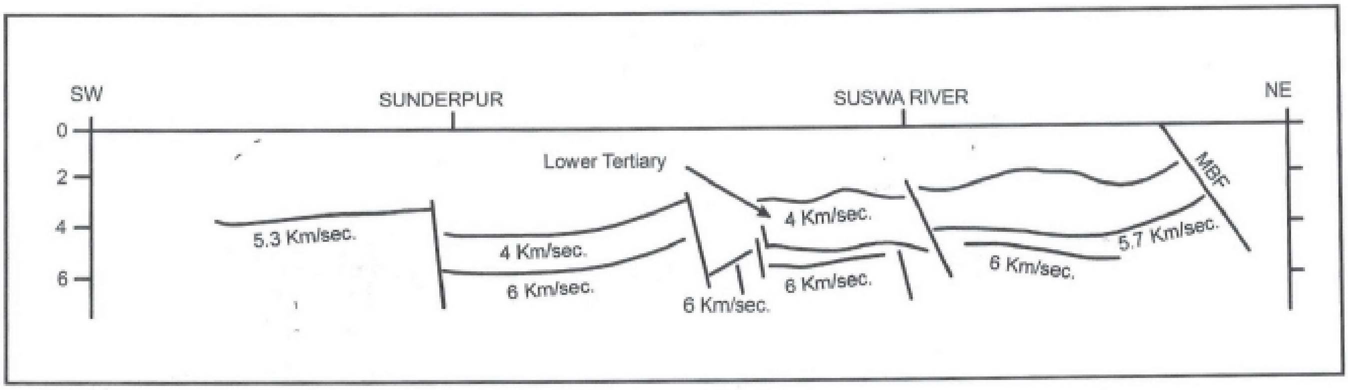

Figure 3. Sahranpur-Dehradun Refraction Profle.

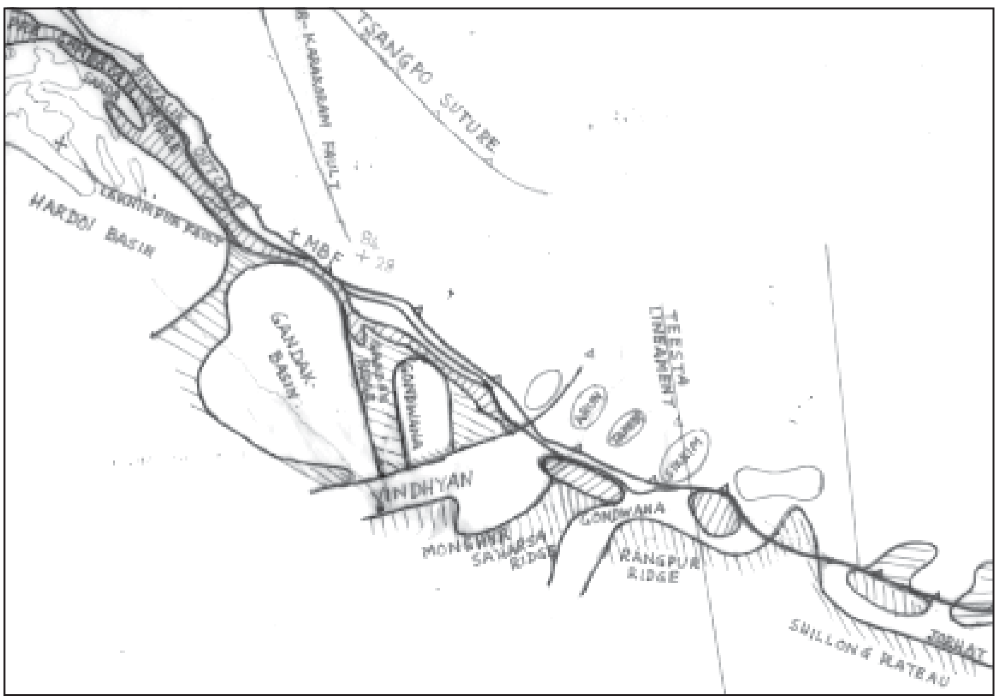

Figure 4. Contact of Ganga Valley with Himalaya.

STRUCTURE OF THE FOREDEEP

As a first step the geology and gravity data have been put together to form a map showing the block structure of North India (Fig. 1). These are the Marwar, Aravalli, Bundelkhand cratons, the South Vindhyan Basin, and the Monghyr Saharsa ridge (which is a northeast extension of the southern peninsula. The Marwar craton is terminated on its eastern edge by a major fault. On the gravity picture this is indicated by a crowding of contours. A refraction seismic profile was shot from Amritsar upto Pathankot, and this unerringly brought out the fault near Gurdaspur. The emergence of the lower tertiary to the east of Gurdaspur was evident (Fig.2). Extensive Siwalik deposits outcrop between this fault and the MBF further east.

The northern portion of the Aravalli craton ends in an E-W fault (Fig. 1). Siwalik deposits outcrop between this fault and the MBF to its north. Fig 3 shows a refraction seismic section from Sundepur northwards upto Dehra Dun. This localizes the northern fault of the Aravalli craton. A little to the south of this fault lies the Moradabad fault. Between them they form a narrow ridge (Fig. 4), which extends eastwards to south of Tanakpur. Again Siwaliks outcrop between this ridge and Tanakpur. The ridge proceeds southeastwards as the Sarda Ridge until it intersects the E-W Lakhimpur Fault. It is sheared eastwards parallel to the Lakhimpur fault\ for some

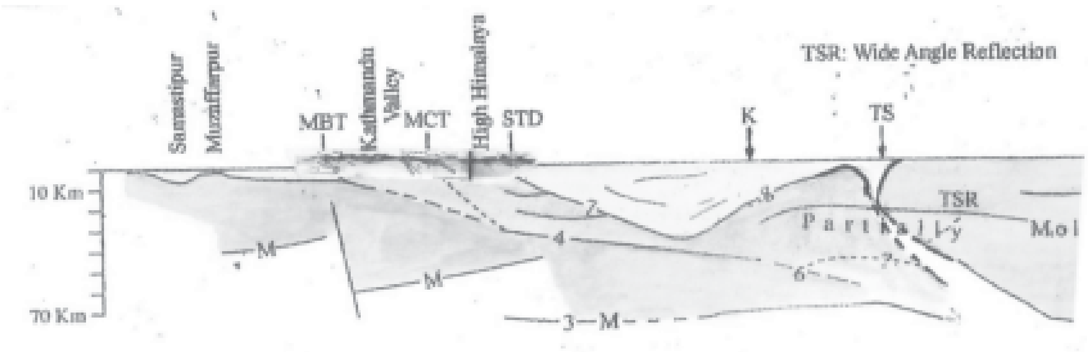

Figure 5. Composite INDEPTH Profile.

distance after which it resumes its southeasterly course upto the northward prominence of the Shillong plateau. All through its length it forms the southern boundary of the Siwalik outcrop. The ridge forms the northern boundary of the pretertiary deposits all the way from the Aravalli Range upto Assam.

The Gangetic plains south of the above ridge have been mapped by seismics and the various pretertiary basins have been isolated. The Hardoi and Gandak basins lie to the south of the Lakhimpur fault and are separated by the Faizabad Ridge. A NW-SE fault is seen along the Gandak river, which is the eastern limit of the Gandak basin. This fault is the western edge of the NW-SE Gandak ridge. A Gondwana basin has been recognized east of the Gandak ridge. This is terminated on its east by the Muzzafarpur fault. The latter is the boundary between the Bundelkhand craton and the south Vindhyan deposits. It continues NE wards into the Lesser Himalaya of Nepal to the west of the Arun River.

The Vindhyan basin is followed by the Monghyr - Saharsa ridge. Gondwanas outcrop on the east of this ridge in the Rajmahal-Garo Gap and plunge northwards under the Siwaliks almost upto the MBF. This Gondwana basin is separated from the Vindhyan basin by the Monghyr Saharsa ridge.

All the pretertiary basins described above are covered by a subsurface wedge of Siwaliks stretching from the Yamuna river in the south upto the northern ridge. This wedge is not affected by the strong thickness variations of the pretertiary sediments. The Siwalik thickness varies from zero in the south upto about 5 km. in the north.

STRUCTURE OF THE HIMALAYA

The above descriptions relate to the foreground basins of the Himalaya. We have now to examine its relation to the Himalayas proper. For this purpose we choose a seismic profile shot by ONGC in Bihar from Samastipur in the south upto Raxaul in the north. This profile cuts across the Gondwana basin east of the Gandak ridge and just starts climbing up the northern ridge. The "Indepth profile" to its north more or less aligns with and proceeds north upto the Tsangpo suture. The composite section is shown in Fig. 5. The figure clearly brings out the detachment surface between the subducting Indian plate and the Himalayan thrusts above it. One can also recognize the Tibetan plate in the north pushing the Indian upper crust and the Tethys sediments to form the various Himalayan thrusts. The significant point however is not the thrusts (which are well known), but the presence of two huge faults in the lower crust and the corresponding Moho. Each of these faults has a throw of about 30 km. and together they bring the Moho down from about 35 km. in Nepal upto 75 km. or more in S.Tibet. The southern one of these two faults lies close to the MBF and the northern one lies near the foot of the High Himalaya. The southern fault can be taken to be the contact of the Siwalik outcrops with the northern ridge in the plains.

Fig.6 is the regional satellite gravity anomaly picture of the Himalayas and Tibet. One can recognize the presence of unusually large gradients in several places. Two such places are seen in the intersection with the "Indepth profile" These coincide with the two huge faults that have been identified on the profile. We thus recognize the signature of the faults on the gravity anomaly map.

In order to correctly localize these faults, we extract the residuals from the gravity anomaly map (Fig.7). The northern fault is seen to closely follow the foot of the peaks of the High Himalayas. The southern fault is very close to the MBF. Towards the west the Lakhimpur fault is brought out. To the north of the Lakhimpur ridge one recognizes a prominent low. This is the syncline on which the Garhwal Nappe

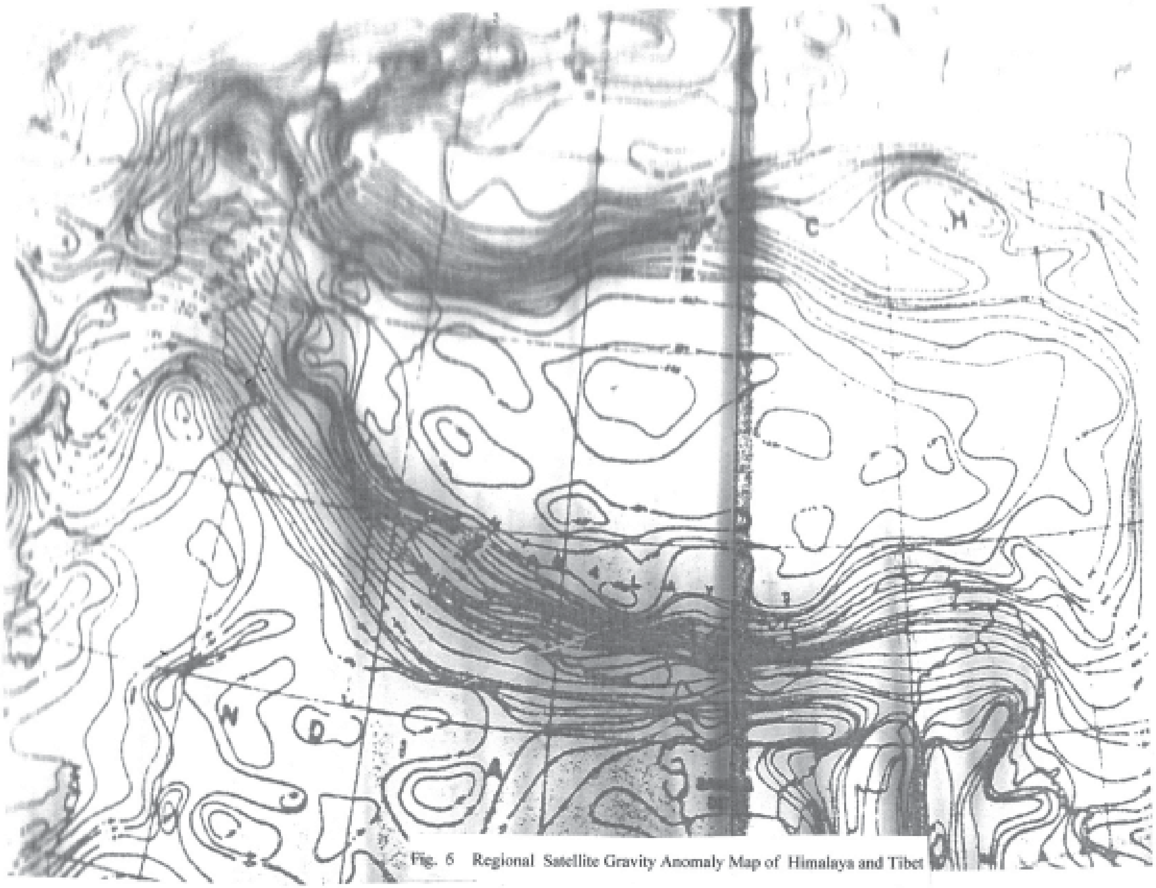

Figure 6. Satellite Gravity Anomaly Map of Himalaya and Tibet.

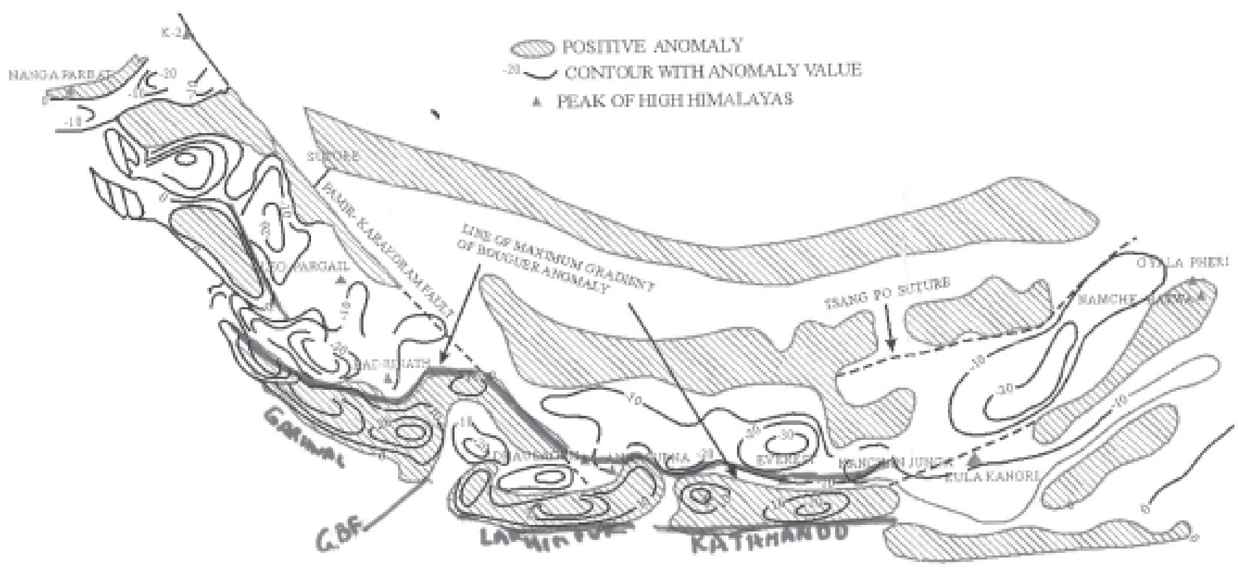

Figure 7. Residual Gravity Anomaly Map of Himalaya and Tibet.

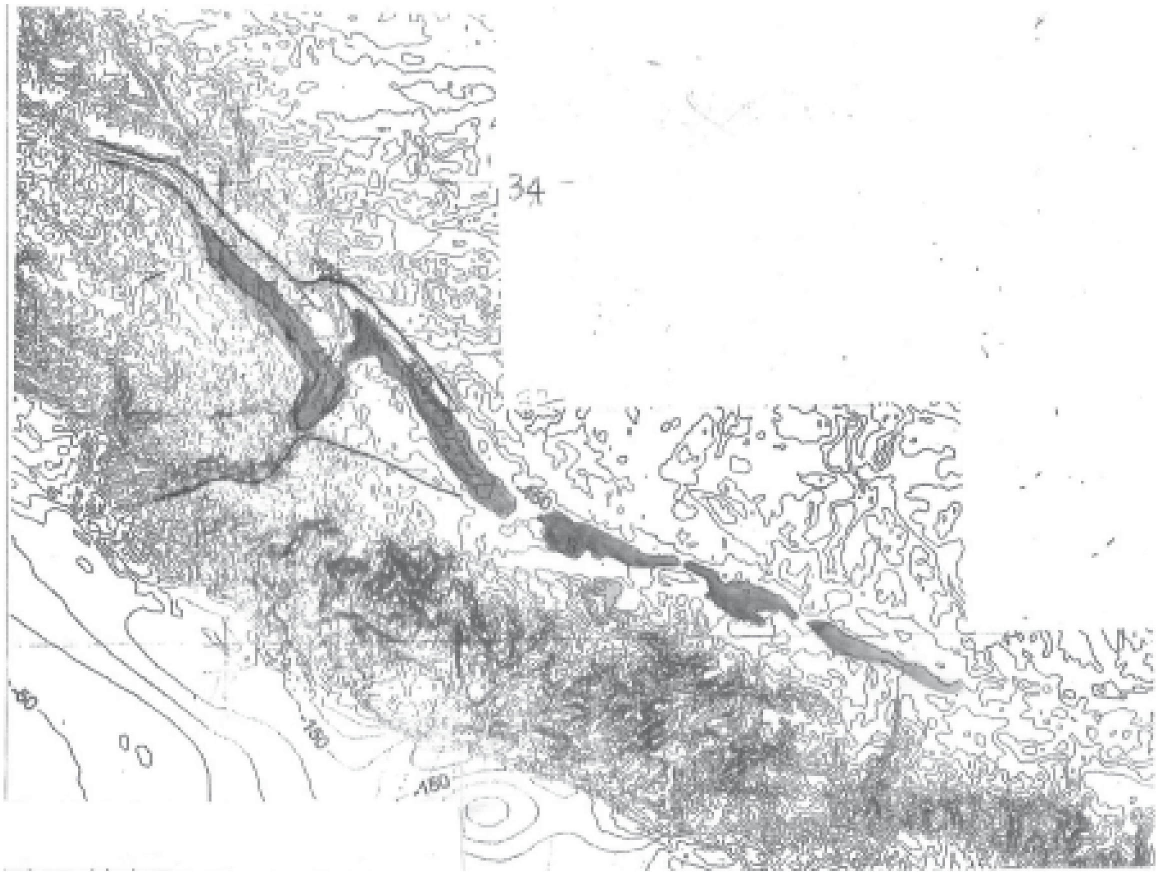

Figure 8. Unfiltered Satellite Gravity Map of Himalaya and Tibet

is built. The high in Nepal is abruptly cut off in the east and is apparently shifted southwards. This is the effect of the Teesta Lineament. In the north one notices the Tsangpo and BNS sutures. In the northwest Himalayas, the fault at the foot of the Great Himalayan Range is the western edge of the Spiti Basin. The general picture in that area shows the NW Himalaya to be a unit independent of the EW-Himalaya to the south. The dividing line is the Sutlej / Shali window.

Fig. 8 is the unfiltered satellite gravity anomaly map of the Himalayas and Tibet. One can qualitatively see the division of the area into the NW Himalayas and the EW Himalayas separated by the Sutlej window. The eastern end of the Spiti Basin is occupied by the Tso-Morari dome. It is terminated in the south by the Kaurik Fault. The gravity picture shows the extension of the dome southeastwards after a shear across the Kauri Fault. In the south it turns eastwards to become the Rakshas anticline. The Ladakh Range is clearly marked out. Fig. 9 is a sketch map of the area of the Great Himalayan Range and the areas to the north and northeast of it. The Kauri Fault is seen to extend west along the Sutlej river into the Lesser Himalaya separating the NW from the EW Himalaya. It serves as a major shear line.The sedimentary contact of the Spiti basin with the Great Himalayan Range is sheared eastwards. Similar is the case with the Tso-Morari dome. The Indus suture is deflected eastwards. The Indus river is correspondingly displaced. The southern part of the Tso-Morari Dome is the water divide between the Indus and Sutlej rivers. The Gurla Mandhata dome is separated from the Rakshas anticline by a narrow EW trough.

The Himalayan Gondwanas form an interesting study. All the way from the Kathmandu region upto Arunachal Pradesh the Himalayan thrusts are underlain by Gondwanas in the region of the MBF. The occurrence of Gondwanas as a window in the Ranjit Valley idicates that a corresponding basin exists below the thrust between the MBF and the High Himalayas from Nepal upto Arunachal Pradesh (Fig.11).

Fig.10 is a reproduction from Gansser's book showing the section across the Kumaon Himalayas between the northern edge of the Garhwal Nappe and

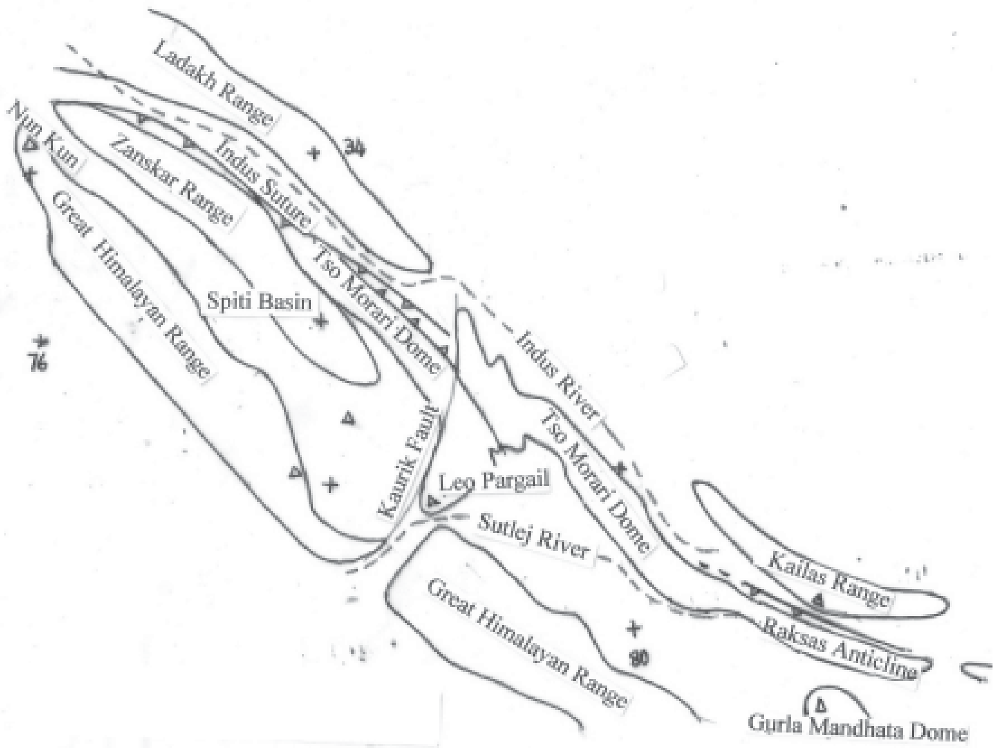

Figure 9. Sketch Map of High Himalayas of Himachal Pradesh and Kumaon

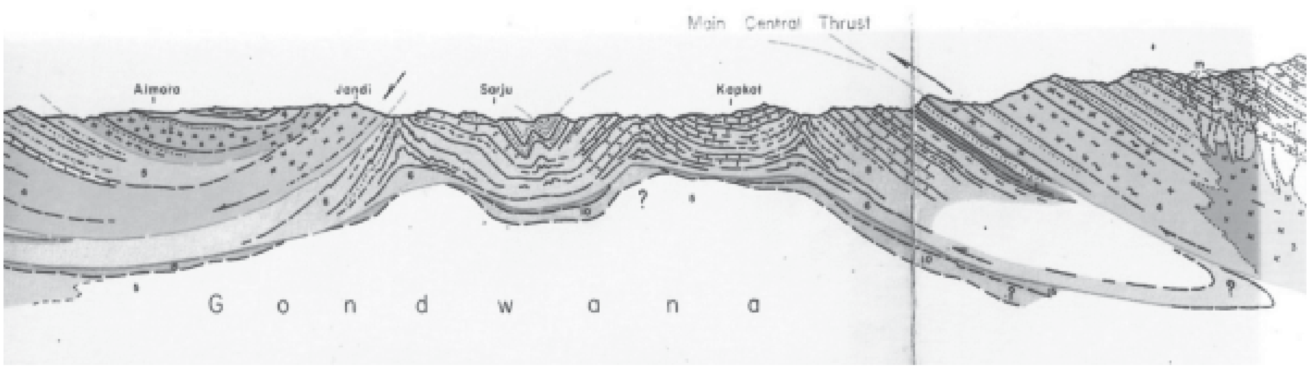

Figure 10. Section across Kumaon Lesser Himalaya

the Tsangpo suture. He has indicated the presence of Gondwanas upto the MCT. Moreover Gondwanas have been mapped below the Kashmir Nappe. One can thus postulate the existence of a long Gondwana rift south of the High Himalayas from Kashmir to Arunachal Pradesh. Apparently this formed the dividing line between the Precambrian shield in the south and the Tethys ocean in the north. The rift is contained between the two major faults that have been shown in the Indepth section. It is interesting to note that a similar situation prevails in the east coast. The coastal Gondwanas intervene between the southern cratons and the southern ocean represented by the Bay of Bengal. These are connected to the Himalayan Gondwanas through the West Bengal basin and the Rajmahal Garo Gap.

The above description of the broad structure of the Himalaya and the Ganga plains is to emphasise that powerful tools are available for the detailed study of these areas as well as for the rest of the country. It also opens the way for some practical programmes for the detailed study of structures. Two of the possible programmes are described below. The first is a fundamental study of the large scale structure of the

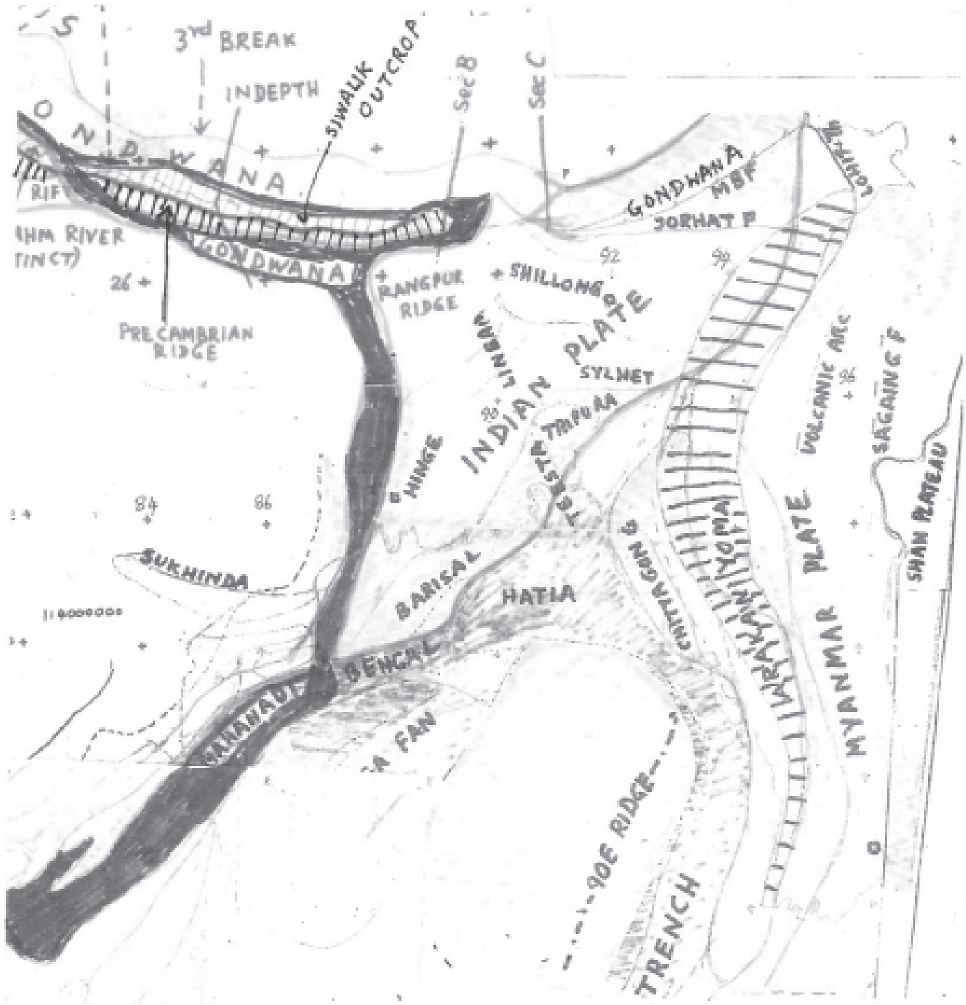

Figure 11. Himalayan Gondwanas.

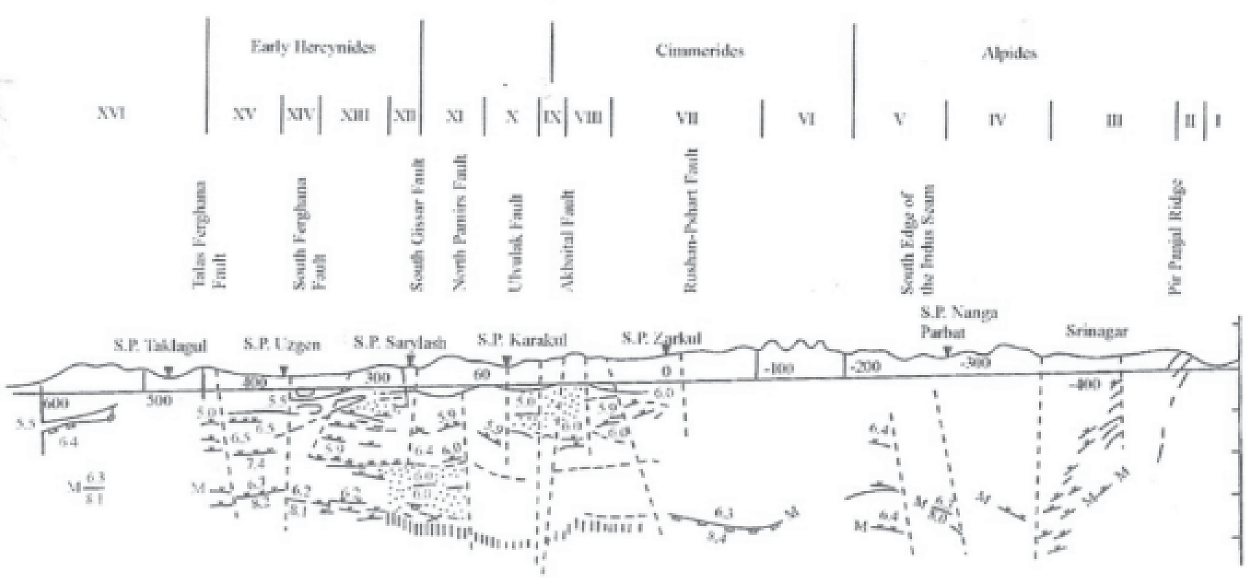

Figure 12. Deep Seismic Section from Kashmir to Pamir.

Himalayas, not so much from the surface, but from its foundations. The second is a renewed attempt to explore for hydrocarbons in the tertiaries in Himachal Pradesh and the Punjab plains.

Strategy for development of model for the Deep Himalaya

The mapping of the Himalayas has been the territory of the great Himalayan geologists of the Geological Survey of India over the last century. Several other foreign geologists have been involved, the prominent among them being Gansser and Tony Haagen. An excellent geological map has been published in Gansser' s book on the Geology of the Himalayas. While the surface observations are beyond dispute, their projections into the subsurface (say beyond 4 or 5 km.) become increasingly uncertain as the depth increases. The penetration has been slightly increased by the study of earthquakes in the region. This however reveals only some of the semi horizontal slip planes, but does not penetrate deeper into the crust.The reasons given for the Himalayan uplift are quite vague. In short, our definite knowledge of the Himalayas does not extend beyond the first 5 or 10 km. although the crust is known to be over 75 km. in thickness. Geophysical methods have to be used to solve this impasse.

Geophysical data acquired during recent years are:
a. Satellite Gravity anomaly maps of Himalayas and Tibet (Fig.6)
b. Deep seismic sounding section from Kashmir north upto the Pamir (Fig.12)
c. Deep seismic sounding section from the Ganga Valley in India in a northerly direction through Nepal, the High Himalayas, S.Tibet upto the Tsangpo suture.(Fig. 5)

The DSS section from Kashmir to Pamir indicates two major faults. The first is a NW-SE deep fault in the Naoshera region. The second is another very big fault north of the Kashmir Valley. These faults produce substantial variation in crustal thickness across them. The DSS section between the Ganga Valley and the Tsangpo suture likewise shows two faults of a throw of about 25 km. each at Moho level in the vicinity of the MBF and the foot of the High Himalaya respectively. The crustal thickness increases from about 35 km. in the Ganga Valley to over 75 km. near the suture in two distinct stages. The increase in thickness is thus a discontinuous function . These faults propagate into the upper levels also, perhaps along some of the thrust planes. The sudden changes in crustal thicknesses bring forth the principles of isostasy into play. The change from 35 km. in Ganga Valley to around 55 km. in Nepal is accompanied by an isostatic uplift in the latter leading to the elevation of the Lesser Himalaya. The further increase from 55 km. to over 75 km in S.Tibet is likewise accompanied by a further uplift to form the High Himalaya and the plateau of Tibet. Thus the two deep faults are the guide planes for the uplift and are directly responsible for the division of the Himalaya into the Lesser and Higher Himalaya.

As explained earlier the satellite gravity picture enables us to trace the course of these faults laterally and we thus have a very good idea of where they lie. It is however necessary to confirm this idea by independent experiment. As stated before two controls are available - the first in the Kashmir-Pamir DSS profile and the second in the Ganga Valley - Tsangpo suture DSS profile. It is thus necessary to shoot two more such profiles- one across the Kumaon Himalayas and another across the NW Himalaya from the Indus plains in a northeast direction upto the Indus suture. All the four 4 profiles mentioned will gives a precise idea of the location of the deep faults as well as the position of the detachment planes not to mention the Moho positions. This data will enable us to form an unchallengable foundation for the comprehensive study of the Himalaya and lead us away from the surface scratching that has gone on for so long.

Hydrocarbons in Punjab and Himachal Pradesh

The search for hydrocarbons in Himachal Pradesh and the Punjab plains presents a very disappointing picture. The presence of gas shows in Jwalamukhi and in the Jammu region was the driving force for the continuing effort. The source of the gas was assumed to lie in the lower tertiary, particularly the Eocene. This concept is unchallengeable even today. While the Eocene is tantalisingly present both in the Jammu area and in the Simla hills area, it has not been possible to establish the continuity of these deposits in the intervening area. A brief analysis of the data may be illuminating. The deep well drilled in the Suruinsar anticline showed the presence of Murrees practically from shallow depths upto 5000 metres or so. The upper section has steep dips but it does not mean that the actual sedimentary thickness is that high. The well did not reach basement due to practical problems. The seismic section however shows that the high velocity basement is not very far off. The surrounding geology requires that the strong basement reflector is the surface of the Jammu limestone. In the outcropping Riasi area the Jammu limestone is overlain by Eocene formations. It is therefore possible that a like situation prevails in the Suruinsar well. In the Jammu area the surface dips form a dip slope and there is no trace of what is referred to as the MFT. Apparently the downward slope continues upto the Marwar craton. In a refraction profile shot from Amritsar to Pathankot, the eastern edge of the Marwar craton lie near Gudaspur, where a conspicuous fault separates it from the Punjab/ Himachal basin. The basement is seen to be very deep and is likely to connect up with the Suruinsar basement. A velocity of 4km./sec. (Lr. Siwalik ?) occurs at a depth of 2km. and persists to beyond 6km. This is a fertile field for the development of Murrees and Eocene which would then rise up the slope of the Suruisar anticline. This deep basin can be connected in a northwesterly direction with the Potwar plateau and with the Lambragoan syncline east of the Jwalamukhi thrust. The gas shows in the Jammu area can be directly related to upward migration from the deep syncline along the dip slope. In the Jwalamukhi area the eastern side is terminated by the MBF and the migration in that direction is ruled out. But there is a distinct slope westwards from the Lambragoan syncline, which leads to migration towards the Jwalamukhi Thrust. It is evident that the main conduit for the lower tertiary is along the deep syncline from southwest of Suruinsar to the Lambragoan syncline. A concerted effort to map this syncline and its flanks could quite likely yield some dividends.

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