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# HYDROCARBON PROSPECTIVITY OF THE GANGA BASIN AND THE FRONTAL THRUST – FOLD BELT OF THE HIMALAYAS : SOME THOUGHTS

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Ladies and Gentlemen, Good morning to you all.

I feel honoured on being invited to deliver the inaugural address on "Himalayan orogen – foreland interaction" in this beautiful city of Lucknow located in the heart of the Foreland. Extending from West Bengal in the east to Jhelum in the west with an average width of about 300 km, the Indo-Gangetic Plain is the longest alluvial plain on the earth (fig.1). Endowed with network of perennial rivers and nutrient rich soil, it has played host to many civilizations since prehistoric times. It has also provided fertile ground for fostering creative excellence in art, literature and philosophy in this part of the world.

The evolution of these vibrant civilizations in Indo-Gangetic plain, however, owes a great deal to the Himalayas to the north, its perennial rivers, nutrient rich soils, the regularity of rainfall and conducive climates. But for the latter the vast plains would have been another Sahara as it probably was prior to Middle Miocene period.

Fig.1. Satellite imagery map of the Himalaya and adjoining foreland

Himalayas, the youngest mountain chain on earth with majestic snow clad peaks including the world's highest peak, Mt. Everest, has many firsts to it. Besides creating and sculpturing the Indo-Gangetic foreland, it has also contributed large volume of sediments which led to the development of the largest submarine feature, the Bengal fan and the largest alluvial fan, the Kosi fan. The amount of detritus shed by the Himalayas is of several orders of magnitude higher than what could have been accommodated in the foredeep. This becomes obvious when one comprehends the huge volume of post-Oligo-Miocene sediments in Bengal and Indus fans. We need also add to it the large volume of sediments contained in one of the largest deltas-Bengal delta-and the huge clastic thickness in the Indus trough. The foredeep therefore, appears to be a sort of geodynamically controlled settling tank straddling between the rising Himalayas and the ultimate repositories - the Bay of Bengal and the Arabian Sea. Both deltas and offshore fan building processes initiated during Oligocene.

I would like to share with you some thought on certain critical aspects having bearing on the prospectivity perceptions of Himalayan orogen and its peripheral foredeep

keeping in view the theme of the seminar. In Outer Himalayas we have well recorded Cenozoic sedimentation history from Palaeocene to Middle Eocene with Late Eocene represented by a hiatus. There is no conclusive evidence of occurrence of Oligocene either. Would it not then be logical to think that withdrawal of Subathu Sea at around 45 Ma is indicative of first positive movement in the Himalaya and concomitant down-flexing of cratonic lithosphere leading to initiation of the foredeep. The spatiotemporal aspects of this process however, is not very clear partly on account of concealment of the critical areas which hold key to the answer and partly due to removal of stratigraphic record by post orogenic erosion. The micritic grit with profusion of Late Eocene continental fauna probably deposited in deranged lakes and the podsols with hematitic precipitation lend credence to this idea. The red beds of Murree/ Dharamsala/ Dagshai overlying the unconformity then represent the earliest sedimentation cycle within the foredeep which has subsequently been deformed and accreted to the orogen.

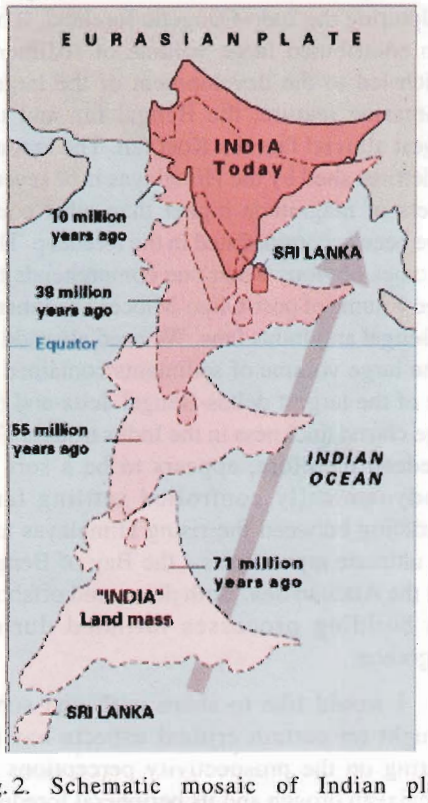


Fig. 2. Schematic mosaic of Indian plate movement with time

It is now believed that India collided with Eurasia some times in Early Eocene (figs. 2, 3). In that event foredeep development should begin concomitantly. The important corollary arising out of this argument is that the foredeep

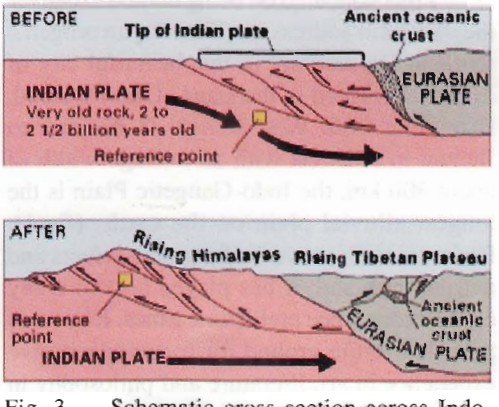


Fig. 3. Schematic cross section across Indo-Eurasian plate showing continental convergence and collision during Palaeogene and Neogene respectively

must have reasonably good thickness of Palaeogene record, overlying the pre-collision Phanerozoic sequence. From exploration point of view it is this pre- and early-foredeep Palaeogene sequence that should house most of the hydrocarbons in the foredeep settings. But for the sporadic occurrence of pre-foredeep succession underneath the Palaeogene Subathu in Lesser Himalaya (Singtali Formation), Phanerozoic successions occur only north of Central Crystalline. However, the occurrence of Palaeozoic-Mesozoic succession in Kashmir Himalayas, south of Central Crystalline undoubtedly establishes the extension of Phenerozoic sea southward. Additionally, Palaeogene foredeep sediments

as reported from the tectonic windows and outliers of Lesser Himalaya corroborate the philosophy of extension of pre-foredeep basin. When viewed in conjunction with the Singtali occurrence in Garhwal Himalaya, it appears that the pre-foredeep and early-foredeep sequences were extensively deposited in the areas what constitute the present-day Lesser Himalaya. It is therefore conjectured that these sequences will be encountered underneath the suprastructure of Himalayan overthrusts.

**The critical factor for exploration viewpoint would be:**

1. Thickness of the Phanerozoic as well as thickness of its thrust overburden.
2. Nature of litho-organofacies of the Phanerozoic package.
3. Diagenesis and thermal maturation
4. Subthrust structural configuration.

Exploration success would largely depend on the successful seismic imaging and geological modelling of the complex thrust accreted terrain of the Himalayan orogen.

Himalayan Foreland attains importance in terms of hydrocarbon exploration due to its vast geographical expanse and more significantly due to the fact that foreland basins worldwide contain significant amount of the world's reserves. During the last five decades of exploration, ONGC has pioneered investigation and generated considerable information in alluvium covered area of the foreland. Interestingly, the foredeep has comparable morphology, tectonic evolution and sedimentation history with other foreland basins of the world. While some of these are profusely petroliferous (Zagros, Canadian Rocky, Alaska, Venezuela), the others have not contributed a single drop of producible hydrocarbon yet. The difference perhaps lies in the geodynamic evolution and sedimentation history of the basin in minute details. Our knowledge about the Himalayan thrust-fold belt and the peripheral foreland is based on voluminous direct geological, geochemical as well as indirect geophysical data. Basin modelling utilizing above knowledge has been carried out to ascertain the critical aspects of basin formation, tectonic evolution, sedimentation history and thermal modification at successive stages.

**The salient points on the subject are outlined as follows:**

- The axis of the foredeep continuously migrated cratonward following post-collision convergence.
- The northern margin of the foredeep underwent progressive deformation with accretion of foredeep wedges to the southward propagating orogenic front.
- The southern margin of the foredeep migrated southward with progressive flexuring and subsidence of northern elements of the flexural bulge.
- The Palaeogene foredeep more or less was confined to the restored position of Lesser Himalayas.
- The Indo-Gangetic part of the foredeep with mainly molassic fill is essentially synorogenic, developed following the accretion of Palaeogene foredeep element with the orogenic belt.
- The overall trend of the foredeep is parallel to the Himalayan front. A number of sub-basins separated by NNE-SSW trending subsurface highs are present from west to east such as Punjab, Ganga and Purnea respectively. Ganga sub-basin is again divisible into few intrabsinal depressions as Sahaspur, Sarda, Gandak and Madhubani. These sub-basins or lows are separated by areas of meagre thickness corresponding to uplifts and subsurface extension of basement ridges (fig. 4).

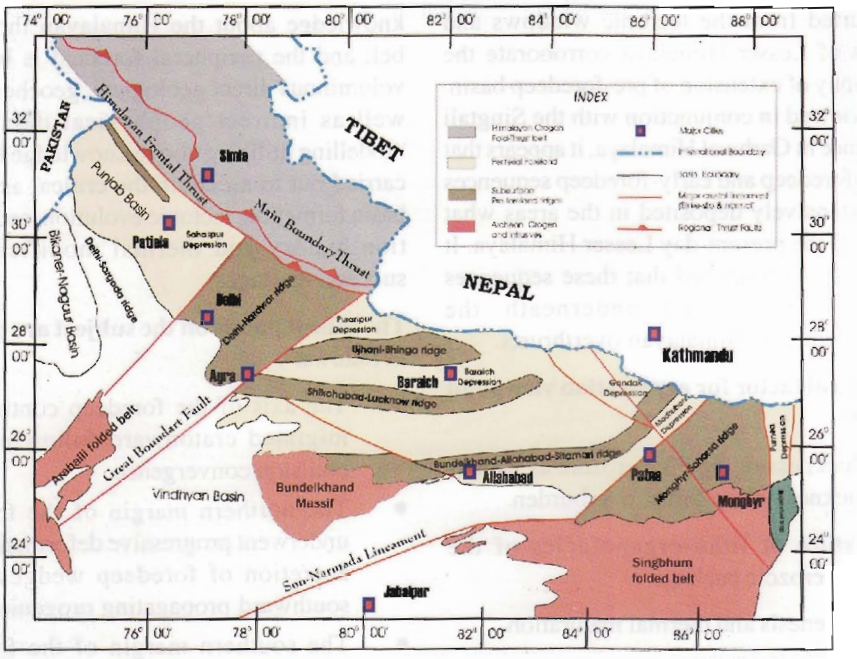


Fig. 4. Tectonic map of Himalayan peripheral foredeep below Ganga-Punjab alluvium

- Sedimentary fill is divisible into two distinct packages:

1. Tertiary siliciclastic package of foredeep.
2. Middle Proterozoic–Early Palaeozoic pre-foredeep mixed siliciclastic and carbonate package of stable passive margin set up.

- The entire Pre-Tertiary represents deposition within a peritidal platform, with spatial variation of lithofacies representative of supratidal to outer shelf (subtidal) environments. The clastic units have very contrasting composition and vary widely from shallow offshore shoal to fluvial at some places.
- Besides the initial trangressive phase of Subathu (Palaeogene foredeep), rest of the Tertiary package is fluvial and represented by stack of repeated fining-up cycles. The state of energy gradually increases with the younging of the stratigraphic section.
- Evolutionary history of the basin starts from Middle Riphean when the rift related passive margin sedimentation started with the deposition of Bahraich Group over crystalline basement. The phase continued upto around 1180 Ma, towards the end of Middle Riphean and there was long phase of non-deposition recorded till 600 Ma. Meanwhile, sediments were thermally modified and transformed to low grade metamorphics which makes it distinct from the younger basin fills.
- The Vendian-Early Palaeozoic sequence from Madhubani to Tilhar represents a phase of continuous platformal deposition, though the depositional limit was defined by pre-existing ridges and few basement controlled transverse faults (e.g. Faizabad ridge, Monghyr-Saharsa Ridge, Gandak fault, Patna fault

etc.). A phase of minor deformation and upliftment is recorded after the deposition of Tilhar Formation followed by renewed rift phase during the deposition of Karnapur Formation (fig. 5).

- The regional upliftment at the end of Middle Ordovician is followed by a major rift phase during Permo-Carboniferous time. Thick Gondwana sediments are reported from Purnea depression to the east of Monghyr-Saharsa Ridge. A major inversion, which was again controlled by the pre-existing basement faults, took place in the basin synchronous with India-Asia collision. Displacement along those faults resulted in the development of linear highs and lows. In the areas precursor to the Neogene foredeep, most of the Mesozoic and the Early Palaeogene was the time of regional peneplanation in which sediments were mostly removed from the highs and preserved within few linear lows across the basin.

- Isochron map at the regional unconformity level at the base of Tertiary package shows a gradual homoclinal slope due north (fig. 6). The wedge-shaped Tertiary foredeep prism thickens gradually due north and attains maximum undeformed thickness of about 6000 m in proximity of Main Frontal Thrust. Further north in the thrust-fold belt, the Tertiary package is thrust accreted and exhumed along several in-sequence thrusts developed at the frontal fold belt of Himalayan orogen.

- The foredeep sediments are not affected by subsequent tectonic modification in Ganga basin except in close proximity of the Himalayan frontal thrust. Basement controlled faults, which are so well developed in Pre-Tertiary section are not much reactivated during the foreland warping and sedimentation. Occasional minor displacement at the lower Tertiary package is noticed at the fringe of Monghyr-Saharsa Ridge and in Puranpur low. An interesting large wavelength, low amplitude warp is recorded near Najibabad.

- Exploration leads have so far been restricted to few surface oil shows (Chamukha, Punch) and gas seeps (Mandalti, Narora, Himriganga) besides

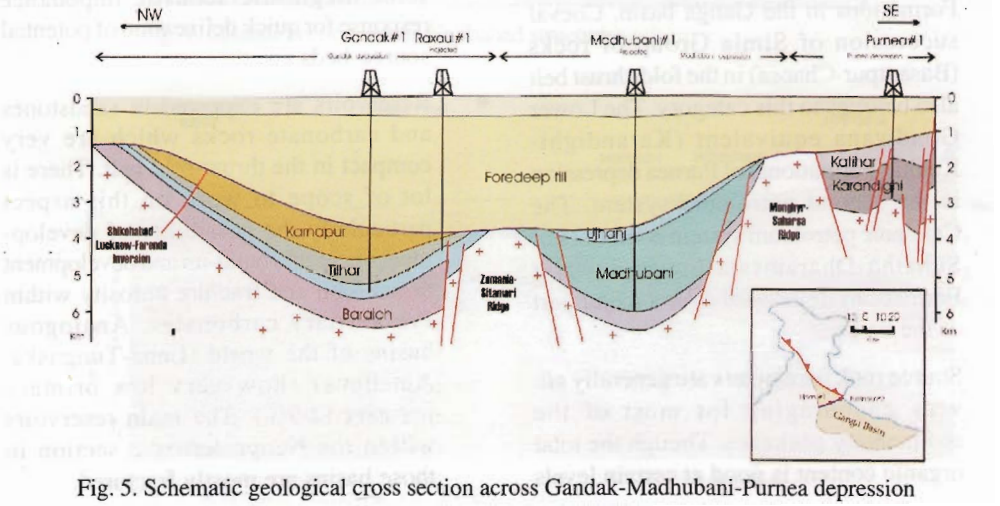


Fig. 5. Schematic geological cross section across Gandak-Madhubani-Purnea depression

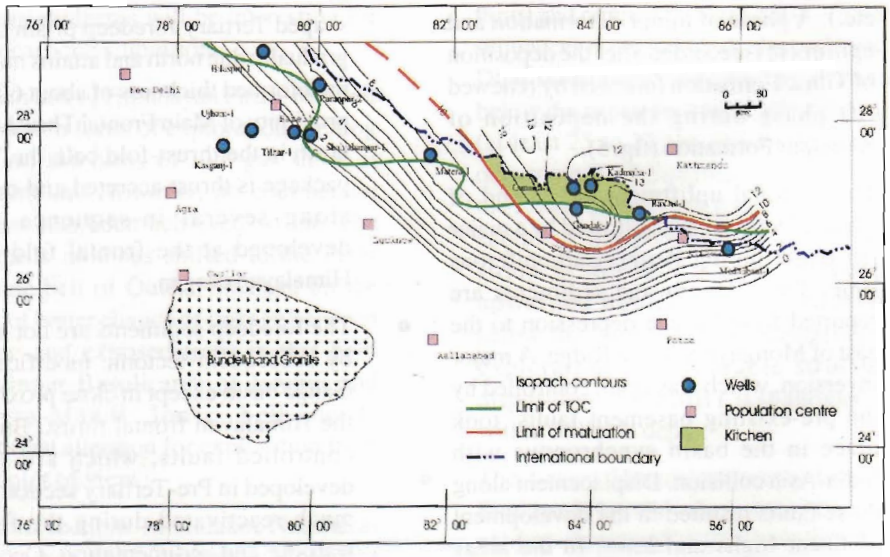


Fig. 6. Isochron map at unconformity level (base of Siwalik) in Ganga Basin and its hydrocarbon kitchen

hydrocarbon shows from drilled wells (Jwalamukhi, Ganauli, Sahajahanpur, Bilaspur) both at Tertiary and Pre-Tertiary levels.

- A three-tier petroleum system i.e. Riphean-Lower Palaeozoic, Permian and Cenozoic is envisaged in this basin. The oldest system is represented by Madhubani-Ujhani-Tilhar-Karanpur Formations in the Ganga basin. Coeval succession of Simla Group of rocks (Basantpur-Chaosa) in the fold-thrust belt also belongs to this category. The Lower Gondwana equivalent (Karandighi-Katihar Formations) of Purnea depression is the second petroleum system. The Cenozoic petroleum system comprises of Subathu-Dharamsala-Lower Siwalik Formations developed over a major part of the basin.

- Source rock parameters are generally not very encouraging for most of the sedimentary packages. Though the total organic content is good at certain levels of all the formations, the overall hydrocarbon generation potential is poor. Pre-Tertiary section is generally overcooked in the thrust-fold belt, whereas the Tertiary package is undermatured. However, as data intensity is still poor in this basin, it is possible to encounter good source facies in isolated pockets. It will be worthwhile to develop some diagnostic acoustic impedance response for quick delineation of potential source beds.

- Reservoirs are expected in sandstones and carbonate rocks which are very compact in the thrust-fold belt. There is lot of scope to work on this aspect particularly the possibility of development of organic build-up and development of solution and fracture porosity within Pre-Tertiary carbonates. Analogous basins of the world (Lena-Tunguska, Amadeus) show very low primary porosity (2-7%). The main reservoirs within the Neoproterozoic section in those basins are mostly fractured.

Structural traps in the Outer Himalaya are very complicated due to intense tectonic activity and often beheading of structural closures due to subsequent erosion. On the other side, the thick Tertiary section of foreland is mostly homoclinal and devoid of readily discernible structural traps. In the thrust-fold belt, thrust-propagated fold, ramp anticline and duplexes are the possible plays whereas in the foreland basin fault closure, low amplitude fold (fig. 7) and stratigraphic traps (wedge-out) are important.

- The Punjab basin is bounded by the Himalayan Frontal Thrust in the north, Delhi-Hardwar Ridge in the east and Delhi-Sargoda ridge in the south. In the west the area is in continuity with the hydrocarbon bearing Potwar province of Pakistan. Petroliferous, Eocambrian Bikaner-Nagaur basin of Rajasthan lies to the south of Delhi-Sargoda Ridge. The latter have emerged due to synorogenic exhumation (flexural bulge) in response to the tectonic loading of the Himalayas. So the Eocambrian basin is expected to extend further north below the Punjab plain (fig. 8). Hence, an estimated 4 km thick Palaeozoic-Mesozoic package below

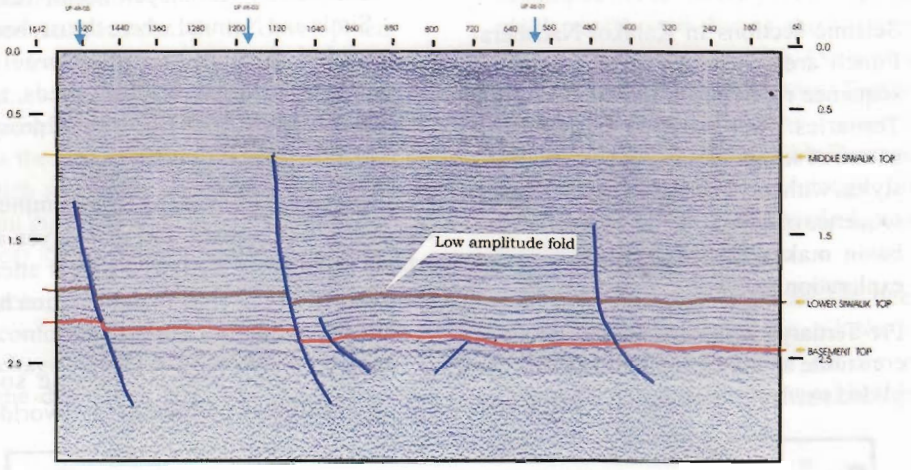


Fig. 7. Seismic section across Najibabad structure.

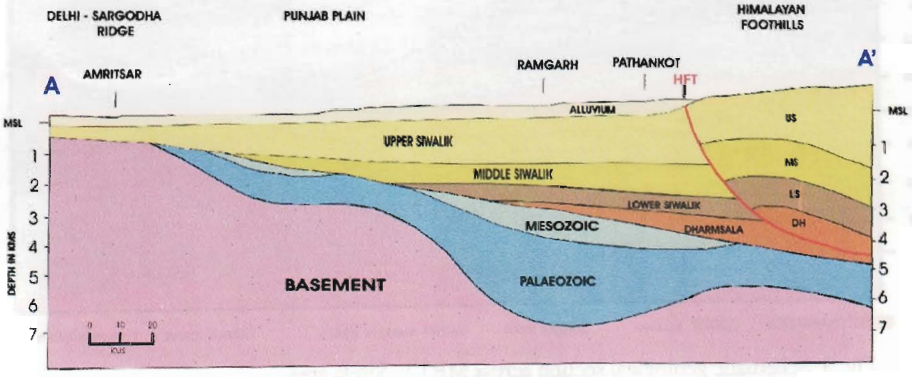


Fig. 8. Schematic section across Punjab Plain.

Tertiary molasses will be interesting for hydrocarbon exploration.

- Median belt of Himalayan thrust-fold belt has been in focus of exploration for long time on the basis of live gas show at Jwalamukhi. However, no commercial success has been achieved so far. The emphasis now has shifted to the inner tectonic belt of Outer Himalaya on the basis of better chance of linkage between source and exposed traps in this belt. Udhampur-Basoli area of Jammu and Kangra-Mandi inner belt needs additional attention for exploration from this point of view.
- Seismic sections in Kalakot-Naoshera-Punch area show presence of deeper sequence repeated by thrusts below the Tertiaries. Remarkable similarities in nature of seismic packages and structural styles, with those of hydrocarbon bearing sequence of adjoining Salt Range-Potwar basin makes this area interesting for exploration.
- Pre-Tertiary rocks in the Lesser Himalaya constitute an allochthonous unit that has glided southwards along a flat-lying sole thrust and ramped up along MBT. Tertiary sequences especially Subathu and Lower Dharamsala are expected to continue below the nappe for appreciable distance (at least 25 to 30 km, fig. 9). Numerous occurrences of Subathu outliers within the Lesser Himalayan zone conclusively establish the presence of Palaeogene strata in this tectonic unit. Possible upwarped autochthonous sediments below the nappe will be interesting for exploration in favourable structural disposition where MBT is shallower and within drillable depth.
- The Lesser Himalayan sector between Simla and Nainital where thrust sheet has glided foreland-ward appreciably, creating large salient needs to be investigated for hydrocarbon prospects in subthrust Tertiaries.

We are still waiting for commercial discovery in this basin. Let us analyze a few critical problems which need proper attention and evaluation and sincere deliberation by the scientific community.

- Established prolific marine source depositional periods of the world like

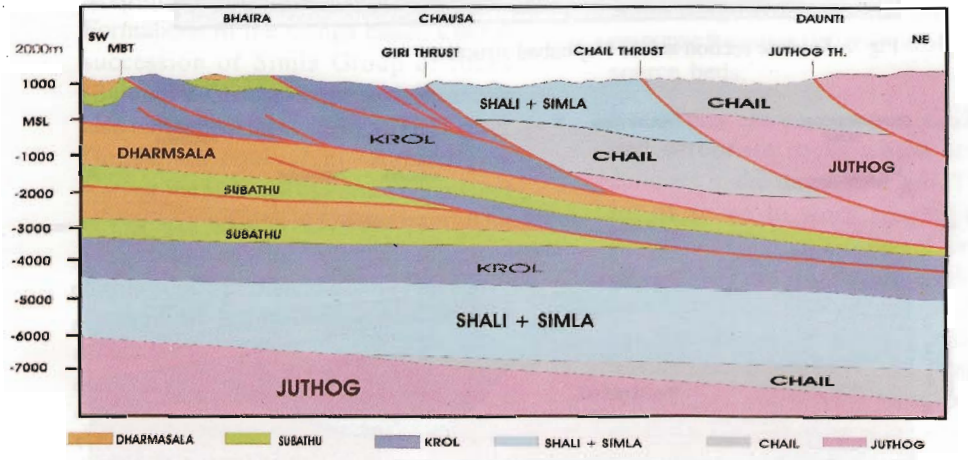


Fig. 9. Schematic geological section across MBT in Simla area.

Silurian, Carboniferous, Jurassic, Cretaceous are mostly absent in this basin as the foredeep evolved only during Palaeogene-Neogene time. The pre-foredeep platformal sequence is best preserved only north of Central Crystalline.

- Optimum thermal maturity is restricted only within smaller pockets in the northern part of Neogene foreland basin. The maturation improves in the thrust accreted package of Inner Tertiary thrust-fold belt of Outer Himalaya. Inherited structural complexity of the belt and intricate breeching due to thrust may be responsible for possible escape of hydrocarbon. Is it possible to identify less disturbed structural traps through some direct or indirect techniques?
- Subsurface imaging of complex thrust-fold belt is a challenge throughout the world. New concepts and technologies are welcome to capture better images in order to refine exploration models.

The essential need of the hour is ideas and innovative concepts which alone will lead to success in near future. Let us try to put our minds together to develop better understanding of geological evolution of foredeep in space and time and identify the areas where critical parameter that constitutes the petroleum system converge, and I am sure this will lead to early breakthrough.