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HYDROCARBON PROSPECTIVITY OF THE STRUCTURES ASSOCIATED WITH HIMALAYAN FRONTAL THRUST (HFT)

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ABSTRACT

Himalayan Frontal Thrust (HFT) is the youngest south-vergent, in-sequence thrust, demarcating the outer margin of the Himalayan thrust-fold belt. A series of longitudinal thrust related folds have developed on the hanging wall of the thrust, which are genetically related to the propagation of the thrust sheet. Folds are mostly ramp anticlines originated through the mechanism of fault bend fold or fault propagation fold. Level of detachment varies from 3000 to 5000 m within the Pre-Tertiary metasediments. Subsidence history depicts an average rate of subsidence of 179 m per million years in the foreland. Amount of subsidence sharply increased from 60 to 463 m/Ma with the sequential accretion of thrust sheets and tectonic upliftment of the Himalaya. Age of HFT is estimated about 1Ma and the timing of maturation of Lower Siwalik is 3Ma. Hence, HFT has generated all post migration structures and are not suitable exploration targets for catagenetic hydrocarbons. Failure of drilled wells supports this view. However, these can act as good traps for biogenic gas at shallow structural levels. Dating of thrust related folds is one of the major key factors for hydrocarbon exploration in Himalaya. The thrust area for exploration should be restricted to 3Ma and older structures, which are undoubtedly prospective and are, supposed to be contained mostly within the inner belt of Outer Himalaya.

Key words: Himalayan Frontal Thrust, Subsidence history, Hydrocarbon exploration.

INTRODUCTION

Thrusting is a dynamic process in the evolution of an orogenic belt. Himalaya, the product of latest global orogeny reached its present height through the accretion of numerous successive thrust sheets generated from time to time since the collision of Indo-Asian plates. A few of them are distinctive regional tectonic markers. Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT) are such important thrusts dividing the entire stretch of orogen into different tectonic belts each of those have characteristic tectono-stratigraphic packages. HFT demarcates the boundary of active fold-thrust belt with the undeformed foreland to the south. It refers to the latest major activity of foreland-ward migration of active Himalayan orogen.

For the entire stretch of Himalayan foothills, the outermost major lineament is Himalayan Frontal Thrust (HFT). It is a moderate angle (30-50^0) reverse fault ramping from the upper part of Janauri Formation at a depth of around 3000 to 5000 m. A number of anticlinal structures are reported immediately on the hanging wall blocks, which are genetically related to the thrust. Mohand, Janauri are a few major structures within similar structural set up in the Western Himalaya (fig. 1). Two wells have so far been drilled to evaluate the hydrocarbon potential of these structures but eventually all the attempts proved unsuccessful. Interestingly, the outer structures of any foreland basin

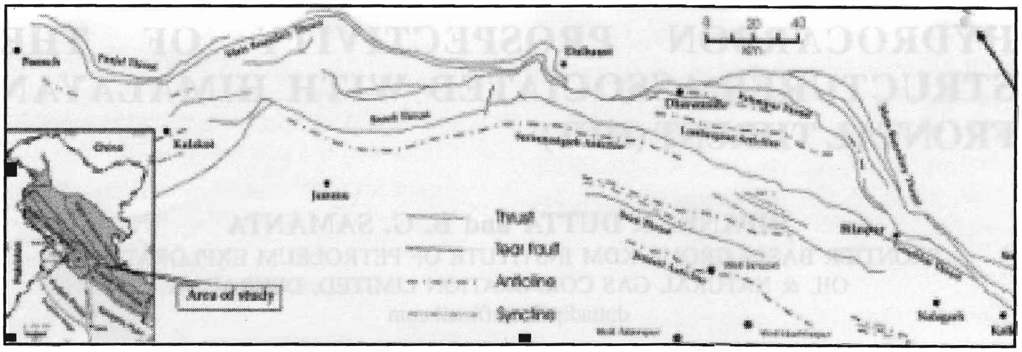
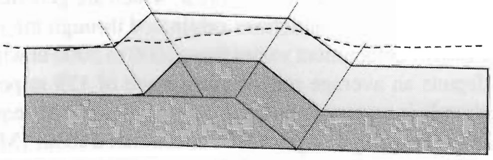
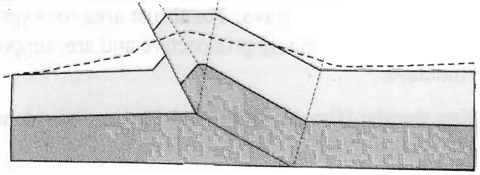


Fig. 1. Regional tectonic map of western Outer Himalaya. HFT is concealed all along with the development of hanging wall anticlines like Janauri.

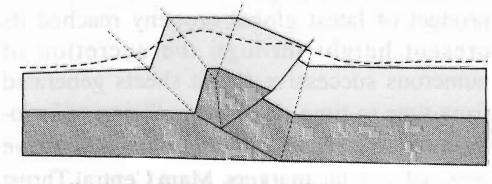
are the easiest targets for exploration and the probability of their hydrocarbon accumulation is also high. In the Rocky and Zagros they are found not only petroliferous but a few are giants. This article is concerned with the nature of Himalayan Frontal Thrust (HFT), its origin, evolution and the possibility of hydrocarbon entrapment within structural traps associated with it.



Ramp anticline



Emergent thrust with eroded folded structure



Structures with emerging backthrust

Fig. 2. Three basic types of structures recorded along HFT in the western sector of Outer Himalaya. Dashed line at the top refers to the level of present day erosion.

HFT AND ASSOCIATED FOLDED STRUCTURES

HFT in most of the places carries the entire Siwalik and a part of Dharamsala package along with the thrust sheet and resting over recent foredeep alluvium. Subsurface seismic images at places are excellent due to the inherited density contrast of Lower Siwalik with the younger sediments. It is a single ramp, generated at a level within the upper part of Pre-Tertiary metasediments and glided over for tens of kilometres, before reaching to its present day surface position. On map, the thrust is identifiable rarely at few isolated sectors, whereas in most of the areas it is concealed. Kinematic restoration done by different workers (Srivastava and Mitra, 1994; Powers, *et al.*, 1998; Mukhopadhyay and Mishra, 1999) proved its concealed nature in major part of the basin. Structures developed on the hanging wall block of the thrust are either fault bend folds or fault propagated folds. Three basic types of structures are recorded (fig. 2), viz. 1. ramp anticline of Janauri type, 2. emergent thrust with eroded folded structure (Mohand type), 3. structure with emerging backthrust (Hardwar type).

Ramp anticline is the most common structure developed along HFT. The detachment plane ramps from about 1000 m within Pre-Tertiary metasediments and flattens along the top of Janauri Formation, as seen in Janauri area (fig. 3). Ramp angle is as low as 20° to 30^{0}. Vertical accretion is measured as around 1km. Structural modelling across Janauri anticline is possible in different ways. As modelled by Mukhopadhyay and Mishra (1999), the structure has been constructed on a ramp emerging from the basal Tertiary unconformity level. In the present study, we proposed an alternate model considering a basal detachment within Pre-Tertiary Janauri Formation. The basic logic is that the amount of cumulative subsidence of the foredeep computed at Hoshiarpur is around 6450 m, whereas at Janauri the top of Janauri Formation is encountered at 4790 m. So, there must be thrust related exhumation of the PreTertiary rock along HFT. Residual gravity picture shows a 10 mgl positive anomaly over Janauri structure within an overall depression of the magnitude of -50 mgal from Adampur to Jwalamukhi.

In case of emergent thrusts, forelimb of the fault propagated fold are breached and is partly eroded out. The exposed HFT as seen in Mohand area and to the western Nepal border are of this type. Fault propagated folds with backthrust is locally developed near Hardwar. The detachment level in this case is also within Pre-Tertiary. Depth of detachment varies all along the HFT, depending on the depth of basement. In Kalka-Ambala area it is shallow (3000 m), whereas in the western part of Punjab plain as well as near Nepal foothills, north of

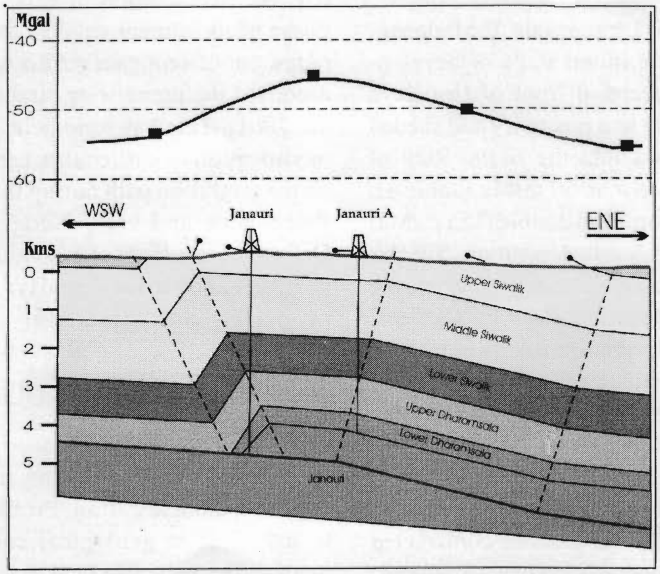


Fig. 3. Ramp anticline developed over HFT in the Janauri sector of Himachal Pradesh.

Gandak depression, it is as deep as 5000 m.

SUBSIDENCE AND EXHUMATION HISTORY

As already mentioned, HFT is the youngest major in-sequence thrust developed within the domain of Himalayan orogen. The youngest foredeep cycle (Upper Siwalik) is glided over along it and hence it is very young. Foreland Subsidence history constructed across HFT depicts its age as 1Ma or even less. The wells, Adampur, Hoshiarpur and Janauri are selected for the study. The first two wells are located on the footwall block whereas the well Janauri is on the hanging wall of the same fault. Comparative study of those offers a picture of maximum burial and exhumation in this part of the basin. Biostratigraphic ages of the respective formations are considered from the published biochronological dates of Raju and Ramesh (1998). However, there are different views pertaining to the age of basal Dharamsala as unconformity of a magnitude of 19.5 Ma is considered above Subathu (Mullick *et al.*, 2002).

During Lower Dharamsala, the Palaeogene foredeep was in initial stage of development. The thrust accreted front of Himalaya was far north having less positivity and sheded mostly finer clastics into the basin. Rate of subsidence was as low as 60 m/Ma (Table 1). The rate became more than double (155 m/Ma) during Upper Dharamsala deposition. Siwalik was the time of rapid subsidence, when the Neogene thrust front prograded southward and came nearly to the position of present day Lesser Himalaya. Rate of subsidence increased abruptly from 182 m/Ma during Lower Siwalik to around 464 m/Ma at the top of Upper Siwalik within a time span of only 16.4 Ma. This implies the phase of most rapid upliftment of Himalayan orogeny. The trend of subsidence constructed for the structurally undisturbed well (Adampur) shows the cumulative amount of subsidence for Lower Dharamsala is about 6450 m, which should be marginally more for the well Janauri, as it is located north of the former well.

At Janauri, basement is encountered at a depth of 4790 m due to the effect of exhumation along HFT. In the subsidence diagram of Janauri, the normal trend of Upper Siwalik subsidence is considered same as Adampur. The amount of exhumation is 1660m and the intersection of the two trends comes at around 1Ma, which refers to the timing of initiation of HFT in this belt (fig. 4). If we consider the break in sedimentation between Subathu and Lower Dharamsala, the overall subsidence rate will only be faster and the age of HFT will even be younger.

Reactivation along the older thrusts during movement of HFT is recorded at many places, as evident in the Banu khad, north of Baijnath where MBT has substantially glided over the Neogene rocks. Even Chail Metamorphics have migrated southward and formed isolated outlier over Middle Siwalik along Pun Khad, to the northeast of Palampur (fig. 4). Reactivation of MBT coeval to this phase of movement resulted in the formation of few out-of-sequence thrusts which ultimately modified the preexisting structures (Dutta, *et al.*, 2001). This has serious implication in the modification of earlier structures, which were on the migration path during the maturation of Palaeogene and early Neogene sediments. Deformation history of individual structures of the Outer and Lesser Himalaya, is therefore be properly evaluated for hydrocarbon exploration.

SIGNIFICANCE IN PETROLEUM EXPLORATION

Petroleum exploration in any foreland basin is a complex affair. Problems pertaining to the inherent geological complexity, data quality and technological constrains lead to refrain people from a high risk-uncertain

Table 1: Data for calculation of subsidence history at the Janauri well of Outer Himalaya.

Formation	Depth interval (m)	Time interval (Ma)	Rate of subsidence (m/Ma)
Upper Siwalik	0-620	0-3.58	463.9
Middle Siwalik	620- 2030	3.58-10.9	273.2
Lower Siwalik	2030-3440	10.9-16.4	181.8
Upper Dharamsala	3440-4440	16.4-23.8	155.4
Lower Dharamsala	4440-4790	23.8-37	60.6

rewards business. Himalayan orogen and its peripheral foredeep is a polyhistory basin which evolved from Proterozoic to recent time and still poorly understood. To an explorationist, one of the most important problem is timing of entrapment with respect to the thermal maturation of the source rock. Structural trap emerged during the sequential development of different thrust sheets is of enormous importance in this aspect. MCT, the primordial thrust emerged from the continental collision is dated around 30 Ma (Najman *et.al.*, 1993). Next important event of thrusting is recorded around 26 Ma, which may represent well the Chail or equivalent Lesser Himalayan thrusts. MBT is dated around or slightly more than 10 Ma (Meigs *et al.*, 1995), which is responsible for the emergence of Pre-Tertiary, Lesser Himalayan succession over Palaeogene foredeep sediments. The entire Palaeogene and a part of Neogene sediments were already deposited within the foredeep during the initial stage of propagation of MBT, which was reactivated from time to time during the later shortening events. HFT is initiated its gliding during 1Ma and exhumed to its present position at a rate of 16.6 cm per 100 years. Since that time, structures on the hanging wall of HFT are under progressive modification with the shortening of the foredeep.

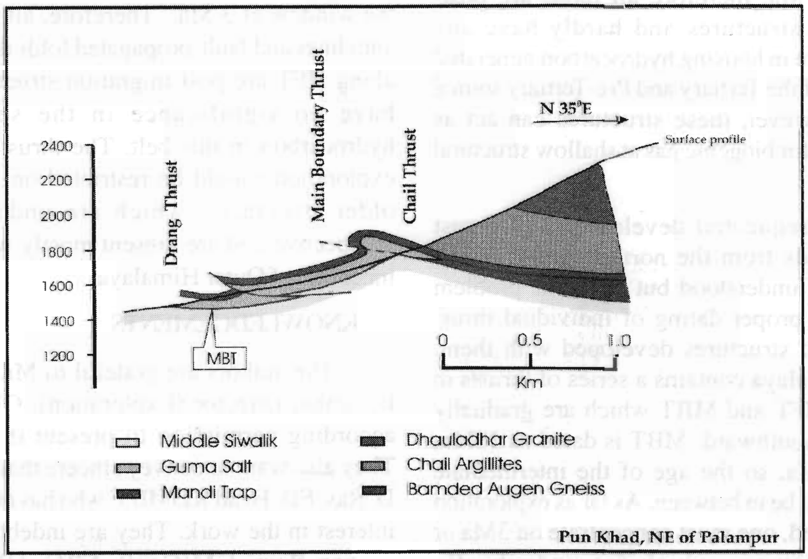


Fig. 4. Southward gliding during reactivation of MBT and Chail Thrust can be coeval with the movement of Himalayan Frontal thrust (after Dutta, Chatterjee, Shukla and Sharma, 2001).

Like other foreland basin, Himalayan foreland has a low geothermal gradient. For Ganga basin thermal gradient is calculated as 2.1^{0}C/100 m and for Punjab basin it is around 2^{0}C/100 m. Optimum temperature of maturation is reached at a depth of 2800 m in the present day foredeep set up. Subathu and Lower Dharamsala sediments at around 10 Ma reached the depth, whereas Lower Siwalik entered within maturation window during 3 Ma. Palaeogene formations gradually wedged out in the median belt of Outer Himalaya as the foredeep gradually migrated due south with the shifting of orogenic front. Subathu and Lower part of Dharamsala, which are considered as potential Palaeogene source are either absent or thinly developed below the Frontal thrust. Lower Siwalik is better developed as local paludal pods within an overall continental molassic facies, which can provide sufficient organic matter to cook and generate hydrocarbon in this part of the basin. But the problem of entrapment remains critical. As the ramp anticlines and fault-propagated folds developed along HFT are dated as 1Ma, therefore all those are post-migration structures and hardly have any significance in housing hydrocarbon generated from any of the Tertiary and Pre-Tertiary source rocks. However, these structures can act as good traps for biogenic gas at shallow structural level.

The sequential development of thrust related folds from the north to south of the foreland is understood but the basic problem lies in the proper dating of individual thrust and related structures developed with them. Outer Himalaya contains a series of thrusts in between HFT and MBT which are gradually younging southward. MBT is dated as 10Ma, HFT is 1Ma, so the age of the intermediate thrusts must be in between. As far as exploration is concerned, one must concentrate on 3Ma or older structures, which are undoubtedly prospective because of their pre-migrational existence. Inner belt of Outer Himalaya contains a few such structures (Sarkaghat, Paror) which may be prospective in light of this model.

SUMMARY

In the outermost part of the Himalayas the structures which are genetically related to the Himalayan Frontal Thrust can be grouped into three basic types: 1. ramp anticline of Janauri type. 2. emergent thrust with eroded folded structure (Mohand type). 3. structures with emerging backthrust (Hardwar type). The level of detachment at places lies within Pre-Tertiary Janauri Formation. Subsidence history analysis depicts an average rate of subsidence of 179 m per million years in the foreland. Amount of subsidence sharply increased from 60 to 463 m/Ma with the sequential accretion of thrust sheets and tectonic upliftment of the Himalaya. HFT initiated its gliding during 1Ma and exhumed to its present position at a rate of 16.6 cm per 100 years. Subathu and Lower Dharamsala sediments reached maturation at around 10Ma, whereas Lower Siwalik entered the window at 3 Ma. Therefore, all the ramp anticlines and fault-propagated folds developed along HFT are post migration structures and have no significance in the search of hydrocarbon in this belt. The thrust area for exploration should be restricted on 3Ma and older structures, which are undoubtedly prospective and are present mostly within the inner belt of Outer Himalaya.

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