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SEARCH FOR HYDROCARBON IN GANGA BASIN: SOUTH-EASTERN PART OF GANDAK DEPRESSION MERITS FURTHER PROBE

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ABSTRACT

The sequence undelrying the regional unconformity and above the Vindhyan Sequence in Ganga Basin is termed as "Intermediate Sequence" in common parlance. The Sequence has been variosuly named by different workers and has been debated regarding its age but not on its hydrocarbon potential credentials.

The detailed mapping of IMS along 2400GLK of 2D seismic data in the Gandak Depression of Ganga Basin, where it is expected to be best developed, and integration with electrolog and well data has been carried out.

The mapping and analysis has brought forward the presence of a low at the IMS level in the south-eastern part of the Gandak Depression, which appears to be sourced by the channels. This Low and the connecting channels are expected to provide locales of good porosity and may serve as good reservoir facies. The maximum sedimentary thickness of 1250 m is worked out in the deepest part as revealed by the isochronopach map and sediments in this zone exhibit early stage of maturation. A regionally acceptable source facies, inadequate maturity and poor reservoir characteristics due to compaction have been the gray areas of petroleum exploration in Ganga Basin, hence identification of referred locale offers an attractive proposition.

Key words: Hydrocarbon search, Ganga Basin, Gandak Depression.

INTRODUCTION

The Indo-Gangetic Plains constitute a large geologic province, covering an expanse of over 3 lac sq. km. The area has been under active exploration by ONGC and OIL becuase of favourable geotectonic set-up, considerable sedimentary thickness and many oil, gas seepages/fields falling on same latitudes across the area both in the east (Assam Basin) and west (Kohat-Potwar). With continuing exploration efforts, during last four decades, the eluding success in finding viable hydrocarbon accumulations in the Ganga Basin coerced to focus on development of alternate models/concepts. Also, a meagre number of drilled wells in the basin of such a huge dimension does not suffice to understand the many missing linkages for comprehending the whole basin. Though, the geology of the basin concelaed under thick alluvium cover has been largely constrained with the volume of data made available by the past exploration works (Fuloria, 1969; Aditya *et al.*, 1976; Mukherjee and Sharma, 1984; Chaturvedi *et al.*, 1988; Chugh *et al.*, 1989; ONGC-BP joint study, 1991; Chattopadhyaya *et al.*, 1999; Pramanik *et al.*, 1996; Fuloria, 1996; Raiverman *et al.*, 1999). Many intricacies regarding possible presence of Palaeogene sequence, controverises relating

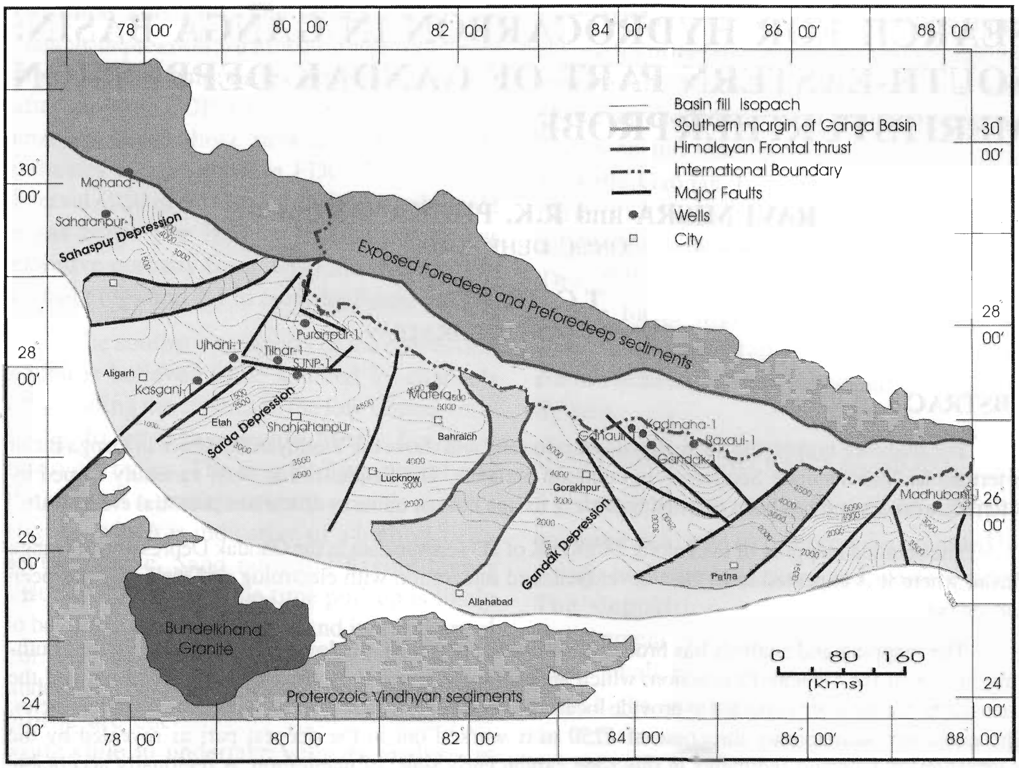


Fig. 1. Basement tectonic map of Ganga Basin with major structural elements

to assigning stratigraphic age to the so called Intermediate Sequence (Karnapur Formation, Shukla *et al.*, 1993), carbonate build-ups, etc. still need to be resolved.

The above cited knowledge gaps provide the essential directions to work upon. In this regard, the mapping and expatiation of tectono-sedimentary patterns of Intermediate Sequence (IMS) in Gandak Depression is vital from hydrocarbon point of view.

GEOLOGY AND TECTONIC SET-UP

The Ganga Basin, in the north, is welded to Himalayan orogen all along its length while in the south, Bundelkhand massif and Rajmahal Volcanic Plateau form the limit. Absence of Vindhyan sediments across Delhi-Kalka ridge in west and Mungher-Saharsa ridge in the east are considered as limits of the Ganga Basin (fig.1). The western and eastern limits of the Gandak Depression are marked by Faizabad and Sitamarhi subsurface ridges respectively separating it from Sarda on west and Madhubani Depression in the east.

The basement in Ganga Basin uniformly dips towards NE, causing the overlying sedimentary thickness to gradually increase towards north up to 9-10 km. Bouguer anomaly map shows more or less uniform regional slope towards the north with a value from 60 milligal in the south and attaining a maximum value of 210 milligal near Nepal border. Lonescu and Laurian (1979) interpreted maximum depth to the basement at 11500 m from the Bouguer anomaly map. The Bouguer anomaly map (fig. 2) shows a prominent low trend corresponding to

Gandak Depression. This depression is very well brought out on magnetic anomaly map also (fig. 3) southeast of Motihari.

The Basin falls in polyhistoric, pericratonic foreland basin category, which witnessed its origin in early Proterozoic in extensional regime and evolved through many phases to attain the present convergent foredeep category. The thick sedimentary sequences do not truly reflect the continuous sequence of basin evolution and significant gaps in sedimentary deposition are noticed. The major hiatus inferred from the drilled well data seems to span from Cambrian/Ordovician till the onset of Tertiary deposition. The Intermediate Sequence, which is selectively preserved in some lows of the basin just below the regional unconformity (Tertiary-Pre-Tertiary) and recognized by some workers as the topmost unit of Vidhyans, is debated in terms of assigning an unanimous age (Ordovician to Cretaceous) in absence of confirmatory evidences.

The two major episodes,which governed the tectono-sedimentary set-up, are separated by a regionally recognizable unconformity. The Pre-unconformity sedimentary package basically belongs to platform facies laid down in the depressions carved out of basement floor because of sub latitudianl ridges. The basement is represented by metamoprhic (Bijawars) or igneous rocks, which can be traced back towards south where they are exposed as Bundelkhand massif. Subsequent to Vindhyan overlay, a break in sedimentation is manifested by a marked unconformity above the Vindhyan. The remnant erosional ridges and aggradation features seen in the seismics are evidences of the erosional hiatus. During Early Palaeozoic(?) again, an arm of sea from north encroached the down warped parts between the ridges in Sarda and Gandak depressions loading a considerable thickness of shallow marine sediments (as evidenced by the presence of glauconite in some of drilled wells). Subsequent regression caused exposure of sediments and denudation, which lasted, probably from Silurian to the onset of Tertiary sedimentation (approx. 350 Ma). This vast span of time has had maximum impact of denudation on the sedimentary veneer above the Vindhyan and eroded IMS to 1600-1800 m in deepest part. Some basic intrusives have been reported at the base of IMS (Raxaul-I) towards northeastern margin of Gandak Depression, which have been correlated with the Rajmahal Volcanics of Cretaceous age (Fuloria, 1996).

TECTONO-SEDIMENTARY ANALYSIS OF INTERMEDIATE SEQUENCE (IMS)

The top of the Intermediate sequence (regional unconformity) is contoured in the time range of 1400 m (TWT) in the south to 3100 m (TWT) towards north showing a dip direction of northeasterly trend. The base is contoured at a time range of 1600 m to 3400 m with a general northeasterly trend. The interval velocities show a jump of 1100 m near the top of the sequence in the Gandak well and 1500 m in Ganauli well, signifies entrance into a hard and compact zone from the overlying Siwaliks. Seismically, a near transparent zone at the top, topped by an almost uniformly running strong reflector identifies the beginning of IMS. The IMS, as evidenced from mapping, has not been subjected to large-scale structuring or structural deformation. Two major fault trends have been mapped along the eastern and western margin of the depression aligning with the paleo-ridges. The faults are largely normal and hade towards either east or west. Minor horst-like features are also noticed along some lines. In general the faults tend to die out towards the top and very few of them affect the overlying Tertiary sediments. Most of the faults trend NW-SE and some WNW-ESE trending faults are seen in southern part. The Time

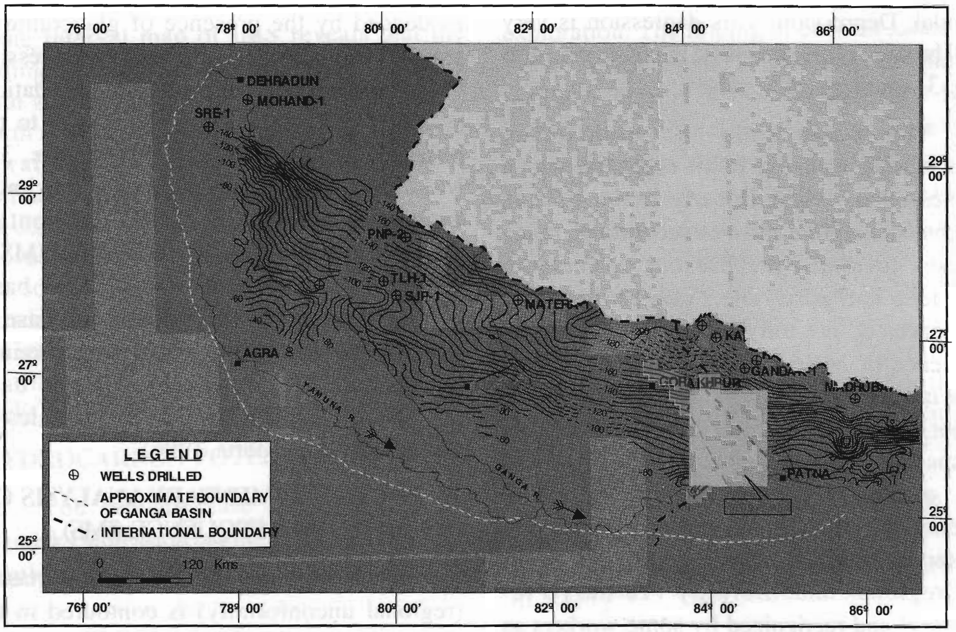


Fig. 2. Bouguer Anomaly map of Ganga Basin

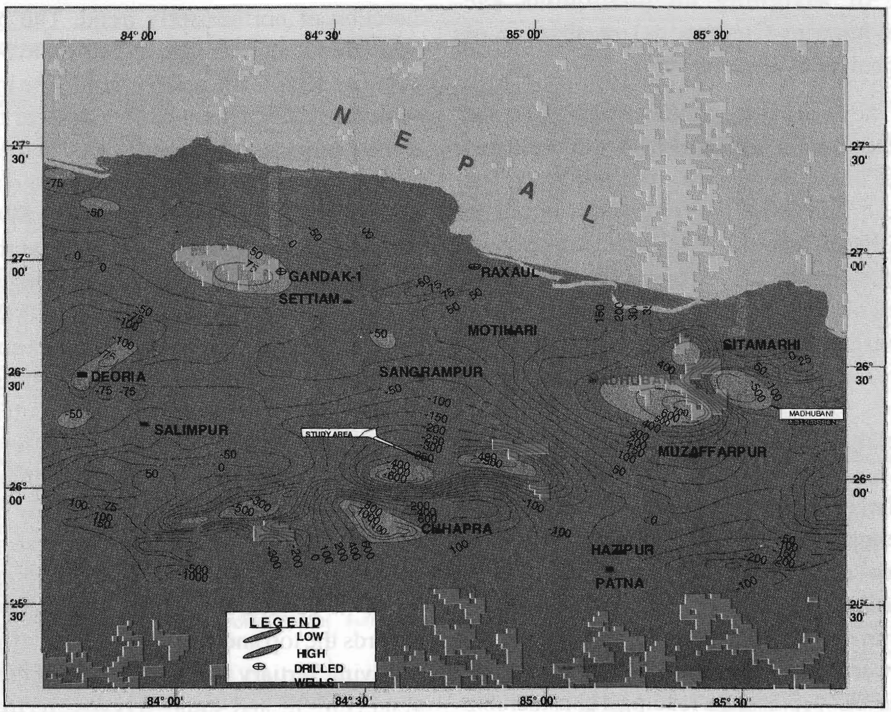


Fig. 3. Vertical Magnetic Anomaly map of Gandak and Madhubani depressions

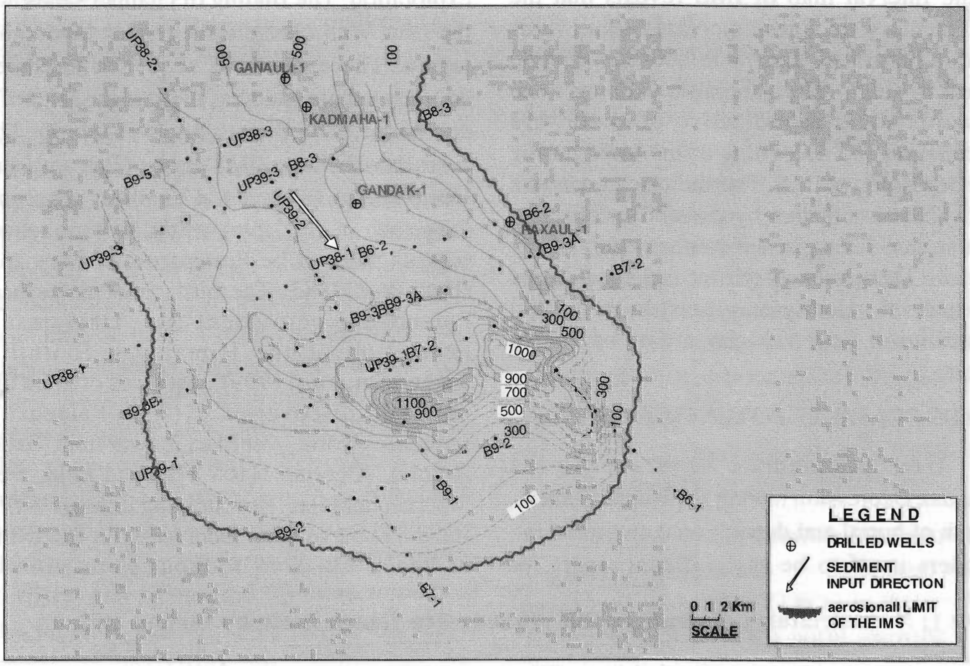


Fig. 4. Time interval map of Intermediate Sequence

Interval map (fig. 4) shows a depocentre in the central part which trends NW-SE with a maximum thickness in the southeastern part of the depression. A maximum thickness of 1250 m is expected in the deepest part, which is reasonably well supported by the gravity and magnetic data interpretations.

The IMS can be divided into two subunits. The upper subunit in a drilled well (interval 3780-4130 m) has sediments with fresh pyroclasts of feldspars embedded in fine silty matrix and the lower one (4130-4997 m) is predominantly shaly/silty sequence with abundance of algal matter. Lithologically, upper unit is dominated by siltstones which is chocolate brown to maroon and greenish grey to grey, hard and compact feebly calcareous and minor sandstones which are moderately hard, compact, greenish grey to brick red, very fine grained. The lower unit is predominantly shale, which is chocolate brown to greenish grey, moderately hard and thin bands of light pink quartzose sandstone. A thick band of blackish grey gabbro has been reported in the drilled well, which is also found in the sidewall cores at 4825 m.

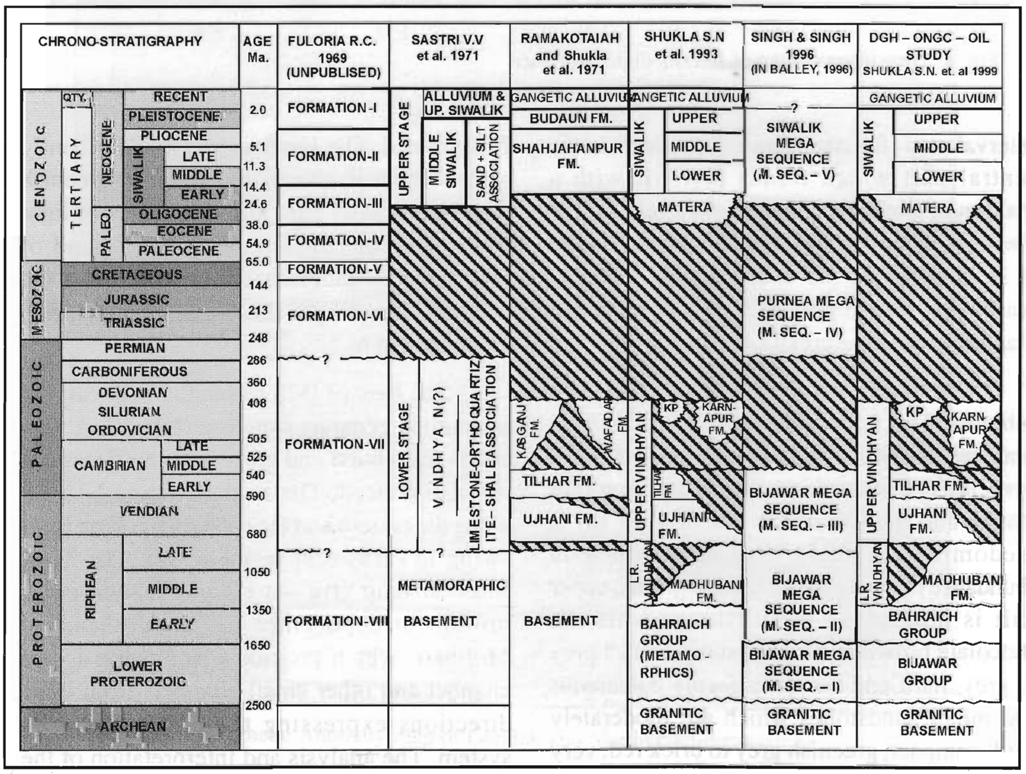
The base of IMS has faults with varying magnitude generaly trending NW-SE. A few, small-scale horst and graben forming features are also noticed. The faults trending NW-SE along the eastern and the western basin margins swing towards east in the south. The Time Interval map (fig. 4) clearly brings out a prominent depocentre to the southeast of Motihari, which provide culmination to the channel and other small channels from other directions expressing the palaeo-drainage system. The analysis and interpretation of the

Time Interval map of IMS reveals that the sedimentary thickness increases southwards with a prominent furrow in between running north to south. The general thickening trend towards south is indicative of southward inclination and deepening of the basin during the deposition of IMS. This indicates a northern provenance and thereby possibility of deep-sea source facies in the southern part of the Gandak Depression. A seismic facies map based on interval velocity may provide the spatial distribution (low velocity areas) of source rocks.

HYDROCARBON POTENTIAL OF IMS

The Intermediate Sequence, in the Gandak Depression having requisite thickness, depth of burial and depositional environment, renders itself to be a significant target for exploration. The finding of channel sands and the Low with clastic infill render favourable locale. The age of the sequence has been strongly debated and has divided the scientific community into three schools (Table-1). The first school believes 'IMS' to be of Precambrain-Cambrian age (i.e. a part of Vindhyan sequence, Pramanik *et al.*, 1996) while another school regards them to be Proterozoic to Mesozoic (Datta *et al.*, 1985). The third school places them Palaeogene equivalent (i.e. Dharamsala Formation of the Himalayan foothills, Raiverman *et al.*, 1999). Instances of giant oil/gas field discoveries exist in Palaeozoic sequences world over like Ghawar field (Saudi Arabia), Algerian Hassi Massoud field, west Siberian fields etc. Encouraging impetus within India also have been received with discovery of heavy oil from Jodhpur Formation of

Table 1: Nomenclatures of stratigraphic sequences in Ganga Basin by various authors



equivalent age in Baghewala, Rajasthan. Besides, finding of oil from Palaeozoic fractured basement rocks in Borholla-Champang area of Assam basin is also worth noting. Oil discoveries are reported from Cambrain to Tertiary all along the Tethyan belt, hence Ganga Basin needs to be further probed.

The IMS is belived to have a marginal to fair source rock potential. The sequence has evidences of deposition in shallow marine environment. Though any source facies of regional extent is not workable in the depression, the shale unit in the bottom of IMS and few isolated streaks indicate fair to good source rock characteristics e.g. Interval 4487-90 m, 4998-01m with C org% 1.28 and 6.95 in Gandak-1 (Chawla *et al.*, 1985).

The maturity of sediments in this part of depression has been worked out to be in the early maturation zone in the deepest part on the basis of VRO data (fig. 5) (Table-2).

The IMS with seismic interval velocity ranging from 3.7 to 3.9 km/sec indicates a clastic sequence and can be considered worthy as a reservoir. The marginal marine nature as evidenced by glauconite and limonite (cored interval 5336-5342 m of Ganauli-1) is also indicative of good reservoir characteristics. The porosity of IMS in Gandak-1 has been worked

Table 2 : Maturation modeling at the base of IMS (along profile B7-02) Gandak Depression.

Age (Ma)	Depth (m)	temp(c)	temp(k)	Vro (calc)
0	0	25	298	0.2019
104.94	1849	61.98	334.98	0.40211
434.94	1849.1	61.982	334.98	0.49095
499.94	5099.0	126.98	309.98	0.79182

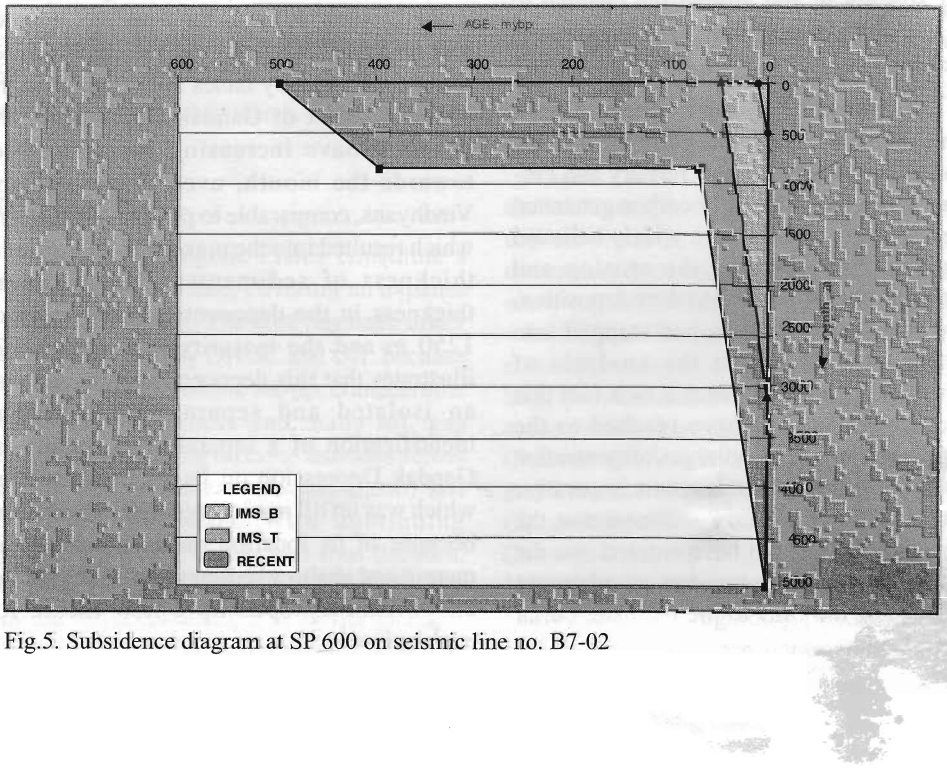


Fig.5. Subsidence diagram at SP 600 on seismic line no. B7-02

out to be 2 to 15%. The seismic profiles in Gandak depression are mostly single fold hence dependable seismic facies can be worked out, after shooting CDP data with detailed velocity analysis along those profiles. The log data indicates a cross over in FDC, CNL logs in Interval 4950 m-5035m indicating possibility of a gas zone. The IMS in Kadmaha-1 shows effective porosity from 3.8-6.5% by Neutron-Density logs and 4.1 to 6.6% by Sonic log.

The southern extremity of the depression which is believed to be sourced by channels contributing the clastics in the low is inherently likely to be a favourable locale for good reservoir facies. The time pull-up underlying the channel is present in some seismic profiles (fig. 6), which is indicative of a high velocity section above. Sand normally having higher velocity than shales, the time pull-up is likely to be due to the presence of sand in the channel cut. Gas chimney effects (fig.7) related to underlying channel sands, as seen in a seismic profile are encouraging signs. It would be worthwhile to undertake velocity analysis at closer spacing in and around the channel to have a fair idea of the reservoir characteristics of the area.

Entrapment of hydrocarbons in Ganga Basin is liable to be questioned in view of the profound hiatus between the Tertiary and Pre-Tertiary sediments. The hydrocarbon generated in the Vindhyan and IMS are widely believed to be breached away by the erosion and enduring hiatus subsequent to their deposition, provided these formations had stepped into cooking window. From the analysis of geochemical data, it becomes a tacit fact that the sediments in IMS have reached to the temperature, that was in initial gas/oil generation zone in the deepest parts. It seems imperative that as a result of Tertiary sedimentaton the sediments in IMS could have entered into the second-generation phase due to adequate subsidence of the IMS to the requisite burial and overload.

If this were the case, the overlying unconformity itself can provide seal for entrapment in suitable locales of this part. However, the IMS in itself contains streaks of claystone and shale at the top, as encountered in wells Gandak-1 (Singh *et al.*, 1992) and Ganauli-1 and Kadmaha-1 to check the migratory path and provide local capping. Thus, IMS in itself offers optimum combination of the basic ingredients (of Generation, Migration and Entrapment) and perceived to constitute an independent Speculative Petroleum System.

DISCUSSION AND CONCLUSIONS

Deposition/sedimentation of IMS occurred in a bowl like depression bounded by palaeo-highs on its eastern and western sides. The deposition occurred in near-shore environment. Subsequent to deposition of IMS many small feeder channels originated from these highs incising into the IMS and dumped the sediments in the depocentre. Because of the general sedimentary thickening of the IMS towards south as apparent from the seismics and time interval map, comparatively deeper marine sedimentary facies are expected in the southward part of Gandak Depression. The channels have increasing incision effect towards the mouth, even down into the Vindhyans, comparable to present day canyons which resulted into the maximum depositional thickness of sediments. The maximum thickness in the depocentre to the order of 1250 m and the maturity data (Vro~ 0.7) illustrates that this depocentre might serve as an isolated and separate kitchen. The identification of a separate low within the Gandak Depression on its southern margin, which was up till now considered insignificant because of its location on the up-dip basin margin and shallow sedimentary cover, may in all probability open up a new locale for exploration.

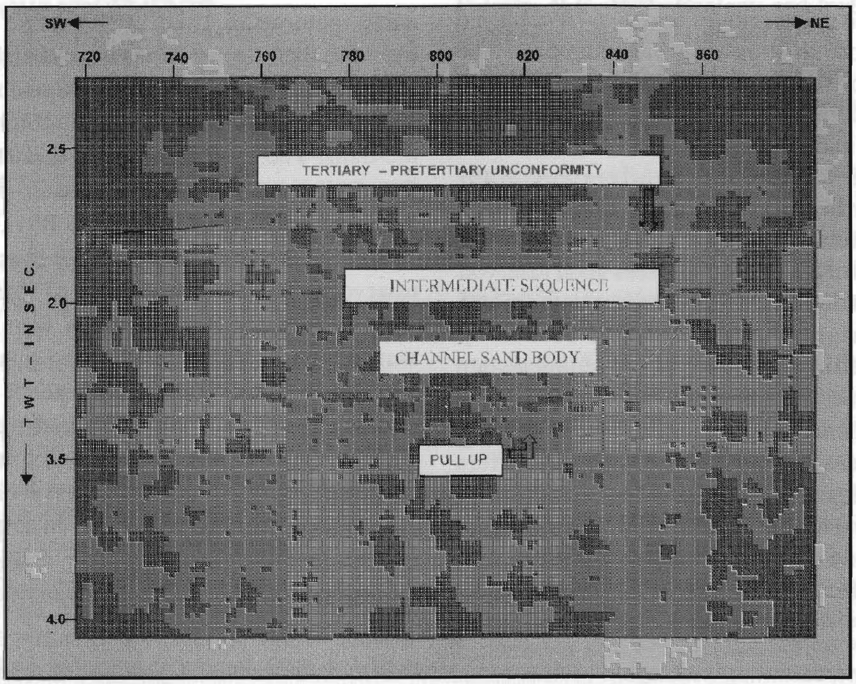


Fig. 6. Channel sand body in the Intermediate Sequence

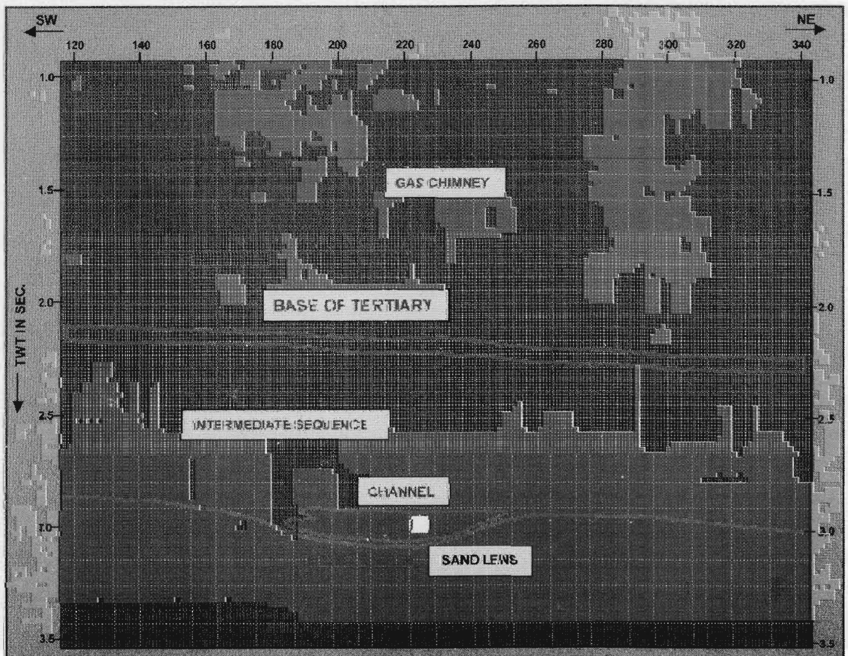


Fig. 7. Seismic signatures showing channel sand body in Intermediate Sequence

The palaeo-ridges seems to have played active role in supplying the sediments. The truncation of IMS along seismic profiles B6-1 and B7-2 in the proximity of S-E depocentre hosting maximum thickness of IMS are the suitable locales for stratigraphic traps (Raiverman *et al.*, 1999; Misra, 1999). The sand bodies within these channels and those in the depocentre are likely to possess good reservoir characteristics, especially those near the mouth of southeastern channel, where because of sharp fall in gradient, coarser sediments are liekly to have been dumped in proximity to the mouth. In that case, the area close to this low on the eastern and western flanks offers suitable stratigrpahic traps and can be interesting for exploration. The maturation plot (fig. 5) and maturation modeling at the base of IMS (Table-2) indicates VRO 0.79, exhibits the early maturation zone in this part, which indicates that if generation of hydrocarbons is initiated, it may find place for entrapment in the up-dip wedges and other suggested stratigraphic traps. The sandstone lenses deposited by the channel, seen in all the seismic profiles adjoining the depocenter like B7-2, B91-, UP39-1 etc. in all probability may provide the suitable reservoirs (fig. 8). The paucity of close grid seismic data control especially around the mapped low, prohibits the detailed anlaysis of this feature whose virtues render them to be a significant proposition for hydrocarbon exploration and may rejuvenate exploration interest. Ganga Basin primarily being a structurally lean active zone, an approach towards deliberate search for combination and stratigraphic traps may fetch rich dividends.

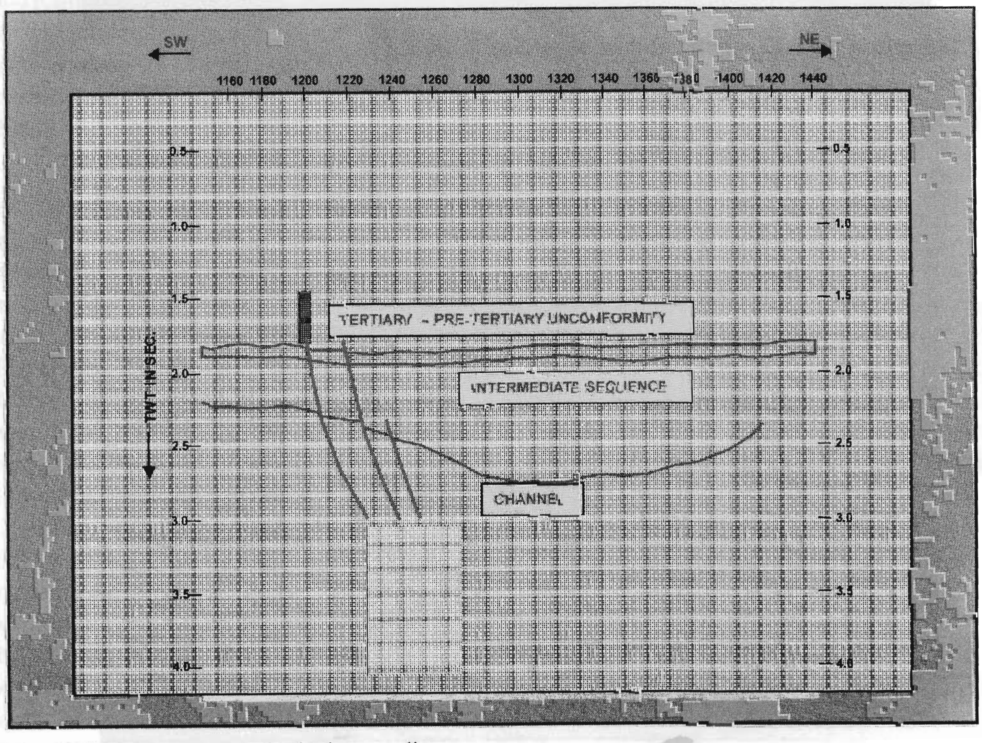


Fig. 8. Channel sand body in the intermediate sequence

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