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Extension of the Vindhyan Proterozoic Sedimentary Sequences in Ganga Basin- Geoscientific Evidences and Implications for its Hydrocarbon Prospectivity

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Summary

In view of difference in opinion on the age of Pre-Tertiary sediments in Ganga Basin, present study was carried out to understand the inter-basin connectivity of the Vindhyan with the Ganga Basin. The study involved generation of new geochronological data, review of biostratigraphic data and study of geoscientific data for synthesis and integration. Outcrop samples from the northern fringe of Vindhyan Basin in Gwalior-Karauli area and subsurface samples of Ganga basin were subjected to Zircon U-Pb dating. Proterozoic sedimentary sequences of Chambal Valley, Vindhyan Basin have been correlated (seismic and electrolog) with the pre-Tertiary sequences in wells of Sarda depression, Ganga Basin. Inter-basinal cross-sections connecting Vindhyan with Ganga and Himalayas from Chambal and Son Valley demonstrate the connectivity of these basins during Proterozoic period. Geochronological studies indicate that the Lower Palaeozoics (probable equivalent of Karnapur Formation) are present in Ganga Basin and the Bahraich- Ujhani- Tilhar sequences in Ganga Basin are correlatable with the Upper Vindhyan. The study has resulted in inferring that both Lower and Upper Vindhyan are extending into the Ganga Basin. Lower Vindhyan equivalent deeper targets having good source potential can be inferred to be prospective in analogy with the Son Valley, Vindhyan Basin.

Keywords: Vindhyan Basin, Ganga Basin, Proterozoic Sedimentary Sequences, Zircon U-Pb dating

Introduction

The Proterozoic cratonic basins developed since the Early Paleoproterozoic have widespread global development and comprise of relatively less deformed and unmetamorphosed to little metamorphosed thick sedimentary sequences. These basins resulted in the development of stable continental landmass that remained a coherent entity throughout the Phanerozoic. The study area forms part of the Aravalli-Bundelkhand craton situated north of the Central Indian Tectonic Zone (CITZ) and the Aravalli-Delhi fold belt forms its western margin. The Chambal Valley Vindhyan sedimentary sequences separate the Archaean Banded Gneissic Complex (BGC), including the Berach Granite of the Aravalli terrain, from the Bundelkhand Granite Massif. Geophysical data indicate that the Aravalli-Bundelkhand Craton constitutes the basement beneath the Ganga Basin and Lesser Himalayas (Fig.1).

Consequent upon the split of Gondwanaland and separation of India from Australia around 128Ma (Gambos et al. 1995), the northward flight of Indian plate started and the sequence of events that followed until its collision with the Asia resulted in rapid changing of the geological set-up in its northern margin during Late Cretaceous-Early Tertiary times. The main events as a result of this collision being the rise of the Himalayas and the development of the Indo-Gangetic foredeep. It is widely accepted that sedimentation, magmatism and deformation events of the Lesser and Higher Himalayas have much in common with those recorded from the northern half of the peninsular region of India comprising the Bundelkhand and Aravalli Archaean provinces which were open in their northern part towards the proto-Tethys. The Ganga Basin which lies in between the two is no exception since the Pre-Tertiary sequences underwent deposition and deformation from Early Proterozoic through Late Proterozoic to Early Paleozoic in the northern platform margin of the Indian plate.

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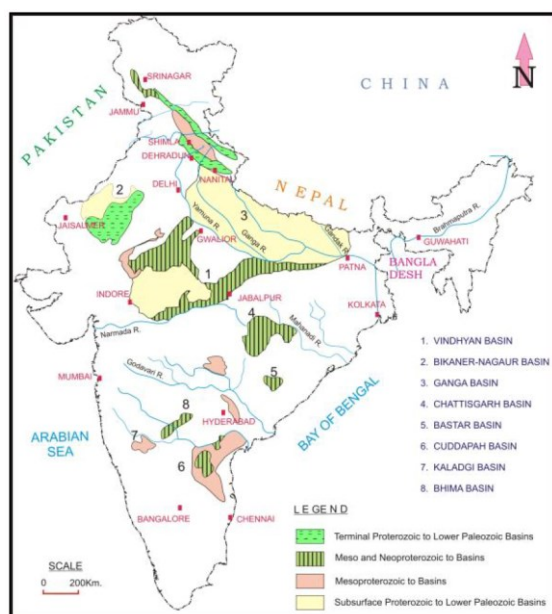


Fig.1. Map showing the distribution of Proterozoic basins in different parts of India. Note the location of the Great Vindhyan Basin opening towards north in the present day Lesser Himalayas.

Age Controversy of Pre-Tertiary Sediments of Ganga Basin

The status and age of the Pre-Tertiary sequence of Ganga Basin has long been a subject of controversial issue. Currently discordant views exist on the age of the Vindhyan and Ganga basins from the recent geo- and biochronological data. Since long, the sediments of Ganga Basin were considered to be of Proterozoic age but acritarch studies by Prasad and Asher (2001) christened the sediments of Ganga Basin as of Paleozoic age. Since Proterozoic sediments are present in the north (Himalayas) and south (Vindhyan basin), the sediments in the intervening Ganga basin are also expected to be of Proterozoic age. Salujha (1973), first reported remains of acritarchs and algae in Tilhar Formation from the UJ-S1 well considered them to be closely related to Upper Vindhyan, particularly the upper part. Sastry et al. (1971), while discussing the tectonic framework and subsurface geology of the Ganga Basin divided the whole sedimentary sequences into two stages: Lower and Upper while considering the lower stage representing limestone-orthoquartzite-shale association of probably Vindhyan origin and upper stage belonging to Siwalik Group. Maithy et al. (1983), studied microbiota from the drill core samples of Ujhani well-DX considered the biota of Ganga Basin below the unconformity to have closer

similarity with the Upper Vindhyan biota. Saxena (1992) on basis of his observation assigned Pre-Cambrian to Cambrian age on the basis of microbiota from the subsurface pre-Tertiary sequence in Gandak depression of Ganga Basin and correlated with the Chambal Valley Vindhyan. Sharma (1993) has also correlated the Pre-Tertiary sequences encountered in SPN well-A with the Upper Vindhyan. Subsequently, Shukla et al. (1994) in their lithostratigraphic classification of Ganga basin have divided the pre-Tertiary section into four formations characterized by a marked change in lithology. The lowermost formation represents the Lower Vindhyan Group and the overlying three units the Upper Vindhyan Group. Viridi (1995) has also advocated the extension of the Vindhyan into the Ganga Basin and their continuity in the Lesser Himalayas. In the recent study of Ganga Basin by Mehrotra et al. (2010), have found that the composition of acritarchs is represented by the forms commonly found in the Cryogenian and Ediacaran (Neoproterozoic) sediments and correlated them with the Upper Vindhyan.

In view of the paleogeographic set-up of the Indian plate since the Paleoproterozoic and considering the difference in opinion on the age of Pre-Tertiary sediments in Ganga Basin, it is imperative to understand the inter-basin connectivity of the Vindhyan of Chambal Valley with the Ganga Basin and towards north with the Himalayas.

Study Area

The study area selected for the above study comprises a transect in the northern part of the Indian peninsula comprising the Son and Chambal Valley parts of the Vindhyan Basin through the Sarada depression of western part of Ganga Basin and the Himalayas in the north up to the Main Central Thrust (MCT) including the Lesser Himalayas. This is presented in the geological map as shown in Fig.2. The southern boundary of Ganga Basin is delimited by the exposures of the Bundelkhand Massif and the adjoining Vindhyan outcrops implying that these outcrops present on the boundary of these two basins extend in subsurface of Ganga Basin also. Besides, the conspicuous feature present on the map are two saddles namely Dholpur saddle and Meza saddle in the west and east respectively through which the two basins must have been linked during the Proterozoic period. Further, it is seen that most of the basins end abruptly against master faults or exposures of basement but in case of these basins, two openings in the form of these saddles have been left out which is a characteristic of this paleo-

Greater Vindhyan Basin. These appear to be connecting link between the two basins.

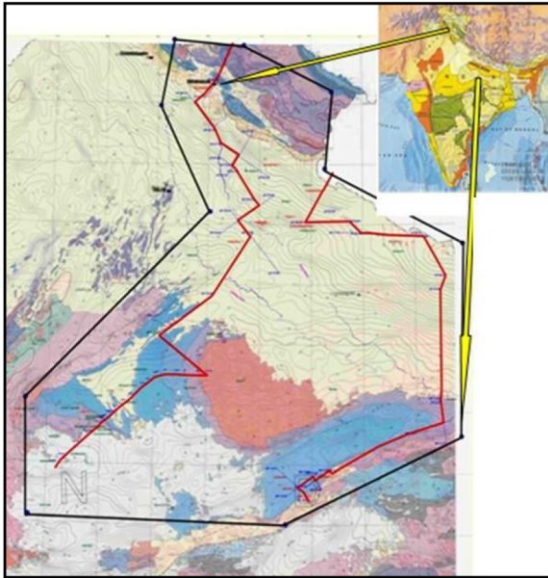


Fig.2 Geological Map Showing the Study Area along with the location of two regional profiles.

In Ganga Basin, major depressions are present in the northern parts adjoining the Himalayan foothills which are separated from each other by the possible Precambrian promontories from the Indian shield. Since these elements constitute active Precambrian zones, their maximum influence is registered on the oldest sedimentary sequence overlying the basement i.e., in the Vindhyan. These were uplifted and eroded, as is evidenced by a basin-wide unconformity at the top of the Pre-Tertiary sequences.

Methodology

An attempt has been made to establish the inter-basin connectivity of the Vindhyan basin, Ganga basin and Himalaya on the basis of evidences obtained from the following criteria:

- Use of gravity data and integrating it with the outcrop data.
- Intra-basin Correlation of Proterozoic sedimentary cycles on the basis of seismic and electrologs.
- Comparison of broad sedimentological characteristics of outcropping Vindhyan in Gwalior-Karauli area with the subsurface sequences encountered in drilled well in Ganga Basin.
- Carrying out outcrop sampling in the northern fringe of Vindhyan Basin in Gwalior-Karauli area

and study of cores of drilled key wells of Ganga Basin for age determination by geochronological dating (U-Pb) of sediments and outcrop samples.

- Preparation of regional seismo-geological sections demonstrating inter-basin connectivity.
- Taking into consideration the results of the recent acritarch studies in subsurface samples of Ganga Basin and available published literature.

Inter-basin connectivity from gravity data

In order to have a holistic view of these basins, a composite gravity map of Vindhyan and Ganga basins was generated. It shows continuation of various features thus leading to infer possible extension of sediments / features from one basin to other. Vindhyan outcrops are present in Karauli and Gwalior area. Karauli lies in gravity low whereas Gwalior is close to Bundelkhand gravity feature. Well KSJ-A and Karauli are located on the opposite end of same large gravity high. Karauli and Ganga Basin are connected through a gravity low having saddle in between Dholpur and Gwalior. The gravity values continuously deepen in this low towards NE. In the SW, this low is connected to the Chambal area where the Vindhyan outcrops are present.

This low represents the opening of Vindhyan Basin into the Ganga Basin and corresponds to Dholpur saddle. Similar opening is seen in the case of Meza saddle and thus the extension of Vindhyan is postulated into the Ganga Basin.

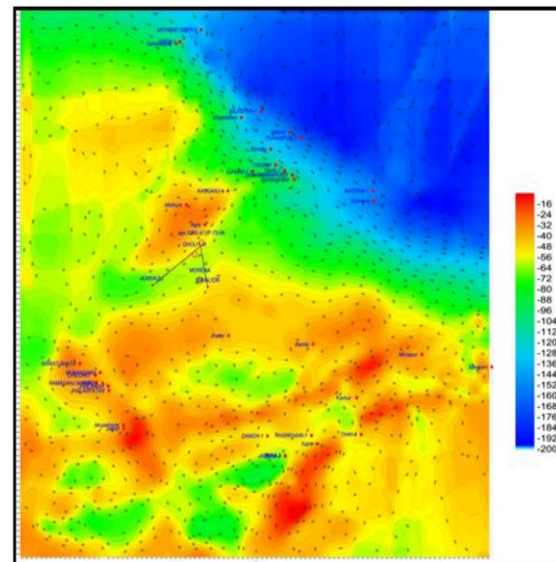


Fig.3 Composite gravity map of Vindhyan and Ganga Basin

Inter-basin connectivity from Seismic Data

Inter-basin connectivity from seismic data of the Chambal Valley Vindhyan with Sarda depression of Ganga Basin has been attempted with the help of key seismic link line UP G3-0F which is a dip line (Fig.4). This is the southernmost line located in the SW part of Sarda Depression of Ganga Basin and closest to the outcropping Bhandar sediments in the Gwalior-Karauli area further south. All the reflectors are seen to continue upwards further southwest towards Gwalior-Karauli area and have been apparently eroded. There is no evidence of onlap or truncation against the Gwalior/ Basement observed in the seismic. In fact, relative thinning of the strata is observed towards south which probably was due to concomitant uplift of the Bundelkhand Massif (Fig.5).

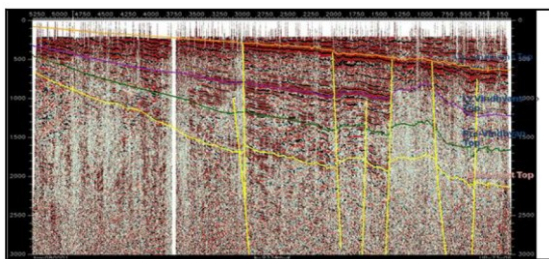


Fig.4. Interpreted seismic section showing the extension of Vindhyan into Ganga Basin

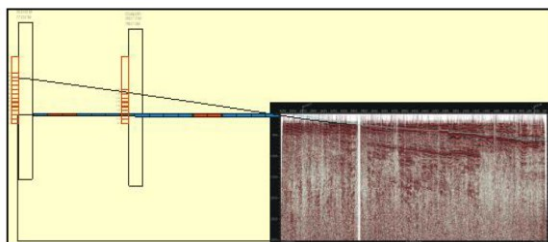


Fig.5 Correlation of the Vindhyan strata exposed in Gwalior-Karauli area with the subsurface in the seismic section in the Ganga Basin

The seismic package of Ganga and Vindhyan basins below Tertiary and their seismic signature were studied. Four seismic reflectors corresponding to top of Basement, Pre-Vindhyan, Lower Vindhyan and Unconformity between Tertiary and Pre-Tertiary (Upper Vindhyan) were identified and correlated. Study reveals that the seismic signature of Pre-Tertiary sequence of Ganga Basin is similar to that in Chambal Valley, Vindhyan Basin.

One of the interpreted seismic multipanel is shown in Fig.6. This is a SW-NE profile which is the nearest line to the outcropping Bhandar Group of Chambal Valley located further south in Gwalior area. This is a key link profile which clearly demonstrates that the Vindhyan sediments extend into the Ganga Basin with a gradual thickening towards NE in a gently dipping homocline. The strata appear to have undergone differential uplift as well as suffered erosion prior to the deposition of the Tertiary Siwalik sediments. The faults are deep seated and steeply dipping to sub-vertical.

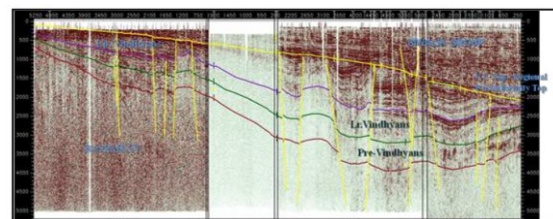


Fig.6. Interpreted seismic multipanel showing extension of the Vindhyan and older sedimentary package in Sarda depression of Ganga Basin and the subsurface configuration of the Basement and Proterozoic sediments

The striking feature seen on seismic is the presence of inversion zones. It is observed that across the inversion zones, such as Tilhar inversion and Semri-Hazara inversion, the Pre-Tertiary sedimentary thickness reduces and beyond inversion zones, the thickness is restored. Inversions are also seen in the Vindhyan Basin where also the sedimentary thickness reduces considerably. Several ridges are present which have divided the basin into four depressions viz. Sahaspur, Sarda, Gandak and Madhubani from west to east. Pre-Tertiary sequences do not appear to continue on these ridges but on either side of these ridges, complete sedimentary column is present. Similar analogy can be extended for inter-basinal areas viz. from Ganga to Vindhyan where Bundelkhand Massif separates these two basins but strata emerge on both sides of it. In fact, two openings in the form of Dholpur and Meza saddles are available for extension of Vindhyan sediments into Ganga Basin.

Correlation of Pre-Tertiary (Proterozoic) sedimentary cycles in Ganga Basin

The correlation carried out of the Pre-Tertiary (Proterozoic) sedimentary cycles on the basis of seismic and electrologs in Sarda depression of Ganga Basin show the subsurface configuration and correlatability of these sequences across the Sarda depression.

Comparison of broad Sedimentological characters and Lithostratigraphic Correlation

On the basis of sedimentological studies and the distribution of fossil bearing horizons in the Himalayas, Singh (1979) proposed that the Lesser and Central Himalaya constitute an integral part of the Peninsular Indian shield. The unfossiliferous orthoquartzite-shale-carbonate sequences of Lesser and Central Himalaya represent Precambrian sediments, deposited in a shallow tidal sea. This unfossiliferous nature of the Lesser Himalayan sediments demarcates the northern limit of Indian plate.

The Lesser Himalayan sediments are characterized by the dominance of mature sandstones (orthoquartzite). Some of these show a unique association of orthoquartzites interbedded with basic lava flows (Sundernagar Quartzite, Berinag Quartzite), which seem to be a typical association of Proterozoic age in some parts of India and in other shield areas of the world. Geomorphologically, the Lesser Himalaya depicts a mature and a highly evolved terrain showing pronounced synclinal hills and anticlinal valleys, and a well-established entrenched drainage system which indicates that probably the Lesser Himalaya remained a landmass since Precambrian times and had enough time to develop mature landscape and drainage. Therefore major part of Himalaya is the integral part of the Peninsular Indian shield and is made up of mostly Proterozoic rocks. The extension of Peninsular India below the Gangetic Alluvium into the Himalaya is also supported by the presence of orthoquartzites etc. of Proterozoic age.

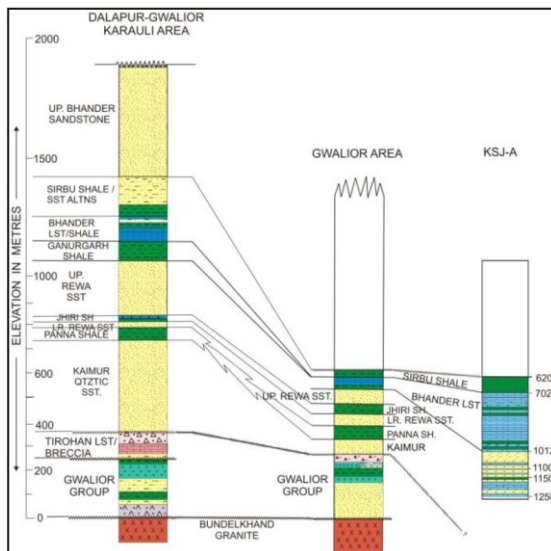


Fig.7 Lithostratigraphic Correlation of the Outcropping Vindhyan Sediments in Gwalior-Karauli area of Chambal Valley with the subsurface Pre-Tertiary (Proterozoic) Sediments in well KSJ-A in Sarda Depression of Ganga Basin

Comparison of broad sedimentological characters of the outcropping Vindhyan sediments in the Gwalior-Karauli area of Chambal Valley with the nearest well KSJ-A (Fig.7) in Sarda depression of Ganga Basin has been made and lithostratigraphic correlation has been carried out.

Construction of Inter-basinal Regional Seismo-Geological Profiles

In order to establish the inter-basinal correlation and to demonstrate the connectivity of Vindhyan and Ganga Basins and the Lesser Himalayas during the Proterozoic eon, two regional profiles were constructed. One of these is shown in Fig.8.

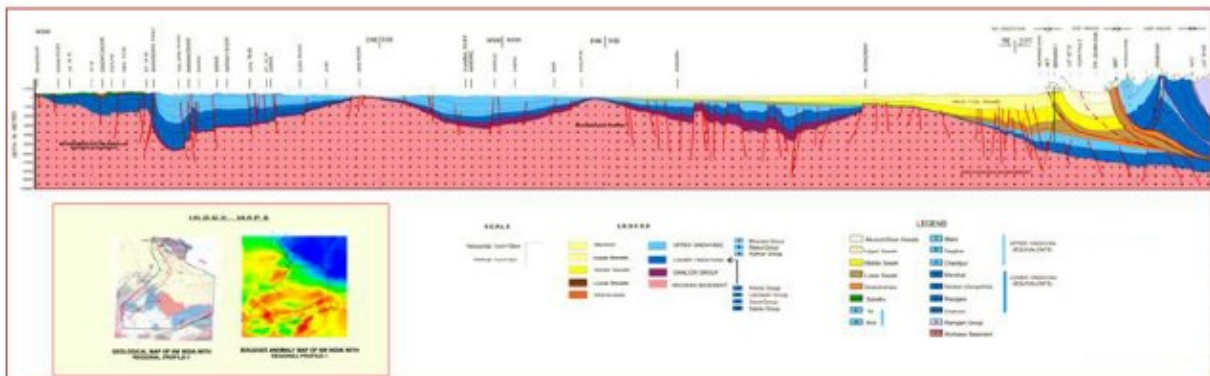


Fig.8. Inter-basinal regional Profile-1 showing the presence and subsurface extension of Vindhyan equivalent Proterozoic sediments in Ganga Basin and Himalayas demonstrating inter-basin connectivity during the Proterozoic eon



Data Synthesis

Since age of these sediments has been a debatable issue, it was considered necessary to assimilate different data sets to arrive at a scientifically tenable conclusion. The age data determined biostratigraphically shows wide variation from geochronological age data which makes it imperative to logically conclude the controversy considering other data sets. Prasad and Asher (2001) earlier had determined ages of Ganga Basin sediments based on the acritarchs to be Early to Late Cambrian (Tremadoc) and Late Ordovician to Early Devonian sequences. However, studies by Mehrotra et al. (2010) have demonstrated on the basis of acritarch studies that the Pre-Tertiary sequences in Ganga Basin are of Cryogenian and Ediacaran (Neoproterozoic) sediments and correlated them with the Upper Vindhyan. Recently Zircon U-Pb dating has been carried out in the subsurface of Ganga Basin on core samples and outcrop samples of Kota-Jhalawar and also from the Gwalior-Karauli area of Chambal Valley, Vindhyan Basin in Rajasthan. The results are at great variance to the biostratigraphically determined ages of Ganga Basin. Compatibility of these ages has been checked with other datasets and the veracity of the ages has been established. After subjecting the above geochronological data sets to (i) Lowest age as the upper limit of stratigraphic age (ii) Stratigraphic order of superposition and geoscientific studies, the geochronological conclusions drawn for the drilled sequences in Ganga Basin and also the outcrop samples of Chambal Valley, Vindhyan Basin are shown Table-1 below:

Table-1
Geochronological Ages of Outcrop samples of Chambal Valley, Vindhyan Basin and Subsurface samples of Ganga Basin

Vindhyan Basin (Chambal Valley)		Ganga Basin (Sarda Depression)	
Group/Formation	U-Pb age	Group/Formation	U-Pb age
Lower Bhandar	<775 Ma	Karnapur	<523 Ma
Rewa	<1140 Ma	Tilhar	<943 Ma
		Ujhani	<1063Ma
Kaimur	<1150 Ma	Bhraich	<1175 Ma

Establishment of Inter-Basin Connectivity

The inter-basin connectivity between Chambal Valley, Vindhyan basin and the Ganga Basin has been demonstrated with the help of key seismic line UP G3-0F. This is the southernmost line located in the SW part of Sarda Depression of Ganga Basin and proximal to the outcropping Bhandar Group sediments in the Gwalior-Karauli area further south. Study of the seismic data reveals that the Pre-Tertiary package correlated from wells in this line is found to continue near the surface which is covered by the Gangetic Alluvium. All the reflectors are seen to continue upwards further southwest towards Gwalior-Karauli area and have apparently been eroded. There is no evidence of onlap or truncation against the Gwalior/Basement observed in the seismic. In fact, relative thinning of the strata is observed towards south which probably was due to concomitant uplift of the Bundelkhand Massif.

The seismic and electrolog correlation has been broadly extended from Chambal and Son Valley, Vindhyan Basin into the Sarda depression of Ganga Basin extending upto the Himalayan Foothills demonstrating the correlatability of different Pre-Tertiary (Proterozoic) sedimentary cycles in Vindhyan and Ganga basins and the Himalayas.

Field investigations carried out by one of the author (RS) on the outcropping Vindhyan in Gwalior-Karauli area have shown that the sediments of Gwalior Group as well as the overlying Upper Vindhyan exhibit sub-horizontal to very low dips ranging from 2° to 5° towards WNW in Gwalior area with locally northerly dips forming a gentle homocline inclined very gently towards north-northwesterly direction.

The inter-basin linkage of Vindhyan with Ganga and the Himalayas has been also demonstrated in Regional Profile-1 spanning a length of 1010Km wherein the geological model constructed with the help of outcrop and seismic data from Mandsaur to Karauli in Chambal Valley, Vindhyan Basin passing through wells in western part of Sarda depression, Ganga Basin to MND-A well in the Himalayan Foothills wherein Vindhyan equivalent Mohand Formation was encountered. In order to further demonstrate the extension and presence of Vindhyan equivalent sediments in the Lesser Himalayas beyond Main Boundary Thrust (MBT) upto Main Central Thrust (MCT) the geological cross-section was further extended through Dun Valley to Mussoorie upto Barkot



encompassing the Lesser Himalayas wherein the continuation of Lower as well as Upper Vindhyan (= Mandhali, Chandpur and Nagthat, Blaini, Infra-Krol and Krol) sequences is very much evident (Fig.8).

On the basis of geochronology studies carried out by detrital zircon U-Pb dating, it is now well established that the Pre-Tertiary sediments of Ganga Basin are fairly well correlatable with the Bhandar Group sediments of Chambal Valley, Vindhyan Basin of Meso-Neoproterozoic and also in the Lesser Himalayas thus establishing the presence of a large Great Vindhyan Basin in the northern margin of Indian plate during the Proterozoic era. These sediments range in age from 1175±48Ma to 523±53Ma (Meso Neoproterozoic age).

Implications for Hydrocarbon Prospectivity

It is suggested that in Ganga Basin the wells should be targeted to the Lower Vindhyan sequences which have good source rock potential as observed in Son Valley, Vindhyan Basin where it is now well established with gaseous hydrocarbons being observed in several drilled wells. The present study has thus opened up a new play for hydrocarbon exploration in Ganga Basin. It may be recalled that in well SPN-A, the oil and gas show in the fractured cores cut in the upper part of Karnapur Formation had indicated presence of migratory hydrocarbons with wet gases from deeper source and has also been substantiated by the studies by Mehrotra et al. (2010). It is opined that this deeper source is likely to be the source facies of Lower Vindhyan equivalent sediments need to be targeted for hydrocarbon exploration.

Conclusions

- Inter-basin connectivity of Vindhyan-Ganga-Himalayas during the Proterozoic eon has been established.
- For the first time, zircon U-Pb dating of subsurface samples of Ganga Basin has been carried out along with outcrop samples of Chambal Valley in the northernmost fringe of the Chambal Valley, Vindhyan Basin.
- Both Lower and Upper Vindhyan are continuing to Ganga Basin.
- The Lower Palaeozoics, probably equivalent to Karnapur Formation, are present in the Ganga Basin.

- On the basis of U-Pb dating, the Bahraich-Ujhani-Tilhar sequences in Ganga Basin seem to be broadly correlatable to Upper Vindhyan of Chambal Valley and range in age from 1175±48Ma to 523±53Ma (Meso-Neoproterozoic).
- Lower Vindhyan equivalent deeper targets having good source potential can be inferred to be prospective in analogy with the Son Valley, Vindhyan Basin and thus enhances the hydrocarbon prospectivity of Ganga Basin.

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