

Geological Model and Prospectivity Perception of Ganga-Punjab Basin: Exploration Status, Global Analogy and Opportunities

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Abstract

Ganga-Punjab Basin is a wide, linear Tertiary foredeep developed on a Proterozoic-Early Palaeozoic platform during Himalayan orogeny. The entire Ganga-Punjab basin covers an area about 3,30,000 sq. km in the states of Punjab, Haryana, Uttarakhand, Uttar Pradesh and Bihar. The western part of this NW-SE oriented basin is known as Punjab Plains where the major rivers are flowing towards west (Jhelum, Sutluj). The central and the eastern part of this foredeep is known as Ganga Basin having major Rivers (Yamuna, Ganga, Ghaghra, Gandak) flowing towards east. Punjab Plains is delimited by Jhelum fault at the west and Delhi-Ambala-Kalka ridge at the east whereas, the Ganga Basin is situated between Delhi-Ambala-Kalka ridge in the west and Monghyr-Saharsa ridge in the east. Himalayan Frontal Thrust (HFT) marks the northern boundary and Delhi Sargoda ridge, Precambrian Bundelkhand massif and Vindhyan outcrops delimit the southern margin of this basin. Globally, the economic significance of hydrocarbons occurring within the foredeeps and underlying platform is enormous. Few prolific hydrocarbon producing basins of the world like Zagros, Western Canada, Alaska, Venezuela are of this category and an attempt has been made to compare the essential petroleum parameters of Ganga Basin with these global analogous basins. A Generation-Migration-Entrapment chart has been prepared for this basin showing probable Source-Reservoir-Trap facies quantifying the values of the petroleum facies. This kind of chart is very useful for petroleum system modelling and decision making. Hydrocarbon resources of this basin is prognosticated as ~128 MMT0E (*Hydrocarbon Resource Ass.* 2017) and envisaged to confine in Tertiary (Lower Siwalik) and Neo-Proterozoic Plays (Ujhani-Tilhar-Karnapur).

Exploration Status

The entire basin is tectonically subdivided into sub-basins separated by basement ridges formed by major faults. From west to east they are Delhi-Kalka-Shimla Ridge, Chandausi high, Bundelkhand/ Faizabad Ridge and Monghyr-Saharsa Ridge with four prominent depressions in between i.e., Sahaspur, Sarda, Gandak and Madhubani depressions (**Figure 1**). Exploratory

efforts have been made in search of hydrocarbon in Ganga Basin especially focusing these lows. The basin is fully covered by gravity-magnetic survey, more than 22000 GLK of 2D seismic survey, ~400 SKM 3D seismic and surface geochemical surveys. ONGC, OIL and Cairn India have drilled 17 exploratory wells and 4 Structural wells in Ganga Basin which are distributed in various depressions like 1 in Sahaspur depression, 9 in Sarda depression, 5 in Gandak depression, 2 in Madhubani depression. So far in Punjab Basin 4 exploratory wells (A-1, H-1, J-1 and J-2) and 1 structural well (Z-1) were drilled by ONGC. Most of the drilled wells in Ganga-Punjab Basin have been targeted strati-structural/ structural prospects to chase the hydrocarbons of Neo-Proterozoic-Paleozoic (?) sequences consist of Ujhani, Tilhar and Karnapur formations. No encouraging hydrocarbon success has been ascertained so far.

Present Study

A comprehensive geo-scientific analysis of Ganga-Punjab Basin has been carried out integrating 2D NSP lines with old 2D vintages. The seismic interpretation clearly brings out sub-surface structural highs and depressions shown in **Figure 2** where the sedimentary package is broadly grouped into two units, Pre-Tertiary/ Vindhyan equivalent below (Bahraich, Ujhani, Tilhar, Karnapur) and Siwaliks (Lower, Middle & Upper) above which is separated by Tertiary-Pre-Tertiary Karnapur regional unconformity (**Figure 3 and 4**).

The interpretation suggests the foredeep sediments are least affected by subsequent tectonic modification. Attribute analysis like Frequency and RMS amplitude were attempted to delineate structural and stratigraphic features and in few lines. The RMS amplitude close to the top of Karnapur formation (**Figure 3**) was very high and prominent which facilitated the demarcation of Tertiary-Pre-Tertiary regional unconformity. The basement controlled faults are well developed in Pre-Tertiary Vindhyan equivalent section and were not much reactivated during the foreland warping and sedimentation (**Figure 4**). Minor displacement at the Lower Tertiary level can be identified at the fringe of major ridges. Ordovician upliftment resulted a

prolonged phase of non-deposition till the formation of foredeep sediments. Isochron map at the regional unconformity level at the base of Tertiary package shows a gradual homoclinal dip towards north. The wedge-shaped Tertiary foredeep prism thickens gradually towards north and attains maximum undeformed thickness ~ 6000m near sub-thrust of HFT (Figure 5).

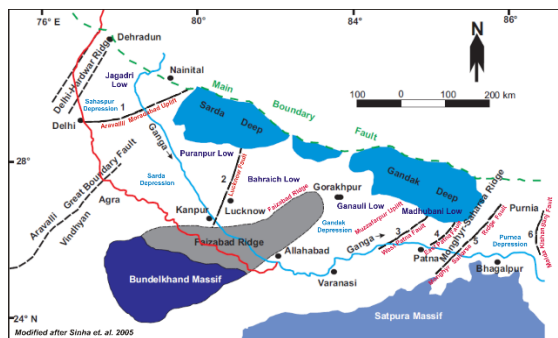


Figure 1: Major faults, Ridges, Lows in Ganga Basin

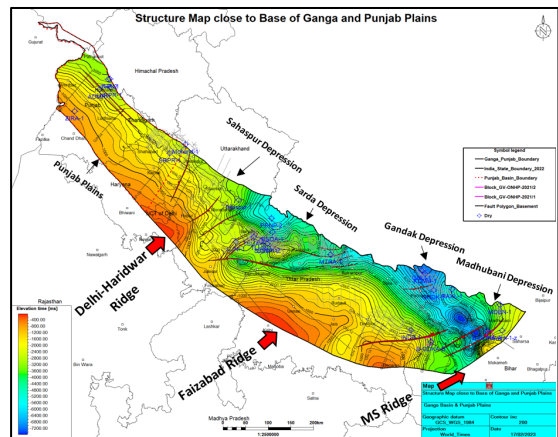


Figure 2: Time structure map at Basement top

Geological Model of Ganga Basin

The overall trend of the Gangetic foredeep is parallel to the Himalayan front. G&G interpretation clearly delineated four sub-basins separated by areas of lesser thickness corresponding to uplifts and subsurface extension of basement ridges (Figure 2). The Pre-Tertiary (PT) sediments below the regional unconformity appear to have been preserved within the depressions (Sahaspur, Sarda, Gandak and Madhubani) which were controlled by prominent fault trends i.e., NNE-SSW & E-W respectively. Moreover three 1st order sequences (Megasequences) are clearly identifiable in the Proterozoic sequences based on reversal of Basin scale depositional slopes and regional angular unconformities (Figure 6). This PT sequences are represented by platformal sediments deposited in extensional regime and believed to have extended up to Cretaceous in few depressions. A profound deep erosion of

approximately 500 ma has drastically reduced the PT sedimentary cover. It is conjectured that the deeper part of the lows in the basin has preserved such facies which escaped the erosional impact to certain extent and more complete succession can be expected to be present there.

An *Intermediate Sequence* (IMS=Karnapur Formation), (Mishra et al., 2005) is placed in between the Siwaliks above and the Vindhyan below. The sequence is bounded by distinct unconformity at top & bottom and well visible in seismic reflection (Figure 3). In Gandak depression, the IMS has favorable thickness, depth of burial and optimum depositional environment which makes a viable target for exploration.

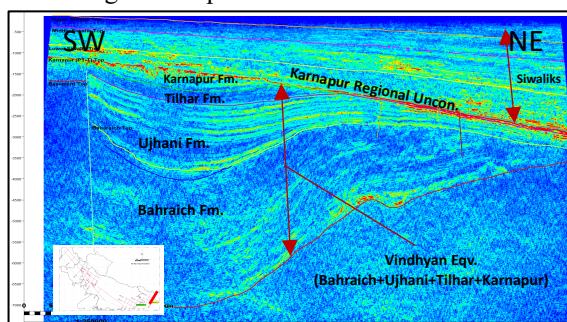


Figure 3: RMS Amplitude along Line XY-23. Regional unconformity (top of Karnapur Fm.) is very prominent separating undeformed Siwaliks (above) and deformed Vindhyan equivalent Fm. below

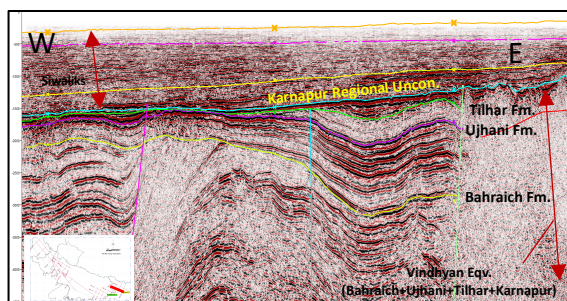


Figure 4: Seismic interpretation in XY 20 showing undeformed Siwaliks (above) and deformed Vindhyan equivalent Fm. below

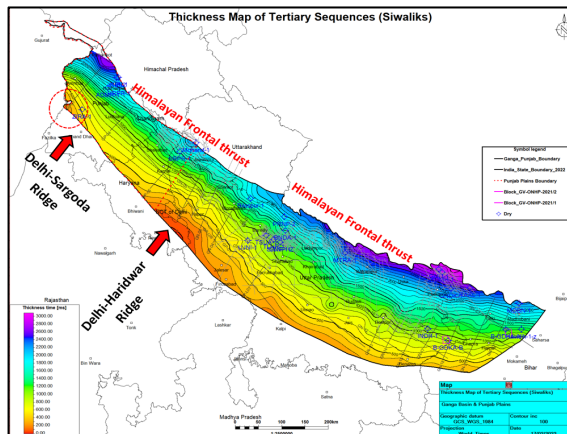


Figure 5: Isochron map of Tertiary Package showing thickness gradually increases towards north

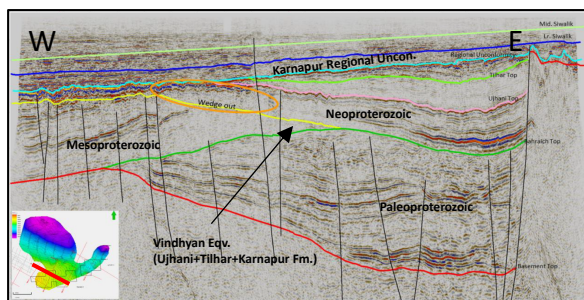


Figure 6: Paleo-Meso-Neo Proterozoic sequences showing different paleo-basinal slope

Prospectivity Perception of Ganga Basin

It has been observed that the major transgressive phases (Silurian, Mid & Up. Devonian, Uppermost Jurassic and Upper Cretaceous) correspond to the major source facies of the world were not developed in this basin. The Upper Proterozoic and Cambrian-Ordovician cumulatively represent only 0.4% of effective source rock of the world (Ulmishek and Kleme, 1991). The pre-foredeep passive margin sequence represented by Ujhani, Tilhar and Karnapur formations which were deposited in a shallow marginal marine set up were probably regressed during Mid Ordovician (Karnapur Formation?).

The overall lean source character of pre-foredeep sediments is primarily due to the scarcity of organic productivity aided by unfavourable chemical environment for preservation. Based on biostratigraphic studies, Prasad & Asher, 2002 proposed top of Karnapur Formation up-to Mid-Silurian to Mid Devonian and strongly advocated the presence of Palaeozoic in Ganga Basin, though most of the workers reject such young ages of the pre-foredeep sediments and confine it within Neoproterozoic.

Kumar et al., 2002 suggested that Type II and III kerogen are reported from most of the Pre-Tertiary formations which are algal derived and partly from primary metazoans in post-Cambrian sediments. Sedimentation was taking place on a vast epicontinental sea with water depth of few meters and rarely reaching the required anoxia within its thin water column. The more or less consistently fair source rock character of Karnapur Formation can be related to enhance organic productivity during Neo-Proterozoic/ Lower Palaeozoic. The basal transgression related to the formation of Gangetic foredeep was very short and restricted to the inner foreland belt. A package of about 6 km thick foredeep clastics are recorded mainly within the lows and dominantly continental throughout. The low energy meandering system of Mathera and Lower Siwalik gradually grades to high to very high energy braided

alluvial fan of Middle and Upper Siwaliks. The absence of basal transgressive facies, significantly reduces the chances of getting good source rock in this foredeep. However continental source facies are expected to develop locally with Type III kerogen in some part of the basin. TOC of Lower Siwalik around 0.5% in most of the drilled wells supports the view.

Gas indication: Sub-surface Hydrocarbon shows have been reported during drilling and production testing in Ganga Basin. In Sarda depression, TL-1, MT-1, SJH-1 and 1(D), BL-1 and TS-1 have indicated hydrocarbon shows. In Gandak depression hydrocarbon indications were observed in GDK-1, GNL-1 and in Madhubani depression, MD-1 within Karnapur and Lower Siwalik. Surface gas shows have been reported from Narora and Fazilnagar. In the adjoining Nepal foothills, a few gas shows have been reported at Dailekh (Padukasthan) and in Kathmandu Valley. Adsorbed gas survey of samples collected from shot holes in Tilhar-Bilaspur-Bareilly and Pawayan-Mohamadi-Shahjahanpur area have shown zones of interest near Nigohi and Bilaspur. Alleged oil and gas investigations were also carried out in three locations of north Bihar. The origin of surface show of gas in Nayagaon and Sultanganj in the riverbed of Ganga is probably of biogenic origin since its composition shows the presence of methane only and absence of any higher hydrocarbon gases.

Source Rock: The nature of source rock, its quality, thickness, areal extent are still not well known in this basin. Sporadic data is available from different stratigraphic levels which shows organic richness at places.

Ujhani Fm.: Algal Source, Type- IIB-IIIC, TOC: 0.57-5.8%, S₂: 0.22-11.26, HI: 33-59, Tmax: 423-478, VR₀: 2.50, 3-3.5. **Karnapur Fm.:** Algal Source, Type: IIB-IIIC, TOC: 0.27 to 3.49%, S₂: 0.14-8.58, HI: 237-306, Tmax: 372-432, Vro: 0.29 to 0.36 **Lower Siwalik Fm:** TOC upto 8.18%, IIB-IIIC Type, S₂: 4.75 - 29, HI: 314 - 467, Tmax: 375-440, VR₀: 0.23-0.60

Maturation: Geothermal Gradient recorded in few wells are like SAH-1: 1.75°C/100m, MT-1: 1.74°C/100m, 2.1°C/100m, TL-1: 1.72°C/100m, 3.33°C/100m, 2.54°C/100m, BD-1: 1.89 °C/100m, MD-1: 1.53°C/100m, HA-1 & 1Z: 1.77°C/100m, SJH-1: 2.15 °C/100m, RX-1: 1.55°C/100m, BL-1: 2.63°C/100m (around 2.88°C /100m against the Vindhyan section)

According to Kumar et al., 2002, Vitrinite reflectance data calibrated with geothermal gradient shows a part of Tertiary package is reaching maturation window below 4630m in the deeper part of foredeep like

Puranpur Low and Gandak Low. The pre-foredeep platformal sediments were subsided at the most down to 4000m during Mid Ordovician time and were not affected by further vertical movement till the formation of foredeep.

Prakash & Kumar (1991) postulated the formation of Monghyr-Saharsa ridge at the beginning of Eocene. **Raiverman et al. (1983)** also opined that the Faizabad ridge was uplifted before Palaeogene, that means the pre-foredeep sediments were buried at a depth of 4 km for a period of time of 500 ma, it must have generated hydrocarbons before Himalayan orogeny.

Geochemical survey in this area were thoroughly studied and analysed to understand the potential of the source rock and its role in generation of HC within the basin. **Uniyal et al., 1991**, analysed the stable isotope geochemistry indicated Tertiaries are non-marine while the Pre-tertiary sediments are of mixed to marine depositional environment. Based on the analysis of Methane dominated gas samples **Gupta et al., 1997** suggested biogenic/bacterial origin. **Tewari et al., 2007**, analysed oil sample and chloroform extract from water samples and concluded fluorescence not indicative of petroleum. **Prasad et al., 2007**, concluded Lower Siwalik are of sapropelic/humic in nature and marginally matured to immature based on VRo and Tmax values though **Mamgain et al., 1993**, observed that Lower Siwalik formation is organically rich and has very good potential to generate HC. The organic matter is of mixed type (III & II). **Shukla et al., 2009**, indicated gas is late thermogenic in origin, wet gas, possibly formed by the extensive cracking of oil. Isotopic composition of methane indicated that gas is not likely to be associated with liquid hydrocarbons. **Prasad et al., 2007** observed Ujhani Formation has good to very good mature source rock sequences (TOC%: 1.72-5.8, Tmax (460°-470°C) and VRo 1.1%. These source rock layers were suggestive of late peak oil window and attained a maximum 94% kerogen conversion. **Berry et al., 1993** suggested the Pre-Tertiary sequence contains algal derived-sapropelic matter with excellent maturity and in some cases over mature.

Thus, based on the present study two hydrocarbon plays can be envisaged i.e. **Late Neoproterozoic-Early Paleozoic Play (?)** which is composed of alternations of shale, siltstone, sandstone and limestone. Potential source rocks within Ujhani, Tilhar (?) and Karnapur formations are envisaged to have generated hydrocarbons that migrated towards up-dip at favorable locales. **Tertiary Plays (Lower Siwalik-Lower Siwalik?)** has fair to good source rock potential, which may be mature in deeper part of the

basin. Lower Siwalik sandstones have good porosities and the shales within thick Siwalik succession overlying may act as seal.

Geological Model of Punjab Basin

The seismo-geological model of Ganga and Punjab Plains clearly indicates, Delhi-Haridwar ridge has separated Punjab Plains from Ganga Basin. Within the Punjab Plains, the basement top gradually gets shallower towards the east and deeper towards west. The thickness of Siwaliks (Upper, Middle and Lower) and Neo-Proterozoic Karnapur Formation are less in comparison to Ganga Basin. Presence of Dharamsala at the north-western low is envisaged in Punjab Plains based on its presence in wells J-1 and J-2 at the up-thrust of HFT. Presence of Subathu is doubtful in Punjab Plains and if exists the thickness will be meagre. Here also, like the Ganga Basin, the regional unconformity (Karnapur Formation top) separates Cenozoic (Siwalik-Dharamsala) and Neo-Proterozoic.

Prospectivity Perception of Punjab Basin

Hydrocarbon exploration scenario of Himalayan fold belt and associated Ganga-Punjab foredeep are similar to the producing foredeep of Italian Alps and Apennines chains. These two mountain chains constitute a thrust belt-foredeep-foreland system where several petroleum systems have been developed in undeformed terrigenous Plio-Quaternary foredeep wedges, especially biogenic gas. This gas accumulation has paramount economic importance and makes Italy most important hydrocarbon province in the southern Europe (**Figure 7**).

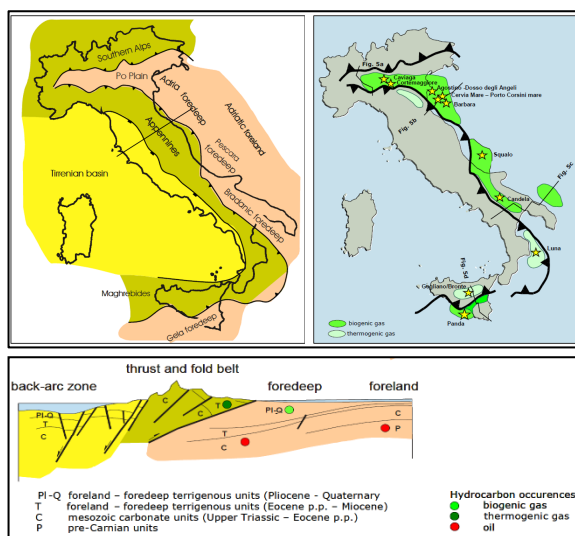


Figure 7: Map of Italy showing fold belt and foredeep. Occurrences of biogenic gas is mainly in terrigenous foredeep wedges (similar set up like Punjab Plains) *Source: Exploration Country Focus: Italy*

In comparison to the basinal area, it appears that Punjab Basin has not been systematically explored so far. In well H-1, continuous gas shows recorded from 3190m to 3440m. In well J-1, presence of gaseous HC observed 2990-3095m at different intervals. These sub-surface gas shows are encouraging in exploration point of view.

Adsorbed gas anomalies which were observed south of Gurdaspur and SE of Jalandhar where presence of Methane (C1), Ethane (C2), Propane (C3), iso-butane (iC4) and n-butane (nC4) hydrocarbons were reported. The geochemical analysis suggests that these gases are of catagenic origin, petroliferous in nature and have emanated from subsurface hydrocarbon pools.

Based on the drainage anomalies and satellite data, morphotectonic analysis was carried out in Punjab Plains which suggests presence of at least 5 anomalies in Punjab Plains. The developed anomalies are Anomaly 1 (NE of Ambala), Anomaly 2 (south of Hoshiarpur), Anomaly 6 (Mukerian city), Anomaly 7 (around Pathankot city) and Anomaly 8 (north of Gurudaspur city) **Figure 10b**). These anomalies indicate presence of sub-surface highs/ structures within Punjab Plains.

Residual gravity anomaly map and Time thickness map of Karnapur Formation (NeoProterozoic) depicts patches of highs and lows i.e. locales with variable thickness are present below regional unconformity. The maximum thickness of this Karnapur Formation is ~800 ms near Sahaspur depression. The geochemical data suggests presence of good source facies (TOC upto 3.49%) and porosity (6-8%) but the Tmax (425, 432) and VRo (0.29-0.36) data indicates the sediments are relatively immature. However, presence of gas in Karnapur formation during drilling in wells SJP-1, GND-1 and GNL-1 indicate gaseous hydrocarbon has been generated and migrated from the deeper source and a petroleum system i.e. Karnapur-Karnapur and Karnapur-Dharamsala-Lower Siwalik can be envisaged in Punjab Plains.

Analogous foreland basins across the globe

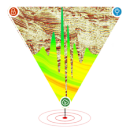
The economic significance of hydrocarbons occurring within the foredeeps, underlying platform and within the older rift sequences is immense. Few of the prolific hydrocarbon producing basins of the world like Zagros, Western Canada, Alaska, Venezuela etc. are of this category. It is interesting to note that few of them are rich in hydrocarbons, however most of them contain relatively small volume. A rigorous exercise is required to understand the key factors of hydrocarbon

generation, migration and retention within a basin. Comparison of geological factors is an essential prerequisite in this context. An attempt has been made to synthesize systematically the essential petroleum parameters of few hydrocarbon producing foreland-foredeep basins and tried to compare with the available data of Ganga basin (**Table 1**).

Conclusion and Opportunities

The entire Ganga-Punjab Basin covers a vast area of 330000 sq. km having 5-6 km thick Proterozoic and ~3 km thick Cenozoic foredeep sediments (**Figure 8 & 9**). The economic significance of hydrocarbons occurring within the foredeeps and underlying platform in Ganga-Punjab basin appears enormous when it is compared with the producing basins like Zagros, Western Canada, Alaska, Venezuela etc. VRo and geothermal gradient data indicate Tertiary and Pre-tertiary sediments might have attained maturation window below ~4000m in the deeper part of the basin like in Purnapur and Gandak low in Ganga Basin. Time structure and thickness maps of important reservoirs and source sequences like Lower Siwalik Fm., Dharamsala Fm., Karnapur Fm, Tilhar Fm., Ujhani Fm and Bahraich Fm. facilitated in defining the depositional limits and depocenters of the mapped horizons. Generation-Migration-Entrapment (GME) chart prepared for this basin helped to delineate probable Source-Reservoir-Trap facies and probable plays. The results of seismic interpretation and attribute analysis have brought out more than 20 prospective areas in the entire basin falling within and outside the three active OALP acreages (2 of ONGC & 1 of Cairn). The identified prospects are mapped as structural highs, fault closures and stratigraphic/wedge out features confined to mainly in Neo-Proterozoic play. Moreover few identified missed opportunity may be further probed in future OALP. The thickness of sediments in Punjab plains is an issue for hydrocarbon exploration. The thickness progressively increases towards NW at the sub-thrust of HFT and estimated as 4200m. Analysis of gravity anomaly map brings some hope in finding out the corridor of gravity low. Similar local depressions/ sags with presence of relatively thick sediments are also identified in 2D NSP lines. These lows indicate preservation of entire sedimentary sequence is possible which will be interesting and suitable for hydrocarbon exploration in this sector (**Figure 10a**). Morphotectonic analysis was carried out in Punjab Plains which suggests presence of at least 5 anomalies in Punjab Plains (**Figure 10b**).

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Basins	Location	Depositional window	Time of formation of foredeep	Thickness	Depositional setting	Fluid	Source	Reservoir	Seal	Trap	Thermal Gradient	Depth of maturation
Zagros	South west of Zagros collision zone	Infracambrian to Recent	Late Eocene	Foredeep fill: 1000 - 2500m Pre foredeep sediment: 2500 - 5000m	Foredeep: Upper Eocene to Lower Miocene tropical marine sedimentation (carbonate- evaporite) Lower Miocene onward continental molasse Pre-Foredeep Platform: A prolonged and stable history of passive margin	Oil, gas, condensate. Heavy oil in Paleozoic section	Twelve levels of good source facies in argillaceous carbonate and shale	Dominantly carbonate reservoirs from Cambrian to Miocene. Siliciclastic reservoir also present in Cretaceous and Eocene	Regional evaporite seal present. Shale also occurs at	High amplitude anticline/dome and fault related	3.4°C/100m	2000m+
Eastern Venezuela	Constituted of two foreland subbasins: Guarico and Matuini	Cambrian to Recent	Eocene in to Mid Miocene	Guarico sub basin: 5000m (Max). Avariz 3500m Maturin Subbasin: 8500-14000m	Foredeep: Late Eocene to Oligocene Shallow marine shale List and deltaic sandstone overlain by Early Miocene molasse. Basin was in part uplifted and eroded during Mid Miocene to Pliocene. Further up fluvial Pliocene deposits. Pre-Foredeep Platform: Late Jurassic rifting and Cretaceous to Late Paleocene	The marginal fields at the southern fringe contain heavy to medium gravity oil (10°-35° API). Light and medium gravity crude (20-50°) are reported from a few pockets from deeper part of the basin.	Upper Cretaceous Querecual and San Antonio Formations - Type II & III kerogen, TOC: 0.25 to 6.6% S ₂ : 15 - 454 mg/ Hc/g Toe, HI (av)= 400-700 Oligocene Merecur & Robleico Formations Miocene Oficina and Chaguarmas Formations	All siliciclastic reservoirs	Shale cap from most of the formations.	Dominantly normal and reverse fault closures and thrust related anticlines. Producing zone ranges in	2.4° c/100m (surface Temp 23°C).	2500m+ Peak of oil generation in subthrust 7000m Long distance migration (150 to 325 km) is envisaged during Late Miocene.
North Slope Foreland Basin, Alaska	It covers the entire northern Alaska part of NW Canada and Northeastern Siberia.	Mississippian to Recent	Mid Jurassic	Foredeep fill: 6000m. Pre foredeep sediment: Av. 1000m, at places upto 4000m Basement is at 10 Km depth along the axis of the foredeep	Foredeep: Older parts of the fill Jurassic to Early Cretaceous are relatively thin and mostly deep marine sequence including Turbidites. Younger parts (Late Early Cretaceous onward) of the fill consists of thick prograding basinal, basin slope, shallow marine shelf to continental molasse. Pre-Foredeep Platform: A passive margin transgressive sequence initiated with nonmarine elastics followed up by widespread shelfal carbonate and shale.	Both light low sulphur oil as well as heavier, and high sulphur oil (volumetrically more than half of the known in-place oil)	Cretaceous Canning Fm Cohille Group Torok Fm Hue Shale HRZ Pebble Shale Unit Kalubuk Fm. Jurassic shale. Triassic shale	Foreland reservoirs are subquartzose - lithic sandstone but pre-foreland are mature quartz-chert arenite.	Intraformational shale in fold thrust belt and structural cum stratigraphic trap in coastal plain.	Faulted anticlinal traps in the north 2.4 - 4.7° c/100m Lower gradient to the south 15 to 2.5° c/100m	Higher thermal gradient in the north 2.4 - 4.7° c/100m Lower gradient to the south 15 to 2.5° c/100m	Ro: 6 reaches at 1500m in the north and 4500m to the south.
Ganga Basin	A part of Himalayan frontal foredeep parallel to the Himalayan orogeny.	Early Proterozoic to Recent	Late Eocene	Foredeep fill: Avg. 3500m (Max.-4800m Ganauli-1) Pre foredeep sediment: Avg. 1000m. (Max.-2500m thick in Madhubani-1)	Foredeep: During Cenozoic (Early Eocene), the Ganga-Punjab Basin evolved as a consequence of filling up of a foredeep Basin which had come into existence due to the flexing down of Indian plate following the collision of India with Asia. Subsequently deposition of Shallow marine to fluvial sediments took place during Late Paleogene and molasse sediments Siwalik Supergroup during Neogene Pre-Foredeep: Initially the Basin was an intracratonic rift Basin & deposited Meso Prot.	Gas indication only during drilling of TL-1, MT-1, SIP-1 & 1D, BL-1, TS-1 (Sarda Dep.), GND-1 & GN-1 (Gandak Dep.), MD-1 (Madhubani Dep.) and HS-1 and JN-1 (Punjab Plains)	Ujhani: Algal Source-Type: IIB-IIIC, TOC: 0.57-5.8, S ₂ : 0.22-11.26, HI: 33-59, Tmax: 423-478, VR0-2.50, 3-3.5 Karnapur: Algal Source, Type: IIB-IIIC, TOC: 0.27 to 3.49, S ₂ : 0.14-8.58, HI: 237-306, Tmax: 372-432, VR0: 0.29 to 0.36 Lower Siwalik: TOC upto 8.18, IIB-IIIC Type, S ₂ : 4.75 - 29, HI: 314-467, Tmax: 375-440, VR0: 0.23-0.60	Ujhani, Tihar Fm: Sandstone and limestone in the Neoproterozoic succession Karnapur Fm: fracture porosity along with primary porosity of 6-8% Siwalik: Siwalik has better reservoir potential compared to older sequences.	Ujhani, Tihar & Karnapur Fm: Shale within Ujhani & Tihar Fm, and clays within Karnapur and Lr. Siwalik	Stratigraphic traps as wedge out	Geothermal Gradient SAH-1: 1.75°C/100m, MT-1: 1.74°C/100m, TL-1: 2.1°C/100m, TD-1: 1.72°C/100m, 3.23°C/100m, 2.54°C/100m, BD-1: 1.89°C/100m, MD-1: 1.53°C/100m, HA-1 & IZ: 1.77°C/100m, SJH-1: 2.15 °C/100m, RX-1: 1.55°C/100m, BL-1:	Vitrinite reflectance data calibrated with geothermal gradient shows a part of Tertiary package is reaching maturation window below 4630m in the deeper part of foredeep like Purnapur Low and Gandak Low.

Table 1: Comparison with analogous Foreland & Proterozoic Plaformal basins of the world (Mod. after Kumar et al. 2002)

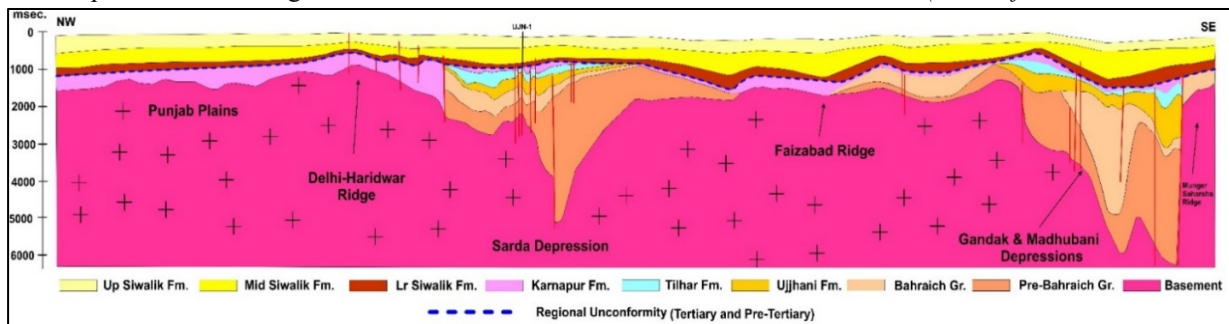


Figure 8: Seismo-Geological Section through Ganga Basin and Punjab Plains

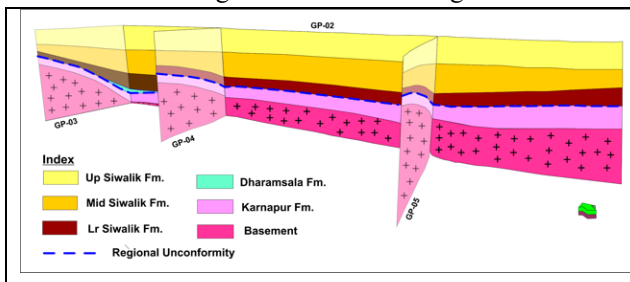


Figure 9: Seismo-geological model of Punjab Plains

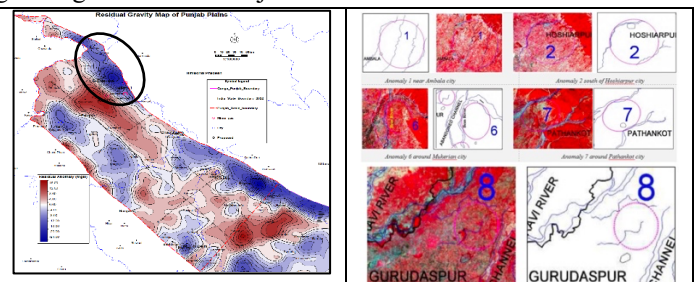


Figure 10 (a): Residual Gravity map of Punjab Plains showing a major low at the north-west. (b) Morphotectonic anomalies