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Hydrocarbon Potential of Meso to Neo Proterozoic Chhattisgarh, Khariar, Ampani, Indravati and Sukma Basins of Bastar Craton, India

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Abstract

The Indian Peninsula hosts several Meso to Neoproterozoic basins (1600-542Ma), referred to as 'Purana basins' that preserve thick successions of mildly deformed and weakly metamorphosed/un-metamorphosed sedimentary rocks with metamorphic grade maximum up to lower greenschist facies. Origin of these basins is still poorly understood and there are several models of basin evolution. A riftogenic origin has been referred to by many authors due to thermal subsidence during Proterozoic times. Recent workers have proposed the idea of intra-/epicratonic models. Few suggest these Purana basins have well-defined boundaries and not an erosional remnant or a tectonic depression. Bastar Craton in Central Indian Shield holds such few Meso to Neoproterozoic cratonic sags/ basins like Chhattisgarh, Khariar, Ampani, Indravati and Sabari/ Sukma basins (from North to South). These Proterozoic basins in Bastar Craton are located mainly in the state of Chhattisgarh and few extend in Orissa. Chhattisgarh Basin is located in the northern part of the Bastar Craton and oriented in E-W direction. It is the third largest Proterozoic basin with an aerial extent of 33,000 Sq. Km having ~2300-2500 m thick mixed siliciclastic-carbonate-phosphorite/evaporate succession. The estimated areas of Khariar, Ampani, Indravati and Sukma basins are approximately 1500, 300, 5360 and 700 Sq. Km. respectively. Successions representing the Khariar, Ampani, Indravati and Sukma basins occur as outliers within the Bastar craton and aerially separated by gneissic basement and lithostratigraphically correlatable with Chhattisgarh succession. Due to large size, thick sedimentary sequence and availability of more geochemical data, hydrocarbon prospectivity perception in Chhattisgarh Basin is better understood than Indravati, Ampani, Khariar and Sukma basins in Bastar craton.

Geology, Tectonics and Stratigraphy of the Meso-Neoproterozoic basins

Central Indian Tectonic Zone (CITZ), erstwhile Satpura Mobile Belt, separates the Bundelkhand–Aravalli craton (referred as the North Indian Block, NIB) from the remaining three nuclei (Singhbhum-Bastar-Dharwar), which constitute the South Indian Block (SIB). Bastar Craton (also referred as the Bhandara Craton) in the SIB constitutes a triangular protocontinental nucleus in between the Singhbhum craton at the NE and the Dharwar craton at the SW. The boundaries in between these cratons are marked by linear belts of Gondwana sediments i.e the Mahanadi Graben at NE and Pranhita-Godavari Graben towards SW respectively. The southeastern margin of the Bastar Craton is bounded by the Eastern Ghats orogenic belt. The Meso to Neoproterozoic Chhattisgarh-Khariar-Ampani-Indravati-Sabari/ Sukma basins are overlying on Palaeoarchaean granite gneisses of the Bastar Craton (**Fig. 1**) *(Mohanty, 2015)* Contacts of these basins with the mobile belts are tectonic, probably, thrusted and showing some degree of deformation and metamorphism of the sediments.

Chhattisgarh Basin: The Meso-Proterozoic rocks of Chhattisgarh Basin unconformably overlie on a metamorphosed and deformed basement complex of Archaean granites and gneisses of the Bastar Craton. After that siliciclastic dominated Singhora and Chandarpur groups were deposited. Thereafter, Raipur and Kharsiya groups and their equivalents (dominantly carbonates with intermittent punctuations by siliciclastics) were deposited. These wide range Proterozoic siliciclastic and carbonate sediments range between continental, transitional and marine (shallow to deep). The basin is divided into two sub-basins, Hirri sub-basin (~25000 Sq. Km) in the west and Baradwar sub-basin (~8000 Sq. Km) in the east, separated by NW-SE trending sub-surface Sonakhan high (high density metamorphic schist belt or greenstone belts) below the Chhattisgarh Basin. Two small proto-basins *(Das et al., 1992)* containing the oldest sequences occur in the east at Singhora and Barapahar.

Khariar Basin: It is an irregular, oval shaped basin which covers an area of 1500 Sq. Km and contains ~1000 m thick sediments. The N-S trending Khariar basin, situated in the SE corner of the Chhattisgarh basin, unconformably overlies granites and basic rocks of the Bastar craton. The sedimentary rock sequence in Khariar Basin is classified as Pairi Group which has been subdivided into six formations viz. Devdahra Sandstone, Kulharighat Formation, Neor Formation, Galighat

Sandstone, Tarjhar Formation and Ling Dongri Sandstone on basis of the overall arenaceous, arenaceous-argillaceous and argillaceous-calcareous nature of the litho-units.

Ampani Basin: It is located at the interface between the Bastar Craton and Eastern Ghats Mobile Belt (EGMB) and comprising of ~300 m thick clastic deposit belongs to varying depositional set-up. Ampani Basin represents a basal conglomerate (2 m), followed by sub-arkosic sandstone (180 m), Siltstone (20 m) and purple shale with calcareours interbands (70 m) *(Balakrishnan & Mahesh Babu, 1987).* The basal conglomerate unconformably overlies the bastar granitoids containing quartz-mica schist enclaves. The Ampani succession records deposits of continental fluvial, shallow marine (delta, shoreface) and basinal distal shelf (below storm wave base), in an order of superposition showing a fining-upward stacking pattern and deposited in a transgressive mode.

Indravati Basin: It is located south of Khariar and Ampani basins with an aerial extent of ~5360 Sq. Km having ~500-550 m sedimentary thickness. It is classified into four formations i.e., Tirathgarh Formation, Cherakur Formation, Kanger Formation and Jagdalpur formations which are unmetamorphosed, unfossiliferous, largely undeformed shales, dolomites, sandstones, quartz arenites, limestones and conglomerates sequences unconformably overlies the Archean gneissic. A E–W-trending Sirisguda Fault parallel to the Indravati River, divides the basin into two halves.

Sabari/ Sukma Basin: South of the Indravati basin, a triangular shaped basin ~ 700 Sq. Km near Sukma is called Sabari Basin after the Sabari River that flows in the middle of the basin *(Das et al. 2001).* The Sabari succession consists of basal conglomerate and quartz arenite, best exposed along the Sabari River section, pass upward to a variegated limestone unit with laterally impersistent purple shale in between. The upper part consists of purple, buff and grey shale.

Table 1: Comparative Generalised Stratigraphic Chart of the Proterozoic Basins in Bastar Craton, modified after *Saha and Patranabis-Deb, 2014*

Age (Ma)			Chhattisgarh Basin		Khariar Basin		Ampani Basin	Indravati Basin		Sabari Basin	
650 Ma	Chhattisgarh Super Group		Kharsiya Gr.	Maniari/ Nandeli Shale (300)							
				Sarnadih Sst (250)							
			Unconformity								
840 Ma			Raipur Gr. (1900)	Maniari Shale (70							
				Hirri Dolomite (70)							
1000 Ma		Meso-Proterozoic (1600-1000 Ma)		Churtela/ Tarenga Sh. (180)				Indravati Group	Jagdalpur Fm. (200-250)	Sabari Group	Shale
				Saradih/ Chandi Lst (670)							
				Gunderdehi Shale (430)					Kanger Lst. (150-200)		Limestone
				Sarangarh/ Charmuria Lst. (490)							
				Bijepur Shale (100)							
1200 Ma			Chandarpur Gr. (400)	Kansapathar SSt. (20-200)	Pairi Group (600-1000)	Recent to sub-recent Ling Dongri SS. (60-120) Tarjhar Fm. (100-250) Galighat SS. (150-300) …Unconformity….	Purple Shale (70) Siltstone (20) Sandstone (180) Conglomerate (2)		Cherakur Fm. (50-100)		Shale
				Chopardih Shale (20-200)							
				Lohardih Conglomerate (20) …Unconformity…					Tiratgarh Fm. (50-150)- Chitrakot and mendri members		Conglomerate
1350 Ma 1600-1500 Ma			Singhora Gr. (400)	Chhuipali Shale (300) Bhalukona SSt. (20) Saraipali Shale (60) Rehatikhol Conglomerate (20)		Neor Fm. (40-160m) Kulharighat Fm. (80-120) Devdahra SS. (10-80)					
Unconformity											
Archean Greenstone and TTG											

Inter-basinal Correlation: Analysis of different tuff units in Chhattisgarh Basin like Ampani tuff 1446±21 Ma {U–Th–total Pb), Khariar tuffaceous units (1455±47 Ma) and Singhora (c. 1500 Ma, U-Pb SHRIMP data) suggest contemporaneous ages. Moreover, thermal events at ~1000 Ma has been reported from Chhattisgarh basin and in Indravati Basin at the top of their stratigraphic sequences. Thus, the occurrence of tuffaceous units of the same age (base and at the top of stratigraphic sequences) in these four spatially separated basins (Singhora Basin, Khariar Basin, Ampani and Indravati basins) strongly suggests their contemporaneity.

Interpretation of NSP data in Chhattisgarh Basin

Studies regarding the prospectivity perception was initially carried out by Remote sensing based structural and spectral studies for geological mapping in Chhattisgarh Basin with limited field checks by KDMIPE where a number of geomorphic highs with high degree of confidence to represent

subsurface structural highs were been identified (**Fig. 2)**. Later on, to evaluate hydrocarbon prospectivity interpretation in 2D NSP data (1914 GLK) (**Figs. 3-5**) was carried out where major group tops (Basement, Singhora Group, Chandarpur Group) and reasonably thick formations like Charmuria Limestone and Chandi Limestone were interpreted.

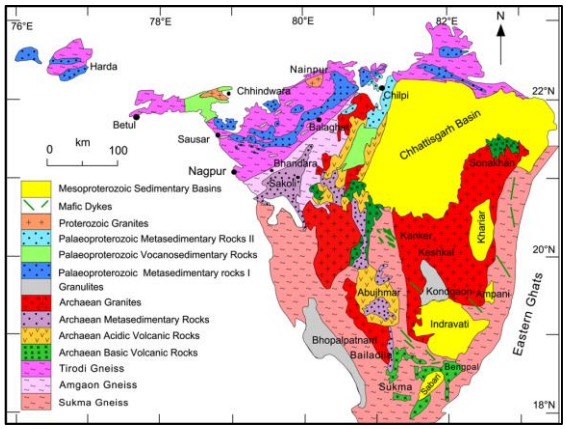

Figure 1: Generalized geological map of the Bastar Craton *(Mohanty 2015).*

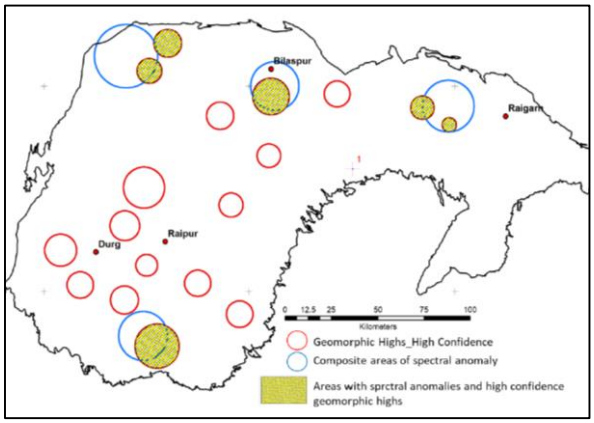

Figure 2: Overlap areas of spectral anomaly & geomorphic highs suggest probable areas of structural highs & may accumulate hydrocarbon

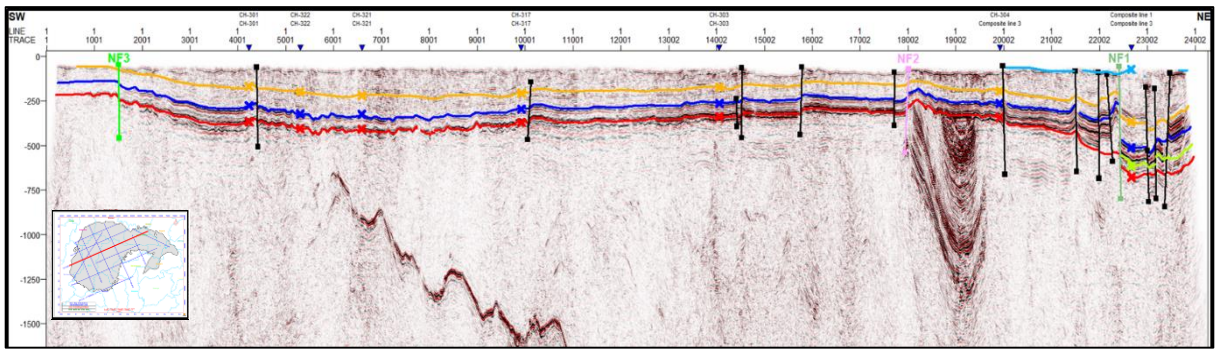

Figure 3: NSP seismic sections CH-308, *Basement top (Red), Singhora Group top (Green), Chandarpur Group top (Blue), Charmuria Limestone top (Orange), Chandi Limestone top (Sky Blue)*

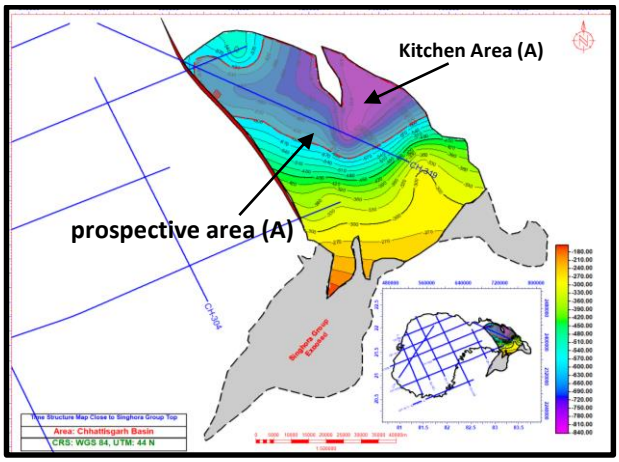

Figure 4: Prospective area A in Singhora Group Top

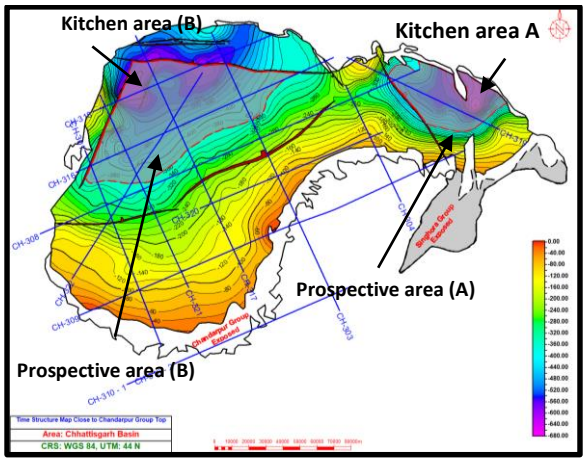

Figure 5: Prospective areas A and B in Chandarpur Group top

Time structure map of Singhora top indicates it is exposed at the southern part and marked in grey colour. Singhora group, the oldest stratigraphic sequence was deposited and restricted at the eastern part of Chhattisgarh Basin due to initiation of proto-basin at this part and presently falling in Bardwar sub-basin. Prospective area A is forming against the western normal fault at the Singhora level in Bardwar sub-basin. Time structure map of Chandarpur top exhibits a prominent high trend at southern basin margin, a moderate high at the northern part of the basin, two prominent lows one at the north

eastern corner and another near the northern basin margin are present. Two prospective areas are forming at the Chandarpur Group, one at the eastern Bardwar sub-basin low and another near Hiri sub-basin low. In case of Bardwar sub-basin a normal fault at the west is forming a fault closure (Prospective area A). In Hiri sub-basin, the southern bounding normal faults, western bounding normal fault, and one northern bounding fault are forming a fault closure and Prospective area-B.

Summary

1. Prospectivity Perception: Chhattisgarh Basin

In Chhattisgarh Basin no drilling for hydrocarbon exploration has been carried out, though the sedimentary thickness and facies appears sufficient for generation-migration and accumulation of hydrocarbon. Two speculative petroleum systems are envisaged in the Chhattisgarh Basin: The Chuipalli-Lohardih Petroleum System (PS) in Singhora-Chandrapur Groups and Chandi-Chandi PS within Raipur Group. A GME chert of Chhattisgarh basin is shown in **Table 2**.

Source rock: Source rock and Rock-Eval studies of few surface samples were carried out by ONGC and other agencies in last few years. In Singhora Group, Saraipalli and Chuipalli shales recorded avg. TOC values of 0.43% and 0.57 % respectively *(Chakraborty, 2021 per.com).* Chandrapur Group exhibits TOC in the range of 1.1–2.4% *(Paul 2005)*. Based on geochemical studies it is observed that black shales in the Chaporadih Formation (Chandrapur Group) have good organic matter to serve as a probable source rock. However, low organic matter richness with a maximum TOC% of 0.20 with S2 values showing the amount of hydrocarbons generated from the samples is negligible and cannot be considered as source rock *(Samal et al., 2007).*

A rich fossil assemblage of carbonaceous metaphytes referable to eukaryotic algae, preserved on the bedding surface of grey carbonaceous shales belonging to Saraipali Formation of Singhora Group is recorded in and around Tushgaon village, Mahasamund District, Chhattisgarh state which is indicative of intertidal, marine mid neritic stable shelf, warm environment for the Saraipali sedimentary deposits.

Shales in the Raipur Group exhibit TOC of 0.01–0.45% with black shales of the Raipur Group, including Charmuria, Gunderdehi and Chandi formations, which may have some potential for hydrocarbon generation if mature. Adsorbed soil gas surveys carried out by NGRI and DGH in 2004 have suggested that hydrocarbon generation may not have taken place in this basin. Rock Eval studies on samples from Chhattishgarh Basin indicates a maximum TOC of 1.75% in shales of Hirri Formation implying a good organic matter richness. However, in the other samples, the TOC is found to be low and varies from a maximum of 0.13% to a low of 0.02%.

Table 2: Generation-Migration-Entrapment (GME) Chart of Chhattisgarh Basin. Source: *# Samal et.al. 2007, ## Chakraborty, 2021* Paul 2005, ** Mazumder et al, 2020, ^ Siawal et al, 2017*

Era	Meso-Proterozoic														Neo-Proterozoic	
Age (Ma)	1500			1350			1200							1000		650 (?)
Group	Singhora Group (400 m)				Chandrapur Group (400 m)			Raipur Group (1900 m)							Kharsiya Gr (550 m)	
Formation	Rehatikhol Conglomerate	Saraipali Shale	Bhalukona Sandstone	Chhuipalli Shale	Lohardih Conglomerate	Chaporadih Shale	Kansapathar Sandstone	Bijepur Shale	Charmuria Limestone	Gunderdehi Shale	Chandi Limestone	Tarenga Shale	Hirri Dolomit	Maniari Shale	Sarnadih Sandston	Nandeli Shale
Thickness (m)	20	60	20	300	20	20-200	20-200	100	490	430	670	180	70	70	250	300
Dep. Environment	Alluvial fan, Braid plain	Shelf	Beach-Foreshore-Shoreface	Shelf	Fan Delta, Braid Delta	Shoreface-Shelf	Tidal delta, Foreshore/ Beach, Estuarine	Muddy shelf & Shelf Lagoon	Shelf	Shelf, Subtidal	Subtidal to Intertidal, Platform	Intertidal, Supratidal	Shallow marine	Extremely Shallow marine	Tidal flat, Fluvial	Shelf
Porosity	Dense & Tight rocks				Very Less primary porosity. Fractures may generate secondary porosity											
Permeability					Rock Bulk density 2.27–2.81 gm/cc, indicate poor reservoir. Secondary porosities may be generated in fractures & may enhance permeability											
TOC		## 0.43% (avg.)		## 0.57% (avg.)	* 1.1–2.4%, # 0-0.20%			* 0.01–0.45%, ** 1.75 % (Hiri Shale) and TOC Ranges: 0.02% to 0.13%								
S2					# 0.0 to 0.05 mg/g			# Negligible								
HI	Due to low S2 value, HI and Tmax values are not taken into consideration															
Oil/Gas show	No oil & Gas shows reported															
Source Rock		Source		Source		Source Black shale		Source	Source	Source	Source	Source	Source Good OM	Source		
Reservoir Rock	Dense & Tight rocks, Poor candidate as Reservoirs						Reservoir		Reservoir		Reservoir		Reservoir			
Cap Rock						Cap		Intra-formational shale may act as Cap								Cap
Stratigraphic Trap	Intercalation of Shale & Limestone, Up dip pinch out, Fractured Chandrapur, Raipur & Kharsiya Groups															
Structural Trap ^															Structural trap	
Gen-Mig-Accu ^																
Preservation ^																
Critical Moment ^																

Reservoir rock: The samples of Chhattishgarh basin show bulk density of 2.27–2.81 gm/cc, indicating poor reservoir character. However, secondary porosities may be generated through fractures. Rich assemblages of stromatolites are reported from limestones in the Chandi Formation (Raipur Group) which may serve as potential reservoirs. The Mesoproterozoic Chandrapur and Raipur group successions comprises of thick extensive delta lobes sandstones which have good reservoir properties and probable exploration targets *(Patranabis-Deb & Chaudhuri, 2007).* However, the sandstones and limestones in Singhora group are relatively denser and tighter.

Seal rock: There are also no proven seals in the Chhattisgrah Basin. Potential limestone reservoirs of the Chandi Formation (Raipur Group) could be sealed by the 180 m thick Tarenga Shale *(Ram, 2005).* Potential reservoirs in fan delta conglomerate and sandstones reservoirs of the Lohardih Formation (Chandarpur Group) could be sealed with the enclosing prodelta muds.

2. Prospectivity Perception of Indravati basin

Among the smaller basins south of the Chhattisgarh Basin, Indravati basin has considerable basinal area ~5360 Sq. Km. The thickness of sedimentary sequence is ~500-550m, which appears insufficient for generation-migration and accumulation of hydrocarbon. No seismic investigations and exploratory drilling have been carried out in this basin. No sub-surface information relevant to oil exploration is available. Few data on petroleum system elements are available which are summarised below:

Source rock: Purple Shale of Cherakur Formation (10-20m thick), Interbedded and intercalated shales in Kanger Formation and Jagadalpur Stromatolitic Limestone of Indravati Group have the potential to act as a source rock.

Rock eval analysis of one sample from Kanger Formation (purple shale) was carried out. The TOC content is 0.02% which indicates poor organic matter richness. S2 value is 0.07 mgHC/g rock and indicates there is no hydrocarbon generation capacity for the studied sample. Tmax and HI value of this sample can't be taken into consideration as S2 value is very low (<0.5mg HC/g rock).

Adsorbed soil gas analyses was carried out by NGRI in 2007 in the Indravati Basin and surrounding areas showed the presence of low concentrations of methane and absence of ethane, propane, butane, and pentane. Methane concentration range varies from 0-22 ppb. Distribution of methane concentration in soil in the Indravati basin is classified into three groups, C1 = >11 ppb (6 samples), C1 – 7-11 ppb (17 samples) and C1 = < 7 ppb (181 samples). Most of the study area has low to intermediate concentration of C1. The anomalous values are located in the Boringuma – Umarkote section, in the north west of Kondagaon and a few in Gidam – Jagdalpur – Sukma areas. Out of these anomalous areas the Boringuma – Umarkote, south of Gidam and the vicinity of Jagdalpur appear to be promising for future hydrocarbon exploration.

Reservoir rock: Quartz Arenite in Chitrakoot Member of Tiratgarh Formation, Arkosic sandstone of Cherakur Formation, Grey Limestone of Kanger Formation and stromatolitic dolomite of Jagdalpur Formation are the likely reservoirs in this basin.

Table 3: Possible Generation-Migration-Entrapment (GME) Chart of Indravati Basin

Era	Meso-Proterozoic					Neo-Proterozoic & Palaeozoic
Age (Ma)	1500 Ma				1000Ma	
Formation	Tiratgarh Formation		Cherakur Formation	Kanger Formation	Jagdalpur Formation	
Member	Mendri Member	Chitrakot Member				
Thickness (m)	50-150		50-100	150-200	200-250	
Dep. Environment	Near shore/ Mudflat/ Beach	shallow shelf	shelf to near shore	shoreline to shallow shelf/ passive margin tectonic set up		
Porosity	-		-	-	-	
Permeability	-		-	-	-	
TOC				0.02		
S2				0.07		
HI				-		
Tmax				450		
Oil/Gas show	No oil/gas shows in the basin but adsorbed soil gas analyses indicates presence of low concentration methane (0-22 ppb) in soil of Indravati basin					
Source Rock			Purple Shale of Cherakur Fm. (10-20m)	intercalated shales in Kanger Formation	Jagadalpur Stromatolitic Limestone	
Reservoir Rock		Quartz Arenite in Chitrakot Member	Arkosic sandstone of Cherakur Formation	Grey Limestone of Kanger Formation	Stromatolitic dolomite of Jagdalpur Formation	
Cap Rock				Laminated shale at the top, Interbedded & intercalated shales at the base of Kanger Formation	Purple, buff and olive shales in Jagdalpur Formation	
Stratigraphic Trap				Interbedded & intercalated shales in Kanger & Jagdalpur Formation		
Structural Trap						
Gen-Mig-Accu						
Preservation						
Critical Moment						

Cap rock: Purple, buff and olive shales in Jagdalpur Formation, laminated shale at the top of Kanger Formation, Interbedded and intercalated shales at the base of Kanger Formation may act as possible cap rocks. A GME chert of Indravati basin is shown in **Table 3.**

3. Prospectivity Perception of Khariar and other basins

Khariar Basin has a basinal area (1500 Sq. Km) with relatively thicker sedimentary sequence ~1000m compare to other sedimentary basins located south of Chhattisgarh basin. So far, no surface and sub-surface geochemical data is available for this basin. GME model of Khariar basin (**Table 4**) is purely sedimenatological data driven in absence of any lab data. PSM elements in this basin are still speculative in nature and proper sedimentological and geochemical investigations are essential to establish the prospectivity of Khariar basin. Based on available datasets Khariar basin appears to be low prospective. South of the Khariar basin, Ampani basin is an isolated outcrop of a 300 m thick sandstone-shale succession covering 300 Sq Km. South of the Indravati basin, a triangular basin of 700 Sq Km near Sukma is called Sabari Basin having very less sedimentary thickness. Basins like Ampani and Sukma can be discarded primarily due to their less areal extent and insufficient sedimentary thickness.

Table 4: Possible Generation-Migration-Entrapment (GME) Chart of Khariar Basin

Era	Meso-Proterozoic												Neo-Prot. Palz.
Age (Ma)	1500 Ma				1350 Ma							1200 Ma	
Group	Pairi Group (600-1000m)												
Formation	Devdahra Sandstone	Kulharighat Formation (80-120)			Neor Formation	Galighat Sandstone (150-300)				Tarjhar Formation (100-250)		Ling Dongri Sandstone	Recent to Sub-Recent	
Members		Indrawan	Gawarmund	Bhursi		Matul pahar	Dharpani	Bhaludigi	Job Sst	Amjhar	Bamendev sst			
Thickness (m)	10-80	10-30	60-80	2-10	40-160	30-80	20-80	60	20-41	30-35	6-40	60-120		
Dep. Environment	Shallow marine-littoral, Beach	Euxinic deep marine condition	Shallow water, stable shelf	Intertidal to Supratidal	Tidal flat, periodic euxinic condition	Fluvial to shallow marine shelf environment				Shelf		Arid and terrestrial condition		
Porosity	-	-			-	-				-		-	-	
Permeability	-	-			-	-				-		-	-	
TOC	-	-			-	-				-		-	-	
S2	-	-			-	-				-		-	-	
HI	-	-			-	-				-		-	-	
Oil/Gas show	-	-			-	-				-		-	-	
Source Rock		limestone-dolomite and black shale	Shale with limestone dolomite	Stromatolitic limestone, algal mat	Intercalated shale		Shale-Siltstone	shale		Shale				
Reservoir Rock	Pebbly sandstone				Sandstone	Sandstone			sandstone		Siltstone, sandston	sandstone		
Cap Rock		Shales in Neor Fm and in Dharpani, Bhaludigi, Amjhar members												
Stratigraphic Trap		Interbedded & intercalated Shales in Neor Fm & in Dharpani, Bhaludigi, Amjhar members												
Structural Trap														
Gen-Mig-Accu														
Preservation														
Critical Moment														

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