PaperID **AU372**

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New Approach in Hydrocarbon Resource Assessment of Potentially Prospective Basins- A Case Study of Satpura Basin, India

Abstract

Hydrocarbon resource assessment is a data dependent process, hence, selection of a particular method or combination of methods depending on the data availability is one of the key factors for meaningful resource assessment of any basin, especially in frontier basin, with meagre data. In this study a new approach for assessment of undiscovered hydrocarbon resources of potentially prospective basins is discussed which combines the 'Play' based approach of NPD and 'Total Petroleum System' approach of USGS to get undiscovered resources for potentially prospective basins. A case study of Satpura Basin has been carried out with this new approach for its play-wise and assessment unit-wise resource assessment.

Introduction

Globally, industry best practices for hydrocarbon resource appraisal follow the Play assessment method developed by Norwegian Petroleum Directorate (NPD, 2016). Another method used globally, developed by USGS for the World Petroleum Resource Assessment 2000, is based on the concept of 'Total petroleum system (TPS)' with assessment unit as basic unit for resource assessment. TPS is defined as the essential elements (source, reservoir, seal and overburden rocks) and processes (generation-migration-accumulation and trap formation) as well as genetically related petroleum that occurs in seeps, shows and accumulations, both discovered and undiscovered, whose provenance is a single pod or closely related pods of active source rock. While applying these methods analogy is drawn from producing basin as reserve data is not available for potentially prospective (frontier) basins. Thus there is a huge subjectivity associated with the assessment.

A new approach has been adopted in the present study combining the 'play' based approach of NPD and Total Petroleum System approach of USGS to get Play-wise undiscovered hydrocarbon resources of a basin. This approach reduces the subjectivity of drawing analogy from analogous basin. The workflow for the suggested new assessment approach is given in Fig.1

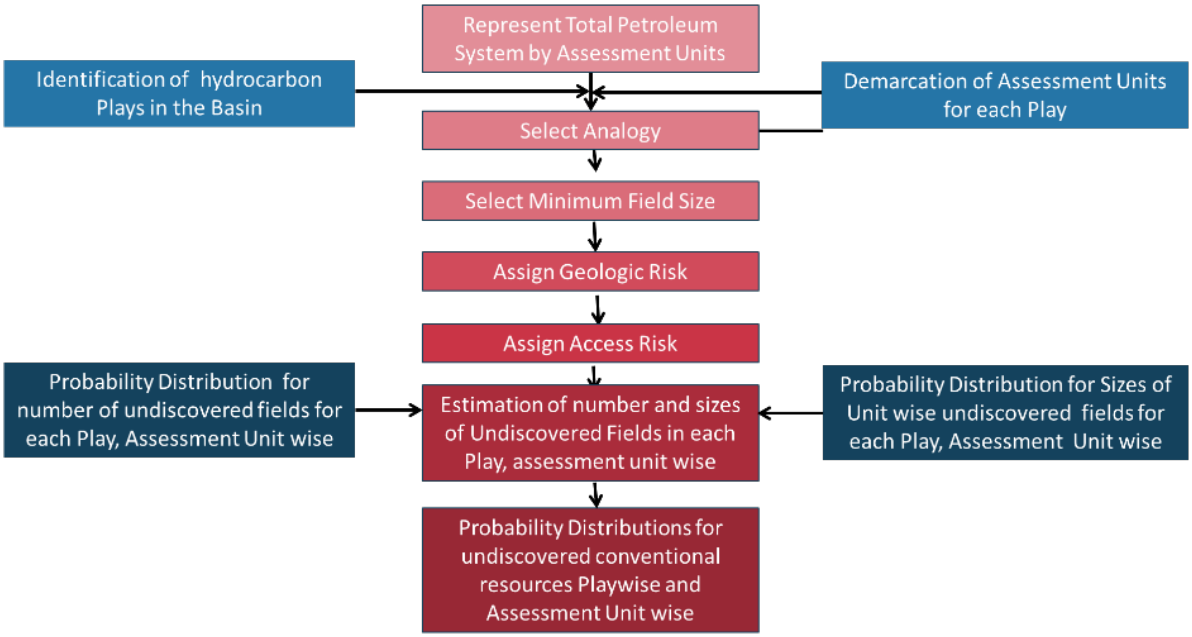

Fig.1: Flow diagram showing key steps of the adopted methodology for Hydrocarbon resource assessment for Undiscovered Conventional Resources

Application of new approach to Potentially Prospective Satpura Basin

Satpura Basin, a potentially prospective Gondwana Basin of India, has been identified for application of this new approach. Gas discovery from Gondwana deposits of Krishna-Godavari Basin has established the presence of hydrocarbon in Indian Gondwana basins. Thermo-genic gas seepages at number of places and flow of water with dissolved gas from first drilled well Anhoni-1 in Satpura Basin have widened the scopes for exploration. Moreover, the volume of exploration data available (Table-1) in this basin is just adequate for application of this new approach.

Satpura Basin is located south of Narmada River and extends from Jabalpur to Lokartalai-Mohapani area. It is an intra-cratonic trans-tensional basin covering an area of 8200 skm. Deposition of Gondwana sediments initiated during Late Carboniferous time and continued through Permian right up to the Early Cretaceous time (Fig.2). The eastern and westernmost parts of the Satpura Basin are covered by Deccan Trap flows, which erupted during Late Cretaceous/Paleocene (Fig.3).

Chronostratigraphy				Group	Formation	Thickness (m)	Generalised Lithostratigraphy	Environment of Deposition
Eon	Era	Period	Epoch					
Phanerozoic	Ceno	Pal	Pal	Upper Gondwana	Deccan Trap		Basalt, Dolerite	Sub areal eruption/ Intrisives
	Mesozoic	Cretaceous	Late		Lameta	50	Lmst., conglomerate, sst, clay	Fluvio-Lacustrine to Marine
			Early		Jabalpur	50-100	Sst, conglomerate, clay, coal, carbonaceous shale	Fluvial to Fluvio-Lacustrine
		Jurassic	Late					
			Middle					
			Early					
		Triassic	Late		Bagra	50-100	Pebbles, conglometrate, variegated clay	Fluvio-Lacustrine
			Middle					
			Early		Denwa	350-1500	Clay, sst, conglomerate	Fluvio-Lacustrine
					Pachmari	750	Sst,pebble, red clay	
	Paleozoic	Permian	Late	Lower Gondwana	Bijori	300	Sst, shale, coal	Fluvial Swamp
			Middle		Motur	750	Sst, clay, siltstone, shale	
					Barakar	250-450	Sst, shale, coal	
			Early		Karharbari			
					Talchir	400	Green clay, sst,siltstone, shale, shell frags diamictites	
Precambrain				Basement				

Fig.2: Generalized stratigraphy and environment of deposition in Satpura Basin (After Veevers and Tewari, 1995)

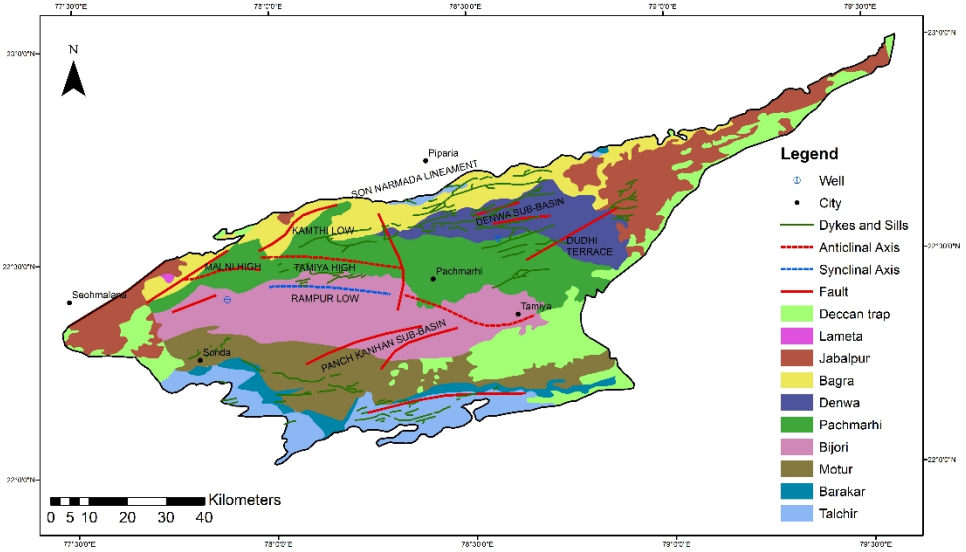

Fig.3: Geological map of Satpura Basin

Area Of The Basin	8200 Sq.Km.
Geological Surveys	7276 Sq.Km.
Geophysical Surveys	
GM Data	8451 Stations
2D Seismic	1433.51 GLK, 73.4 GLK (Refraction)

3D Seismic	Nil
Exploratory Drilling Coverage	
No. of Exploratory Wells	Two
Meterage	4010 M And 3856 M In Anhoni-1 And Jhirna-1
No. Of Prospects Drilled	Two
No. Of Fields Discovered	Nil
Geochemical/ Source Rock Data	Source Rock, Gas seepage data available

Table-1: List of Exploration data available in Satpura Basin

Elements of Petroleum System:

Source Rock: Potential source rocks are essentially confined to the Middle Barakar and Upper Bijori Formations. However, Bijori Formation is lean in organic matter richness and Motur Formation has fair organic richness & remaining source potential in few areas of this basin (Katiyar et al., 2009). Organic matter input in Satpura Basin is predominantly terrestrial. Marine facies of Talchir Formation may also hold some maturity for source rock development. This basin is considered to be having good source rock development for generation of wet and dry gas as evidenced from the presence of type-III kerogen.

Reservoir: Sandstones with moderate to good porosity and permeability within Barakar, Motur, Bijori and Panchmari formations have good reservoir rock potential. Subsurface data from the well Anhoni-1 show sonic porosities around 3-10%, 2-10%, 3-9% and 12-10% within Barakar, Motur, Bijori and Panchmari formations respectively. The flow of non-commercial gas from Anhoni-1 indicates good primary porosity and permeability however, secondary porosities may also develop near the faults.

Cap Rock: The local argillaceous intervals and a number of shale bands of varying thickness of Gondwana sequence can act as effective cap rocks in this basin.

Traps: Satpura is a heavily faulted basin and fault closures in the downthrown side are supposed to be the main traps here. The traps are envisaged to be small in size.

Migration & Timing of migration: It is observed that much of the faulting in Satpura took place in Middle Barakar time and the critical moment was at the end of Jurassic i.e. 143 ma. Syn-sedimentary faults formed during deposition of Talchir, Barakar and Matur formations are supposedly older to hydrocarbon generation. Hydrocarbon migration in Satpura basin has been envisaged to be vertical and fault controlled. However, lateral migration also may not be uncommon. Tertiary migration along fault fractures and thermal cracking due to intrusive activities are the unfavourable factors for preservation of hydrocarbon in this Basin.

Total Petroleum System: Hypothetical Permian – Cretaceous petroleum system has been considered as the geologically defined total petroleum system in this Basin. The Basin is considered as gas prone as revealed from the presence of mainly Type-III kerogen in the source rock.

Hydrocarbon Resource Assessment

Identification of Analogue Basin/Calibration Area: On the basis of the petroleum system elements and basin type, Cooper Basin, Australia has been identified as the analogue basin of Satpura as both are gas prone Gondwana basins with Permian source rock with similar geological history of Gondwana sediments. Minimum, most likely and maximum values of parameters like Bg and NGL/Gas ratio have been drawn from analogous Cooper Basin for undiscovered prospect size estimation.

Play Fairway and Identified Plays: Based on the analysis of available exploratory data, three prospective plays have been identified in Satpura Basin within Early to Late Permian (Lower Gondwana) and Triassic to Cretaceous (Upper Gondwana). Detailed description of identified plays of Satpura Basin is given in Table-2. In Early Permian Play, resource assessment has been carried out separately for Talchir and Barakar Formations. Similarly in Middle to Late Permian play both Motur and Bijori Formations have been dealt with separately. However, in the case of Triassic to Cretaceous Play structure contour maps of various formations could not be prepared due to poor seismic data resolution. Hence the resources have been estimated for the play as a whole by extrapolating the Bijori level prospects as the prospects of Upper Gondwana. In this paper the resource estimation of Barakar Formation (Early Permian Play) is discussed in detail to illustrate the new methodology.

Play Fairway	Early Permian	Middle To Late Permian	Triassic To Cretaceous
Formations	Talchir and Barakar	Motur and Bijori	Pachmarhi, Denwa, Bagra, Jabalpur and Lameta
Source(S)	Early Permian (Barakar Fm)	Early Permian (Barakar Fm.), Late Permian (Bijori Fm.)	Early Permian (Barakar Fm.), Late Permian (Bijori Fm.)
Trap Types	Fault closures, Stratigraphic	Fault closures, Stratigraphic	Fault closures, Stratigraphic

Migration System	Vertical, fault controlled	Vertical, fault controlled	Vertical, fault controlled
Depositional System	Fluvio-glacial, fluvio-lacustrine	Fluvio-lacustrine	Fluvio-lacustrine
Reservoir And Porosity Types	Sandstone with porosity ranging from 1% - 4% (Barakar Formation)	Sandstone with porosity ranging from 1% - 8% (Motur Formation); 1% - 10% (Bijori Formation)	Sandstone with porosity ranging from 1% - 4% (Pachmarhi, Denwa, Bagra, Jabalpur and Lameta Fms)
Comments	Conventional Gas Prone	Conventional Gas Prone	Conventional Gas Prone

Table-2: Description of Plays in Satpura Basin

Demarcation of Assessment Units: Satpura Basin has been divided into four assessment units (Fig.4) for hydrocarbon resource assessment on the basis of tectonic elements, bouguer gravity anomaly, magnetic intensity, structure contour maps and thickness maps.

Number and Sizes of undiscovered Prospect Determination Play-wise: Structure Contour maps on top Barakar Formation has been analysed for identification of undiscovered structural and / or combination (strati-structural) trap prospects (Fig.5) play-wise and assessment unit-wise. Table-3 shows the various input parameters considered for the estimation of sizes of undiscovered prospects in Barakar Formation. For calculating the area of undiscovered prospects, the fault closure areas have been measured directly from structure contour map. The variation in thickness, porosity etc. have been estimated from the two drilled wells in the basin. A hydrocarbon saturation of 70% has been assumed since it is a gas case. The Bg values taken from analogous Cooper Basin are depth corrected for Satpura Basin. Similarly NGL / Gas ratios have been considered from Cooper Basin.

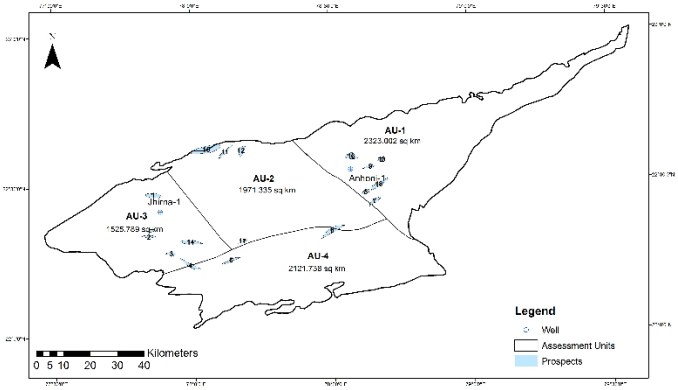

Fig.4: Assessment units along with prospects identified in Barakar Formation, Early Permian Play, Satpura Basin

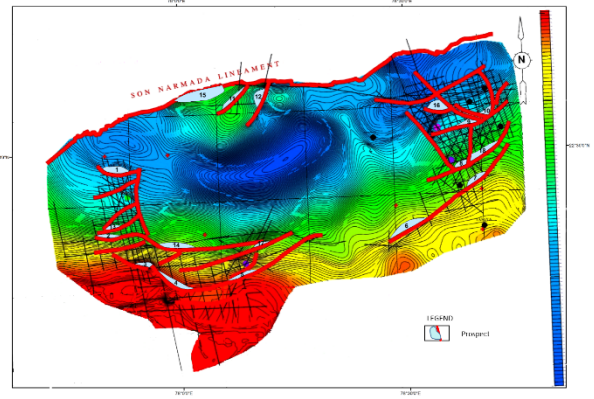

Fig.5: Structural and / or combination (strati-structural) trap prospects identified in Barakar Formation, Early Permian Play

Prospect No.	Area sq.km	Net pay Thickness(m)	Porosity %	Saturation%	1/Bg	IIHC MMtOE
1	6.949	35	0.05	0.7	300	2.55
2	3.247	30	0.06	0.65	300	1.14
3	2.705	27	0.04	0.7	300	0.61
4	6.866	25	0.06	0.7	300	2.16
5	3.791	20	0.05	0.65	300	0.74
6	10.438	18	0.04	0.65	275	1.34
7	4.653	18	0.035	0.7	250	0.51
8	2.893	20	0.045	0.65	275	0.46
9	2.936	35	0.07	0.7	275	1.38
10	2.583	35	0.06	0.7	250	0.95
11	4.47	25	0.05	0.65	275	0.99
12	5.844	23	0.055	0.7	300	1.55
13	2.252	35	0.035	0.65	300	0.53
14	7.82	27	0.04	0.7	275	1.62
16	22.799	20	0.05	0.65	275	4.07
17	7.16	30	0.06	0.7	275	2.48
18	1.664	27	0.05	0.65	250	0.37
19	7.127	15	0.035	0.65	275	0.67

Table-3: Number and sizes of Undiscovered Prospects of Barakar Fm. of Early Permian Play

Minimum Field Size: The economic cut off of field size is needed to know the undiscovered number and sizes of the fields in a basin. USGS assessment has considered the size of the minimum economic field to be 1 MMBOE.

In the present study a similar cut off of the minimum field size is assumed due to unavailability of minimum field size studies in any of the Indian frontier basins.

Geologic and Access Probability: The probabilities of occurrence (from 0 to 1) for Charge (adequate petroleum charge for an undiscovered field > minimum size), rocks (adequate reservoirs, traps, and seals for an undiscovered field > minimum size), and timing (favourable geologic timing for an undiscovered field > minimum size) are multiplied to give the geologic probability or the probability of the presence in the assessment unit of at least one field as large as the user-defined minimum size. Access probabulity is the probability that at least part of the assessment unit will remain politically and technologically open to petroleum-related activity. When the geologic probability is multiplied by the access probability, the product is total geologic probability for the assessment unit. Since Satpura is an accessible onland basin, the access probability is considered as one. However, the geologic probability (product of fluid, rock and migration / timing of migration of fluid probability) is estimated to be varying from 0.5 to 0.65 in various plays of this basin as existence of hydrocarbon is proved but there is no commercial discovery here. Since the basin is divided into assessment units on the basis of similar depositional history and tectonics etc., a single value of geological probability is assumed for each assessment unit. Table-4 & 5 shows the various probability values of input parameters, while Table-5 geologic and access probabilities considered Assessment unit wise.

AU	Number of Undiscovered Fields			Size of Undiscovered Fields (bcfg)			NGL/gas ratio for undiscovered fields (bngl/mmcfg):		
	min (>0)	Most likely	max	min	Most likely	max	min	Most likely	max
AU-1	3	5	7	15	50	80	20	40	60
AU-2	1	2	4	12	35	60	20	40	60
AU-3	2	4	6	18	55	90	20	40	60
AU-4	2	4	6	10	25	40	20	40	60

Table-4: Input parameters for Barakar Formation, Early Permian Play

AU	Geologic Probability				Accessibility Probability
	Charge	Rock	Timing	Total Geologic Probability	
AU-1	0.8	0.8	0.9	0.58	1
AU-2	0.8	0.9	0.9	0.65	1
AU-3	0.8	0.8	0.9	0.58	1
AU-4	0.8	0.7	0.9	0.50	1

Table-5 Assessment unit-wise geologic and access probabilities considered for Barakar Formation

Probabilistic Analysis & Simulation: Various distributions (minimum, most likely, maximum cases) are envisaged for number, size and co-product ratios of undiscovered fields. *'Emc2', a Monte-Carlo* simulation program (USGS) samples from these distributions and calculates a forecast of undiscovered resources. This procedure is iterated a specified number of times and the distributions of forecasts are presented in both tabular and graphical formats**.** Results are presented in both risked and non-risked distributions. The simulation for the hydrocarbon (gas in this case) resources is carried out play-wise and assessment unit wise.

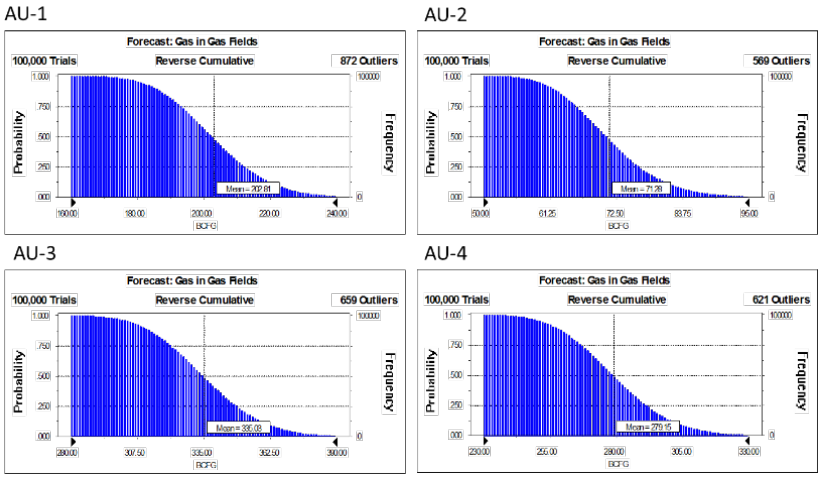

Fig.6: Hydrocarbon resource Simulation Figures of Barakar Formation AU-wise

Results: The play-wise and Assessment unit wise assessed hydrocarbon resources of Satpura Basin following the new assessment approach are placed in Tables-6 & 7.

AU	Play	Formation	Unrisked MMtOE	Geologically risked MMtOE
AU-1	Early Permian	Talchir	1.001	0.577
		Barakar	5.769	3.323

	Middle to Late Permian		2.481	1.250
AU-2	Early Permian	Talchir	1.698	1.100
		Barakar	1.892	1.226
	Middle to Late Permian		absent	absent
AU-3	Early Permian	Talchir	1.433	0.825
		Barakar	10.41671388	6
	Middle to Late Permian		0.715	0.360
AU-4	Early Permian	Talchir	2.306	1.162
		Barakar	8.079	4.072
	Middle to Late Permian		absent	absent
All AU	Triassic to Cretaceous		1.609	0.926
Total			**37.403**	**20.823**

Table-6: Assessment Unit wise unrisked and risked undiscovered hydrocarbon resources of Satpura Basin

Play	Unrisked MMtOE	Geological risked MMtOE
Early Permian	32.598	18.287
Mid. to Late Permian	3.196	1.61
Triassic to Cretaceous	1.609	0.926
Total	**37.403**	**20.823**

Table- 7: Play-wise un-risked and risked undiscovered hydrocarbon resources

Conclusions

The new assessment approach, which combines the merits of total petroleum system concept of USGS methodology and play assessment approach used by the Norwegian Petroleum Directorate (NPD), has been applied for the hydrocarbon resource assessment of potentially prospective Satpura Basin. The process considers a Permian-Cretaceous total petroleum system (TPS) in this Basin and hydrocarbon resources for three plays viz., Early Permian, Middle to Late Permian and Triassic to Cretaceous have been assessed. The results obtained are in fairly good agreement with earlier assessments.

In this approach the subjectivity associated with geological analogy is reduced considerably. Additionally both risked and unrisked resources are assessed play-wise and assessment unit-wise in potentially prospective basins with scanty geoscientific data availability. On the basis of this assessment, initial prioritisation of areas for exploration can also be done.

Acknowledgement

The authors express deep gratitude to Dr. Harilal, ED-HOI, KDMIPE for his sustained interest in the work and guidance during preparation of the paper. The authors are indebted to Sh. U. C. Pradhan, GM (Geology)-Incharge, BRG-1 for critical review of the paper. Support and inputs from colleagues of KDMIPE are thankfully acknowledged. The views expressed in the papers are of the authors and not necessarily of the organisation they belong to.

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