Integrated Velocity and Depth Analysis-A case study of Hatta Area, Son Valley, Vindhyan Basin

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Abstract

The Proterozoic Vindhyan Basin has been under active hydrocarbon exploration for over six decades but commercial production rates have eluded the basin until recently drilled wells in Son Valley Sector which showed commercial production rates from Jardepahar Porcellanite Formation. To further analyze and tap into the extent and scale of this discovery, in the absence of 3D seismic PSTM or PSDM data, a 2D Seismic velocity model was attempted for better understanding of the area. Velocity model building and depth analysis is an integral part of seismic interpretation process in oil and gas exploration. A velocity generated in course of 3D PSDM processing is considered more accurate as compared to 2D velocities. This study is first of its kind in Hatta Area of Son valley in Vindhyan Basin where a comparative study of 2D seismic velocity model and 3D PSDM velocity, is carried out. The study focuses on not only bringing out thickness and velocity variations in Vindhyan sequences but at the same time geological inferences and interpretation of the same. Additionally, the study also brings out understanding of paleo-depositional environment of Vindhyan basin. The study is useful to evaluate, plan and de-risk future prospective hydrocarbon locales in terms of depth and well planning.

Introduction

The Proterozoic Vindhyan Basin is under active hydrocarbon exploration. In pursuit of the same and pushed by the commercial discovery in Hatta area, focused exploration is currently in progress in the Hatta area located towards the northern margin of the western part of Son Valley Sector. The area of study encompasses more than 450 sq. km. in the Hatta set-up and contains a thick sequence of shallow marine clastic and carbonate sediments belonging to Meso-Neoproterozoic Semri Group of Vindhyan strata (Figure 1a).

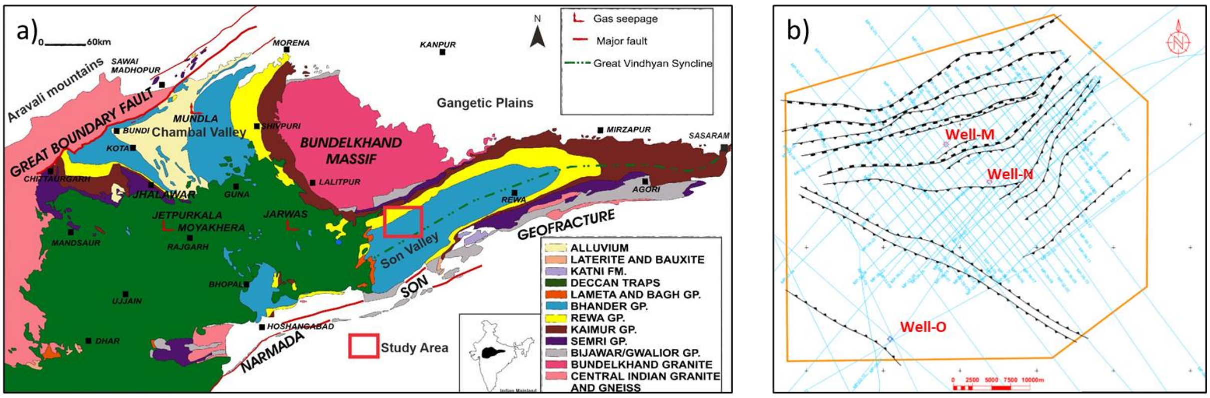

Figure 1: (a) Base Map of Son Valley showing study area in red square (b) Seismic location map of the study area showing interpreted faults based on 2D seismic data

Vindhyan Basin is divided into the Son valley sector to the East and Chambal valley to the West. The Basin fill in the Son Valley constitutes a considerable thickness of about 2 to 6 km of varyingly deformed sedimentary succession, which is divisible into carbonate dominated Lower Vindhyan and clastic dominated Upper Vindhyan sequences separated by a large hiatus (Figure 2). Vindhyan sediments mainly constitutes seven major formations which includes alterations of limestone and shale sequences interrupted by a volcanic event in between leading to deposition of Jardepahar Porcellanite which has proven to be prospective with Gas discovery in Well-M (Figure 2). The basal part of Lower Vindhyan (Semri Group) consisting of Arangi, Kajrahat, Jardepahar and Charkaria formations, overlying the Base of Vindhyan sequences, represent an alternating transgressive-regressive depositional cycle in the shallow 'Purana' sea with carbonate build up (Kajrahat) followed by a period of sub-marine and sub-aerial volcanism (Jardepahar Porcellanite) and overlain by a thick regionally pervasive transgressive shale deposit (Charkaria Shale). These together constitute the petroleum system for Well-M gas zones.

Arangi shale is considered to be potential source rock which is organically rich. Jardepahar Porcellanite Formation predominantly comprises of volcano-clastic sediments with alternation of shale, siltstone and limestone whereas Kajrahat Limestone Formation is predominantly carbonate. The Charkaria Olive shale is of regional extent is acting as a seal. The sedimentary sequences of the basin are highly compacted and tight in nature leading to the Formation of unconventional tight reservoirs having low porosity (1-3 %) and ultra-low permeability (<.01 mD).

The basin has evolved through a poly-phase geological history. Initial tectonic evolution of the basin is controlled by basement related rift tectonics, which formed a number of horst and grabens. In later phase of tectonic evolution, the basin witnessed episodic compressional events (Ram, 1996; Sharma et al., 2015). There are suggestions of an initial compressive pulse during post-Jardepahar time, followed by relative tectonic quiescence and finally a major compressive event in post Rohtas time (end of Lower Vindhyan deposition).

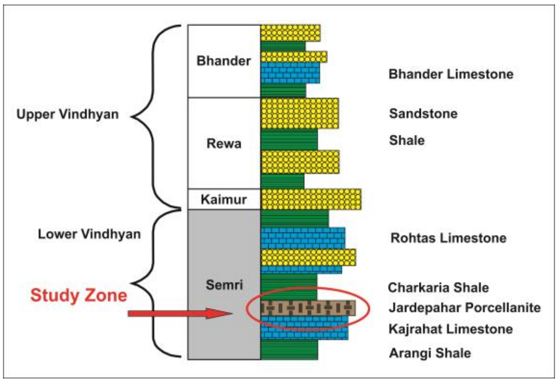

Figure 2: General stratigraphy of the area.

This study was taken up following the gas discovery in one of the well of Hatta area. For early monetization, assessing further prospectivity and evaluating target depths in drillable locations, it became obligatory to have time to depth domain conversion. Generally, time to depth conversion is regular process which is carried out in interpretation projects but it was a challenge in this part particularly in view of the area being in very early part of exploration with multiple vintages of 2D seismic data available only. Thus, not much prior understanding of regional thickness and depth of Vindhyan sequences was known.

The study encompasses 2D seismic velocity volumes and data of three wells (Sonic, Check shots etc.) (Figure 1b) for 2D Seismic velocity modeling. In subsequent year, 3D seismic data was acquired and ES360 PSDM processing was carried out which brought the 3D PSDM velocity volume. Velocity results from both the methods, depth variations as well as their implications in interpretation have been compared in the study.

Basic Theory

Velocity modeling is a process to obtain grid-based velocity distribution over an area where as Velocity volume from 3D PSDM is already gridded in seismic resolution in nature which is resulted from PSDM processing. Velocity modeling can be carried out with either of following forms of velocity: RMS Velocity, Interval Velocity and Average Velocity. 2D seismic stacking velocity volumes are RMS (Root mean square) velocities. Dix equation (Dix,1955) is used to convert RMS velocities to interval velocities (equation 1) and then average velocities can be calculated using interval velocities (equation 2).

$$V_{int(n)} = V_{rms(n)} \quad when\ n{=}1$$
$$V_{int(n)} = \left[\frac{t_{(n)} V^2_{rms(n)} - t_{(n-1)} V^2_{rms(n-1)}}{t_{(n)} - t_{(n-1)}}\right]^{.5} \quad when\ n \geq 2 \qquad (1)$$
$$Z_{(n)} = Z_{(0)} + \sum_{m=1}^{n} V_{int(m)} * (t_{(m)} - t_{(m-1)})$$
$$V_{avg(n)} = (Z_{(n)} - Z_{(0)})/(t_{(n)} - t_{(0)}) \qquad (2)$$

$V_{rms(n)}$ = is the RMS velocity of n^{th} sample, n>=1
$t_{(0)}$ = is the time part of the seismic datum

$Z_{(0)}$ = is the depth part of the datum
$Z_{(n)}$ = is the computed depth at the n^{th} sample
$V_{int(n)}$= is the computed interval velocity between samples n and (n-1)

2D seismic velocity is not spaciously equally distributed. Therefore, in 2D Seismic velocity model, to obtain even distribution from sparse data, we require an interpolation method. Geostatistical interpolation techniques can be easily deployed in such cases as ours. Ordinary Kriging method for interpolation has been used for its utility in sparse data handling. On the other hand, Earth Study 360 (ES360) PSDM is a versatile cluster-based depth migration tool that simultaneously uses the full recorded wave field within a controlled aperture to generate amplitude preserved, multi-dimensional, subsurface angle gathers. ES360 processing brings out additional detail and accuracy in imaging through its migration and the model-building process and therefore velocity obtained from this method more accurate depiction of subsurface compressional velocities.

Methodology

The study was carried out using two exploratory wells (Well-O, Well-N), one discovery well (Well-M), 2D Seismic stacking velocity volumes and ES360 PSDM processed 3D Seismic velocity volume (Figure 1b). In order to obtain velocity model from 2D volumes, interpolated average velocity volume calibrated with wells is required. Average velocities were obtained after converting RMS velocities to interval velocities using Dix equation. Converted interval velocities show few anomalous values which are not reliable as they do not resemble the geological understanding of the area, which were not considered (Figure 3a). The cleaned interval velocities are then used to calculate average velocities through gridding of the volume in 100 m x100 m to get values in our study area. Ordinary Kriging interpolation geo-statistical method is applied to obtain average velocities to generate a gridded volume where our data is not present.

Further in the process, the obtained results were calibrated with well data through tying of the identified formation tops. The calibration parameter, which is the ratio between well average velocity and seismic average velocity (equation 3) was calculated. The calibrated average seismic velocity volume was then generated using equation (4). This process of getting calibrated seismic velocity model is referred to as velocity modeling and subsequently time to depth conversion was achieved by using the calibrated seismic velocity volume.

$$Calibration\ ratio = \frac{Well\ Velocity}{Seismic\ Velocity} \quad (3)$$

$$Calibrated\ Seismic = Calibration\ ratio * Uncalibrated\ Seismic \quad (4)$$

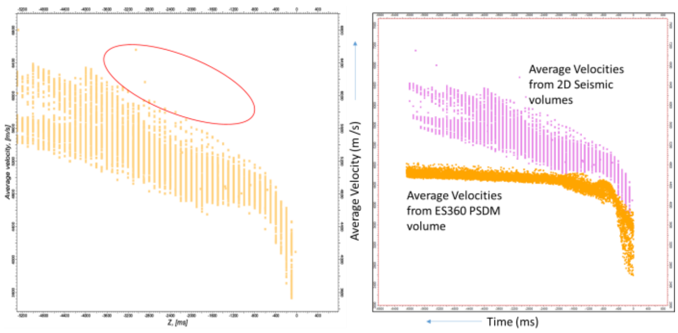

Figure 3: a) Removing anomalous velocity values (i.e., point in the ellipse) b) Comparison of well calibrated Average velocities obtained from 2D Seismic volumes and ES360 3D PSDM volume.

On the other hand, ES360 PSDM processing 3D velocity volume was received and calibrated using three wells Well-M, Well-N and Well-O. For further use, the PSDM interval velocity was converted to average velocity so that a comparison study may be carried out.

Result and Discussion

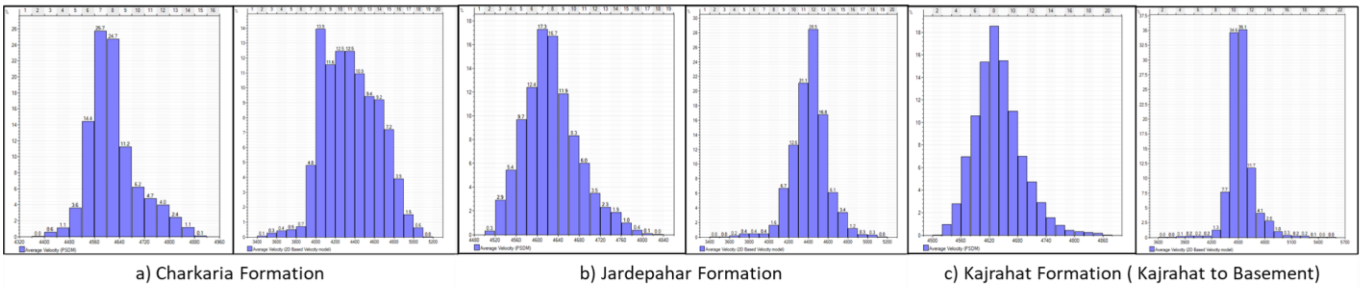

Figure 4: Histogram representation of velocity variations obtained formation wise. (Figure in left shows Average velocity histogram from ES360 3D PSDM volume whereas right figure shows Average velocity histogram from 2D Seismic velocity model)

Charkaria Formation (Average Velocity (m/s))				Jardepahar Formation (Average Velocity (m/s))				Kajrahat Formation (Kajrahat to Basement) (Average Velocity (m/s))			
ES360 3D PSDM		2D Velocity Model		ES360 3D PSDM		2D Velocity Model		ES360 3D PSDM		2D Velocity Model	
Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
4622	77	4429	320	4627	52	4425	210	4636	47	4508	165

Table 1: A comparative chart showing variations in terms of mean and standard deviation.

The Arangi-Kajrahat-Jardepahar petroleum system is envisaged to be active in the area of study. Formation wise histograms of average velocity obtained from ES360 3D PSDM volume and 2D Seismic velocity model, shows the variations as present (Figure 4). The mean average velocity for Charkaria, Jardepahar and Kajrahat formations remain nearly same. Standard deviation values show that velocity values from 2D Seismic velocity modeling is higher than ES360 velocity volume which implies higher degree of velocity variation within a single formation and thus may be less accurate. Depth relief maps of Charkaria, Jardepahar and Kajrahat top as obtained from 2D Seismic velocity modelling and ES360 3D PSDM (Figure 5) show minor variations at Charkaria level and correlate well in Jardepahar and Kajrahat levels except few places (Figure 5a-f).

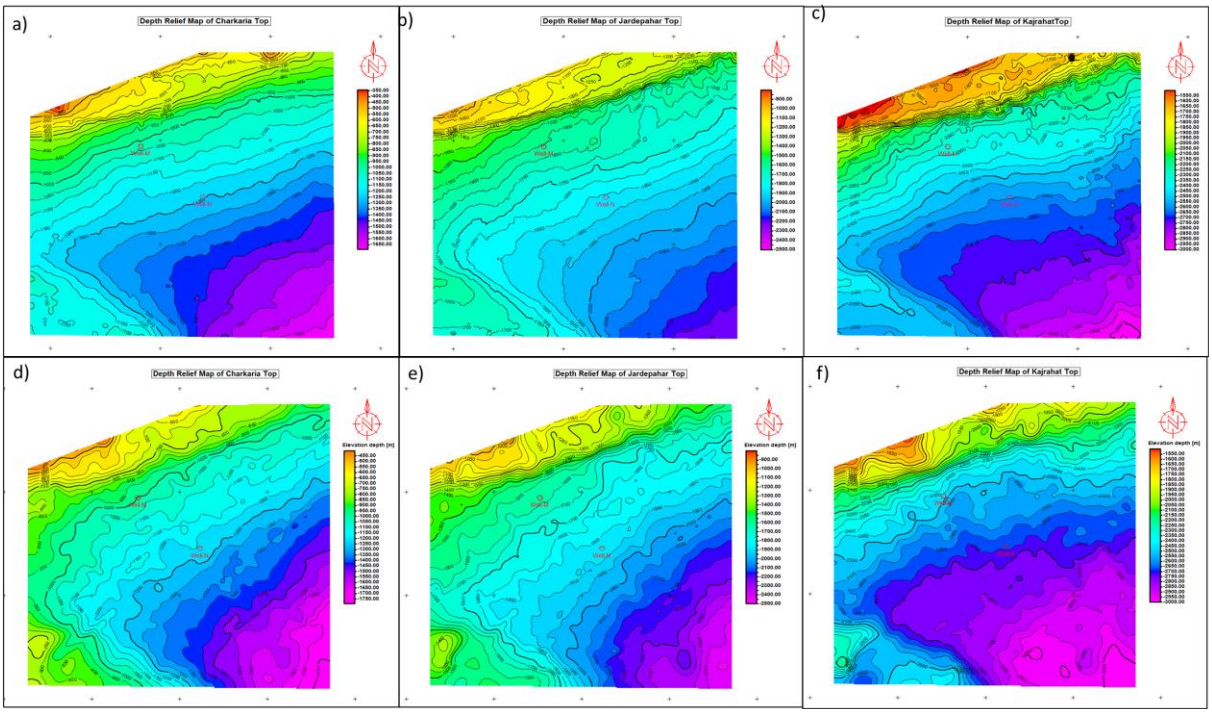

Figure 5: Depth relief maps from ES360 3D PSDM: a) Charkaria Top b) Jardepahar Top c) Kajrahat Top. Depth relief maps from 2D Seismic velocity modeling: d) Charkaria Top e) Jardepahar Top f) Kajrahat Top. (Depths are w.r.t. MSL)

Additionally, isopach maps of Kajrahat, Jardepahar, Charkaria and Rohtas - Charkaria sequence were generated to understand paleo-depositional environment, depocenter configuration and thickness variation in the area. Isopach maps of Kajrahat and Jardepahar formations from both the methods indicates the presence of depocenter towards South-West direction (Figure 6e-h). Thickness of the Kajrahat formation from both the methods shows thickness variation of 1000m to 2700m (Figure 6g & 6h). Absolute thickness error distribution map of Kajrahat top indicates the areas of maximum error which is mostly focused in the North (Figure 7c) and relatively uniform distribution elsewhere, thus providing confidence in the 2D based depth estimation. Isopach map of Jardepahar formation from 2D Seismic velocity modeling resulted in thickness variation of 450m to 1000 m whereas ES360 3D PSDM resulted thickness variation of 450 to 900 m for Jardepahar formation (Figure 6e & 6f) and absolute thickness error map shows that most of the area is covered with less error value (Figure 7b) which again depicts that depth estimation is good in the area. Isopach map of Charkaria formation from the PSDM shows that the formation thickness ~ 550 m is uniform in the study area and gradually increasing towards North-East (Figure 6c). Figure 9c also shows that depocenter for Charkaria is in North-East direction where thickness is varying from ~350m to 960m. 2D Seismic velocity modeling resulted in thickness variation of ~400m to 700m but not with any trend (Figure 6d). Absolute thickness error distribution map shows that minimum error of less than 50m lies in the NW-SE direction which is also passing through well-M and well-N. It also depicts that depth estimated in nearby area of wells are good but as we go away as seen in Figure 7b, our confidence decreases in depth estimation. Isopach map of Rohtas to Charkaria top thickness indicates that there is again another episode of change in depocenter to South-East direction. Thickness variation from 2D based method is ~600m to 1300m whereas from the PSDM is ~550m to 1200m which is nearly same (Figure 6a & 6b) except extra thickness is seen in the PSDM map in South-East direction. A high trend is observed in 2D based result in South-West direction which is not seen in ES360 3D PSDM based result.

Thus, it is observed that during initial syn-rift depositional phase, as depicted by isopach maps of Kajrahat and Jardepahar, depocenter is in South-West direction which corresponds to 1.8-1.7 Ga in age. Later, in subsequent tectonic stages, as seen from Isopach map of Charkaria siltstone band and Jardepahar (Figure 9a), depocenter has moved to North-East direction and then at the time of closing of the Charkaria sequences depocenter again shifts to Southern direction (Figure 9b). Furthermore, when younger formations Rohtas to Charkaria Top was depositing and at the time of Lr. Vindhyan closure which corresponds to the Columbia super-continent building, depocenter was present in South-East direction (Figure 6a & 6b). A Seismic composite section passing through our study area shows the thickness variation and change of depocenter within Charkaria formation (Figure 8).

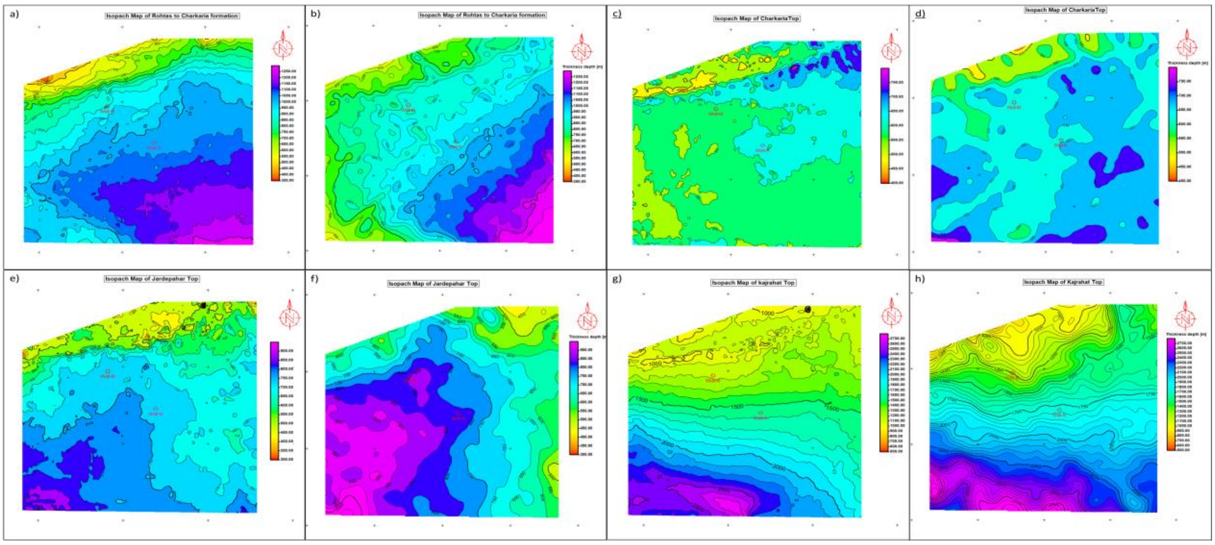

Figure 6: a & b: Isopach map of Rohtas to Charkaria Top (2D based modeling & ES360 respectively) c & d: Isopach map of Charkaria Formation (2D based modeling & ES360 respectively) e & f: Isopach map of Jardepahar Formation (2D based modeling & ES360 respectively) g & h: Isopach map of Kajrahat to Basement Top (2D based modeling & ES360 respectively)

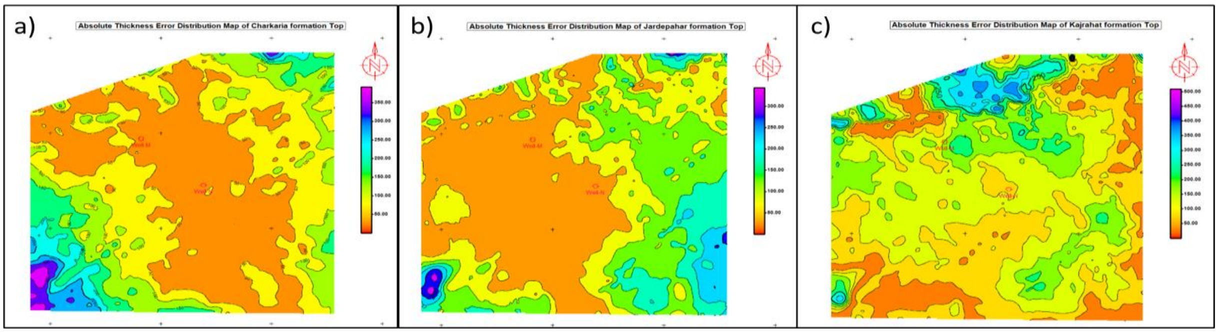

Figure 7: a) Absolute Thickness Error Distribution map of Charkaria Formation b) Absolute Thickness Error Distribution map of Jardepahar Formation c) Absolute Thickness Error Distribution map of Kajrahat to Basement Top Formation

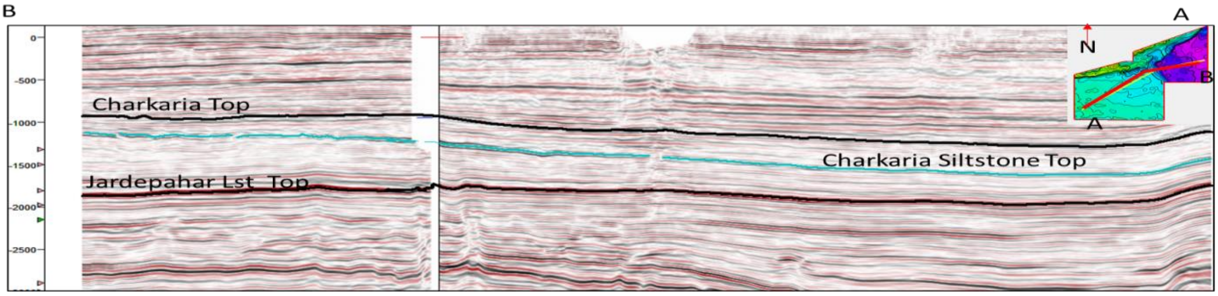

Figure 8: A composite section in the Hatta area showing change in nature of depocenter in the Charkaria formation.

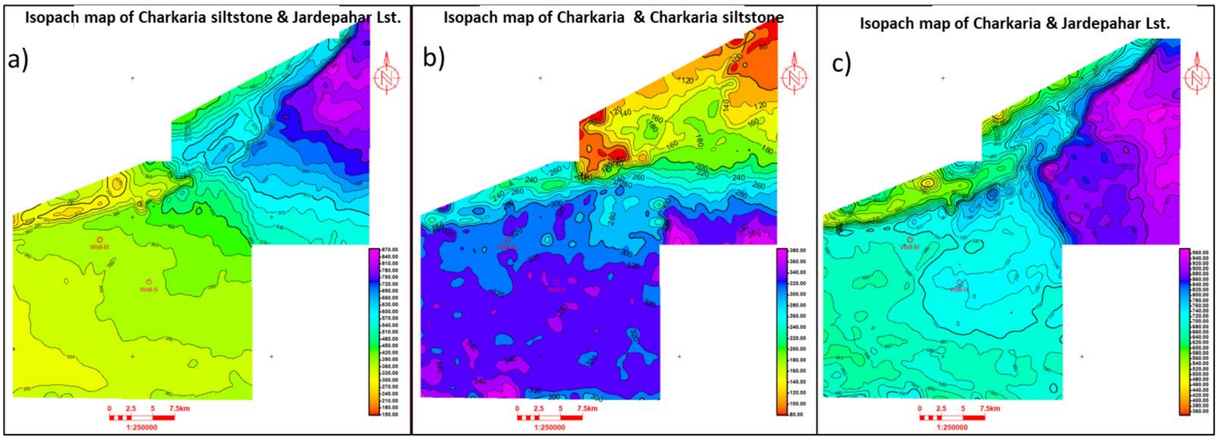

Figure 9: a) Isopach map of Charkaria Siltstone to Jardepahar Top b) Isopach map of Charkaria Top to Charkaria Siltstone c) Isopach map of Charkaria Formation

Conclusion

Vindhyan Basin consists of tight reservoirs with very poor primary porosity which is enhanced by presence of fractures. Therefore, in well planning, a precise depth estimation becomes very important to hit pay fractures accurately. Depth estimation and its associated error probability is also needed to be analyzed for successful well completion. With proper depth estimation, we can de-risk our well completion. Since 2D Seismic velocity model and ES360 3D PSDM has only utilized Well-M, Well-N and Well-O, there is scope for further modification and refinement as and when more subsurface data is available. The absolute thickness error map shows the high-risk areas for venturing into hydrocarbon exploration. 2D Seismic velocity modeling may prove to be as good as 3D PSDM velocity when there are more wells to calibrate velocities.

Isopach maps of Lower Vindhyan sequences brought out the shifting of depocenters with passage of geological time which also depicts change of paleocurrent direction and basin tilting events. Depocenter was shifted from South-West to North-East, North-East to South-west and then South-West to South-East within the Lower Vindhyan framework. These major tectonic events can be corroborated with worldwide events, for which further research is required. From hydrocarbon exploration point of view, shale and limestones within Kajrahat and the Arangi Formation act as a kitchen and that kitchen was present in South-West direction as observed in the form of depocenter.

Migration of hydrocarbon has been from South-West direction to North, North-East which may be targeted to further expand the Jardepahar play.

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References

Dix, C. H., 1955, Seismic velocities from surface measurements, Geophysics, 20, 68-86

Ram, J., Shukla, S.N., Pramanik, A.G., Varma, B.K., Chandra, G. and Murty, M.S.N.,1996, Recent Investigations in The Vindhyan, Basin: Implications for the Basin and Tectonics, Memoir Geological Society of India, 36, 267-28

Sharma, R., Sahoo, M., Negi, M.S. and Kumar, J., 2015, New Insights into the Tectonic Evolution of the Vindhyan Basin revealed by Structural Modelling Studies carried out in Son Valley, 3rd South Asian Geosciences Conference and Exhibition, New Delhi, GEO India-2005036