An Optimal Approach for Shale Gas Feasibility Study in Cambay Basin, India – A Case Study

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Abstract:

Most of the major E&P Companies operating in India is in a quest to unlock the domestic Shale Gas reserves which could help India to meet its growing energy demand. Different studies and scientific research reveal that the Cambay Shale Formation in the Cambay Basin can be considered to be one of the best potential candidates for a Shale Gas play in India. Therefore our study is aimed to assess the feasibility of exploration for Shale Gas in the major depocenters of the Cambay Basin. We have used the Petroleum System Modeling approach after building a 3D geological model, especially focusing on the Broach depression in the Cambay basin. The study incorporates various cross-sections, depth contour maps, thickness maps for the area in the geological model building process. Different petroleum system aspects of the study area are being evaluated in the model, which has been calibrated using vitrinite reflectance data from existing wells. Three special features of the petroleum system modeling approach for unconventional namely adsorption, organic porosity and geomechanics, are applied in the area of interest to evaluate the Shale unit. Organic porosity modeling helped to gain insight into the porosity developed in the kerogen through maturation of the Cambay Shale. Geomechanical modeling provided better identification of the areas where the Cambay Shale was more brittle. Finally, a Play Chance Mapping approach has been adapted to integrate all the key outputs of petroleum system analysis to delineate potential plays having a higher chance of success for Shale Gas exploration. This unique integrated modeling approach helped us to identify Shale play areas with higher potential in the Cambay Basin.

Introduction:

Shale Gas is one of the growing unconventional resources in the near future. In Indian context, Cambay Shale is one of the major potential candidates for Shale play analysis. Our present study is focused in the major depocenters of the Cambay Basin to assess the feasibility of exploration for Shale Gas using Petroleum System Modeling approach (Fig. 1). This Petroleum System Modeling approach consisting of data integration, unconventional Petroleum System Modeling and traffic signal mapping have been attempted in order to identify the most prospective area in Cambay basin by assessing all the risk factors associated with major petroleum system elements. The entire workflow is discussed in the following section of this write-up.

Data integration:

The project work commences with data integration from different sources. Based on available geological cross-sections, depth contour maps and literature study, we have generated depth maps for the top of the following formations: Top of alluvium, Tarapur Shale, Kalol Formation, Cambay Shale, Olpad and Basement. From different geological information, the Cambay Shale formation has been sub-divided into

three major units: Upper, Middle and Lower Cambay Shale. Once the Geological Model has been prepared the model has been used for Petroleum System Modeling in order to identify the play for Shale Gas.

In this Modeling approach the main focus was pertaining to Cambay Shale which is considered to be the potential unconventional source in Indian context. Hence, to achieve the objective of this study, we scouted some important input parameters like Langmuir isotherm of Cambay Shale and took logical assumption for incorporation in the Petroleum System Modeling workflow.

Results and Discussion:

The detail Petroleum System Modeling allows us to understand the adsorption capacity of the source along with expulsion from source to reservoir. The analysis of the result always starts from the maturity of the source. The main Cambay Shale source lies in Oil Window maturity range at present towards the Northern part of Cambay basin but in the Broach depression, Cambay Shale shows the maturity in the range of the Wet Gas window. As we are assessing for Shale Gas potential of the Cambay Shale, the foremost focus should be the area lying in the Gas window depth range. Apart from this maturity analysis majorly we need to put emphasis on overall adsorption capacity of the kerogen in the source along with estimated Gas content (Methane). We also take into account the organic porosity of the source which is created with increase in maturation of kerogens. Apart from aforementioned outcome of the modeling the other important factor that we need to focus is geomechanical properties of the target Shale. This mainly includes the brittleness and fracture proneness of the Shale. Now we are going to discuss the major characteristics of Cambay Shale inferred from this Modeling approach.

A. Model Calibration – Model calibration is the way to validate the Petroleum System Model with the real data from existing well. Here, we used vitrinite reflectance data from 2 key wells to calibrate the thermal model (Fig. 2). The vitrinite reflectance data for the two wells show a very good match with the modeled vitrinite reflectance graph (Fig. 3 & 4).

B. Present day Maturity – We are here evaluating the Middle part of the Cambay Shale. In the Broach and Tarapur depressions, Cambay Shale mainly lies in Wet Gas window whereas the rest of the portion it had attained ranges from main to late Oil window. From the maturity assessment, it is observed that the Broach depression in South Cambay exhibits higher maturity than the North Cambay areas (Fig. 5). As we are assessing for Shale Gas plays, in Tarapur and Broach depression the depth ranges in correlation with the Gas window range observed in the Cambay Shale lie in 3000 - 4000 m window.

   Along with maturity window the other important parameter has been analyzed is the Transformation Ratio (Fig. 6) of the Shale unit. This parameter describes which part of the source kerogen has been converted more into hydrocarbon.

C. Porosity of Cambay Shale – The compaction trend of Cambay Shale is used to derive the porosity at the particular depth with geological time. The lithology of Cambay Shale varies a lot laterally as well as this doesn't reflect a clean shale lithology. We have considered the compositional variation of Cambay Shale and took into account of the compaction trends of various clay minerals (like Illite, Kaolinite etc.) and Quartz of the Shale unit. In unconventional approach as we model the porosity increase for kerogen conversion (Organic Porosity) that also corresponds to the high maturity area (Fig. 7). Now, the total porosity takes into consideration of above mentioned organic porosity in addition to the normal Shale porosity (matrix porosity) (Fig. 8).

D. Cambay Shale Gas potential – Shale Gas potential of Cambay Shale is considered by getting insight of the adsorption capacity of Shale. We have executed the Adsorption Modeling to evaluate the shale unit which has maximum adsorption capacity (Fig. 9). In order to evaluate the adsorption capacity, Langmuir temperature, pressure and volume are taken into account to estimate the source rock capacity of retaining hydrocarbon. Apart from that we also have been able to speculate the area in Cambay Shale where the Shale can hold maximum Methane gas (Fig. 10).

E. Geomechanical property – Geomechanical evaluation of the Shale is one of the major concerns in unconventional study. Based on the geomechanical behavior of the shale components, we can be predicted that which area should be behaving brittle and which area is more fracture prone. In order to overview these properties we will look at the fracturing property which shows the permeability increase due fracture and yield line distance that postulates the rock that is close to Mohr envelop. If the yield line distance is positive that means already the rock is fractured and if it is negative that suggests it is not fractured yet. In the Broach area if we look at the fracturing property it is quite evident that fracturing creates a huge permeability in the Broach depression (Fig. 11).

   On the other hand yield line distance of Shale units near about broach depression shows the Mohr diagram is crossing the Mohr envelop and the yield line distance value ranges near about -2 MPa to -3 MPa (Fig. 12). The blue color is showing the yield line distance value of positive magnitude that stands for the less brittle zone which is not so fracture prone.

F. Pore Pressure Prediction – We estimated pore pressure and identified the area of overpressure in the Cambay Shale (Fig. 13). While observing the result this is quite evident that in the Broach depression Cambay Shale shows a quite high pressure. In the Broach depression, the Pore pressure mainly ranges between 90 to 115 MPa while in Tarapur depression the pore pressure is relatively less around 55-70 MPa.

G. Play Chance Mapping – Once we obtained all Petroleum System Modeling result, we performed Play Chance Mapping in order to extend the entire workflow to focus on the areas for feasible Shale Gas plays. We have created chance of success maps for all the parameters analyzed above for Shale Gas feasibility study. With the help of proper transformation function, the property maps were converted into Chance of success maps scaled in probability units. All these maps are then stacked together to get a final Chance of Success Map (COS) at the basin scale (Fig. 14). This map show that in quest of Shale play, Broach depression hosts the most effective play for Shale Gas after considering all the key elements like maturity, gas content, adsorption Capacity, Mechanical properties etc. and the combine chance of success for Shale feasibility is approximately 40%-50%. Apart from that, Tarapur depression also shows around 10-15% chance of success for Shale feasibility.

Conclusion:

In this section of this technical write up we want to conclude the study by discussing the final result with the objective that we set at the beginning of the study. The goal of this project was to identify the most potential play area (feasibility of Shale Gas plays) in the Cambay basin. So, through the source rock assessment from different aspects like maturity, adsorption capacity, Geomechanical properties, inherent porosity etc. we came up with some chance of success maps for all the above properties. And finally we stacked them together to get the common play in basin where all the aforementioned properties are in desired range. From this play analysis based on the chance of success value two plays (Broach

depression and Tarapur depression) could be considered as potential area for Shale gas exploration. For further assessment, we can incorporate new parameters in this study and update accordingly at any stage of exploration.

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List of Figures:

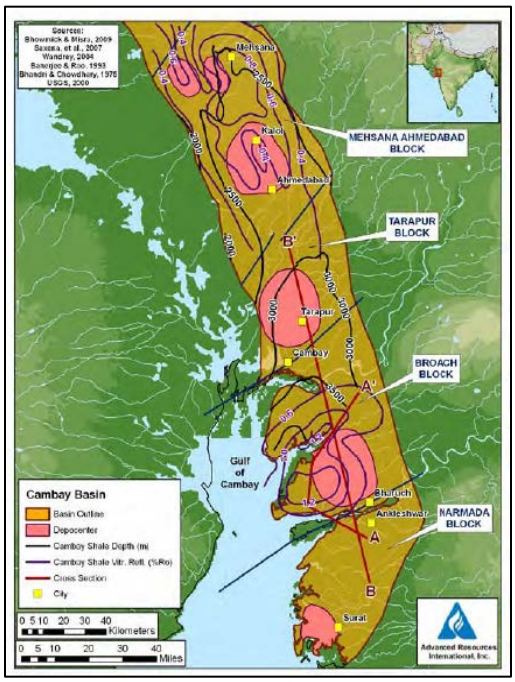

Fig 1: Cambay Basin with Major Depocenters

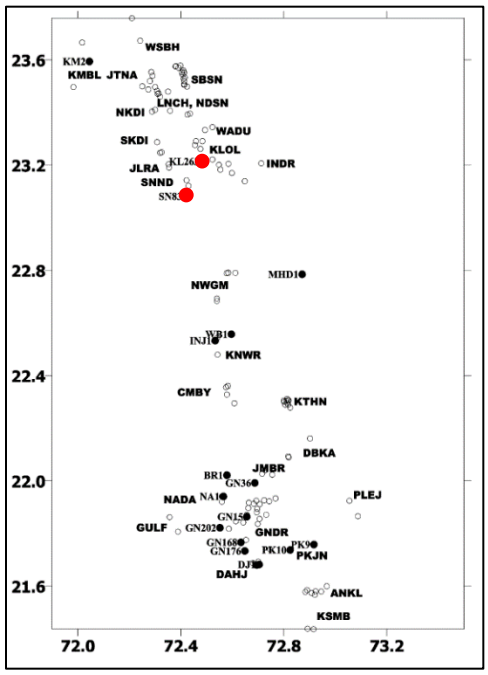

Fig 2: Location of calibration wells

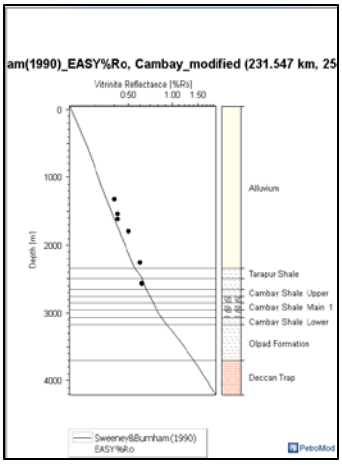

Fig 3: Vitrinite Reflectance Calibration at SN83

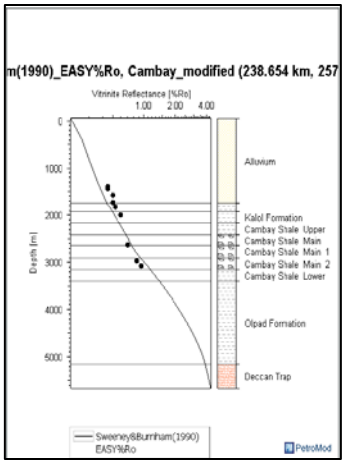

Fig 4: Vitrinite Reflectance Calibration at KL263

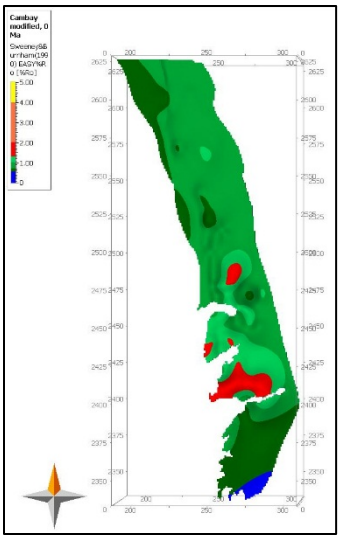

Fig 5: Vitrinite Reflectance Map of Middle part of Cambay Shale

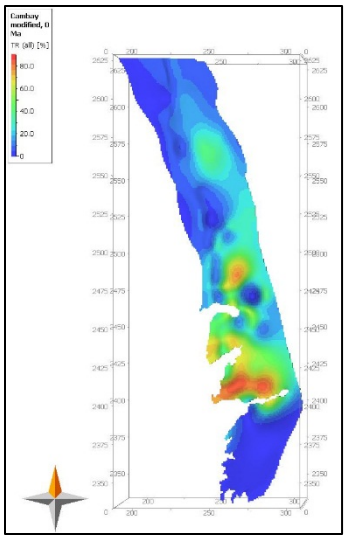

Fig 6: Transformation Ratio map of Middle part of Cambay Shale

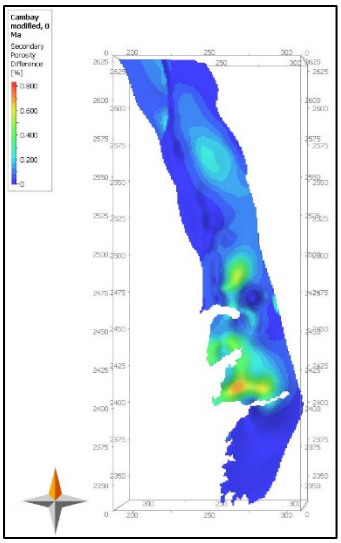

Fig 7: Organic porosity Map of Middle part of Cambay Shale

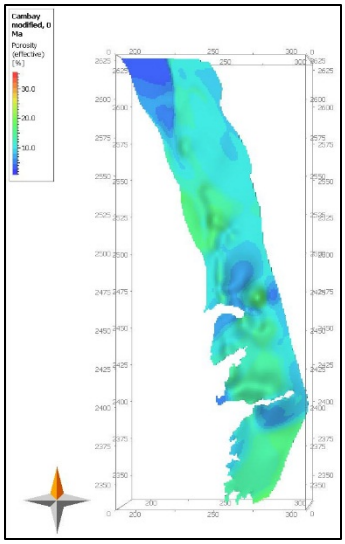

Fig 8: Porosity Map of Middle part of Cambay Shale

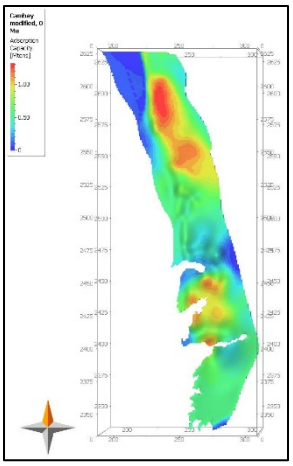

Fig 9: Adsorption Capacity Map of Middle part of Cambay Shale

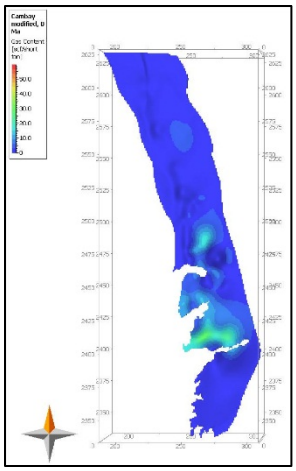

Fig 10: Methane content Map of Middle part of Cambay Shale

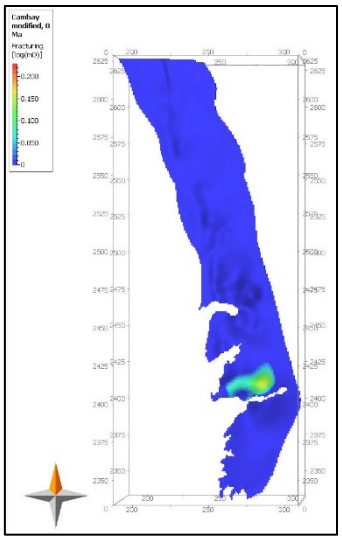

Fig 11: Fractured Permeability Map of Middle part of Cambay Shale

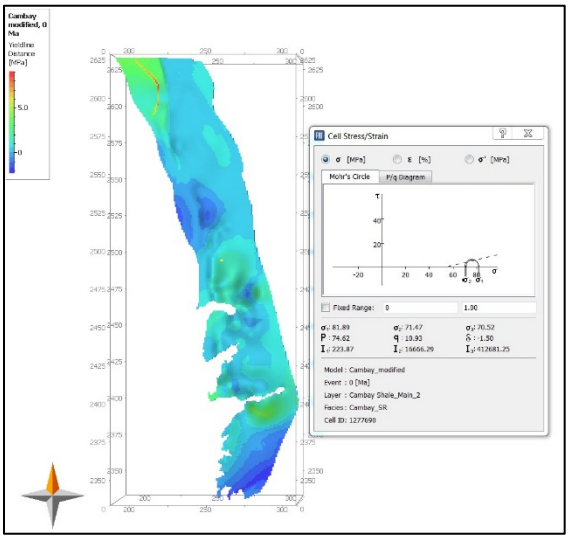

Fig 12: Yield line distance Map of Middle part of Cambay Shale with Mohr diagram

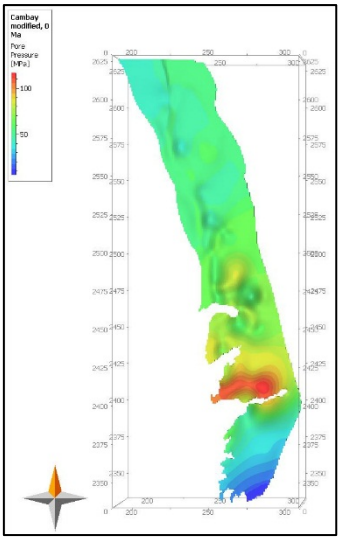

Fig 13: Pore Pressure Map of Middle part of Cambay Shale

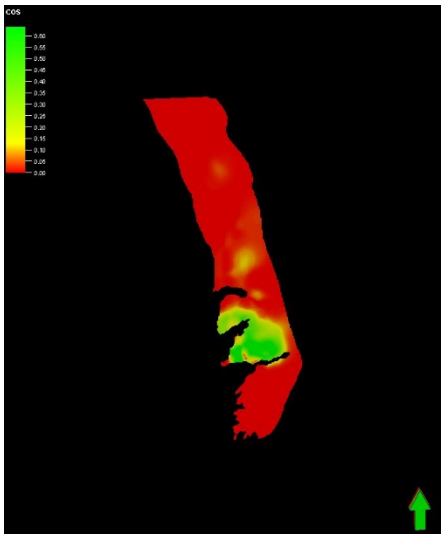

Fig 14: Final Chance of Success Map of Middle part of Cambay Shale