



Assessing Shale Gas Resource in the Broach Depression of Cambay Basin, India: An Integrated Exploration workflow

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Summary

The assessment of unconventional resources in shale plays is a challenging task in the present context of exploration in India, as regional investigations of their economic potential are scarce. In contrast, regional play evaluations to assess conventional resources are now commonly based on the characterization of petroleum systems elements describing subsurface geological conditions as an input for uncertainty and economic resource assessments. Despite ongoing efforts to improve decision making, the Indian E&P industry lacks a reliable and consistent resource quantification approach similar to the methodologies used in conventional workflows.

In this case study we have attempted to identify the 'sweet spots' of an emerging unconventional play in the Older Cambay Shale in the Cambay Basin, located in western part of India. Aim of the here described investigations was to depict areas of the play with the highest chance-of-success (COS) related to technical feasibility as the basis of a subsequent Shale Gas resource assessment.

A thorough petroleum system analysis approach has been adapted for the evaluation of the Older Cambay Shale in the Broach Depression in Cambay Basin, India. Input data for the initial geological model building process was based on various published geological cross-sections, depth contour maps, thickness maps of the area. In addition to (I) thermal maturity and (II) generation modeling, the assessment of the petroleum system was focused on three additional aspects of an unconventional play: (III) adsorption capacities, (IV) organic porosity and (V) geomechanical properties of the Older Cambay Shale.

This approach enabled a comprehensive understanding of retained hydrocarbon in the shale units with estimation of maturity, gas-in-place, overpressure, organic porosity and favorable brittle areas inside the shale unit. The assessment of probabilistic volumes of identified sweet spot areas was done in taking into account hydrocarbon saturation, porosity and net to gross ratio of potential units, with respect to the corresponding geological chance of success.

Using a robust and integrated play analysis, we have been able to identify the risk elements that have the greatest impact on both geological COS, the uncertainty for the estimation of potential volumes in places and their economic assessment. The here proposed resource and risking workflow which integrates all the available information enables explorationists to identify the economic potential of the shale gas plays in the Broach Depression.

1. Introduction:

The here presented study aims to perform a rigorous resource assessment for shale gas resources in deeper part of the Cambay Basin. In order to achieve the goal of this project, we have carried out a petroleum systems modeling study with a distinct focus on calibration and quantitative assessment of three parameters:

- 1) Organic Porosity,
- 2) Adsorbed gas and
- 3) Geomechanical properties.

The results of these three modeling scenarios in addition to other output maps from detailed petroleum systems analysis have been converted different chance-of-success (COS) for sub-elements and further stacked into a combined COS map for the play. With that we have been able to identify a potential sweet spot in the basin, which resembles the area of interest for a subsequent resource assessment studies and economic evaluations.

2. Adopted Methodology

The input of any rigorous resource assessment is a consolidated geological model, for the current project constructed using all public available geological and geophysical data (reference 4). The petroleum systems studies of the shale play took the following elements of the Cambay Basin sediments into consideration thermal maturity modeling, to get an understanding of the heat flow history of the region, and a high-resolution generation and migration simulation, including pore pressure modeling, to

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evaluate the potential of retained hydrocarbon in the Cambay Shale.

Main workflow of petroleum systems modeling for unconventional resources:

A. Thermal maturity modeling: The thermal history of a petroleum systems model is derived from the heat flow history and burial depth of the formation through geological time. The thermal history is replicated through geological time and source rock maturity is computed based on its thermal history.

B. Pore pressure modeling: A Pore pressure model is calculated based on the porosity of the formation derived from library depth-compaction curves. A 3D stress model along with a Terzaghi model has been taken into account to build a consistent geomechanical model which in turn was used to recalibrate and refine the pore pressure calculation. A full PVT controlled 3D simulation as performed for the current study also allows to take hydrocarbon generation pressure into account to estimate pore pressure.

C. Organic porosity modeling: Apart from matrix and fracture porosity, organic porosity plays an important role in the evaluation of shale reservoirs. Organic porosity is generated during hydrocarbon generation process from kerogen and is directly related to the maturity and transformation of the kerogen.

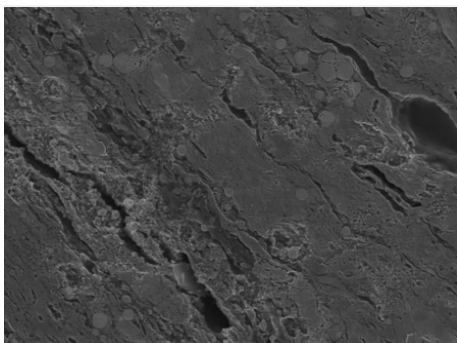


Figure 1: Generation of pore spaces in Kerogen during Maturation process (Microscopic image: reference 5)

D. Adsorption modeling: The adsorption model helps to estimate the volume of retained hydrocarbons and the free methane content in shale pore spaces. Secondary cracking has to be taken into account in the simulation, as it is an important factor in shale feasibility studies, responsible for cracking of oil to methane (C_1). A 4-component adsorption model has been used in the shale gas analysis here, as the sorption factor varies with different components. We have

used the Symington model for component adsorption and the Langmuir model for the bulk adsorption.

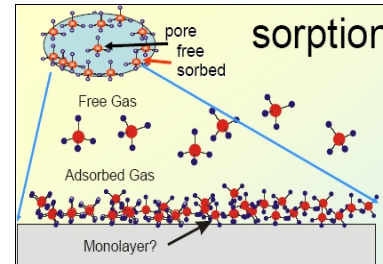


Figure 2: Adsorbed and Free Gas in Pore spaces (reference 5)

E. Geomechanical modeling: Geomechanical model is another indispensable part for any shale play analysis, as the model enables to identify the brittle zone - which is better suited for any shale gas exploitation. In addition, the overall stress regime of the region can be evaluated (reference 2), based on the geomechanical properties of the rock.

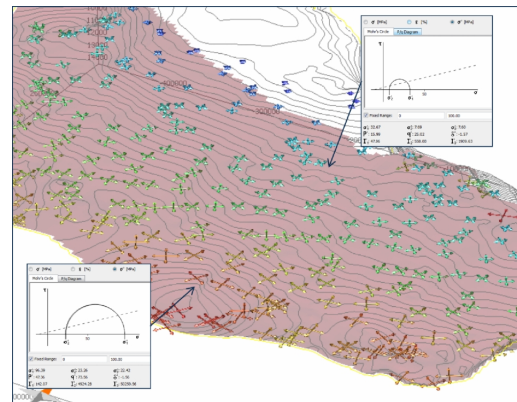


Figure 3: Geomechanical model showing the stress direction and Mohr envelope of each cell for brittleness analysis (reference 5)

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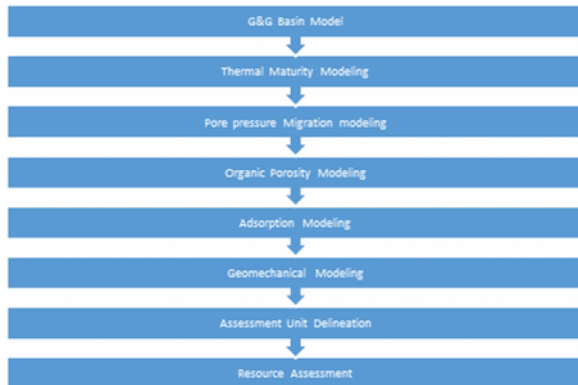


Figure 4: Main workflow adopted for this study

3. Sweet Spot Delineation in Older Cambay Shale:

The petroleum systems modeling approach as described above has been essential to understand the adsorption capacity, retention potential of the Older Cambay source along with expulsion from source to reservoir. A thorough evaluation of the source rock maturity is the starting point for any evaluation of the shale gas. For the potential of the Older Cambay Shale, the highest potential for a successful shale gas exploitation is given in the source rock areas which are at present day in the gas window.

The major characteristics of the Older Cambay Shale from the combined petroleum systems simulations are:

A. Present day maturity evaluation – In the Broach Depressions, the Older Cambay Shale maturity potentially lies predominantly at present day in the Wet gas window, whereas the rest of the portion attained ranges from main to late Oil window (Figure 5). The depth ranges of the Older Cambay Shale in correlation with the gas window range lie in between 3000-4000 m window.

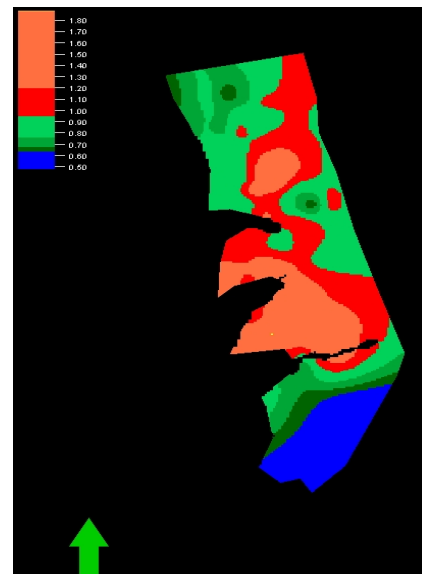


Figure 5: Present Day Maturity Map (showing Vitrinite reflectance values) of Older Cambay Shale inferred from Thermal Modeling

B. Porosity evaluation: The compaction trend of the Older Cambay Shale is used to estimate the porosity at different depth ranges with geological time. The lithology of the shale unit shows some significant lateral variations. Compositional variations of various clay minerals (Illite, Kaolinite, etc.) and Quartz of the shale unit have been taken into account for compaction trends. Figure 6 shows the organic porosity of Older Cambay shale.

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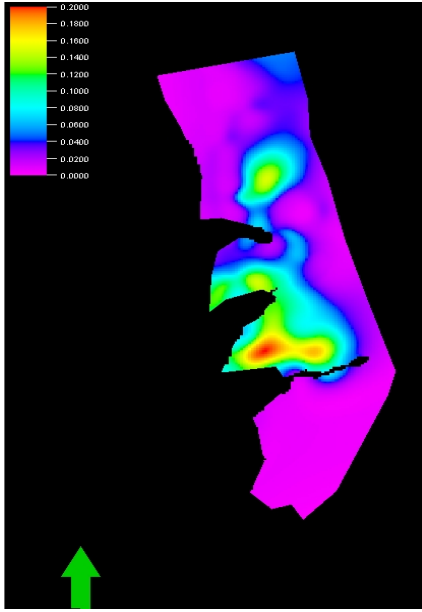


Figure 6: Organic Porosity (in m³/m³) Map of Older Cambay Shale inferred from Organic Porosity modeling

C. Gas-in-place potential: Figure 7 shows the Gas-In-Place potential of Older Cambay shale. The gas potential of the Older Cambay Shale is in direct correlation with the adsorption capacity of the shale unit. In order to evaluate the adsorption capacity, Langmuir temperature, pressure and volume are taken into account to estimate the capacity of the source rock to retain hydrocarbons. The rigorous petroleum systems approach applied as enabled to depict the area in the Older Cambay Shale where the shale potentially can hold maximum methane gas amounts.

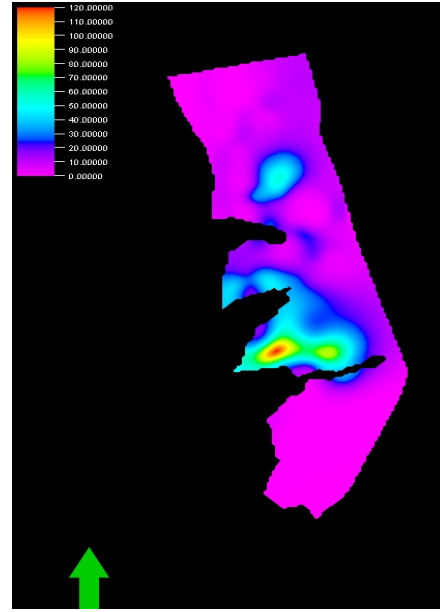


Figure 7: Gas-In-Place (in Scf/Ton) Map of Older Cambay Shale inferred from Adsorption Modeling

D. Geomechanical evaluation: One of the key elements of any unconventional resource assessment is the geomechanical evaluation of the shale. In our case study we have been able to generate a reliable map representing the stress conditions of each cell, via its in-situ differential stress state and its relation to a Mohr-Coulomb failure envelope. This map is used as a proxy to delineate areas of high COS in terms of existence of natural fractures and/or ease of hydraulic stimulation (Figure 8). This map is based on basin-scale geomechanics calculated from the tectonic history and stress conditions in the basins.

Here we have looked at the fracturing property and yield line distance that postulates the rock that is close to Mohr envelop. If the yield line distance is positive that means the rock is already fractured at present day and if it is negative that suggests it is not fractured yet. The yield line distance of the shale units in the Broach depression shows the Mohr diagram is crossing the Mohr envelop at many places, indicating more brittle zones.

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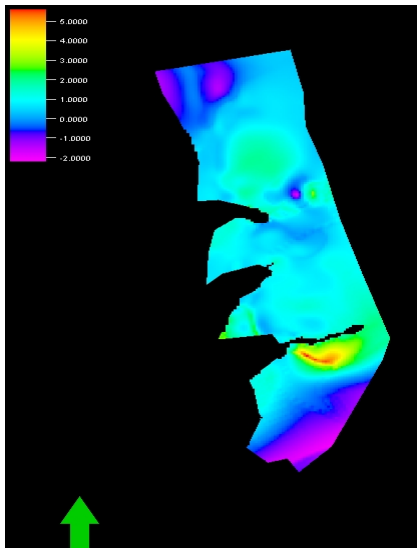


Figure 8: Brittleness Map which is representing stress difference with Mohr envelop (MPa) of Older Cambay Shale inferred from Geomechanical Modeling

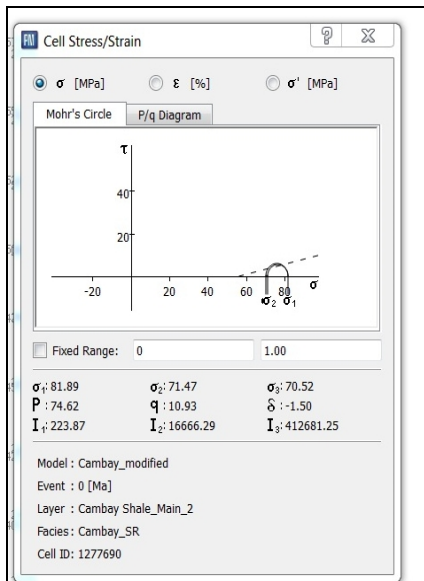


Figure 9: The Mohr Envelop is being represented where the Brittleness map value is close to zero which in turn envisages the fracture prone area

E. Pore pressure evaluation: The performed pore pressure calculation enabled to identify areas of overpressure in the Older Cambay Shale. While analyzing the result of the petroleum systems simulation it is quite evident that in the Broach Depression the Older Cambay Shale shows a quite high pressure (Figure 9) ranges between 90 to 115 MPa.

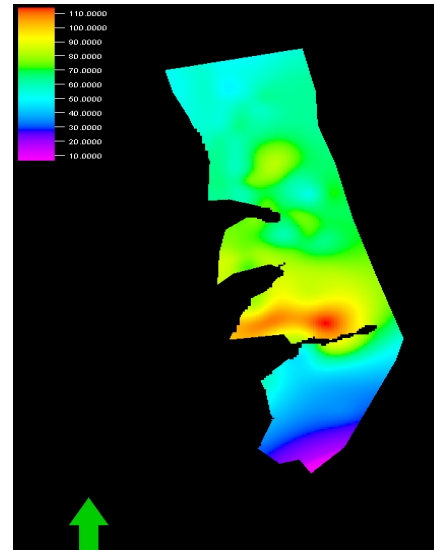


Figure 10: Pore Pressure (in MPa) Map of Older Cambay Shale inferred from Pore Pressure Modeling

F. Sweet spot delineation: All the simulation results from the performed petroleum systems analysis (section A to E), have been integrated into a consistent and geology based we performed play chance mapping exercise in order to depict the shale gas related sweet spots in the formation Chance-of-success (COS) maps for all the geological and geochemical parameters analyzed above have been generated for a respective shale gas feasibility study. With the help of tailored transformation functions the property maps were converted into probability units, depicted in chance-of-success maps. All sub-element maps have subsequently been stacked (probabilities multiplied) together to get a combined COS map of the Older Cambay Shale. The combined COS map in figure 10 shows the sweet spots areas in the Broach Depression after considering all the key elements like maturity, gas content, adsorption capacity, mechanical properties and the combined COS values (for Shale Gas feasibility).

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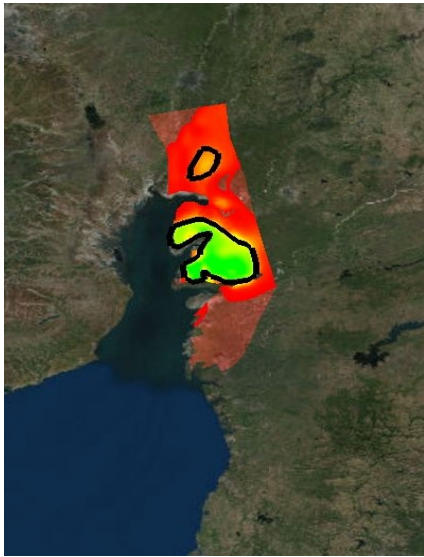


Figure 11: Combined Play Chance Map of Older Cambay Shale showing Sweet Spot areas delineation in Older Cambay Shale

G. Resource Assessment in Broach depression – The assessment unit in Broach depression obtained from sweet spot delineation has been considered for probabilistic volumetric analysis. All the risk factors and uncertainties are taken into account to do this kind of volumetric assessment (reference 1, 3). Through this analysis we came up with a graph (Figure 12) which shows the Older Cambay resource volume with respect to the corresponding Geological Chance of success to obtain that particular volume. This analysis combines all the Petroleum System analysis output and the volumetric parameters together to estimate the resource. We have adapted the Shublik and Eagle Ford Shale model (reference 3) for the probabilistic volumetric analysis as the analog data.

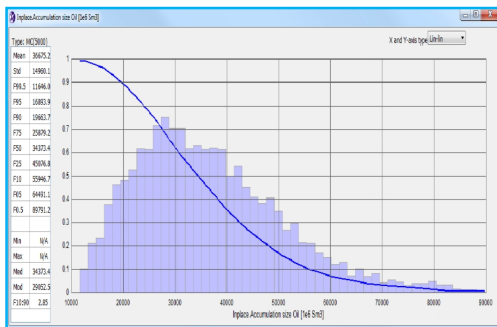


Figure 12: Resource Diagram of Older Cambay Shale

4. Conclusion:

The goal of this project was to identify the most potential play areas of Older Cambay shale for Shale Gas feasibility in the Broach depression of Cambay basin and execute probabilistic volumetric analysis of assessment unit incorporating both the risk factors and the volumetric parameters using Shublik and Eagle Ford Shale model as analog. With an estimation of the risked in-place resources completed, we have considered an integrated workflow in order to characterize an exploration campaign and have integrated the uncertainty of the subsurface model.

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