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An Assessment of Geothermal Energy Potential in Gandhar area of Cambay Basin, India: 3D Basin Modeling Study

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Abstract

The quest for energy independence, economic growth and environmental sustainability increasingly suggests the importance of renewable energy sources. Geothermal energy is known to be one of the clean energy resources. Basins with geologic rifts, in general, being associated with crustal thinning and mantle upwelling are favourable locales for the geothermal energy. In view of the potentiality of Cambay Basin, an intracratonic rift graben, a maiden attempt has been made to enhance the understanding, delineate possible locales and assess the geothermal resource potential of Gandhar area using 3D Basin Modeling techniques.

The static geological model used for thermal modeling comprises of eight depth maps at key stratigraphic levels along with present day topography (DEM). The final model has thirty one sub-layers based on spatio-temporal facies variations, paleogeography analysis and computed average porosity/permeability from core data.

The study is suggestive of high thermal regime with good aquifer conditions in the Hazad Member of Ankleshwar Formation. The average porosity and horizontal permeability maps show favourable aquifer conditions in the central part of the Gandhar-Pakhajan area. The isotherm map within Hazad Member reveals presence of three areas having temperature >130ºC which is desirable for harnessing geothermal energy. Further, the Gandhar-Pakhjan Low has the maximum temperature of 149⁰C.The study infers a favourable geothermal system, mainly confined to the central part of Gandhar-Pakhjan and Nada area with indicative geothermal resource base (P_{25} years) estimated to be 1187 MW for the Hazad Member of Ankleshwar Formation.

Introduction

Thermal modeling through 3D Basin Modeling technique involves dynamic forward modeling of geological processes in a sedimentary basin. The static geological model, comprising of structural and stratigraphic models, constitutes the essential inputs for thermal modeling studies. The structural model, prepared based on the seismic data interpretation, comprises of depth surfaces and faults defining the tectonic framework; while the stratigraphic model incorporates lithofacies variations as inferred based on sedimentological and log data analysis, depositional environments, erosion / hiatus. The thermal modeling, involves heat flow analysis and temperature determination after calibration with the parameters such as BHT, VRo and AFTA etc., deterministic computations to forward simulate (i.e. from geologic past to present) the thermal history along with change in geo-mechanical properties of different lithofacies i.e. temporal and spatial distribution of porosity and permeability. 2D / 3D visualization of outputs such as heat flows, geothermal gradients, porosity and permeability overlays / maps for required depths or horizons is achieved directly from the model to assess and harness the geothermal energy potential.

In this paper we focus on an understanding of the various elements of geothermal energy system, possible thermal regime and porosity & permeability of Gandhar area of South Cambay basin,India. and their implications of the results on geothermal prospectivity of the area through (1) Identification of high temperature (>130⁰C) areas in Hazad sands,(2) Temperature map of the Gandhar area,(3) Identification of associated / suitable aquifers with good porosity and permeability along with an indicative assessment of the geothermal energy resource potential of the Gandhar area. This can be harnessed by using well doublets which are not producing hydrocarbon now.

Geology of the Area

The Cambay Basin is a narrow NNW-SSE trending elongated intracratonic rift graben situated in western part of India. The basin extends from Luni River in the north to Tapti River in the south and is about 425 km long. The basin was formed by rifting along Precambrian Dharwarian trend (NNW-SSE) while Aravalli-Delhi (NE-SW) and Satpura trends (ENE-WSW) have controlled the structural style of the basin. The Basin has Deccan Trap of Late Cretaceous to Early Paleocene age as technical basement over which 7 km (+) thick Cenozoic sediments were deposited. A complex network of faults has compartmentalized the basin into distinct tectono-sedimentary domains bordered by major transfer faults. The Cambay Basin is subdivided into five major tectonic blocks (Fig.1) based on major basement faults which from south to north are:-

I. Narmada -Tapti Block II, Jambusar - Broach Block III, Tarapur - Cambay Block IV. Mehsana – Ahmedabad Block and V. Sanchor - Patan Block

Present study is confined to an area of 9000 Sq. km. of Broach - Jambusar block i.e. the area falling between Mahi and Narmada rivers in South Cambay basin. Detailed account of lithostratigraphic framework of the Basin documented by Pandey et.al, 1993 has been considered (Fig.2).

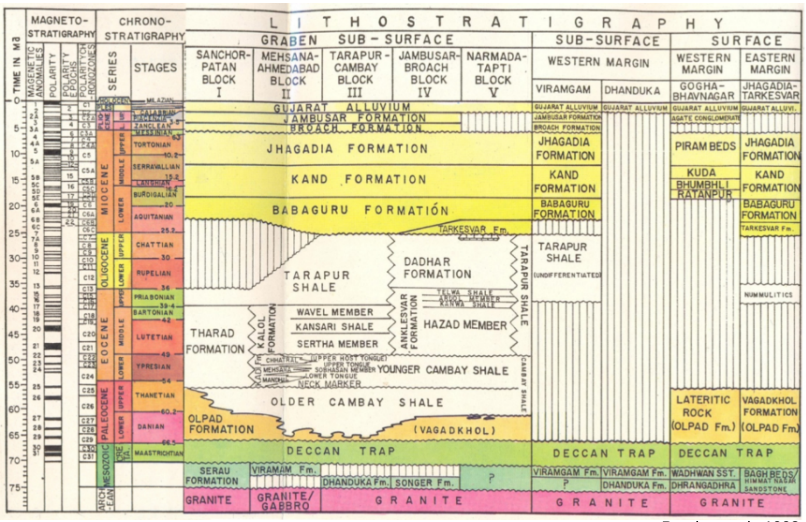


Fig.1: Tectonic map of Cambay Basin

Fig.2: Lithostratigraphy of the Cambay Basin

Pandey et al., 1993

Basic Work Flow: The basic workflow in the study involves: (Fig.3).

Fig. 3: Basic Workflow of Thermal Modeling Study

Model Building

Eight depth maps have been prepared by analysing data of more than 183 wells and by interpreting 2D seismic lines and 3D seismic volume across the area i.e. Trap Top, Paleocene LST Top - Rift Climax Top (Olpad/OCS equivalent), Paleocene Top, Early Eocene Top, Middle Eocene Top, Late Eocene Top, Oligocene Top and Miocene Top. These maps have been used to build initial model geometry with 100m*100m grid resolution in PetroMod (Ref: Bahuguna et al., KDMIPE, 2015). The present day topography map is prepared based on DEM data (Source: USGS). For incorporating Geothermal System elements into the model, the initial model geometry (having 8 key stratigraphic depth surfaces) is subdivided into different layers via layer splitting based on spatio-temporal facies variations observed in electro log correlations and paleogeography analysis across the basin. Average porosity and permeability have been computed from the core data for Hazad Member of the Ankleshwar Formation. The Hazad Member has been divided into three main units from bottom to top by analyzing well data and electrolog correlations i.e. Sand-A Unit, Sand-B Unit and Sand-C Unit (Fig.4). The Sand-A Unit consists of GS-0 to GS-3 sands, Sand-B Unit consists of GS-4 to GS-9 sands and Sand-C Unit consists of GS-10 to GS-12 sands. These three units are separated by thin shale layers. The average porosity and permeability based on core data is used for the calibration VRo and corrected temperature data of key wells were utilized to construct regional calibrated Heat Flow maps. The final geometry is having thirty two layers based on respective facies maps (Fig.5).

Fig. 4: NW-SE Electrolog Correlation passing through wells A to H

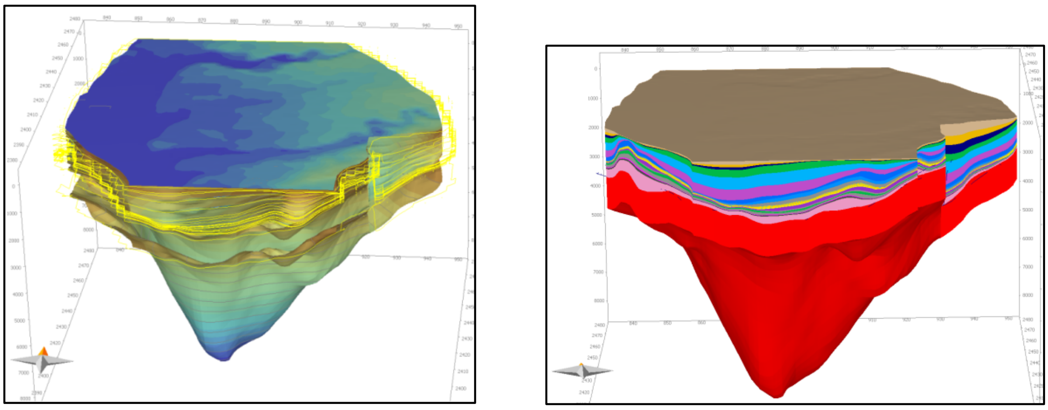


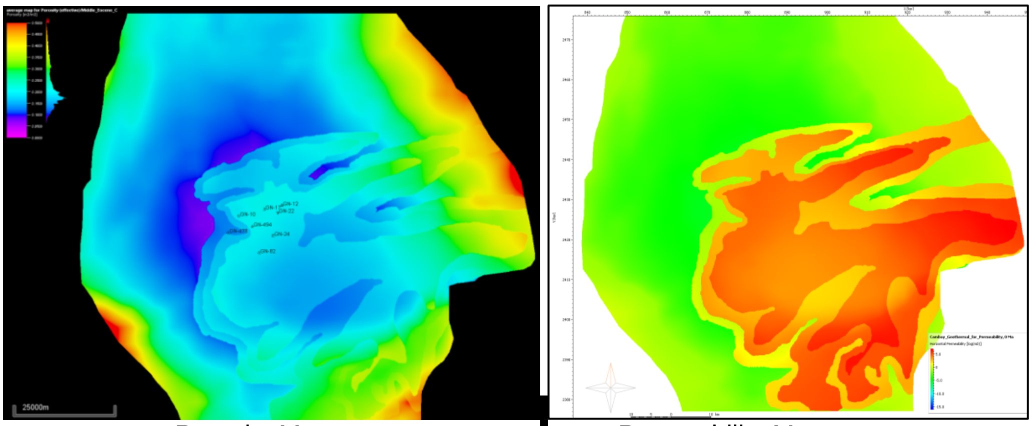
Fig.5: Final Model Geometry

The Model has been simulated and after calibrations the results have been analyzed:

Calibration and results

Different scenarios have been simulated based on the VRo and Temperature data. Good calibration has been achieved. The results of the porosity, VRo & temperature calibration of few representative wells from different locations are given in Figs.6, 7&8.

Fig.6: Porosity Calibration for the A and G wells



Porosity Map Permeability Map

Fig. 7: Porosity and l Permeability Map: Unit -A

Fig.8: VRo and Temperature Calibration for the wells

The Temperature of different units of Hazad Member was calculated in PetroMod. Isotherm overlay of the section passing through Gandhar-Pakhajan area (Fig.9) showing the temperature window of 130^0C isotherm. The present day temperature cube indicates surface temperature in the range of 27^oC to 29^oC while maximum temperature observed is ~357^oC at the bottom near the basement (Fig.10).

A B C D

Fig.9: Isotherm along E-W Section passing through Wells A, B, C and D

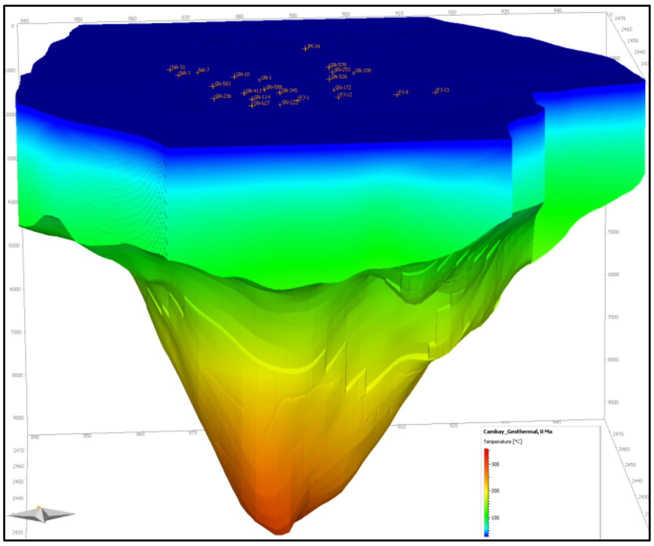


Fig. 10: Isotherm Cube: Present Day

The Isotherm maps and combined overlay (Facies, Depth and Temperature) of all the three units were analyzed by defining the area having temperature >130^0C to calculate the geothermal resource base. Isotherm maps of top unit (C) indicates overall temperature in the range of 30^oC to 145^oC, while maximum temperature 147.2^oC and 149.8^oC is observed in the middle unit (B) and the bottom most unit (A) of Hazad sands respectively, which is mainly confined in the central part of the Gandhar-Pakhajan area. The isotherm map within top unit (C) of Hazad sands shows that there are two main areas having temperature more than 130^0C. The total area of 453 sq. km., 689 sq. km. and 917sq. km. having temperature window more than 130^0C is available calculated within Top (C),Middle (B) and Bottom (A) units respectively in the area (Figs.11 to 14).

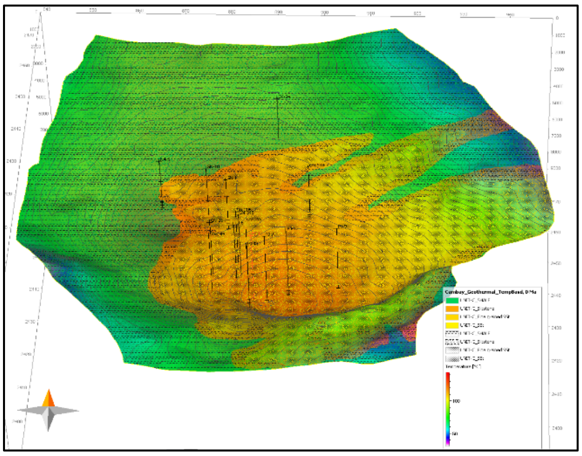


Fig.11: Combine Overlay: Facies with Isotherm within top Unit (C) of Hazad Member

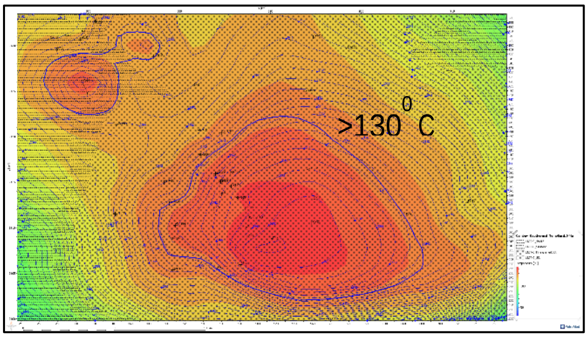
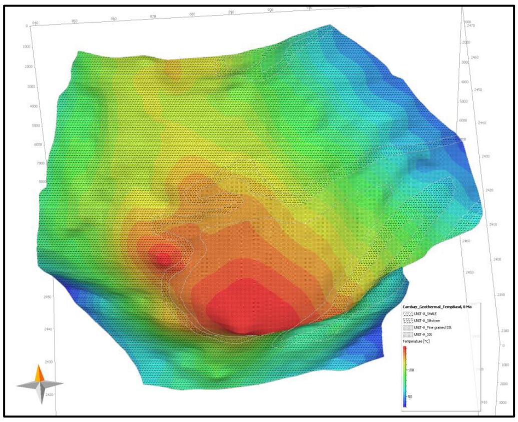


Fig.12: Isotherm showing area confined by >130^0C within top Unit (C) of Hazad Member


Cambay_Geothermal_TempBasd, 0 Ma
UNIT-A_SHALE
UNIT-A_Siltstone
UNIT-A_Fine grained SSt
UNIT-A_SSt
Temperature [°C]
100
50

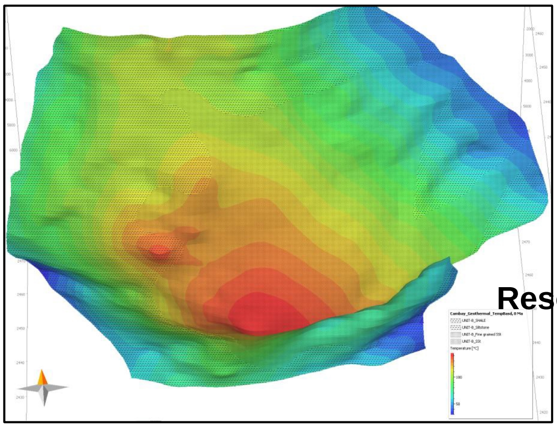


Fig.13:3D Overlay of Facies and Isotherm: Unit-B
Fig.14:3D Overlay of Facies and Isotherm: Unit-A
Fig.13:3D Overlay of Facies and Isotherm: Unit-B
Fig.14:3D Overlay of Facies and Isotherm: Unit-A

Resource Base

Resource base is calculated (Muffler LJP, 1970-78) for all the three units of Hazad Member. Calculation summary of the Bottom unit (A) is shown in Fig.15. The calculated resource base is 393.75 MW, 641.83 MW and 151.283 MW for Unit-A, Unit-B and Unit-C respectively.

• Reservoir Thermal Energy in joules(J)	**Geothermal Energy after conversion through ORC**
qR=ρc*a*d*(t-tref)	(qWhe)= qWH*0.1*(0.27777*10^-3) Wh
• "ρc" is volumetric specific heat of rock plus water (2.7 j/cm3°C)	(taking ORC plant conversion efficiency 10% & 1 Joule= 0.2777/1000W
• "a" is reservoir area (917km2)	**qWhe=0.0774*10^15 Wh**
• "d" is reservoir thickness (50m)	
• "t" is reservoir temperature (140°C)	P (25 Years)= qWhe/(25*7860)
• "tref" is reference temperature at the surface (50°C)	(taking Full Load hours ~ 92%)
qR= 11.14 * 10^18 joules	
Geothermal Recovery Factor (Rg)= qWH/qr	**$P_{(25\ years)}$= 393.75 MW**
"qWH"is Geothermal Energy Recoverd at the well head	
"qR"is Geothermal Energy Originally in the Reservoir	
(Rg = assumed to be 25% for all hot-water reservoir) which implies	
qWH= qr*Rg= 2.785*10^18J	

Fig. 15: Resource Base Calculation: Unit 'A' (This unit is having an area of 917 sq.km. (temperature window >130^{0}C) with average reservoir temperature 140^{0}C).

Resource Base Summary indicates that the total geothermal resource **(P_{25})** for the Hazad Member is **1186.843 MW in** the study area.

Conclusion of the study

- Average porosity and horizontal permeability maps of all the three units show favorable aquifer conditions in the central part of the Gandhar- Pakhajan area.
- Desired Geothermal window (>130^{0}C) is observed with an increasing trend from top to bottom units of Hazad Member in the study area.
- The E-W section with isotherm passing through Gandhar-Pakhajan low clearly depicts that the area having more than 130^{0}C temperature is falling below ~3150m.
- Maximum temperatures of 145^{0}C, 147.2^{0}C and 149.8^{0}C are observed within the top, middle and bottom units of Hazad Member respectively with an area of 453 sq.km., 689 sq.km. and 917 sq.km. respectively.
- Based on analysis of all the geothermal elements, a favorable geothermal system is envisaged in the study area, which is mainly confined to the central part of Gandhar-Pakhajan area apart from the Nada area. These are the suitable areas for harnessing geothermal energy.
- Geothermal resource base (P_{25}) is estimated to be 1186.843MW for the Hazad Member of Ankleshwar Formation in the study area.

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