

Hydrocarbon exploration in unconventional reservoirs through synergistic approach: A case study in North Cambay Basin

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Summary: Cambay basin is one of the most explored sedimentary Basins in India. The hydrocarbon exploration in Cambay Basin has gradually become more challenging as the easy-to-find oil have been mostly explored and exploited especially from Mid Eocene Kalol and Hazad plays. Hence, present exploration focus of Cambay Basin requires a paradigm shift in finding new plays in old field and also to explore unconventional and deeper plays in Cambay Shale and Olpad formation. Exploration and exploitation of hydrocarbons from thin, discrete silt laminae within transgressive argillaceous Cambay Shale provides immense exploration challenges owing to the difficulties in identification of dispersal patterns and its fine and sparse occurrence within Cambay Shale. Present study attempts to bring out a model for distribution of thin silt laminae within Cambay Shale integrating available G&G data.

Introduction: Cambay basin is one of the major onland producing basins of India where presence of hydrocarbon has been established through exploratory drilling during late 1950s and early part of 1960s. Geologically, Cambay Basin is an elongated NW-SE trending intra-cratonic aborted rift basin. The present day structure of Cambay rift basin is a result of multiphase tectonic evolution involving several extensional and compressive episodes which affected the western margin of Indian plate during Tertiary period. Regionally, the basin has been subdivided into five tectonic blocks, separated by prominent cross trends (Fig:1).

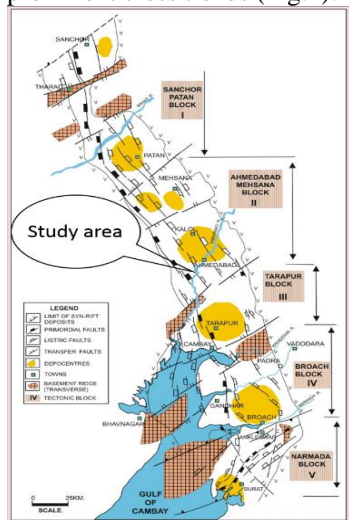


Fig:1: Tectonic Map of Cambay Basin (after ONGC)

During its course of evolution, Cambay Basin has experienced multiphase tectonic evolution with several extensional and late stage compressive deformation manifested in the sedimentary records. The structural evolution of the Cambay basin can be categorized into Syn- rift, Post- rift and late Post- rift phases (Madan Mohan, 1995). During Syn-rift phase, the basin architecture was characterized by several horsts and grabens. As a result, Syn rift sedimentary column shows variable thickness across the basin caused by differential subsidence along extensional normal faults. Towards the end of Post rift stage, the depositional surface got mostly peneplained as exhibited by almost uniform thickness of Post Miocene sediments. Inversion structures were formed during later part of Basin evolution due to compressional tectonic activity (Kundu et. al.1993).

Prior to deposition of Tertiary sediments, Cambay Basin experienced extensive outpour of Deccan basalts (Deccan Trap) during Late Cretaceous to Early Paleocene covering large tracts of western and central India. The Deccan Trap overlies the Pre-Cambrian Basement/ Mesozoic sediments (?) and is overlain by Olpad Formation with an erosional unconformity. During Paleocene, the basin continued to remain as a shallow depression, receiving deposition of fanglomerate, trap conglomerate, trapwacke and claystone facies, under a fluvial regime. During Early Eocene, a conspicuous and widespread transgression resulted in the deposition of a thick, dark grey, organic rich and pyritic shale sequence, known as the Cambay Shale. This shale sequence has been divided into Older and Younger Cambay Shale based on litho-assemblage, floral/faunal characters and stratigraphic position. Younger Cambay Shale sequence is occasionally having carbonaceous layers and underlies deltaic Kalol Formation in Ahmedabad block of North Cambay Basin. Capturing the spatial as well as vertical distribution of fine silt laminae within Cambay Shale sequence is a challenge for exploration in Cambay Basin.

In the present study area covering Nawagam field, persistent exploratory efforts by ONGC has established commercial hydrocarbon from Mid Eocene Kalol play and Paleocene Olpad play. Exploration and exploitation of hydrocarbon from fine silty layers within Cambay Shale was not under focus of exploration during initial exploratory phases in Nawagam field. However, commercial production has been obtained from silty reservoirs within Cambay Shale in Nawagam field on

activation and stimulation after hydro-fracturing in some of the drilled wells including NG-A, B, C etc.

Brief Geology of the study area: The present study area covering Nawagam field is located in Ahmedabad block of North Cambay Basin. Geological set up of the area suggests two prominent intra basinal highs, NW–SE trending Miroli–Nawagam High and NE-SW trending Nandej– Wasna High. Both the highs merge leading to EW trending Nawagam-Wasna Ridge which separates Jetalpur Low to the north from Tarapur Depression to the south (Fig.2).

Strati-structural entrapment for faulted rising flanks of Jetalpur Low and stratigraphic accumulation within low are prospective locales for quest of YTF hydrocarbon (Chatterjee et.al. 2013). The area has undergone polyphase tectonic evolution and signature of tectonic inversion has been found in sedimentary successions.

Objective: Present study is an attempt to identify reservoir distribution within argillaceous Cambay Shale sediments through re-evaluation of log data and seismic attribute analysis.

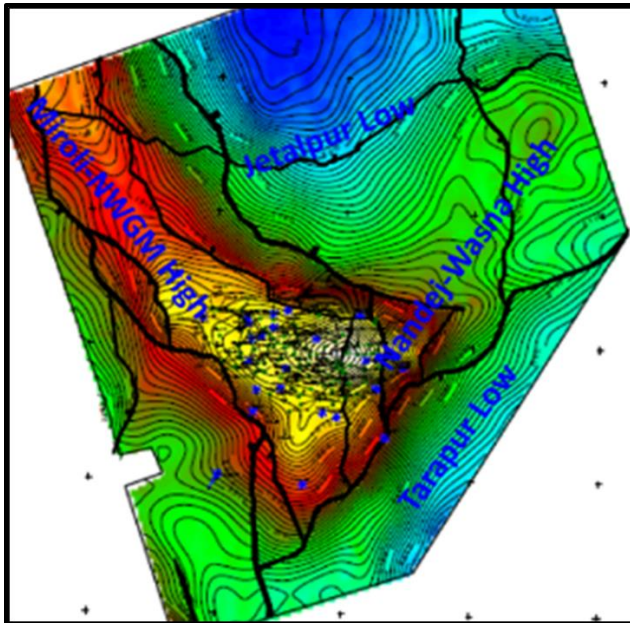


Fig.2: Structural elements of study area

Tectono-Stratigraphy: The Cenozoic sedimentary succession of the Cambay Basin has been deposited over

the Deccan basalts (Deccan Trap) of Late Cretaceous to Early Paleocene age. The Deccan Trap overlies the Pre-Cambrian Basement/ Mesozoic sediments. During the syn-rift phase, the Basin was characterized by several highs and lows owing to faulting along major fracture planes. The Tertiary sedimentation initiated with the deposition of Olpad Formation under a predominantly fluvio-swampy setting and comprising basaltic trapwash, claystone and siltstone litho-facies. Olpad Formation is overlain by Early Eocene Older Cambay Shale (OCS) which is a result of widespread transgression across the basin. This OCS sequence has been overlain by Younger Cambay Shale (YCS). During Post-Rift phase, regression of sea took place with onset of progradation of deltaic sequences resulting in deposition of fluvio-deltaic sediments of Middle Eocene Kalol Formation in North Cambay Basin. Subsequently, Basin experienced another episode of major transgression during Late Eocene-Early Oligocene which was responsible for the deposition of the Tarapur Shale over large area. Neogene sediments were deposited in dominantly fluvial setting and huge thickness of Babguru, Kand and Jhagadia formations were deposited due to continued subsidence. During late phase of Basin evolution, structural inversions took place as compressional tectonic regime was prevalent.

Established Hydrocarbon Plays: In the study area of Nawagam field, hydrocarbon is established in multilayered reservoirs within Mid Eocene Kalol Formation and in Paleocene Olpad Formation consists of number of pay zones. Besides, silty layers within Cambay Shale has also emerged as potential pay in terms of hydrocarbon exploration in the study area.

Methodology: Present study attempts to bring out a model for hydrocarbon accumulation in fine silt layers within Cambay Shale in the Nawagam field. A focused and synergistic approach has been undertaken to delineate the distribution of reservoirs within argillaceous Cambay Shale Formation. As a first step, two prominent Shale marker beds namely CBS Marker-1 and CBS Marker-2 have been identified on logs within Younger Cambay Shale of drilled wells within Cambay Shale section which is also well correlatable on 3D seismic data (Fig.3). Based on intervening prominent shale markers, the Cambay Shale section in drilled wells of study area has been differentiated into three packs CS unit-3, 2 and 1 in stratigraphically younging order (Fig.4).

Structural framework of three units within Cambay Shale has been analysed with the help of Time structure maps prepared at CBS Marker-I and CBS marker-II horizon tops. Presently, around 9 wells are on production from reservoirs within Cambay Shale mostly on artificial lift after hydro-fracturing. The log data of producing wells have been integrated with the newly reprocessed 3D seismic volume and hydrocarbon prospectivity of Cambay Shale sequence in the Nawagam field have been re-evaluated. Log data has been processed using multi-mineral approach in ELAN Software using Quartz,

Heavy Minerals & Clay (Illite + Kaolinite). The mineral model has been identified on the basis of core analysis and cross-plots. Water Saturation has been commuted using Indonesian Equation. Standard Petrophysical Parameters ($a=0.62$, $m=2.15$ & $n=2$) have been used in the absence of petrophysical study on cores in Cambay Shale. Log reprocessing of wells under production (Fig.5) and re-evaluation of logs of other drilled wells in the area suggests promising intervals in number of drilled wells (Fig.6) which may further open up exploration area for Cambay Shale in the field.

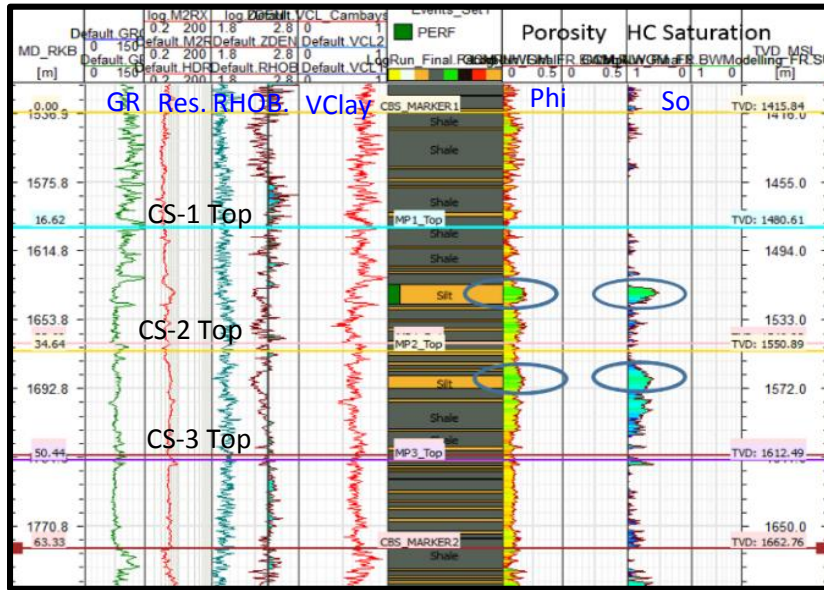


Fig:5: Log motif of well A showing tested HC bearing intervals within Cambay Shale

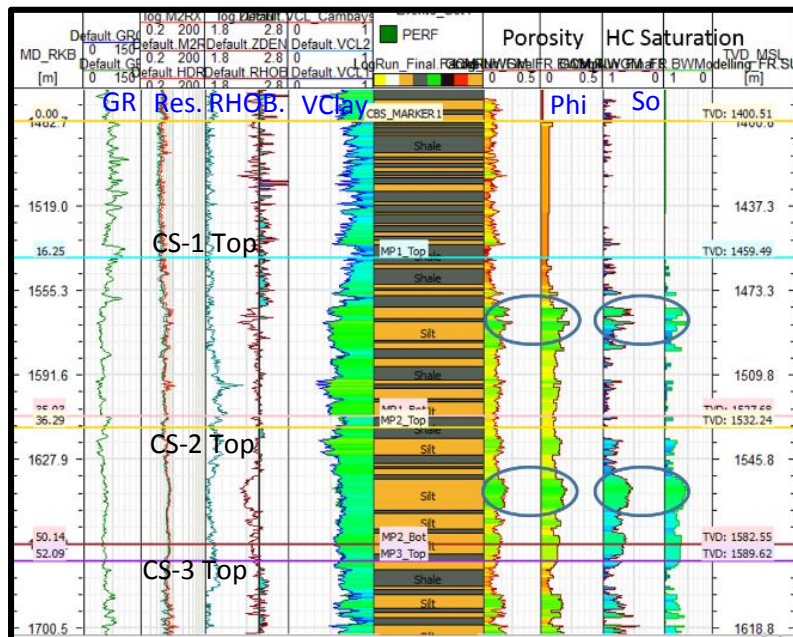


Fig: 6: Log motif of well N showing envisaged HC bearing intervals within Cambay Shale

Although the fine silt reservoirs within Cambay Shale are often beyond seismic resolution, an attempt has been made to demonstrate spatial distribution of discrete silt layers with the help of seismic attribute. Spectral Decomposition attributes have yielded a reasonably close validation with that of drilled well data. RMS amplitude were extracted from frequency sub volumes at CBS Marker-I & II horizon levels. After detailed analysis, 30hz frequency sub volume was found to be validating most of the drilled wells in Cambay Shale. Drilled well data and seismic interpretations were used as inputs and a fine scale Geo cellular Model of 50*50*1 dimension was prepared to capture the reservoir distribution within Cambay Shale. After preparation of structure model including horizon and fault models, facies model was prepared which was guided by spectral decomposition attribute and regional understanding of provenance for sand input. The facies distribution model output was used as input to property modelling. The petrophysical property distribution maps thus generated show reservoir distribution of fine silt layers within Cambay Shale.

Discussion: The hydrocarbon entrapment in thin, discontinuous silty layers within Cambay Shale are mainly stratigraphic in nature and governed by distribution of the reservoir facies within Cambay Shale. The dip of maximum similarity attribute and Time structure maps clearly reveal presence of two major set of fault trends longitudinal NNW-SSE and transverse E-W at Cambay Shale marker top (Fig.7a & 7b). The propagation of porosity and HC saturation as brought out by property maps (Fig.8) delineate possible better reservoir facies distribution which is corroborated with the regional sand model with possible sand entry from N-NW during episodes of regressive pulses. The drilled well data penetrating Cambay shale section in the field also validate the model to a large extent.

With the inferred entrapment model for the hydrocarbon accumulation within Cambay Shale in Nawagam field, a new area for exploration of Cambay Shale has been emerged and provided impetus to search of YTF hydrocarbon in Cambay Basin by bringing a new play to contribute in oil and gas production.

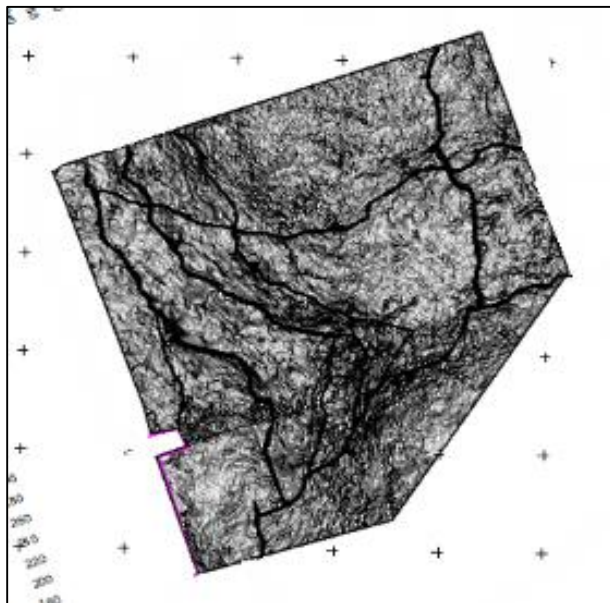


Fig:7a: Dip of max similarity attribute close to Cambay Shale Marker-I

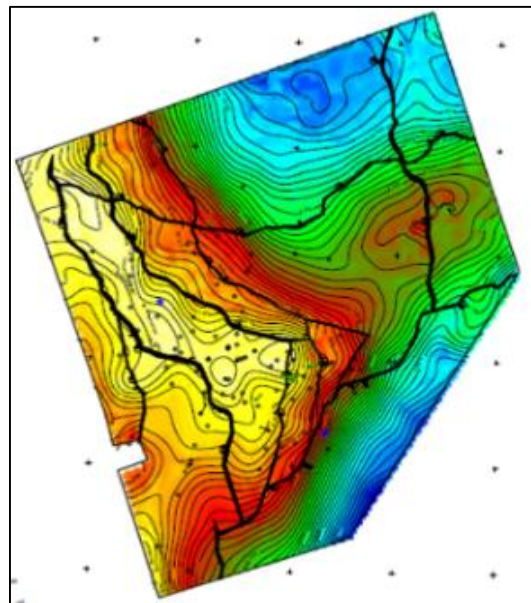


Fig:7b: Time structure map close to Cambay Shale Marker-I

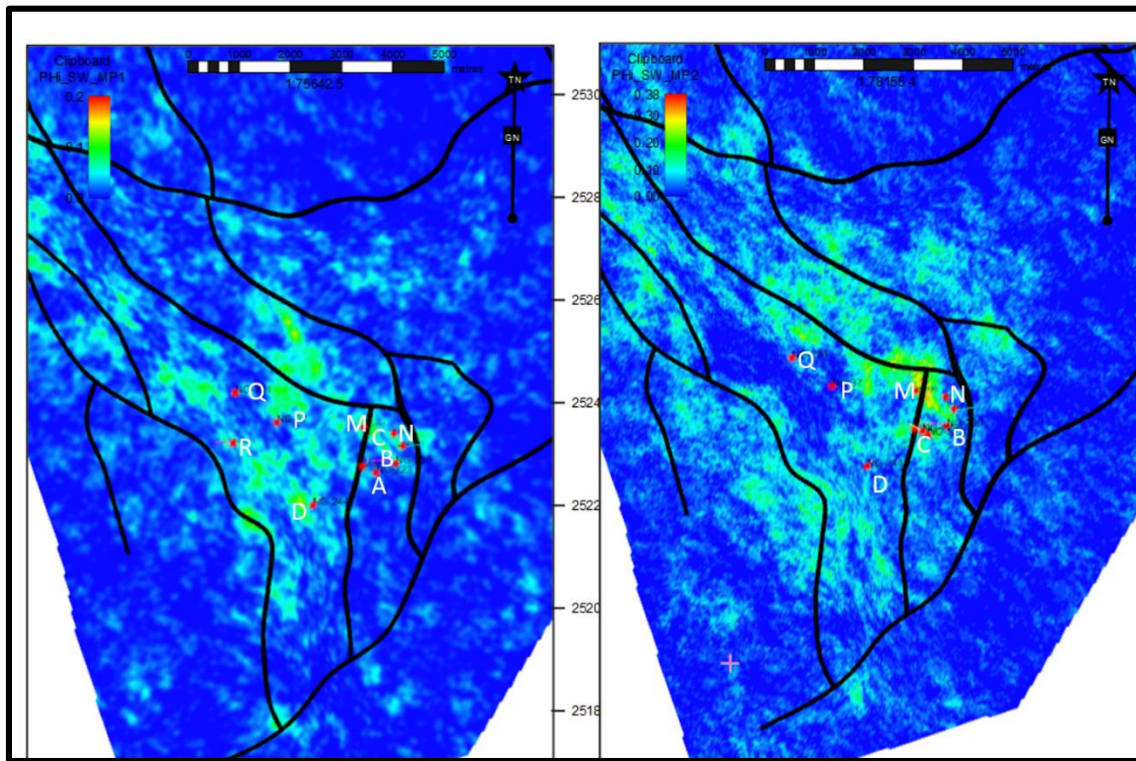


Fig:8: Petrophysical Property distribution map (Phi-So) after Geo-Cellular Modelling at CS Unit-I and CS Unit-II

Conclusion:

The dispersal of fine scale silty reservoirs within Cambay Shale has been brought out integrating seismic and well data in Nawagam Field of Cambay Basin.

The reservoir property distribution maps prepared in the study suggest locales for development of better reservoir areas within Cambay Shale in the Nawagam field.

More intense and focused exploration for Cambay Shale will generate more data points and in turn would further help in fine tuning the entrapment model.

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Views discussed in the paper are personal opinions and understandings of the authors and not necessarily be of ONGC's view.

Selected References:

- Kundu, J.K., Wani, MR., Badhe,S., Banga, R., Thakur, R.K., Sarala, I., DuttDev and Dutta, N.G., 1993.** Integrated Geological studies and hydrocarbon prospect evaluation in Cambay Basin. ONGC Unpublished Report.
- Madan Mohan, 1995.** Cambay Basin-a promise of Oil and Gas potential. Journal of The Palaeontological Society of India. V.40, p.41-47.
- Chatterjee C. L. et. al., 10th SPG Conference, 2013,**p 178. Sediment Architecture of Half Graben Play and Its Hydrocarbon Implication in and around Jetalpur Low, North Cambay Basin, India.