Deep Gas Exploration In Cambay Basin, India – A Case Study

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Summary

Exploration for natural gas in deep sedimentary Basins has acquired importance worldwide with the decreasing rate of success in discovery of shallow conventional reservoirs. The present study aims to assess the feasibility of exploration for deep gas in major depocenters of Cambay Basin. Deep Gas or Basin centred gas is defined as an abnormally-pressured, gas-saturated accumulation in low-permeability reservoirs lacking a down-dip water contact.

Four major depocentres namely Patan and Warosan Depressions in Mehsana Block, Wamaj depression in Ahmedabad Block and Tankari Depression in the Broach Block were identified for detail study on the potentiality of Deep gas occurrence. The depressions were identified as these had good amount of Synrift fill deposits which have poor reservoir properties i.e generally they do not have good porosity and permeability. Moreover, as per the available source rock data these depocenters have fair to good source rock potential in Synrift sequence.

Out of the four depocenters studied, Wamaj Low seems to be having very good potential for deep gas exploration. The gas and dry gas window are estimated at 3450m and 4050m respectively. Presence of gas (C1) during drilling of Olpad section in one well in Kalol Field can be considered as positive evidence in support of generation of gas in the deeper part of the low and is discussed as Case Study here.

Introduction

Exploration for deep-gas in deep sedimentary basins has acquired importance worldwide as a frontier energy source. Deep-gas or Basin centred gas accumulations (BCGA) is defined as an abnormally-pressured, gas-saturated accumulation in low-permeability reservoirs lacking a down-dip water contact. Although ‘tight gas sands’ are an important type of basin-centered gas reservoir, not all of them are basin centred gas accumulations (Law, 2002). Tight gas reservoir lacks a formal definition, and usage of the term varies considerably. Law and Curtis (2002) defined low-permeability (tight) reservoirs as having permeabilities less than 0.1 millidarcies.

Deep Gas- Exploring an Unconventional Reservoir

The search for deep-gas exploration is considered to be an unconventional reservoir exploration. Conventional reservoirs have high- to medium permeabilities from which hydrocarbons can be produced at economic flow rates without any special recovery process. On the other hand, an unconventional reservoir (e.g., tight-gas sands) is one that cannot be produced at economic flow rates without massive stimulation treatments or special recovery processes and technologies.

Attributes common to BCGS

Basin Centred Gas Systems are of thermal origin and found to be regionally pervasive accumulations where reservoirs may be isolated or vertically stacked and abnormally-pressured. Gas accumulations are down-dip from normally-pressured, water-bearing reservoirs and do not have down-dip water contacts (Fig. 1). They are of low permeability (<1.0 md) and porosity <13%. There are two basic types of BCGSs viz. direct and indirect. A direct type is defined as having a gas-prone source rock while an indirect type is defined as having an oil-prone source rock.

The source for deep gas is Humic, type-III organic matter in coal beds and carbonaceous shale /hydrogen rich shale. The reservoirs are generally siliciclastics and the thickness ranges from single isolated reservoirs of few feet thick to vertically stacked reservoirs of several thousands feet. Seals are in form of lithologic, permeability or water blocks as capillary pressure seals. The gas is trapped in the deepest part of the basin, rather than on the flank of the basin. Gas water contact occurs at the updip end of the accumulation, rather than the downdip end. In this system gas is in a dynamic state of updip migration, rather than in static equilibrium as found in conventional traps. BCGA is indicated to be dynamic where gas losses at the updip water/gas contact and is in rough balance with downdip gas influx.

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from adjacent, active source rocks. Over pressured gas accumulations are the result of thermal generation of gas in low permeability rocks where gas accumulation rates are higher than rates of gas loss - dynamic stage. Gas prone source rocks and low permeability reservoirs should be in close proximity to each other.

The focus on deep-gas exploration is at its infancy in India, however it is being practised for more than thirty years in USA, Canada and erstwhile USSR. In USA major deep gas producing basins are the Permian, Gulf Coast, Anadarko and Rocky Mountain basins. At present, more than 25% of daily U.S. gas production is recovered from tight and unconventional reservoirs.

Deep Gas Potential in India

In all probability reservoirs for deep gas exploration can be found in any geological setting. Theoretically, basin centered/deep gas system do occur in axial part of the rift basin, the foredeep part of the foreland basin or the synclinal part of the orogenic belts. In India, a number of sedimentary basins viz., Cambay Basin, Assam - Arakan Basin, Krishna-Godavari Basin, Cauvery Basin and Mahanadi Basin appear to be prospective for basin centered gas exploration.

Deep Gas Potential in Cambay Basin

Cambay basin - a narrow, elongated, intra-cratonic rift basin of Late Cretaceous age, is situated in the western part of the Indian Shield in the state of Gujarat. The basin covers an area of about 56,000 sq.km. (Fig. 2). The Cambay rift basin contains different sub-basins with varying sediment fills. Some of the depressions like Patan, Warosan, Wamaj, Tarapur Bharuch and Tankari etc. are good locales where deep gas/basin centered gas can be expected. There is a good chance of striking deep gas in Cambay Basin based on the following observations -

- A thick pile of siliciclastic sediments are available in the basinal lows with moderate to good source potential.
- Type-III organic matter is expected to be present in syn-rift sediments in the basinal lows.
- High pressure and temperature has been encountered in deep wells.
- Water-bearing reservoir facies have encountered within synrift section in few deep wells which may act as updip water contact in the lows for entrapment of deep gas.
Stratigraphic outline

The generalized stratigraphy of Cambay Basin is given in Fig. 3. The target stratigraphic unit for deep gas exploration in Cambay Basin i.e., Olpad Formation constitutes the syn rift sediments for which Deccan basalts of Upper Cretaceous to Lower Paleocene age form the technical basement. The synrift sediments consists of Trap conglomerate, Trap-wash, claystones and siltstones deposited in continental to lacustrine setting. Post rift Cambay Shale Formation of Early-Middle Eocene overlie the Olpads.

Methodology

The present study is based on integration of seismic, well and geochemical data. Initially data of 26 major depocenters of Cambay Basin (Kundu et.al, 1992) were scanned as reconnaissance phase to identify depocenters favorable for deep gas. Consequently four depocentres viz., Patan and Warosan in Mehsana Block, Wamaj in Ahmedabad Block and Tankari in the Broach Block were identified for detail study (Fig.4). These lows have thick Synrift deposits and at deeper levels have sediments with poor porosity and permeability. Moreover the source rock data indicates that these depocenters have fair to good source rock potential in Synrift sequence.

The initial approach adopted was to undertake the structural analysis of synrift sequence in individual fault blocks within each depression. Having established the structural framework, stratigraphic analysis of the lateral variation in depositional geometries, stacking patterns and lateral facies variation of the rift fill was undertaken. This was followed by sequence analysis through well-logs coupled with the biostratigraphic details. These were then calibrated with multi channel 2D seismic data and extent of sequences demarcated. Based on the maps generated at Olpad and trap level few hypothetical deep well locations
were identified for geochemical modeling to ascertain the maturity and possibility of deep gas occurrence. Finally, on integration of all the information obtained from various maps generated and geochemical data, the hydrocarbon potential of the area for deep gas exploration has been analysed to demarcate areas of interest.

The initial approach adopted was to undertake the structural analysis of synrift sequence in individual fault blocks within each depression. Having established the structural framework stratigraphic analysis of the lateral variation in depositional geometries, stacking patterns and facies of the rift fill was undertaken to assess the tectonic significance of these stratigraphic packages. This was followed by Well-log sequence analysis coupled with the biostratigraphic studies and finally integrated to define the various sequences i.e Trap, Olpad and Cambay Shale for detailed correlation. These were then calibrated with seismic data of the respective depocenters and seismic correlation was carried out.

Since the synrift fill Olpad Formation is the target sequence for deep gas exploration the mapping was mainly concentrated to Trap and Olpad Formation. Based on the maps generated few hypothetical deep well locations were identified for further Geochemical modeling to ascertain the maturity and possibility of deep gas occurrence.

Finally, on integration of all the information obtained from various maps generated and geochemical data, the hydrocarbon potential of the area for deep gas exploration has been analysed to demarcate areas of interest.

Interpretation and Discussions

During Early Rift phase, extension is created by numerous small faults, generating accommodation space in the depocenters which are quickly in-filled by sediments. In this period, the half grabens formed distinct sub-basins and were isolated from each other by basement highs, as evidenced by sediments lapping onto and thinning over these highs. Though these half grabens were not connected during the initial stage of rifting, but they were filled with similar patterns of sedimentation. The Early Syn-rift sequence therefore, displays variable facies and is highly asymmetrical.

At the early part of rifting the steep gradients of horst blocks of Deccan Traps became vulnerable to weathering and erosion. Trap derived poorly sorted materials were transported as slides and slumps, along the steep flanks of the horst blocks and subsequently accumulated at the suitable depocenters mainly as trap wash.

It is inferred that out of the four lows studied, Wamaj Low is probably the best low suited for deep gas exploration and the findings of the study as case study is discussed below.

Wamaj Low

Wamaj Low is situated in the Ahmedabad Block of Cambay Basin. This low is flanked on the east by Kalol high, on the west by Jhalora high and to the southwest by Sanand high. There is no well drilled down to trap in this low, however few wells have been drilled either on the flanks of the low. The deepest well, Well-A was drilled on the eastern rising flank of Wamaj Low down to a depth of 4507m and terminated within Olpad Formation. Few recently drilled wells though drilled in the axial part of the low are also terminated within Cambay Shale.

To understand stratigraphic variations three regional electrolog correlation profiles were generated through Sanand, Jhalora, Kalol and Ognaj Fields. One such east-west profile is given in Fig.5

![Fig. 5: Electrolog Profile along wells D,A,B and c in the study area.](image)
The Well-A has given important lead for deep gas potential in Wamaj Low. This well was terminated within Olpad Formation at a depth of 4507m and the Olpad section in this well is 1857m thick. To the west of the low the drilled thickness of Olpad is much less and is of the order of approximately 800-1000m as is evident from wells drilled in Jhalora and Sanand Fields which have been drilled on the highs. High pressure gas zone in the upper Olpad section was encountered followed by a comparatively lower pressure regime below it. Also, a water bearing sand is present much below the high pressure zone followed by a number of gas shows encountered while drilling. The occurrence of C1 increases with depth which is suggestive of occurrence of dry gas in and around the well bore area and also indicates gas accumulation at deeper part of the low which could have escaped towards the flank. This is a favorable situation for deep gas where a high pressure seal and an updip water contact are observed.

As per Quantitative Genetic Modelling of Cambay basin (Ray et.al., 2001), Olpad Formation in Wamaj Low has generated around 2900 BCM of gas, which is maximum amount of gas generated in any of the lows in Cambay Basin for Olpad Formation.

Time contour map at the top of Trap (Fig.6) indicates presence of two distinct lows in the area. The first low lies in the northern part with a depth of 5700m (5050ms).

The low is flanked by two marginal normal faults. The western flank is steeper than the eastern flank. The second low is seen in the southern part at a depth of 5260m (4600ms). At the top of Olpad level (Fig.7) also, the deepest portion of the low is continued at the northern part at 2975m (2600ms). The top of Olpad is gradually shallowing towards south. It suggests that sedimentation in the low continued with the reactivation of the faults creating a good thickness in Olpad section. The E-W axis of the Low at Trap level has been shifted to NW-SE at the Olpad level. The maximum thickness of Olpad formation (more than 2750m) is observed in the northern part (Fig. 8). The low seen at the Trap level is formed due to rifting whereas the low at the Olpad level is formed by erosion and synsedimentation. This may be due to the development of N-S fluvial system at the time of late rift. This fluvial system has developed a number of alluvial fan bodies which may be of good locales for conventional hydrocarbon accumulation.

On the basis of these maps two hypothetical wells were planned for geochemical modeling for deep gas
expansion. The first hypothetical well SWN is placed in the northern low on seismic line X (Fig. 9) and the second well SWS is placed in the southern part of the low down dip of Well-A on seismic line Y (Fig. 10). The amount of generated hydrocarbon in wells SWN and SWS is estimated at 6.44MMt/sqkm and 4.94MMt/sqkm from Olpad source rocks. Kerogen transformation in Olpad source rock ranges between 81-88%. Expelled hydrocarbon in wells SWN and SWS estimated from Olpad source rock is 6.03MMt/sqkm & 4.48MMt/sqkm respectively. In hypothetical wells SWN and SWS, oil window, gas widow, and dry gas window are estimated at 2000m, 3450m and 4050m respectively.

**Conclusions**

- Tight gas reservoirs in deep basinal lows have a huge future potential for gas exploration.

- While drilling through Olpad section in Well-A, number of gas shows with increase in C1 with depth is suggestive of occurrence of dry gas in and around the well bore area. This indicates that there may gas accumulation at deeper part of the low. Besides this a
high pressure gas zone and a water bearing sand was also observed in upper part of the Olpad.

- Pre requisites that define basin-centered gas accumulations viz., low permeability, abnormal pressure, gas saturated reservoirs and no down dip water leg are found best favorable in the Wamaj low.

- The Geochemical modeling suggests the top of dry and wet gas window in the Wamaj low are at a depth of 4050m and 3450m respectively.

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