Hydrocarbon Prospectivity in the Stratigraphic Traps within Cambay Shale, Broach Sub Block, Cambay Basin, India.

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ABSTRACT: Broach sub block lies in between Mahisagar and Narmada river of South Cambay basin,Gujarat India. Gandhar and Jambusar are the two prolific oil and gas producing fields in this block. Most of the discovered oil was found in Hazad sands of Ankleshwar formation of Middle to Upper Eocene age. But some oil was also produced from the sands within Cambay Shale formation of Paleocene to Lower Eocene age. An attempt has been made to predict the hydrocarbon distribution and prospectivity of these sands. An analogy was inferred from producing Linch sands of equivalent age of North Cambay basin.

INTRODUCTION : Cambay basin in the Western Indian state of Gujarat is a fairly well explored productive basin (Fig.1). The Broach sub block lies in the southern part of the basin. It is bounded on the north by the Mahisagar river and in the south by Narmada river. It is bounded by basin marginal faults in the east and west. Most of the discovered oil in this block is in Hazad sands of Ankleshwar formation. But some oil is also produced from deeper pays in Cambay shale and Olpad formation of Paleocene to early Eocene age. In this paper an attempt has been made to predict the distribution pattern and hydrocarbon prospectivity of the sands within Cambay shale of Paleocene to lower Eocene age (Fig.2).In a basin with geological history of deltaic

sedimentation, entrapment conditions formed in time and space witnesses varying degree of structural and stratigraphic control over hydrocarbon accumulations. Search for deeper pays within Cambay shale is envisaged for hydrocarbon accumulation.

The Cambay shale was deposited during Paleocene to lower Eocene age. (Fig.3). Five to twelve layers of dirty, partly lithic sands are present in the Cambay shale and have been considered as potential exploration target for hydrocarbon accumulation. The Cambay shale is having maximum thickness of approximately 2800m in N-S oriented Tankari depression, the depression is 8 km wide and is the main kitchen for hydrocarbon generation (TOC 3-14% and S2 3-9). The Cambay shale formation progressively pinch out on both sides of the depression. On the eastern margin it pinches out and shows a progressive onlap. On the western margin which corresponds to present day Gulf of Cambay, Hazad formation transgresses the Olpad Formation of Paleocene age. So far no detailed work has been carried out to know the depositional pattern of these sands. So a methodology was adopted to critically examine the well and seismic data, thickness variation of Cambay shale and the sand provenance.

Based on the studies carried out, it is envisaged that Cambay shale was deposited during major marine transgression and the sand deposited within it, under short regressive cycles. These sands are argillaceous and developed as an isolated lobe at specific locales (Fig.4). The seismic events correspond to this unit shows high amplitude reflections (Fig.5). This unit is drilled in well #A of Nada area in which number of hydrocarbon shows were observed. The main depositional lobe is present in the western edge of the block, close to

the present day shoreline. In the Malpur, Barkhodra, Nada area (Fig.1), well # B was drilled up to Trap while wells #A and #C (Fig.2) were terminated in the deeper part of Cambay shale. Out of these well C has produced oil & gas whereas well# A had shown oil and gas indications.

The potential target are high amplitude events which corresponds to sand and shale alternations. These sands occurs as pinchout in northwestern and southeastern flank of Tankari low. The paleoriver system in the northeastern part of the area played an important role in bringing the sediments along pre existing paleozoic or older faults. The number of prolific sands present in the Cambay shale are well within the oil window with insitu entrapment conditions and can be targeted for hydrocarbon exploration.

GEOLOGICAL CHARACTERIZATION: Five to twelve layers of dirty, partly lithic sands are included in the Cambay shale of Broach block. These deeper sands have been considered as a potential targets for petroleum explorations. An extremely thick accumulation of Cambay shale is observed in N-S oriented Tankari depression (Bordeneva,1997). On the eastern margin, the lower part of the Cambay shale formation pinches out first, showing progadational onlap towards east. In the southeastern part of the study area, the Hazad formation unconformably overlies the Olpad, while only 20m to 240m of the upper part of the Cambay Shale devoid any sand development were found in Dabka in the northeastern part .

On the western margin, which corresponds to the present day Gulf of Cambay, the Hazad formation transgresses the Olpad, while 35m to 100 m of Cambay shale is present in eastern part of Gulf of Cambay.

This formation is mostly conformable to gradational and had intertounging relationship with underlying Olpad Formation. It has unconformable relationship with overlying Kalol Formation in the north part of the basin and Ankleshwar Formation in the south.

Cambay shale is assigned Paleocene to Lower Eocene in age (Govindan,1987). It is subdivided in the older Cambay shale and Younger Cambay shale. On the northeastern and western side of the Tankari depression, the Cambay shale below Hazad base include the following succession from top to bottom:

1) A monotonous fissile shaly interval occasionally carbonaceous, 100 to 200m thick deposited in low energy conditions.
2) A thickening upward silty interval often associated with few meters thick coal seam. This interval is widely correlatable in Jambusar-Broach block.
3) Another monotonous shale interval, often carbonaceous, thickening from 50 to 150m in Nada Malpur area, to 700 – 800m in Gandhar and Jambusar wells.
4) Deeper, the shales includes 9 to 12 layers of lithic dirty sands, 2 to 10m thick.

STRATIGRAPHIC CONTROL: The sands within Cambay shale occurs as isolated remnants encased laterally, underlying and overlying sediments within older Cambay shale. The distribution varies from intercalations of sands and shale to scattered sand bodies. The sands are deposited in lagoonal to paludal environment. The Ankelshwar – Aliabet ridge (Fig.1)

might have acted as a subaqueous barrier separating a shallow lagoon in the north from the open shallow sea in the south. These sands were transported from short distance and dumped into adjacent marshy lands.

REVIEW OF EXPLORATORY DATA : Extensive analysis of well data revealed broadly four distintictive sequences. In Nada area, the sands found deeper than 3600m are argillaceous. On the other hand three layer within older Cambay shale are relatively clean and two sands which were tested, flowed oil and gas (Fig.5). In South Malpur area well C drilled up to 3107m but did not reach Olpad formation. The lowermost sands were argillaceous and poorly sorted. These were tested but had not shown any flow. The sands present within older Cambay shale are clean, when tested they flowed oil & gas. This is the only sand which gave oil production @10 m3/d. In Bharkhodra area sand present within the interval 3050– 3054m had given little oil & gas (Fig.4).

South of the study area in Gandhar, the two sands tested at 3900 m & 3600m within Cambay Shale flowed little gas. The log evaluation of these sands shows 12m of net sand thickness, porosity ranges from 15-20 % and water saturation of hydrocarbon pay sands ranges from 60-70%.

DEPOSITIONAL ENVIRONMENT : Cambay shale in Broach – Jambusar area deposited in Paleocene to Middle Eocene age in axial part while in flanks it may be of Early Eocene age (Prakash,1999). Cambay shale in general was deposited in marginal marine conditions and occasionally shallow inner netritic conditions which prevailed during Early Eocene. In Jambusar –

Gandhar area the Cambay shale probably deposited as lagoonal facies during Paleocene. The shales were deposited during major marine transgression and the sands corresponds to short sequential oxic episodes (Sharma, 1989).

SEISMIC FACIES ANALYSIS: The seismic events corresponding to this pack exhibits clinoforms, chaotic, wavy nature, downlaps, onlaps on underlying formation, the continuous and discontinuous events suggest that this pack may comprises of sand and shale alternations, deposited as low fill sediments as a separate system, ideally suited for hydrocarbon accumulations (Fig.6,7). The high amplitude pack is sandwiched between two source rocks namely Olpad and the overlying Cambay shale (Fig.8).

EVOLUTION AND SEDIMENTATION HISTORY: Broach bock is a deep syncline containing more than 6000m of Cenozoic sediments (including more than 3,500m of Neogene). This is the maximum known thickness of sediments in the basin. The syncline is an asymmetrical sag with sedimentary thickness decreases rapidly to the south towards the ENE- WSW aligned Narmada fault and rather gently in all other directions.

The Cambay shale is deposited during synrift to rift fill stage. This phase corresponds to the formation of system of NNW-SSE horsts, grabens and semigrabens with examples of block tilting (Biswas 1982). The intensity of the synrift tectonics diminishes progressively and became mild during Cambay shale deposition, with however minor phase which provoked a small angular unconformity at the limit between Older/Younger Cambay shale. From the middle Eocene to the end of early Miocene, the Broach block remain quiescent with no more fault activity or block tilting, but only differential

subsidence which provoked the formation of large size depressions (Dhar,et al 1987). The structure map at Y marker top(which is very good seimic and log marker in younger Cambay shale) indicates a broad NE-SW oriented Tankari low and fault hading towards south in the northern part of the area. To the south the depression is limited by basin margin which corresponds to Narmada block , to the west by Bharkhodra and Malpur highand to the east by Jambusar terrace (Fig.10). From the isopach map of Cambay shale(Fig.11) it is observed that there are two major depocenters, i.e. one in the south and another in the north which is known as Tankari depression. Apart from these small depocenters observed around Gandhar and Jambusar area. The paleotectonic cross sections across Broach area shows the shifting of depocenters during the deposition at different time (Fig.12). The shifting of depocentres is oscillatory in nature and is confined to east-west direction. Hence it confirms the lateral migration of hydrocarbons to the paleo highs and the rising flanks on the eatern and western part of Tankari low (Panda,et al 1994).

EXPLORATION MODEL : Exploration for stratigraphic reservoirs within Cambay shale is an predictive effort based on assimilation and interpretation of all the prevailing subsurface informations. As such, Cambay shale deposited in lagoonal to shallow marine environment, the sands within this formation corresponds to short regressive episodes. They were transported over short distance and dumped into adjacent swampy and marshy areas. The sediments were brought by a system of rivers to the swampy depression, debris resulting both from local erosion and from the erosion of the Aravali mountains, located to the northeastern part of the area(Prasad,1996). The

river system was probably related to pre-existing Paleozoic or older faults (Fig.9) which still governed today the course of rivers such as Mahisagar, Dadhar and Narmada. As no sands are found in northeastern part of the study area, it is therefore inferred that sands were coming mostly from Paleo-Dadhar river , but also from a paleo – Narmada, as sands are included in the Cambay Shale (LS-1 and LS-2) of the Ankelshwar fields, where they produce little oil. After meandering on the Jambusar terrace and in the Tankari depression, river reached the Nada-South Malpur-Barkhodra area where wave action would have enhanced the sorting and cleanliness of the sands (delta front and long shore bars) (Mayor et al, 2004).

HYDROCARBON GENERATION POTENTIAL: The Cambay shale is the main source rock, it is found to be thermally well matured and falls within the oil window. In most part of the study area the TOC ranges from 2.25 to 2.0%,average HI from 150 to 100mgHc/gm TOC and the total hydrocarbon generated and expelled ranges from 0.73 to 1.40 and 0.11 to 0.5MMt/sq km (A.Banerjee,et al 2002). Examination of source rock data indicate that the oil maturation is concentrated in the central part of the block. It also suggest that the direction of hydrocarbon migration is likely from the centre to the flanks of the Tankari depression (Fig.13).

MIGRATION OF HYDROCARBONS : The accumulation of oil and gas in these structures are mainly due to the primary migration of hydrocarbons from the source beds into the adjacent reservoir rocks. After the deposition of sufficient thickness of overburden, the hydrocarbons has migrated into the immediately overlying or adjacent porous beds, and then accumulated in the

structurally highest part. It seems that the great volume of source rock present in this basin would have a vast hydrocarbon generation potential, it appears that amount of hydrocarbon so generated had filled the reservoir rocks in the presently known oil bearing structures many times over and again (Fig.9). It is likely that they must have migrated updip to the margins of the basin. It is envisaged that some of this oil at least may have trapped in the zones of pinch out and wedge out of deeper sands (Saraf,1998).

Seismic Attributes Studies

The attributes studies were carried out within younger and older Cambay shale to understand the depositional trends viz,. The RMS and near to Younger Cambay shale and Older Cambay shale OCS top indicates high amplitude distribution in northern part of Tankari PEL, extreme northeastern part of the study area and in the western flank of Tankari low These high amplitude and low frequency distribution may be attributed to the presence of reservoir facies. The sand input is from the northwest in the western part and from northeast from the eastern part of the study area.((Fig.14 -15). It is envisage probable presence of sand in the western and eastern rising flank of the Tankari low and they may be explore for hydrocarbon accumulation.

CONCLUSION : The sands deposited within Cambay shale were developed at specific locales and as sand – shale intercalation. Five to twelve layers of dirty, partly lithic sands are deposited within Cambay shale and has been considered as potential hydrocarbon targets. These sands occurs as high amplitude events. The potential targets for sands within Cambay shale are the pinchout in northwestern and southeastern flank of Tankari depression. The

paleo-river system was probably related to pre-existing Paleogene or older faults which can be inferred as prominent provenance from the northeast.

An analogy has been inferred from producing Linch sands in north Cambay basin where there are hydrocarbon occurrences from west to east i.e. from Mehsana horst to Warosan depression. Similar depositional pattern occurs in Tankari depression which can be targeted as potential hydrocarbon accumulations.

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