

CAMBAY BASIN - A PROMISE OF OIL AND GAS POTENTIAL*

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INTRODUCTION

The Cambay Basin constitutes a typical marginal aulocogen (Biswas *et al.*, 1993) - a type of pericratonic basin - along the western continental passive margin of Indian Plate (fig.1). The basin experiences different stages of extensional tectonic episodes, essentially confined to Cenozoic era, and related stratigraphic evolution. The tectono-stratigraphic set up principally facilitates the maturation of Lower Eocene source facies and distribution of various play styles within prime clastic reservoir facies of middle Eocene age.

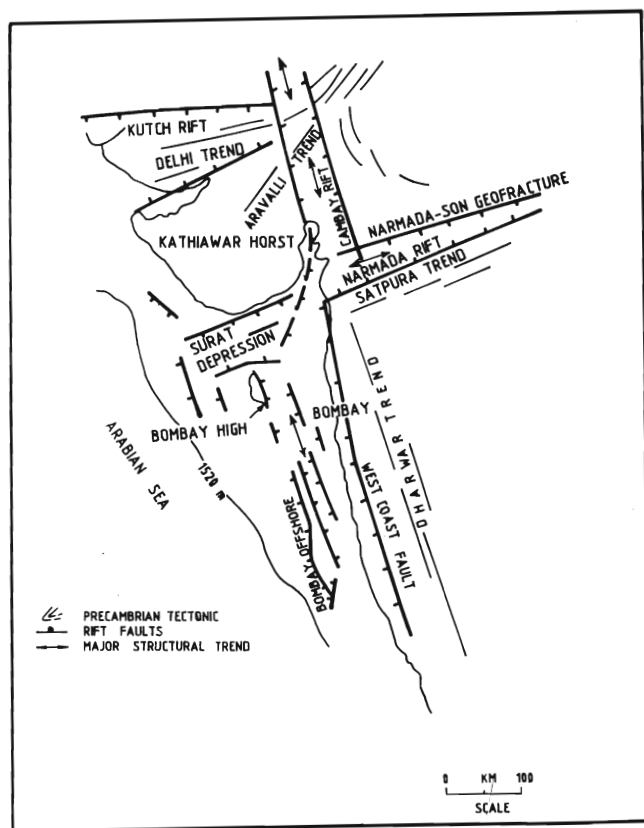


Fig. 1. Regional tectonic trends along western margin of India (Biswas, 1982).

EXPLORATION HISTORY

Hydrocarbon exploration in Cambay Basin goes back to 1958 and since then persistent geoscientific search has led to discovery of total of 79 Oil and Gas fields in the Cambay Basin. Discovery of oil in Ankleshwar structure in Narmada block in 1960 had given a new

boost at the dawn of exploration in the basin. Subsequently in 1983, discovery of Gandhar field with multi-pay stratigraphic trap in Broach-Jambusar block speeded up the exploration activities.

Accelerated exploration activities steadily increased the resource potential from 6.8 billion barrels in 1985 to 13.5 billion barrels in 1990 (fig.2). With the ongoing

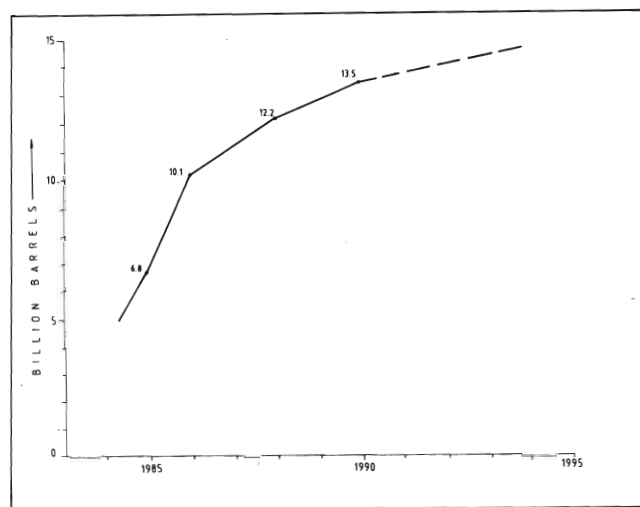


Fig. 2. Established and projected resource potential in Cambay Basin.

discoveries, the initial geological reserve has gone up from 2.5 billion barrels in 1975 to 7.6 billion barrels in 1993 (fig.3). Modern techniques such as 3-D seismic survey, shear wave survey, etc. are applied for indepth search of hydrocarbon, and the evolved geological insights would further help for enhancement of reserves. Oligo- Miocene reservoir from Gulf of Cambay spurts alive the promise for future offshore exploration in the basin.

TECTONICS

The initiation of rifting took place during the Late Triassic/Early Jurassic separating the Indian Plate from the African Plate. The western margin of the Indian plate is characterised by a suite of rift system (fig.1). The regional tectonic is an overprint of the lithospheric stretching, and the subsequent rift propagation took place along the pre-existing tectonic elements. The rifting episode along the western plate is younging southward. (Biswas, 1982)

The Cambay rift geometry typically exhibits a sinusoidal basin track roughly along the Dharwarian trend (NNW-SSE). The basin width narrows down

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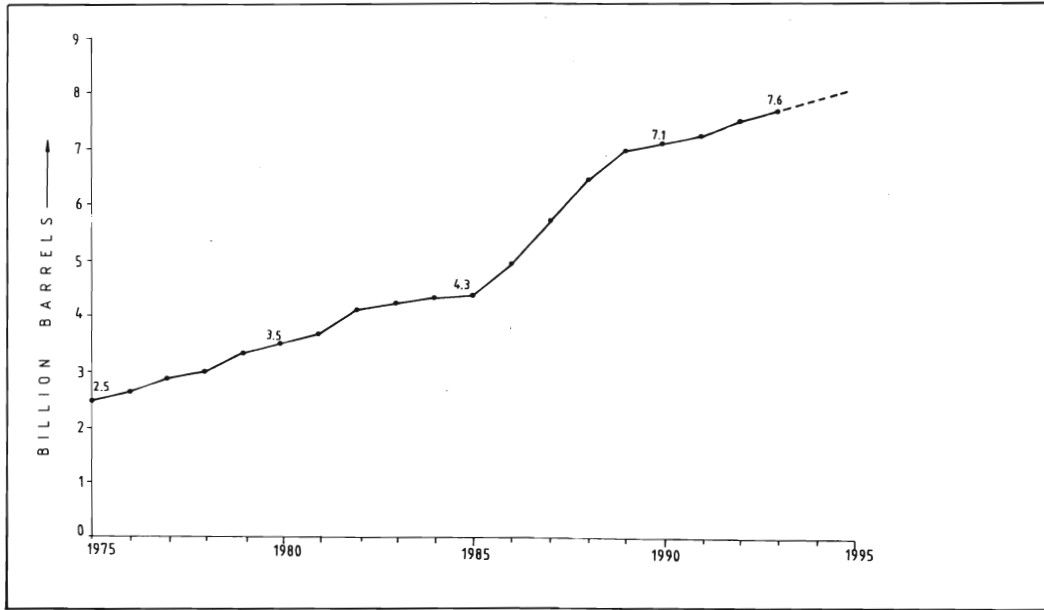


Fig. 3. Total geological reserves of Cambay Basin.

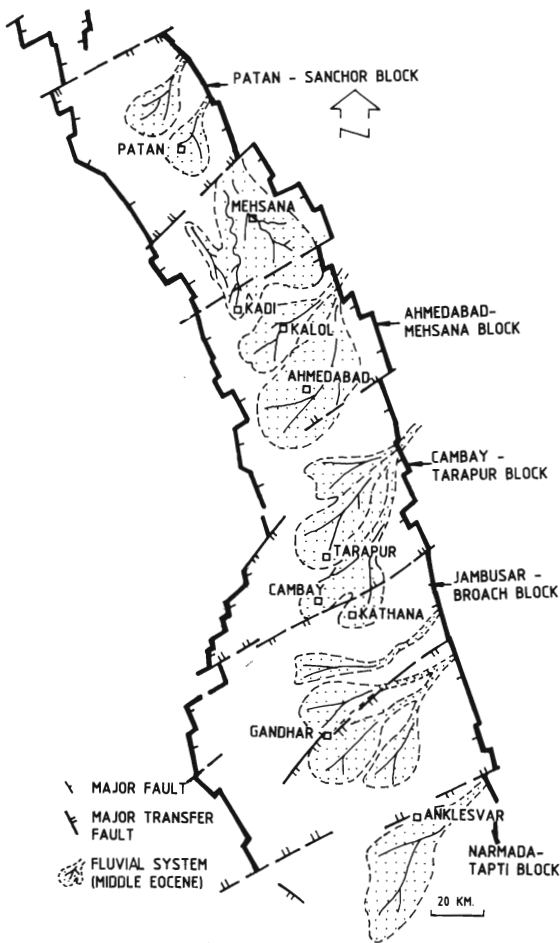


Fig. 4. Different tectonic blocks of Cambay rift basin linked with each other by transfer faults. Also seen the onset of major fluvial system.

towards northern part, indicating possible diminishment of rift propagation, and the rift track infers an overprint of oblique tensional/trans-tensional dynamics, thus exhibiting a typical half graben style (Thakre and Padhy, 1993). Similar to the other rift basins, the basin evolution is related to lithospheric thinning (B-factor) mechanism either by thermal expansion or pure shear/simple shear couplet of McKenzie, 1978 and Wernicke, 1985. The Cambay basin rifting took place around 65 ma, concomitant with the eruption of Deccan volcano during rift-drift transition phase of the Indian Plate. The rift initiation is characterised by basin bounding extensional fault (listric/planar normal fault) facilitating the initial basin subsidence with the upliftment of the basin margin or rift shoulders. The basin is divided into different tectonic blocks (fig.4) linked each other by transfer fault system. The structural evolution of the Cambay basin can be categorised in three phases :

1. Syn-rift phase
2. Post-rift phase
3. Late post-rift phase

During syn-rift phase, the basin tends to be of asymmetric nature and is characterised by inter basinal highs and lows (fig.5). Reactivation of oblique faults and basinal uplifts resulted in Devla-Malpur uplift (Broach-Jambusar block), Kalol uplift, Nawagam-Dholka high (Ahmedabad block), Sanand-Jhalora uplift (Mehsana block) and Wayad and Wansa highs in Patan block. The basin subsidence continued along the extensional faults.

The trappean fault activity ceases to a greater extent during post-rift phase (Thermal Subsidence stage) and subsidence continued due to rapid crustal cooling and sedimentary load deposited by principal fluvial systems.

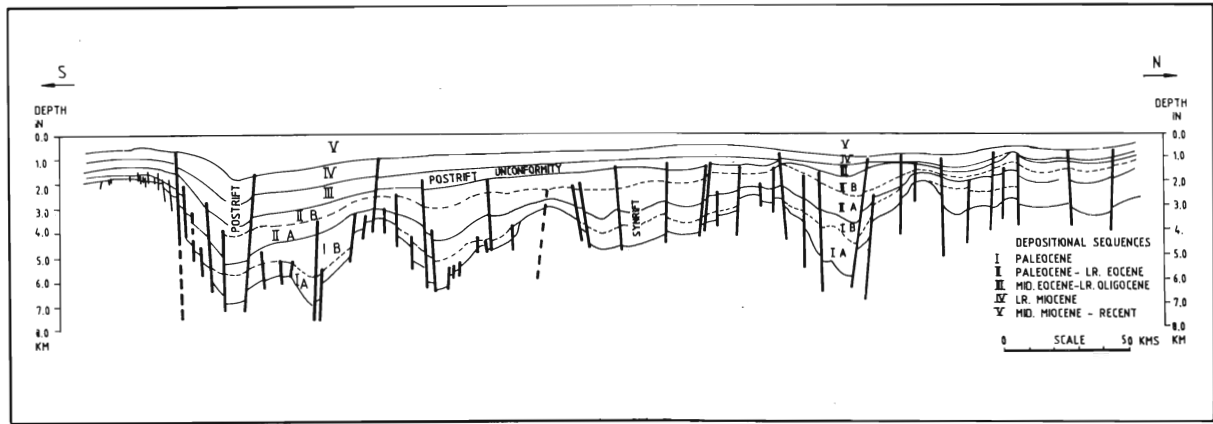


Fig. 5. Geological cross section along Cambay rift Basin (Kundu *et al.*, 1993).

Late post-rift phase is characterised by reverse separation along fault plane resulting in structural inversion within the basin (Ahuja *et al.*, 16990; Kundu *et al.*, 1993). It may be mentioned that this type of structural readjustment within rift tectonics can be attributed to thermal contraction and isostatic compensation of the sediments (Shannon and Nayar, 1989).

The Narmada geofracture was reactivated during post-Miocene time down throwing Broach-Jambusar block considerably (Mathur *et al.*, 1968; Raju and Srinivasan, 1983).

The phases of basin evolution through syn-rift, postrift and structural inversion stages broadly confirm the tectonic cycles such as formative, negative, oscillatory and positive put forth by Raju (1968).

TECTONO-STRATIGRAPHY

Stratigraphic data from exposures in the western margin (Dharangadhra sandstone of upper Jurassic, Wadhwan sandstones of lower Cretaceous) and eastern margin (Bagh bed of Cretaceous age) amply indicate onset of infrarift stage (Thakre and Padhy, 1993) of the basin during the late Jurassic to early Cretaceous time. Some of the deep well data in the northern part of the basin and also from Broach block confirm the above finding. However, the rift initiation under extensional tectonism practically set forth, concomitant with the Deccan volcanism, during 65 ma. The tectono-stratigraphy of the basin is classified as syn-rift phase, post-rift phase and late post-rift phase.

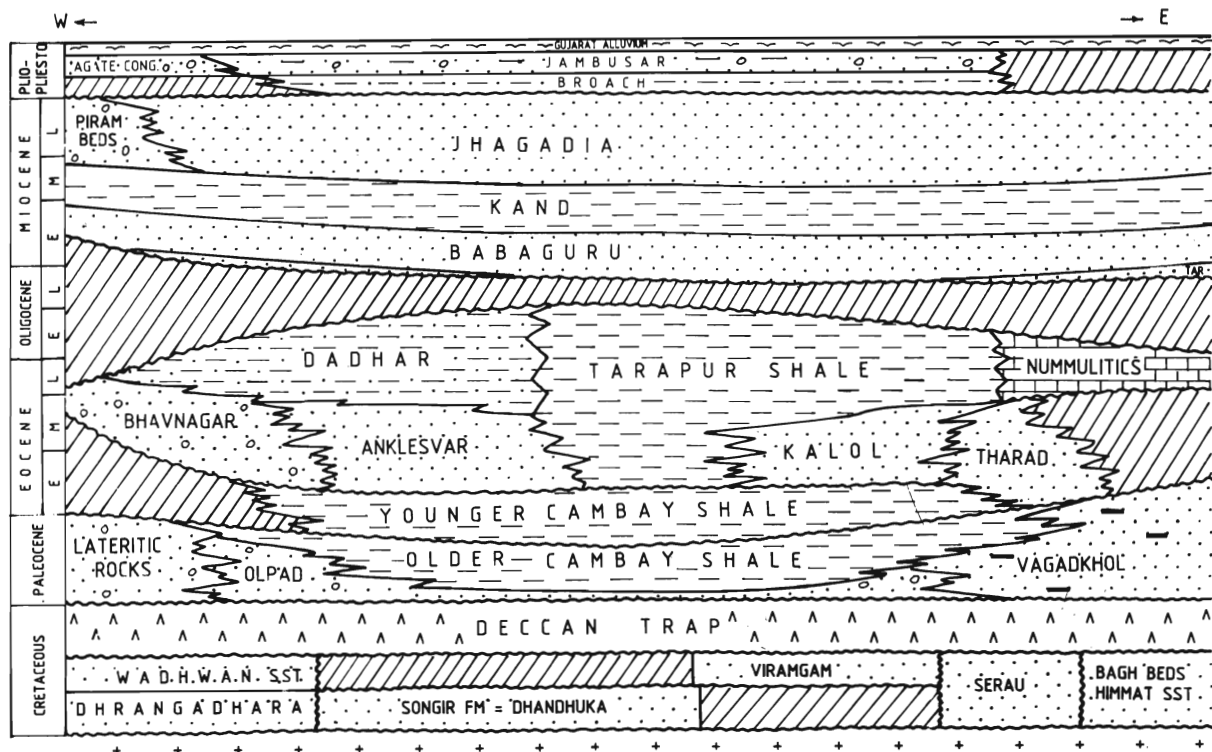


Fig. 6. Stratigraphy of the Cambay Basin.

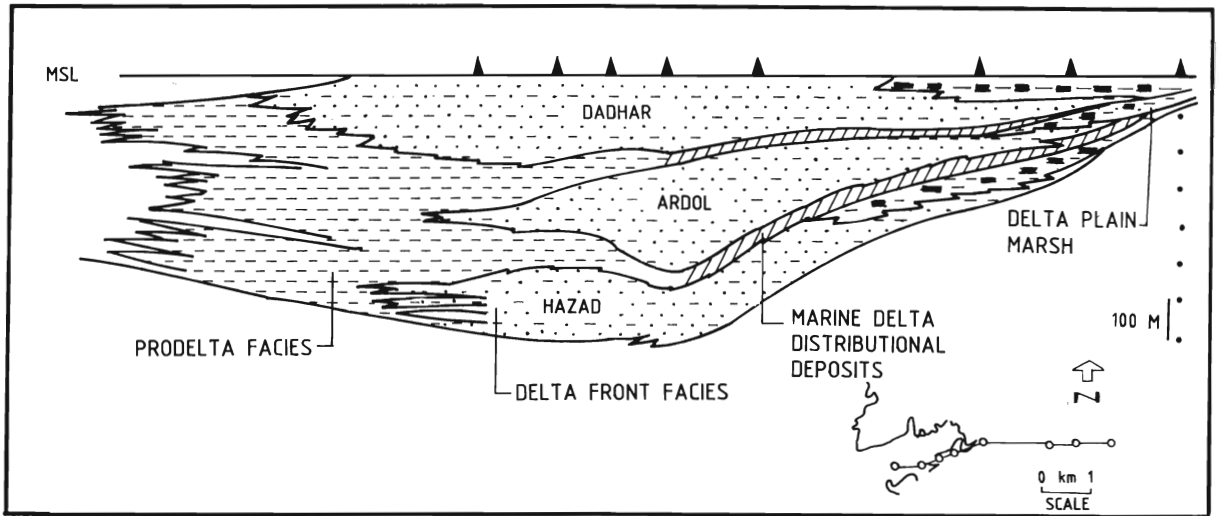


Fig. 7. Progradational deltaic sequence in Broach depression (Mohan and Bhattacharya, 1990).

Apart from Pre-Cambrian basement and thin Mesozoic sediments encountered in a few wells, the stratigraphy of the basin is essentially of Cenozoic age (fig.6). The Deccan trap constitutes the technical basement which is regionally unconformably overlain by Olpad Formation. During synrift phase the basinal highs

and lows were originated due to activation and subsidence of the basin along major fault systems. Olpad nonmarine sediments essentially constitute the trap derivative materials from the uplifted fault blocks. At places Olpad sediments interfinger with the overlying older Cambay Shale and towards basin margin these

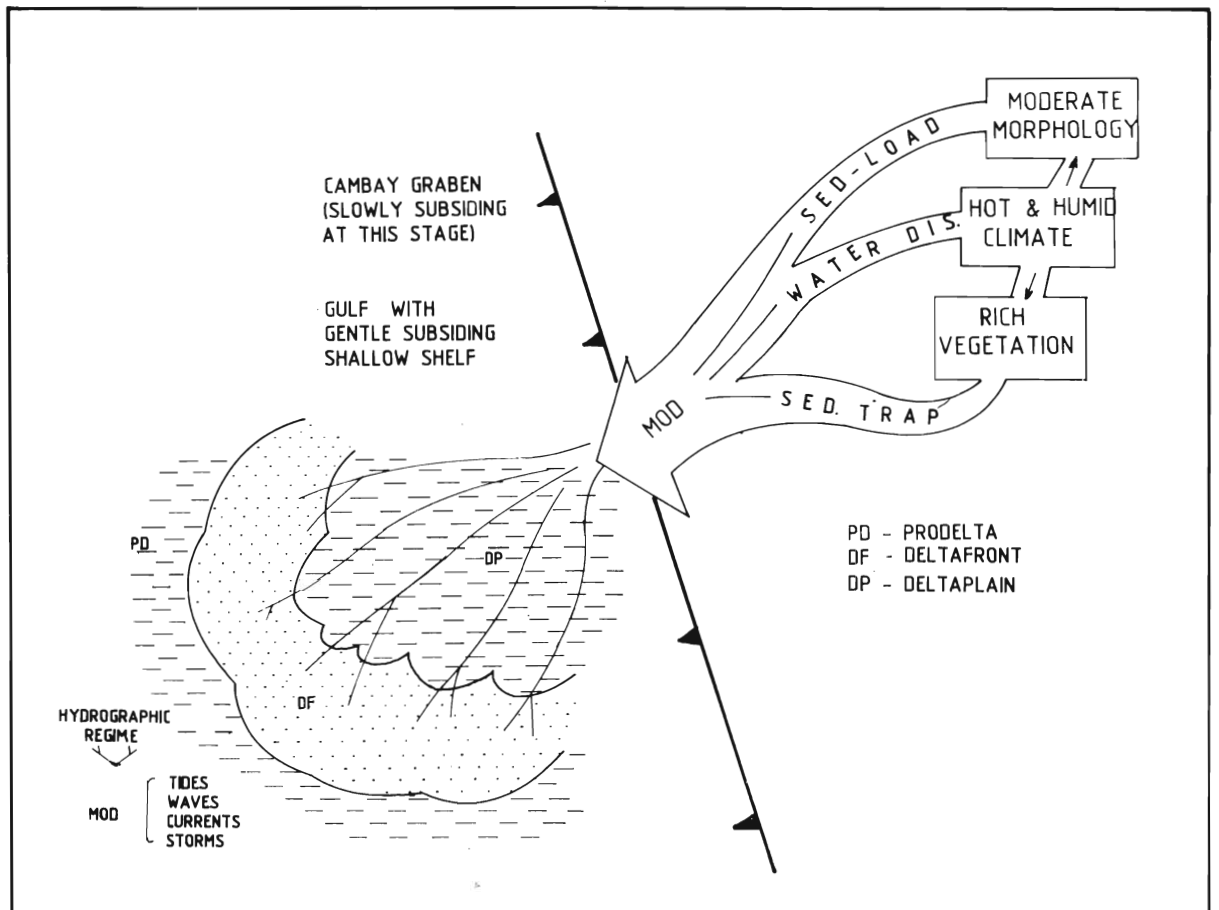


Fig. 8. Moderately constructive lobate delta in the Gandhar area (Mohan and Bhattacharya, 1990).

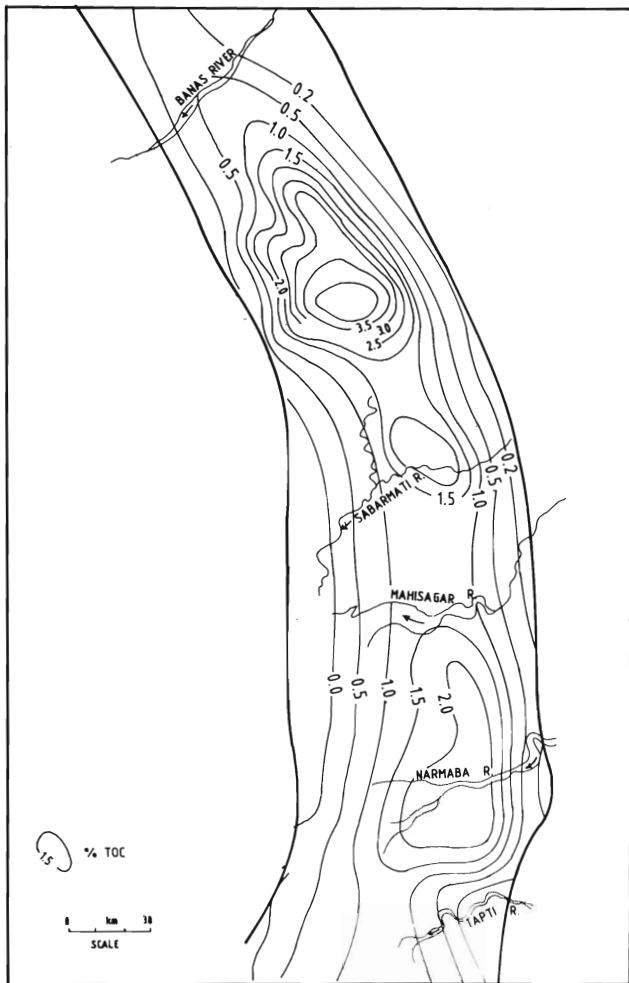


Fig. 9. Total organic carbon (TOC) contour in the Cambay Shale.

exhibit a typical alluvial fan complex, which acts as a moderate reservoir facies.

The basin witnessed first marine transgression during Lower Eocene time depositing the organic rich Cambay Shale. The Lower Eocene tectonic upliftment of the Cambay Basin is expressed by a regional unconformity between the older Cambay Shale and the overlying younger Cambay Shale.

The Cambay Shale is mostly devoid of fauna except for some Palaeocene planktic foraminifera and *Nummulites burdigalensis* near the base of the Cambay Shale. Within the older Cambay Shale, some development of arenaceous sequence is observed in the Mehsana-Ahmedabad block and these, being close to the source facies, are at places hydrocarbon bearing. The younger Cambay Shale in Mehsana and Patan sub-blocks are characteristically represented by distinct regressive facies (Mandhali and Mehsana Members of Kadi Formation), which is a prolific reservoir facies in the northern part of the Cambay basin. The third regional unconformity in the basin is characterised by a thin middle Eocene

transgressive phase (near to 'Y' marker in South Cambay basin and 'B' marker in the north Cambay basin).

Post-rift phase (Thermal subsidence) of the basin is characterised by onset of distinct fluvial system depositing Middle Eocene clastic facies (fig.4), which constitutes the prime regional reservoir rock. This is represented as Kalol formation in the northern part and Hazad Member in the Narmada and Broach-Jambusar blocks. It may be emphasized that the influx of sediment is largely from the north, north-east provenance and the oblique fault system of the basin facilitated the smooth onset of west seeking alluvial systems. The fluvial cycles constitute progradational deltatic sequence (fig.7) and one of the ideal constructive lobate deltatic deposits (Mohan and Bhattacharya, 1990) is the Gandhar Oil field (fig.8) in the Broach Depression. The basin witnessed regional transgression during late Eocene depositing the Tarapur Shale (regional cap facies). The sand facies deposited within this Shale act as good reservoir facies at places in the northern part of the basin.

The late phase of the Cambay Basin experienced structural inversion resulting in favourable conditions for hydrocarbon entrapment. The Neogene sequence is characterised by post-Kand regional unconformity and, the depositional environment of the sediments is principally continental-fluvial in the north and lagoonal-intertidal in the south (Raju and Srinivasan, 1983).

THERMAL HISTORY

The thermal history of the basin is characterised by initial high heat flow followed by cooling as the rift aborted. The average heat flow is of the order of 2.07 HFW (Gupta *et al.*, 1970). The normal geothermal gradient is of the order by 34 - 40_c/km and at places it goes upto 50-60_c/km (Panda *et al.*, 1985).

Very high thermal anomaly is observed around Cambay-Kathana area in Cambay-Tarapur tectonic block (fig.4). In general, in rift tectonics, the high heat flow zone can be attributed to lithospheric thinning (Wernicke and Tilke, 1989). Interestingly, this part of the basin is characterised by high gravity anomalies, bouger anomaly + 37 mgals (Negi, 1952).

HYDROCARBON SYSTEM

Source Potential

Favourable thermal history with high heat flows followed by cooling effect has facilitated for generation and preservation of hydrocarbon in the Cambay Basin. The syn-rift organic rich Cambay Shale constitute the principle source facies of Kerogen type II / III and total organic carbon (TOC) is higher in the northern basin (fig.9), whereas maturity level is higher in the south.

However, the gross organic composition in the basin seems identical (fig.10).

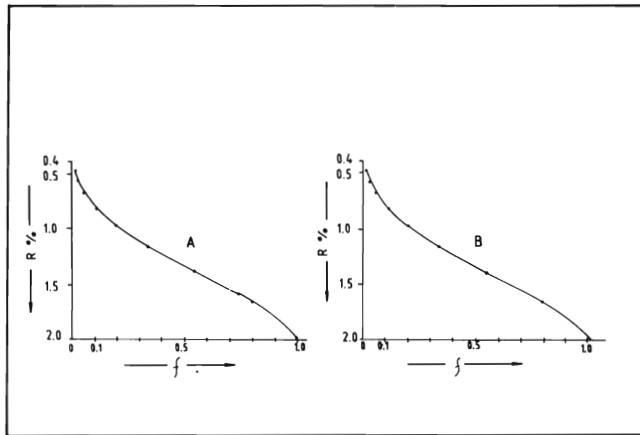


Fig. 10. Fraction generation (f) curve showing similarity in gross organic composition in Broach-Jambusar block (A) and Ahmedabad-Mehsana block (B). (Banerjee and Rao, 1993).

Early oil generation and expulsion took place in the northern part of the basin. Isotope and biomarker studies indicate subsequent entrapment close to the source facies thus undergoing short distance migration.

At places, low maturity (VRo = 0.4-0.5) oil in Meh-sana sub-block is attributed to oil generation from coal (Mehrotra *et al.*, 1991). The source potential towards northern part of the basin, i.e., in Tharad and Sanchor appears to be deposited in lacustrine environment.

In the southern part, the oil generation took place since Middle Eocene and basin wide oil migration took place in Early Miocene time.

Exploration Play System and Entrapment Style

Broadly, it is observed that the exploration play system is associated with different tectonic episodes of basin evolution and it can be classified as follows :

- * Syn-rift exploration play system.
- * Post-rift exploration play system.
- * Late post-rift exploration play system.

Fractured trap, on the eastern margin in Broach block, also yields oil. Possibility of inter-trappean acting as reservoir facies may not be overruled. Palaeocene to Early Eocene rock types (Olpad) constitute the important reservoir facies associated with syn-rift phase of the basin. These rock types typically constitute alluvial fan complex along the rift margin and on the low side of the basin bounding listric normal faults close to the basin margin areas. Towards basinal side, it sometimes juxtaposes with the Cambay Shale (source facies) and lateral petrophysical variation and facies changes help in entrapment of hydrocarbon. The trap style is generally polyseal drape over anticlines as observed in the Unawa area in Meh-sana block or lateral facies changes.

The clastic reservoir facies deposited within the older Cambay Shale can broadly be classified as deposits associated with transgressive phase or wave/tide/storm dominant deposits. The reservoir rock occurs on lenticular sand bodies. The close association of these bodies, for example, in South Kadi, Linch area (Ahmedabad - Mehsana block) infers the possible short distance migration and the entrapment style is of polyseal nature. Broadly, the trapping style is structural (fault closures, roll-over anticlines, inversion anticlines) and stratigraphic (wedge-out, pinch-out) in nature (fig.11).

In the northern part of the basin, during the late syn-rift phase, onset of fluvial system has resulted in extensive development of reservoir facies (Kadi formation). The early post-rift phase constitute the principal reservoir facies. Aravalli exposures to the north-east of the rift basin constitute the main provenance and sediments deposited by various fluvial systems in the basin resulted in various strati-structural traps.

The late post-rift structural inversion phase has given rise to a number of structural traps (within Middle Eocene), notably the giant Ankleshwar Oil Field. The late post-rift stratigraphic sequence bears exploration importance after oil strike in the Gulf within Oligo-Miocene sediments. Presence of hydrocarbon within Neogene sequence has also been established in Ankleshwar structure and from some of the wells in Meh-sana sub-block. Evidently, these traps are more of structurally controlled type.

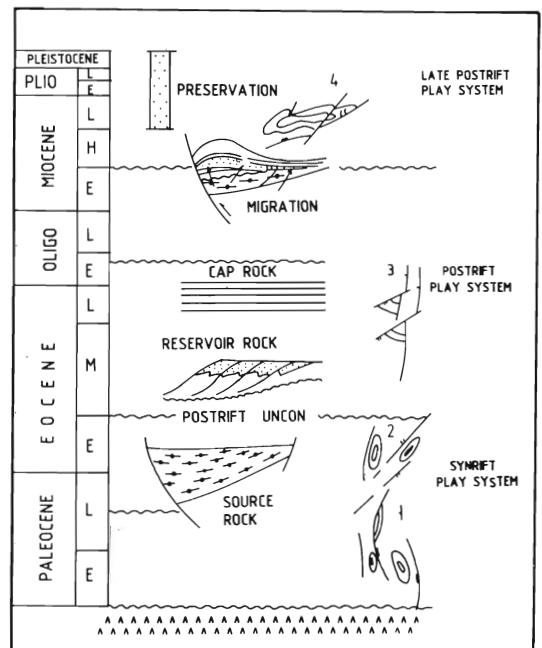


Fig. 11. Entrapment styles observed in different stages of rift development in Cambay Basin.

Exploration Frontier

Adjudging the tectono-stratigraphic overprint on exploration play system in the Cambay extensional basin, the future unconventional avenues for exploration are :

- Possible Mesozoic Prospect in Narmada, Broach-Jambusar blocks, specially along western rift corridor.
- Fractured trap/Intra-trappean along eastern and western margins of the basin.
- Isolated clastic deposits in deeper source facies within the older Cambay Shale.
- Fractured shale and silt reservoirs within the Cambay shale over geomorphic highs.
- Lacustrine prospects in the northern part of the basin (Sanchor-Tharad Block).
- Neogene play in the Gulf and further offshore region.

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