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

T.K. Mathuria[1], A.C. Julka[1], P.K. Dimri[1], and P.B. Pandey[1]

Search and Discovery Article #10326 (2011)
Posted June 20, 2011

*Adapted from extended abstract presented at GEO-India, Greater Noida, New Delhi, India, January 12-14, 2011

[1]Block I Western Onshore basin, ONGC, Vadodara, India (mayadhar2005@rediffmail.com)

Abstract

The Broach sub block lies between the Mahisagar and Narmada rivers 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 the Ankleshwar Formation of Middle to Upper Eocene age. But some oil was also produced from the sands within the 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 (Figure 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 the Ankleshwar Formation, but some oil is also produced from deeper pays in the 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 the Cambay Shale of Paleocene to lower Eocene age (Figure 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 the Cambay Shale is envisaged for hydrocarbon accumulation.

The Cambay Shale was deposited during the Paleocene to Lower Eocene (Figure 3). Five to twelve layers of dirty, partly lithic sands are present in the Cambay Shale and have been considered as potential exploration targets for hydrocarbon accumulation. The Cambay Shale has a maximum thickness of approximately 2800 m in the 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 pinches 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, the Hazad Formation transgresses the Olpad Formation of Paleocene age. So far no detailed work has been carried out to understand the depositional pattern of these sands, so a methodology was adopted to critically examine the well and seismic data, and determine the thickness variation of the 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 (Figure 4). The seismic events corresponding to this unit show high amplitude reflections (Figure 5). This unit is drilled in well A of the Nada area in which a 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 (Figure 1), well B was drilled up to Trap while wells A and C (Figure 2) were terminated in the deeper part of the Cambay Shale. Out of these wells, C has produced oil and gas, whereas well A had oil and gas indications. The potential targets are high amplitude events which corresponds to sand and shale alternations. These sands occurs as pinchouts on the northwestern and southeastern flanks of the 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 potential targets for petroleum explorationists. An extremely thick accumulation of Cambay Shale is observed in the 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 the east. In the southeastern part of the study area, the Hazad Formation unconformably overlies the Olpad, while only 20 m to 240 m 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 35 m to 100 m of Cambay Shale is present in the eastern part of the Gulf of Cambay. This formation is mostly conformable to gradational and has intertounging relationships with underlying the Olpad Formation. It has and unconformable relationship with overlying Kalol Formation in the north part of the basin and the Ankleshwar Formation in the south. Cambay Shale is assigned to the Paleocene to Lower Eocene (Govindan, 1987). It is subdivided into the older Cambay Shale and Younger Cambay Shale. On the northeastern and western side of the Tankari depression, the Cambay Shale below Hazad base includes the following succession from top to bottom:

1) A monotonous fissile shaly interval, occasionally carbonaceous, 100 to 200 m thick deposited in low energy conditions.

2) A thickening upward silty interval often associated with a few meters thick coal seam. This interval is widely correlatable in the Jambusar-Broach block.

3) Another monotonous shale interval, often carbonaceous, thickening from 50 to 150 m in Nada Malpur area, to 700-800 m in Gandhar and Jambusar wells.

4) Deeper, the shales includes 9 to 12 layers of lithic dirty sands, 2 to 10 m thick.

Stratigraphic Control

The sands within Cambay Shale occur 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 (Figure 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 a short distance and dumped into adjacent marshy lands.

Review of Exploratory Data

Extensive analysis of well data reveal broadly four distinctive sequences. In Nada area, the sands found deeper than 3600 m are argillaceous. On the other hand, three layers within older Cambay Shale are relatively clean and two sands, which were tested, flowed oil and gas (Figure 5). In South Malpur area well C drilled as much as 3107 m but did not reach the Olpad Formation. The lowermost sands were argillaceous and poorly sorted. These were tested but did not shown any flow. The sands present within older Cambay Shale are clean; when tested they flowed oil and gas. This is the only sand which produced oil at 10 m^3/d. In Bharkhodra area sand present within the interval 3050-3054 m had given little oil and gas (Figure 4).

South of the study area in Gandhar, the two sands tested at 3900 m and 3600 m within Cambay Shale flowed little gas. The log evaluation of these sands shows 12 m 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 was deposited during the Paleocene to Middle Eocene in the axial part, while on the flanks it may be of Early Eocene age (Prakash, 1999). Cambay Shale in general was deposited in marginal marine conditions and occasionally in shallow inner netritic conditions which prevailed during the Early Eocene. In Jambusar-Gandhar area the Cambay Shale was probably deposited as lagoonal facies during the Paleocene. The shales were deposited during major marine transgression and the sands correspond to short sequential oxic episodes (Sharma, 1989).

Seismic Facies Analysis

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

Evolution and Sedimentation History

Broach bock is a deep syncline containing more than 6000 m of Cenozoic sediments (including more than 3500 m of Neogene). This is the maximum known thickness of sediments in the basin. The syncline is an asymmetrical sag with sedimentary thickness decreasing rapidly to the south towards the ENE- WSW aligned Narmada fault and rather gently in all other directions.

The Cambay Shale was deposited during the synrift to rift-fill stage. This phase corresponds to the formation of a 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, however with a 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 remained quiescent with no more fault activity or block tilting, but only differential subsidence which provoked the formation of large-sized depressions (Dhar et al., 1987). The structure map at Y marker top (which is a very good seimic and log marker in the Younger Cambay Shale) indicates a broad NE-SW oriented Tankari low and fault heading towards the south in the northern part of the area. To the south the depression is limited by basin margin which corresponds to the Narmada block, to the west by Bharkhodra and Malpur highand, and to the east by Jambusar terrace (Figure 10). From the isopach map of Cambay Shale (Figure 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 the Tankari depression. The paleotectonic cross sections across the Broach area shows the shifting of depocenters during the deposition at different times (Figure 12). The shifting of depocentres is oscillatory in nature and is confined to the east-west direction. Hence it confirms the lateral migration of hydrocarbons to the paleo highs and the rising flanks on the eastern and western parts of the Tankari low (Panda et al., 1994).

Exploration Model

Exploration for stratigraphic reservoirs within Cambay Shale is a predictive effort based on assimilation and interpretation of all the prevailing subsurface information. As such, Cambay Shale deposited in lagoonal to shallow marine environment corresponds to short regressive episodes. They were transported over a 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 (Figure 9) which still govern today the course of rivers such as Mahisagar, Dadhar and Narmada. As no sands are found in the northeastern part of the study area, it is therefore inferred that sands were coming mostly from the Paleo- Dadhar River, and also from a the 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, the 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 and is found to be thermally well matured and falls within the oil window. In most parts of the study area the TOC ranges from 2.25 to 2.0%, average HI from 150 to 100 mgHc/gm TOC and the total hydrocarbon generated and expelled ranges from 0.73 to 1.40 and 0.11 to 0.5 MMt/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 suggests that the direction of hydrocarbon migration is likely from the center to the flanks of the Tankari depression (Figure 13).

Migration of Hydrocarbons

The accumulation of oil and gas in these structures are mainly due to primary migration of hydrocarbons from the source beds into the adjacent reservoir rocks. After the deposition of sufficient thickness of overburden, the hydrocarbons 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 (Figure 9). It is likely that they must have migrated updip to the margins of the basin. It is envisaged that at least some of this oil may have been trapped in zones of pinch-out and wedge-out of deeper sands (Saraf, 1998).

Seismic Attributes Studies

Seismic attribute studies were carried out within Younger and Older Cambay Shale to understand the depositional trends. The RMS and near to Younger Cambay Shale and Older Cambay Shale OCS top indicates high amplitude distribution in the northern part of Tankari PEL, extreme northeastern part of the study area and on the western flank of the Tankari low. The 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 the northeast from the eastern part of the study area (Figure 14 and Figure 15). The probable presence of sand is envisaged in the western and eastern rising flank of the Tankari low and they may be explored for hydrocarbon accumulation.

Conclusions

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 the Cambay Shale and are considered as potential hydrocarbon targets. These sands occur as high amplitude events. The potential targets for sands within Cambay Shale are the pinchout in northwestern and southeastern flank of the Tankari depression. The paleo-river system was probably related to pre-existing Paleogene or older faults which can be inferred as the 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 the Mehsana horst to the Warosan depression. Similar depositional patterns occur in the Tankari depression which can be targeted for potential hydrocarbon accumulations.

Acknowledgements

Authors are grateful to management of ONGC Ltd. for permission to contribute this paper, and Shri D.P. Sahasrabudhe (ED Basin Manager) for valuable suggestions and guidance to justify the ideas conceived in the paper.

Selected References

Banerjee, A., S. Pahari, M. Jha, A.K. Sinha, A.K. Jain, N. Kumar, N.J. Thomas, K.N. Misra, and K. Chandra, 2002, The effective source rocks in the Cambay Basin, India: AAPG Bulletin, v. 86/3, p. 433-456.

Biswas, S.K., 1982, Rift Basins in Western Margin of India and Their Hydrocarbon Prospects with Special Reference to Kutch Basin: AAPG Bulletin, v. 66/10, p. 1497-1513.

Bordenave, M.C., 1977, Appraisal of Cambay basin, Petroleum Potential of Broach block, Unpublished Oil and Natural Gas Commission (ONGC) Report, Dehradun, India, p. 52-67.

Chandra, P.K, and L.R. Chowdhary, 1969, Stratigraphy of the Cambay Basin: Bulletin of the Oil and Natural Gas Commision, Dehradun, India, v.6/2, p. 37-50.

Dhar, P.C., M.K. Mukherjee, M. Jain, S. Chawla, and A. Sood, 1987, Hydrocarbon prospects of the western Broach Depression, Cambay Basin, Gujarat: Bulletin of the Oil and Natural Gas Commission (ONGC), Dehradun, India, v. 24/2, p. 39-58.

Govindan, A., 1987, Age, Paleoenvironment and biostratigraphic correlation of South Malpur, Unpublished Oil and Natural Gas Commission (ONGC) Report, Dehradun, India.

Mayor, S., S.S. Sawkar, A.K. Das, G. Ram, D.S. Randhava, and S.P. Painuly, 2004, Identification of Prefered Reservoir development in Olpad formation for the exploration of deeper prospects Broach block, Cambay Basin: 5th Conference & Exposition on Petroleum Geophysics, Hyderabad, India, p. 388-395.

Prakash, C., 1999, Sedimentological differentiation of Cambay shale and Olpad section in Nada, Devla and Bharkodra areas, Unpublished Oil and Natural Gas Commission (ONGC) Report, Dehradun, India, p. 1-7.

Prasad, B., 1996, Basement configuration and distribution of depocentres of Cambay basin KDMIPE, Unpublished Oil and Natural Gas Commission (ONGC) Report, Dehradun, India.

Saraf, S.C., 1998, Prospect evaluation of Eocene succession in Northern part of Tankari depression Broach block, Cambay Basin, KDMIPE Unpublished Report, India.

Sen, G., 1997, Hydrocarbon prospecting within Olpad and Cambay Shale sequence in eastern part of North Cambay basin, Unpublished Oil and Natural Gas Commission (ONGC) Report, Dehradun, India.

Sharma, D.C., 1989, Biostratigraphy and paleoenvironmental history of Cambay basin, Unpublished Oil and Natural Gas Commission (ONGC) Report, Dehradun, India, p. 1-7.

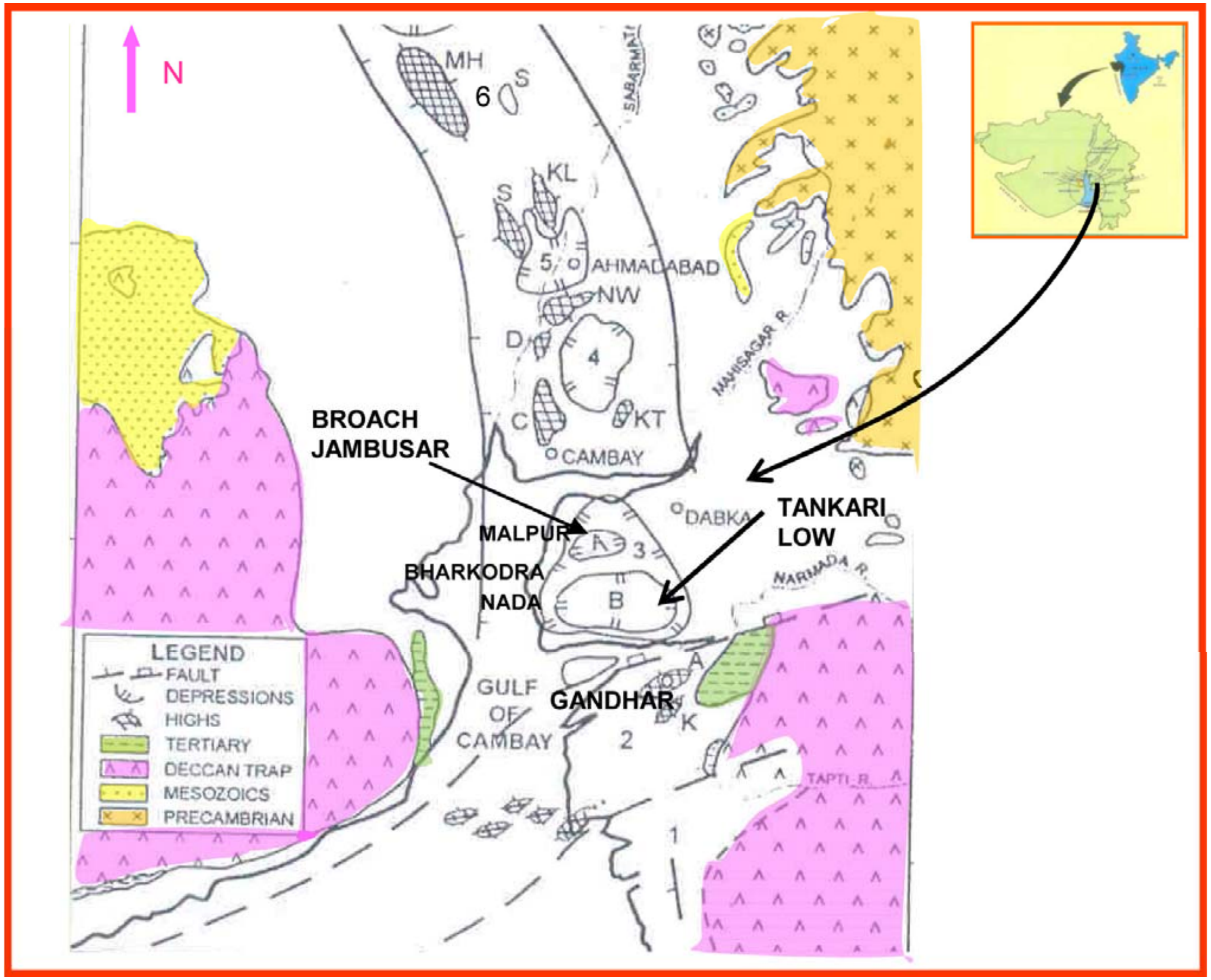

Figure 1. Tectonic map of Cambay Basin showing the depressions and highs (modified after Chandra et al.,1993) and locations of studied areas. Depressions: 1. Surat, 2. Narmada, 3. Broach-Jambusar, 3A. Broach Low, 3B. Tankari Low, 4. Cambay-Tarapur, 5. Ahmadabad-Mehsana, 6.Warason. Structural highs: K-Kosamba, A-Ankleshwar, KT-Kathana, C-Cambay, MH-Mehsana horst.

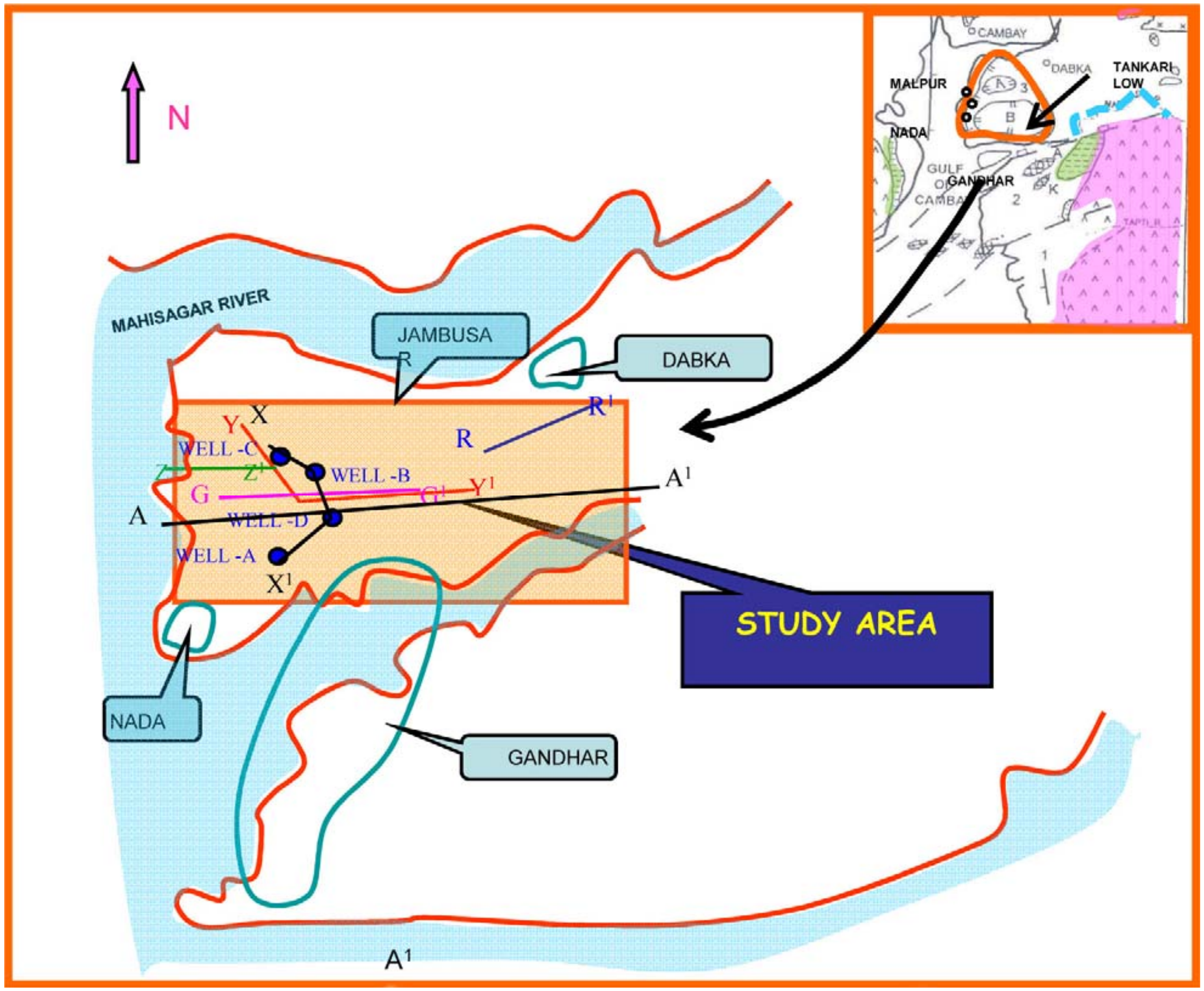

Figure 2. Location map of study area showing locations of log and seismic profiles.

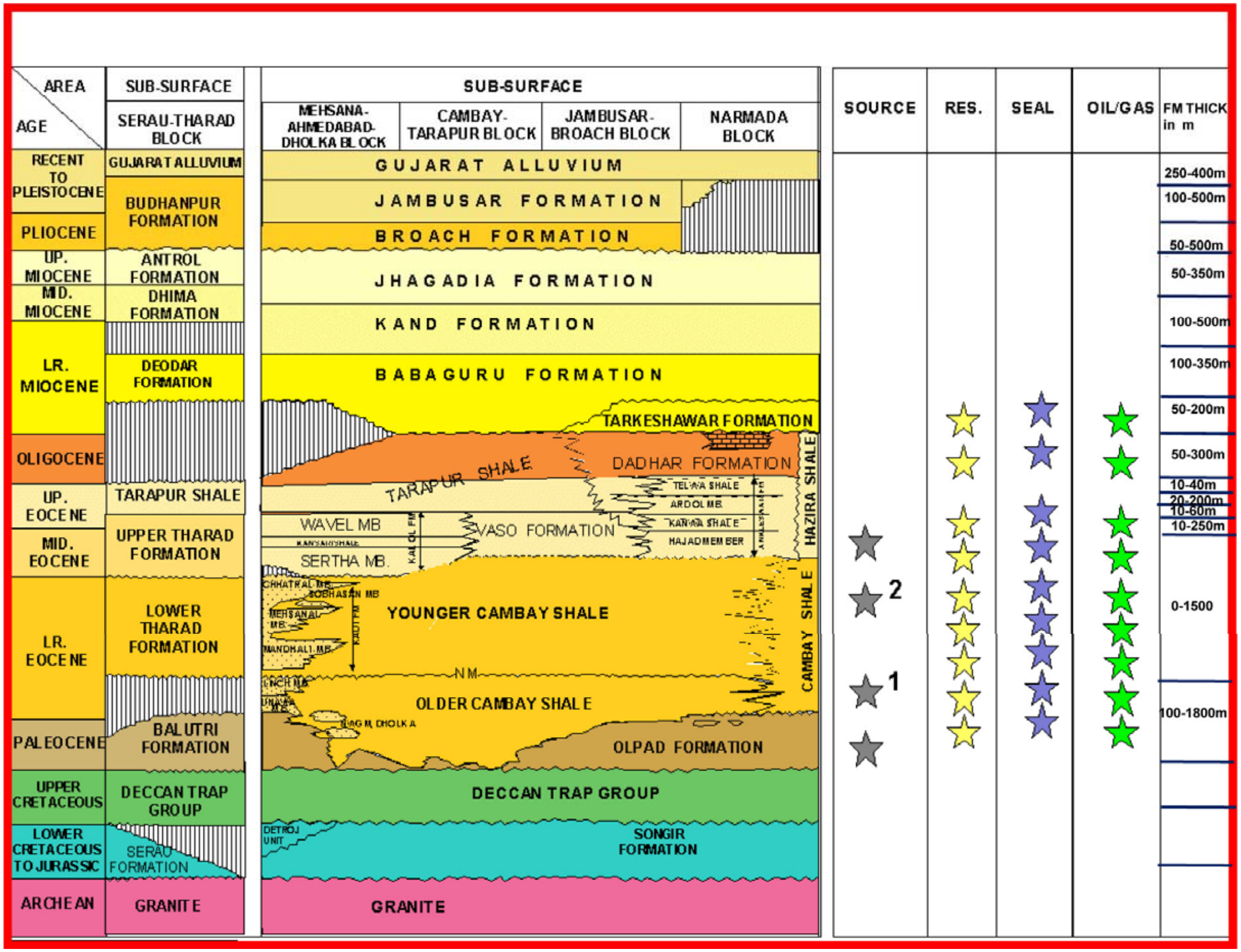

Figure 3. Stratigraphy of Cambay Basin (modified after Chandra and Chowdhary,1969).

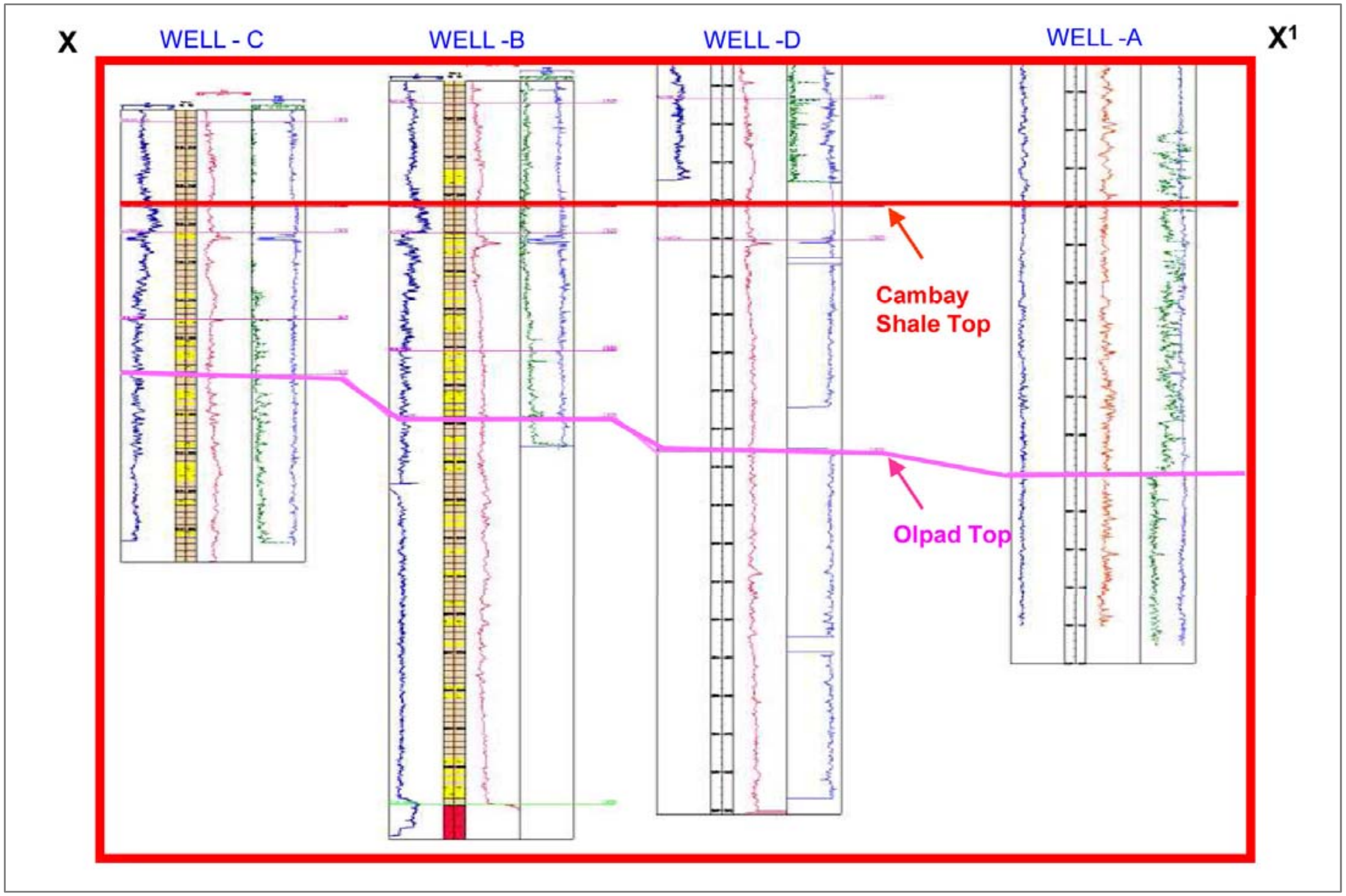

Figure 4. Log correlation along wells C, B, D, and A showing distribution of sands within Cambay Shale (see Figure 2 for locations).

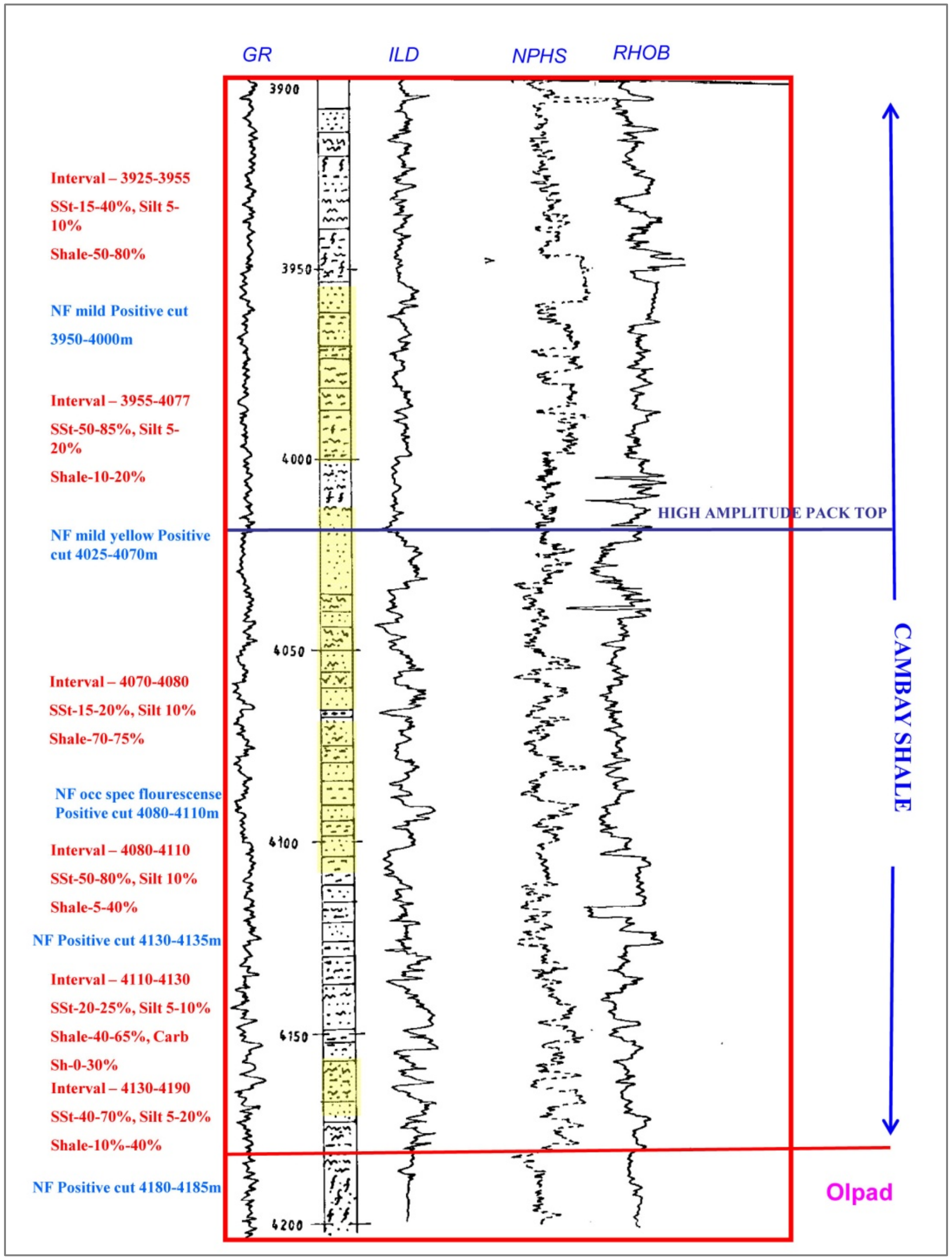

Figure 5. Composite log of Well-A showing sand intercalations within Cambay Shale.

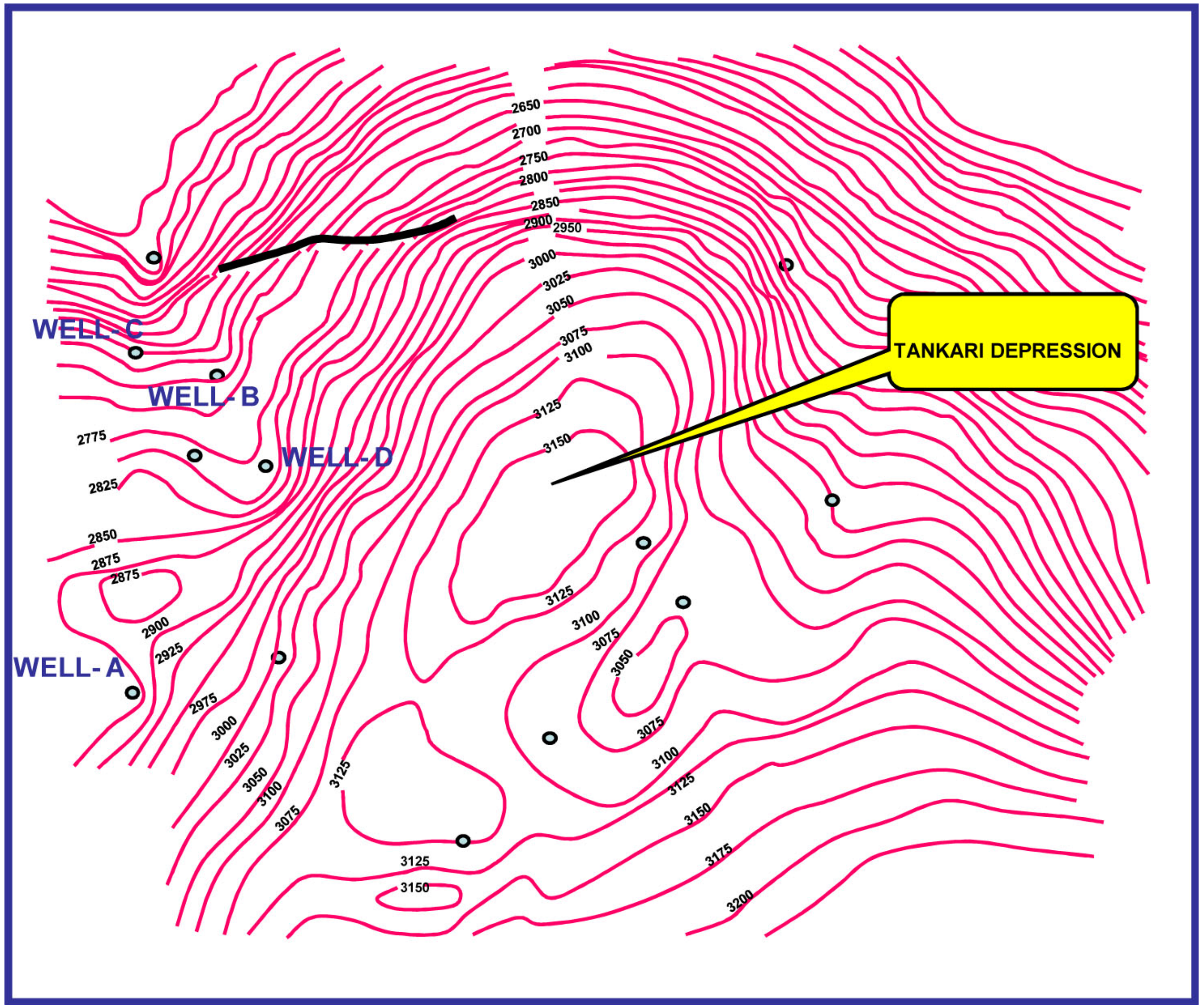

Figure 6. E-W seismic section passing through the Tankari Depression (see Figure 2 for relative location).

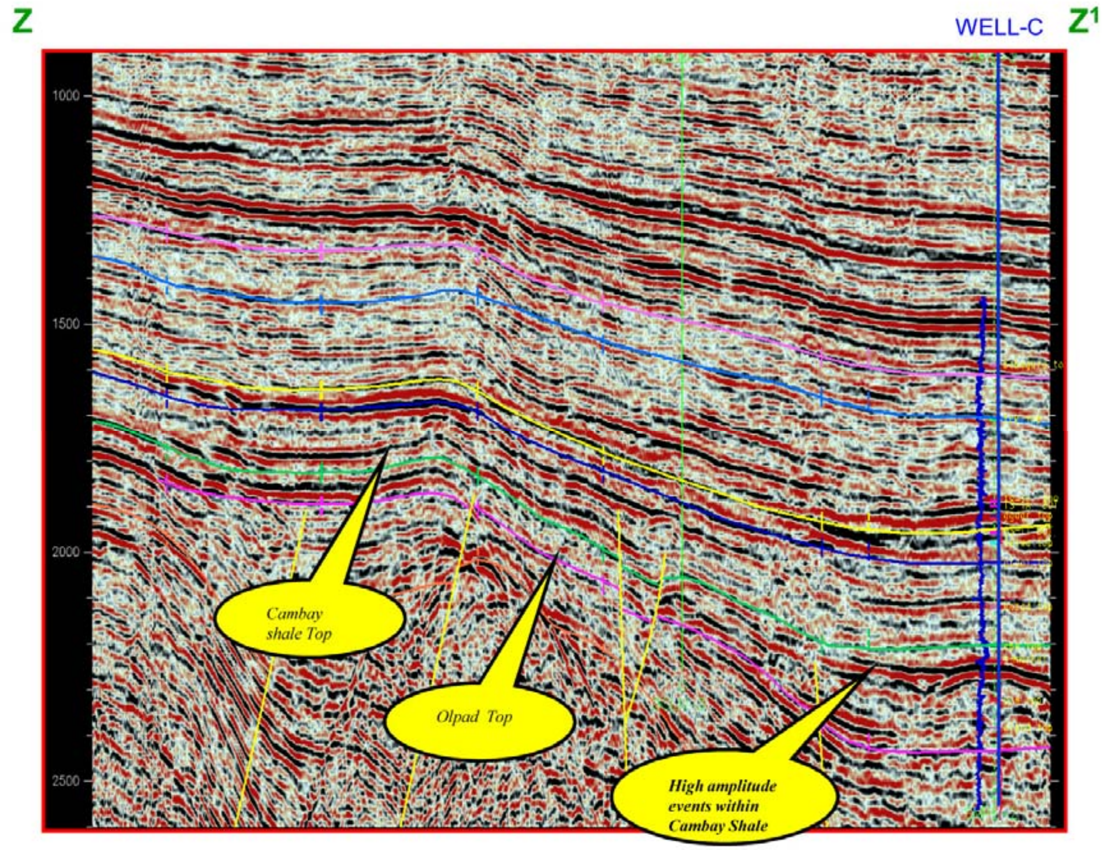

Figure 7. Seismic section passing through Malpur and western part of Jambusar Broach block. (see Figure 2 for location).

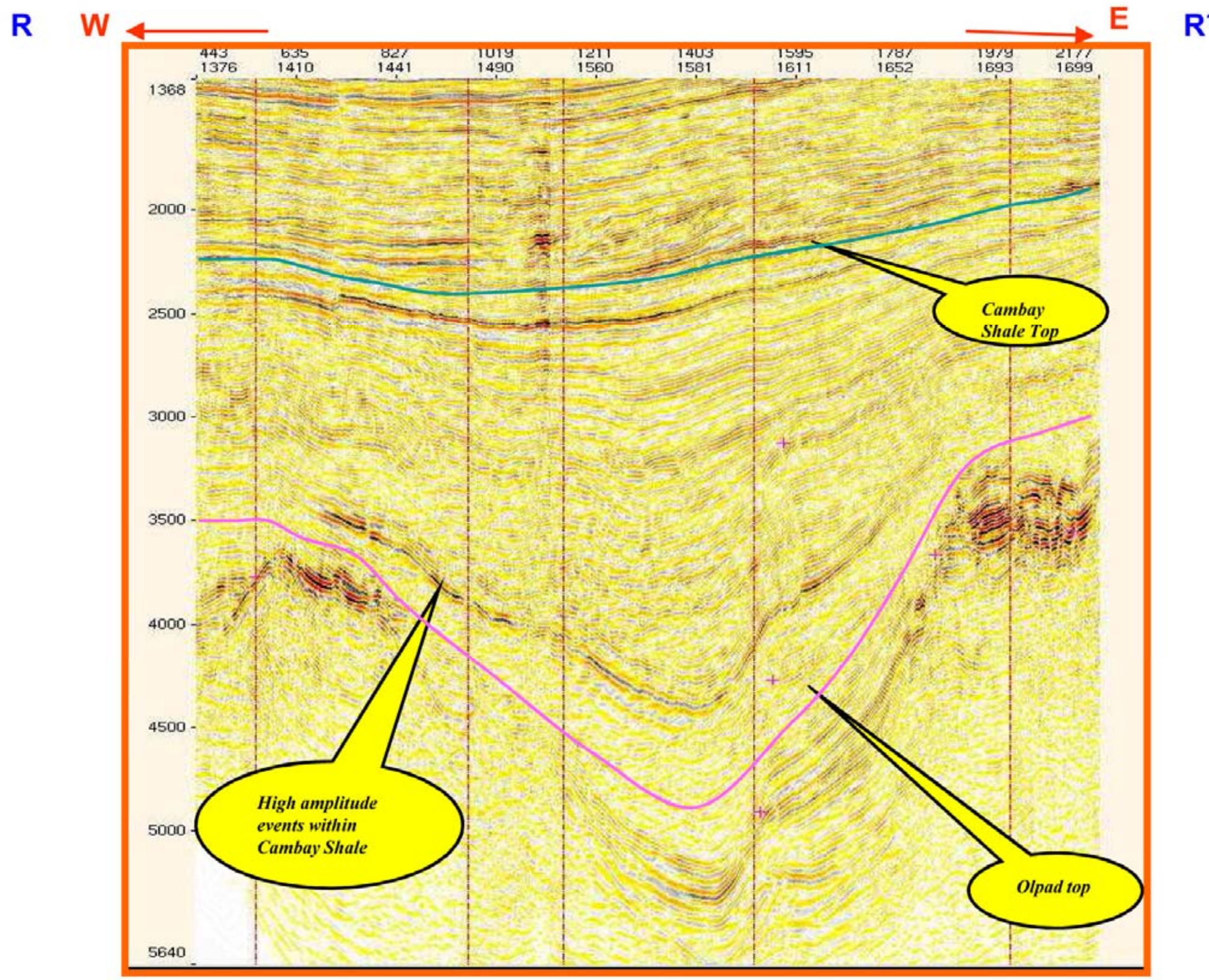

Figure 8. E-W seismic section along the Tankari depression (see Figure 2 for location).

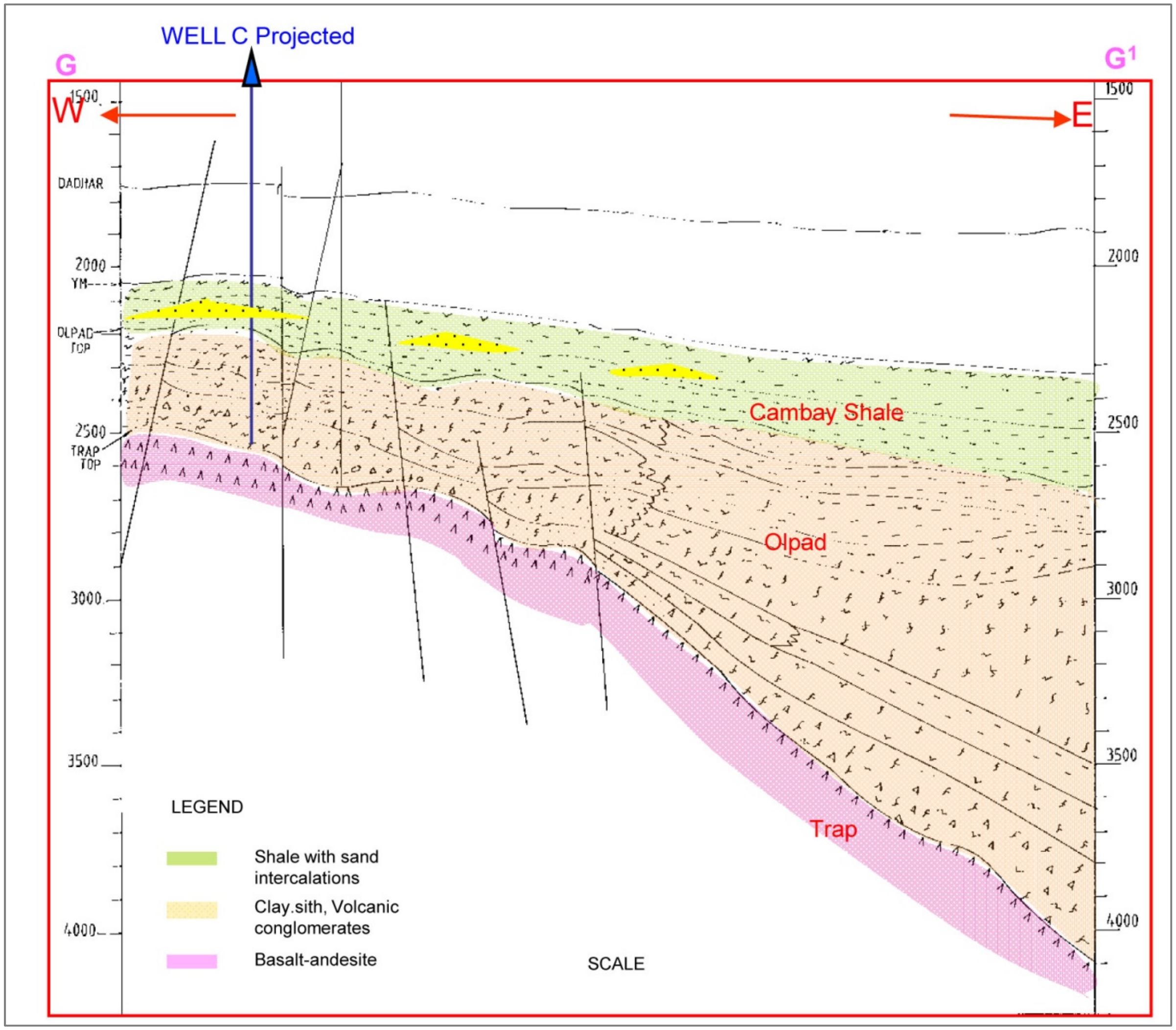

Figure 9. E-W geological cross section within the study area (see Figure 2 for location).

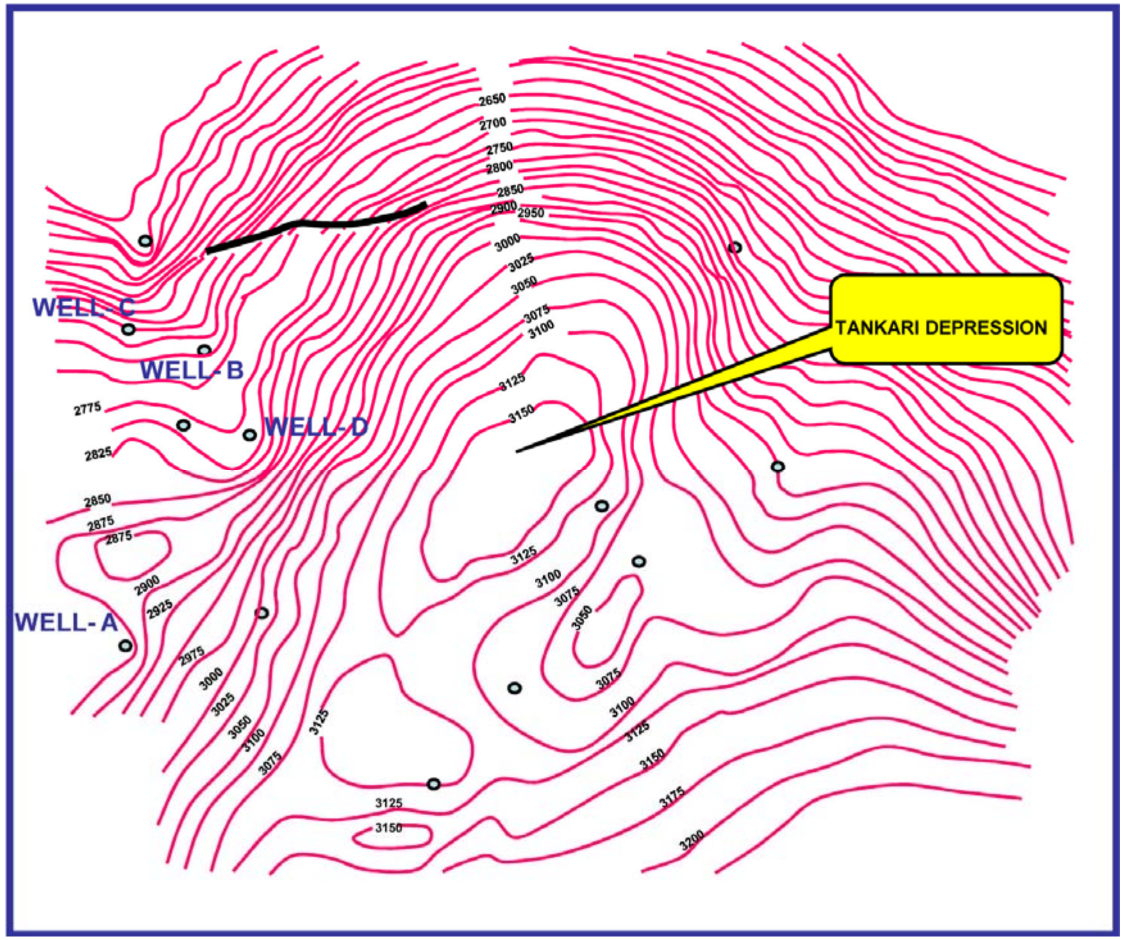

Figure 10. Structure contour map near Y marker top of the study area (modified after Bharsakle et al., 2004).

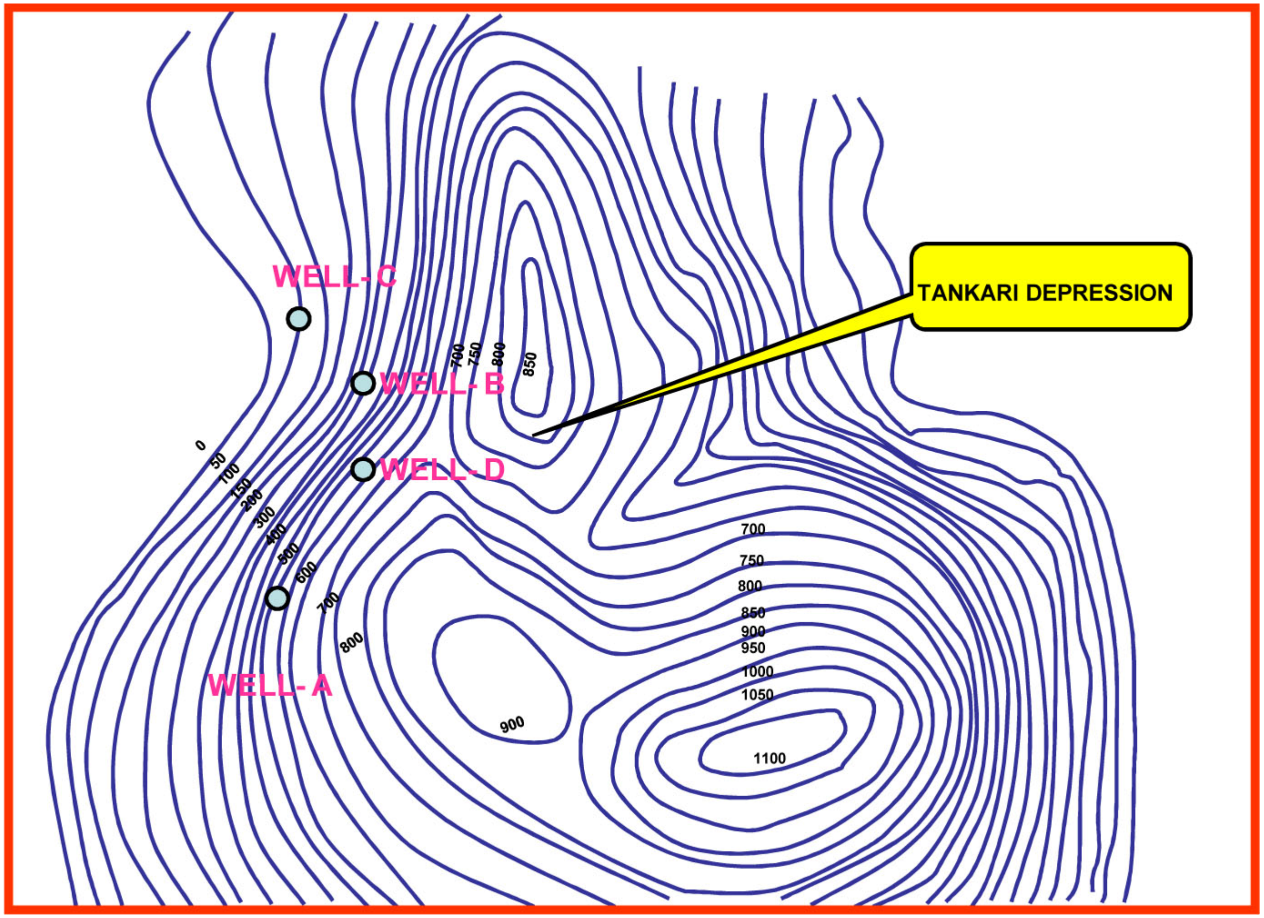

Figure 11. Isopach map of Cambay Shale in the study area (modified after Bharsakle et al., 2004).

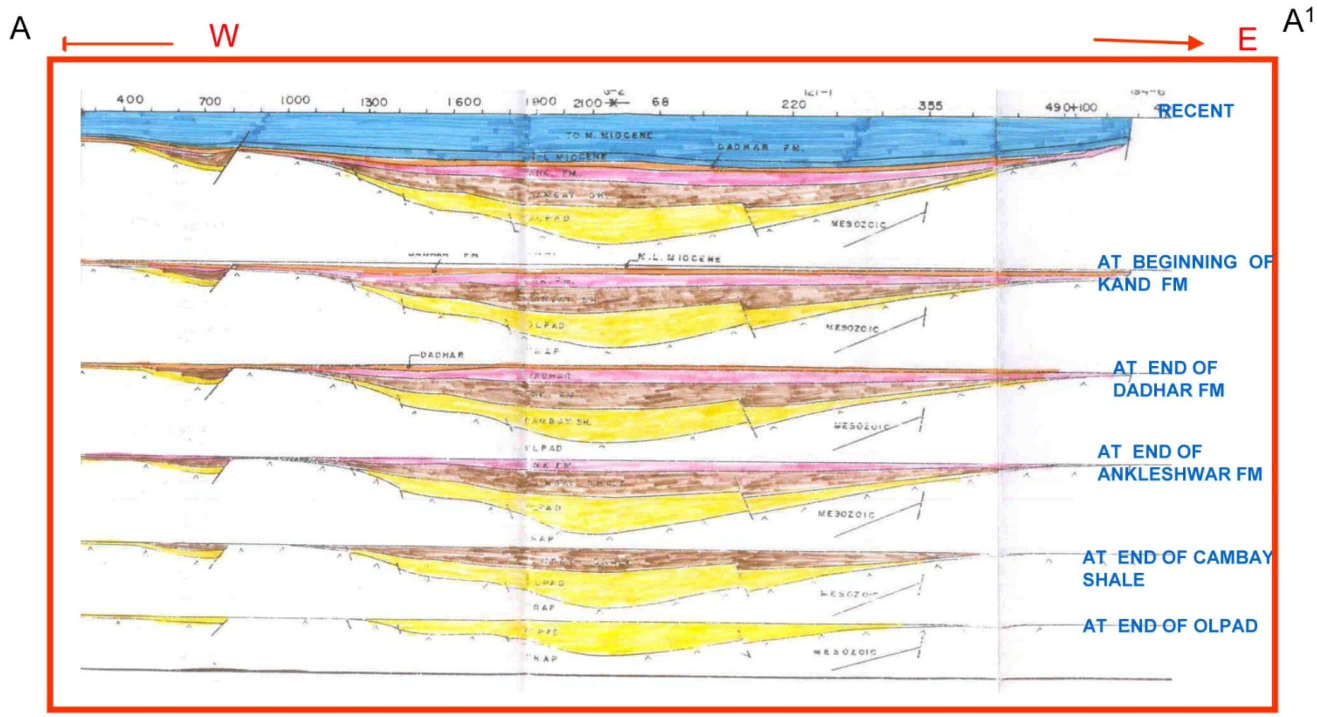

Figure 12. Paleotectonic cross sections across the Broach area showing shifting of depocenters at various times (modified after P.K. Panda et al., 1994).

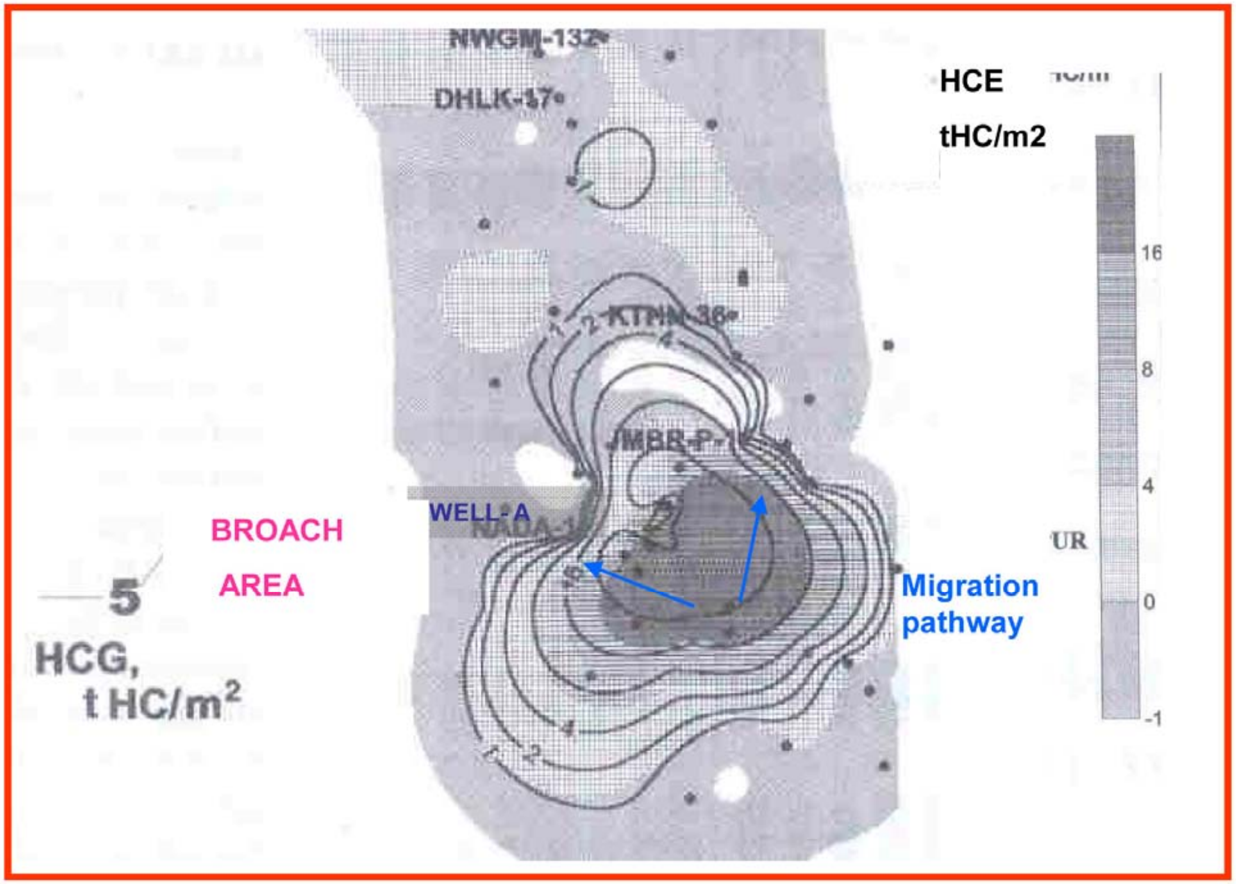

Figure 13. Hydrocarbon generated (HCG) and hydrocarbon expelled (HCE) from the Cambay Shale Formation. The HCG (solid contours) and HCE (shaded) are in metric ton hydrocarbon/m^2. Positive and negative HCE areas signify hydrocarbon expulsion and possible accumulations areas respectively.

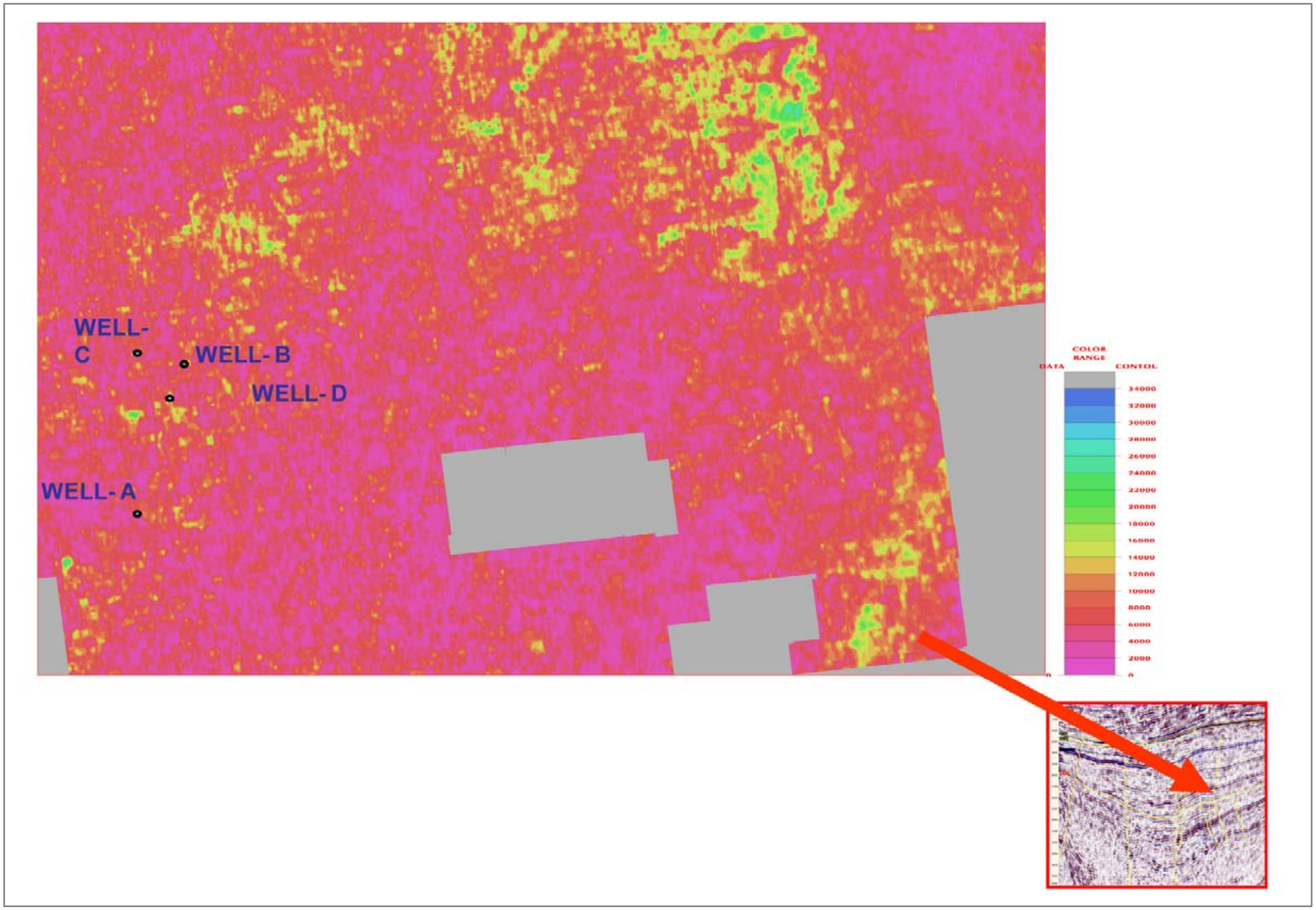

Figure 14. RMS seismic amplitude within Younger Cambay Shale (100 ms window).

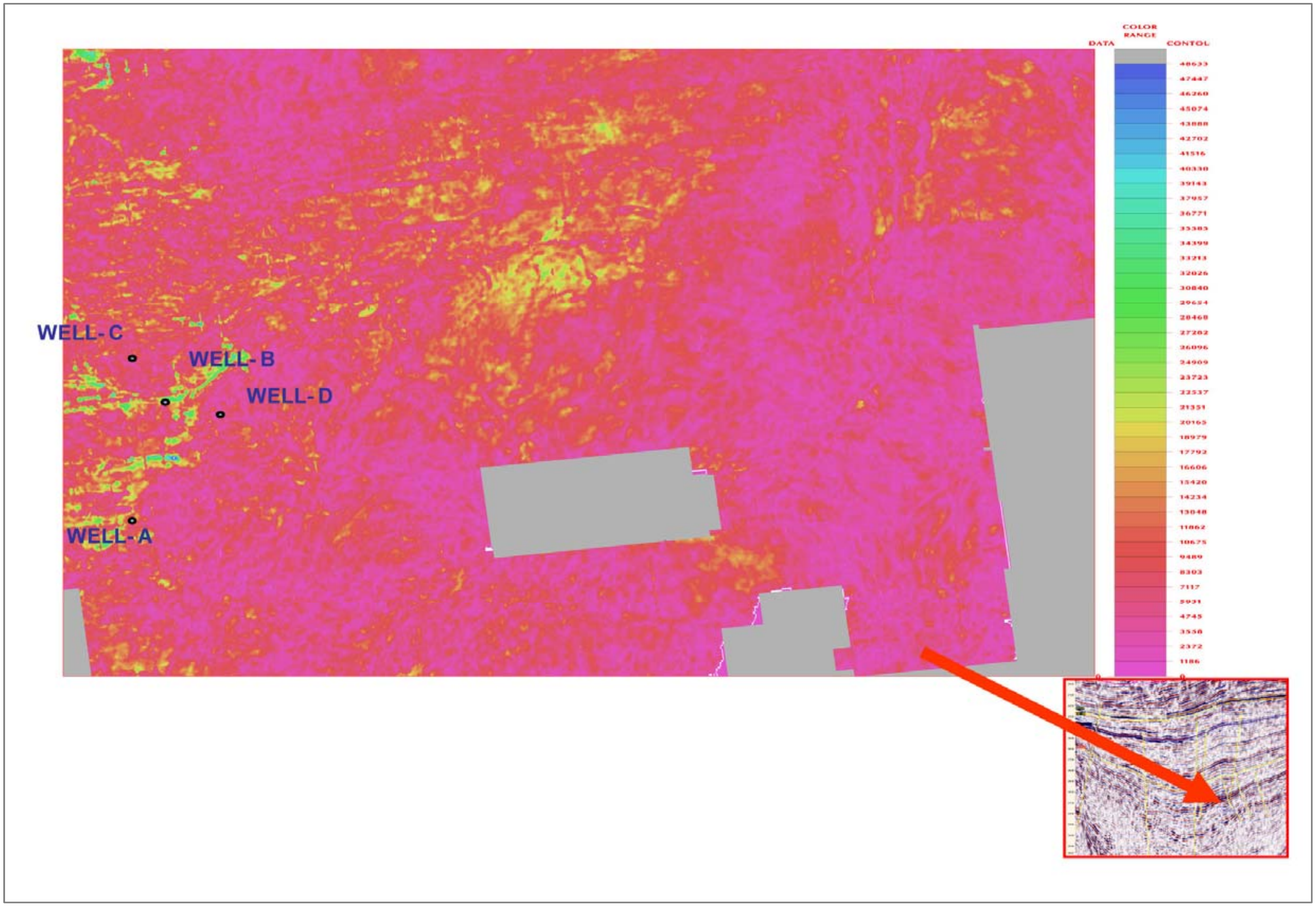

Figure 15. RMS seismic amplitude within Older Cambay Shale (100 ms window).