Identification of Shale Gas by VSP & Well Log Data

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Summary

An attempt has been made to identify shale gas zone with the help of VSP (Vertical Seismic Profiling) & well log data in a parametric well, Well-A drilled by ONGC in the Jambusar area of Cambay basin, Gujarat, India. The integrated study of zero offset VSP data pertaining to Well-A in conjunction with surface seismic data and various well logs helped to identify potential shale gas zones showed good correlation in Cambay shale.

There are few zones where VSP, well log data and surface seismic data are giving the good correlation which indicates likely to presence of shale gas in Well-A of Jambusar area.

Introduction

Shale gas is one of the important unconventional energy sources. It is natural gas produced from shale. It has been a game changer of the world energy market. Shale gas development is biggest energy innovation of recent times. It has become an increasingly important source of natural gas in the United States over the past decade, and interest has spread to potential shale gas in Canada, Europe, Asia and Australia. In India, shale deposits are found across the Gangetic plain, Assam, Rajasthan and many coastal areas. Broadly four basins viz. Cambay, Krishna-Godavari, Cauvery and the Damodar Valley are estimated to have commercial shale gas reservoirs. Recently, Oil and Natural Gas Corporation Ltd. (ONGC) has taken up initiative to explore and harness these resource potentials.

Shale formations act as the source as well as the reservoir for the natural gas. Each shale gas reservoir has unique characteristics. Shales ordinarily have very low permeability to allow significant fluid flow; most shales are not commercial sources of natural gas. Due to low matrix permeability, shale gas production in commercial quantities requires fractures at large scale.

Mapping the distribution of shale gas sweet spots and identifying their thermal maturity, organic carbon richness and natural fracture network using seismic data are of critical importance for shale gas field exploration and development.

Study has been carried out on one of the well from Jambusar area (Broach-Jambusar Block) of Cambay basin. The zero offset VSP data pertaining to the Well-A has been correlated with the set of other wire line log data and surface seismic data to identify various shale zone encountered in the well.

The present paper describes efforts made to evaluate the shale gas potential in a super deep Well-A drilled by ONGC in the Jamubsar area of Cambay Basin.

General Geology of Cambay Basin

Cambay Basin is an intracratonic rift graben located in the western part of India. The general basinal axis is NNW-SSE, but swings are noticed across major lineaments/ faults. Entire basin is divisible into five tectonic blocks (Figure 1), based on transverse fault system, and the associated depocentres are governed by rifted basement.

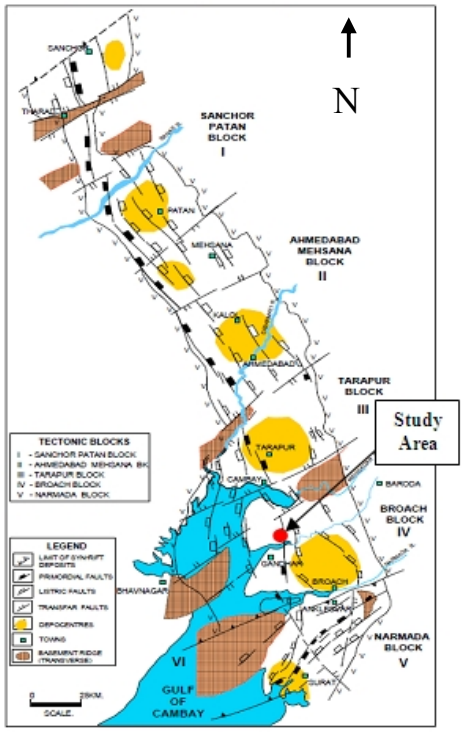

Figure 1: Map showing tectonic blocks of Cambay Basin (Mishra & Patel, 2011) and the study area.

A thick column of fine grained clastic sediment termed as 'Cambay Shale' is present in major depressions like

Broach,Tarapur and Patan etc. as shown in Figure 1. It belongs to Upper Paleocene to Middle Eocene age. This formation has been proved as an excellent source rock for generation of oil and gas in the basin. The study area falls in the Broach-Jambusar Block is shown in Figure 1 as red circle. This block has sediments up to 7 km at the depocenter.

Generation Potential of Cambay Shale

Isopach map of Cambay Shale is shown in Figure 2. Thickness of the Cambay shale varies widely from 50m to 70m over structural highs like Mehsana horst, Ankaleswar high to more than 1000m in Broach, Tankari, Tarapur and Patan depressions. The temperature gradient has been observed to be varying from 3° - 6 ° C/100m in different parts in the basin. This has provided a very favorable geological environment setting for hydrocarbon generation in the Shale in all depocentres (Mishra & Patel, 2011).

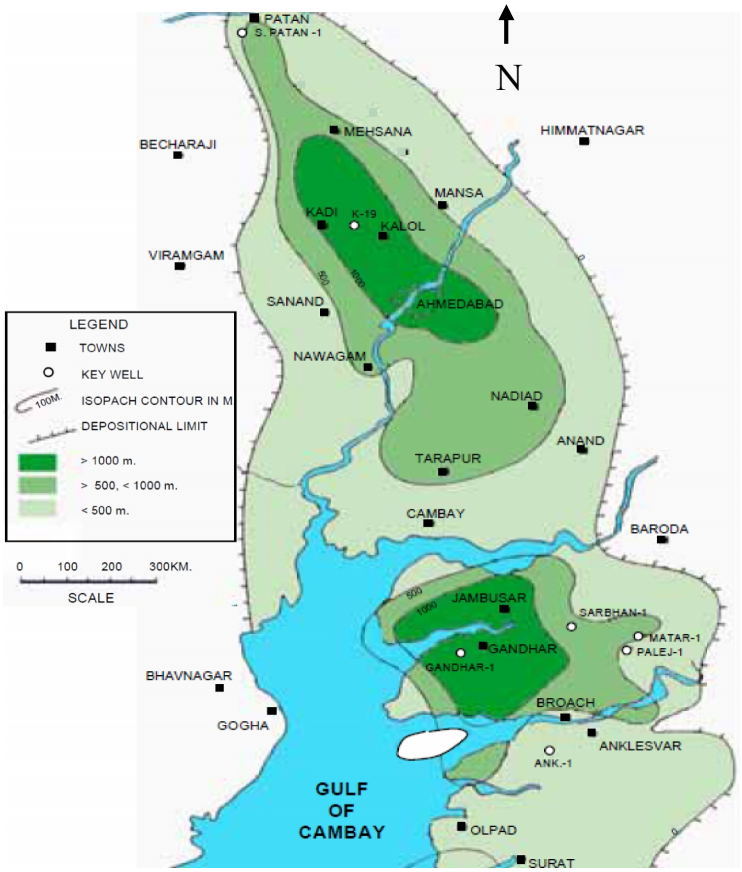

Figure 2: Isopach map of Cambay shale, DGH (2009)

Figure 3 shows the total organic carbon (TOC) content; organically rich source sequence and Kerogene type and sediments have mixed type II and III organic carbon matter.

It has been noticed in some places that organic content of shales increases towards depocentres.

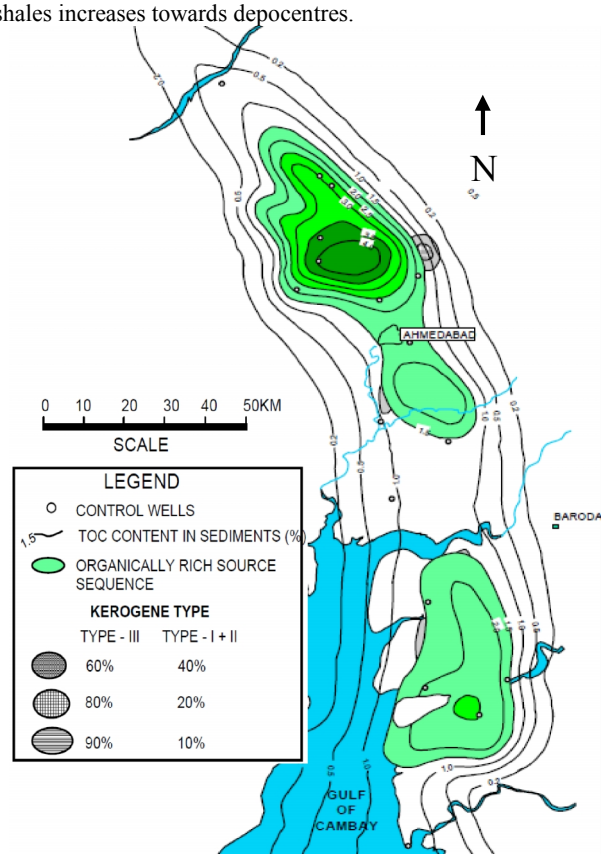

Figure 3: Map showing distribution of Kerogen type and TOC in Cambay Shale, DGH (2009)

According to Mishra & Patel (2011) the Cambay Shale has undergone different phases of maturation at different stratigraphic levels and depressions. After the expulsion of oil and gas from the shale in different depocenters, the remaining hydrocarbon generated has been trapped in pores, fractures and in kerogen surfaces either in free state or adsorbed state. In context of the geological setting of the basin in general and with special reference to Cambay Shale, there is likely presence of excellent reservoir character like pores, fractures and significant amount of kerogens. Also in many places, the shale shows good brittleness. Thus Cambay Shale holds tremendous potential for generation and storage of shale gas.

Cambay Shale comprises of two sections viz. YCS (Younger Cambay Shale) and OCS (Older Cambay Shale). OCS contains fewer sands and comprises of black shale. In northern part, YCS is thick and includes various prolific reservoirs whereas in southern part, it is not developed. Figure 4 shows the maturity map of middle part of Cambay Shale. Where green colour is showing oil window, blue one for peak oil generation region and pink depicts wet gas.

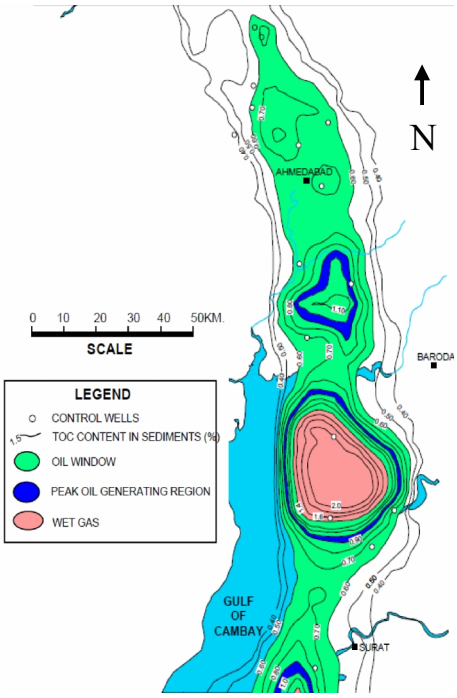

Figure 4: Maturity map of middle part of Cambay Shale (DGH, 2009)

Evaluation of Shale Gas

According to Emsley et al. (2011) shale gas resources can be evaluated with the combined study of surface seismic, VSP, well log and FMI. There are few key factors for development of shale gas and these include identification of sweetspots and distribution of brittle or plastic zone. Schematic of a workflow that can be used in the evaluation of shale gas resources is shown in Figure 5.

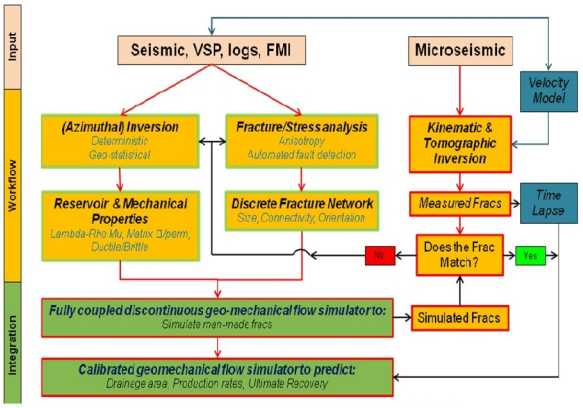

Figure 5: Schematic of a workflow that can be used in the evaluation of shale gas resources (Source: Emsley et al., 2011).

About Well-A

Parametric well, Well-A was drilled to explore hydrocarbons in Mesozoic sediments, Fractured Deccan Trap, Olpad formation, Cambay shale and the pinchout prospect of Ankleswar formation. The well had to be terminated at the depth of 5502m in weathered Deccan trap because of technical reason. It is one of the deepest well available in Broach-Jambusar block of Cambay Basin. Location of well-A is shown in Figure 6.

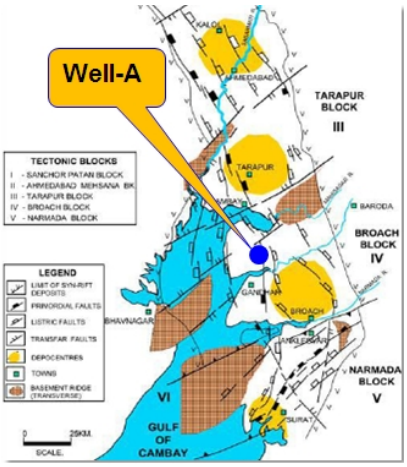

Figure 6: Location of well-A

Stratigraphy & lithology encountered in the Well-A is shown in Table 1 & Table 2 respectively.

Table 1: Stratigraphy of the Well-A

Formation Top	Depth (m) w.r.t. KB
Jhagadia	868
Kand	1035
Babaguru	1405
Tarkeshwar	1720
Dadhar	1822
Telva	1970
Ardol	1990
Kanwa	2260
Hazad	2292
Cambay Shale	2330
Olpad	2989
Deccan Trap	5447+

(Source: Unpublished Well Completion Report of ONGC)

Table 2: Lithology in deeper part of Well-A

Depth (m)	Lithology
1720-1827	Mainly shale with claystone and silty sand
1822-1970	Mainly coarse to medium grained sand
1970-1990	Mainly shale
1990-2260	Mainly coarse grained sand with shale/clay
2260-2292	Mainly shale
2292-2330	Mainly sand, medium lime grain with some amount of shale
2330-2989	Mainly shale with very small silty sand
2989-4090	Mainly shale with claystone and minor amt. of trap wash with calcite
4095-4365	Mainly claystone
4365-4685	Mainly trapwash with claystone
4685-4745	Mainly claystone
4745-5410	Alternation of trap wacke and claystone
5410-5502	Trap, trap wack and clay stone

(Source: Unpublished well completion report of ONGC)

VSP Data Analysis

Zero offset VSP was carried out in Well-A from 579 - 2949m (from MSL).

VSP Acquisition Parameter

(1) Recording instrument : DSS-10 A
- a) Number of Channels : 2
- b) Format : SEG 'B'
- c) Record length : 7 sec
- d) K-gain : 36db
- e) Sampling Interval : 2ms
- f) Lo-Cut : 6Hz
- g) Hi-Cut : 125Hz
- h) Notch : IN

(2) Geophone Tool used : Geolock-H (3 Comp)

(3) Energy Source:
- a) Type : Airgun (single)
- b) Volume of Airgun : 129 cu. inch
- c) Operating pressure : 2000PSI
- d) Offset : Approx. 56m
- e) Pit depth : 3m

(4) GL & KB
- Ground Elevation : 13.61m
- Kelly Bushing (KB) : 21.23m

(5) Meterage window (From KB) : 2970-600m

Depth interval
- 2970m - 2340m : 30m
- 2340m – 1400m : 20m
- 1400m - 600m : 100m

The processed output is shown in Figure 7 & Figure 9. Zoomed portion of Figure 6 from 2200-2949m is shown in Figure 8.

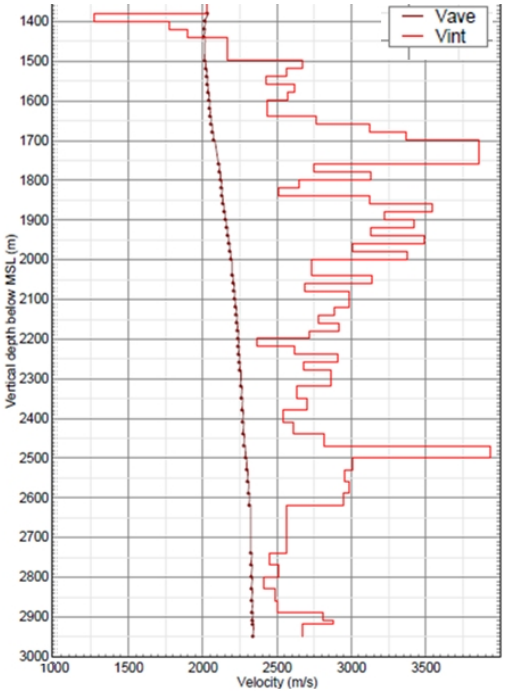

Figure 7: Average & interval velocity with depth

It is observed that Interval velocity is nearly flat from around 2620m to 2890m (Figure 7). Average velocity is also nearly constant from around 2620 to 2890m (Figure 8). Few zones are identified within dotted blue colour.

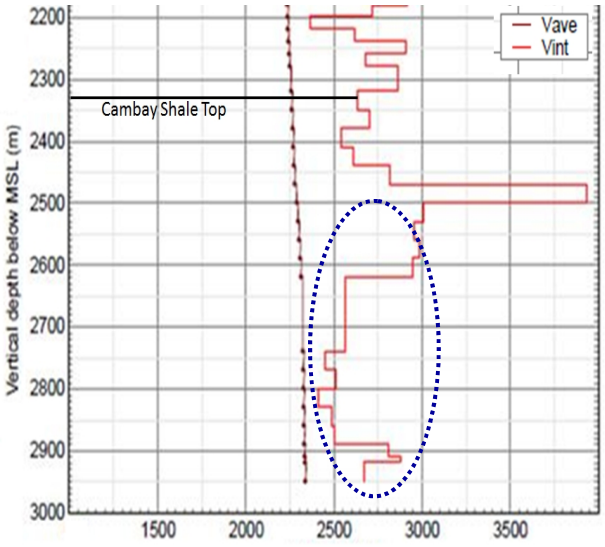

Figure 8: Average & interval velocity in Cambay Shale

Integrated correlation of well logs of Well-A, synthetic seismogram, corridor stack of VSP data and seismic section of 2D line are matching well as shown in Figure 9.

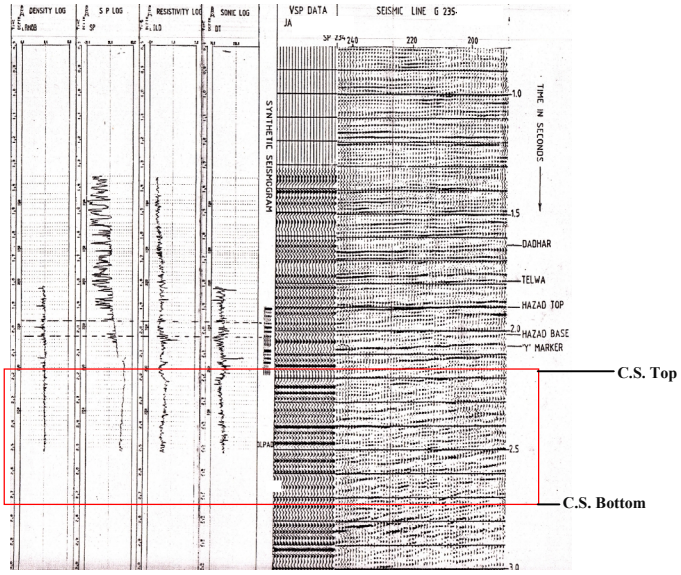

Figure 9: Integrated correlation of well logs of Well-A, synthetic seismogram, corridor stack of VSP data and seismic section of 2D line. (Source: Unpublished Report of ONGC)

Petrophysical Data Analysis

The primary data used for petrophysical analysis of shale formations are the same as those used for conventional reservoir analysis – gamma ray, resistivity, porosity and acoustic – with the addition of neutron capture spectroscopy data.

Gaseous zones in particular formation are identified based on following few observations:

- Gamma Ray log: High gamma ray counts to identify organic rich shale formations
- Resistivity log: The resistivity in gas-bearing shales are usually higher than those surrounding shales
- Sonic log: Lower interval velocity values
- Density log: Slight decrease or not much change
- Caliper log: Less caving, consistent values
- VSP data: Low & constant Interval velocity
- Surface seismic: Feable events, very low reflection zones and constant stacking velocity

Velocity (m/s), density (gm/cc), gamma (API) and Caliper (Inches) logs of Well-A are shown in Figure 10 and its zoomed portion is shown in Figure 11. Caliper log indicates that well condition was not disturbed from depth 2345 – 2989m as shown in Figure 10. Probable shale gas zones are identified within red box (2345 – 2989m).

Observations

The data pertaining to Cambay Shale has been observed in 3 zones in VSP, well log and surface seismic data. At the top of Cambay Shale, a zone is noticed in 2345-2412m. Cutting TOC data shows good TOC values in the range 2-2.5 wt% at this depth (CEWELL report). VSP data shows that Interval velocity is low and surface seismic also showing low reflection events at this interval.

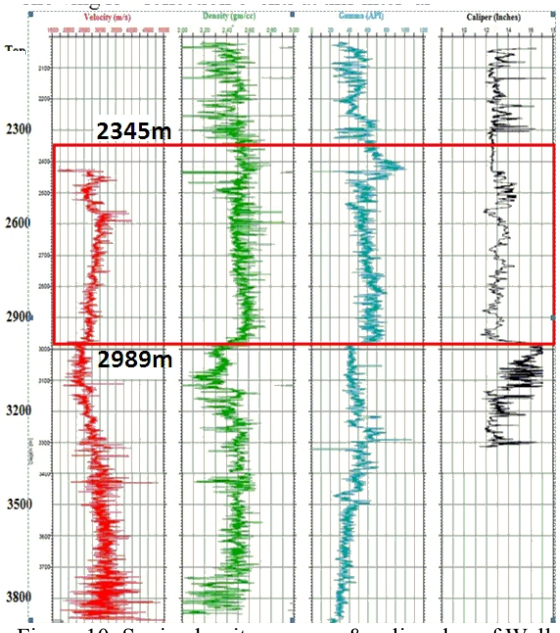

Figure 10: Sonic, density, gamma & caliper log of Well-A

In the middle part of Cambay Shale, a high resistivity and low gamma ray section without much change in porosity logs has been developed in the intervals: 2455-2480m. The zone is having TOC range from 1.5 to 2.5 wt% and shows some character of conventional reservoir. However, VRo (Vitrinite Reflectance), data is negative (~0.6 Ro). VSP data shows that Interval velocity is high in these depths. This zone requires further scrutiny to find out its shale gas potentiality.

Entire bottom section of Cambay Shale appears interesting in wells Well-A (2532-2990m) with average TOC of the order of 2.0 wt% (CEWELL report). In our analysis, VSP data shows that Interval velocity is very low and constant around 2532-2949m and average velocity is also constant from around 2600-2949m also giving clue about potentiality of shale gas. Surface seismic are also showing low reflection events and costant stacking velocity in this depth as shown in Figure 10 & 11.

Middle part of above section (2820-2898m) in well shows some decrement of TOC and VSP data shows constant interval velocity at this interval. VR value in the bottom part of this section in well is 0.8 Ro. As in other nearby fields, in this field also this section shows some lamination of high resistivity layers. Drilled section of Olpad Formation in well is not interesting from shale gas point of view (CEWELL Report). Total organic content & Vitrinite reflectance of Well-A at different identified depth are given in Table 3. Results of VSP & wire line log data of Well-A at different identified depth are given in Table 4.

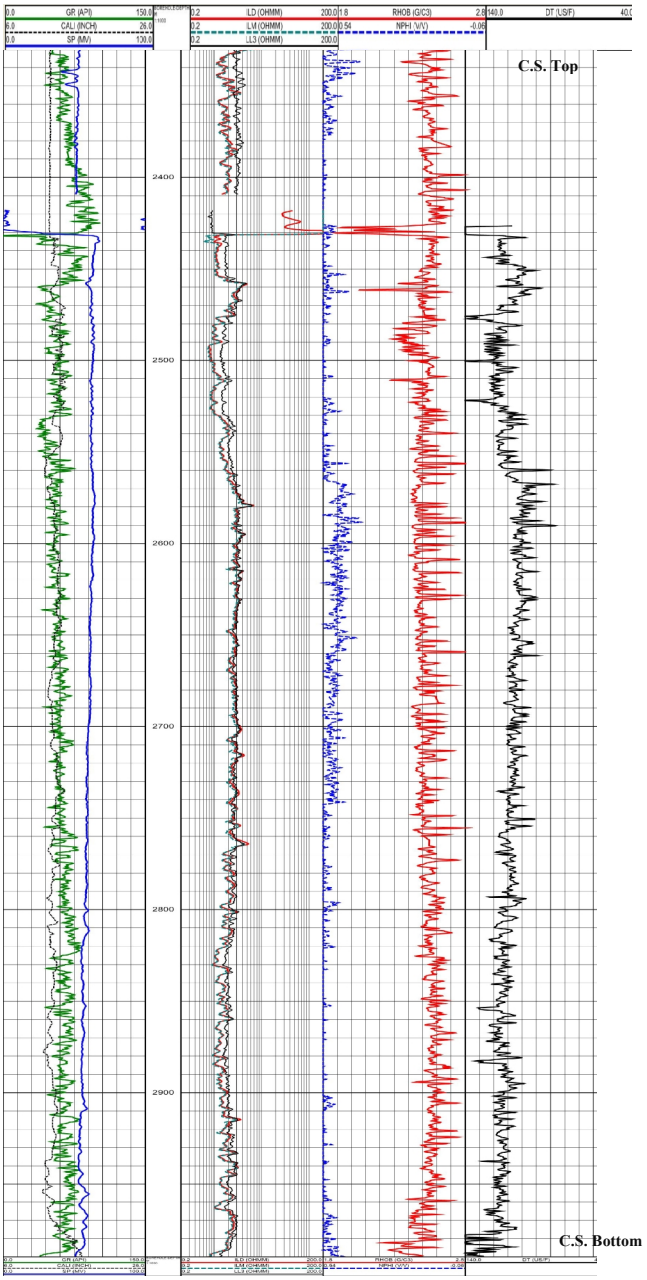

Figure 11: Gamma ray, caliper, resistance, density, neutron and Sonic log of Well-A

Table 3: Total organic content (TOC) & Vitrinite reflectance (VR) of Well-A indifferent zones

Zone	Depth (m)	TOC (%)	VR
I	2345-2412	2-2.5	-
II	2455-2480	1.5-2.5	~0.6 Ro
III	2532-2990	2.0	-

(TOC & VR values are taken from CEWELL Report, 2013)

Table 4: Results of VSP & wire line log data of Well-A in different zones

Zone	Depth (m)	V_{int}	Sonic	Density	Gamma Ray	Calip	Res.
I	2345-2412	L	NA	NC	H	NC	L
II	2455-2480	H	L	NC	L	NC	H
III	2532-2990	L & NC	H & NC	NC	H	NC	H

V_{int}= Interval Velocity, NC= Nearly Constant, NA=Not Available, H= High & L=Low as compared to nearby trend of data

Surface Seismic

Pre Stack Time Migrated (PSTM) 3D seismic data from Gandhar 3D merged volume around Well-A was studied. This data was taken. PSTM seismic sections along Inline & crossline direction, passing through Well-A, are shown in Figure 12 & 13 respectively. Depth and two way travel time (TWT) of Cambay Shale top and Cambay Shale bottom is given in Table 5. Possible shale gas potential Zone I – III along the Well-A was marked on the basis of very low reflection zones and costant stacking velocity as shown in Figure 12 & 13.

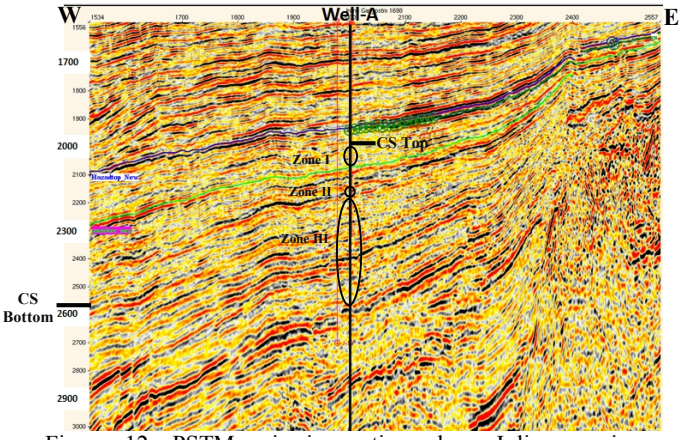

Figure 12: PSTM seismic section along Inline passing through Well-A

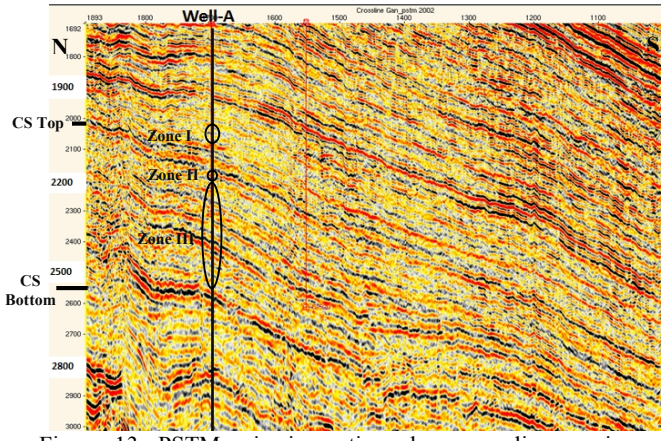

Figure 13: PSTM seismic section along crossline passing through Well-A

Table 5: Depth and Two way travel time (TWT) of Cambay shale top & Cambay shale bottom

Formation	Depth (m)	TWT (ms)
Cambay Shale Top	2330	2035
Cambay Shale Bottom	2989	2540

Deliberations

Based on combined analysis of VSP data, well log data, surface seismic and TOC three zones are identified as shown in Table 4 for shale gas potential zones in Well-A. Out of three zones identified, zone III in depth interval 2532 -2990m seems to be more interesting for shale gas prospectivity as VSP data shows low/constant average and interval velocity and Surface seismic are also showing low reflection events and costant stacking velocity in this zone. Correlation of various well logs viz. density, self-potential, resistivity & sonic logs of Well-A is shown in Figure 8. Integrated correlation of these well logs of Well-A, synthetic seismogram, corridor stack of VSP and seismic section of 2D line passing through well are presented in Figure 9.

Conclusions

- Nearly constant average and lower interval velocity in the deeper part of Well-A indicates shale gas potential zones.

- With the help of integration study of zero offset VSP data, surface seismic, TOC and well-log data, three probable shale gas zones are identified. Out of above three zones Zone III (2532 -2990m) within Cambay Shale have seems to have better potential.

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