10th Biennial International Conference & Exposition

P 159

Delineation of Thin Reservoir Pay Sand and it's Prediction in Saurashtra Dahanu Area, Western Offshore Basin, India-A Case Study

B.K Singh, P.V.V. Satyanarayana, K. R. Nambiar, U.G. Marathe,*

Summary

The delineation and prediction of thin pay sands is a challenge in hydrocarbon exploration especially when the thickness is below the conventional seismic resolution. A thin gas bearing sandstone reservoir within Daman Formation of Upper Oligocene age is encountered in the Saurashtra- Dahanu area of Western Offshore Basin, India. The block covers an area of 2500 sq. km. and six wells have been drilled so far for exploration of hydrocarbon to test prospectivity within Early Eocene to Early Miocene sequences. Two of the wells produced hydrocarbon gas in commercialquantity from Daman reservoir pay sands of 3-5m thickness. In the third well, thin 3 mts sandstone within same Daman Formation is interpreted to be hydrocarbon bearing although it was not conventionally tested. These thin sandstone reservoir occur at a depth of around 2600-2700m (TVD) and cover a distance of ten kilometers between two farthest tested hydrocarbon wells. The attributes generated to delineate and predict its distribution with conventional seismic data did not give desired results and using the λ/4formulae, required thickness of about 15m was calculated for generating meaningful attribute. An attempt was, hence, made to delineate these thin reservoir pay sands using FUGRO-Jason software. Result based on S impedance volume and Vp/Vs volume demonstrates that delineation of thin pay-sandstone can give desired results in the Saurashtra Dahanu and nearby areas.

Keywords: *Inversion, Mumbai Offshore*

Introduction

Hydrocarbon exploration is not only cost intensive but also risk reward is skewed in favour of bigger discoveries. However, with global oil prices ruling over $100/bbl, efforts to tap every conceivable hydrocarbon reservoir get priority. Thin hydrocarbon reservoirs are challenging in terms of its delineation and prediction and new techniques and softwares are increasingly being used.

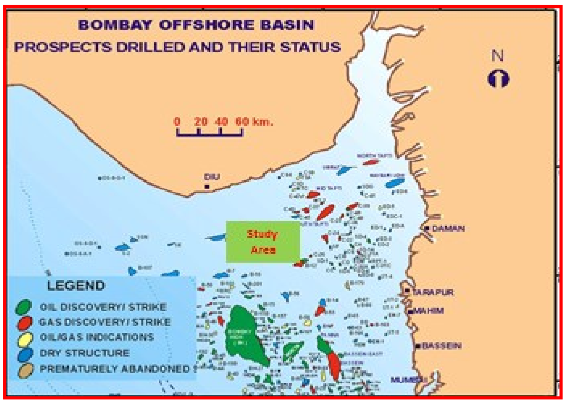

Fig. 1 Location Map of the study study area and the oil & gas fields in Mumbai Offshore Basin

The Saurashtra –Dahanu block covering an area of 2500 sq. km. is situated in the north of Bombay Platform in Western Offshore Basin, India **(Fig. 1)** Six wells have been drilled so far in this area out of which two have produced gas in commercial quantity and the third is interpreted to be hydrocarbon bearing.The tested wells, B-9-A and B-9-C have flowed gas @ of around 300,000 m3/day but the thickness of pay-sand is less than 5m though the distance between these two wells is around 10km. Since amplitude based attributes generated from conventional seismic data did not give meaningful interpretation to delineate these thin reservoir pay sands, Fugro-Jason's inversion software was employed to predict likely extent of these pay sands in a limited area.

Geological Background

The Saurashtra-Dahanu block is situated to the north of Bombay Platform, south west of Tapti-Daman area and east of Saurashtra depression. It has an area of 2500 sq. km. with B-9 field in the north western part with drilled wells B-9-A, B-9-B, B-9-C, B-9-D, B-9-F and B-9-Gand

ONGC, Mumbai, India,
* *birendra1963@yahoo.com*

B-12-9 field in the south eastern part with drilled wells B-12-9-A, B-12-9-Band B-12-9-C (Fig. 2).

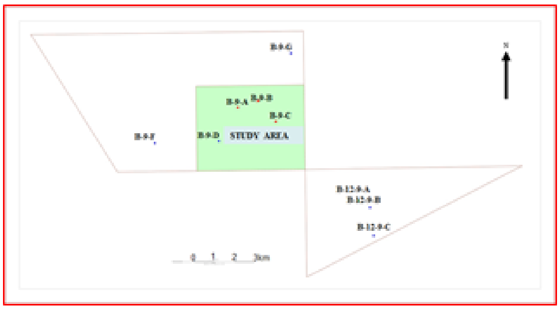

Fig. 2 Location Map of Saurashtra-Dahanu Area showing drilled wells and study area

The sedimentary fill in the drilled wells range from 3000 to 4400m (unpublished well completion reports). The deepest well, B-9-D, which encountered basaltic basement at a depth of 4250m was terminated at 4433m. The basin consists of sediments from Paleocene to Recent and overpressures have been encountered within Eocene, Early Oligocene, Late Oligocene and Early Miocene respectively (Nambiar et. al., 2010). The generalised stratigraphy is given in Fig.3.

The B-9 structure is a north east-southwest trending inversion structure formed due to reactivation of north east- south west trending fault(Fig.4). However the intensity of the structural strain is more pronounced in the eastern part, where wells B-9-A, B and C are drilled, as compared to western part, where B-9-D is drilled. The B-12-9 field in the south eastern part is located on a basement high and has been subjected to rotational movement. The strike slip movement has resulted in the structuring along B-12-9A and its north western corridor. The small structures formed are broadly east-west trending.

The Panna formation of Paleocene to Early Eocene with mainly Type- III and Type-II organic matter is the dominant source rock unit. Hydrocarbon accumulation is proved within sands of Daman Formation of Late Oligocene age and Mahuva carbonates of Early Oligocene age. The migration is through deep seated faults whereas shales provide effective top seals

Age	Formation	Thickness (m)	Lithology	Environment of Deposition	Bathymetry (m)
Recent to Late Miocene	Chinchini	1430			
Middle Miocene	Bandra & Tapti	400		Carb. platform Prodelta	
Early Miocene	Mahim & Bombay	600		Pro delta Poorly agitated platform interiors	
Late oligocene	Daman	480		Tidal flat & near shore environment	20-30
Early Oligocene	Mahuva	520		Shallow open marine	10-30 40-100
Eocene to Paleocene	Panna	570		Inner Neritic Open circulation shelf	10-20
Createaceous	Deccan Trap	400(+)			

Fig. 3 The Generalized statigraphy of the area

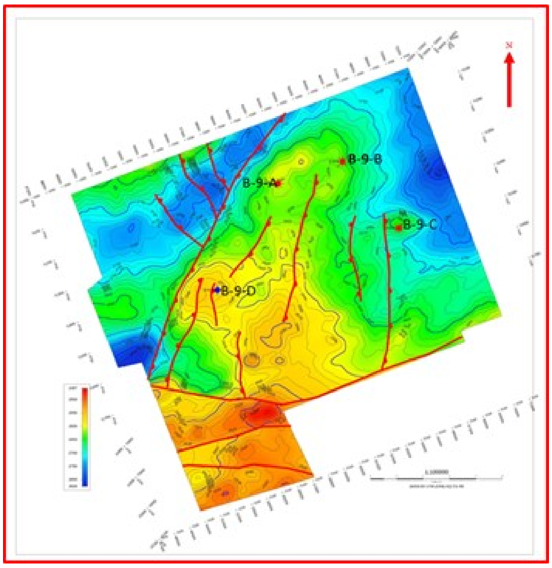

Fig.4 Structure Map of Daman Pay of Study area

Delineation of Thin Daman Pay Sands

The study area has 4 exploratory wells, out of which three wells are gas bearing. The area is covered by 3D seismic surveys. The original volume was processed as prestack merged PSTM processed volume and the study area forms part of this volume.

The late Oligocene (Daman) pay sand varies in thickness from 3 to 4.5m. (**Fig.5**) Objective of the present study is better delineation of the likely distribution of this particular pay sand. Horizon correlation was done using Landmark's seiswork software and inversion software Fugro Jason was used for carrying out deterministic inversion.

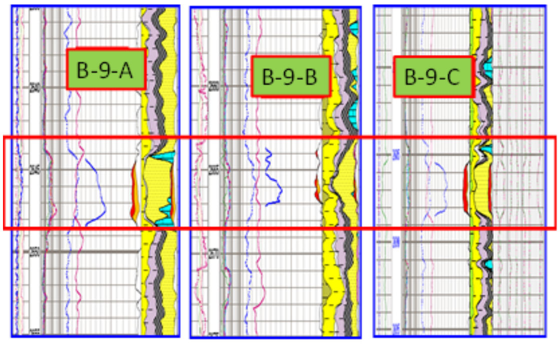

Fig.5 Elan processed logs showing thinDaman Pay sand in wells B-9-A, B-9-B and B-9-C Seismic and well database

Three seismic volumes – Main B-9, North of B-9 and West of B-9 were earlier merged at prestack level and PSTM processed. Part of the merged volume corresponding to study area was conditioned and five angle stacks (5-11deg, 11-17deg, 17-23deg, 23-27 deg and 27-35deg) were generated. As part of conditioning, residual velocity analysis was done and the velocity volume so generated was used for generation of flat gathers which was subsequently used for generation of angle stacks. Processes those were not friendly with amplitude preservation were not used. Fig. 6 shows the pre and post conditioned gathers. A marked improvement in flattening of events post conditioning is visible. The data used is of normal polarity i.e. increase in impedance is a trough.

The study area has four exploratory wells (B-9-A, B-9-B, B-9-C and B-9-D). Gamma ray, resistivity, P sonic, density and porosity logs are available in all the wells. However all the data were having spikes and sometimes discontinuous. Hence, electro-log data was conditioned before interpretation. The S wave log of only well B-9-C was used to conclude the study.

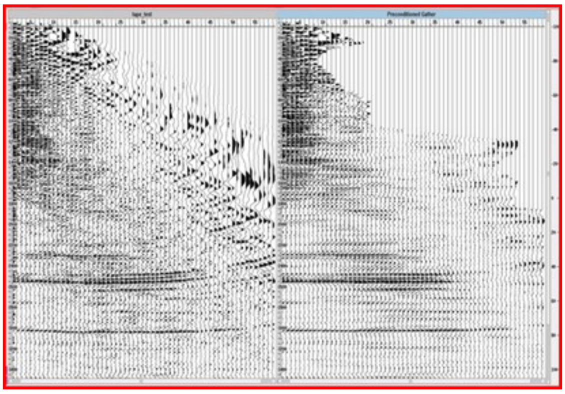

Fig.6 :Pre and Post conditioned gather of Inline 1553 and Crossline 3341. Marked improvement observed in post conditioned gather

Project Creation and Data Loading

A deterministic inversion project restricted to area of interest was created using Fugro Jason Software. Five angle stacks corresponding to 5-11deg, 11-16deg, 16-23deg, 23-29 deg and 29-35deg were loaded in the project. Well logs, geologic picks and time depth relation of four wells viz. B-9-A, B-9-B, B-9-C and B-9-D were loaded. Three horizons correlated in seiswork were imported to this project. The imported horizons were smoothed and interpolated for further use. Small set of PSTM gathers around well bores were also loaded for analysis and quality checking.

Seismic Data QC

To know the suitability of seismic data in inversion studies, quality of the data was checked. The data was analyzed to know

- amplitude histogram
- Amplitude time and frequency
- Data alignment
- Average amplitude spectra

All the stacks were checked for data clipping and skew. The data set was found to have no amplitude bias, no clipping and insignificant skew.No anomalous frequency and absence of significant footprint in the zone of interest is seen, however, few notches are present in the data. Alignment among all five stacks is variable, both laterally and vertically. Average amplitude spectra of all five stacks are shown in the Fig.7. No average amplitude spectra issue is present in the data as the spectra bandwidth is decreasing with far angle stacks.

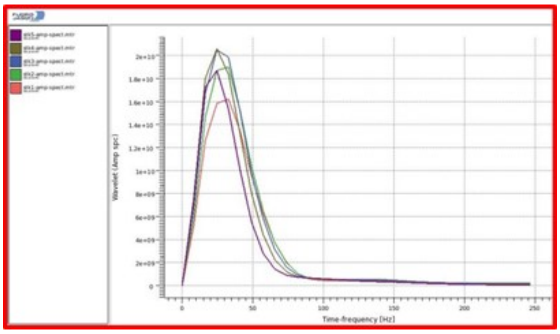

Fig. 7: Average Amplitude Spectra of different angle stacks. Farthest angle stack showing lower frequency content

Feasibility Study

Feasibility study on available data was carried out by crossplotting different properties. Initially P impedance and Gamma Ray logs of all wells were crossplotted to know whether any separation exist between the two properties (**Fig.8a).** These crossplots show that the lithology is not separable on the basis of P impedance and Gamma ray logs. Another crossplot of Vp/Vs and P impedance of well data having shear logs was attempted **(Fig.8b).** On log scale, good separation exists whereas on seismic scale separation of a few samples exist which further decreases once we filter the data to seismic bandwidth. Simultaneous inversion was considered a better option for delineation of this type of sand based on vp/vs property.

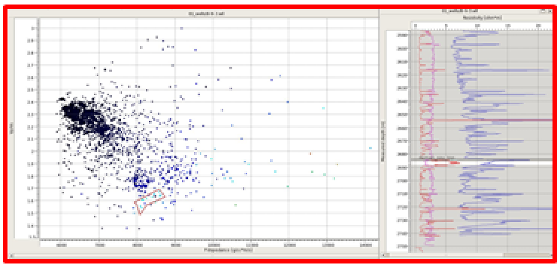

Fig. 8a: Cross plot of P impedance and vp/vs of well B-9-B. Lithology is separable to some extent based on these properties.

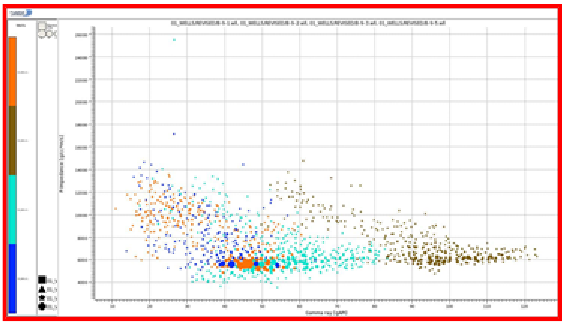

Fig. 8b: Cross plot of P impedance and Gamma ray of wells. Lithology is not separable on the basis of these properties

Horizon Correlation

Three horizons viz. Daman Top, Daman Pay and Mahuva were correlated using Landmark Seiswork software in the whole study area. These horizons were exported to Jason project for use. Interpolation and smoothening of these horizons were done in the Jason project.

Well calibration and wavelet extraction

The seismic well tie enabled to bridge the gap between the time and depth domains. The seismic well ties have been done for individual wells, e.g. the log input in the seismic well tie process is a log set that is created well-by-well. The sonic (P sonic) and the density (density) logs have been used as an input in the seismic well tie process. The seismic well tie workflow included an interactive sonic calibration process, wavelet extraction and generation of a synthetic seismogram.

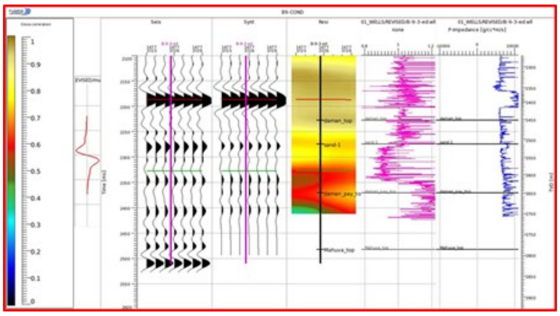

Fig.9 Sonic calibration window for well B-9-C

Sonic calibration process:

The sonic log has been matched to the time depth relationship for the wells where the data are present. The

TD relationship is considered to give more accurate seismic 'average' velocities than the sonic log. The TD relations are available for all 4 wells. By selecting a log set from the well, the window was populated with a sonic track and the primary check-shot. The sonic log is further calibrated by incorporating check-shot data. Sonic calibration window for well B-9-C is shown in **Fig9**.

Wavelet extraction process

The wavelet extraction process is performed by selecting the seismic volume and input log sets of interest. The output from the wavelet extraction process is a modified extracted wavelet, a synthetic trace and a depth-time curve, which might be different from the output in the sonic calibration process.

Synthetic seismogram

Synthetic seismograms have been generated in order to derive insight into the physical significance of reflection events contained in seismic sections. The synthetic seismogram represents the seismic response to vertical propagation of an assumed source wavelet through a series of horizontal layers of different acoustic impedance. Synthetic seismograms have been computed across a section of stratigraphic change and have been compared with observed data. The final synthetic trace in some cases bulk shifted stretched and squeezed to align it to the real seismic data.

Multi well wavelet for zero offset seismic

All the four wells calibrated separately have given 1 wavelet each. These wavelets were used to generate a single wavelet which was used for acoustic impedance inversion.

Extraction of AVO/AVA wavelet

Multi well wavelet is a representative wavelet for zero offset seismic. Near offset seismic volume has been used for zero offset stack volume. The zero offset wavelet extracted was used to extract AVO/AVA wavelets for different stacks. These wavelets were used for simultaneous inversion.

Model Building and Model Generation

A low frequency trend model was created for use in simultaneous inversion. The two main components of the model building are:

Model Builder: It creates all the parameters needed to generate a 3D model. Its output is a solid model

Model Generator: It starts from the solid model and generates a 3D data volume for all trace locations.
The purpose of the low frequency trend model is twofold.

- To generate a set of laterally continuous horizons which are used to define the constraints and the time gate for inversion.
- To generate a cube of interpolated logs which are used as low frequency trend in the inversion process.

Acoustic Impedance Inversion

INVERTRACE^{PLUS} module was used for acoustic impedance inversion. Fugro Jason Acoustic Impedance Inversion estimates P-impedance volume by using the information contained in the input seismic volume. The process is accomplished in three steps:

- P-impedance contrasts are estimated which create synthetics that honour the input seismic.
- P-impedance contrasts are integrated to create P-impedance traces.
- P-impedance is optimized by modifying the low frequency trend and enforcing the additional constraints.

All the parameters were properly tested before final application. All the outputs generated were checked for establishing the authenticity of inversion result.

Simultaneous Inversion

Rock Trace module of Fugro Jason was used for simultaneous inversion. The low frequency model prepared earlier was used for low frequency trend in this process. The output volumes generated were P impedance volume, S impedance volume and Vp/Vs volume which were used in interpretation.

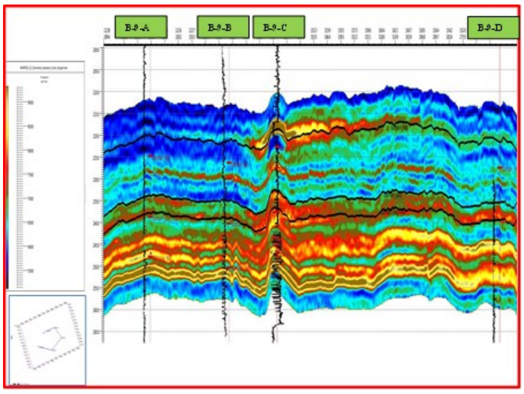

Fig.10 P impedance plot along RC line passing through wells B-9-A, B-9-B, B-9-C and B-9-D showing distribution of Daman Pay Sand along this line

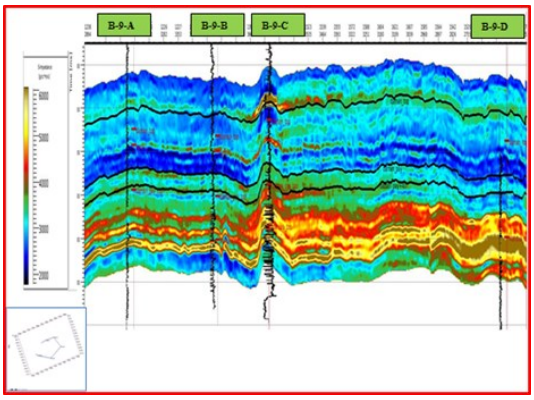

Fig.11 S impedance plot along RC line passing through wells B-9-A, B-9-B, B-9-C and B-9-D showing distribution of Daman Pay Sand along this line.

Interpretation of Results:

Different output volumes were studied singly and in combination with other volumes. The Daman pay reservoir is not visible as a single unit; rather it is visible as a composite unit. Fig.10 shows RC line through wells B-9-A, B-9-B, B-9-C and B-9-D with P impedance. Fig.11 shows the same RC line with S impedance in which Daman pay marker of wells is distinguishable on this section. Fig.12 shows Vp/Vs along the RC line. Daman pay marker is clearly demarcatedalong this line as is evident from the above plots.

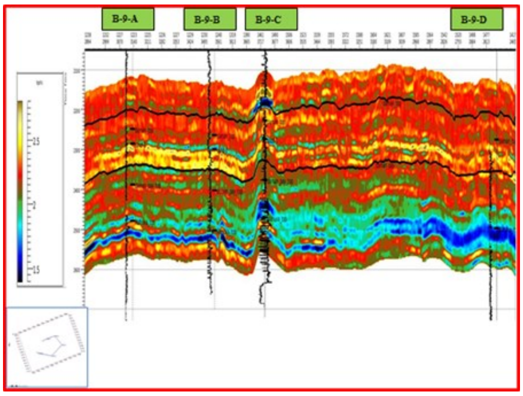

Fig.12 Vp/Vs plot along RC line passing through wells B-9-A, B-9-B, B-9-C and B-9-D showing distribution of Daman Pay Sand along this line.

The whole volume was sliced to understand the spatial distribution of P impedance, S impedance and Vp/Vs. The RMS of horizoncorresponding to Daman payshows the distribution of S impedance and Vp/Vs which may be the distributionof Daman pay in the study area (Fig. 13).Similar attributes for Vp/Vs volume of same window is shown in Fig.14.This interpretation is corroborated by drilled wells data.

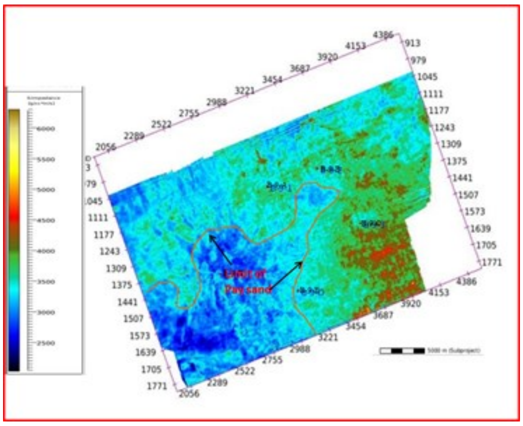

Fig.13 RMS of S impedance (window length 38ms to 42ms) from Daman Pay Horizon showing probable distribution of Daman Pay Sand. The area towards east, northeast and northappears to be more favorable locale of this sand.

Conclusion

Late Oligocene Daman pay sands of 3 to 5m thickness in Saurashtra-Dahanu area in western offshore basin could not be delineated by using amplitude based attribute studies.Simultaneous inversion using Fugro-Jason software was used to generate the P impedanace, S impedance and Vp/Vs volumes.The RMS of horizon slice corresponding to Daman pay shows the distribution of S impedance and Vp/Vs which corresponds to probable distribution of Daman pay sand in the study area.The pay sand distribution pattern derived from the inversion study is corroborated by the well data in the area.

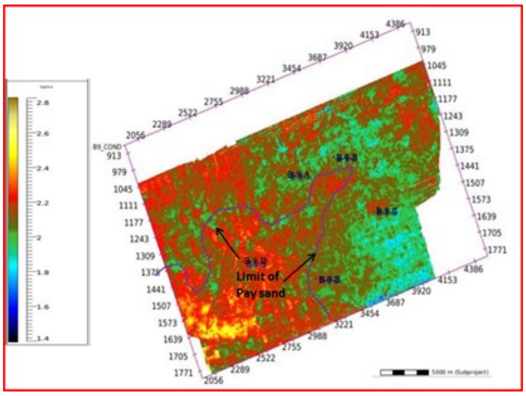

Fig.14 RMS of Vp/Vs (window length 38ms to 42ms) from Daman Pay Horizon. The area towards east and north east and north appears to be more favorable locale of Daman Pay Sand

Acknowledgement

The authors sincerely acknowledge the ONGC authority for permittingto publish the work of this study. The authors are also grateful to ED-COED, WOB, Mumbaifor his valuable guidance during the course of the work. Authors are also thankful to colleagues of the KS Block, WOB, Mumbai for their fruitful discussions.

Views expressed in this paper are those of the authors only and the data utilized is not going to affect ONGC's business interest in any way.

References

Brown, A R, 1991, Interpretation of 3D seismic data, AAPG Memoir 42.

Kallweit, R.S. and Wood, L.C., 1982, The limit of resolution of zero phase wavelets: Geophysics, V 47, p. 1035-1046.

Well Completion reports of Wells B-9-A, B-9B, B-9-C, B-9-D, B-12-9- A and B-12-9-B (Unpublished ONGC reports)

Nambiar, K.R., et al, Distribution of Overpressure and its Prediction in Saurashtra Dahanu block,Western Offshore Basin, India :APG conference, Delhi, India, 2010.