PS Time-Depth Modeling in High Pore-Pressure Environment, Offshore East Coast of India*

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Abstract

Time-depth conversion becomes challenging in a complex geological environment. This study investigates plausible models between depth and interval velocity in a high-pressure depositional environment. The VSP data of six wells from three basins in the offshore East Coast of India have been analysed to estimate the high-pressure boundaries, depositional breaks and lithological boundaries. The time-depth modelling to understand the high-pressure environment has been tested on four models: a) the linear interval velocity model in depth, b) the linear interval velocity model in time (TWT), c) the average velocity model in time (OWT) and d) the exponential interval velocity model in time (OWT). A decrease in interval velocity evident on well data is utilized for identification of high-pressure boundaries on seismic data accurately only if, it provides a consistent fit to both time-depth and velocity-depth data. The results indicates that the average velocity model in time (OWT) is the most suitable model among the four models tested in this work for time-depth conversion for high pore pressure environments in the offshore East Coast of India. It is recommended to use this analytical velocity model for derivation of normal compaction trend in this area for optimal time to depth conversion. From the analysis of additional data of different basins, it was observed that the velocity drop might not be always due to the presence of high pore pressure. It could also be due to the change in lithology or the presence of erosional boundaries.

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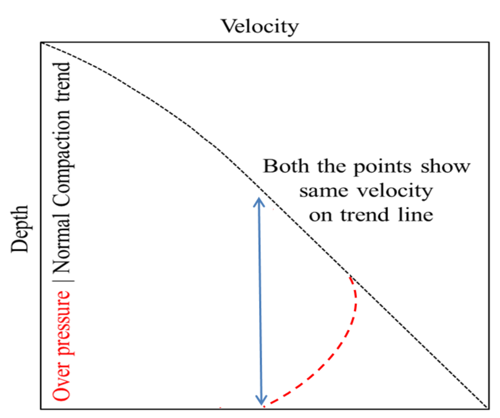
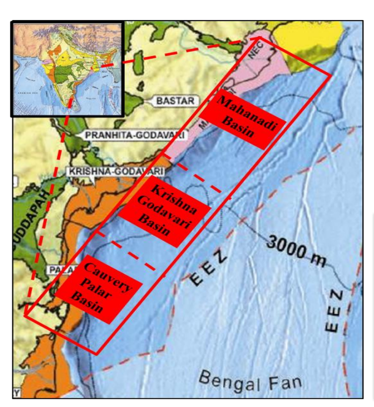
Introduction

Abnormal pore pressures occur in almost all types of reservoirs. Fluid pressures in the pore spaces of rocks affect various aspects of petroleum exploration and production (Bruce & Bowers, 2002). Generally subsurface-sediments follow a gradual increase in velocity with depth because of the effect of compaction but the presence of erosional channel bodies breaks this trend and shows a sudden decrease in velocity, which are recognized, as high pore-pressure zones (Fuloria 1993). These high pore-pressure zones can be predicted from well log and seismic data. However, this requires an appropriate time-depth model that should be used in seismic data processing for integration of well velocities with seismic data.



Relationship between depth and velocity in case of high pore-pressure environment

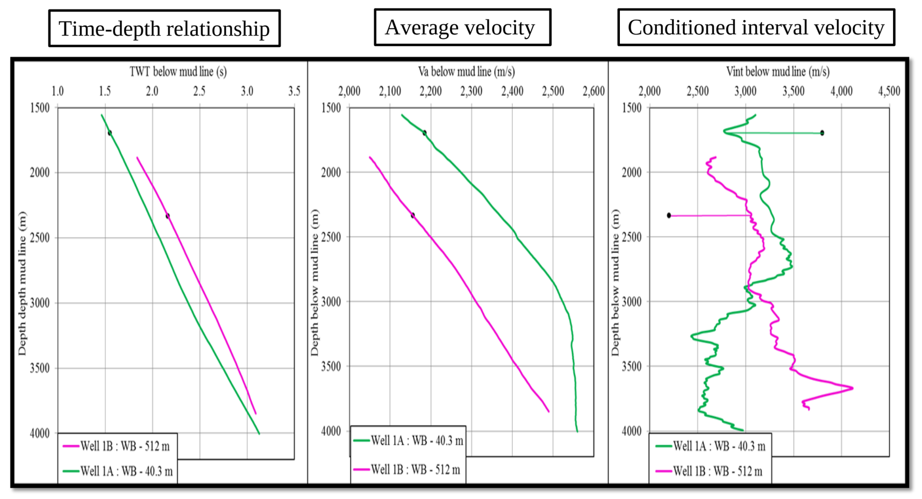
The present study performs time-depth modeling for high-pressure depositional environment along the offshore eastern coast of India.



Map showing location of three sedimentary basins of India. Mahanadi basin, Krishna-Godavari basin and Cauvery-Palar basin. Source – www.dgh.org

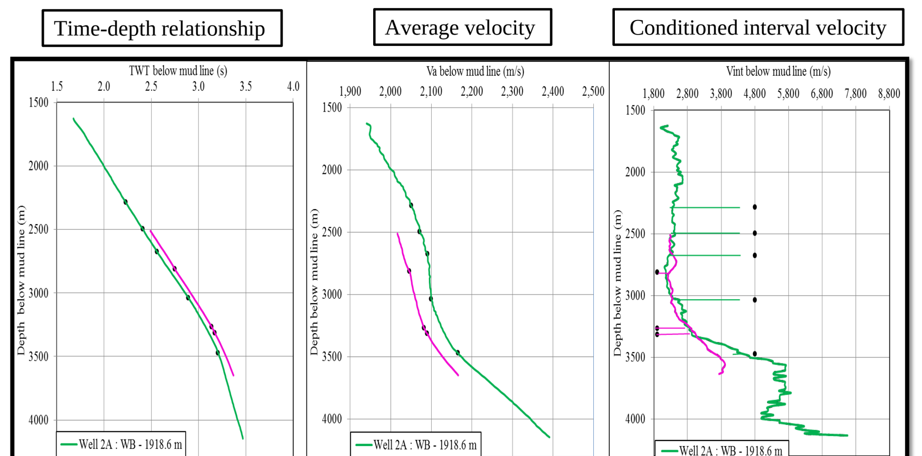
Six Wells VSP Data

Time-depth relationship | Average velocity | Conditioned interval velocity



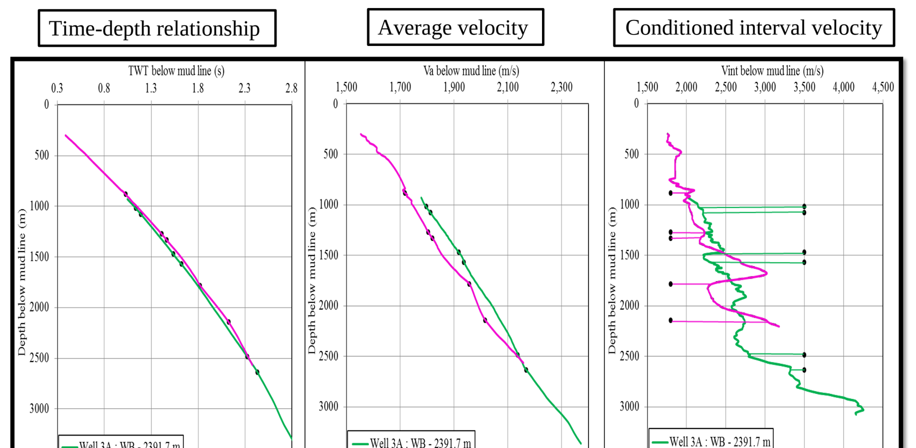
- Water Depth: 512m and 40.3m
- Data represents offshore High Pore-Pressure environment.
- Geological Age markers are plotted on data using black dots

Time-depth relationship | Average velocity | Conditioned interval velocity



- Water Depth: 808m and 1918.6m
- Data represents tectonically uplifted, decompacted environment
- Geological Age markers are plotted on data using black dots

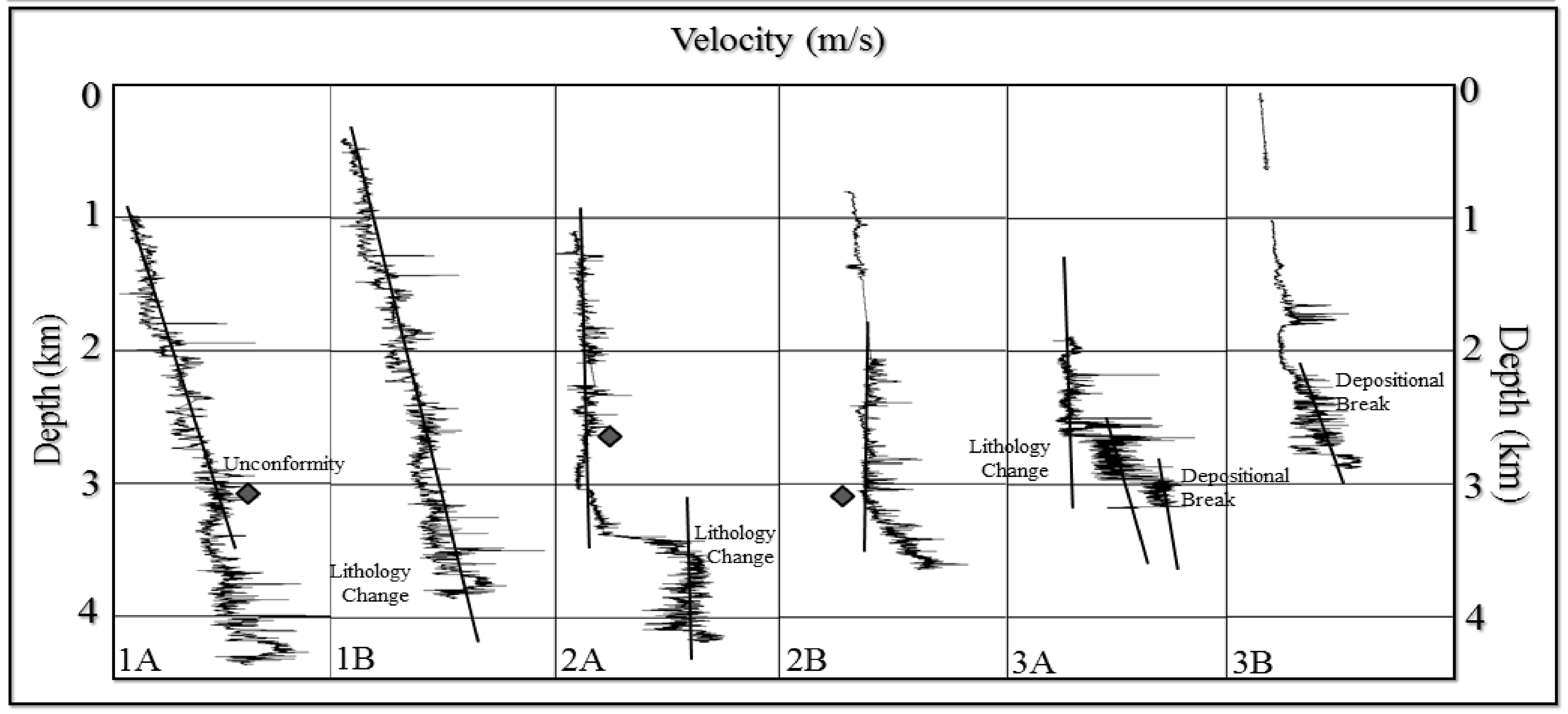
Time-depth relationship | Average velocity | Conditioned interval velocity



- Water Depth: 1185m and 2391.7m
- Data represents presence of lithological unconformity boundaries
- Geological Age markers are plotted on data using black dots

Interval velocity trend of six wells -

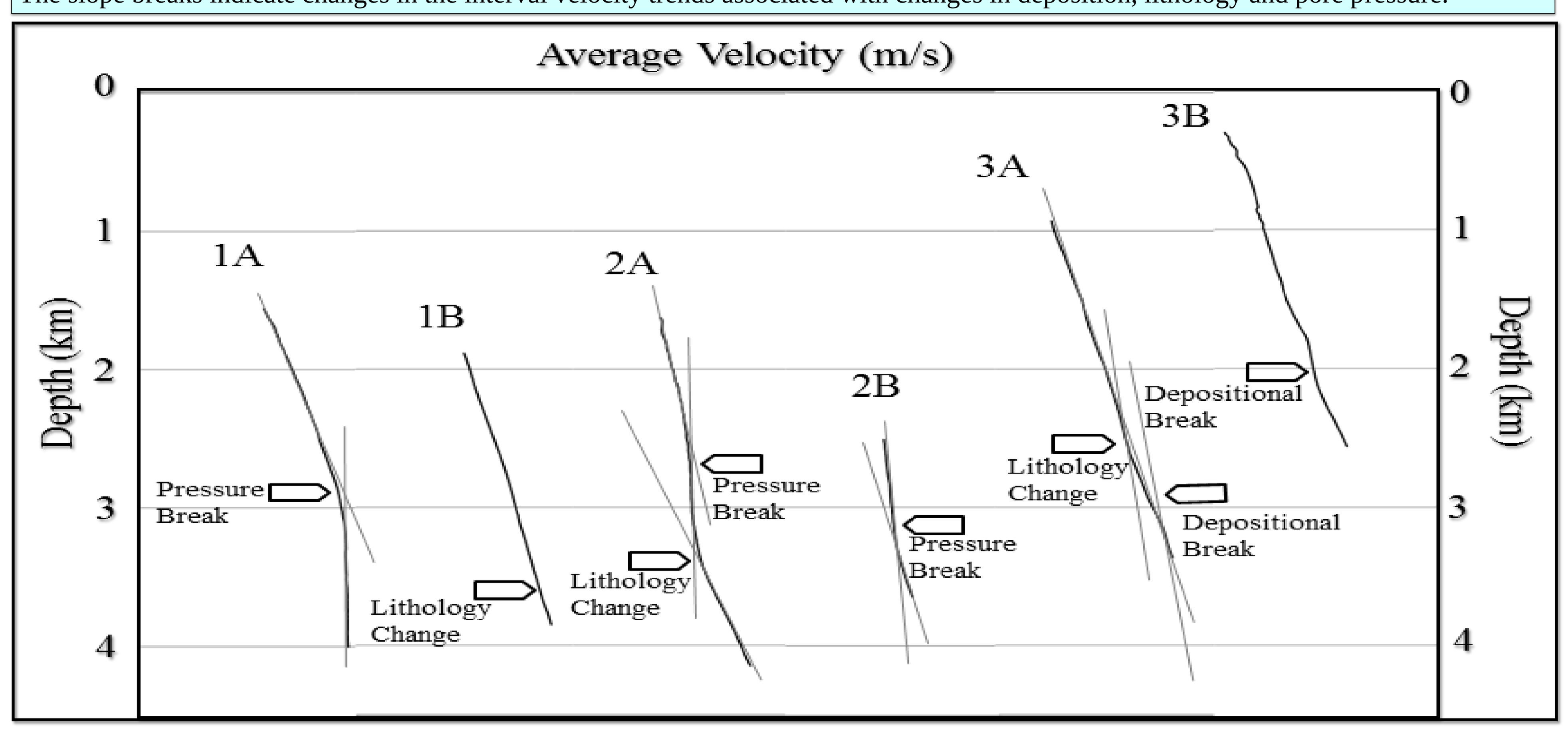
The signature of high pressure boundaries, depositional breaks and lithological boundaries are analyzed from sonic log data of 6 wells of different basins. The zone of interest lies between 2 and 3 km below the water column.



Sonic-velocity versus depth for six wells, 1A, 1B, 2A, 2B, 3A, 3B. Approximated normal compaction trend has been shown as smooth lines. Overpressure zones are indicated by diamonds. Calibration of unconformity boundaries, lithological boundaries and depositional breaks have been done using available wireline logs (Including gamma-ray and mud logs)

Average velocity trend of six wells -

The Average velocity curves for the six wells wells using VSP checkshot data. The slope breaks indicate changes in the interval velocity trends associated with changes in deposition, lithology and pore pressure.



Average-velocity versus depth for six wells, 1A, 1B, 2A, 2B, 3A, 3B. All of the important trends observed in interval velocity are manifest as slope changes in the average velocity plot of VSP data

Why VSP Data ???

- Provides direct time-depth values, irrespective of bore-hole conditions
- Relatively noise free as compared to sonic data

"While dealing with real data, signal to noise ratio of the data is of paramount importance."

Few fact's about Average Velocities

Average velocity is closely akin to seismic stacking velocity. Stacking velocity does not always need to be converted to interval velocity to infer pressure anomalies and for lithological breaks.

There are ***four observations***:

- An increase in slope (toward the vertical) indicates a reduction in interval velocity.
- A decrease in slope (toward the horizontal) indicates an increase in interval velocity.
- A sharp slope break indicates an abrupt interval-velocity change.
- A smooth transition in the slope of the average velocity implies the same in interval velocity.

"Average velocity slope change gives an idea about appropriate filtering of interval velocity across the boundaries".

Requirements for Empirical Model (Bell, 2002)

Various properties are desired of an empirical model used to characterize noisy data.

- First, *the model parameters should be fairly in-sensitive to the range of the data* and the number and placement of individual data points. A corollary is that the model can be used to confidently extrapolate data into regions where the model applies but data are lacking.
- Second, the differences between the values predicted by the model and the actual data points (the residuals) should be small and *randomly distributed about zero*.
- Third, consistent values of the parameters should be obtained where fitting the data with *mathematically equivalent statements, for example, using sonic transit time(ds) rather than Vi*.
- A fourth criterion is a *bias towards small number of parameters*. Any given data series can be fit perfectly with enough degrees of freedom, but extra parameters commonly fit noise rather than signal and tend to violate the previous criteria.

Selected Empirical Models

Four two-parameter models are selected for analyses. All the models yield a reasonable starting value, V_o = 1500 meter/second at zero depth. Well 1A : WB – 40.3 m selected for testing.

Model-1 : "A linear interval velocity model in depth"

$$V_i = V_o + kZ$$

Model-2 : "A linear interval velocity model in time (Two-Way-Time)"

$$V_i = V_o + kT$$

Model-3 : "An average velocity model in time (One-Way-Time)"

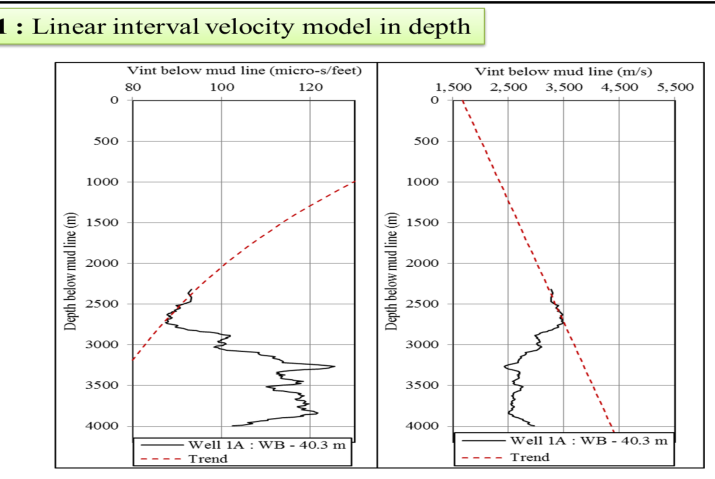
$$V_a = V_o + kT/2$$

Model-4 : "An exponential interval velocity model in time (One-Way-Time)"

$$V_i = V_o e^{kT/2}$$

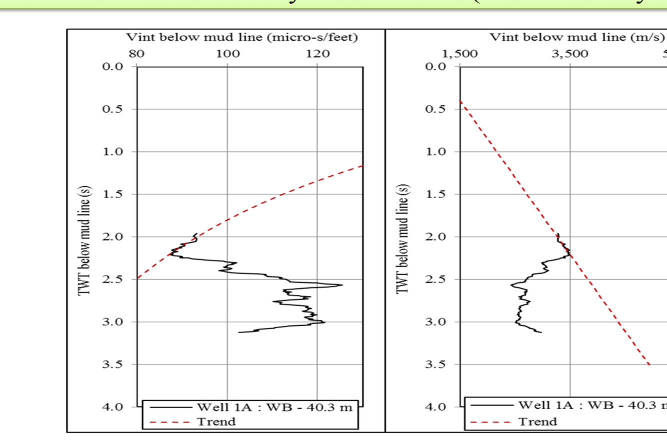
(Slotnick, 1936)

Model-1 : Linear interval velocity model in depth



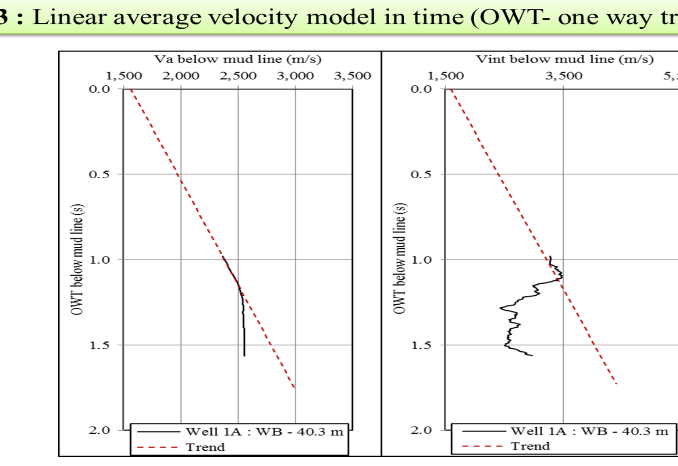
(b) shows the plot of interval velocity with depth while,
(a) shows the equivalent plot of sonic curve (slowness in micro-second/feet) with depth

Model-2 : Linear interval velocity model in time (TWT- two way travel time)



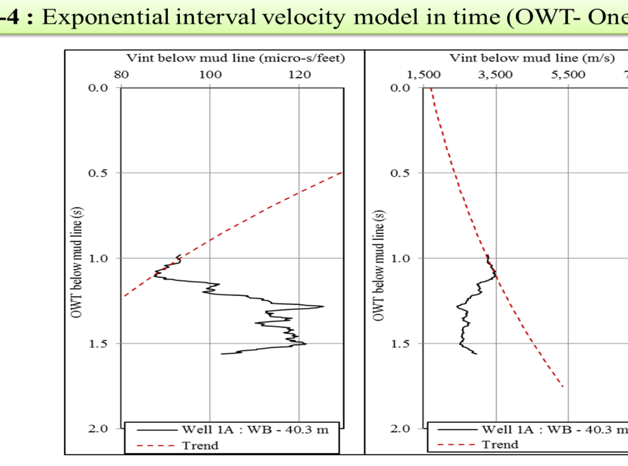
(b) shows the plot of interval velocity with TWT while,
(a) shows the equivalent plot of sonic curve (slowness in micro-second/feet) with TWT

Model-3 : Linear average velocity model in time (OWT- one way travel time)



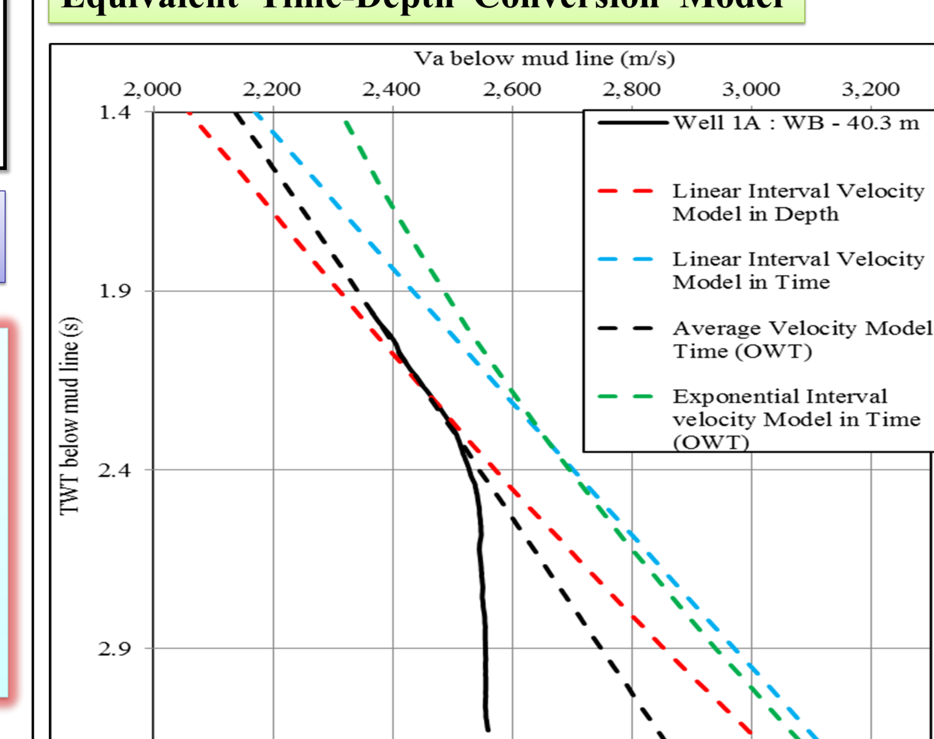
(b) shows the plot of average velocity with OWT while,
(a) shows the equivalent plot of interval velocity with OWT

Model-4 : Exponential interval velocity model in time (OWT- One way travel time)



(b) shows the plot of interval velocity with OWT while,
(a) shows the equivalent plot of sonic curve (slowness in micro-second/feet) with OWT

Equivalent Time-Depth Conversion Model



Summary and Results

- Objective of understanding of high pore pressure environment in terms of depth-time modeling.
- Velocity works as the key parameter to connect well data with the seismic data. Few offshore wells VSP data have been analyzed for this purpose.
- Well 1A encountered the highest pore pressure which has been selected for final analysis.
- Average velocity model in time (OWT) has come as the best model for time-depth conversion for high pore pressure environment.
- These results can be used for conversion of seismic data from time to depth domain as a representative of background shale trend for this area.

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