PS Analytical Velocity Modeling for Offshore East Coast of India: An Approach Using VSP Time-Depth Dataset*

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Abstract

Worldwide hydrocarbon exploration is moving towards reducing the cost of deep-water drilling due to tumbling oil prices. It became a timely demand to do an effective and efficient analysis of existing database(s). Therefore it is very essential to utilize the existing well data for further drilling and understanding of the basin. Data from more than 50 exploration wells is available from offshore region of the east coast of India, which spans water depths from 40.8m to 3100m. Of 13 wells in the Mahanadi basin, 6 wells showed very high pore pressures. Data from 27 wells in the Krishna-Godavari basin are from the Pleistocene/Pliocene to deeper targets represented by the Cretaceous). The Cauvery basin underwent huge erosion during Cretaceous times, very well reflected on interval velocity plot of data from 11 wells. Difference in geology of each basin is well reflected on interval velocity plots. V0-K method, which is the best known way of depth conversion of seismic reflection travel times, was applied on this dataset. This method had given excellent results in Gulf of Mexico and UK West of Shetlands areas. But large errors were produced while using it for time-to-depth conversion in Indian offshore basins. To constrain and test the accuracy, several other models were analysed (derived from V0-K method). Four models have been tested to understand different geological environments using time-depth data. The results indicate that average velocity model in time is very suitable for Mahanadi basin. For Cauvery basin, linear interval velocity model in time gives the optimum solution, while for shallow targets in Krishna-Godavari basin the well known "linear interval velocity with depth" (V0-K method) gives the optimal solution. For deeper targets in Krishna-Godavari basin the same relationship is applicable after incorporating a correction for uplift. Solutions have been verified on pre-stack seismic data, by considering the proposed model as equivalent guide function during velocity picking. These analytical velocity models are quite suitable for optimal time to depth conversion in this area; they can be updated further with addition of new datasets.

Selected References

Al-Chalabi, M., 1994, Seismic velocities - a critique: First Break, v. 12/12, p. 589-596.

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Analytical Velocity Modeling for Offshore East Coast of India: An Approach Using VSP Time-Depth Dataset

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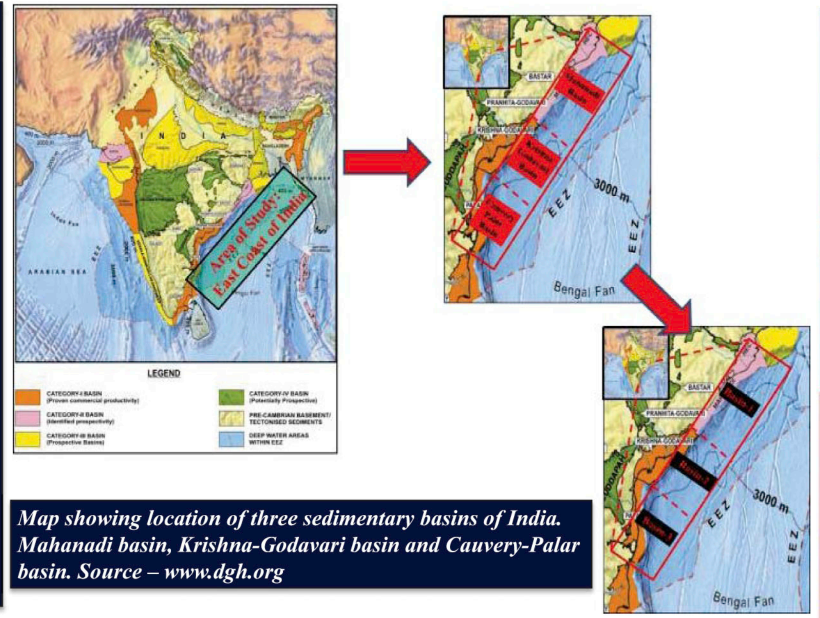
INTRODUCTION

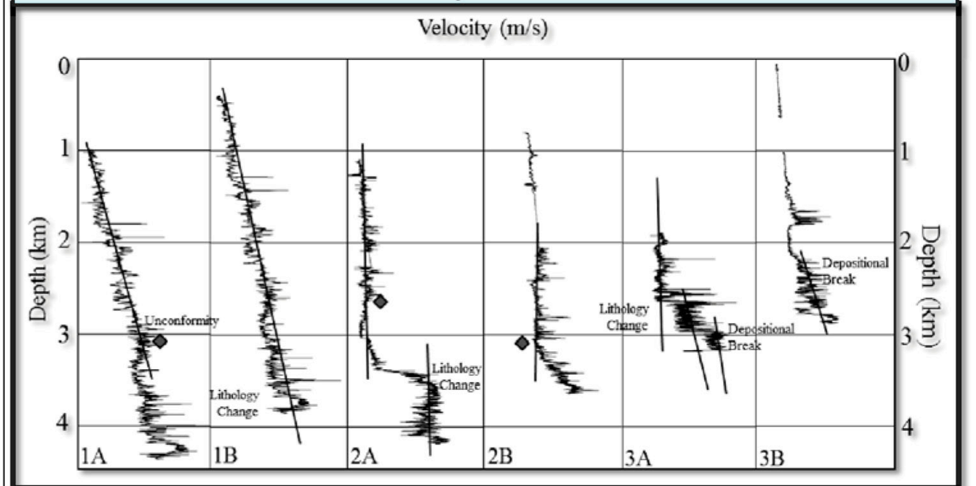
Worldwide hydrocarbon exploration is moving towards reducing cost of deep-water drilling due to tumbling oil prices. It became a timely demand to do an effective and efficient analysis of existing database(s). Therefore it is very essential to utilize the existing well data for further drilling and understanding of the basin.

- *Data from more than 50 exploration wells is available from offshore region of east coast of India, which spans water depths from 40.8m to 3100m.*
- *Out of 13 Wells in Mahanadi basin, 6 wells showed very high pore pressures.*
- *27 wells of Krishna-Godavari basin are from different geological setings (shallower targets are from Pleistocene/Pliocene, deeper targets are from Cretaceous).*
- *Cauvery basin underwent huge erosion during Cretaceous times;; this is very well reflected on interval velocity plot of data from 11 wells.*
- *Difference ingeology of each basin is well reflected on their interval velocity plots.*



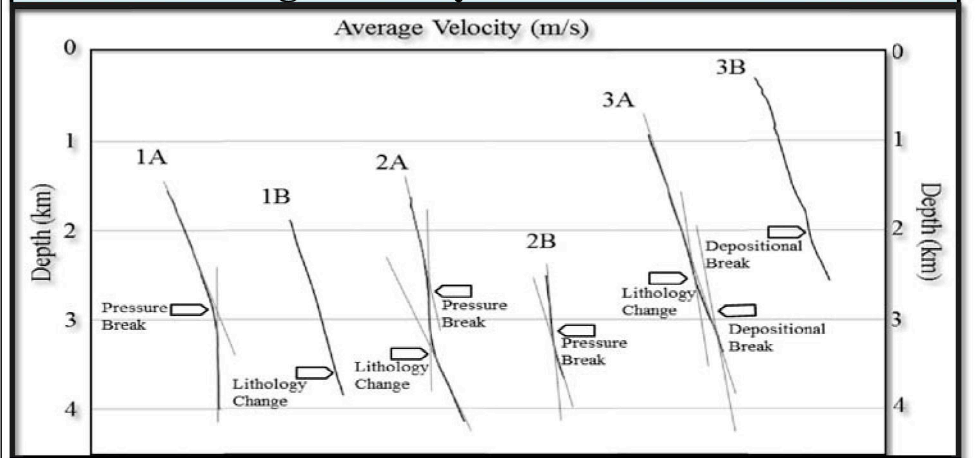
Map showing location of three sedimentary basins of India. Mahanadi basin, Krishna-Godavari basin and Cauvery-Palar basin. Source – www.dgh.org

Interval velocity trend of six wells



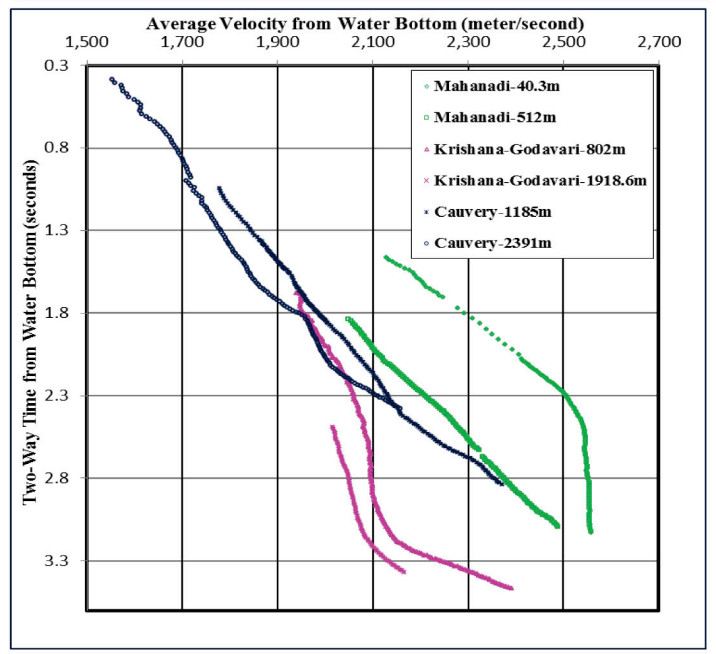
Sonic-velocity versus depth for six wells, 1A, 1B, 2A, 2B, 3A, 3B. Approximated normal compaction trend has been shown as smooth lines. Calibration of unconformity boundaries, overpressure zones, lithological boundaries and depositional breaks have been made using available wireline logs (including gamma-ray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

Average velocity trend of six wells

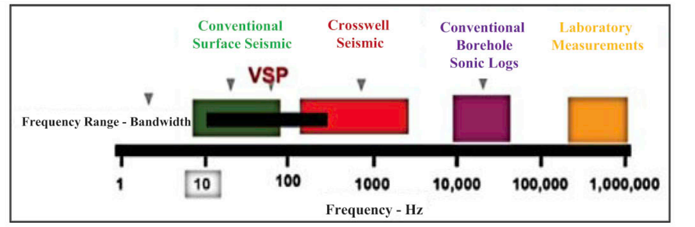


Average-velocity versus depth for six wells, 1A, 1B, 2A, 2B, 3A, 3B. All the important trends observed in interval velocity are manifested as slope changes in the average velocity plot of VSP data

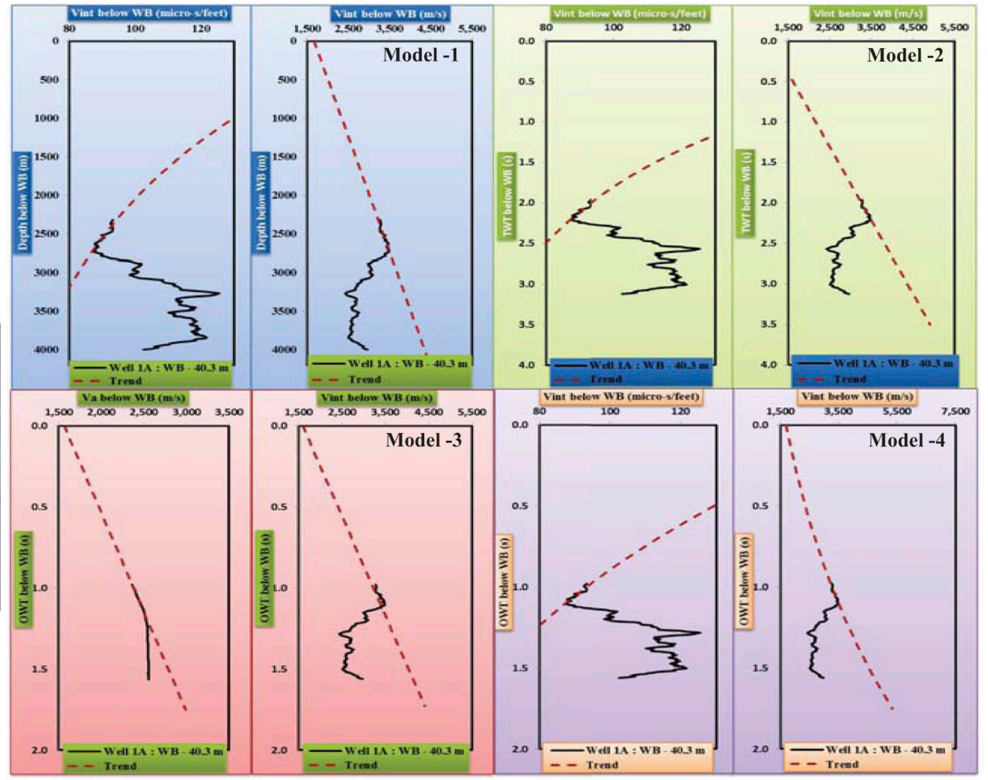
GEOGRAPHICAL VARIATION IN VELOCITY TRENDS ACROSS THREE BASINS

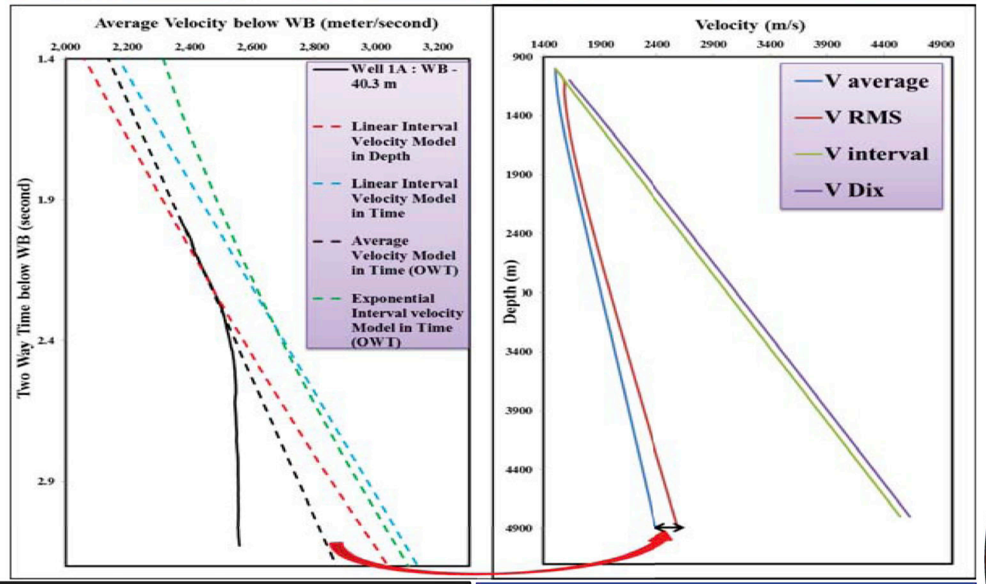


Why VSP Data ???



- *Source: "Seismic wavelet" – close to surface seismic data*
- *Frequency: Lies between Sonic and Surface Seismic (more close to SS)*
- *Direct time-depth – Can be converted in any form of velocities*





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*

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 Interval velocity Vi*.

A fourth criterion is a *bias towards small number of parameters*.

Empirical Models Tested on Three Basins Data

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 displayed above:

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)"

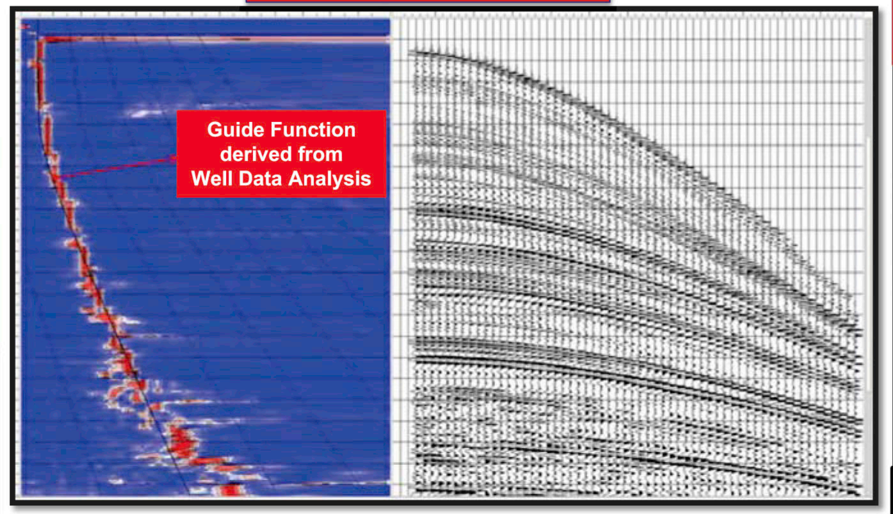
$$V_a = V_o + kT/2$$

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

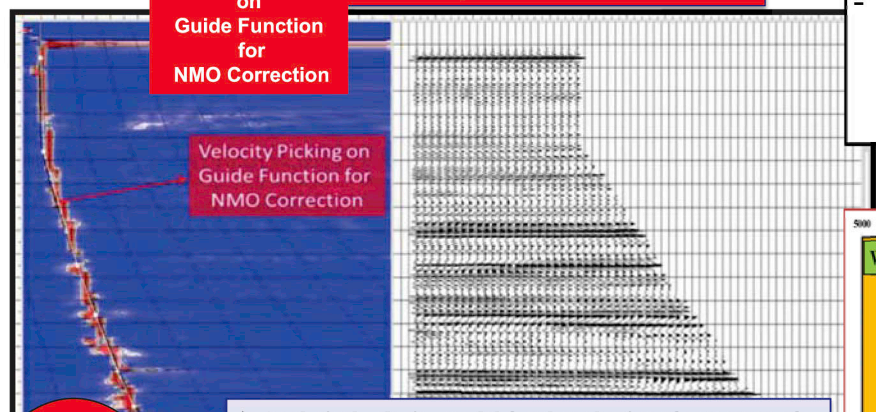
$$V_i = V_o e^{kT/2}$$

(Slotnick, 1936)

Cauvery Basin - Well-6



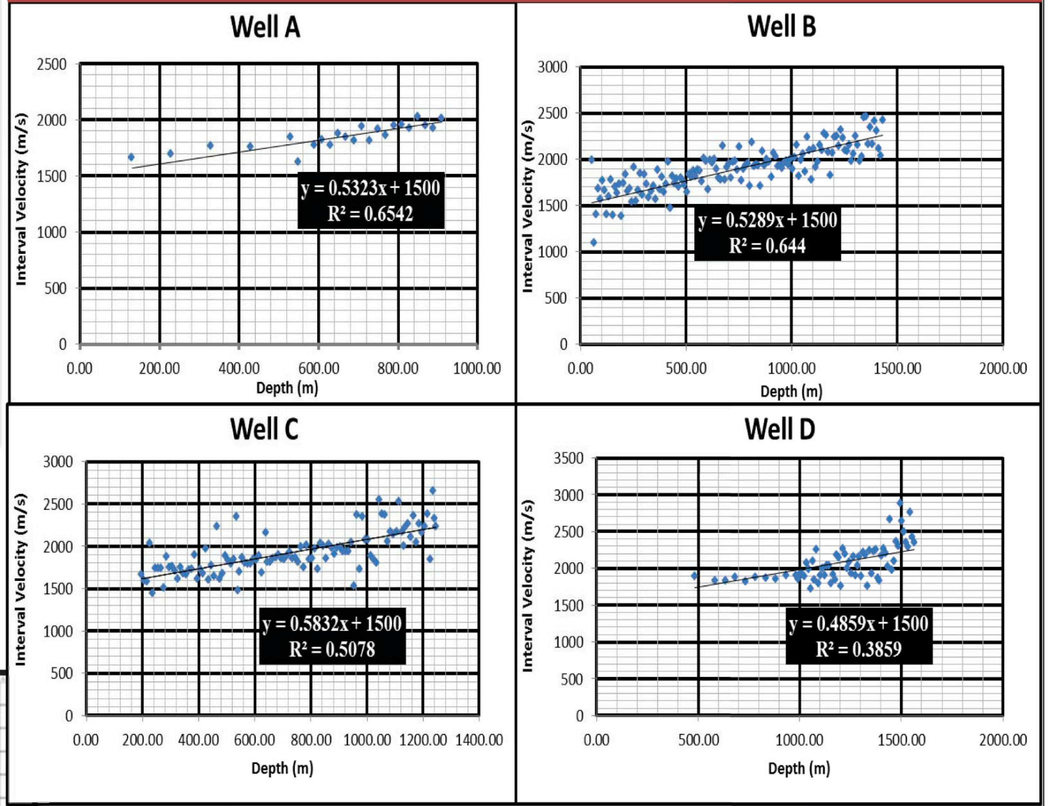
Cauvery Basin - Well-6



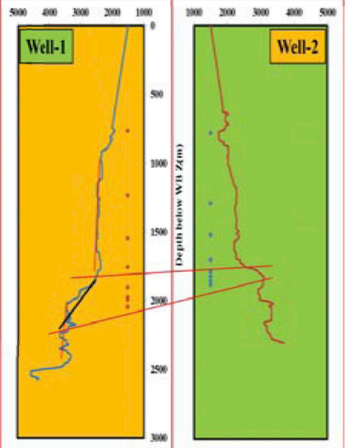
Conclusions...

- **Analytical velocity model for three basins of east coast of India**
  - Mahanadi basin - High pore-pressure environment
  - Krishana-Godavari basin – Decompacted uplifted environment
  - Cauvery basin – Erosional environment
- **Background shale trend relationship for time-depth conversion**
  - Mahanadi basin - Average velocity with depth
  - Krishana-Godavari basin – Linear interval velocity with depth
  - Cauvery basin – Linear interval velocity with TWT (Two way time)*
- **Applications**
  - Geoscience Interpretation
    - Identification of drilling targets in deeper areas (*below Mesozoic*), Improved interpretation in geologically complex areas
  - Quick planning of wells
    - Cost estimation, Safety, Usable holes
  - Uncertainty estimation in frontier areas, ultra-deep water areas

Analyses of Time-depth relationship for four wells of shallow play types (Pleistocene/Pliocene) – Krishna Godavari basin



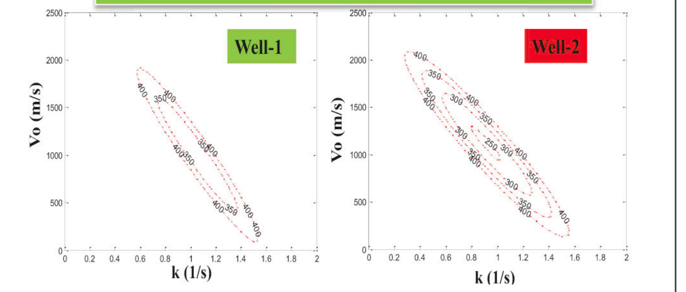
Linear Interval Velocity with Depth : $V = V_0 + kZ$



Uplift Estimation is Required ..... Application of Parameter Estimation Technique

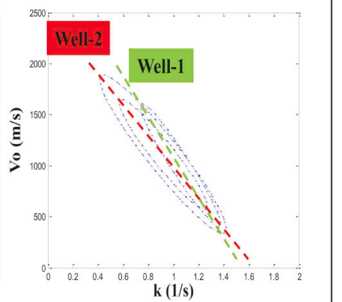
Analyses of Time-depth relationship for deeper play types (Below Cretaceous) – Krishna Godavari basin

RMS contours in Vo-K space for Well-1 & Well-2



Two Step Process:

- I[st] step is establishing the region of overlap between the two units.
- II[nd] is compensating for the effect of decompaction.



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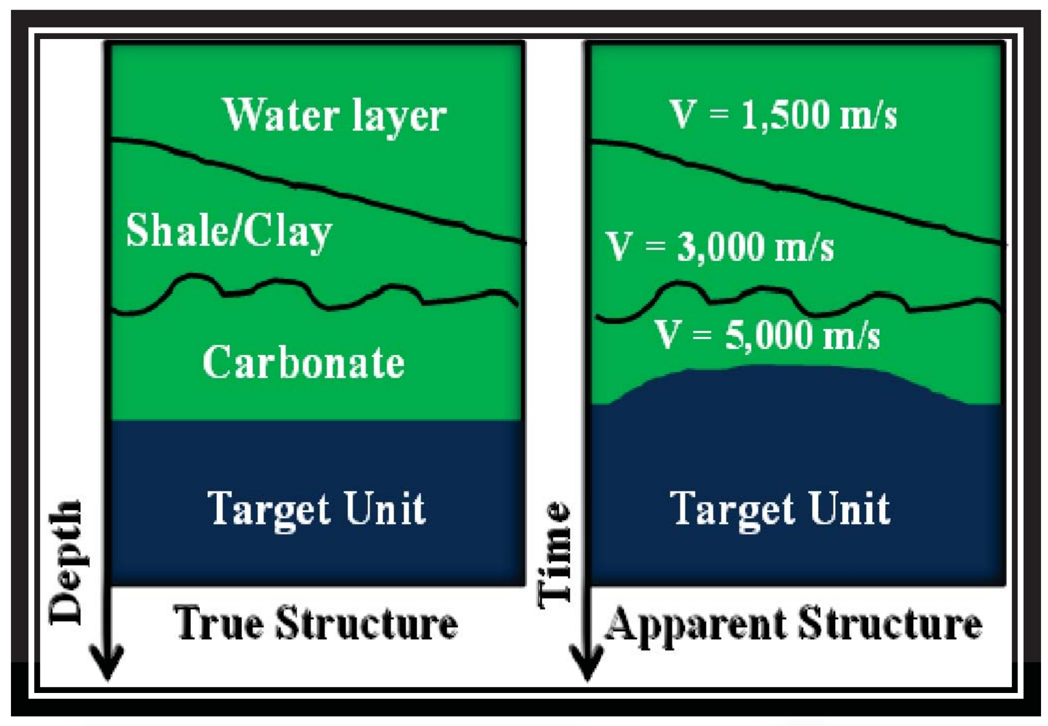
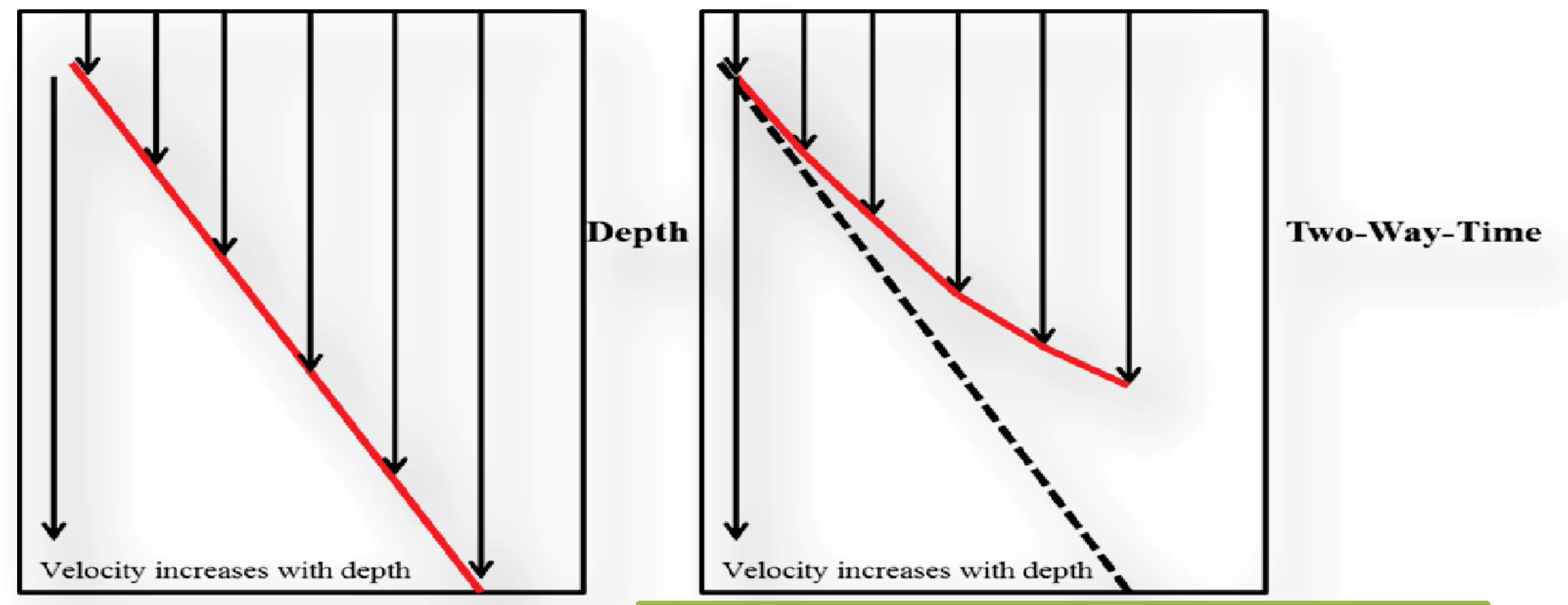
Why Depth Conversion ???

- Recording of seismic data takes place in time domain, to solve the purpose of resolving deeper subsurface layers.
- Basic seismic data processing takes place in time-domain.
- Seismic data interpretation is made in the same domain.
- But the reality is "*Subsurface rocks exist in depth*".
- Whatever attribute is utilized to find hydrocarbon reservoirs from seismic data, ultimately the data needs to be converted in depth domain. Therefore ,

Time-depth conversion is an essential part of any exploration activity.



Structural interpretation: Pitfalls of interpreting time sections



A linear fault in depth

Same planar fault in depth appears "listric" when displayed in two-way time

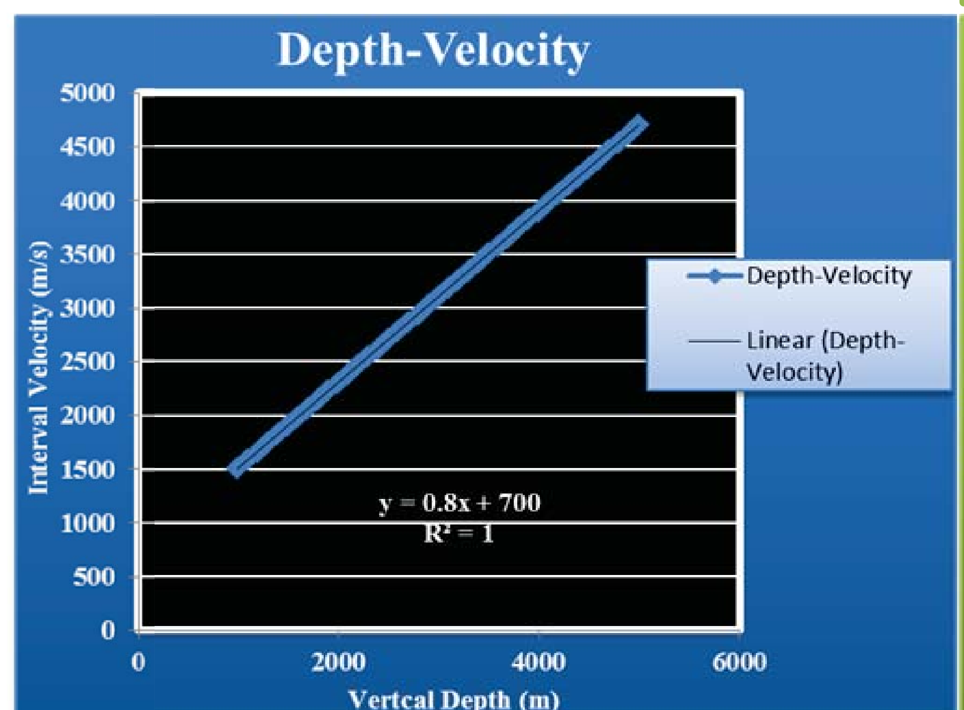
Difference between Imaging & "Depthing"

Purpose of Imaging:

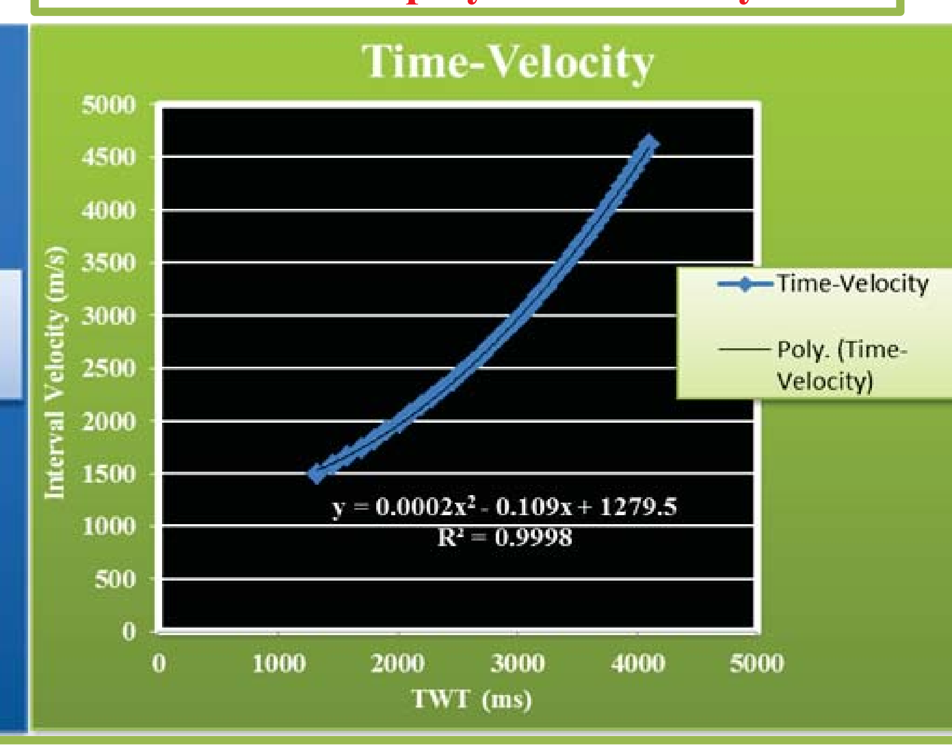
1. Repositioning of reflectors
2. Collapse diffractions
3. Produce correct relative structural picture

Purpose of Depthing:

1. Convert seismic times to actual depth
2. Produce predictions of depth away from wells
3. Absolute vertical calibration



Linear depth-velocity relationship on Synthetic Depth-Interval Velocity Model



Same velocity will follow exponential relationship while plotting corresponding to TWT (Two -Way Time)

What comes first Imaging or Depthing ???

Imaging is done first

Imaging is mainly a lateral correction

Depthing is strictly a vertical correction

Depthing is done after imaging

Imaging uses imaging velocities (horizontal and vertical components)

Depthing uses vertical propagation velocities (vertical component only)

Process

Depth Migration uses optimal velocities for structural imaging

Convert to time Using optimal velocities for structural imaging

Depth conversion using vertical propagation velocities

Result

Image correctly Positioned laterally

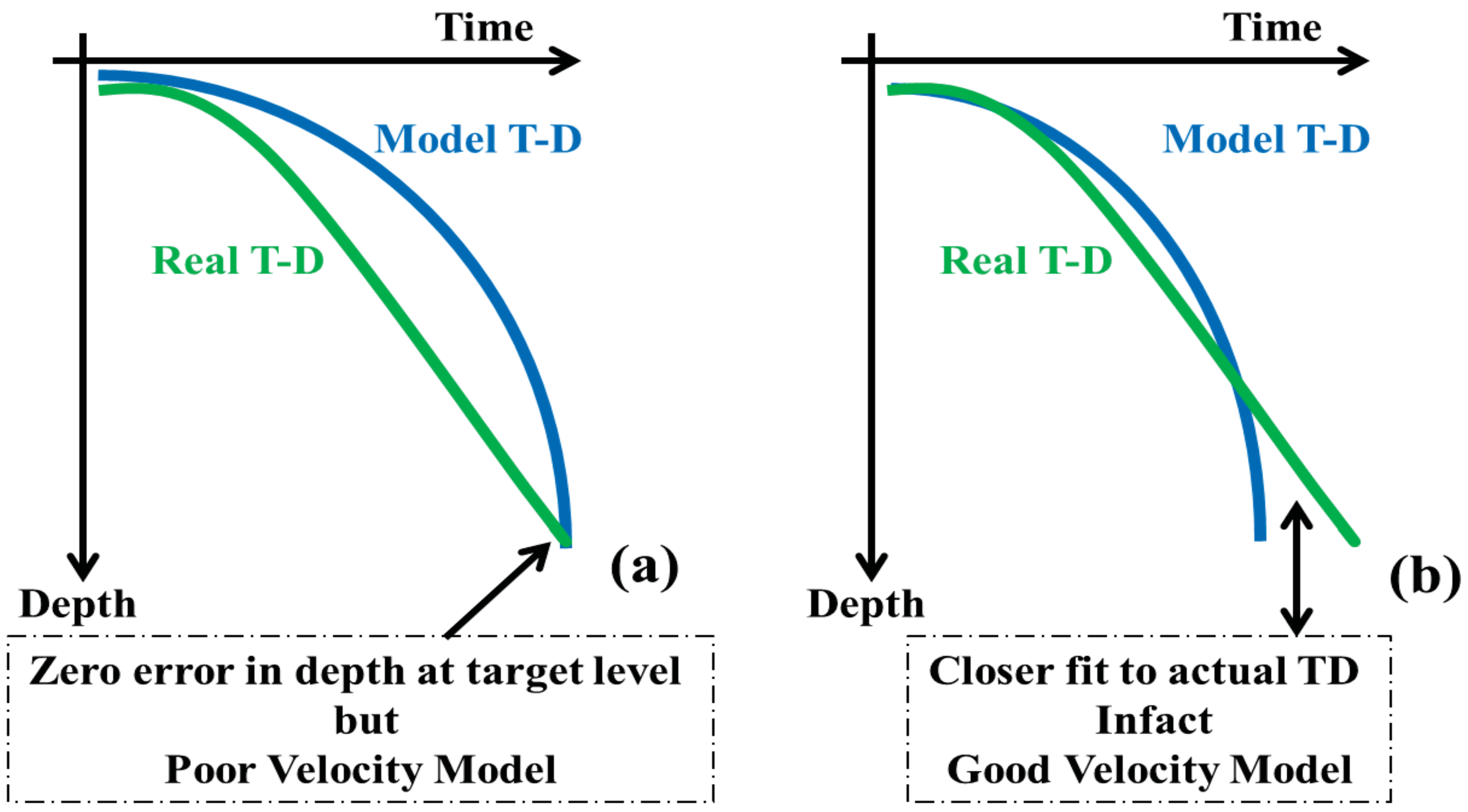
Now in time domain

Actual depth

References:
1. Al-Chalabi M., 1994. Seismic velocities - a critique, First Break, 12, no. 12, 589-596.
2. Edward L. E., Nick J. Crabtree, Jan Dewar, 2001. True Depth Conversion: More Than A Pretty Picture, Scott Pickford, A core Laboratories Company. CSEG Recorder, 11-22
3. P.J. Lyon, P.J. Boult, A. Mitchell, and R.R. Hillis, Improving fault geometry interpretation through 'Pseudo-depth' conversion of seismic data in the Penola Trough, Otway Basin, PESA Eastern Australasian Basins Symposium II, Adelaide, 19-22 September, 2004

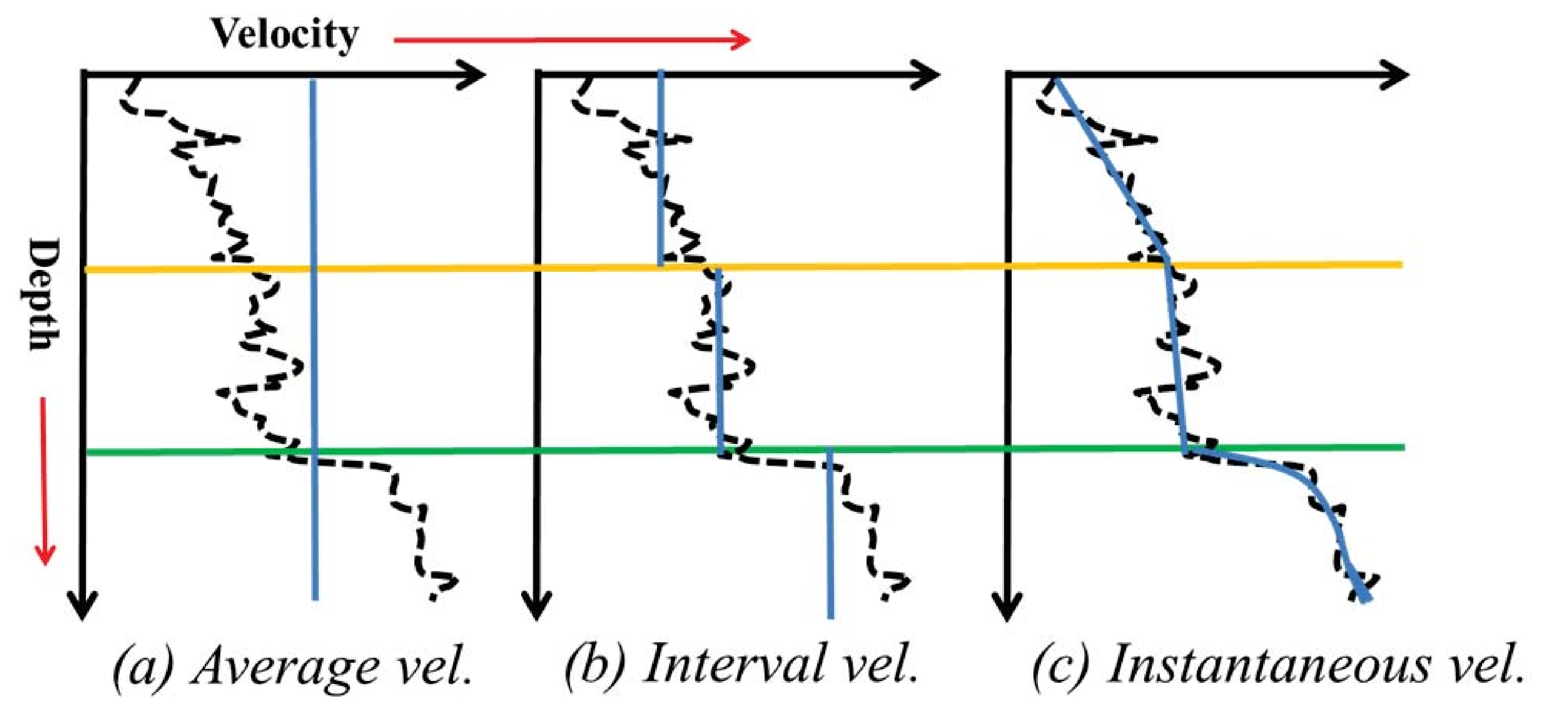
Methods of Depth Conversion

Direct Time-Depth Conversion



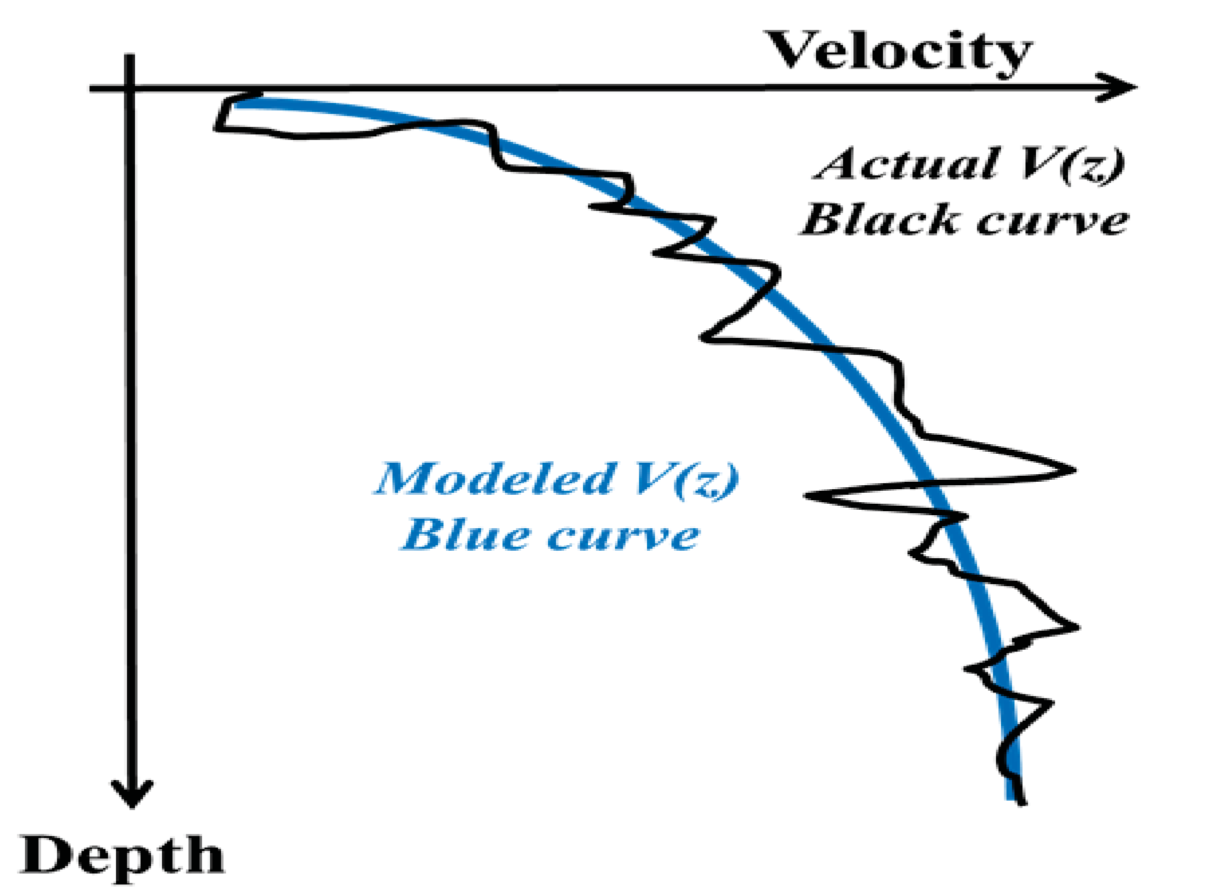
Optimization in velocity modeling: (a) One minimizes the error at tie point (direct conversion) but model does not represent the true geology but (b) when one honors the true function the error at the tie point increases.

Velocity Modeling for Depth Conversion



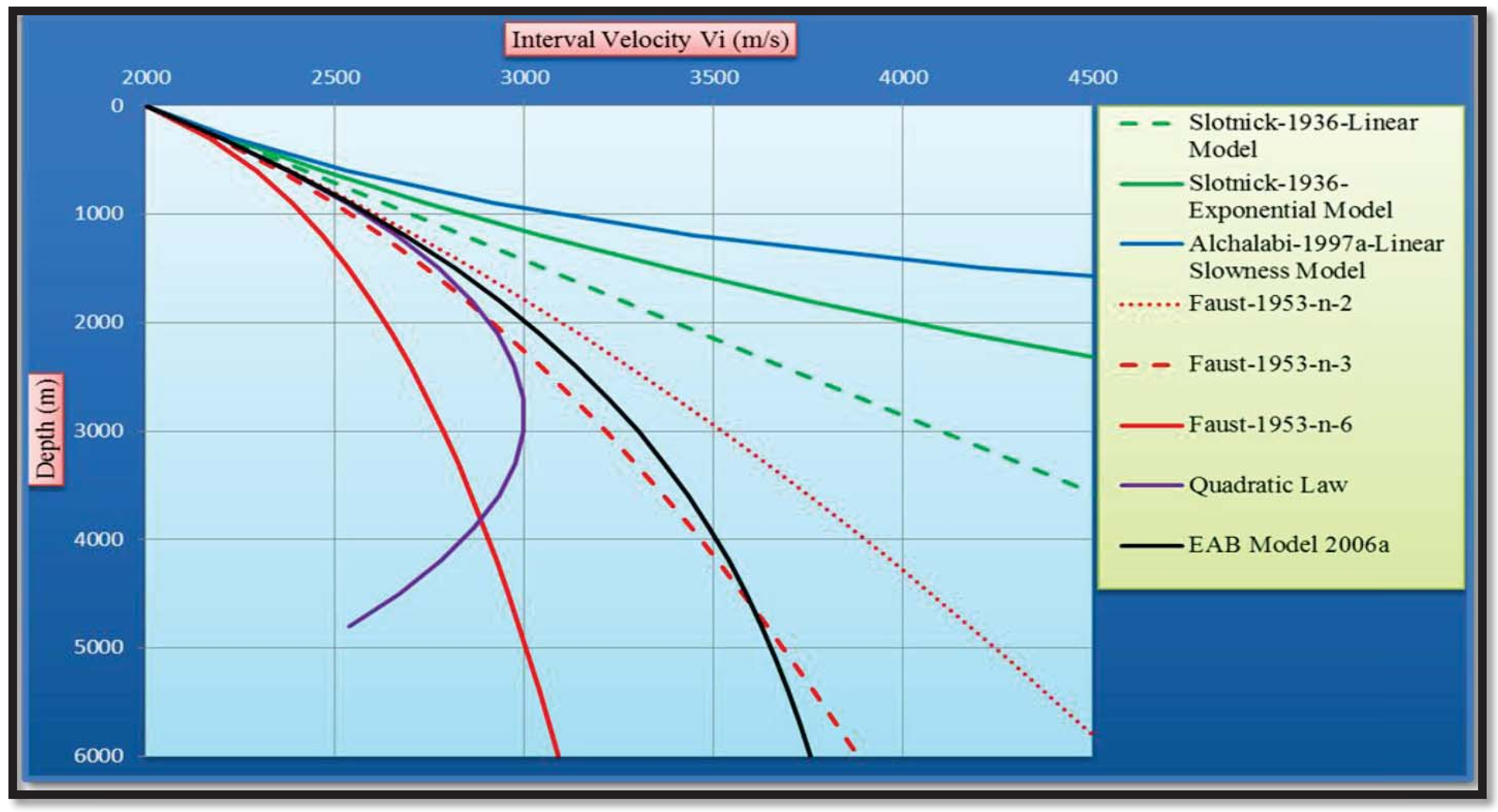
Three levels of detail in modeling velocity. (a) Simplest level is average velocity from top to down (b) Bit more complex is: assign a constant interval velocity to each layer within a given well (c) Complex one is: instantaneous velocity modeling of the dataset; this type of curves provides velocity variation over very small depth increments.

Robust Velocity Modeling



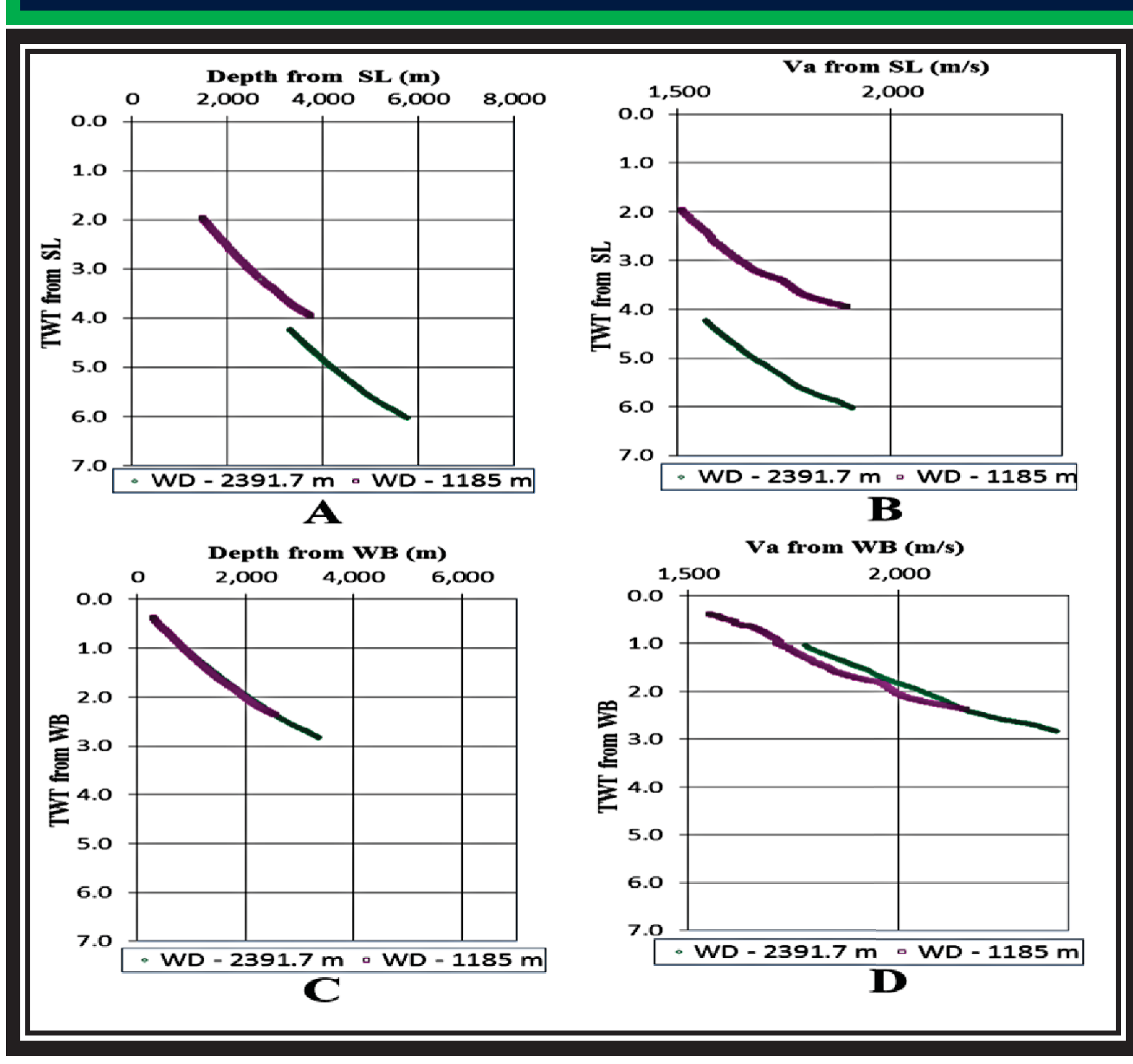
Analytical function describes a smooth variation of velocity with depth, much smoother than the high frequency fluctuations observed on well interval velocities.

Instantaneous / Analytical Velocity Modeling



Plot of various Analytical models available in literature: Slotnick-1936-Linear Model, Slotnick-1936-Exponential Model, Alchalabi-1997a-Linear Slowness Model, Faust-1953-n2, n3, n6, Quadratic law and EAB – Exponential Asymptotically Bounded Model

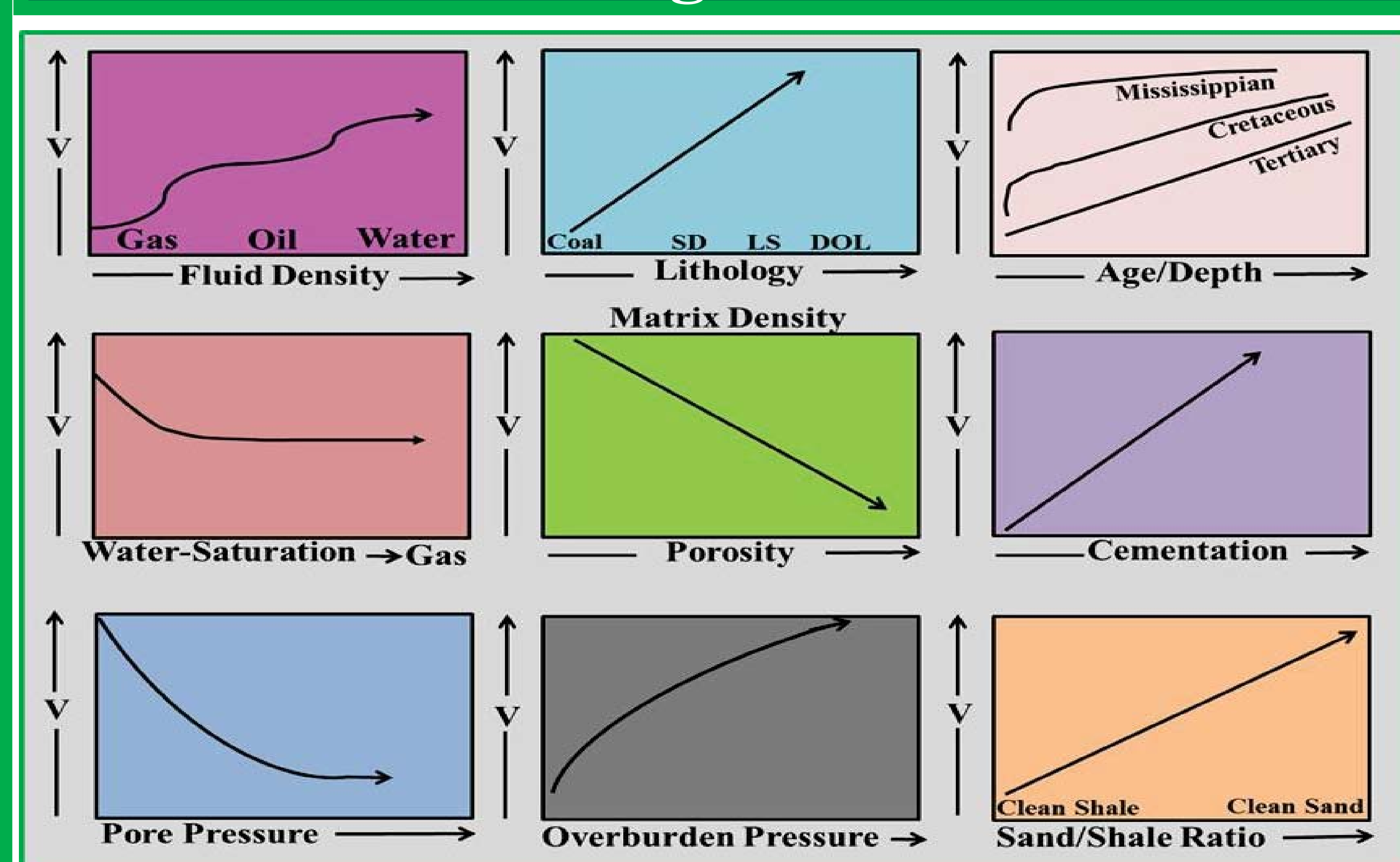
Effect of Water column on Velocities



Effect of water column on time-depth and average velocity curves. Variable water depth obscures compaction relationships. (A) time-depth curve with regards to sea level (B) average velocity with regards to sea level (C) time-depth curve with regards to sea floor (WB); (D) average velocity with regards to sea floor. TWT = vertical two-way travel-time; SL = sea level; WB = Water Bottom

"The solution for the parameters of analytical velocity versus depth is inherently nonunique. This nonuniqueness means that there is no particular parameter combination that represents 'The' solution.'" Alchalabi (1997a)

Factors Affecting Seismic Velocities



Factors affecting Seismic Velocity: Qualitative Overview (Hilterman, 2001)

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1. Edward L. E., Nick J. Crabtree, Jan Dewar, 2001. True Depth Conversion: More Than A Pretty Picture, Scott Pickford, A core Laboratories Company. CSEG Recorder, 11-22
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