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Sensitivity Analysis for Simultaneous Inversion of Angle limited seismic stacks

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Summary

A forward modeling and inversion study is presented to understand and characterize the sensitivities of simultaneous inversion to (i) The number of stacks, (ii) data quality in terms of S/N ratio and (iii) velocity model for low frequency. Synthetic angle stacks were generated by forward modeling, the same data was inverted and the results analyzed. This paper discusses the process and the conclusions that can be drawn based on the results.

Introduction

The main objective of seismic inversion is to transform seismic reflection data into a desired rock property that can help in squeezing meaningful information from it. Good quality seismic data can lead to optimum elastic property data thereby minimizing the uncertainty in reservoir estimates. In this study forward modeling and inversion of synthetic data was done to determine the optimum angle range, the number of angle stacks to be used, as well as determine the seismic data adequacy for generating a reliable elastic property volume. The generation of the low frequency model for the inversion is also discussed.

Method

The method involves generation of an Earth model using the P-Impedance, S-Impedance and density logs from wells, the model framework and interpreted horizons. The framework, in the form of a spreadsheet, describes the ordering of the horizons in space and time and their behavior at faults. Horizons provide the structural information. Interpolation of the input log information between wells is done along layers, respecting both stratigraphy and faults. Quality control is done to make sure that well anomalies should not propagate throughout the model.

Ricker wavelet was used for generating angle stack traces. Noise can also be added with the Gaussian distribution function as it was done here when analyzing data adequacy. The Figure 1 describes the forward modeling work flow.

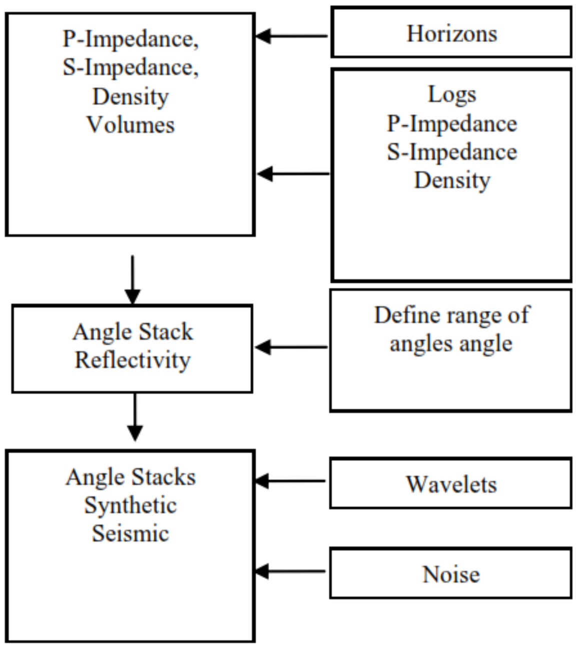

Figure 1 Forward Modeling (Workflow)

Simultaneous Inversion and results

Simultaneous angle dependent seismic inversion converts the synthetics seismic reflectivity of multiple partial angle stacks to elastic property contrasts and simultaneously integrates low frequency information to produce a broadband model of the elastic properties of the subsurface. The output of the inversion is controlled by constraints and settings that are optimized based on comparisons at the well locations and other quality controls.

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The Earth Model (elastic properties) was used to derive angle reflectivities for the different synthetic seismic angle stack ranges using the full Zoeppritz equation. These reflectivities are convolved with the synthetic Ricker wavelets for synthetic seismic angle ranges. The following angle stacks were generated:

12 angle stacks (max 65 deg with 5 deg increment)
11 angle stacks (max 60 deg with 5 deg increment)
10 angle stacks (max 55deg with 5 deg increment)
8 angle stack (max 45 deg with 5 deg increment)
6 angle stacks (max 35 deg with 5 deg increment)

Further another similar set of angle stacks was generated with incorporation of noise. Noise was added with Gaussian distribution function in above different angle ranges with a mean 0 and standard deviation of 1.0 (Figure2). The inverted results are compared with wire line log in terms of cross plots (Figures 3, 4, 5and 6) and well logs (Figures 7, 8, 9, and 10).

In the case of inverted result from 12 angle stacks the correlation in density with wire line log is 95% (Figure3) and Vp/Vs 94 %(Figure5). But in case of 6 angles stack density becomes 57% (Figure 4) and Vp/Vs 93% (Figure 5). The noise content in synthetic seismic data can drastically changes these elastic properties as depicted in Tables 1 and 2.

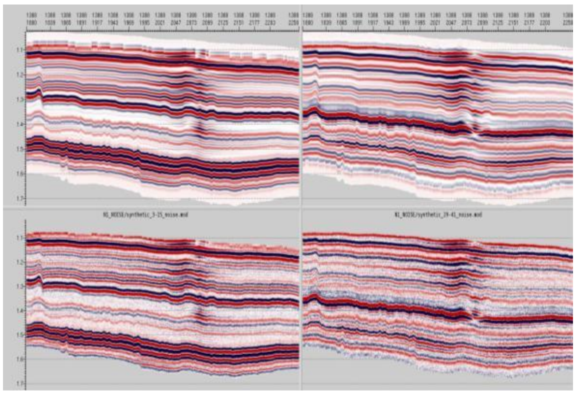

Figure 2 Synthetic data created through Forward Modeling without and with Noise

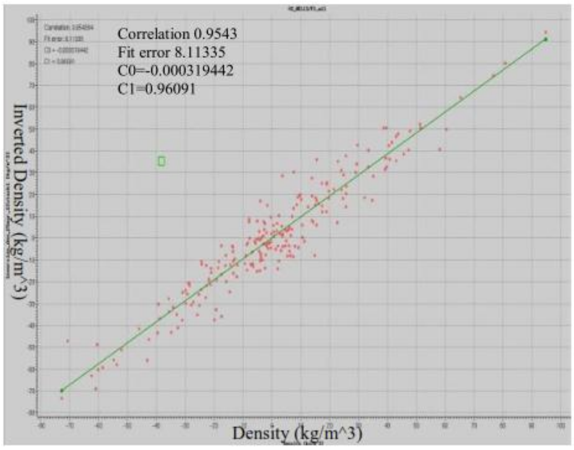

Figure 3 Twelve angle stack band pass log density vs. inverted density. There is less scattering and high co relatable inverted density.

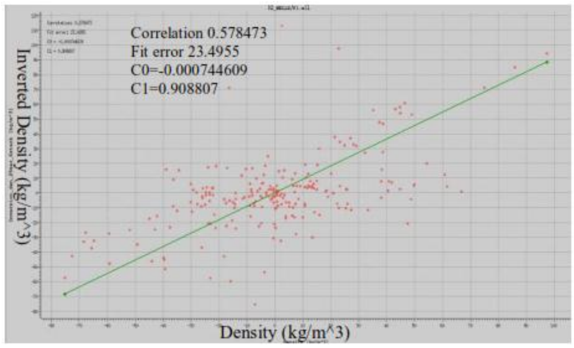

Figure 4 Six angle stack band pass log density vs. inverted density. There is more scattering and less co relatable inverted density.

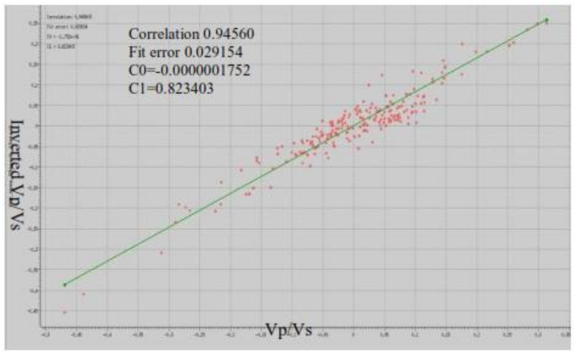

Figure 5 Twelve angle stack band pass log Vp/Vs vs. inverted Vp/Vs. Less scattering and high co relatable Vp/Vs.

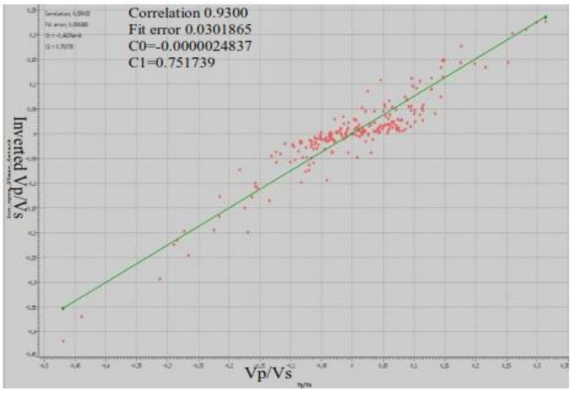

Figure 6 Six angle stack band pass log Vp/Vs vs. and inverted Vp/Vs. There is moderate scattering and moderate co relatable inverted Vp/Vs.

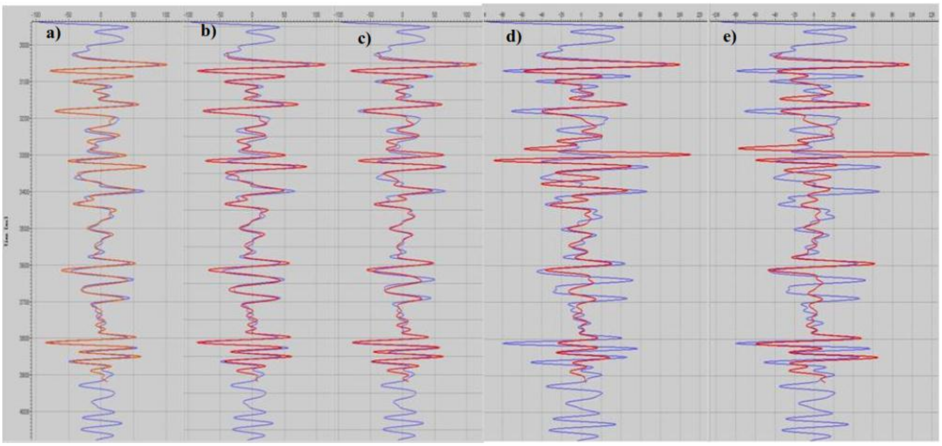

Figure 7 Inversion density results using different number of angle stacks. logs are in blue; inverted density are in red; inversion results using (a) 12 angle stack), (b) 11 angle stack, (c) 10 angle stacks, (d) 8 angle stacks and (e) 6 angle stacks .It is observed that bigger differences in the inverted density caused by different number of angle stacks, twelve angle stacks (a) gave the best match of inverted density to logs density.

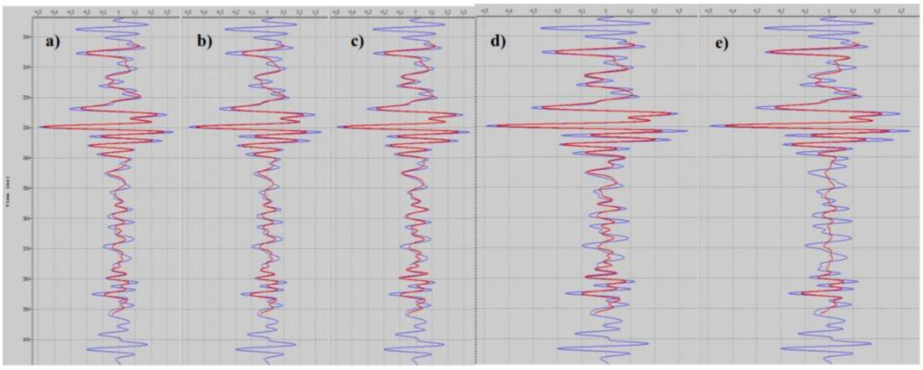

Figure 8 Inversion Vp/Vs results using different number of angle stacks. logs are in blue; inverted Vp/Vs are in red; inversion results using (a) 12 angle stack), (b) 11 angle stack, (c) 10 angle stacks, (d) 8 angle stacks and (e) 6 angle stacks .It is observed differences in the inverted Vp/Vs caused by different number of angle stacks, (a) 12 angle stack) (b) 11 angle stack and (c) 10 angle stacks gave the best match of inverted Vp/Vs to logs Vp/Vs. With the (d) 8 angle stacks and (e) 6 angle stacks inverted Vp/Vs showing bad match.

Seismic gathers conditioning

Proper seismic data conditioning is essential for reliable inversion results, especially when reservoir characterization and lateral prediction studies are done (Veeken and Da Silva, 2004). To objectively estimate the accuracy of an elastic impedance inversion cube, the interpreter must be acquainted with the input seismic data and what re-processing steps were applied to prepare the seismic data for inversion. Some key items should be examined: input seismic data quality, velocity data quality and inversion algorithm, depending on the inversion method, the data types may include post migration seismic data. Figure 9 shows the gather data set in various stages of seismic data conditioning. The data was inverted after each of the three seismic data conditioning steps and the results compared. Notable improvements in Vp/Vs and density can be observed after each stage of seismic data conditioning. It is seen that density follows the log trend when de-stretch data is used. (Figure 10-12).

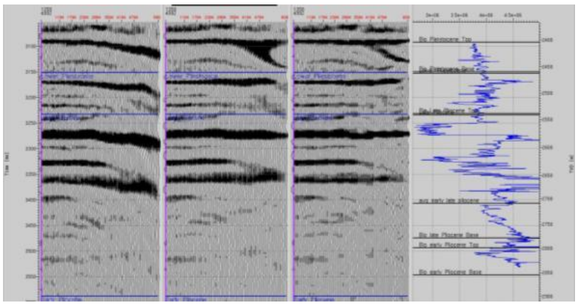

Figure 9 Left panel: Original offset gather showing noisy and NMO residuals; Mid panel: Offset gather after high density analysis; Right panel: Offset gather followed by flattening and de-stretching; P-impedance log. Flatten and de-stretch are good quality seismic data.

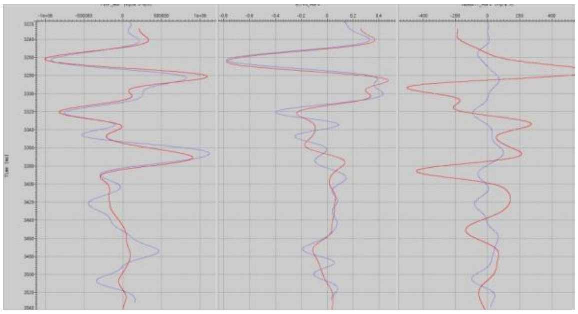

Figure 10 Comparison of inverted P-impedance, Vp/Vs and density to logs. Logs are in blue; (a)inverted P impedance,(b)Vp/Vs and and(c) density with the original offset gathers are in red; the inverted P impedance(a),Vp/Vs(b) have acceptable match to the logs. The inverted density(c) is negative correlation with the density log.

Since the P impedance is mostly provided by near offset data and Vp/Vs and density information is mainly influenced by far offset data.

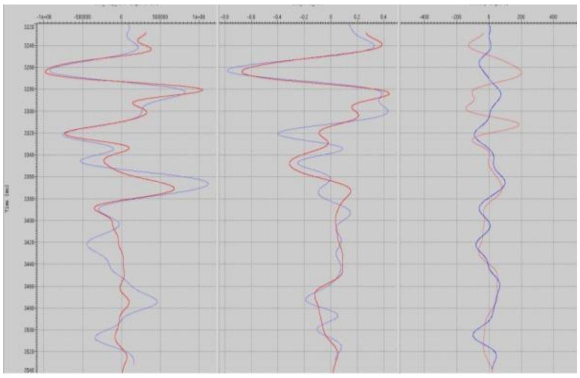

Figure 11 Comparison of inverted P-impedance, Vp/Vs and density to logs. Logs are in blue; (a)inverted P impedance,(b)Vp/Vs and and(c) density with the offset gathers after high density analysis are in red; the inverted P impedance(a) ,Vp/Vs(b) have moderate match to the logs. The inverted density(c) is not showing match with the density log after high density velocity analysis.

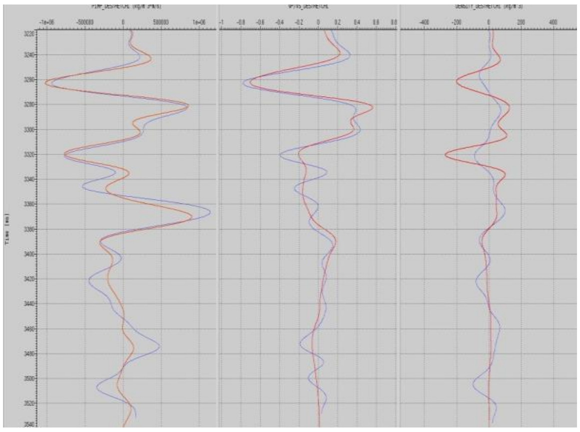

Figure 12 Comparison of inverted P-impedance, Vp/Vs and density to logs. Logs are in blue; (a)inverted P impedance,(b)Vp/Vs and and(c) density with the offset gathers offset gather followed by flattening and de- stretching are in red; the inverted P impedance(a), Vp/Vs(b) have very good match to the logs. The inverted density(c) is acceptable and positive correlation with the density log.

Velocity effect for background trend

A low frequency model is required to provide information below the seismic bandwidth. A correct low frequency model will remove side lobes and provide absolute values for the elastic properties that are required for quantitative interpretation. The low frequency model must be consistent with the geology and therefore often requires interpretation and iteration to achieve the desired results.

Low frequency model was built using information from seismic velocities, well log data and rock physics relationships. The model was iteratively updated to take into account results from band pass inversions.

Conditioned velocity high cut to 1 Hz (blue curve corresponding to re-picked velocity) was showing good match with well velocity and therefore conditioned seismic velocity of this frequency range (till 1 Hz) was used in low frequency modeling inversion workflow (Figure 14). The frequency content of this model can be limited to 1 Hz. background elastic properties trend model. 1 Hz was chosen over 2 Hz as it matched better with the well data (Figure13and14). Unfocused information about highcontrast layers directly above or below the reservoir causes residual side lobes and other artifacts within the reservoir, leading to incorrect imaging close to high contrast layers.

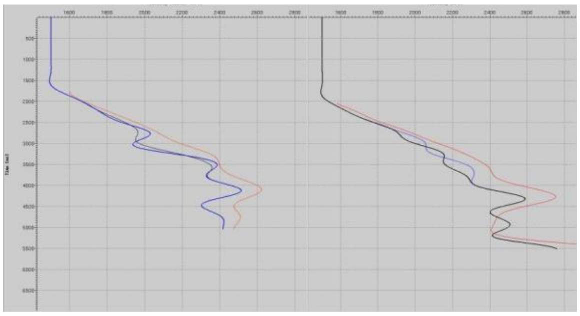

Figure 13 Comparison of two interval velocity to logs velocity. Logs velocity are in black; vintage velocity (poorly picked) are in red; the re-picked velocity are in blue filtered at 2Hz high cut; Re-picked velocity is closed the log velocity ,but it is non smooth and not used for inversion workflow.

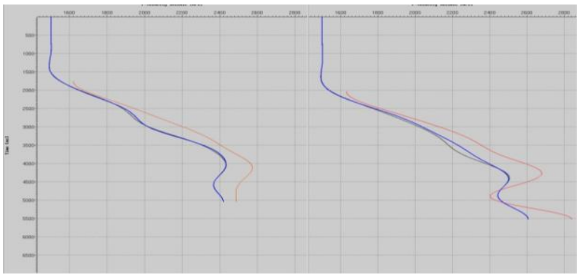

Figure 14 Comparison of two interval velocity to logs velocity. Logs velocity are in black; vintage velocity (poorly picked) are in red; the re-picked velocity are in blue filtered at 1Hz high cut; Re-picked velocity have very good match to the log velocity, it is used for inversion workflow

The Angle calculation done with the 1 Hz high cut filter and compare to 2 Hz high cut filter as shown in Figure13& Figure14. That indicates interval velocity does not have reliable information beyond 1 Hz.

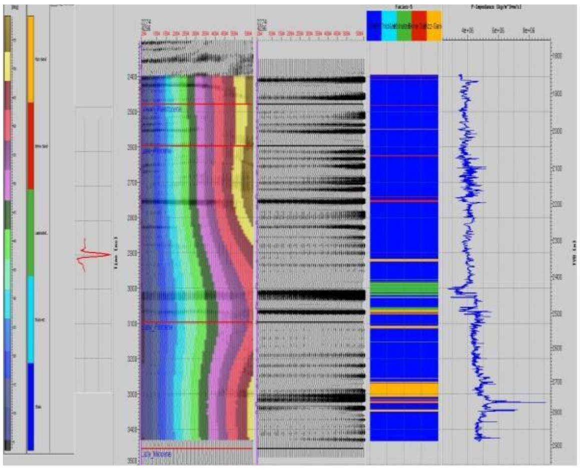

Figure 15 Angle range QC using smoothen interval velocity 2 Hz high cut)-(a) incidence angle overlaid on seismic gather; (b) synthetic gathers; (c) litho logy log (d) P- impedance log. The 2Hz interval velocity is noisy. It is not used for offset to angle transformation. (Y Yauhi and P William et al.2006)

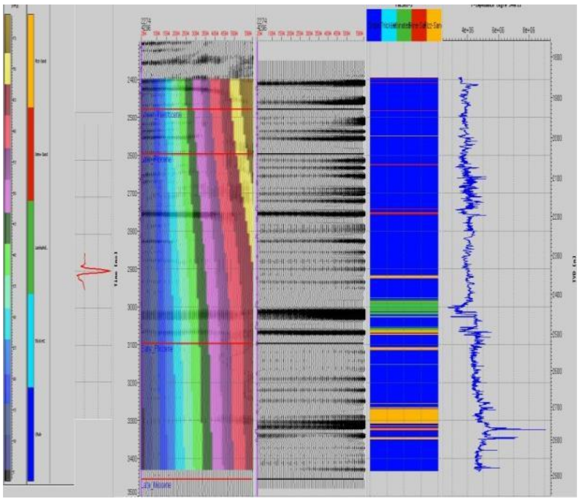

Figure 16 Angle range QC using smoothen interval velocity 2 Hz high cut)-(a) incidence angle overlaid on seismic gathers; (b) synthetic gathers; (c) litho logy log (d) P- impedance log.1Hz high cut smooth interval velocity is used for offset to angle transformation (Y Yauhi and P William et al.,2006)

No of Stacks (Max Angle)	Inverted Parameters					
	P Impedance		Vp/Vs		Density	
	Correlation	Misfit (kg/m^3*m/s)	Correlation	Misfit (None)	Correlation	Misfit(kg/m^3)
12 (65°)	0.99	22149	0.94	0.0291	0.95	8.11
11 (60°)	0.99	20516	0.94	0.0266	0.92	11.12
10 (55°)	0.99	21930	0.95	0.0271	0.90	11.72
8 (45°)	0.99	21750	0.93	0.0314	0.70	18.82
6 (35°)	0.99	17222	0.93	0.0301	0.57	23.49

Table1: Sensitivity analysis for different number of angle stacks, without Noise for optimum density inversion (angle 5°). P impedance is mostly provided by near offset data and density information is mainly influenced by far offset data, the quality of inverted density was improved primarily by increasing the number of more angle stacks.

No of Stacks (Max Angle)	Inverted Parameters					
	P Impedance		Vp/Vs		Density	
	Correlation	Misfit (kg/m^3*m/s)	Correlation	Misfit (None)	Correlation	Misfit(kg/m^3
12 (65°)	0.98	31936	0.88	0.0273	0.82	15.5
11 (60°)	0.98	30646	0.88	0.0271	0.66	21.7
10 (55°)	0.98	30547	0.87	0.0262	0.59	30.8
8 (45°)	0.98	34402	0.82	0.0580	0.28	8.39

Table2: Sensitivity analysis for different number of angle stacks, with noise for optimum density inversion (angle 5°). Adding noise in the same synthetic angle stack the inverted Vp/Vs and density correlation decreases.

Conclusions

- The number of angle stacks along with good signal-to-noise ratio plays a major role in the inversion process for obtaining better Vp/Vs ratio and density.
- Seismic data conditioning of gathers, like high density velocity analysis followed by flattening and de-stretching are also essential processing steps for obtaining flat gathers up to a significant high angle range. These flat and de-stretched gathers, in turn, help to get more number of angle stacks.
- The role of low frequency velocity model in the inversion process is ascertained. Here, in this paper, conditioned velocity with 1 Hz high cut was showing a reasonably good match with the well velocity and is used for the ultra low frequency background trend in this inversion workflow.

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