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Low frequency modeling and its impact on seismic inversion data

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Summary

Integration of low frequency model during seismic inversion enhances the qualitative and quantitative interpretation levels of seismic inversion results. Information required to build low frequency model primarily comes from the well data. In some geological environment it is possible to make a simple interpolation or extrapolation of the well data within a basic geological framework to have a reasonable low frequency model. Often greater geological constraints are required which can be incorporated in various ways.This paper summarizes the various methodologies for making low frequency model. An attempt has also been made to have analytical look on the suitability of low frequency model. The impact of low frequency model of seismic inversion data is also analyzed.

Introduction

Rock and reservoir parameters computed from the inverted rock properties can be inaccurate, leading to wrong drilling and development decisions due to lack of low frequency information on conventional seismic data. (Whitecombe and Hodgson 2007,Ozdemir et al 2007).It is important to understand that missing low frequencies and their modeling from well data can cause bias in inverted rock properties irrespective of any inversion algorithm.

The seismic data is bandlimited, it lacks the low frequencies that are essential for relative to absolute property conversion. Bandlimited nature of seismic would also mean that it is relative with respect to some absolute trend. The seismic data is generally of the range from 6-8Hz to 60-80Hz. In case of seismic acquired for high frequency purposes the lower limit even starts from 15Hz. Though in case of our seismic data the lower limit stands at 12 Hz. So it was required to patch up this 0-12 Hz region from some method.The extreme end of frequencies (0-2 Hz) can be obtained from seismic velocity data, the low end (2-12 Hz) can be obtained from well data and the high frequency end, to a certain extent, can be obtained from geostatistical procedures.

We here use Q-marine data for our study. It is lacking in low frequencies upto 12 Hz. Generally it is observed that all high frequency seismic data lacks in low frequency content. The reason for this is a scope of a different paper.

Seismic data is inverted for physical properties of rock like acoustic impedance shear impedance, poisson ratio and density etc. Since the seismic data is bandlimited so in the absence of low frequency model the inverted physical properties are bandlimited or relative. In order to translate the inverted data for petrophysical properties for quantitative interpretation like porosity or fluid content we require absolute impedances, density or vp/vs. To achieve this absolute property we need low frequency modeling to compensate for the missing band of the seismic data.

Low Frequency Modeling

Low frequency modeling is an important aspect of obtaining absolute rock properties. Low frequency is the background information of the data and the high frequencies are the details of the data that adjust themselves with the background. The low frequency information can be regarded as the mean trend of the data and the higher frequencies are the deviation from that mean trend.

We divide the low frequency modeling aspect into three parts
1. Background trends
2. Intermediate trends
3. Anomalous signatures

Generally shale acts as a background in most of the reservoirs. So the shale trends are the Background trends.

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Any deviation from this shale trend is an anomalous signature. Removing the background trend from the data would reveal out the anomalous geobodies.

We have introduced one more category as the intermediate trend .This intermediate trend (2-12 Hz) separates out itself from the compaction or depth influenced background trend (0-2 Hz).This intermediate trend is the void that we have in our data. We have seismic velocity data covering the entire exploratory region. This seismic velocity data can provide the compaction or depth trend (0-2Hz).But for intermediate trends we don't have any information spreading to the entire areal extent. We have only sparse well control to feed for this area.

The data used for the low frequency modeling are
1. Interpreted horizons
2. Seismic interval velocity data
3. Well log data (high cut filtered)

Two methods were used for building the low frequency model and the data was inverted using both the methodologies.
Method 1: Low Frequency model using well data and horizons.
Method 2: Background Low Frequency model from 0-2 Hz using seismic interval velocity data and Intermediate Low Frequency model from 2-12 Hz using well data and horizons

For each of these two methods the following schemes were used
Scheme1: Using well logs as it is
Scheme2: Shale trend modeling and Sand modeling
Framework building, velocity calibration, shale model building, sand model building and finally merging into complete low frequency model are the procedures those are involved in low frequency model building.

Framework building

Geological model framework was built to provide the background trend using the seismic interpreted horizon. This framework model defines the stratigraphic and layering scheme. This model includes the entire regional horizon.

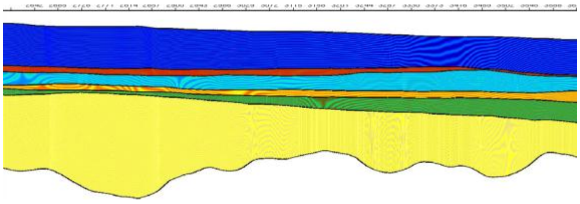

Figure 1: The geological framework model depicting the layering scheme.this framework model was populated by wireline logs. Different colors represent different stratigraphic units.

The layering scheme of framework model was populated by the well logs for the low frequency model building. The layering scheme uses 2ms sampling interval.

Velocity Calibration

Velocity calibration plays important role in low frequency model building process. Seismic interval velocity data was used. The velocity obtained from the well logs is of high frequency of the order of KHz. So a high cut filter was applied at 1Hz with a slope of 1Hz on this well velocity. On the other side pseudo log from the seismic interval velocity volume was extracted at well locations. As the frequency of the velocity data was predominantly up to 1.5 Hz so logs from both the well velocity and seismic interval velocity were kept to this value using high cut filter of 1Hzwith 1Hz slope.

The well velocity was divided by seismic interval velocity (both in high cut form) within the gate of well log availability. This division provides us with calibration factor log.

As the seismic interval velocity was up to 7 seconds but the well velocity log was available in limited region so there was the need to extend the well velocity log and calibration log. This calibration factor log was extended beyond the region of well log availability by extending it using a constant value of unity. This unitary value was used to retain the seismic velocity as it is where the well log is not present.

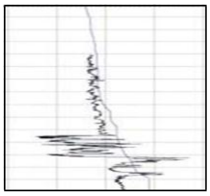

Figure 2: P-velocity wireline log (black) and seismic interval velocity log (blue).

These calibration factor logs were then interpolated using the framework. This gave us calibration factor volume. This calibration factor volume was multiplied with the seismic interval velocity volume to furnish calibrated interval velocity volume.

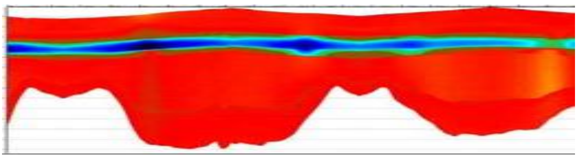

Figure 3: Calibration factor volume from a line near well. The red shows the region where wireline log information was absent.

The red portion in the calibration factor volume represents the part where the well log velocity was not available and the calibration factor logs were extended with the unity value (i.e. 1). In this part seismic velocity will remain as it was.

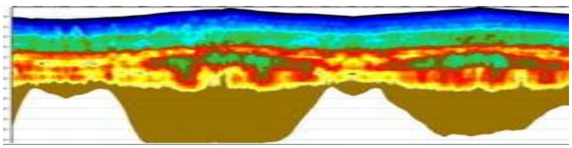

Figure 4: Calibrated velocity volume from the same line near well. The velocity increase from violet to red color.

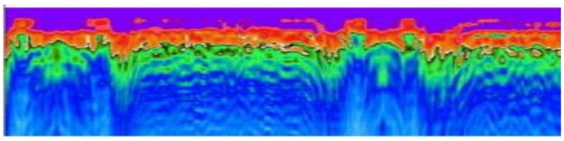

Figure 5: Spectra of calibrated velocity volume from the same line near well. The black line demarcates the cutoff (1.5Hz) above which we don't have significant amplitude in the spectra.

Background low frequency models were built for various properties using the 0-1 Hz with 1Hz slope component from the calibrated seismic interval velocity volume.

The wireline P-velocity logs were crossplotted against the P-impedance logs. The intention was to achieve the trendline. The data points fall in a linear trend. Following equation was obtained and the ultra low frequency model for Pimpedance was constructed using this equation taking calibrated velocity model as an input.

(P-impedance) = M * (P-velocity) + B

The correlation coefficient was 0.983284.

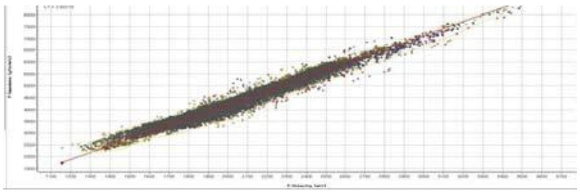

Figure 6: Crossplot between wireline P-velocity and P- impedance logs. The data falls into almost perfect linear trend.

After obtaining the ultra low frequency model for p-impedance the next job was to construct ultra low frequency model for density and Vp/Vs. Next crossplot between wireline P-impedance and density log was made. Obtained equation was used to construct the ultra low frequency density model.

The following relation was used. The correlation coefficient was 0.868.

Density = M *(P-impedance) + B

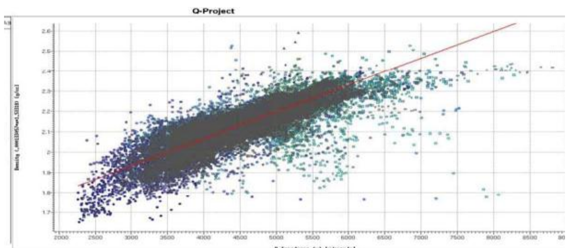

Figure 7: Crossplot between wireline P-velocity and Density logs. This data has a linear trend.

Next crossplot between P-impedance and Vp/Vs was made. The trend was fitted for the shale region as the shale is background. The shale trend was not fully parabolic so the equation used was not parabolic instead we opted for fourth degree equation since it was fitting properly.

The equation used is following.

$Vp/Vs = A*(P\text{-impedance})^4 - B*(P\text{-impedance})^3 + C*(P\text{-impedance})^2 - D*(P\text{-impedance}) + E$

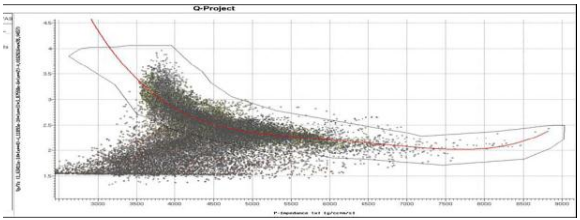

Figure 8: Crossplot between wireline P-velocity and Vp/Vs logs. The trend is polynomial for shales.

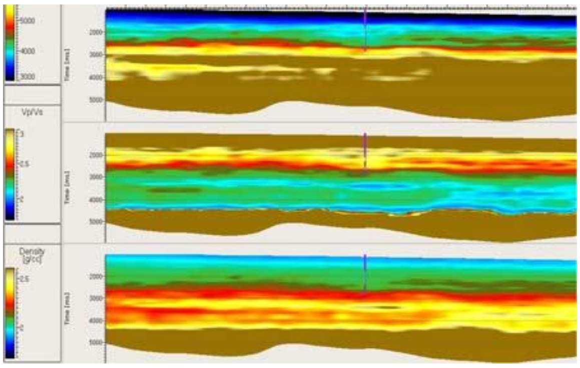

Figure 9: Ultra low frequency models of P-Impedance, Vp/Vs and density (from up to down).

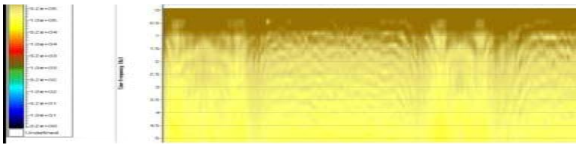

Figure 10: Spectra of the ultra low frequency model.

Simplistic models using the well log information only

We started with simplistic models to test their impact on inverted data. These models were the simple interpolation of well log information within the geological framework. These wireline logs were high cut filtered at 12Hz.

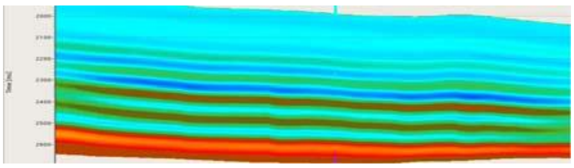

Fig 11: Low frequency model generated from well log interpolation.

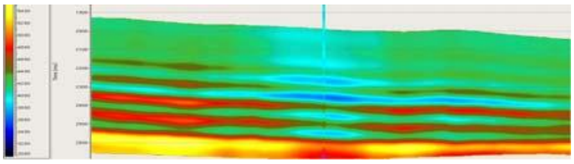

Fig 12: Low frequency model generated from well log interpolation and merged with velocity data for background trend.

Shale Trend model building

First the shale wells were constructed by chalking out the sand zones and replacing them with the background shale line.

Then these logs (p-impdenace, density and vp/vs) were extrapolated using the equations derived from the crossplots made in ultra low frequency modeling.

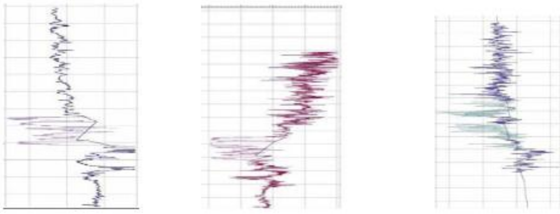

Figure 13: The shale logs overlain by sand logs for P- Impedance, Vp/Vs and density.

Then these shale well logs were interpolated using the geological framework using the nearest neighbour interpolation technique with a sampling of 2msec.

Two categories of shale models were made one with the intention of providing the low frequency model using the wells alone and the other with the motive of mixing the ultra low frequency models with the shale models that start from 1Hz with 1Hz slope called as method 1 and 2.

Low Frequency Shale Trend model using only wells

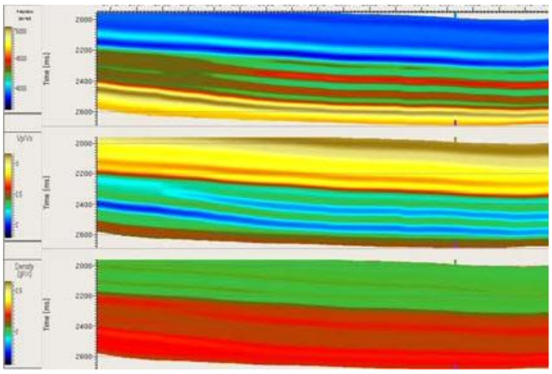

Figure 14: Low frequency shale trend models of P- Impedance, Vp/Vs and density overlain by the shale logs.

Low Frequency Shale trend model using wells and seismic velocity

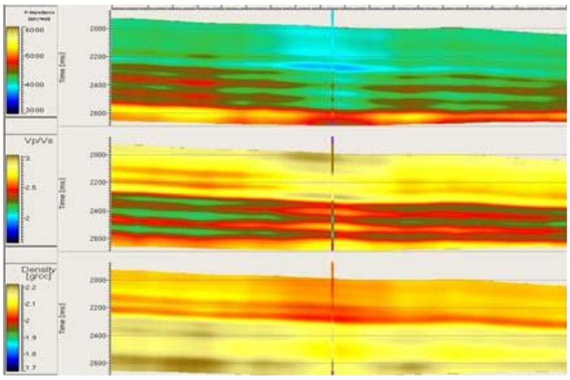

Figure 15: Low frequency shale trend models using wells and velocity for P-Impedance, Vp/Vs and density overlain by the shale logs.(velocity contribution was used from ultra low frequency model.

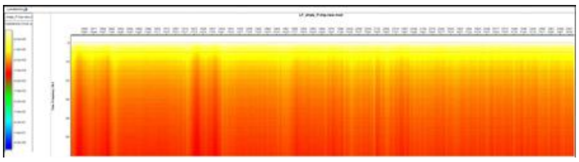

Fig 16: Amplitude spectra of background trend and intermediate trend merged P-impedance shale model. The spectra show the spectral band that is missing in seismic data and is to be compensated.

Sand modeling

Having built the shale trend models sand trend modeling was to be done. Sand low frequency trend model building was attempted after running the first pass of the seismic inversion inverting the seismic for P-impedance, S-impedance, density and Vp/Vs in a bandlimited manner.

A crossplot was made between bandlimited P-impedance and S-impedance logs colored with water saturation log to identify the possible gas sand prone bodies and to further reflect these regions in the bandlimited volume (reflected by simultaneous occurrence value of p-impedance and s-impedance that indicate gas sand presence from bandlimited logs and then using these values in bandlimited volumes as an indicator of possible gas sand presence).

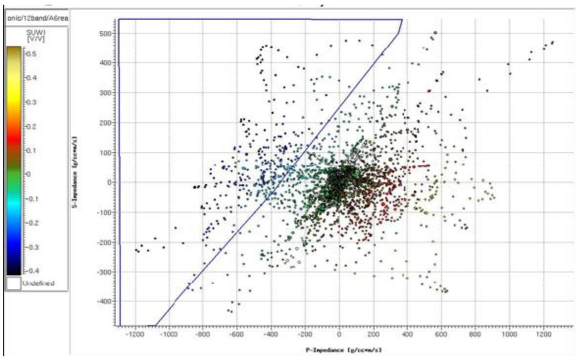

Fig 17; Crossplot between bandlimited p-impedance and s-impedance log colored with water saturation log. The data values within the polygon were used for sand body rendering.

A Geobody check was made using bandlimited P-impedance and bandlimited Simpedance to locate the portions of possible gas sand regions. The skeleton or the geometry of these geobodies was saved. The bandlimited volumes of pimpedance, Vp/Vs and density within this saved frame were separated out and were termed as our sand trend models.

We only show here P-impedance models. Models for Vp/Vs and density can be similarly achieved.

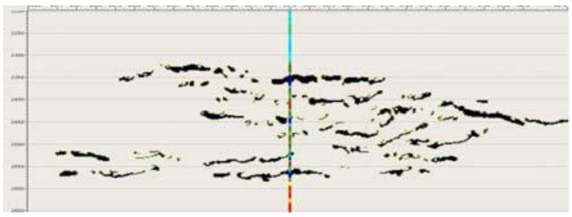

Fig 18: Sand model for P-Impedance.

Complete Low frequency trend model

These sand models are then merged with the shale models to provide the complete low frequency trend models. These final trend models are then used in full bandwidth inversion job.

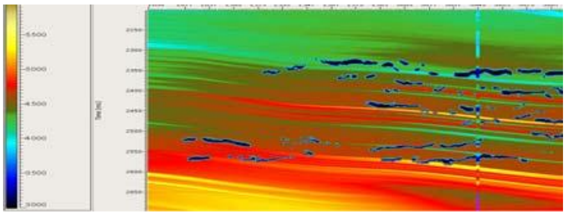

Fig 19: Complete low frequency model (shale + sand) for P-Impedance.

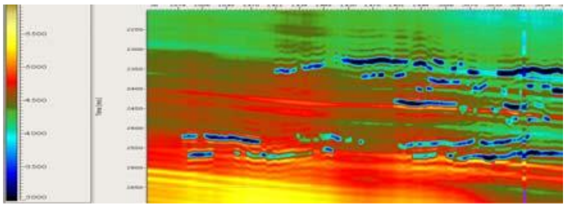

Fig 20: Complete low frequency model (shale + sand) for P-Impedance for intermediate trend. Seismic velocity was used for background trend.

Full band Inversion

These low frequency models a) simplistic model using well information only b) simplistic model using velocity information for background trend and well information for intermediate trend c) shale model –sand model d) using velocity information for background trend and shale sand information for intermediate trend were used for inverting to absolute data. We found that the results obtained from shale–sand modeling were better .Even in shale sandmodeling the results from without usage of velocity were better than usage of velocity. This could be due to calibration errors and localized velocity problems.

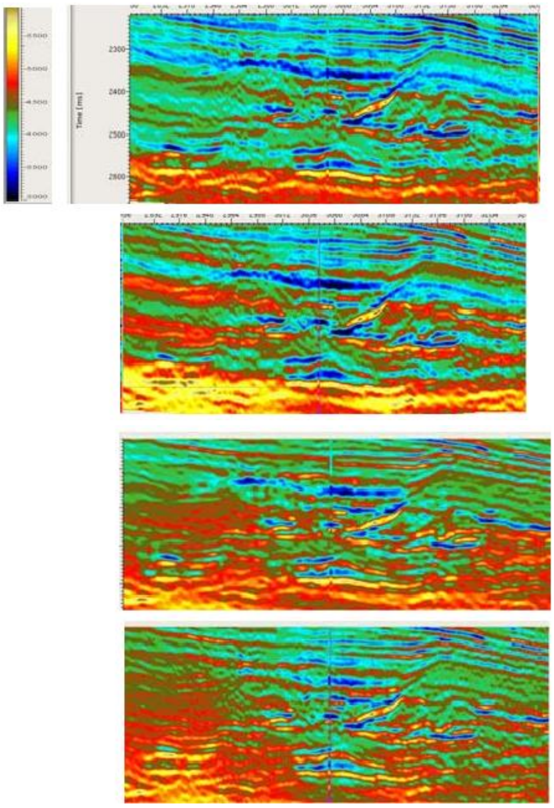

Fig 21: Inverted data from low frequency model a) simple well log b) well log and velocity c) shale sand model d) shale sand model and velocity.

Impact of low frequency on Inverted data

Generally for the intermediate trends portion we only have well log information. This well log information is sparse. It is often said that the interpolation of these well logs within the geological framework will not do justice for intermediate trend modeling since sparseness of well information requires geostatistical interpolation scheme and different schemes can give different results for the intermediate trend.

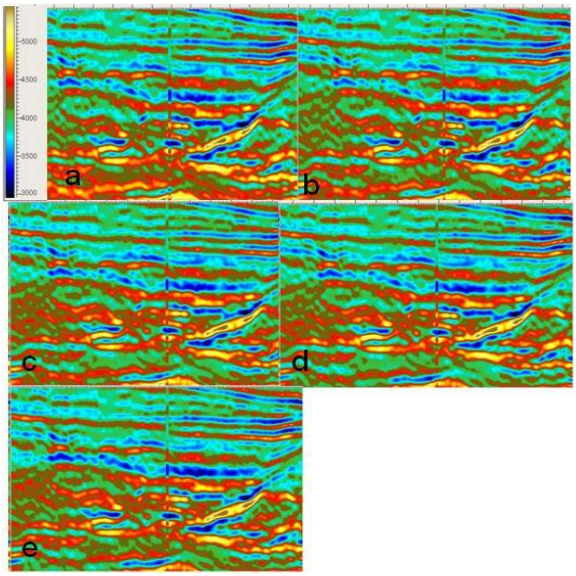

Fig 22: Inverted data from low frequency model with a frequency gap of a) 2-12 Hz b) 4-12 Hz c) 6-12 Hz d) 8-12 Hz e) 10-12 Hz shale sand model and velocity.

So we tested the inverted results by keeping the gap in intermediate trends. We inverted the data by keeping the gaps 2-12Hz, 4-12Hz, 6-12Hz, 8-12Hz, and 10-12Hz.

We found that there were not much differences between the inverted data results because of gap in the intermediate trends. Though the differences increase slightly with depth. The difference between wireline and inverted results were relatively more than the differences among inverted results having gap of various intermediate trends.

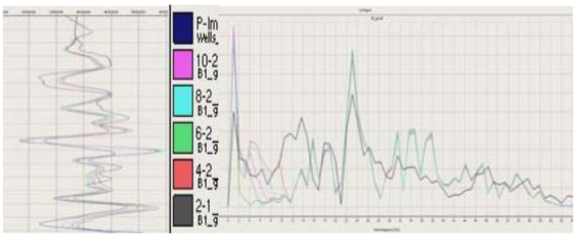

Fig 23: Wireline P-impedance data and pseudo logs from the inverted data utilizing low frequency model with the frequency gaps of 2-12 Hz, 4-12 Hz, 6-12 Hz, 8-12 Hz, 10-12 Hz .On right side spectra of the same logs.

Conclusions

We have shown here various schemes for low frequency modeling and their impact on full band inversion. We find that the shale sand modeling can deliver good results. Generally shale trends don't change significantly laterally and could be good indicator of compaction trends. We also used sand signatures so as to incorporate it in the complete trend model. The lack of intermediate trends also doesn't deteriorate the result to a significant degree. We found that there were not very significant differences in the inverted data results for various gaps in intermediate trends.

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