Comparison of Band-limited and Colored Seismic inversion methods to estimate acoustic impedance of F3 block Netherlands - A case study

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Summary

The acoustic impedance estimation is very significant for characterizing the reservoir. This work aims to use and compare the results of two generic seismic post-stack inversion methods for characterizing the reservoir. These methods are Band-limited inversion (BLI) and Colored inversion (CI). By combining well log and band-limited seismic data, the acoustic impedance (AI) inversion is obtained, which shows high-resolution subsurface information. Band-limited inversion (BLI) and Colored inversion (CI) methods are applied to the post-stack data of F3 block, Netherlands. The data are inverted into P-impedance volume in each case. The results of the investigation show that both the inversion techniques have mutually compatible impedance volumes with an average correlation coefficient of 0.97 and 0.74 respectively, for BLI and CI. Both methods of inversion show low impedances ranging from 2500-6500m/s*g/cc between 1100ms and 1800ms time. The difference of impedance obtained from both the methods is estimated to -757 to 741 m/s*g/cc. Compared to Colored inversion, Bandlimited Inversion provides excellent results.

Introduction

Seismic inversion is a technique that seeks to extract the physical characteristics of rocks and fluids from underlying models. The method is used to estimate petrophysical properties from seismic and well-log data (Maurya and Singh, 2017; Maurya et al., 2018). Nonetheless, there are several limits to seismic AI inversion. First, the seismic frequency range is narrow to about 15-60Hz; thus, the input data for inversion at low and high frequencies are missing (Russell and Hampson, 1991; Maurya and Sarkar, 2016). Second, the uniqueness of the solution may lead to multiple possible geological models regular with observations. (Russell, 1988). Third, the process of inversion undergoes numerous problems such as multiple reflections, failures of transmission, geometric distribution, and absorptions depend on frequency (Larsen et al., 1998). To reduce these doubts, additional information such as well log data, which includes both low and high frequencies absent from seismic data, is generally included to restrict the variance from the preliminary guess model of the solution. Therefore, the final results are based on seismic data as well as added information but are also reliant on the techniques of inversion used in this study (Ferguson and Margrave, 1996; Haris et al., 2017). The flowchart of the present study is shown in Figure 1.

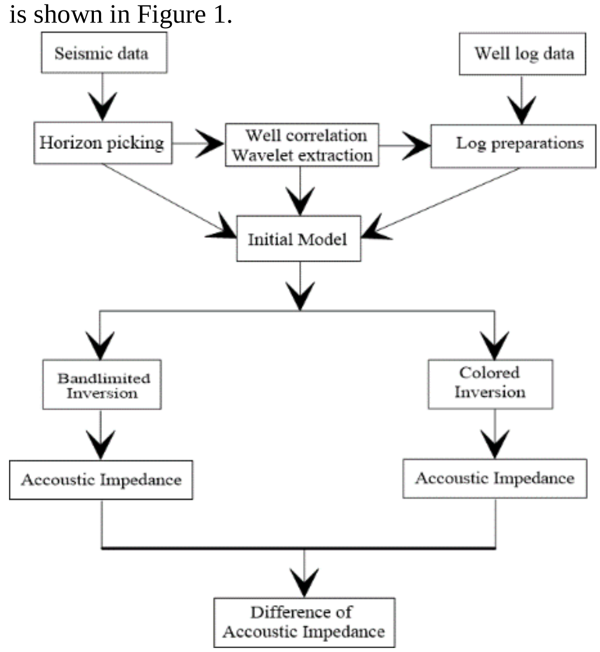

Figure 1: Flowchart of the study.

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In this study, offshore 3D post-stack seismic data of the F3 block, Netherlands, is used. The survey was conducted in an area of 384 square km in 1987. Within the survey area, there are four vertical wells, all of which had sonic and gamma-ray logs. The well log depth was around 1700ms. The F02-1 well position is 362 inline and 336 cross-line, F03-2 772 inline and 848 cross-line, F03-4 442 inline and 1007 cross-line and F06-1 244 inline and 387 cross-line. The field of seismic surveys extends for all volumes from Inline 100 to750 and X-line 300 to 1200. The P-wave, density S-wave and check shot logs are the critical data required for the inversion procedure. An open-source seismic database platform (dGB Earth Sciences) provides seismic and well data.

Methodology

In this study, two types of seismic inversion methods namely bandlimited and colored inversions, are used for the analysis. These methods are described briefly in the following segments.

a. Bandlimited Inversion

Band-limited impedance inversion (BLI) transforms post-stack seismic data into an impedance, density, and P-wave velocity. The band-limited impedance method begins with specifying the relationship between the seismic trace and seismic impedance (Ferguson and Margrave 1996). Thus, define impedance as follows.

$$\xi = v\rho \quad (1)$$

The standard incidence reflection coefficient can be estimated as follows.

$$r_j = \frac{\xi_{j+1} - \xi_j}{\xi_{j+1} + \xi_j} \quad (2)$$

Where ξ_j is j^{th} layer seismic impedance and r_j is j^{th} and $(j+1)^{th}$ interface seismic reflectivity. Solve the above equation for $(j+1)^{th}$ layer impedance, we have the following equation.

$$\xi_{j+1} = \xi_j\left(1 + \frac{2r_j}{1 - r_j}\right) = \xi_j\left(\frac{1 + r_j}{1 - r_j}\right) \quad (3)$$

Thus, the impedance of n^{th} layer if we understand first layer impedance can be expressed as follows.

$$\xi_n = \xi_1\left(\frac{1 + r_1}{1 - r_1}\right)\left(\frac{1 + r_2}{1 - r_2}\right) \ldots\ldots\ldots\ldots \left(\frac{1 + r_{n-1}}{1 - r_{n-1}}\right) \quad (4)$$

It is necessary to estimate the acoustic impedance of the first layer from a continuous layer above the target area to calculate the impedance of the nth layer (Maurya and Singh 2015). The j^{th} layer impedance can, therefore, be intended as follows.

$$\xi_{j+1} = \xi_1 \prod_{k=1}^{j}\left(\frac{1 + r_k}{1 - r_k}\right) \quad (5)$$

Divide above equation (5) by first layer impedance ξ_1 and take both side's logarithm, we have the following equation.

$$\ln\frac{\xi_{j+1}}{\xi_j} = \sum_{k=1}^{j} \ln\frac{1 + r_k}{1 - r_k} \approx 2\sum_{k=1}^{j} r_k \quad (6)$$

The last phase follows from an estimation for ln which is valid only for small r. Now we have ξ_{j+1} on solving equation (6).

$$\xi_{j+1} = \xi_1 \exp\left(2\sum_{k=1}^{j} r_k\right) \quad (7)$$

Model the seismic trace as scaled reflectivity, $S_k = \frac{2r_k}{\gamma}$, then the above equation becomes as follows.

$$\xi_{j+1} = \xi_1 \exp\left(\gamma \sum_{k=1}^{j} S_k\right) \quad (8)$$

Consequently, the above equation integrates the seismic trace and then exponentiates the outcome to provide a trace of impedance (Waters 1987).

To perform time to depth conversion because well log data is in-depth domain and seismic data is in the time domain and as seismic inversion use both information together hence need to convert them in the same domain. For this purpose, the synthetic trace is generated from well logs and matches with seismic trace. If the match is good then OK, if not good then stretching and squeezing is performed to the synthetic data to match them properly. The good match condition provides time-depth relation which is used to scale seismic data.

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b. Colored Inversion

Lancaster and Whitcombe (2000) developed a quick process for seismic data known as colored inversion (CI) which produced prominent interest among interpreters. In this analysis, we follow the procedure proposed by Lancaster and Whitcombe (2000) to accomplish fast-track color inversion.

The colored inversion is a method where the acoustic impedance spectrum extracted from log data is used to calculate the operator's spectrum. This operator's phase is -90 degree which enables the impedances to be generated by its association with the reflectivity sequence (Lancaster and Whitcombe 2000). The steps to derive the operator is the following: First, the acoustic impedance is measured and plotted against the frequency for all wells in the area. The regression line matches the amplitude spectrum of the acoustic impedance to represent the impedance spectrum in the subsurface on a log-log scale. Second, the seismic spectrum is measured from the seismic traces near to the wells. Such two spectra are used to measure the operator spectrum which converts the seismic spectrum into the typical impedance spectrum. Third, the final spectrum is associated with a-90 degree phase shift to achieve a desired time-domain operator as seen in Figure 2. Colored inversion is quick and suitable for 3-D dataset applications.

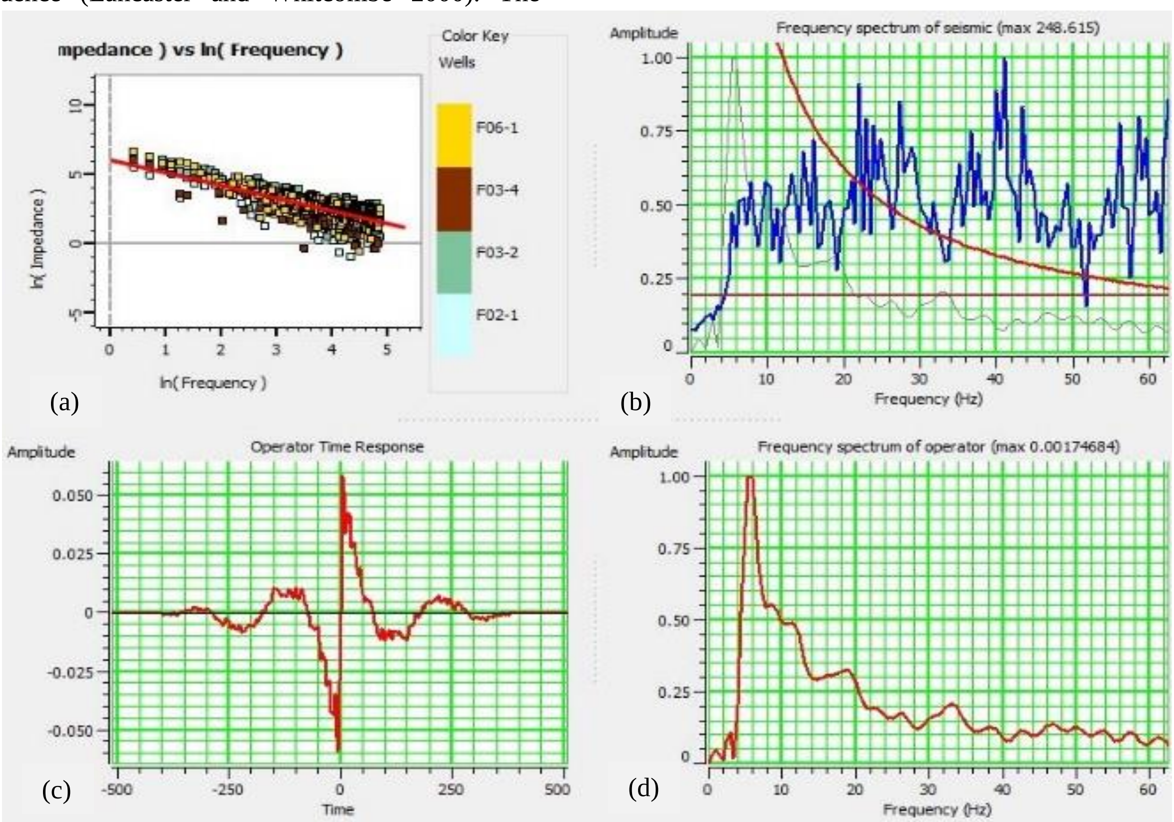

Figure 2: (a) cross plot of AI and frequency from all wells, (b) Seismic spectra close to the wells (blue). Redline parallels to the f spectrum. The spectrum of the operator (black) is the ratio of these two spectra, (c) Operators Time response and (d) Operators Frequency spectrum.

Results and discussion

In this study, we have used Band-limited inversion and Colored inversion methods to estimate P-impedance of the subsurface. Figure 3 shows the inversion analysis for the Band-limited inversion technique. From figure 3, one can notice the

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correlation coefficient to be 0.97 and error is 529.08m/s*g/cc. Further, the cross plot between original P impedance and inverted P impedance is shown in Figure 4. These results show that the inverted impedance is very close to the original impedance. Further, figure 5 shows the inversion analysis result of the Colored inversion technique. The correlation coefficient is 0.74 and error is 354.47m/s*g/cc. The cross plot between original P impedance and inverted P impedance is shown in figure 6. This cross plot and inversion analysis depict the good performance of the colored inversion algorithm. But one can also notice that the band-limited inversion is slightly better as compared with the colored inverted results. Further, both methods are applied to the entire post-stack seismic volume to get impedance volume. The cross-section of inverted impedances are shown in figure 7. Figure 7a is inverted impedance at inline 245 estimated using the BLI method, and figure 7b shows a cross-section of inverted acoustic impedance at inline 245 generated using the colored inversion method and figure 7c shows the difference between 7a and 7b. From the figure (Figure 7), one can notice that the formation impedance variation is ranging from 2500m/s*g/cc to 6500m/s*g/cc. This impedance is comparatively low, and hence one can conclude that the loose formation is present in the study area. From the inverted sections, one can also notice that the resolution of the band-limited section is greater as compared with the colored inversion results.

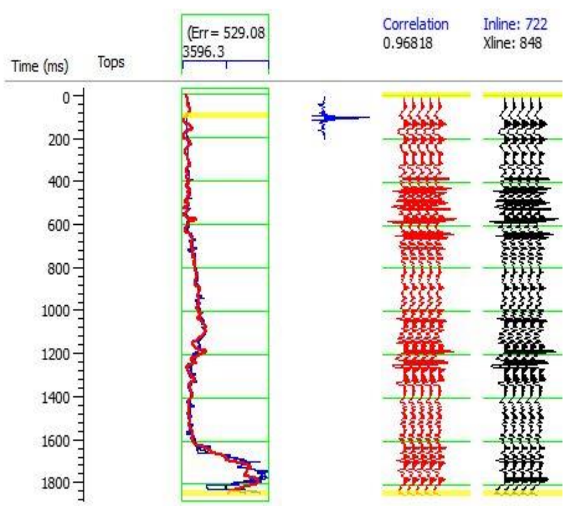

Figure 3: Inversion analysis of bandlimited inversion. The correlation and error are mentioned at the top of the figure.

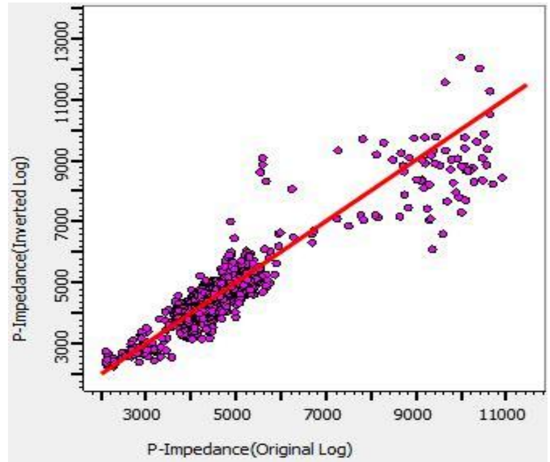

Figure 4: Crossplot between original P impedance and inverted P impedance obtained by band-limited inversion.

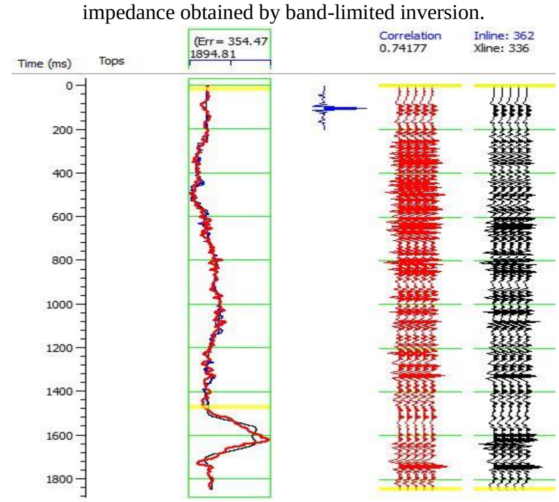

Figure 5: Inversion analysis performed using Colored inversion. The correlation and error are mentioned at the top of the figure.

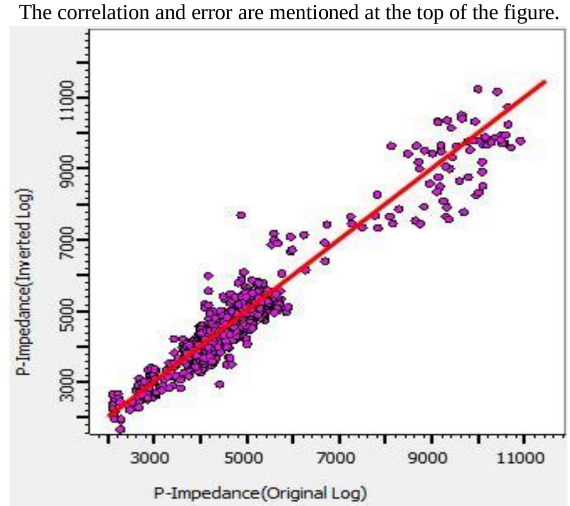

Figure 6: Crossplot between original P impedance and inverted P impedance obtained from colored inversion.

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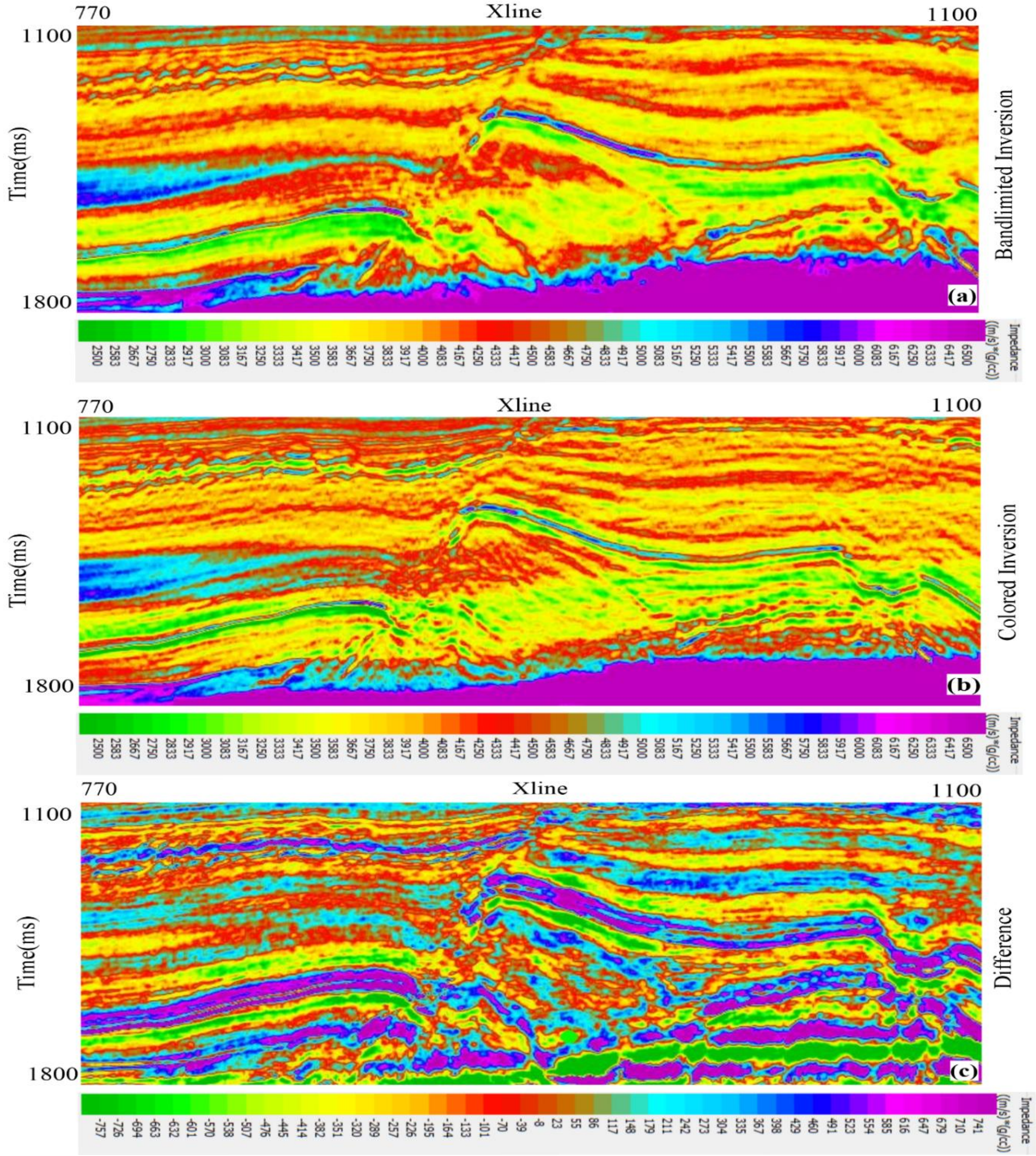

Figure 7: Cross-section of inverted impedance at inline 245 generated using a) band-limited inversion, b) colored inversion methods, and c) difference between two.

Further, the difference between the inverted section from the band-limited and colored inverted section is generated and displayed in Fig. 7c. The variation is -757 to 741 m/s*g/cc which again shows that both methods deviate with each other in some particular location. But overall, both methods provide satisfactory results with bandlimited methods that have greater resolution.

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Conclusions

In this study, the seismic datasets from the F-3 block, Netherlands are used for comparative analysis of two types of post-stack inversion techniques. These methods are band-limited inversion and colored inversions. Both post-stack inversion methods are used to obtain the impedance section. From the analysis, we have drawn the following conclusions.

1. The results show that band-limited and colored inversion provides mutually consistent results. The correlation is estimated to be 0.97and 0.74 for BLI and CI, respectively.
2. The analysis shows that the area impedance is ranging from 2500m/s*g/cc to 6500m/s*g/cc which is relatively low and indicates loose formation.
3. The analysis shows that the resolution of the band-limited inverted volume is slightly better than the colored inverted volume. The inverted section is shown for particular Inline and Xline, so there may be any chance that CI inverted volume section is better than BLI inverted volume section, but the overall resolution of BLI inverted volume is better than CI inverted volume. It will be cross verified by inversion results (cross plots and correlation coefficients) of BLI and CI inversion methods.
4. The difference section of both inverted results shows a variation of -757m/s*g/cc to 741 m/s*g/cc which indicates that in some regions, both methods give different values of the impedance.

Overall, it is concluded that the band-limited inversion method provides more accurate results as compare with the colored inversion method results for the post-stack seismic data from the F-3 block, Netherlands.

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