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Seismic Absorption Estimation for Reservoir Prediction Using Prony Decomposition

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Summary

Frequency decomposition provides good structural understanding, but do not resolve fluids accumulations. Amplitudes of seismic wave passing through rocks with reservoirs are damped more, especially at high frequencies. Therefore, frequency decomposition, which takes into account dumping factor (Q) helps to identify reservoirs. The Prony method decomposes seismic signals by damping cosines at short-time intervals, and creates discrete spectrum including values of amplitude, dumping factor, frequency and phase. We first show the advantage of using Prony method for seismic reservoir interpretation by analysing the frequency decomposed seismic sections and the expressed Q-factor component. Then we compare the interpretation results of Prony's method with Quantitative Interpretation and Phase Decomposition technique. We show that the Prony Decomposition is a convenient scanning tool for geo exploration.

Introduction

Frequency decomposition is widely used in geo exploration. It provides opportunities to study in details structures and reflectors below seismic resolution. Despite of many different frequency decomposition approaches, fluids presence and types are still not resolved. Here we demonstrate that the use of Frequency Decomposition by Prony's method (Prony, 1795) helps to interpret structures and amplitude attenuations, which can be associated with fluid presence.

Prony's method is used in many disciplines e.g., in power systems (Hauer J.F., 1990) and radar signatures characterisation (Carriere, R., 1989). Implementation of Prony's method had already proved its usefulness in geo exploration: seismic noise attenuation, structural interpretation, fractured reservoirs and pore pressure predictions (Fomel.S, 2013; Helle H. B, 1993). Introduced by G. R. B. Prony (Prony, 1795) the method allows to decompose observed seismic signals by damping cosines at short-time intervals, and creates discrete Prony spectrum including values of four parameters: amplitude, damping factor (Q-factor), frequency and phase.

In reservoirs, seismic energy is absorbed. The high frequencies are more attenuated than the low frequencies leaving us with lower-resolution image. To understand the nature of wave attenuation, several approaches were suggested in the 20th century (Aki K., 1975). Knopoff investigated attenuation described by non-dimensional quality factor Q (Knopoff L., 1964). He demonstrated that the Q-factor is independent of the frequency in homogeneous rocks, whereas it varies as a first power of frequency in liquids. Significant seismic amplitude damping occurs e.g. in gas chimneys and these amplitude damping are easily visible on seismic sections. On the contrary, in thin reservoirs or structural hidden reservoirs, the amplitude damping is not that strong and is less visible or could be non-visible at all. The Prony's method helps to detect non-visible damped amplitude on seismic sections for all frequencies. Mitrofanov and Priimenko illustrated the use of Prony Decomposition and Filtering on different physical models having scattering and absorbing objects (Mitrofanov G., 2013). In this paper, we will focus on absorption effect to illustrate different cases for reservoir detection.

When we decompose seismic traces by Prony's method into different frequencies or just express Q-factor, we can identify areas where amplitude damping occurs. These areas can be associated with fluid accommodations. Then using Phase Decomposition method (Castagna J., 2016) often helps to separate top reflectors to hydrocarbon (HC) and brine contained. Here we show synthetic modelling for fluid accommodation prediction using Prony's Decomposition. We also compare the interpretation done base on Prony's Decomposed and Filtered seismic data with the classic quantitative interpretation and Phase Decomposition methods.

Prony Frequency Decomposition in comparison with other frequency decomposition methods

Comparing to other frequency decompositions, the Prony's decomposition is based on attenuated sinusoid and therefore, is the closest to the nature of seismic trace. Moreover, the Prony's transform takes into account Q-factor and phase, and does not depend on the chosen time window. The decomposition establishes a discrete spectrum associated with a set of shot-time intervals located along the analysed trace, and can be expressed as

$$\hat{F}(t) = \sum_{i=1}^{N} A_i e^{Q_i t} \cos(2\pi f_i t + \omega_i),$$

where, Q – damping factor, ω - phase, t – time, f – frequency.

Synthetic modelling for Q-factor effect and an example of Prony decomposed and filtered data analysis

To illustrate Q-factor effect we model two simple media: the first one is a Plane Model (Q=1000 everywhere) and the second one is a Model with absorption block (similar to plane model with an inserted block having a Q=10) to simulate fluid accumulation, Figure 1 a and b. The extreme Q values

(10 and 1000) were used to be able to visualise Q-component effect on seismic profile. P-impedance log is used to generate a synthetic seismic trace, which is repeated several times, Figure 1 c. Second synthetic seismic section of the Figure 1 c (on the right) has damped amplitude visible from about 2.6s – start time where the absorption occurs. Figure 2 illustrates amplitude spectra for the two synthetic models. The synthetic model with absorption block shows damping amplitude along all frequency ranges. The bigger amplitude damping occurs at higher frequencies, in our case; starting from about 38 Hz. If we decompose data to the higher frequencies using the Prony's method, we will be able to localise the attenuation and to define fluid accumulation area. Figure 3 illustrates Prony decomposed synthetic seismic for the Model with absorption block and its filtered result for each of four components: amplitude, frequency, phase, and Q-factor.

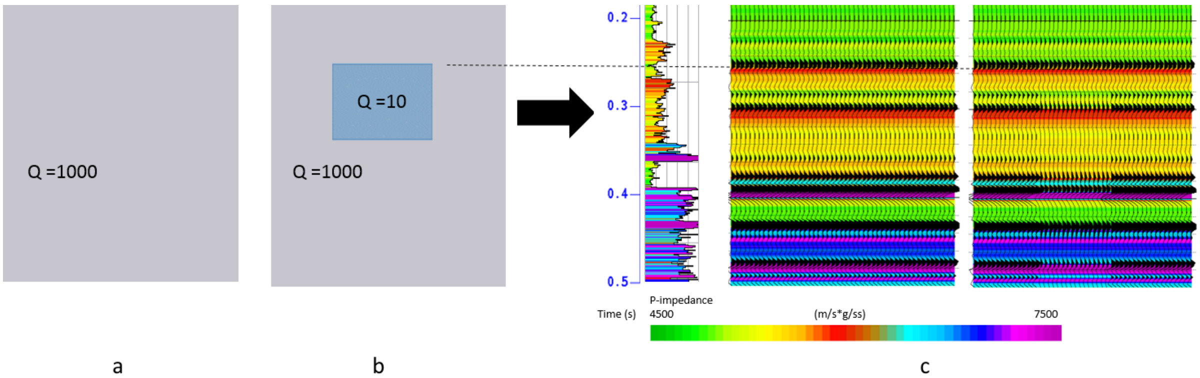

Figure 1 *Media models and their synthetic seismograms. a - Plane model, b - Model with absorption block inserted (Q=10), c -P-impedance log used to generate synthetic traces; synthetic of Plane model and of Model with absorption area inserted. Wavelet parameters used to generate synthetic trace: Bandpass wavelet 5-10-40-125 Hz, 2ms sample rate and 100ms length.*

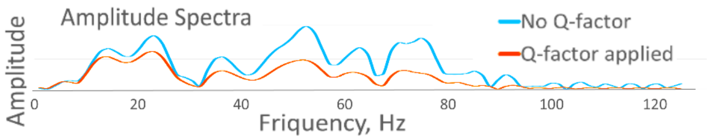

Figure 2 *Amplitude Spectra for Plane Model and Model with absorption block inserted. Model with Q-factor (red color) has less amplitude values - damping amplitudes. The biggest damping occurs for higher frequencies.*

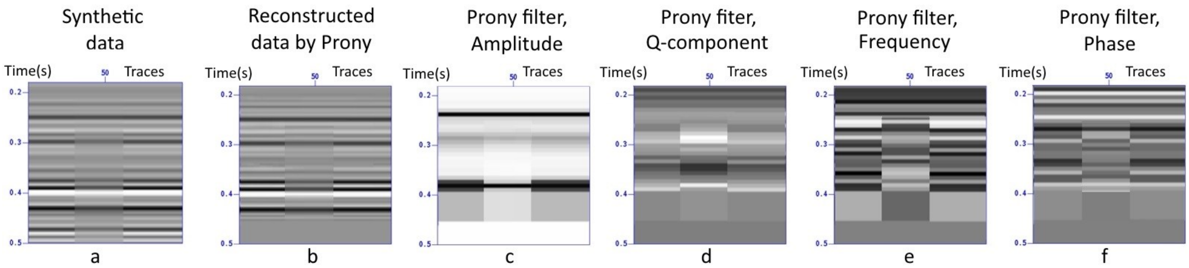

Figure 3 *Prony Filtering data for four components: Amplitude (c), Q (d), Frequency (e) and Phase (f). a - Original Model with adsorption area inserted in traces 30-60 and time 2.62-2.95s; b - Reconstructed data by Prony (frequency from 0 Hz to 125 Hz).*

Analysis of field seismic data by Prony method in comparison with Simultaneous Inversion and Phase Decomposition

Figure 4 shows geophysical interpretation of data by Prony's method and Phase Decomposition in comparison with seismic simultaneous inversion result. The analysis is done in exploration to corroborate idea of HC presence in sandstone layer on top of carbonate structure.

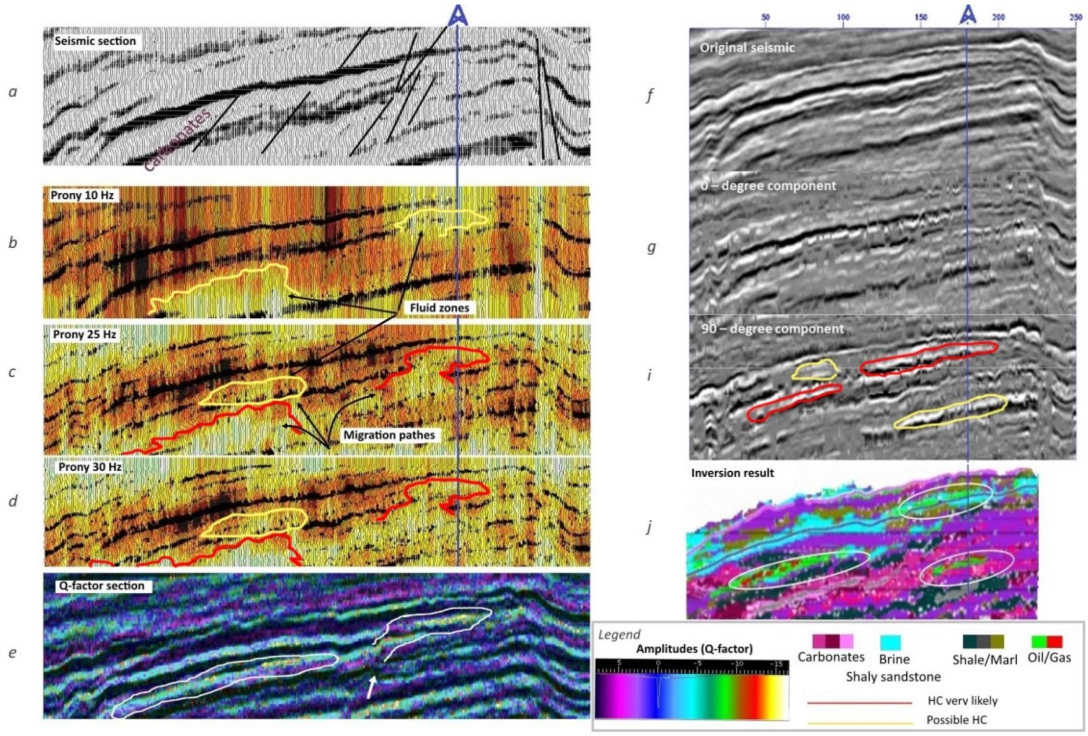

Figure 4 *Geophysical interpretation of data. Left pictures are seismic in wiggle display with some faults interpretation (a), its Prony filtered components of 10 Hz (b), 25 Hz (c), 30 Hz (d) with overlaid energy and Q-factor (e). Zones with amplitude damping (energy absorption) outlined in yellow and red. Black arrows supporting fault systems show suggested fluid migrations. Right pictures are seismic data (f) and its Phase Decomposed sections of 90-degree (g) and 0-degree (i) components. The outlines in red show HC contained reflectors. The picture below (j) is the result of Simultaneous inversion. Lithology and fluid separation is done on P-impedance versus Vp/Vs calculated template.*

The drilling results show that predicted lithology matches with expectation while HC size is not clearly defined. Figure 4 j shows inversion result coloured by cross plot zones section. In this case, we use calculated P-impedance versus Vp/Vs template. The predicted size of HC reservoirs from simultaneous inversion always varies (red and green colours). It depends on the choices of the template zones. Small increases of defined HC zone on the template makes HC prediction spreads down flange in sandstone layer. We illustrate the minimum taken size of the zone – HC on the top of sandstone layer.

Interesting to notice, the combined analysis of Prony's method and Phase Decomposition of stacked data gives reservoir size and fluid almost uniquely. The amplitude-damped zones are well-localised at the high frequencies of Prony's decomposition seismic sections – red and orange outlines, on Figure 4 b-d. In the sandstone layer, two zones of amplitude damping, mostly belonging to the lower part of the layer, are visible. This does not support the hypotheses of HC presence along the entire layer. Another zone with fluid accumulation appears in carbonates, visible on all frequency-decomposed sections. The damped amplitudes can indicate presence of higher porosity rocks filled with any fluids. To distinguish amplitude-damped zones between HC and brine, we use Phase Decomposition technique. According to Phase Decomposition theory, reflectors of layers containing HC should be highlighted on 90-degree component of phase-decomposed seismic and should disappear on the 0-degree component. The outlines in red (Figure 4 i) show reflectors which should contain HC. Thus, from Prony and Phase Decomposition methods, we can conclude that two zones, one on the top of the sandstone layer and the other one in the left flange of carbonates are very likely HC. Inversion result matches with joint Prony and Phase Decomposition methods, even though could not define the HC size. The drilling result for the top sandstone layer was oil-shows.

Q-factor section – the examples of explored structures

Figure 5 illustrates Q-factor sections for two reservoirs. Positive bright spots are amplitude-damping areas. Left picture is the Stetind gas reservoir, Norwegian Sea. Q-factor section indicates reservoir location correctly. Right picture is the Korpfjell structure that was expected to be filled up with HC. However, drilling shows partly filled compartments with gas. White arrows point to the biggest fluid accommodation areas (most negative relative Q-factor values) within the Korpfjell structure and discontinuous localisation that was confirmed by drilling. Structure below marked in oval has not been drilled yet.

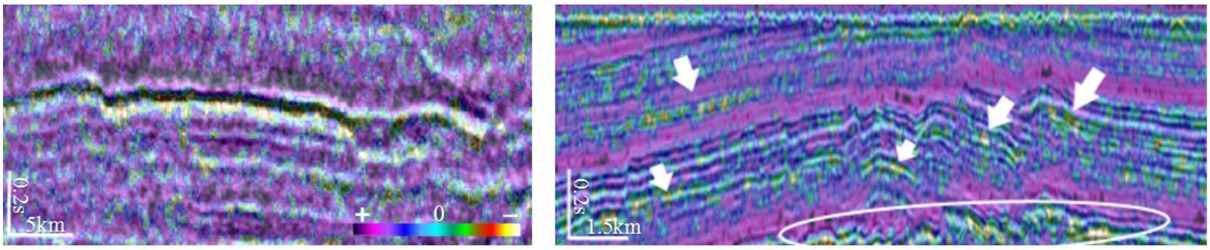

Figure 5 *Q-factor sections: Stetind gas field, Norwegian Sea (left), Korpfiell, gas, Barents Sea (right).*

Conclusion

Prony's Decomposition, which takes into account Q-factor, allows to filter seismic to different frequencies and/or to express Q-factor component, which can be used for fluids localisation prediction. We showed detailed reservoir study and Q-factor sections confirming reservoir localisation. Thus, the Prony Decomposition is a convenient scanning tool for geo exploration.

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