# Potential of Prony and Phase Decompositions for Reservoir Prediction

*Vita V. Kalashnikova, Rune Øverås, Arif Butt and Stéphanie Guidard*
*Pre Stack Solutions-Geo AS, Norway*

## Summary

Prony Decomposition (Prony, 1795) is a unique signal decomposition that takes into account seismic wave attenuation/damping ($Q^{-1}$) as well as phase, frequency and time. The Q-factor retrieved from the seismic data through Prony Decomposition can thus be used to map seismic attenuations. Since seismic waves are more attenuated in reservoirs, especially at high frequencies (Knopoff L., 1964), decomposed seismic signals to different frequencies or Q-factor sections obtained by the Prony method are useful to analyse zones of fluid accumulations, e.g., reservoirs. In addition, we combine Prony Decomposition with Phase Decomposition in order to distinguish between types of fluids in reservoirs. These two methods combined provide an efficient seismic scanning tool for hydrocarbon (HC) reservoir prediction.

## Prony and Phase Decomposition for Reservoirs prediction

Seismic signal decomposition is since long a standard routine in exploration. Structures and reflectors below seismic resolution, can be imaged e.g. with frequency decomposition. To predict HC reservoirs, several techniques mainly based on AVO exist but the results are limited by data quality and human bias. Here, we demonstrate that combining Prony Decomposition jointly with Phase Decomposition can help analyse seismic data to predict/detect HC in formations.

Implementation of Prony's method has already proved its usefulness in many physical disciplines (Hauer J.F., 1990, Carriere R, 1989), including geo exploration: seismic noise attenuation, structural interpretation, fractured reservoirs and pore pressure predictions (Fomel S, 2013; Guoning Wu, 2018, Helle H. B, 1993). Introduced by G. R. B. Prony (Prony, 1795), the method was waiting for the digital age. This method essentially decomposes the observed seismic signals in a series of damping cosines at short-time intervals. The decomposition approaches is natural seismic signals best, in the form of attenuated sinusoid. It creates discrete Prony spectra including values of four parameters: amplitude, frequency, phase and damping factor ($Q^{-1}$).

Seismic waves are attenuated due to energy losses, friction, fluid displacement and geometry. In presence of fluids, higher frequencies are more attenuated than lower frequencies. For example, gas chimneys give lower-resolution seismic image where the edges can be easily identified. The description of wave attenuation nature was suggested by Aki (1975). Knopoff investigated wave attenuation through physical experiments, and he introduced a 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. The Prony's method allows to express the Q-factor from the seismic data and highlights areas where signal attenuation is most significant (e.g., reservoirs, gas zones). Mitrofanov and Priimenko performed several experiments in which they modelled objects with different scattering and absorbing physical properties (like reservoirs) to illustrate the usefulness of Prony Decomposition and Filtering (Mitrofanov G., 2013).

Thus, by using the Prony method, one can positively identify the presence of big fluids' accumulations in structures or formations. The effect also depends on the formation's physical properties. The bigger rock porosity and lighter fluid density, the greater effect we will see on Q-factor seismic section. However, the method cannot give information about fluid type.

Castagna et al. applied Phase Decomposition for seismic signal interpretation (Castagna J., 2016) to help separating hydrocarbon and brine contained reflections. They showed that decomposed seismic signal to 90-degree phase component, highlight a HC contained reflector. When a reservoir is identified on Q-factor seismic section, a phase decomposition of the top of reservoir reflector is performed in order to get information about the fluid reservoir type (HC or brine).

Here we show the application of Prony Decomposition and Phase Decomposition techniques on the seismic data from the Fenja oil and gas field off Norway.

## Application Example: Fenja oil and gas field, Norway

Fenja is an oil and gas discovery in the Norwegian Sea. Figure 1 shows the field outlines and the location of a seismic line across the reservoir used in this study. Two wells confirmed the oil and oil&gas presence.

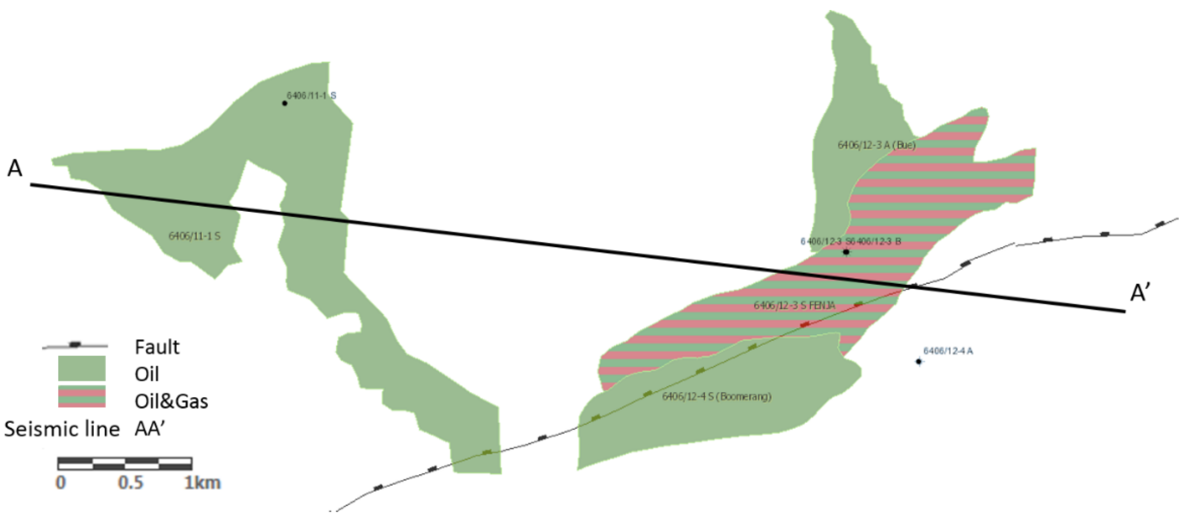


***Figure 1*** *Fenja reservoir map. Outlines and wells location from NPD (www.npd.no)*

Figure 2 illustrates Prony Decomposition and Phase Decomposition techniques applied to the seismic section crossing through the Fenia field. First, the seismic data is decomposed by the Prony method resulting in the seismic traces as Q-factor image. On Figure 2 *a* and *a'*, the Q-factor section overlays the seismic stacked data (seismic staked data is in dense display, where black pick is a soft event). Positive values of the Q-factor section correspond to no- or non-significant amplitude damping and are marked by purple color on the section. On the other hand, the most negative values (white, yellow, red, green and light blue) correspond to zones where the biggest amplitude damping occurs. These zones correspond to the top of the Fenja reservoir and are very likely associated with good porosity reservoirs. We highlight them by the 2 ovals on Figure 2 *a'*. White arrows pointed to the separated amplitudes' damping zones within the same reflectors. Based on the Q-factor section, we can say that the studied formation has whether changes in rocks porosity, presence of other rocks e.g. shale or is affected by faults. Therefore, we cannot see the amplitudes damping through/along the formation. A fluid type cannot be determined at present stage.

According to Phase Decomposition theory, reflectors from the top of the formations containing HC should be highlighted on the 90-degree component of phase-decomposed seismic and should disappear on the 0-degree component. In order to successfully apply this technique, one requires accurate phase and synthetic well modeling.

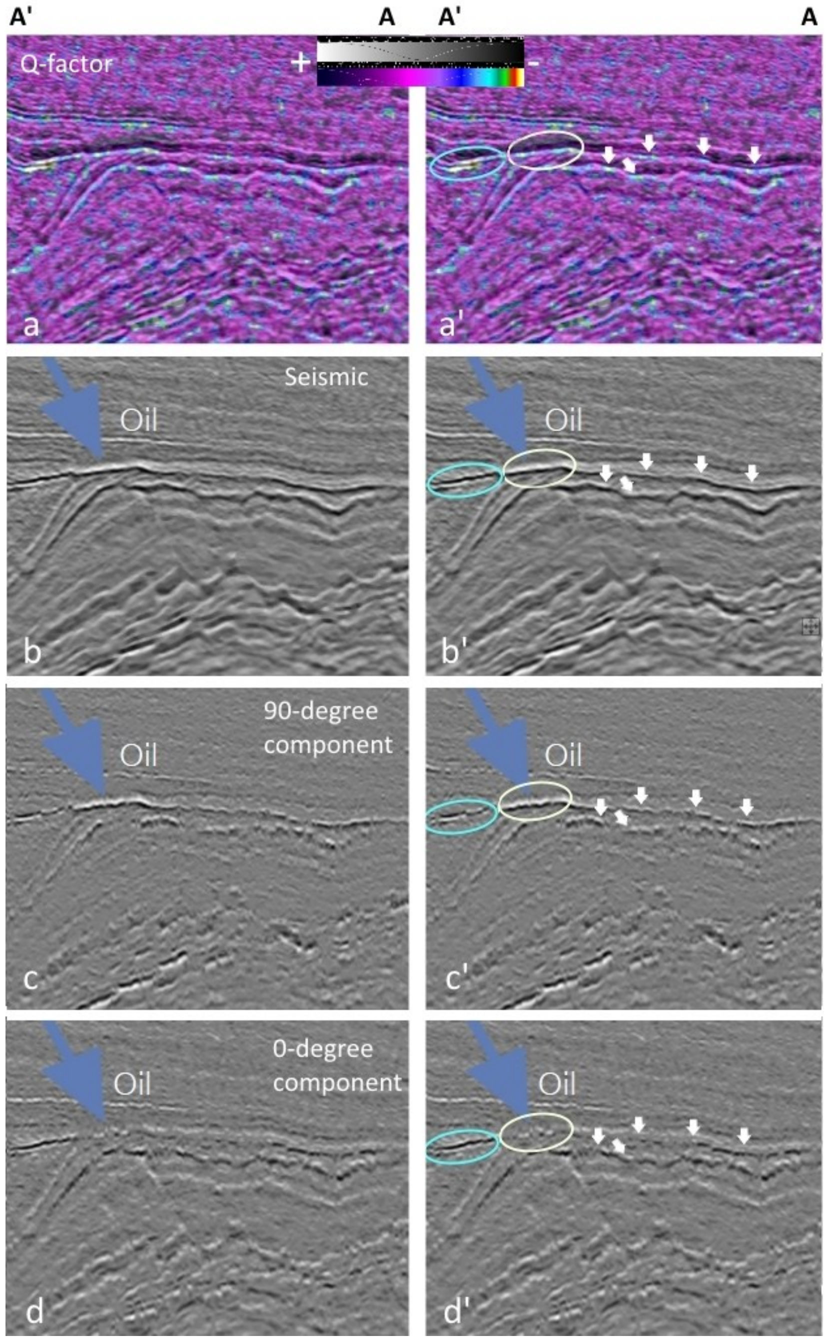


***Figure 2*** *Geophysical interpretation of seismic data based on Prony and Phase decompositions. Left side, pictures (a to d) are analysed data. Their interpretation is shown on the pictures on the right side (a' to d'). (a & a') Q-factor seismic section overlaid by stacked seismic data, (b & b') seismic section (trough is white, soft), (c & c') Phase Decomposed seismic section to 90–degree component, and (d & d') Phase Decomposed seismic section to 0–degree component. Data courtesy Exploro, Norwegian Sea Toolkit$^{TM}$.*

Based on the Phase Decomposition technique, the reflection segments marked by white ovals and arrows, on figures 2c’ and 2d’, are HC indicators (confirmed by the drilled well): the segments brighten on the 90-degree component and disappear on the 0-degree component. On the other hand, the segment marked by blue oval from the same main boundary, on the same figures, is very likely a brine contained reflector and the phase break can be due to faults or fluid type changes. The other zones with biggest damping amplitudes around studied reflections can be considered as brine containing. Drilling results confirmed HC saturation break along studied structure: Figure 1 shows two separate shape of HC within the same formation.

## Conclusions

Through Prony Decomposition, the Q-factor can be reliably extracted from seismic data and used for fluids localization purposed: reservoirs. Phase Decomposition separate reservoirs in HC and brine contained. This was illustrated by the Fenja reservoir study, where we combined both techniques for a confirmed reservoir localization.

The combination of Prony and Phase Decompositions is a good seismic scanning tool in geo exploration to point to promising HC reservoir.

## Acknowledgements

We would like to express our gratitude to Dr. Maarten Vanneste for the inspiring discussion and valuable inputs while writing this article.

### References

Aki, K. and Chouet, B. [1975] Origin of coda waves: source, attenuation, and scattering effects. Journal of Geophysical Research, 80, 3322-3342.
Carriere, R. and Moses, R. L. [1989] High Resolution Radar Target Modeling Using ARMA Models. The Ohio State University. Technical Report 718048-11 Contract No. N0014-89-K-0202.
Castagna J., Oyem A., Portniaguine O. and Aikulola U. [2016] Phase decomposition. Interpretation, 4(3), SN1.
Fomel, S. [2013] Seismic data decomposition into spectral. Geophysics, 76, O69-O76.
Guoning, W, Fomel, S. and Chen Y. [2018] Data-driven time–frequency analysis of seismic data using non-stationary Prony method, Geophysical Prospecting, 66, 85-97
Hauer, J.F., Demeure, C.J. and Scharf, L.L. [1990] Initial results in Prony analysis of Power System response signals. IEEE Transactions on Power System, 5(1), 80-89.
Helle, H.B. and Inderhaug, O.H, [1993] Complex seismic decomposition – application to pore pressure prediction. Extended Abstract of Papers, EAGE 55th Conference & Exhibition, Stavanger, 132–139.
Knopoff, L. [1964] Q. Reviews of Geophysics, 2(4), 625-660.
Mitrofanov, G. and Priimenko, V. [2013] Prony filtration of seismic data: mathematical and physical modelling. Revista Brasileira de Geofísica 31, 151-168.
Prony, G.R.B. [1795] Essai experimental et analitique. Paris. J. l'Ecole Polytech, 1, 24-76.