Development of the Proni filtering method

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Abstract

Some directions in development of a new method of seismic data processing are presented. On the basis of the method different dynamic characteristics (as, for example, attenuation) of seismic signals can be estimated. Analysis of these characteristics variations for reflection seismic signals by space, time and frequencies can be useful for studying and prediction of target horizons features. Different aspects of the approach were studied carefully for both mathematical and physical models. It is very important to say this method is based on a non-linear procedure. New possibilities of the method on real data are shown too.

Introduction

The Proni filtering is based on wave field decomposition using exponentially damping sinusoids. In results a discrete spectrum of four parameters: **amplitude, frequency, attenuation and phase for each seismic signal is determined**. Selection of these parameters and creating of some seismic trace image by different criterions is the Proni filtering procedure (Mitrofanov et al, 1998). When a criterion of the selection consists in separation of frequencies components, the procedure can be considered as analogous to band-pass filtering. But unlike the latter the presented method allows us to obtain good resolution both in time and space domains. This makes possible to study wave field in more detail.

In real data processing additional information about different absorbing and scattering properties of the medium can be obtained in the case of the Proni filtering using. As rule, this information is contained in high-frequency components of wave field, which are covered by low-frequency components with more energy. But the Proni filtering method gives possibility to separate it. Different examples of application of the Proni filtering show that high-frequency components analysis can help us to determine fluid-saturated rocks, fractures and breakdown zones (Mitrofanov et al, 1998; Brekhuntcov et al, 2001; Soares Filho et al, 2002).

The first positive results of the application of this method to real seismic data stimulated deeper analysis of the procedure properties, namely stability for the parameter estimating on wide meaning. This question was very important for the Proni filtration because of it is non-linear procedure. In this connection we analysed different sides of the problem: a seismic signal form influence, stability of the procedure to noise, signals resolution and etc. The analyses were made up by model and real data. During this work special mathematical and physical models were created. On the basis of these models and data there were studied the effectiveness of using of the Proni filtration too (Orlov et al, 1999). The results have shown good noise-stability of the method and ascertain possibilities of the approach in seismic data processing for studying of real media features.

The paper continues to develop the method and to study its properties. For example, estimating of attenuation is a very important step in real seismic data processing, and this task is not so simple to solve. It is connected with non-linear estimating of the parameter and more, with absence of full information about signals form and its position on a trace.

Main points

Early results have shown the discrete Proni spectrum for observed seismic signals can have a rather wide range of parameters. This complicates the problem of identification and estimating of a fixed seismic signal during the process of its separation from real traces. Therefore specific procedures for seismic signals estimation were created. They allow us to identify form of the real seismic signal in the process of estimation of the Proni parameters. This problem was complicated by the fact that in real experiment we have not enough information about the signal location. Then we have to estimate and to analyse the Proni parameters for different intervals. In this case the target signal can be located often near the edge of the analysed interval. Therefore we face with substantial dependence between the Proni transform stability and the analysed signal form. It is illustrated well in Figure 1. In this figure there are given results of estimation of different signal forms on the basis of the Proni parameters without (see Figure 1A) and (see Figure 1B) using the special procedures. In the figure the primary signal of each type is presented by grey line and its evaluation – by black line.

The next point is connected with estimate of the attenuation parameter. We can make it without problem with high accuracy on the basis of Proni transform when a signal position (arrival time) on a trace is known and a form of the signal is dumping sinusoids. But for real seismic signals we have different cases complicating our task. Few important questions connected with it had been solved during our research before we could have a good result for the attenuation parameter estimating. The first of them was connected with stable estimation of attenuation parameter for different time intervals and form of signals. The second one was connected with determination of optimal width of selected intervals. The third question was concerned about principles of the attenuation parameter selection for one signal from a set of signals. Below some results of the task solution are demonstrated.

Results for mathematical models

One simple example of attenuation parameter estimating is presented in Figure 2. In this example we have only one signal and full information about the signal position. In the part A of this figure one can look primary signal (gray line), which is dumping sinusoid with the frequency 40 Hz and the parameter attenuation equaled to 50. In this case the Proni transform was made for time interval with width 0,1 sec from time arrival of the signal 0,08 sec. As one can see the main Proni component with number 1 (see B) gives a good approximation for primary signal and values of the parameters for this component (see C). At the Figure 2C the values of the frequency (see part Fr) and the attenuation (see part Alf), which are connected with the component, are equal to 40 and 50, correspondingly.

We have another situation when the accurate information about a signal position is absent. In this case we need to make up Proni transform for different time intervals. At the Figure 3 an example of such estimating on synthetic model trace is presented. In one's capacity of modelling signal we used the same damping sinusoid with frequency 20 Hz and with attenuation parameter equal to 50. Full set of Proni parameters estimating for different time intervals is given in Figure 3D. As the result we have some approximation for all under consideration trace (see Figure 3 A). Note that in this case we did not use any information about the signal's position on the trace. But we used the special procedures that provided stable Proni transformation. After filtration of these parameters we succeeded in reconstruction of the initial form of the signal in correct time point and with the correct attenuation parameter (see figures 3B and 3C).

More complex models of traces are presented in Figures 4 and 5. Here we have three damping sinusoids for the trace with frequency 20 Hz. But for the first model each of the signal attenuation is equal to 50 and for the second model signals have different parameters of attenuation: 50, 75 and 100, correspondingly to first, second and third sinusoids.

The Proni transformation for these models, which was carried out in moving frame with using of our procedures, gives quite good approximation results (see black line at Figures 4A and 5A). As one can see the more complex model of trace brings to more set of Proni parameters (see right part of figures) and greater variation estimation of the parameters attenuation along time axis (see down part of Figures 4A and 5A). Results of the Proni filtration procedure application are shown at Figures 4B and 5B. As it should be after the filtration the signal position and its form are determined with high accuracy (see black line in these cases). But it was more important for us that the procedure allowed to estimate the attenuation parameter for the each signal very clear (see down part of figures).

Results for a physical model

Physical models are different substantially from the above-mentioned mathematical models. First, despite the fact that the structure of these models is completely known it is not clear what reaction the wave field will have. This makes these models close to real structures. Second, in the study of the model we cannot predict what effects of the model could be shown. Actually the object of study is to find the wave field components, which allows us to show specific features of the analyzed model in a more distinct way.

Let's look at the results presented in Figure 6, which were got for a physical model. The model structure is in figure 6A. It contains an absorbing horizontally asymmetric body between the horizons A and B. The body was made of plastic film and was glued on sheet of organic glass taken as a basis of the model. Then this model was complicated by means of four intermediate horizons, which were added between the main horizons A and F. Such complication of the model is close to real medium and to some extent and allows us to estimate effectiveness of using the Proni filtering in the study of objects in layered media.

Wave picture of this model like a stack section is given in down part of the Figure 6A. The presence of absorbing body in this case results in slight increase of arrivals and substantial decrease of amplitudes of reflections corresponding to the horizon F, under the object. The object itself within the input wave field practically cannot be revealed.

The wave field obtained as a result of physical modelling was processed using the Proni filtering programs. The results obtained after the Proni parameters selection and filtering are given in Figure 6B. It is evident, that frequencies 32 Hz (up stack) and 56 Hz (down stack) can be considered as optimal ones for the given research. The former allows us to reveal distinctly the layered structure of the model and the latter show clearly the absorbing effect of the body. This fact, unlike the model of only one absorbing body, is clearly revealed at high frequencies because the layered medium gives in high frequencies more intense reflections outside the object.

We think that the last model is more important for applying purpose so we observed similar effects in processing of real data, when an absorbing body is revealed the strongest contrast in the medium containing additional reflecting objects near the object.

Real data processing

New possibilities of the method were tested on real data too. Some example is presented in Figure 7. Primary stack is shown in upper part of the figure. A result of the attenuation parameter estimating for this data on high frequency 60 Hz (down part) is shown here. The light colour corresponds to high values of attenuation. In middle part of the figure you can see the ordinary image of Proni filtering for this frequency. You can see that the attenuation parameter gives us some new information, which can be useful for interpretation. When information about two wells was given to us, we could see the difference between areas near wells W1 and W2 because of the well W1 was dry and the well W2 had a high production. In principle these results of real data processing are closed to physical models results, which were shown early.

In our opinion the ordinary presentation of Proni filtering processing gives us more information about scattering features of media for wave fields, and the attenuation parameter allows to separate absorption affects in clearer form. Thus, if we will use both of them we can determine different features of target horizons with bigger accuracy.

Conclusions

Testing of new possibilities of the Proni filtering method was carried out on mathematical and physical models. The results of the study showed good noise-stability of the algorithms. As we can assume it will be a good possibility for location of zones of high attenuation and scattering, which can be connected with petroleum reservoirs, carbonate bodies and faults. Therefore the Proni filtering could show some new specific features of the subsurface in high-frequency domain and thus contribute to modern seismic data processing.

The filtration procedure can be used as separation off isolated components of observed wave field as estimating of fixed Proni parameters. In our opinion for the last one the attenuation parameter is more interesting. The analysis of depending of attenuation parameter on frequency can give important information about rocks features.

Acknowledgments

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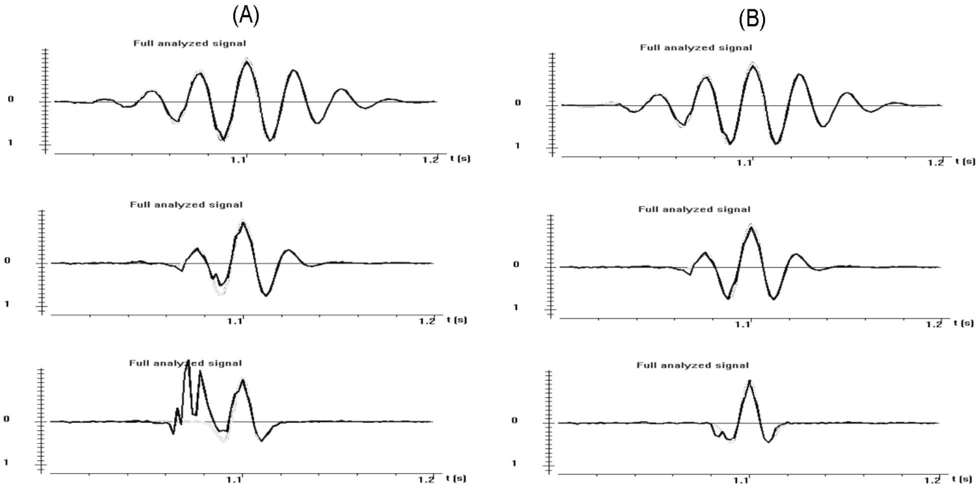


Figure 1.

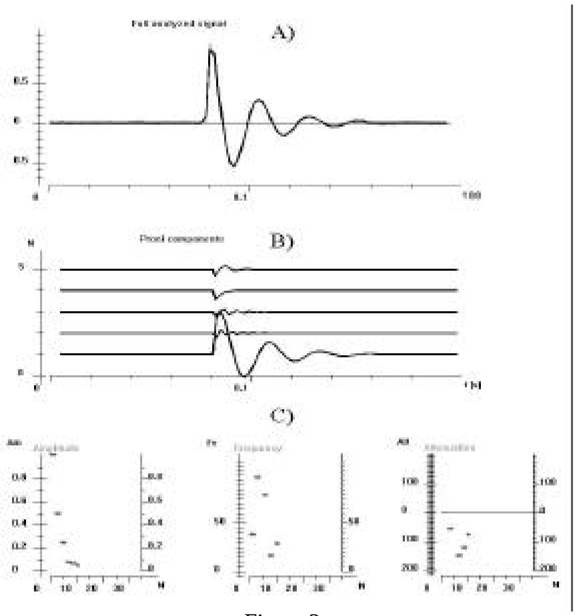


Figure 2.

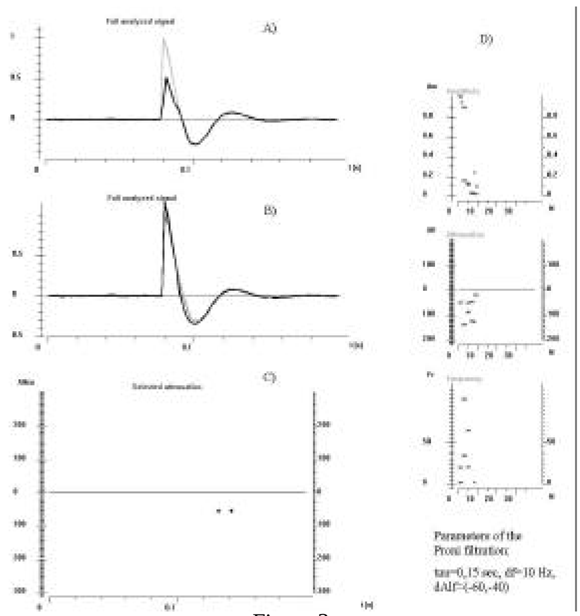
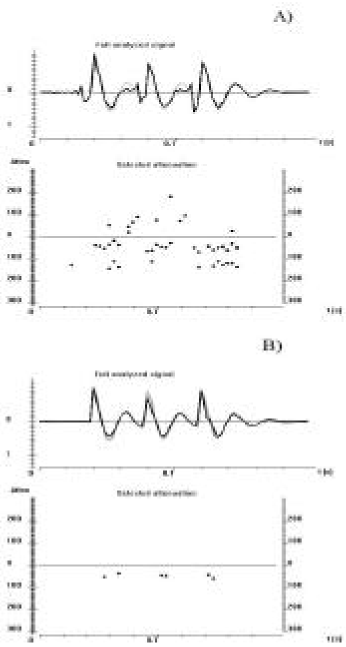


Figure 3.



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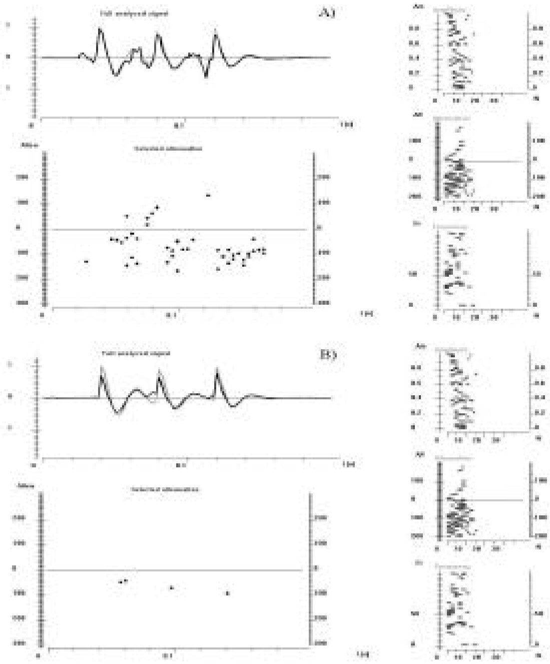

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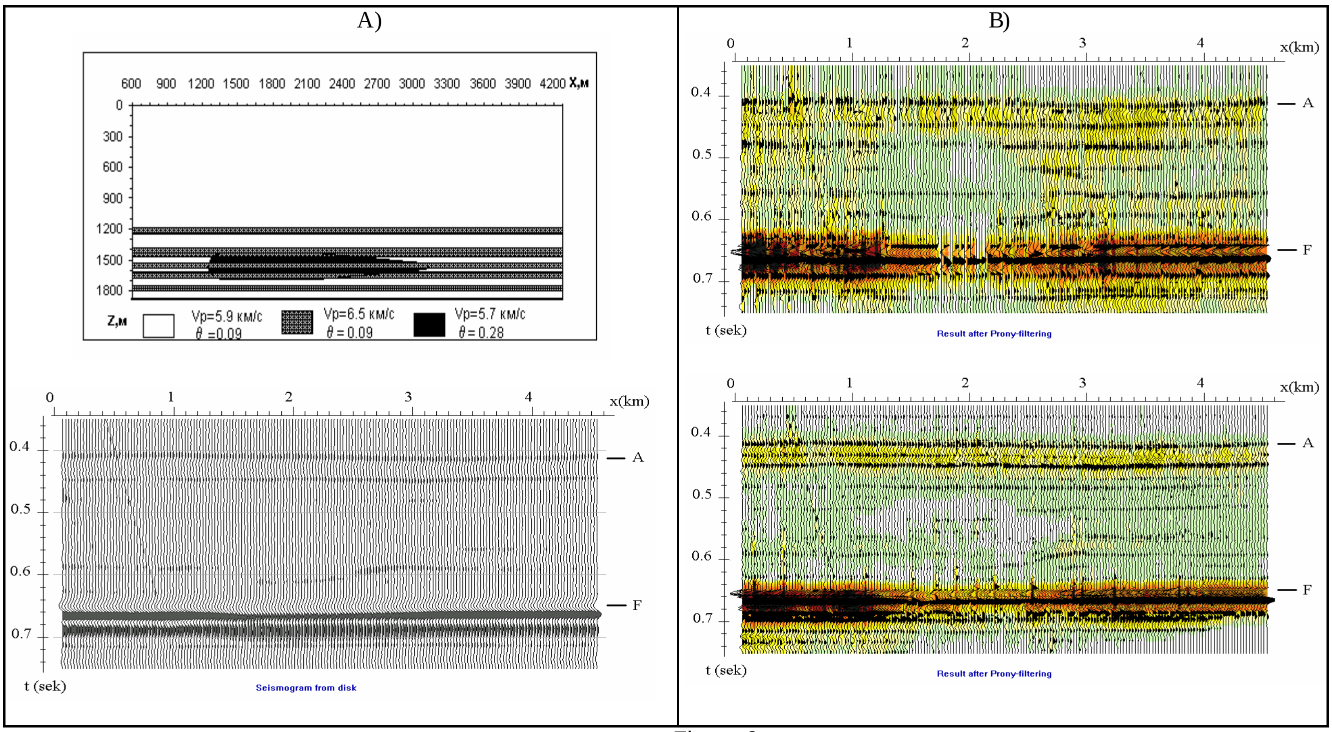
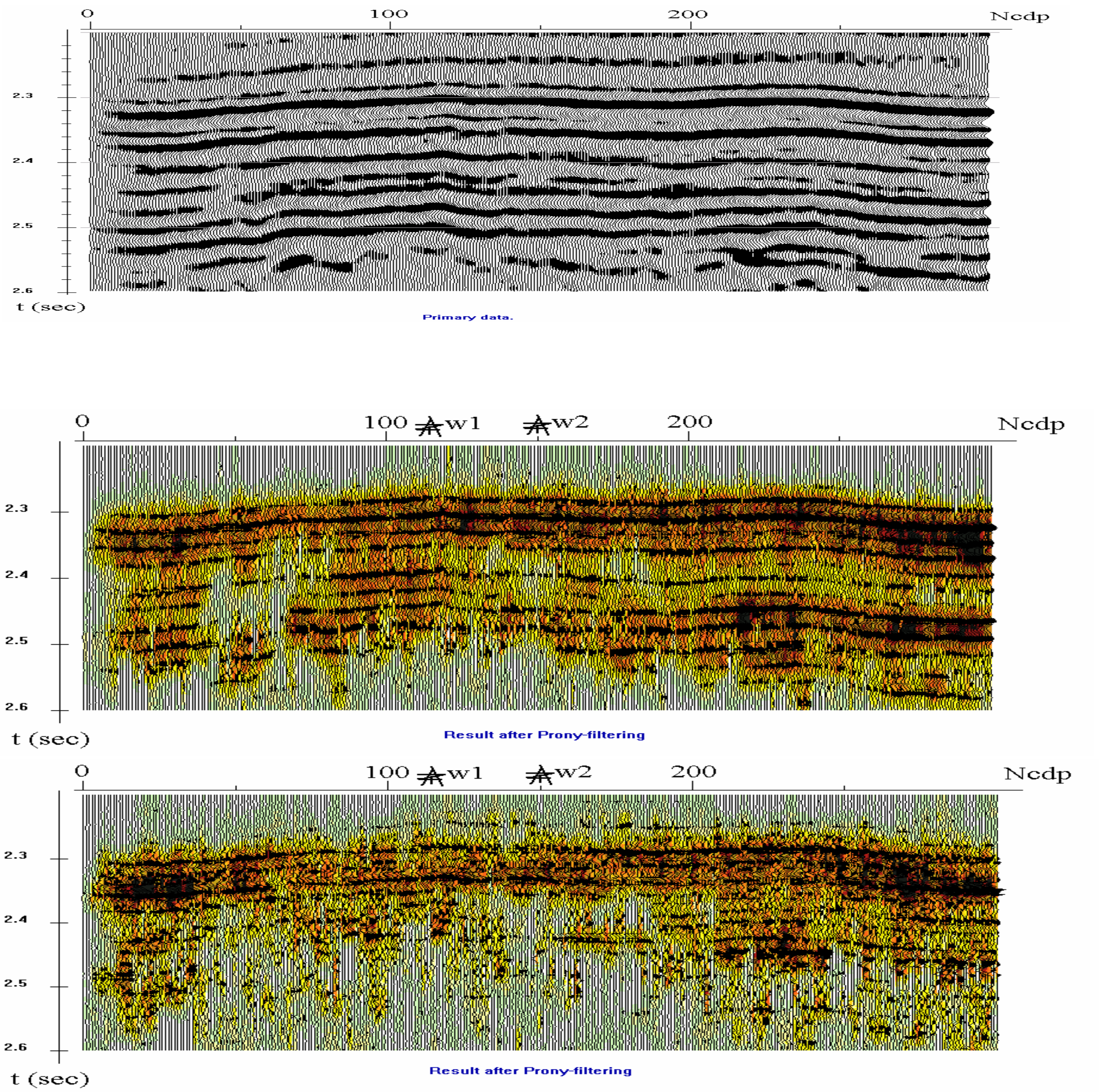


Figure 6.


0
100
200
Ncdp
2.3
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t (sec)
Primary data.
0
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w1
w2
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2.3
2.4
2.5
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t (sec)
Result after Prony-filtering
0
100
w1
w2
200
Ncdp
2.3
2.4
2.5
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t (sec)
Result after Prony-filtering

Figure 7.