Determination of reservoir features by using the Prony filtration and Log-parameter ratios

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Abstract

The Prony filtration method provides a high resolution in study of frequency variations for media response. It allows us to analyze the production horizons features for short time intervals. The analysis is based on the general dynamics Prony parameters, which characterize the frequency variations for each of the time intervals. The parameters can be used for the determination of wells the parameters when a ratio between these parameters and Log-data is available. We discuss two examples of application of the dynamics Prony parameters for prediction of target horizons features. The obtained results show high potential of this technique for the analysis of thin layer objects.

Introduction

The Prony filtration method (Mitrofanov et al., 1998) provides tools for study the features of observed wave field on different frequencies; it results in high resolution in space and time domains. Therefore, we can investigate the frequency-dependent response in detail. In addition, zones with different attenuation can be determined, too, see Mitrofanov et al., 2001. These results can be used for the analysis of the medium absorbing properties or for separation of small structure elements, see Orlov et al., 1999. Hypothesis about non-linear (e.g., power law) dependence between the attenuation of the seismic signal and the frequency is the basis of applications of the Prony filtering to the seismic data analysis. This fact is suggested by physical experiments and can be explained by non-elastic absorption and scattering of the seismic energy in non-consolidated or fluid saturated rocks. Utilization of the Prony filtration method in the real data processing and interpretation was illustrated in several papers, see, for example Brekhuntcov et al., 2001, Mitrofanov et al., 2003.

Only a qualitative evaluation of the results obtained with the Prony method for different frequencies was done up to now. But even such evaluation of anomalous zones, obtained with different attenuation and scattering characteristics, allows us the confidence identification of the target objects. This approach can be used for detailed investigations of various horizons and can help us in determination of well positions too. It is very important, however, to have a quantitative criterion for evaluation of the anomalous zones. Such estimates can be obtained by using energy and coherence characteristics for target intervals, obtained after filtration. The general dynamics Prony parameters are the most stable and informative characteristics for the quantitative estimates. This approach allows us to make maps of the anomalous zones of oil and gas fields; such maps can be used for forecasting and interpretation of the target horizons features. The characteristics used for the qualitative evaluation were not connected with well-log data and, by this reason, we could not evaluate the results obtained in the terms of well-log data. In this paper we will introduce this connection.

The corresponding connection is established using two combined parameters. The first parameter is estimated by the results of the Prony filtration applied to the surface seismic data. The second one is a generalized characteristic of the logging data. The relationship is determined as a functional ratio analyzing a large number of seismic and well data of an oil field. As the result, we obtain equations, allowed us to transform the surface parameters into the interval values of the well-log data. The resulting interval values are the basis for the more accurate interpretation of the dynamics characteristics of the surface data. Therefore, we can use this functional ratio for the prediction of production horizons features in the case when the relationship between these features and the Log-parameters is available.

Method

In the result of application of the Prony filtration we have images of stacked section for different frequencies. These images can be used for determination of the general dynamics Prony parameters. In this case we can estimate the energetic characteristic for fixed time interval for each of the traces. The corresponding time interval, defined after a preliminary interpretation of the real data, is connected with times where the wave, reflected from the target horizon, is available.

Let us denote values of the energetic characteristic, calculated for the fixed trace time interval, as $E^{\mathrm{Pr}}(f_k, t_j, i)$, where f_k is one from the basic filtration frequencies, t_j is the number of the target time interval used for calculation of the energetic characteristic and i is the trace number; $\{E^{\mathrm{Pr}}(f_k, t_j, i)\}$ is a full set of the energetic characteristic values, calculated by using all the images of the stacked section obtained after filtration.

Such set is used for creation of maps, corresponding to the fixed frequency and the target time interval.

The values $E^{\Pr}(f_k, t_j, i)$ can be used for the determination of two types of the dynamics Prony parameters. For the first type of the parameters we use the ratio $E^{\Pr}(f_k, t_j, i)/E^{\Pr}(f_0, t_j, i)$ between the energetic characteristics, obtained for high frequencies, and the energetic characteristics, obtained for main frequency of reflected signals; f_0 is the main frequency. The full set $\{E^{\Pr}(f_k, t_j, i)/E^{\Pr}(f_0, t_j, i)\}$ will be used for creation of the maps. These characteristics and corresponding maps give us a good possibility for simple and accurate indication of the frequency anomalies. Moreover, these parameters depend less of the possible frequency variations, connected with upper part of the geological section.

The second type of the parameters is the ratio $E^{\Pr}(f_k, t_j, i)/E^{\Pr}(f_k, t_0, i)$ between the energetic characteristics, calculated for the different time intervals; t_0 is the fixed time interval used for standardization. This ratio depends less of the possible frequency variations connected with upper part of a geological section, too. The general dynamics Prony parameter can be determined when some main frequency and some standardization time interval are available. This parameter has the following form:

$$K^{\Pr}(f_k, t_j, i) = \frac{E^{\Pr}(f_k, t_j, i) * E^{\Pr}(f_0, t_0, i)}{E^{\Pr}(f_0, t_j, i) * E^{\Pr}(f_k, t_0, i)} \quad (1)$$

The parameter provides more accurate characterization of the frequency-dependent variations and selection of the corresponding zones. Some a relationship between the results of the Prony filtration and the well-log data can be established by using such relation. At that for the well-log data we used the following combined parameter (see Kozybovskii et al., 2003):

$$\mathrm{K}_{\mathrm{Log}} = \sum_{m=1}^{n} \frac{\rho_m^* \cdot \Delta h_m}{\Delta J_m^*}, \quad (2)$$

or

$$\mathrm{K}_{\mathrm{Log}} = \frac{\sum_m \rho_m{}^* \cdot \Delta h_m}{\sum_m \Delta J_m{}^*},$$

where m is the number of a production thin layer from the well tested interval; n is the total number of the layers used for K_{Log} determination; $\rho_m{}^*$ is the resistivity of these layers; Δh_m is the width of the layer; ΔJ_m^* is the relative activity of nature nuclear emanation. $\Delta J_m^{*\,-1}$ is correlated with open capacity of the production layer and $\rho_m{}^*$ is correlated with its saturation. Therefore, the parameter K_{Log} characterizes an effective layer resource of the well. Note that the combined Log-parameter was established for appointed group of production layers in one specific region (Western Siberia). Undoubtedly, it is a very big region and has a big enough group of layers (Neocomian). But it is important to have in mind that for another world region or group of layers the form of this parameter can be different.

Examples

The first example of application of the Prony parameters to the investigation of two areas is concerned to PETROBRAS's data. The primary data were taken from a 3D seismic cube and represented 2D lines. Thus for each of the areas we had a 2D-net with 11 inlines and 11 crosslines; points of the wells location were situated in the central knot (W3 and W4). The net was used for the creation of 5kmx5km maps. The main aim was to study the basic medium characteristics of the target horizons for the selected areas.

Before creation of the maps for all given 44 2D stacked sections there was done the Prony filtration processing with three basic frequencies: 23Hz, 43Hz and 55Hz. After that the energetic characteristic $E^{\Pr}(f_k, t_j, i)$ were calculated for five time intervals. The length of every interval was taken equal to 20ms. The first interval was selected from the picking line of the target horizon and situated 20ms just below of this line. The second interval was taken 20ms over the picking line. The third and all the next intervals were taken through 20ms above one after another. Therefore we had the five intervals and could analyze the medium response for different frequencies along the target horizon line for the time interval 100ms. Obtained values of $E^{\Pr}(f_k, t_j, i)$, with fixed f_k and t_j, were used for the creation of maps.

Figures 1-3 show some of the created maps. The maps, represented in Figures 1 and 2, were created by using the values $\{E^{\Pr}(23, t_j, i)\}$ and $\{E^{\Pr}(43, t_j, i)\}$, respectively. Figure 3 demonstrates the maps, created with the ratio $E^{\Pr}(43, t_j, i)/E^{\Pr}(23, t_j, i)$; frequency 23Hz was taken as the main one in this case. Selection of the maps was done by the following principles. Every figure represents the maps created for four different time intervals (from the first interval up to the fourth one) with one selected frequency and includes 8 maps organized in two columns: the left column represents the maps with well W2, and the right column represents the maps with well W4. As a rule for all color scales the blue color means a strong medium response for the corresponding frequencies, and the pink or red colors show high level of scattering or absorption of the seismic energy. The analysis of maps, created for all time intervals with frequency 23Hz by using the primary values of the energetic characteristics (see Figure 1), shows that both the areas can be similar in general. So, for the first interval (see the first line of maps), situated below the target horizon line, we can look the dark blue areas not far from wells. For the next interval (see the second line of maps) the situation is the same. The last can indicate on good quality of the medium response in these areas. Of course, the structure and the behavior of the response for these frequencies are quite different for each of the areas; for example, the form of dark blue spots is quite different. But we have no enough information for the interpretation of such variations. The situation begins to change when we analyze the maps created by using different time intervals and different frequencies. So, for the first time interval when we change frequency then the response in the nearest area of well W4 increases in contrast to one of well W3 (see the corresponding maps give in Figures 1-2). In the last area some object reminiscent a tongue begins to appear. This object increases for the next time interval in contrast to the area of well W4, where all things have small variations nearby the well position.

When we use the ratio of energetic characteristics the information about behavior of the main frequencies of reflected signals is absent, but on the other hand we have the information about the frequency variations more evidently. Sometimes the last information can be more useful to study the medium features - look at the frequency variations represented on the maps of the second type, created for the time intervals with the ratio between the energetic characteristics obtained for couples of frequencies: 43Hz, 23Hz (see Figure 3). Some object in a tongue form begins to appear near the well W3 position in the figure. This object has origin in the part of the area with the strong response. So, the results, obtained by using the ratio of energetic characteristics, confirm the effects observed earlier in the area of well W3. In the area near well W4 the situation is different absolutely. We can see an interesting situation only in the right part of the mapping area. For the next time interval in the area of well W3 some object, which could be interpreted as a permeability trap, is recognized. The object is located on the left of well W3 and its form is similar to some channel (see the structure of red spots). This object is situated over the object of the second interval and can be connected with them. In the area of well W4 anything can be detected. This area has high scattering and absorption of the seismic energy in this time interval. It is interesting to analyze how the structure is changed for the fourth time interval. For both the areas the strong response begins to show up. There is a good characteristic for possible reservoirs in principal, because it can indicate a good quality of the reservoir cover.

The second example is connected with the processing of 2D seismic data from the North part of the Western Siberia, Russia. It is known that oil and gas condensate reservoirs, having a complex structure, are situated in this area. The target reservoirs are hosted in the shallow layers of the Lower Cretaceous and the Upper Jurassic (on the depth 2600-2900m). In the area under study covered about 2500km^2, more than 70 research wells, discovered a reservoir, were available. The 124 stacked sections were processed using the Prony filtration technology. As the result the maps of dynamic Prony parameters, including the general parameters in form (1), were created.

Using these maps the values of general Prony parameters were estimated in the points of the research wells location. The length of the time interval t_j should agree with the depth interval, where the value of K_{Log} in form (2) was obtained; these intervals must be confirmed with the geological task. The length of the every time interval was taken equal to 15ms, which corresponded to 20m for the depth interval.

As the next step, we attempted to determine the nature of the ratio between $K^{\mathrm{Pr}}(f_k,t_j)$ and $K_{Log}(t_j)$. First of all we tried to determine a type of the ratio function (see Figure 4). The figure represents linear fits for three modifications of $(K_{Log}, K^{\mathrm{Pr}})$. The horizontal axis represents the combined Log-parameter and the vertical axis represents the general dynamics Prony parameter. Figure 4(A) shows the results of approximation for the primary values. We can look that a good approximation was absent and the correlation coefficient was about 0.57. Figure 4(B) shows the results of approximation by using the combination of $(K_{Log}, \ln K^{\mathrm{Pr}})$. In this case we have a logarithmic type of the ratio function. It gives better approximation and higher correlation coefficient about 0.63. But the best linear approximation for these values was obtained for the third type of modification when the combination of $(\ln K_{Log}, \ln K^{\mathrm{Pr}})$ was used (see Figure 4 (C)). In this case, the correlation coefficient was equal to 0.725 and the structure was near to a linear chart. The result indicates the hyperbolic type of ratio function and has been confirmed with another examples.

This research allows us to establish an equation connecting the parameters $K^{\mathrm{Pr}}(f_k,t_j)$ and $K_{Log}(t_j)$ calculated for the target horizons. The analysis of the hyperbolic approximation for different frequencies and intervals sets in the following equation:

$$K^{\mathrm{Pr}}(f_k,t_j) = e^{\;0.3} \bullet K^{\;1/3}{}_{Log}(t_j), \qquad (3)$$

which is the optimal one for the main frequencies and production intervals as a whole. This equation allows us to calculate new maps as the maps of the combined Log-parameter by using the following equation:

$$K_{Log}(t_j) = 0.4 \bullet K^{\mathrm{Pr}}(f_k,t_j)^{\;3}. \qquad (4)$$

By using the maps obtained with $K_{Log}(t_j)$, we created the maps of predicted gas production for a big gas condensate reservoir in the Western Siberia. Moreover, this approach allowed us to identify an extent of a possible hydrodynamic relation for different layers. These results were confirmed by wells data. Therefore the created maps met with approval of geologists and were used in the reservoir characterization and for indication of wells location for drilling.

Conclusions

We have tried to show that this approach is effective not only in processing of seismic data but also can be used effectively in investigation of the reservoir details. In particular, some additional information about the variations of production features for the target horizons can be obtained from the analysis of the time intervals. Such information can be fundamental for thin-layer objects. We introduced the ratio between the combined parameters, estimated from both the surface seismic data and the well data. The results were verified by using the independent well data and provided good quality. These results show the high potential of their application in the analysis of the target objects and can be used to study the properties of the reservoirs of complex structure too. The approach gives additional opportunities for the production feature control in the case of heterogeneous horizons and, in particular, for the reservoir monitoring.

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References

Brekhuntcov, A., Ilein, J., Jedkov A., and Mitrofanov G., 2001. Prediction of production features by Prony filtration results, 63rd EAGE Conference, Expanded Abstracts.

Kozybovskii, A., Fedortsov, V., and Bazhanova, E., 2003. Estimation of the potential production of the Achemovskai thickness, Urengoy area. Oil and Gas, Tumen, Russia, N4, pp. 10-16. (In Russian)

Mitrofanov, G., Zhan Zhitian, and Cai Jiaming, 1998. Using of the Prony Transform in Processing of Chinese Seismic Data, 68th SEG Meeting, Expanded Abstracts.

Mitrofanov, G., Nefedkina, T., Bobryshev, A., Suvin, V., and Popov, M., 2001. Using the Prony filtration for purpose of perspective zones determination in oil and gas reservoirs characterization, Geofisica, Special Issue, pp. 92-100. (In Russian)

Mitrofanov, G., Priimenko, V., and Soares Filho, **D.,** 2003. Development of the Prony filtering method, 8th International Congress of the Brazilian Geophysical Society and 5th Latin American Geophysical Conference, Rio de Janeiro, Brazil, Expanded Abstracts.

Mitrofanov, G., Priimenko, V., Soares Filho, D., Missagia, R., Grochau, M., and Lima, R.,, 2003. Using the Prony filtration in geological and production tasks, 8th International Congress of the Brazilian Geophysical Society and 5th Latin American Geophysical Conference, Rio de Janeiro, Brazil, Expanded Abstracts.

Orlov, Yu., Mitrofanov, G, Rakhmenkulova, I., and Kurdujkova, T., 1999. Testing of the Prony filtering by model data, 61st EAGE Conference, Expanded Abstracts.

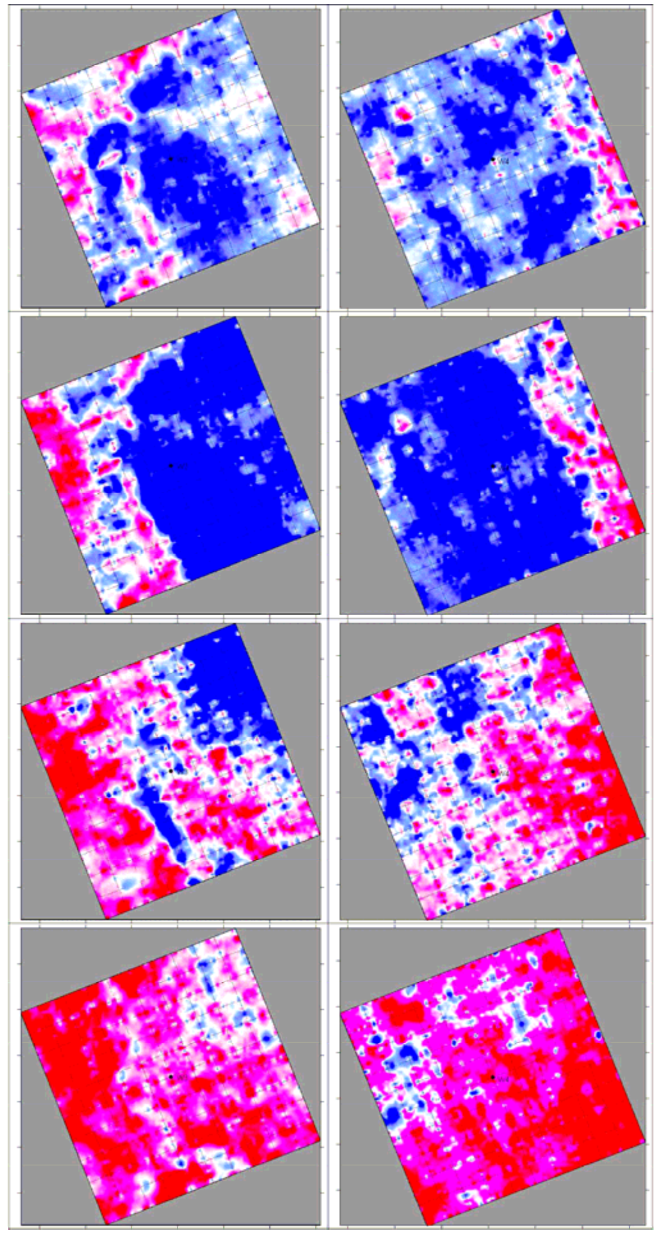

Figure1. An example of maps created for all time intervals for frequency 23 Hz by using the primary values of energetic characteristics.

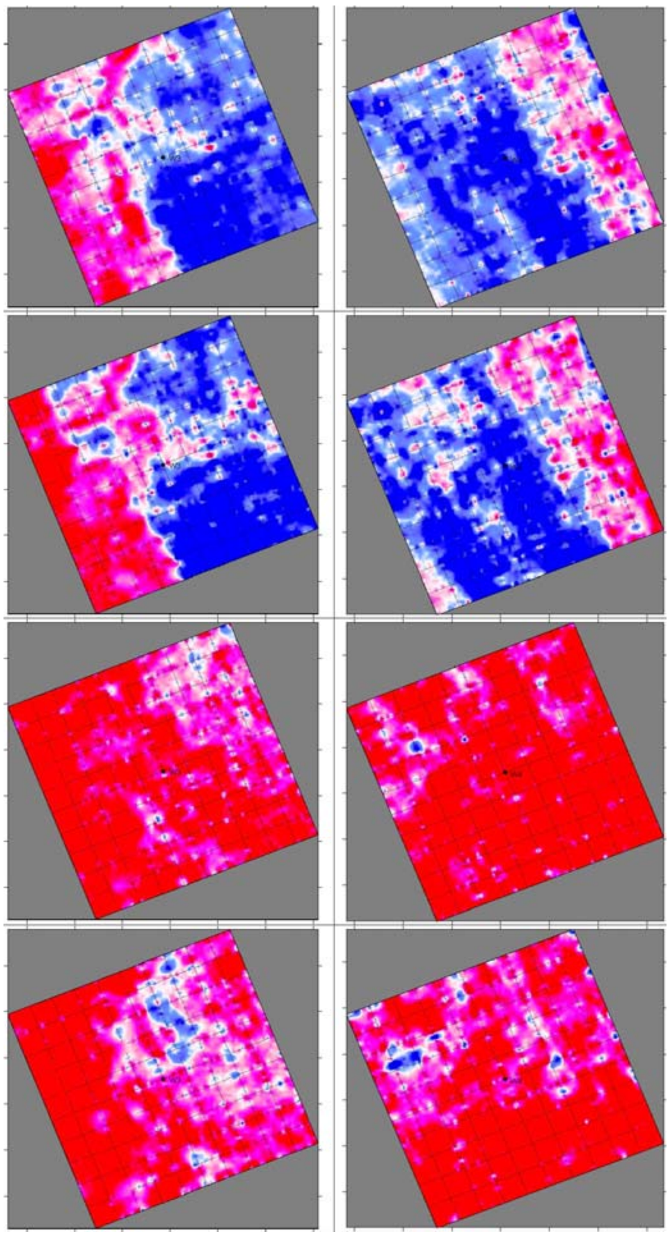

Figure 2. An example of maps created for all time intervals for frequency 43 Hz by using the primary values of energetic characteristics.

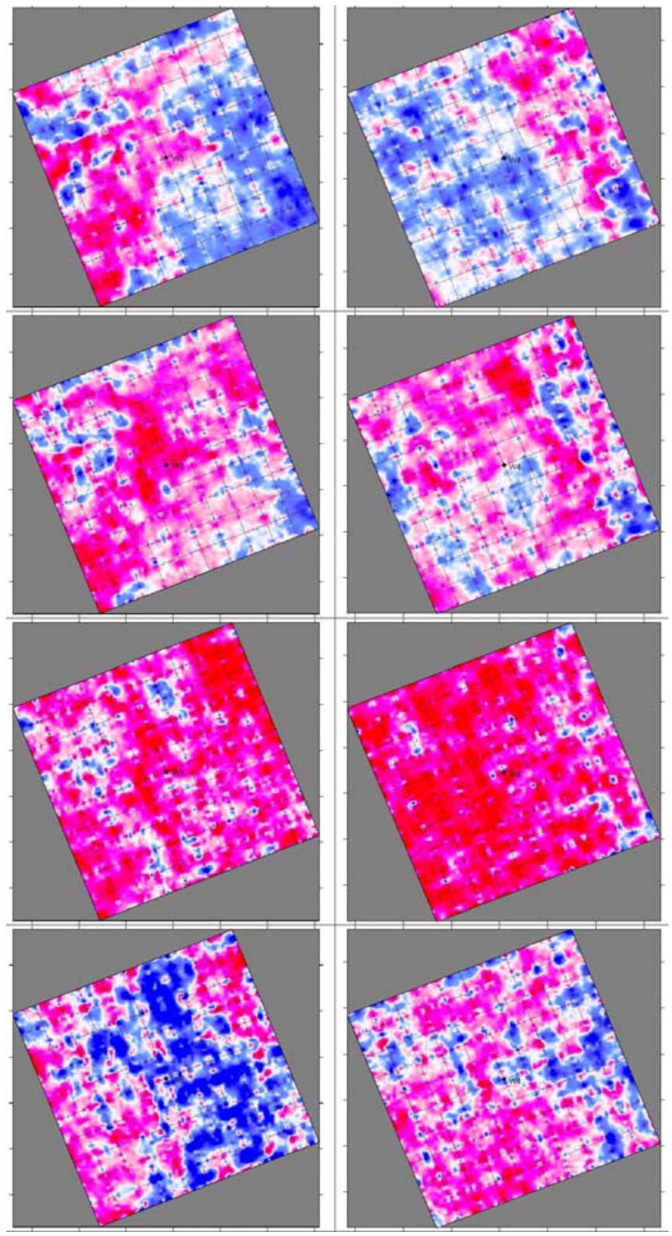

Figure 3. An example of maps created for all time intervals by using the ratios between the energetic characteristics obtained for frequencies: 43Hz, 23Hz.

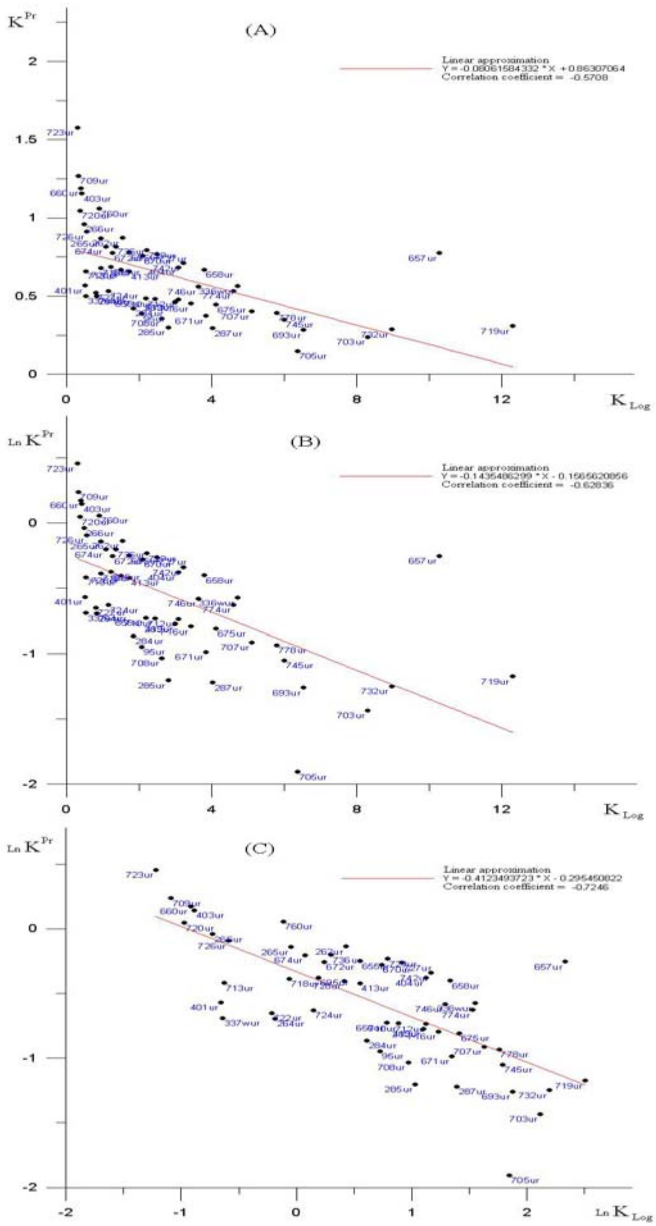

Figure 4. An example from the North part of the Western Siberia, Russia.