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The influence of disturbances and noise of normal distribution on the correctness of geological interpretation of seismic sections with increased resolution

Exploration for hydrocarbons is moving toward increasingly challenging areas, where current seismic imaging methods are reaching their limits. In complex geology, the conventional seismic approaches may fail and result in non-negligible in interpretation and geological model building. One of the problem which seriously disturb the correctness of data interpretation is the presence of noise and different perturbations, particularly when high resolution techniques were applied before. Even when using the most advanced methods of noise suppression or elimination, some signatures of noisy components remain within the processed data. Moreover, any attempt to attenuate these "artefacts" results in also attenuating real reflecting events. The paper presents one of the important problems that substantially affect the legibility and correctness of seismic sections interpretations, where procedures were applied to increase the resolution via widening the frequency range of the complex spectral characteristic. Particular attention has been paid to the analysis of disturbances, which can result from the application of the procedure for complex modification of a seismic record of the spectral characteristic. The fact that various geological environments generate different types of disturbances is an important problem, which primarily makes disturbances analysis difficult. Their common feature is their very unsystematic nature, and hence diverse disturbances value distributions, which can interfere with the input wave field, subject to modification, in various ways – both constructively and destructively. Hence the resultant wave field may contain both additional real information about the environment's structure, and may also present an image resulting, inter alia, from the unintended elimination of actual reflections. The paper discusses the issue of normal distribution disturbances (so-called white noise). Despite the already very rich bibliography devoted to increasing seismic data resolution, the issue of disturbances is marginally considered, first of all due to the difficulties with formulating observations of a general nature.

Key words: seismic wave field, complex spectral characteristic, Gaussian distribution, spectral characteristic modification, spectral modification operator.

Wpływ zakłóceń i szumu o rozkładzie normalnym na poprawność interpretacji geologicznej sekcji sejsmicznych o podwyższonej rozdzielczości

W artykule przedstawiono jeden z ważnych problemów w istotny sposób wpływający na czytelność i poprawność interpretacji sekcji sejsmicznych, na których zastosowano procedury zwiększenia rozdzielczości poprzez poszerzenie zakresu częstotliwości zespolonej charakterystyki spektralnej. Szczególną uwagę poświęcono analizie zakłóceń, które mogą być wynikiem aplikacji procedury modyfikacji kompleksowej charakterystyki spektralnej zapisu sejsmicznego. Dość istotnym problemem, który utrudnia analizę zakłóceń jest przede wszystkim fakt, iż różne środowiska geologiczne generują różne typy zakłóceń. Ich wspólną cechą jest bardzo niesystematyczny charakter i stąd różnorodne rozkłady wartości zakłóceń, które mogą interferować z poddanym modyfikacji, wejściowym polem falowym, w bardzo różny sposób – tak konstruktywnie, jak destruktywnie. Stąd wynikowe pole falowe może zawierać zarówno dodatkowe rzeczywiste informacje o budowie ośrodka, jak też może przedstawiać obraz będący m.in. wynikiem niezamierzonej eliminacji refleksów rzeczywistych. W przedstawionej publikacji omówiono zagadnienie zakłóceń o rozkładzie normalnym (tzw. biały szum). Pomimo, bardzo już aktualnie bogatej bibliografii poświęconej podwyższeniu rozdzielczości danych sejsmicznych, problematyka zakłóceń traktowana jest marginalnie, przede wszystkim ze względu na trudności formułowania spostrzeżeń o charakterze ogólnym.

Słowa kluczowe: sejsmiczne pole falowe, kompleksowa charakterystyka spektralna, rozkład normalny (dystrybucja Gaussa), modyfikacja charakterystyki spektralnej, operator modyfikacji spektralnej.

Introduction

The desire for a detailed reconstruction of geological structure components (both structural and lithological-facies) observed recently results primarily, but not exclusively, from the fact that so-called unconventional deposits became objects of interest in searching for energy (hydrocarbons) sources. Unconventional, these are those whose geological-geophysical and reservoir characteristics significantly differ from the standards known and accepted for decades by the global oil industry.

The seismic method allows obtaining both preliminary reconnaissance in the exploration space, and also reaching – via improved methods for field acquisition and increasingly theoretically deeper founded data processing procedures – more and more detailed elements of structure of objects, being the prospecting targets.

In the past a deposit was understood and seen as an object of clear geometrical-structural features, e.g. anticlines and faults. From the contemporary viewpoint unconventional deposits consist most often of strata, thin in the case of shale gas reservoirs and sometimes quite thick in the case of tight gas sandstone reservoirs, where good reservoir parameters are distributed in a very unhomogeneous way, horizontally or in pockets. In terms of orientation, they are not subject to clear tendencies or trends. Even so, very 'directional' properties, such as anisotropy, frequently changes its intensity along a specific orientation stated in the stratum.

However, it is not only the structure of unconventional objects that is the reason to search for solutions with a high resolution standard. Also, the mining of such objects substantially differs from the known strategy of drilling through the deposit by a system of vertical boreholes. Deposit opening treatments, and in particular hydraulic fracturing, should be mentioned here. The effects of fracturing, both in environments with a rich network of primary fractures and also in environments where primary fractures are hardly identifiable, depend on the mechanical (geomechanical) parameters of this environment. The proper designing of hydraulic fracturing, both in the field of horizontal borehole directing, and of the applied energy, requires knowledge of geomechanical parameters (pressure, stresses, Young's and Poisson's moduli).

The results of seismic surveys are the basic source of the aforementioned parameter knowledge in the space. Instead, the results of laboratory tests on cores, as well as results of selected borehole logging curve interpretation, enable the calibration of seismic results to the range of values considered real. The seismic veolocity is the basic parameter used to evaluate geomechanical measurements. Because of the dispersive relationship between the veolocity and the frequency of the propagating seismic wave, the wave field resolution plays a decisive role in the actual determination of the seismic veolocity. Not only because it decides how thin strata may be reproduced from a seismic record, but also due to the fact that the wave field frequency is responsible for the veolocity range and distribution.

The fact that the accuracy and correctness of the veolocity field reconstruction is fundamental to the geological interpretation needs no comment. Hence, a method to increase the accuracy and depth of geological environment recognition based on the registered seismic vibrations [18], suggested and patented by the author and her team, was subject to tests during the GASLUPSEJSM project's implementation, and for the analysis of potential risks related to the generation of difficult to identify facts the project named *Seismic surveys and their application in detecting shale gas zones' existence. The selection of optimum acquisition and processing parameters to represent the structure and the distribution of petrophysical and geomechanical parameters for prospective rocks* (GASLUPSEJSM), task 2 (area 1C) entitled *Exploring, recognising – Seismic data modelling and processing, including the methodology to determine the required resolution of the seismic wave field in the process of shale formation location, completion and exploration, analysis of a potential risk related to the generation of difficult to identify facts.*

The paper presents changes of the wave image as the effect of simulating the existence of specific disturbances (white noise).

Selected elements of the methodology

The idea applied in the algorithm to increase the resolution of the seismic record suggested by the authors [3, 4, 7, 9] utilises the similarities and differences of an elastic wave field recorded using two different methodologies, i.e. surface seismic prospecting (2D or 3D) and well seismic prospecting (acoustic logging PA or vertical seismic profiling PPS). Borehole seismic prospecting (Fig. 1A) records a wave field of a incomparably higher frequency band, whose analysis implies much more detailed description of the environment than it is possible in the case of surface seismic prospecting. The introduction of spectral characteristic elements of the wave field recorded in the well for the seismic recording allows significant enhancment of the spectral characteristic of the seismic field recorded on the surface, which results in a significant increase in the resolution (Fig. 1b). However, the above process quite often results in the appearance of highly unstable disturbances and noise (both in time and space) on the seismic section subject to the spectral modification, which obviously means that the newly originating reflections are not identified. Hence, the suggested way and method to increase the seismic wave field resolution by widening the range of spectral analysis was additionally analysed, with the aim of studying the influence of the level of disturbances and noise present in seismic sections on the effectiveness of the presented procedure. The influence of noise and disturbances on the results of the interpretation of the seismic wave field of the high resolution standard is much stronger than in the case of so-called conventional seismic prospecting, because the order of detail size reproduced is several times higher.

The testing was carried out on both real field data and also on theoretical seismograms calculated based on the acoustic logging data from this area, using the seismic modelling procedures being the proprietary solutions of the Oil and Gas Institute – National Research Institute employees – Ms. Halina Jędrzejowska-Tyczkowska and Ms. Krystyna Żukowska, developed over many years [5, 10, 12, 13]. The above studies comprised two sequences of actions:

- the first, consisting in the analysis of the spectral characteristics of the used data, introducing the noise and evaluating the level of disturbances degrading the wave image, and also determining the diversification of negative effects of disturbances versus the ratio of signal to noise (S/N) and
- the second, which focused on the elimination of introduced noises depending on the way of their introducting (before and after the application of the frequency band modification procedure).

As mentioned earlier, the procedure for increasing the resolution of the seismic record is aimed at achieving the resolution of the same order as for the borehole data. The given seismic trace $x(t)$, with the adopted pre-set sampling step and for the reflection coefficients trace calculated from the borehole data $r_c(t)$, is expressed by the formula:

$$r_c(t) = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1} \quad (1)$$

where:
v_1, v_2 – veolocity of seismic wave propagation,
ρ_1, ρ_2 – density of geological environment,
the Fourier transformation of the seismic trace $x(t)$ and the Fourier transformation of reflection coefficients $r_c(t)$ are calculated, and then a product of amplitude spectra and a sum of phase spectra are created, obtaining a complex amplitude and phase spectrum. For this complex spectrum an inverse Fourier transformation (FFT^{-1}) is then performed, obtaining the time function $X(t)$, which after the Fourier transformation defines the spectral characteristic of the wave field modification operator, in accordance with the formula:

$$X(\varpi) = \int_{-\infty}^{\infty} x(t) e^{-j\varpi t} dt = A(\varpi)\left[\cos(\Phi(\varpi)) - j \sin(\Phi(\varpi))\right] \quad (2)$$

where:
t – time,
ϖ – frequency,
$A(\varpi)$ – amplitude spectrum of trace $x(t)$,
$\Phi(\varpi)$ – phase spectrum of trace $x(t)$.

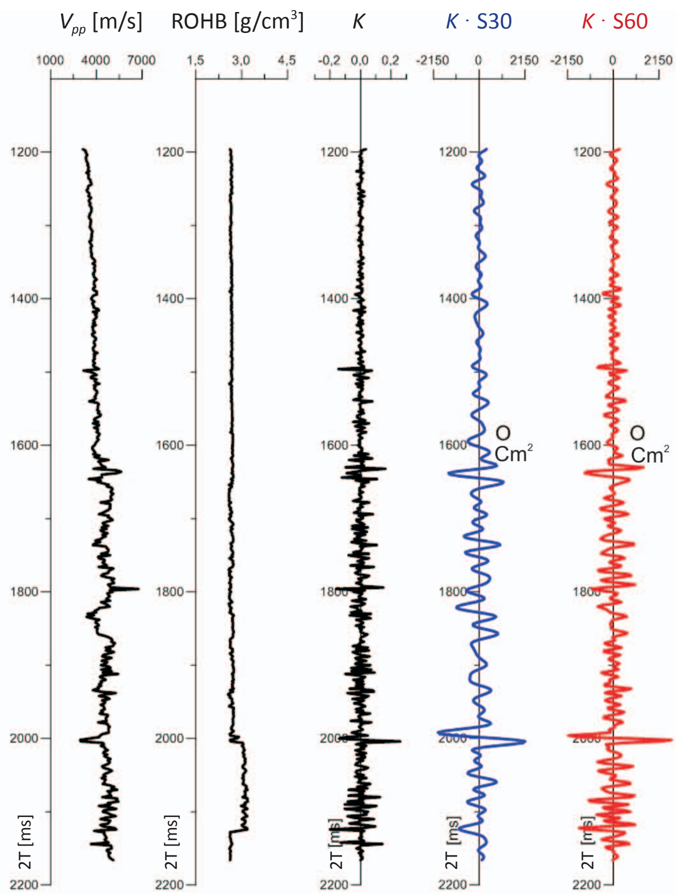

Fig. 1a. Results of acoustic logging in the X-1 borehole in the 1196÷2166 ms interval, presented in the time version

V_{pp} [m/sec] – veolocity of seismic wave propagation, calculated from the PA curve,
ROHB [g/cm³] – specific density,
K – reflectivity function,
$K \cdot$ S30; $K \cdot$ S60 – reflectivity curve after convolution with Ricker's signal (30 Hz and 60 Hz, respectively)

The $X(\varpi)$ operator is applied to the full range of seismic data using computer software, and obtains spectrally modified seismic wave fields, taking into account high frequencies existing only in the borehole data record, which are most directly related to the thin-layer structure of the environment and with the lithofacies variability.

The described procedure is one of the proprietary solutions suggested under the patented method for increasing the resolution [18].

Figure 1a presents, calculated in the time version, basic profiling curves in the X-1 borehole (V_{pp}, ROHB), important for seismic analyses. The calculated reflectivity curve K and synthetic seismograms convolved with 30 Hz and 60 Hz signals shows that obtaining the resolution of the seismic section close to the acoustic logging curve resolution is not possible at the dominating signal frequency of around 30 Hz. The reflectivity curve much better reproduces the seismogram after the convolution with the signal of 60 Hz frequency.

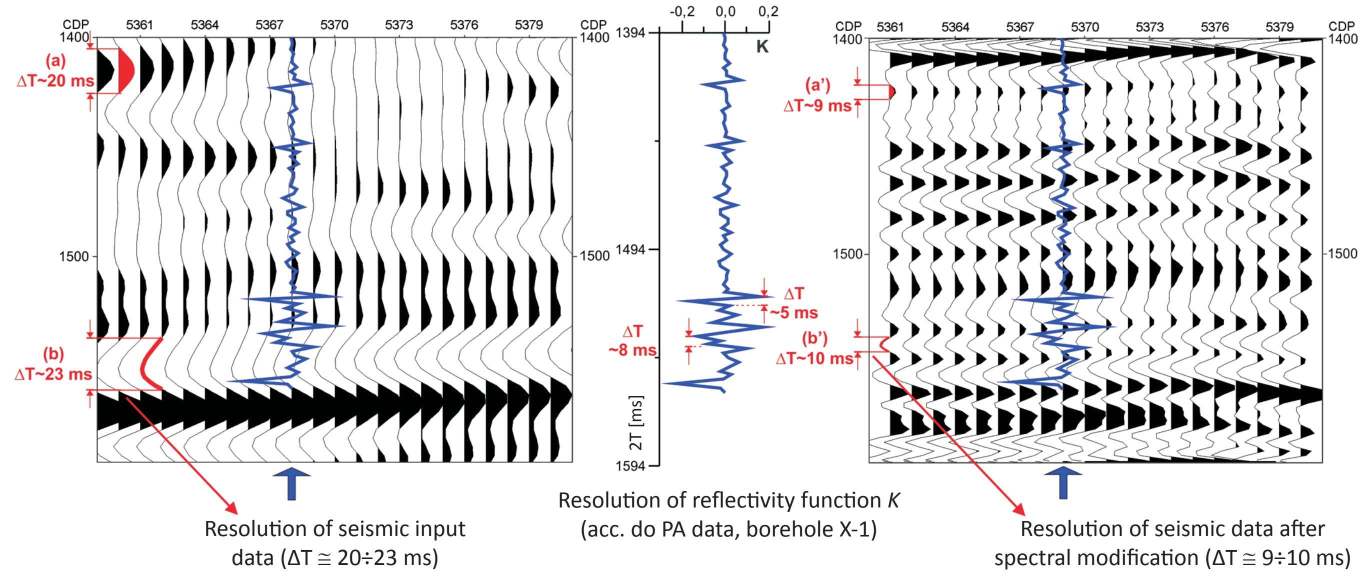

Fig. 1b. A comparison of the time resolution of vertical seismic section XX from the W concession on the seismic data in the PSTM (post stack time migration) version (time migration for the sum) – the left hand side and, after the application of the spectral modification procedure, the right hand side

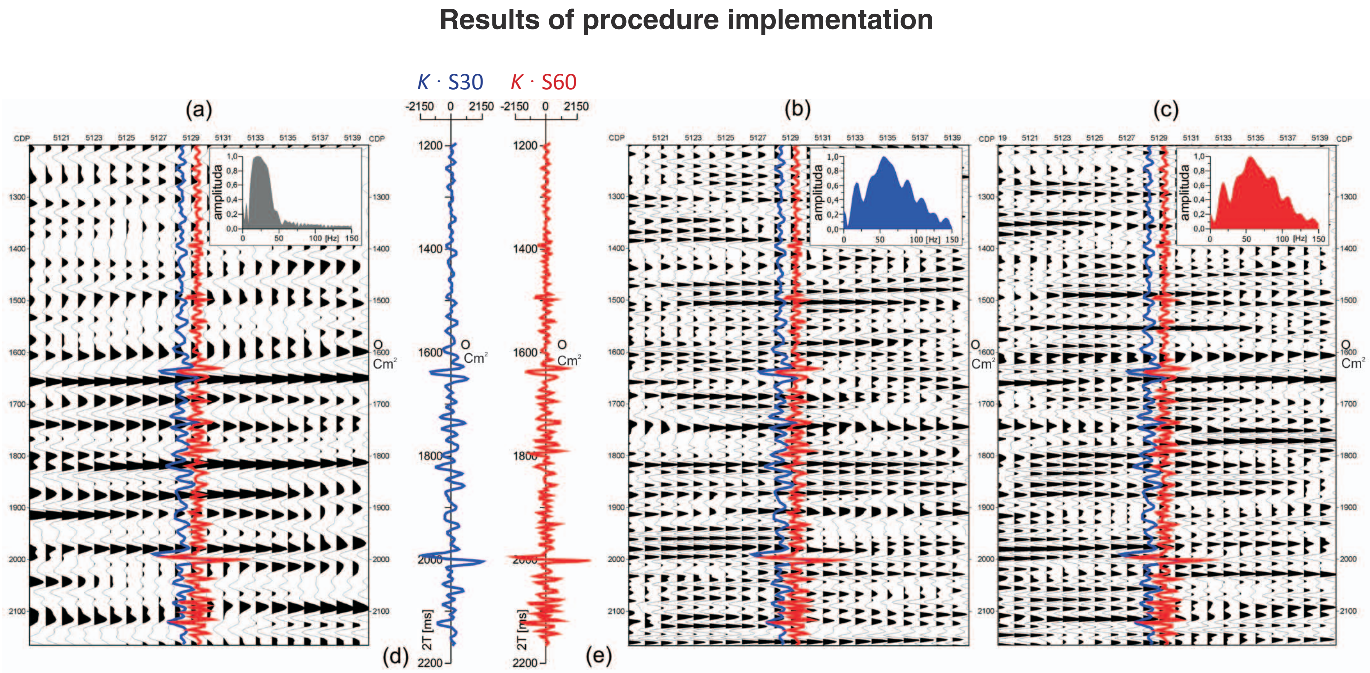

Fig. 2. A comparison of a fragment of input seismic section XX in the 1196÷2166 ms interval, in the vicinity of X-1 (a) borehole with results of its spectral characteristic modification (b) and (c) and with the introduced reflectivity curves from the X-1 borehole (d), (e) (for various elementary signals – Ricker 30 Hz and 60 Hz)

Figure 2 presents a fragment of real seismic section XX from the analysed concession, subject to various options of spectral modification [1(B) and 2(B)], assuming that the ‘target’ frequency of the transformed wave field is the frequency of the complex spectral characteristic of PA logging from the X-1 borehole.

A similar test was performed on the synthetic data generated based on RHBO and PA profiling curves from the X-1 borehole (Fig. 3). An increase in the resolution in the case of convolution with 60 Hz signal does not raise doubts.

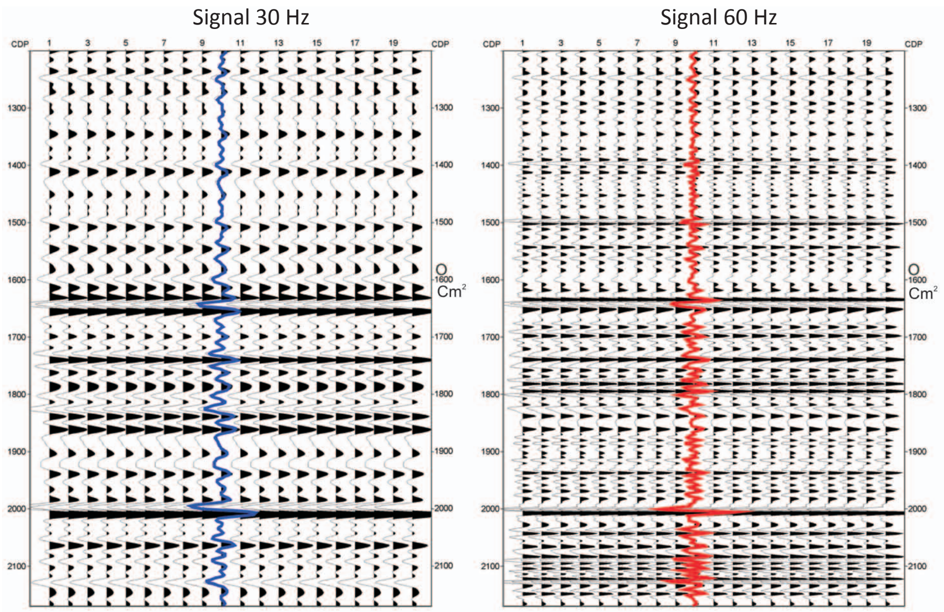

Fig. 3. A comparison of theoretical seismograms calculated based on the results of acoustic logging in the X-1 borehole in the 1196÷2166 ms interval, with assumed different elementary signals (30 Hz and 60 Hz)

The obtained image of the wave field was analysed, observing changes of the spectral characteristic for individual options of the modification operator, differing in the share of the component of data from borehole seismic prospecting and from surface seismic prospecting. For the seismic sections with the dominating signal frequency of around 30 Hz and the effective width of the amplitude spectrum of 13÷55 Hz, and similarly for the 60 Hz signal and the spectrum width of 30÷112 Hz (Fig. 4a, b), the basic difference in the actions sequence is the isolation of phase spectrum features from the seismic and borehole data – option 2.

In the case of the higher-frequency elementary signal (60 Hz) the spectral modification quite significantly shifts begin of the effective amplitude spectrum towards high frequencies (from 20 Hz to 38 and 80 to 95 Hz and also 24 Hz to 36 and 75 to 94 Hz). The advantages of this fact depend strictly on the location of the geological target. Tests were carried out on the synthetic data obtained from a convolution of elementary signals with the reflectivity curve from the X-1 borehole.

Modification parameters adopted for version 2 reproduce the wave field in a more stable way, in a new wider frequency range. Modifications both in versions 1 and 2 (Fig. 5a, b) are close to the theoretical seismograms in the ‘60 Hz signal’

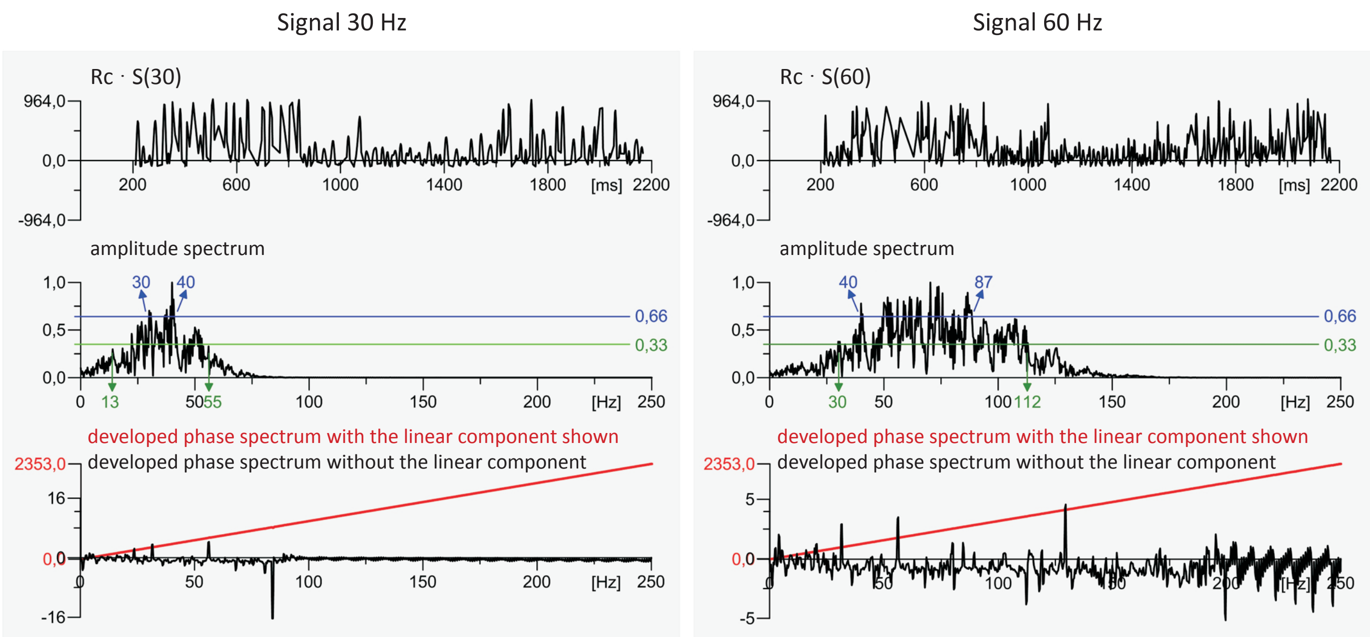

Fig. 4a. An assessment of the frequency range for the borehole data necessary to reproduce the wave field {30 Hz (13-30-40-55); 60 Hz (30-40-87-112)} in the pre-set time interval of (208÷2166 ms), Rc – reflection coefficients curve

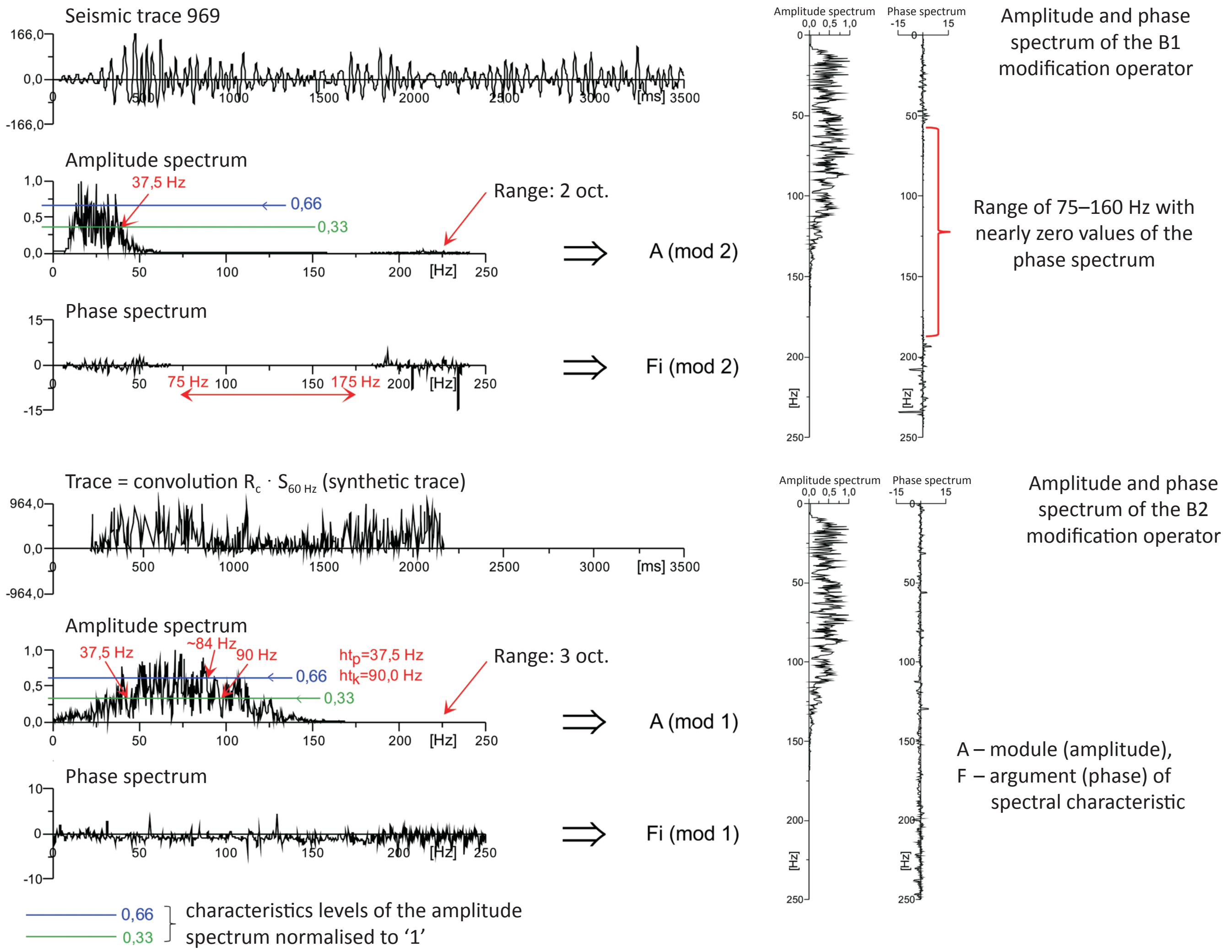

Fig. 4b. The sequence of spectral modification operator calculation on the real seismic and borehole data (concession W, borehole X)

option (Fig. 3 and 6). The close similarity of spectral modification results in versions 1 and 2, implemented applying various spectral modification operators, proves firstly that the reconstructed wave fields originate from identical actual geological facts and a distance of around 300 m (determined by CDP 5120÷5140) from the X-1 borehole location on CDP 5129; secondly they prove that the implemented procedures are correct.

Using so-prepared data, with the wave field structure recognised in detail, the influence of the disturbances existence on the effectiveness of the methodology for the wave field resolution increasing was assessed, both for the theoretical and real data. The option of theoretical seismograms in convolution with ‘30 Hz elementary signals’ was chosen, because it is more difficult to achieve a ‘wide frequency spectrum’ and an increased resolution for the wave field obtained in this way.

Comparing the wave fields, both theoretical and actual, at various stages of processing an obvious reduction of image uniqueness is noticed after the disturbances introduction (Fig. 7). Focusing attention on the 1400÷1800 ms time interval (Fig. 1 and 7), we see that the input time section does not enable reproducing ‘geological’ details visible on the reflectivity curve ‘K’. In accordance with the assumption, the introduced ‘white noise’ of Gaussian characteristic can interfere with the input data, which makes the geological interpretation difficult, in particular in the case of (horizontal) facies variability and a small number of boreholes. In addition, this disturbances may have both a destructive and a constructive nature, depending on the analysed interval [16].

The appearance of new reflections, and even of a phase coherence axis, on relatively small section fragments, to which the noise of a known characteristic was added, does not change the section’s spectral characteristic, which is manifested by a nearly analogous shape of the amplitude spectrum. The percentage of white noise (100% and 200%) only slightly affects the shape of the amplitude spectrum. This is a very important observation because it may become the criterion to separate the noise influence from the unwanted spectral modification effects, if any.

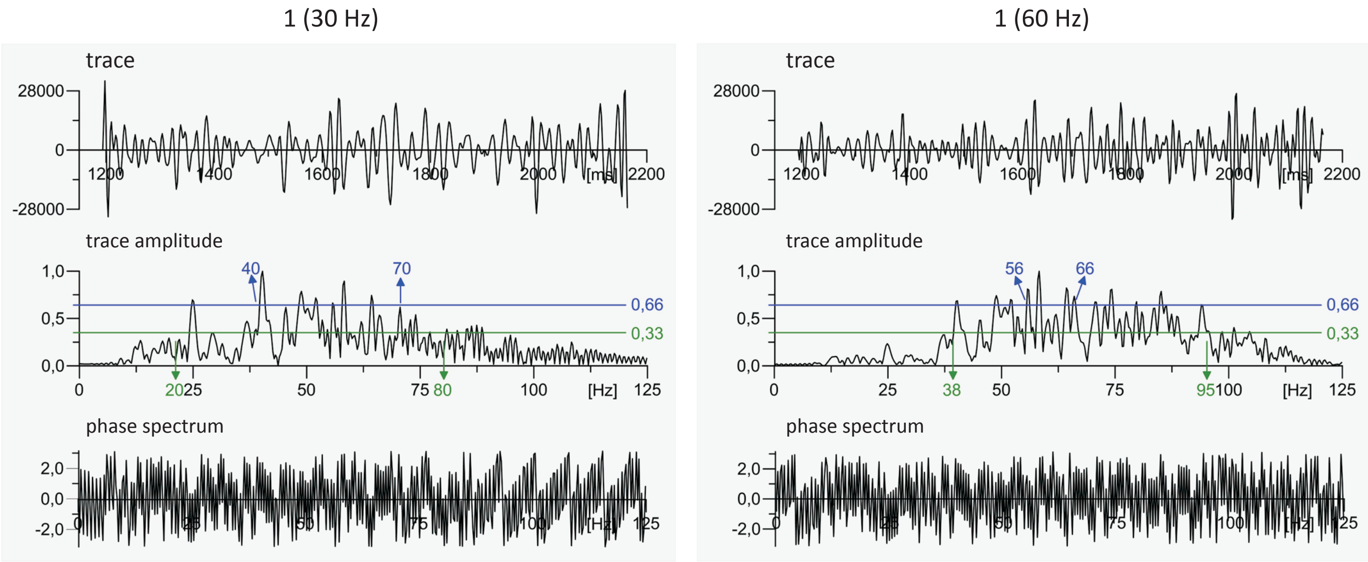

Fig. 5a. Results of spectral modification of theoretical seismic traces in the 1200÷2200 ms interval – option 1 {30 Hz (20-40-70-80); 60 Hz (38-56-66-95)}

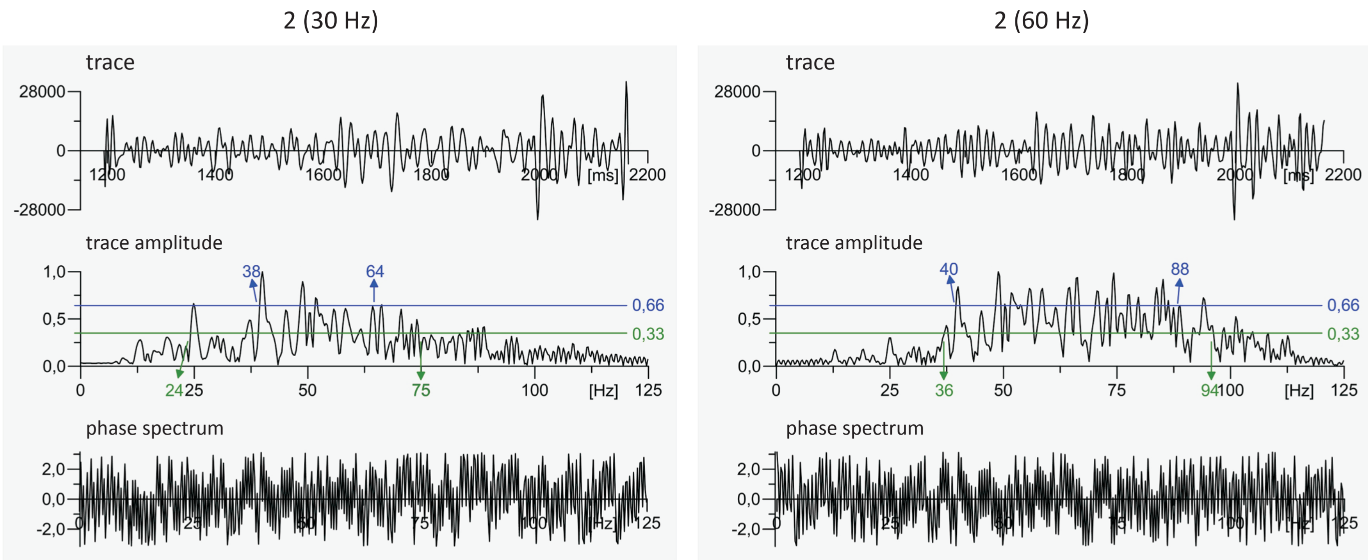

Fig. 5b. Results of spectral modification of theoretical seismic traces in the 1200÷2200 ms interval – option 2 {30 Hz (24-38-64-75); 60 Hz (36-40-88-94)}

Irrespective of the moment in which the applied or random noise occurred on the seismic section, i.e. in the considered case before or after the spectral modification, and also apparently as its effect, it has been noticed that the application of spectral modification on the data with noise (Fig. 8 and 9) somehow orders the wave image, parallel to widening the frequency band as against the input section. It is worth paying attention to the arrangement of reflections in the 1420÷1650 ms interval and to the actual seismic horizon at the time of 1620 ms, determined by a continuous strong reflection. Based on the low-frequency input section – the dominating frequency of the amplitude spectrum of the autocorrelation function FA = 19 Hz (Fig. 7) – it is difficult to tell what the reason is for the reflection decay at 1590 ms. The noise introduction makes the situation additionally difficult.

Instead, the application of spectral modification results in a clear increase in the dominating frequency of the amplitude spectrum FA from the 19 Hz position to the 60÷80 Hz position. The analysis of results presented in Figures 8 and 9 shows that a clearer image is obtained by the elimination of interference prior to the application of the resolution increasing procedure.

The comparison of results presented in Figures 8 and 9 also provides a methodological hint related to the location of the spectral modification procedure in the workflow scheme for the seismic data. The possibility of disturbances with the actual data is the most troublesome issue resulting from the noise and existence of disturbances on the seismic sections,

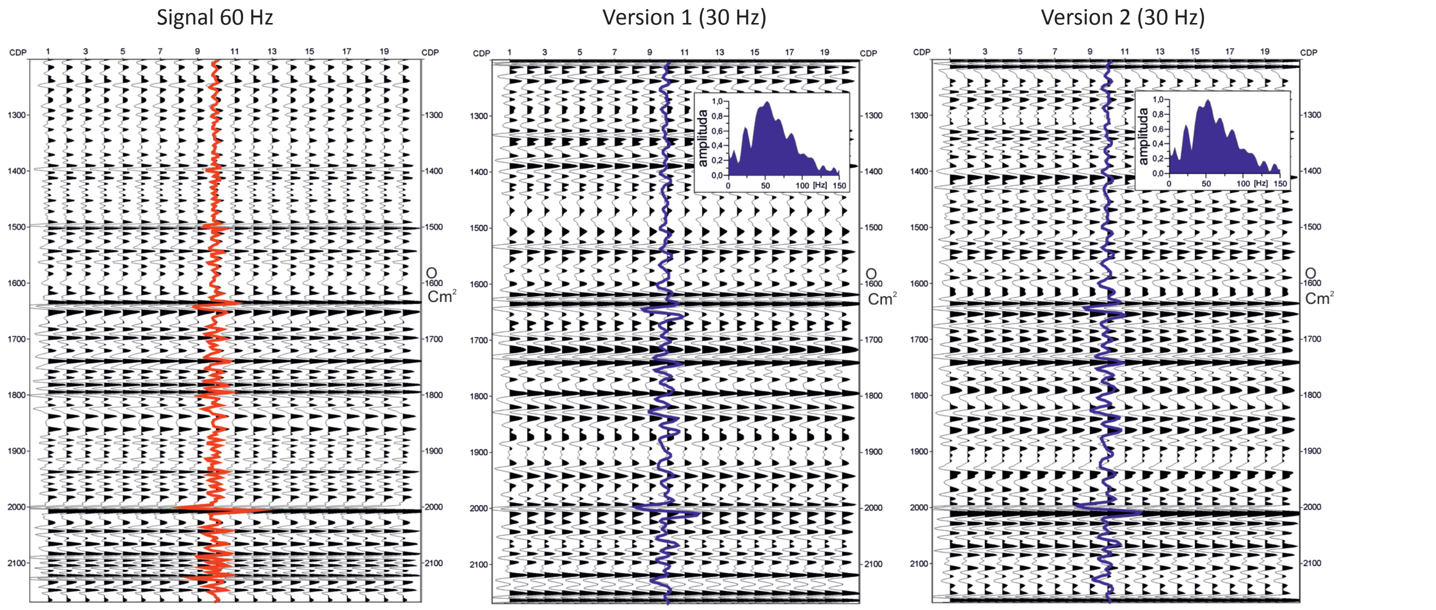

Fig. 6. A comparison of spectral modifications effectiveness in versions 1 and 2, carried out on theoretical seismograms with the 'Ricker 30 Hz' elementary signal, estimated via the similarity between the theoretical seismogram with the 'Ricker 60 Hz' elementary signal. Type 2 modification more accurately matches the wave image with the theoretical seismogram of assumed higher characteristics of the modification operator

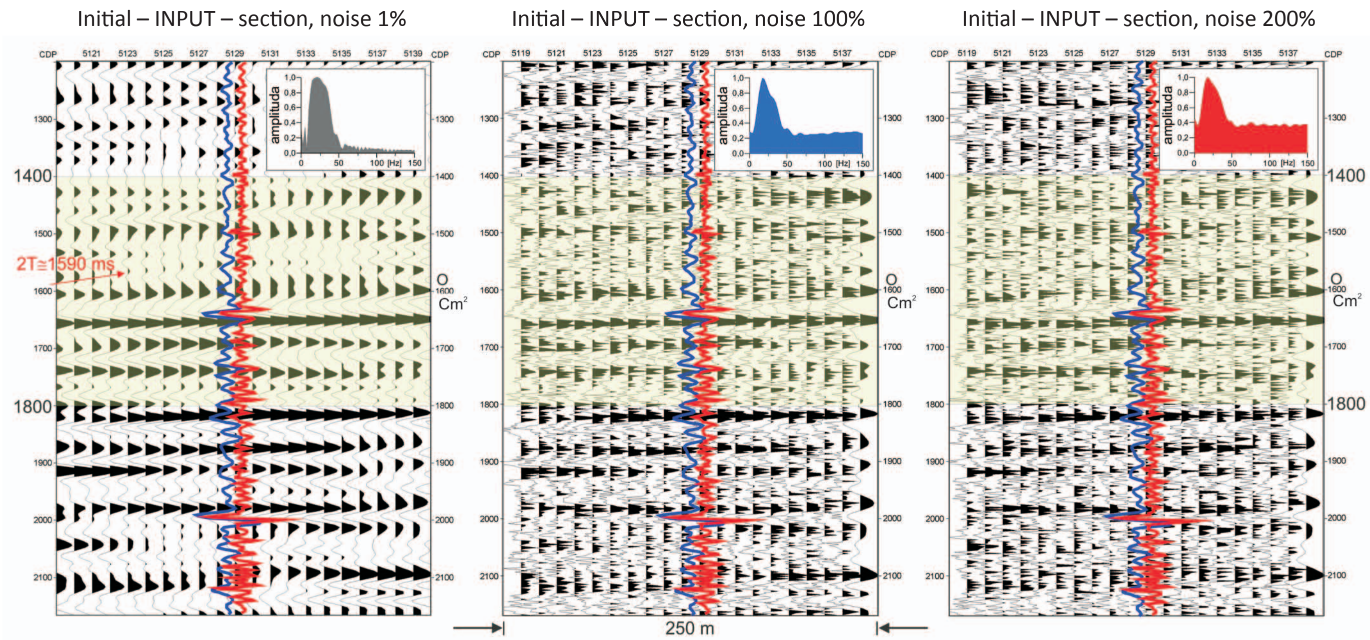

Fig. 7. A comparison of an actual wave field image (profile XX, concession W) after the introduction of noise with various S/N levels

which can introduce both series of reflections (so-called 'artefacts') which have nothing in common with the geological structure, and can also cancel the actual reflections originating from the real strata in the environment.

Figure 10 presents the results of the elimination of noise introduced on the seismic record, subject beforehand to the resolution increasing procedure.

To make credible the wave field image obtained as a result of the spectral characteristic modification, disturbances elimination tests were performed, applying well-known filtering procedures and using the determined parameters of spectral characteristics (Figs. 4, 5a and 5b). The elementary signal characteristic clearly reflects on each version of processing, both for actual and theoretical data. The more stable the signal to noise ratio is along the horizon, the wider the flat part of the FA spectrum (within 2 to 5 octaves).

The results were assessed via the determination of correlation coefficients for consecutive processing options.

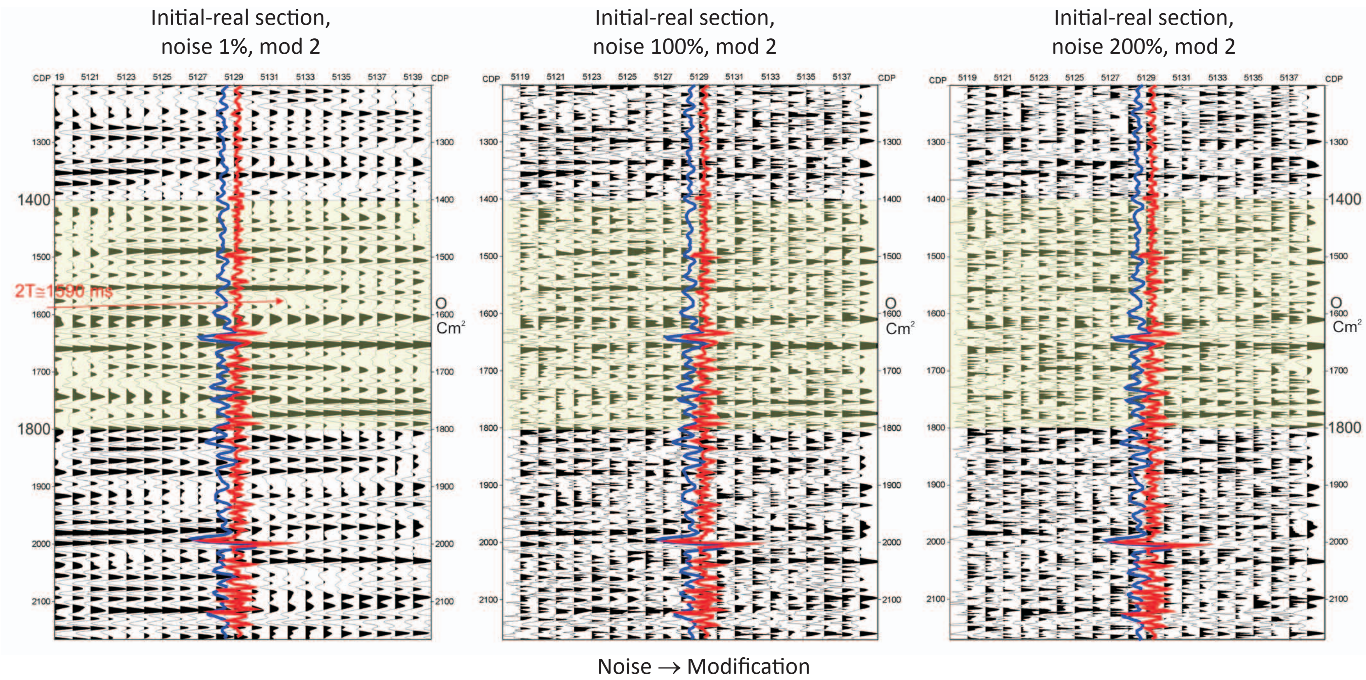

Fig. 8. Impact analysis of the existence of 'white noise' interference present in the seismic data subject to the modification procedure for the spectral characteristic on the real part, to increase the wave image resolution (concession W, profile XX; 100% and 200% noise) – option 2

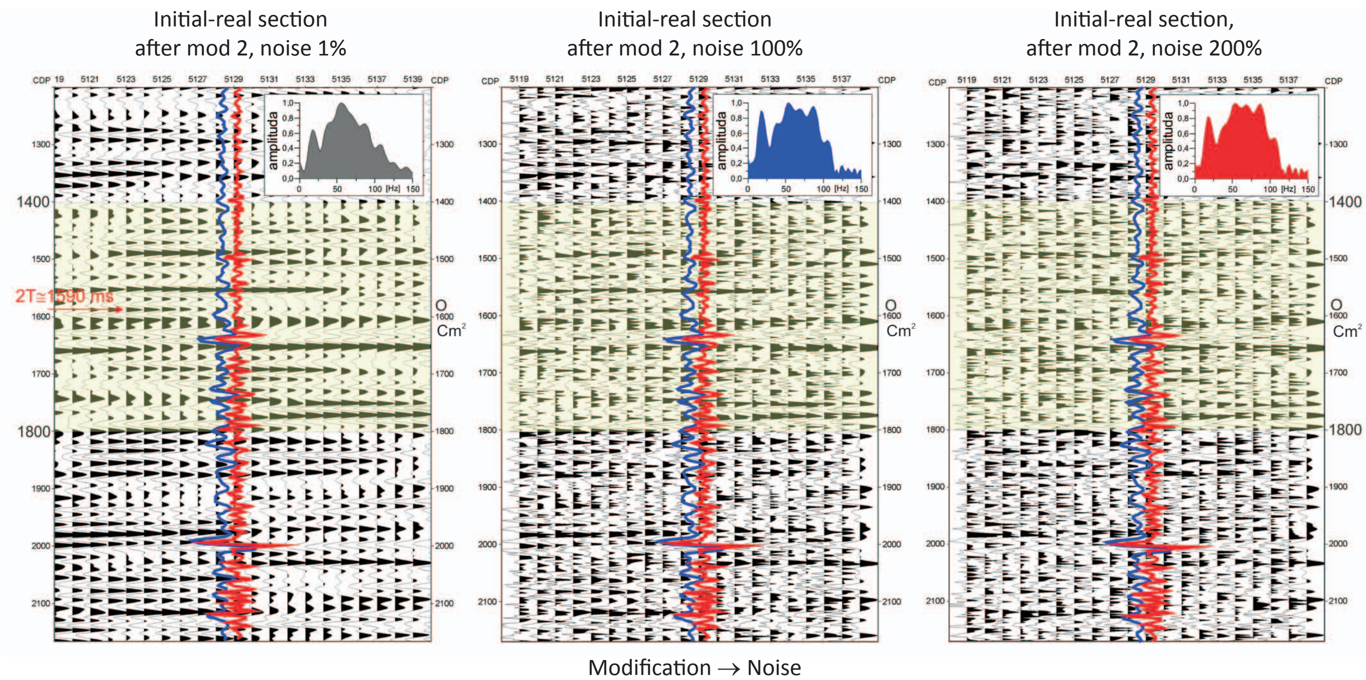

Fig. 9. Analysis of the interference level impact on the effectiveness of selected spectral characteristic modifications for the issue of increasing the resolution of the seismic wave field (concession W, profile XX)

The obtained values could be referred to as unexpected; very low coefficient values were obtained for the correlation of theoretical seismograms, without and with disturbances (Tables 1a and 1b), in the form of white noise of 100% ($C_{kor\,max}$ = 0.111), and also of 200% ($C_{kor\,max}$ = 0.075). Instead, a very high correlation coefficient (0.764) was obtained for the correlation of the actual section subject to two different options of the spectral modification, 1 and 2 (Table 1c). For the discussed example a conclusion could be formulated that the appearance on the seismic section of disturbances of not identified, but also of identified, reasons much more strongly degrades the geological image – the seismic image relationship, than a potential noise (e.g. a numerical noise), being an unwanted side effect of the spectral modification procedure.

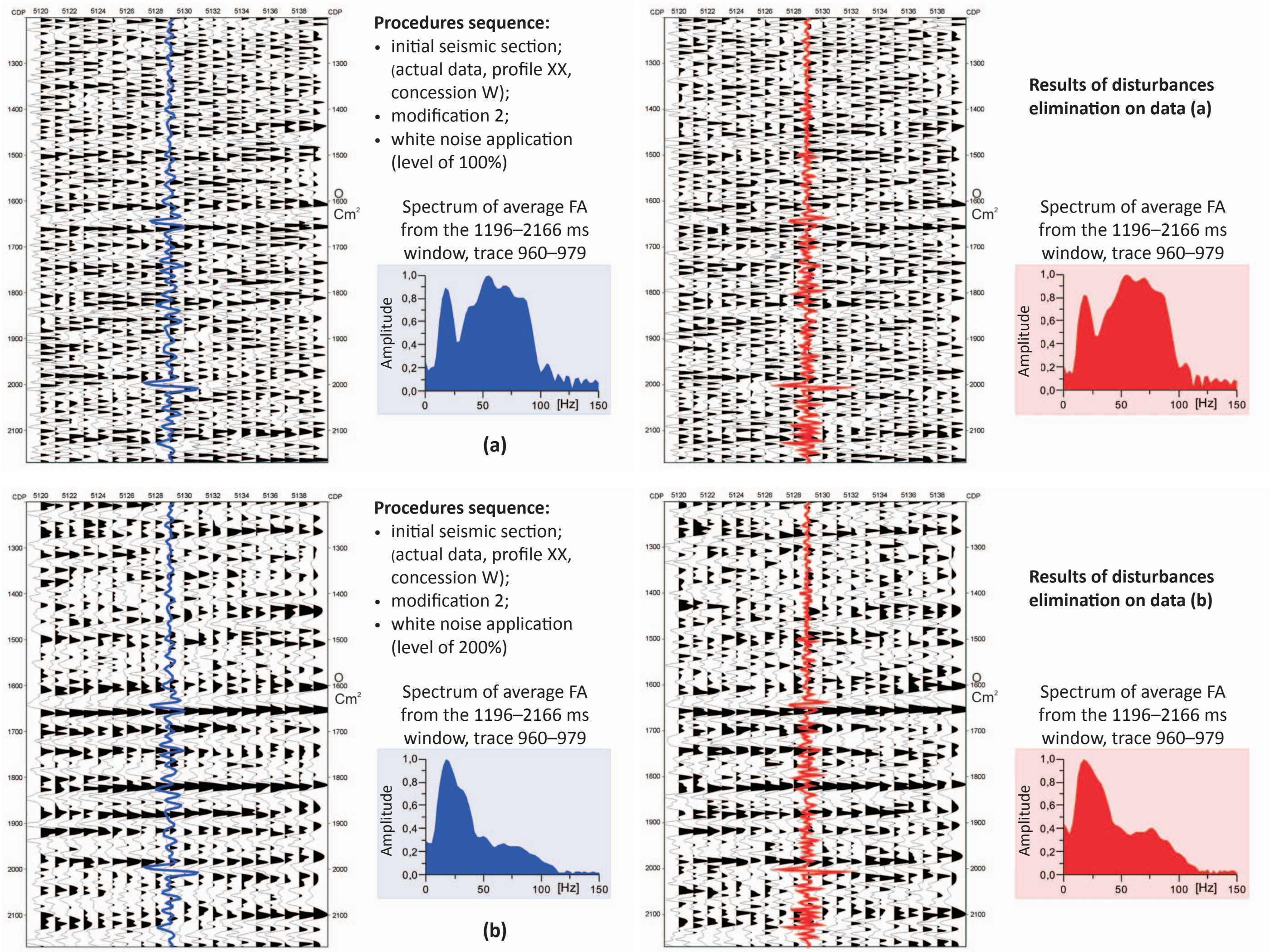

Fig. 10. Results of the 'white noise' disturbances elimination procedure for the seismic data, subject to various data processing operations

Up to now, in an era of applications in seismic data processing, sophisticated and complicated algorithms and computing procedures, a common method for the assessment of seismic data processing results – prepared for geophysical and geological interpretation – consists of visual inspections of such record features as horizon continuity, dynamic differentiation of amplitudes, flatness of reflections series within a collection of a common depth point or of common depth surface, as well as results consistency with the presumed, better or worse recognised geological environment.

The presented paper tries to avoid clearly qualitative assessments. A relatively simple analysis of correlation has been selected as a representation of quantitative methods specifying the similarity of seismic data subject to various transformations in the spectral domain. To predict the scale of quantitative assessments, which could be expected in studies carried out on the modification of the spectral characteristic, two sets of data were prepared on which two test types were performed.

The first set could be referred to as a 'set of obvious cases' and the test results could be easily and properly predicted (Table 1a, b, c).

The second set characterised the results of conversions carried out in the field of spectral characteristic modification (Table 2a, b, c).

The first set presents the results of the analysis of theoretical seismograms testing, calculated as a result of a convolution of reflection coefficients series (reflectivity function) and Ricker theoretical signals (with different dominating frequencies: 30 Hz and 60 Hz). The correlation of differing 'only' in the signal dominating frequency (Table 1a) has turned out to be surprisingly weak (0.117). The application of spectral modification (options 1 and 2) in both cases increased the correlation to 0.334 for the 30 Hz signal (Table 1b) and to 0.260 for the 60 Hz signal (Table 1c).

The second test type comprised the influence of the disturbances share on the similarity of seismic records, spectrally modified (Table 2a, b). In both cases theoretical seismograms

Table 1. Results of the correlation assessment for theoretical sections modelled with 30 Hz and 60 Hz elementary signals (WKS30S60) (a), subject to modification 1 and 2 (WK30B1B2) (b), and subject to modification 1 and 2 (WK60B1B2) (c)

(a) WKS30S60

244 30
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tr nr	1	przesun1170	wsp kor	-.019	sred tr	10.18	sred otw	5.1208
tr nr	1	przesun1172	wsp kor	-.046	sred tr	11.89	sred otw	5.1208
tr nr	1	przesun1174	wsp kor	-.058	sred tr	12.89	sred otw	5.1208
tr nr	1	przesun1176	wsp kor	-.051	sred tr	13.21	sred otw	5.1208
tr nr	1	przesun1178	wsp kor	-.027	sred tr	13.01	sred otw	5.1208
tr nr	1	przesun1180	wsp kor	.004	sred tr	12.47	sred otw	5.1208
tr nr	1	przesun1182	wsp kor	.028	sred tr	11.75	sred otw	5.1208
tr nr	1	przesun1184	wsp kor	.032	sred tr	10.98	sred otw	5.1208
tr nr	1	przesun1186	wsp kor	.014	sred tr	10.28	sred otw	5.1208
tr nr	1	przesun1188	wsp kor	-.017	sred tr	9.75	sred otw	5.1208
tr nr	1	przesun1190	wsp kor	-.044	sred tr	9.46	sred otw	5.1208
tr nr	1	przesun1192	wsp kor	-.045	sred tr	9.44	sred otw	5.1208
tr nr	1	przesun1194	wsp kor	-.012	sred tr	9.60	sred otw	5.1208
tr nr	1	przesun1196	wsp kor	.045	sred tr	9.77	sred otw	5.1208
tr nr	1	przesun1198	wsp kor	.097	sred tr	9.78	sred otw	5.1208
tr nr	1	przesun1200	wsp kor	.117	sred tr	9.54	sred otw	5.1208
tr nr	1	przesun1202	wsp kor	.090	sred tr	9.08	sred otw	5.1208
tr nr	1	przesun1204	wsp kor	.021	sred tr	8.60	sred otw	5.1208
tr nr	1	przesun1206	wsp kor	-.064	sred tr	8.33	sred otw	5.1208
tr nr	1	przesun1208	wsp kor	-.129	sred tr	8.44	sred otw	5.1208
tr nr	1	przesun1210	wsp kor	-.145	sred tr	8.94	sred otw	5.1208
tr nr	1	przesun1212	wsp kor	-.108	sred tr	9.66	sred otw	5.1208
tr nr	1	przesun1214	wsp kor	-.038	sred tr	10.36	sred otw	5.1208
tr nr	1	przesun1216	wsp kor	.033	sred tr	10.77	sred otw	5.1208
tr nr	1	przesun1218	wsp kor	.075	sred tr	10.78	sred otw	5.1208
tr nr	1	przesun1220	wsp kor	.072	sred tr	10.40	sred otw	5.1208
tr nr	1	przesun1222	wsp kor	.032	sred tr	9.79	sred otw	5.1208
tr nr	1	przesun1224	wsp kor	-.022	sred tr	9.18	sred otw	5.1208
tr nr	1	przesun1226	wsp kor	-.057	sred tr	8.76	sred otw	5.1208
tr nr	1	przesun1228	wsp kor	-.056	sred tr	8.67	sred otw	5.1208
tr nr	1	przesun1230	wsp kor	-.019	sred tr	8.87	sred otw	5.1208

max kor .117 na trasie 1 przy przes 1200.0000

(b) WK30B1B2

244 30
Okno : 1192.000000 2166.000000

tr nr	1	przesun1170	wsp kor	.039	sred tr	30.33	sred otw	40.8639
tr nr	1	przesun1172	wsp kor	-.040	sred tr	30.53	sred otw	40.8639
tr nr	1	przesun1174	wsp kor	-.083	sred tr	24.76	sred otw	40.8639
tr nr	1	przesun1176	wsp kor	-.059	sred tr	17.59	sred otw	40.8639
tr nr	1	przesun1178	wsp kor	.023	sred tr	15.97	sred otw	40.8639
tr nr	1	przesun1180	wsp kor	.111	sred tr	24.54	sred otw	40.8639
tr nr	1	przesun1182	wsp kor	.148	sred tr	41.74	sred otw	40.8639
tr nr	1	przesun1184	wsp kor	.107	sred tr	60.45	sred otw	40.8639
tr nr	1	przesun1186	wsp kor	.014	sred tr	73.33	sred otw	40.8639
tr nr	1	przesun1188	wsp kor	-.080	sred tr	78.74	sred otw	40.8639
tr nr	1	przesun1190	wsp kor	-.129	sred tr	81.55	sred otw	40.8639
tr nr	1	przesun1192	wsp kor	-.114	sred tr	88.01	sred otw	40.8639
tr nr	1	przesun1194	wsp kor	-.045	sred tr	98.93	sred otw	40.8639
tr nr	1	przesun1196	wsp kor	.048	sred tr	107.37	sred otw	40.8639
tr nr	1	przesun1198	wsp kor	.113	sred tr	102.98	sred otw	40.8639
tr nr	1	przesun1200	wsp kor	.102	sred tr	80.01	sred otw	40.8639
tr nr	1	przesun1202	wsp kor	.004	sred tr	43.24	sred otw	40.8639
tr nr	1	przesun1204	wsp kor	-.134	sred tr	6.94	sred otw	40.8639
tr nr	1	przesun1206	wsp kor	-.232	sred tr	-13.09	sred otw	40.8639
tr nr	1	przesun1208	wsp kor	-.225	sred tr	-9.63	sred otw	40.8639
tr nr	1	przesun1210	wsp kor	-.098	sred tr	11.01	sred otw	40.8639
tr nr	1	przesun1212	wsp kor	.097	sred tr	32.96	sred otw	40.8639
tr nr	1	przesun1214	wsp kor	.271	sred tr	41.02	sred otw	40.8639
tr nr	1	przesun1216	wsp kor	.334	sred tr	29.99	sred otw	40.8639
tr nr	1	przesun1218	wsp kor	.249	sred tr	6.66	sred otw	40.8639
tr nr	1	przesun1220	wsp kor	.054	sred tr	-15.59	sred otw	40.8639
tr nr	1	przesun1222	wsp kor	-.153	sred tr	-25.18	sred otw	40.8639
tr nr	1	przesun1224	wsp kor	-.270	sred tr	-17.83	sred otw	40.8639
tr nr	1	przesun1226	wsp kor	-.250	sred tr	3.69	sred otw	40.8639
tr nr	1	przesun1228	wsp kor	-.124	sred tr	33.74	sred otw	40.8639
tr nr	1	przesun1230	wsp kor	.029	sred tr	67.46	sred otw	40.8639

max kor .334 na trasie 1 przy przes 1216.0000

(c) WK60B1B2

244 30
Okno : 1192.000000 2166.000000

tr nr	1	przesun1170	wsp kor	.073	sred tr	-2.55	sred otw	27.0887
tr nr	1	przesun1172	wsp kor	-.055	sred tr	-5.28	sred otw	27.0887
tr nr	1	przesun1174	wsp kor	-.155	sred tr	-16.21	sred otw	27.0887
tr nr	1	przesun1176	wsp kor	-.148	sred tr	-28.27	sred otw	27.0887
tr nr	1	przesun1178	wsp kor	-.027	sred tr	-32.90	sred otw	27.0887
tr nr	1	przesun1180	wsp kor	.126	sred tr	-26.49	sred otw	27.0887
tr nr	1	przesun1182	wsp kor	.197	sred tr	-12.48	sred otw	27.0887
tr nr	1	przesun1184	wsp kor	.136	sred tr	1.02	sred otw	27.0887
tr nr	1	przesun1186	wsp kor	-.012	sred tr	6.00	sred otw	27.0887
tr nr	1	przesun1188	wsp kor	-.142	sred tr	.08	sred otw	27.0887
tr nr	1	przesun1190	wsp kor	-.178	sred tr	-10.48	sred otw	27.0887
tr nr	1	przesun1192	wsp kor	-.114	sred tr	-14.59	sred otw	27.0887
tr nr	1	przesun1194	wsp kor	.001	sred tr	-5.78	sred otw	27.0887
tr nr	1	przesun1196	wsp kor	.109	sred tr	10.89	sred otw	27.0887
tr nr	1	przesun1198	wsp kor	.166	sred tr	21.54	sred otw	27.0887
tr nr	1	przesun1200	wsp kor	.146	sred tr	14.10	sred otw	27.0887
tr nr	1	przesun1202	wsp kor	.048	sred tr	-11.80	sred otw	27.0887
tr nr	1	przesun1204	wsp kor	-.092	sred tr	-42.91	sred otw	27.0887
tr nr	1	przesun1206	wsp kor	-.205	sred tr	-60.12	sred otw	27.0887
tr nr	1	przesun1208	wsp kor	-.221	sred tr	-51.71	sred otw	27.0887
tr nr	1	przesun1210	wsp kor	-.116	sred tr	-22.59	sred otw	27.0887
tr nr	1	przesun1212	wsp kor	.060	sred tr	8.07	sred otw	27.0887
tr nr	1	przesun1214	wsp kor	.214	sred tr	20.33	sred otw	27.0887
tr nr	1	przesun1216	wsp kor	.260	sred tr	7.60	sred otw	27.0887
tr nr	1	przesun1218	wsp kor	.172	sred tr	-19.90	sred otw	27.0887
tr nr	1	przesun1220	wsp kor	.006	sred tr	-44.42	sred otw	27.0887
tr nr	1	przesun1222	wsp kor	-.147	sred tr	-54.02	sred otw	27.0887
tr nr	1	przesun1224	wsp kor	-.218	sred tr	-48.84	sred otw	27.0887
tr nr	1	przesun1226	wsp kor	-.193	sred tr	-36.77	sred otw	27.0887
tr nr	1	przesun1228	wsp kor	-.101	sred tr	-24.55	sred otw	27.0887
tr nr	1	przesun1230	wsp kor	.023	sred tr	-12.82	sred otw	27.0887

max kor .117 na trasie 1 przy przes 1200.0000

Table 2. Results of the correlation assessment for theoretical seismograms modelled with the elementary signal of 30 Hz frequency without disturbances introducting and with disturbances in the form of white noise at a level of 100%, subject to spectral characteristic modification 2 (wk30scsbb2) (a) and disturbances in the form of white noise at a level of 200%, subject to spectral characteristic modification 2 (wk30scsab2) (b)

(a) wk30scsbb2

244 30
Okno : 1196.000000 2166.000000

tr nr	1	przesun1150	wsp kor	.098	sred tr	14.40	sred otw	30.4969
tr nr	1	przesun1152	wsp kor	.098	sred tr	13.33	sred otw	30.4969
tr nr	1	przesun1154	wsp kor	.064	sred tr	11.06	sred otw	30.4969
tr nr	1	przesun1156	wsp kor	.014	sred tr	8.13	sred otw	30.4969
tr nr	1	przesun1158	wsp kor	-.028	sred tr	5.32	sred otw	30.4969
tr nr	1	przesun1160	wsp kor	-.051	sred tr	3.41	sred otw	30.4969
tr nr	1	przesun1162	wsp kor	-.050	sred tr	2.86	sred otw	30.4969
tr nr	1	przesun1164	wsp kor	-.027	sred tr	3.71	sred otw	30.4969
tr nr	1	przesun1166	wsp kor	.004	sred tr	5.60	sred otw	30.4969
tr nr	1	przesun1168	wsp kor	.028	sred tr	7.95	sred otw	30.4969
tr nr	1	przesun1170	wsp kor	.035	sred tr	10.18	sred otw	30.4969
tr nr	1	przesun1172	wsp kor	.026	sred tr	11.89	sred otw	30.4969
tr nr	1	przesun1174	wsp kor	.010	sred tr	12.89	sred otw	30.4969
tr nr	1	przesun1176	wsp kor	-.001	sred tr	13.21	sred otw	30.4969
tr nr	1	przesun1178	wsp kor	-.002	sred tr	13.01	sred otw	30.4969
tr nr	1	przesun1180	wsp kor	.001	sred tr	12.47	sred otw	30.4969
tr nr	1	przesun1182	wsp kor	.000	sred tr	11.75	sred otw	30.4969
tr nr	1	przesun1184	wsp kor	-.013	sred tr	10.98	sred otw	30.4969
tr nr	1	przesun1186	wsp kor	-.036	sred tr	10.28	sred otw	30.4969
tr nr	1	przesun1188	wsp kor	-.059	sred tr	9.75	sred otw	30.4969
tr nr	1	przesun1190	wsp kor	-.066	sred tr	9.46	sred otw	30.4969
tr nr	1	przesun1192	wsp kor	-.048	sred tr	9.44	sred otw	30.4969
tr nr	1	przesun1194	wsp kor	-.005	sred tr	9.60	sred otw	30.4969
tr nr	1	przesun1196	wsp kor	.050	sred tr	9.77	sred otw	30.4969
tr nr	1	przesun1198	wsp kor	.095	sred tr	9.78	sred otw	30.4969
tr nr	1	przesun1200	wsp kor	.111	sred tr	9.54	sred otw	30.4969
tr nr	1	przesun1202	wsp kor	.091	sred tr	9.08	sred otw	30.4969
tr nr	1	przesun1204	wsp kor	.044	sred tr	8.60	sred otw	30.4969
tr nr	1	przesun1206	wsp kor	-.010	sred tr	8.33	sred otw	30.4969
tr nr	1	przesun1208	wsp kor	-.049	sred tr	8.44	sred otw	30.4969
tr nr	1	przesun1210	wsp kor	-.061	sred tr	8.94	sred otw	30.4969
tr nr	1	przesun1212	wsp kor	-.047	sred tr	9.66	sred otw	30.4969
tr nr	1	przesun1214	wsp kor	-.024	sred tr	10.36	sred otw	30.4969
tr nr	1	przesun1216	wsp kor	-.009	sred tr	10.77	sred otw	30.4969
tr nr	1	przesun1218	wsp kor	-.015	sred tr	10.78	sred otw	30.4969
tr nr	1	przesun1220	wsp kor	-.038	sred tr	10.40	sred otw	30.4969

max kor .111 na trasie 1 przy przes 1200.0000

(b) wk30scsab2

244 30
Okno : 1196.000000 2166.000000

tr nr	1	przesun1150	wsp kor	.058	sred tr	14.40	sred otw	34.9485
tr nr	1	przesun1152	wsp kor	.106	sred tr	13.33	sred otw	34.9485
tr nr	1	przesun1154	wsp kor	.118	sred tr	11.06	sred otw	34.9485
tr nr	1	przesun1156	wsp kor	.100	sred tr	8.13	sred otw	34.9485
tr nr	1	przesun1158	wsp kor	.064	sred tr	5.32	sred otw	34.9485
tr nr	1	przesun1160	wsp kor	.021	sred tr	3.41	sred otw	34.9485
tr nr	1	przesun1162	wsp kor	-.023	sred tr	2.86	sred otw	34.9485
tr nr	1	przesun1164	wsp kor	-.049	sred tr	3.71	sred otw	34.9485
tr nr	1	przesun1166	wsp kor	-.047	sred tr	5.60	sred otw	34.9485
tr nr	1	przesun1168	wsp kor	-.021	sred tr	7.95	sred otw	34.9485
tr nr	1	przesun1170	wsp kor	.009	sred tr	10.18	sred otw	34.9485
tr nr	1	przesun1172	wsp kor	.031	sred tr	11.89	sred otw	34.9485
tr nr	1	przesun1174	wsp kor	.037	sred tr	12.89	sred otw	34.9485
tr nr	1	przesun1176	wsp kor	.030	sred tr	13.21	sred otw	34.9485
tr nr	1	przesun1178	wsp kor	.014	sred tr	13.01	sred otw	34.9485
tr nr	1	przesun1180	wsp kor	-.009	sred tr	12.47	sred otw	34.9485
tr nr	1	przesun1182	wsp kor	-.036	sred tr	11.75	sred otw	34.9485
tr nr	1	przesun1184	wsp kor	-.063	sred tr	10.98	sred otw	34.9485
tr nr	1	przesun1186	wsp kor	-.078	sred tr	10.28	sred otw	34.9485
tr nr	1	przesun1188	wsp kor	-.073	sred tr	9.75	sred otw	34.9485
tr nr	1	przesun1190	wsp kor	-.043	sred tr	9.46	sred otw	34.9485
tr nr	1	przesun1192	wsp kor	.003	sred tr	9.44	sred otw	34.9485
tr nr	1	przesun1194	wsp kor	.047	sred tr	9.60	sred otw	34.9485
tr nr	1	przesun1196	wsp kor	.075	sred tr	9.77	sred otw	34.9485
tr nr	1	przesun1198	wsp kor	.079	sred tr	9.78	sred otw	34.9485
tr nr	1	przesun1200	wsp kor	.065	sred tr	9.54	sred otw	34.9485
tr nr	1	przesun1202	wsp kor	.040	sred tr	9.08	sred otw	34.9485
tr nr	1	przesun1204	wsp kor	.013	sred tr	8.60	sred otw	34.9485
tr nr	1	przesun1206	wsp kor	-.009	sred tr	8.33	sred otw	34.9485
tr nr	1	przesun1208	wsp kor	-.021	sred tr	8.44	sred otw	34.9485
tr nr	1	przesun1210	wsp kor	-.021	sred tr	8.94	sred otw	34.9485
tr nr	1	przesun1212	wsp kor	-.017	sred tr	9.66	sred otw	34.9485
tr nr	1	przesun1214	wsp kor	-.017	sred tr	10.36	sred otw	34.9485
tr nr	1	przesun1216	wsp kor	-.025	sred tr	10.77	sred otw	34.9485
tr nr	1	przesun1218	wsp kor	-.037	sred tr	10.78	sred otw	34.9485
tr nr	1	przesun1220	wsp kor	-.046	sred tr	10.40	sred otw	34.9485

max kor .118 na trasie 1 przy przes 1154.0000

shift “in plus”
shift “in minus”
position of the zero shift of the correlation function

sc – noise 1%
sa – noise 200%
sb – noise 100%

direction of autocorrelation function calculation

Table 3. Results of the correlation assessment for the actual section (PSTM) subject to two different modifications, 1 and 2 (WK17B1B2)

WK17B1B2

max kor	.764	na trasie	1	z trsa	20	przy przes	-20.0000
max kor	.352	na trasie	2	z trsa	15	przy przes	-20.0000
max kor	.377	na trasie	3	z trsa	16	przy przes	-20.0000
max kor	.361	na trasie	4	z trsa	17	przy przes	16.0000
max kor	.358	na trasie	5	z trsa	18	przy przes	14.0000
max kor	.362	na trasie	6	z trsa	19	przy przes	12.0000
max kor	.343	na trasie	7	z trsa	20	przy przes	10.0000
max kor	.255	na trasie	8	z trsa	6	przy przes	20.0000
max kor	.254	na trasie	9	z trsa	7	przy przes	18.0000
max kor	.246	na trasie	10	z trsa	8	przy przes	20.0000
max kor	.231	na trasie	11	z trsa	9	przy przes	20.0000
max kor	.207	na trasie	12	z trsa	4	przy przes	18.0000
max kor	.202	na trasie	13	z trsa	6	przy przes	14.0000
max kor	.232	na trasie	14	z trsa	1	przy przes	-14.0000
max kor	.236	na trasie	15	z trsa	2	przy przes	-18.0000
max kor	.244	na trasie	16	z trsa	3	przy przes	-20.0000
max kor	.243	na trasie	17	z trsa	4	przy przes	-16.0000
max kor	.249	na trasie	18	z trsa	5	przy przes	-18.0000
max kor	.255	na trasie	19	z trsa	6	przy przes	-20.0000
max kor	.244	na trasie	20	z trsa	7	przy przes	20.0000
===============							
max kor	.764	na trasie	1	z trsa	20	przy przes	-20.0000

Key to the tables:
Window: the interval of records similarity analysis for which the correlation coefficient was calculated,
Column 1 – analysed trace number,
Column 2 – position (ms) of the mutual shift of two records subject to correlation analysis (seismic trace or/and borehole data),
Column 3 – value of calculated correlation coefficient,
Column 4 – value of average amplitude on the analysed current indicated trace, in a moving window of correlation testing,
Column 5 – value of average amplitude on the record (seismic traces or/and borehole data) to which similarity is compared.

with dominating frequency of 30 Hz were tested, in option 2 studying the influence of white noise at levels of 100% and 200%. Such a low value of the correlation coefficient for different synthetic traces, but calculated with the application of an identical reflectivity function, was unexpected, which needs emphasising.

This information can constitute a clarification of many ambiguities appearing in migration procedures and, as a result, in interpretations. It shows a sometimes significant discrepancy between a subjective visual assessment of the wave image by the interpreter and the qualitative assessment supported by calculations.

Conclusion

The issue of increasing the seismic data resolution has a strong impact on the correctness of geological interpretation. However, it is subject to numerous factors affecting the obtained results, which most often do not prove systematised groups of reasons. When determining certain relations for one group of data, most often we cannot transfer them onto another set of data. Therefore, studying the factors resulting in the increase in the seismic data resolution, e.g. such as the signal to noise ratio, is a very important issue.

Moreover, the subject literature, despite the fact that it is rich, considers only the interpretation results of history cases, neglecting almost entirely any methodological-application details (e.g. Improved stratigraphic [15]; High resolution seismic [1]). This results from the fact that nearly all solutions known in the field of high resolution seismic prospecting are the subjects of patents, e.g. a series of CGG Veritas BroadSeis solutions: BroadSeis. Broadband Marine Acquisition, BroadSeis Ultra-Low Frequencies, For the Complete Picture to Explain Your Reservoir, Cornerstone-BroadSeis. State-of-the-Art Marine Broadband Data, BroadSeis. Enhancing Reservoir – AVO & Inversion, BroadSeis. Wavelets without Sidelobes, BroadSeis. Enhancing Interpretation, BroadSeis. Ghost-Free Broadband Source Solution; as well as the method for increasing the accuracy and depth of geological environment recognition based on the recorded seismic vibrations [18].

The method for the analysis of the disturbances influence suggested and presented in the paper is one of many possible and applies to a selected disturbances type, of white noise characteristic, hence relatively simple to eliminate. Therefore, the above solution does not provide an ultimate answer, but shows only a path of effective analysis, which will probably be different for different data.

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Legal and normative acts

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