UDC 550.8

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NEW METHODICAL SOLUTIONS FOR SHALLOW-DEPTH SEISMIC SURVEYING AT DEPOSITS OF WATER-SOLUBLE MINERAL RESOURCES




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The main seismic method, which ensure safety of mining on the water soluble mineral deposits is common midpoint method. We suggest new techniques in the field of integration seismic and seismoacoustics on the shallow dephts. Applying of suggesting techniques is shown while studying structure and characteristics of waterproof layer at Verhnekamskoe potash deposit.

Surface and mine seismic researches with using CDP observations are the main instruments for probable nature and technical origin hazards in water protective pillar limits predictions. Possibility of the most information receiving is in common using surface and mining seismic researches. Example of such kind complex interpretation is presenting. Traditional field of use of borehole seismic is parametric supply for processing and interpretation of surface seismic CMP, but also it can be used in detailed elaboration of borehole environment. Integration of vertical seismic profiling on the reflection waves and surface shallow seismic CMP is presented. 3D seismic is widely use in oil and gas industry. The question of applying 3D seismic on shallow depths is controversial. Parameters for 3D spread are calculated for estimating possibilities such system while solving geological and mining problems on Verhnekamskoe potash deposit.

Key words: *Shallow seismic surveying, borehole seismic surveying, mine seismic, 3D seismic surveying, 3D seismic surveying, waterproof pillar, mining safety.*

In accordance with current development of prospecting geophysical methods it is perfecting geological-geophysical providing of the safe mining of useful minerals soluble in water. Elaboration and perfecting of the apparatus base for collection of the data, increase of calculation power of processing centers permit to improve methodical component of above mentioned direction. Besides, many years of exploiting of such deposits stipulate arising of the new tasks of control of state of mined rock mass in the planned and emergency regimen. The number of methodical works in the field of low-depth seismic prospecting investigations is directed to solution of above mentioned tasks with due regard for current possibilities of the apparatus and processing components.

Complex combination of the surface and underground seismic prospecting

Localization of the natural and technogeneous heterogeneities in the water-proof layer (WPL) is the principal aim in course of fulfillment of the seismic prospecting investigations at the deposits of useful minerals soluble in water. Increase of trustworthiness of the data may be reached by complex combination of the surface and underground seismic prospecting, projected in accordance with demand of the method of repeated overlapping [1]. Realization of the complex ensures additional interpretation advantages owing to combined attributive analysis of the seismic acoustic data of the waves of different direction and different frequency [2].

Construction of coordinated model is begun from coordination of the wave pictures at the fixed reflecting horizons on the base of results of analysis of velocity. Subsequently it is analyzed in details specific features of reflecting horizons of the same name, for example, signs of tectonic disturbances, folds and so on. It is taken into account utmost permissible definition of the methods. In the offered complex of the seismic acoustic observation the structures and calculated estimations of parameters of the wave field, in accordance with the surface low-depth seismic prospecting, have regional character. In the most cases it gives the general conception about anomaly of the one or another interval of the section. Numerical working and further calculation of principal parameters of the mine seismic acoustic data are corrected on the base of obtained interpretative model.

Aim of the mine supervision is definition of character and degree of influence of the natural and technogeneous heterogeneity on WPL, more accurate definition of the bounds of spreading of heterogeneity in investigated rock mass. Working of the seismic acoustic data, directed to identification of found anomalies of the wave fields, may be carried out to the detriment of the structural component of interpretation. Construction of specified seismic geological model of the abnormal objects of the rock mass is carried out on the base of attributive interpretation. Its results permit to estimate the causes of negative changes in the section.

Offered complex has been used in the some mine field of Verkhnekamsky deposit of potassium salt (VKDPS) (Fig.1, *a*). It has been carried out surface seismic prospecting works by means of the method of common deep point (MCDP) (Fig. 1, *b*) within the some plot with supposed negative changes in the worked rock mass. On the base of above mentioned works it has been marked out the zones of the wave anomaly. They were worked out in details by the mine seismic acoustic methods (Fig. 2).

Parameters of the systems of control have been calculated in accordance with investigated interval and with sizes of supposed objects of examination. Registration of the seismic oscillations has been carried out by telemetering systems of collection of the seismic acoustic data (IS-128). The systems ensure registration of the signals within wide frequency range (up to 5 kHz). Mutual location of the surface and mine profiles permits to examine the time sections of different scale and different direction for common deep points within the bounds of the single interpretation model. Displacement of the mine profile relatively to the surface one does not exceed 70 meters in the plan.

Abnormal plots are marked out according to peculiarity on structure of different directions of the wave pictures in adjacent interval. More differentiated structure is observed in high-frequency mine wave field. It increases trustworthiness of geological interpretation. This detailed elaboration of the wave picture is stipulated by distinction in definitions of surface and mine investigations involving horizontal and vertical definition [3, 4]. Vertical definition h depends of the wave length. The last one is defined by ratio of predominant frequencies of reflected waves. Horizontal definition depends of radius of the first Fresnel zone R_{Fr}, that depends of the wave length and remoteness of the object from the line of observation D

$$R_{фр} = \sqrt{D\lambda/2}.$$

The ratios and their numerical values are given in the table.

Additional analysis of the wave field of the mine profile permits to suppose more substantially the nature of the found plots. Thus, maximum damping of the seismic record in high-frequency range may point on the small size of destructive heterogeneities in the section. On the base of above mentioned information and in comparison with a priori geological data it is possible to divide abnormal forming objects to the natural and technogeneous ones. Constancy of character of seismic record of abnormal plots of the section in the total registered range of

Definition, meters

Vertical ($\geq \Delta h = \lambda/4$)		Horizontal ($\geq$ 0,5 R_{Fr})	
Surface records	**Mine records**	**Surface records**	**Mine records**
7–10	1–1,5	25–40	4–8

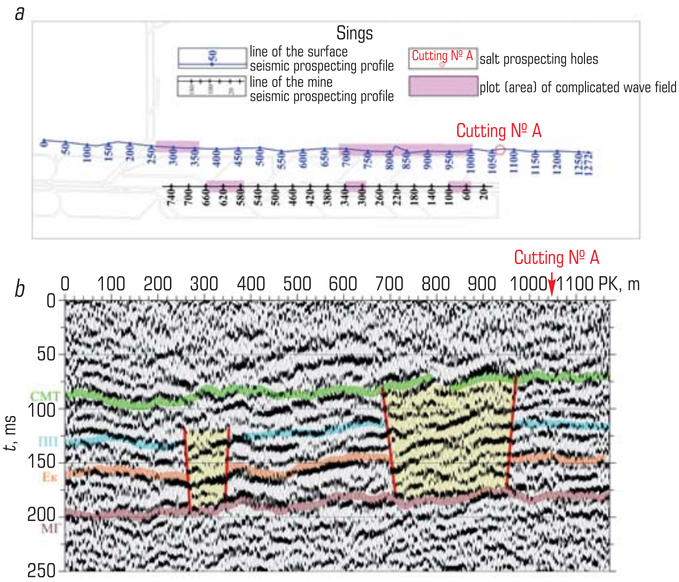

Fig. 1. Low-depth seismic investigations involved in the surface-underground seismic acoustic complex:
a — review scheme of the region of work ; *b* — time section MCDP for surface record

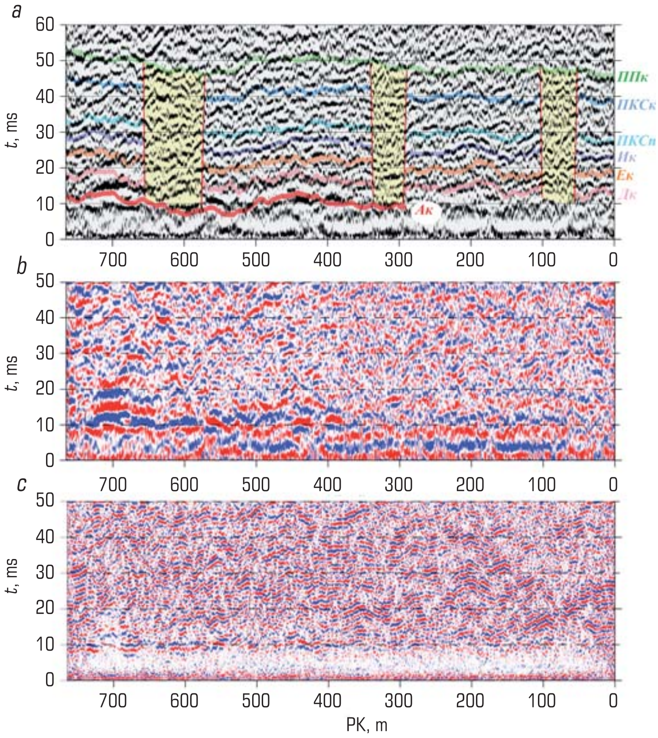

Fig. 2. Results of numerical working of the mine profile
a — time section MCDP; *b* — summary wave field of reflected waves within the range 100–300 Hz; *c* — summary wave field of reflected waves within the range 300–700 Hz

frequency points to natural genesis of heterogeneities. Fig. 2, *b* shows the results of narrow-stripe filtering in different frequency ranges. Maximum damping of high-frequency component is observed at the first plot (Fig. 2, *c*). Bounds of the second plot are less contrasting in accordance with above mentioned sign. Third plot has abnormal character of the seismic record within the all recorded range of frequency. Abnormal parameters of the wave field in its low-frequency zone are extremely weak at the first and second plots (Fig. 2, *b*).

Plots, marked out at the longitudinal profile, are revealed differently on the summary seismic geological section (Fig. 3). At the first plot low-velocity zone damps gradually and are revealed up to the roof of transitional pack. Decrease of damping of velocity at the second plot is localized mainly within the bounds of productive sediments Ak-Ik. Minimum thickness of relatively high-velocity seams of cover salt is marked at its bounds. Within the third plot low-velocity zone is localized in productive sediments without significant correlation with above lying sediments.

Found appropriateness in parameters of the wave field permits to suppose presence of the vertical lengthy zones with the small defects of the rock mass (disconnected local zones of exfoliation, fissuring and so on) within the bounds of the first plot and on the bounds of the second plot. Of the defects are estimated at 0.5–1 meters. Signs of natural lithologic structural changeableness are found at the third plot mainly in productive rocks Ak-Ik. Distribution of structural and physical parameters of appropriateness of change of parameters of the wave field at the market plots indicates different genesis of the last ones. The most probably that at the eastern part of the profile (plots № 1 and № 2) we observe technogeneous genesis and in the western part (№ 3) — natural one.

Above mentioned seismic acoustic observation complex increases accuracy and trustworthiness of spatial interpretative models of mapped heterogeneities of geological section. It is possible in case of further joint interpretation of surface-underground low-depth researches. Owing to joint examination of the wave pictures obtained from the surface and from underground mining workings it is possible to determine more monosemanticly spheres of their spreading along the section. Upper bound has to be determined exactly in case of direction of spreading of resilient oscillations downwards (surface observations), lower bound — in case of direction of the wave upwards (mine observations). Increase of the frequency range, that is recorded in mine seismic prospecting of the wave field, increase significantly definition of interpretative conclusions

Application of the holes seismic prospecting for more precise definition of seismic geological binding of the data obtained in course of low-depth seismic researches

Availability of prospecting and monitoring holes within exploited deposit permits to apply widely holes seismic researches. Traditionally the principal aim of researches is parametric ensuring of working and interpretation of the data of the surface prospecting researches. Besides, some methodical solutions [5] permit to work out in detail structure of the space near the holes at the plots with complicated geological structure. Combination of vertical seismic profiling on reflected waves with the data of surface low-depth seismic prospecting LDSP today is the most effective method of the low-depth seismic prospecting researches.

Generating of resilient waves is carried out along the profile crossing examined hole. Record is fulfilled from the surface to the bottom of the hole by means 24-canals device. On the base of theoretical calculation it has been chosen following parameters of the system of control of vertical seismic profiling: minimum distance X_{min} of generating station from the mouth of the hole 1 meter, maximum distance X_{max} 100 meters, distance between generating stations X_{GS} 2 meters, distance X_{RS} between receiving stations 1 meters. Measurements have been carried out in prospecting hole 70 meters depth. Systems of control with enumerated parameters ensure reliable registration of the direct and reflected waves in fixed interval in frequency range up to 200 Hz.

In recording complex constructed wave field longitudinal reflected waves RR are taken as a having special purpose ones. Other types of the waves: direct longitudinal, direct transversal, multiple and exchange have to be suppressed. Intensive tube- and hydro-waves arise in the interval of casing of the hole. End of the

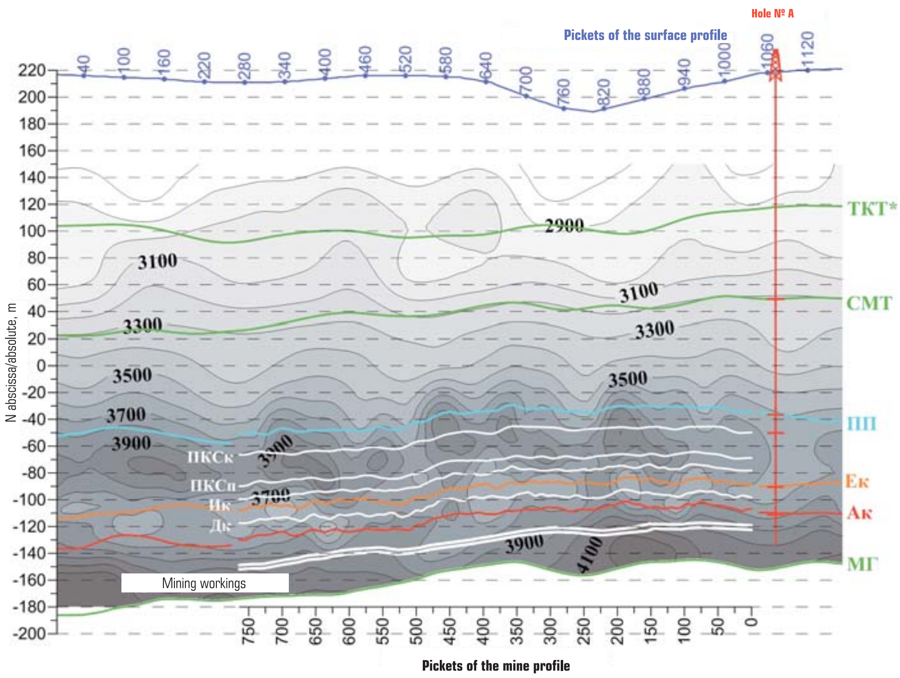

Fig. 3. Summary seismic geological section for the mine and surface seismic prospecting

cement casing shoe is the point of diffraction and makes its contribution in the wave field.

Working of the data of vertical seismic profiling (VSP) within the bounds of the system RadExPro [6] has involved wide range of the procedures: band and reverse filtration; spatial filtration; definition of the shape of impulse of the signal and deterministic deconvolution; introducing of statistical and kinematic amendments; Kirchhoff's transformation for obtain of the sections VSP — OGT; appointment of coherent component of resulting time section.

Accumulation of the seismograms permits to strengthen regular component and to obtain summary time section in the interval from the hole up to middle of maximum remoteness.

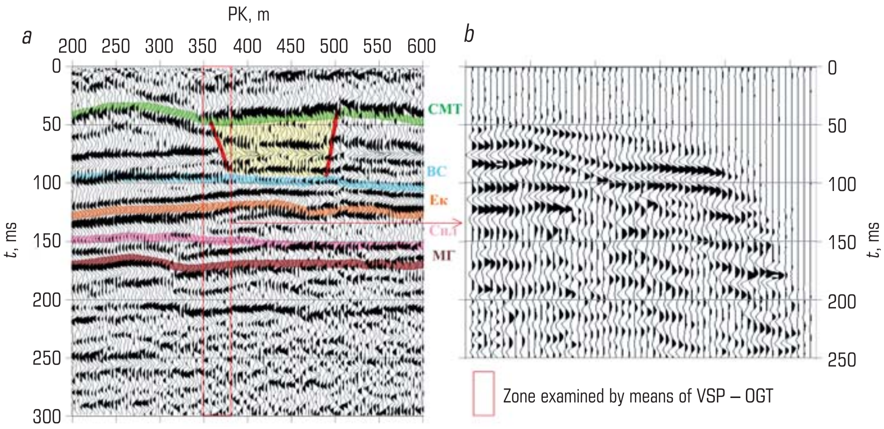

Fig. 4. Comparison of the time sections obtained by the data of low-depth seismic prospecting (*a*) and vertical seismic profiling VSP – OGT (*b*)

Practical testing of the method has been carried out on the territory of the mine field of some salt mine VKDPS. Method of VSP-OGT (Fig. 4) has been used for working out in detail of structure of some plot with complication of the wave field.

Estimation of possibilities of spatial systems in low-depth seismic prospecting

Surface low-depth seismic prospecting mainly is carried out by the single profile lines or by groups of the lines located in accordance with available geological-geophysical data and surface conditions. Experience of the oil prospecting, carried out up to the depth more than 1 kilometer, shows advantages of spatial modifications of seismic prospecting, permitting to restore real location of geological bounds with complicated hypsometry and to restore spatial distribution of the local properties. Significantly increased laborious for organization of the spatial observation is evident. For successful usage of the spatial seismic prospecting (3D) for study of the low depth it is necessary to adapt total technology of the work — beginning from the used systems of prospecting to numerical working and interpretation of the data. Competent projecting of the system of record of 3D-survey and analysis of its possibilities in course of researches in the interval of low depth in comparison with laborious are the important tasks.

On the base of practical experience of two-dimensional seismic researches in conditions VKDPS, with due regard of geological tasks and available material, technical and apparatus possibilities it has been set following principal parameters for system of 3D record: divisibility — not less than 16; size of binary cell (channel) $B_{x,y}$ — 4×8 meters; number of the channels — 288; maximum remoteness X_{max} ~ 400 meters, minimum remoteness X_{min} < 100 meters. Taking into account above mentioned data it has been calculated the templet consisted of 6 lines of receiving (LPP) with 48 channel in every line and of 5 lines of excitation (LPV) with 13 points of excitation in every line. Distance between the lines of receiving and the lines of excitation are 64 meters. It may be changed depending of possibility to lay the profiles on appointed working plot.

As a result, it has been designed spatial system of control for high-definition low-depth seismic prospecting in real conditions of the built-up territory (Fig. 5, *a*, *b*). Its parameters are given below:

Size of the bin in direction in-line (B_x), meters	*4*
Size of the bin in direction cross-line (B_y), meters	*8*
Step of the points of receiving, meters	*8*
Step of the points of excitation, meters	*16*
Number of active channels	*288*
Number of lines of receiving	*12*
Number of lines of excitation	*10*
Total number of the points of excitation	*422*
Total number of the points of receiving	*838*
Maximum remoteness X_{max}, meters	*476*
Minimum remoteness X_{min}, meters	*0.3*
Total number of the seismograms	*780*
Maximum divisibility	*29*
Area of survey with non-zero divisibility, km^2	*0.41*
Total bins	*12838*
Total lines	*157174*

In course of moving of the templet on the area of three-dimensional survey it takes place overlapping along the line of excitation and along the line of receiving. After shooting of the strip of control the templet is moved on three lines of excitation (overlapping two lines). In course of transition to the next strip of control the templet is moved on three lines of receiving (overlapping three lines). Thus, it takes place covering of the working area according to set nominal divisibility (Fig. 5, *c*).

Excluding the border figures divisibility changes from 10 to 24 (average 16). If chosen divisibility is insufficient (low ratio signal/hindrance) it is possible to go from the bin 4×8 to 8×8. In this case divisibility will increase twice as much owing to increase of number of the summed lines within the every bin. Horizontal definition in this case will decrease in direction "in-line". If obtained divisibility is

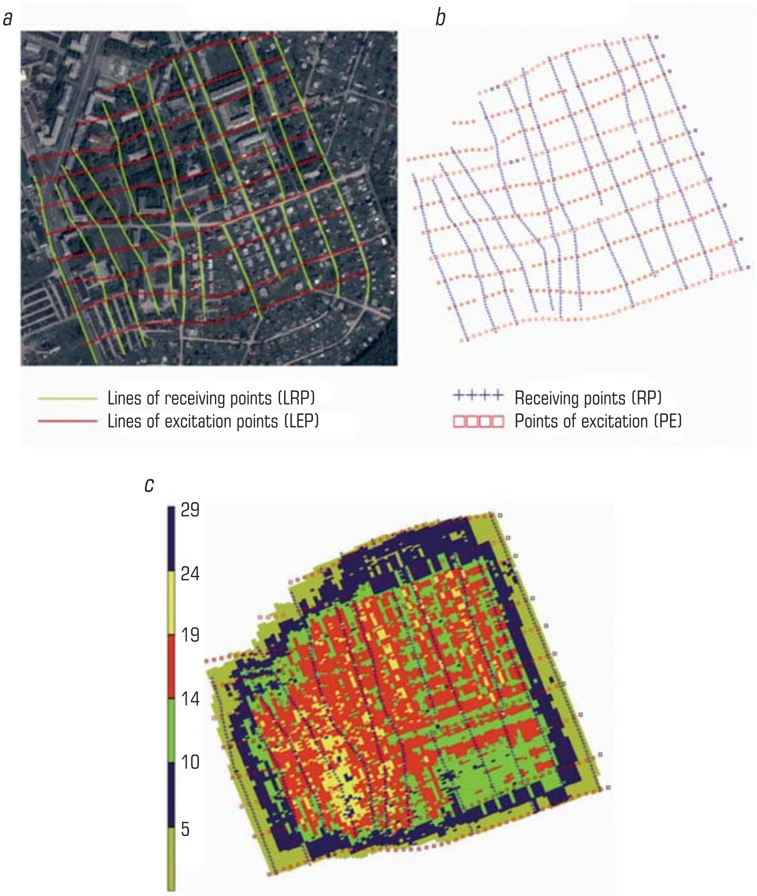

Fig. 5. System of 3D record for low-depth seismic prospecting
a — summary plan of the plot for fulfillment of 3D seismic prospecting works; *b* — location of PP and PV; *c* — distribution of nominal divisibility by area of the work

satisfactory, laborious of fulfillment of spatial survey may be considerably decreased thanks to increase of bin up to 8×8 meters. Thus, it is possible to decrease number of the lines of excitation in the templet from 5 to 3. Correspondingly, number of the "shot" points of excitation in course of fulfillment of the work decreases almost by 1/3 and will be about 520 instead of 780.

For covering of the area with 2D profiles net distance between the profiles has to be comparable with diameter of the first Fresnel zone at supposed depth of searching objects of the profiles. Minimum lateral sizes of un-uniform zone may be found by means of features of the seismic record. They are estimated roughly as two radius of the first Fresnel zone [7]. The last one depends of prevail length of the wave $\lambda = V/f_v$, of the depth of reflecting bound h, average velocity of the seismic wave V and its prevail frequency f_v.

Taking into account depth of research radius of Fresnel zone will change from 20 to 80 meters. So, maximum possible distance between the profiles has to be 90–110 meters. In this case anomaly, comparable with size of the first Fresnel zone, will be crossed two times.

For covering of the area 640×640 meters with the net of 2D profiles, comparable with area of 3D survey, it will be need 6 profile lines with average divisibility 32. For working of the all profiles it will be need 480 points of excitation and 480 recording receiving points.

In case of increase of size of the bin and decrease of number of the lines of excitation in the templet total number of the points of excitation on the area, studied by 2D and 3D methods, will be comparable. In course of usage of spatial systems of control energy of the points of excitation will be used more effective owing to increased number of the active channels. Number of used active channels in 3D system of record is almost twice as much their number for profile works (838 against 480). It increases undoubtedly expenses for fulfillment of the spatial seismic prospecting for obtain of volume of information comparable with two-dimensional seismic prospecting.

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