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Complex Analysis of Geological Data and Use of Velocity Model of MMS on Central Caucasus Sections

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***Abstract*—The article considers the complex analysis of geological data on the basis of the use of the high-velocity model of the microseismic sounding method (MMS) on the sections of the Central Caucasus. At the same time, based on the analysis of the results obtained, the high potential possibilities of the MMS method are shown in conditions of deep development of tectonic processes. Geological and geophysical data confirming the correspondence of anomalous objects to the velocity model of MMS with known structures and tectonic dislocations located at considerable depths are given. It is concluded that the use of MMS has a good prospect. It can become a direction of innovative development not only in the study of deep and oil-and-gas bearing structures, but also in the search for ore deposits through the solution of structural-tectonic, lithologic and morphological signs of ore occurrence control and a systematic understanding of the factors responsible for the formation of metallogenic specialization, geophysical fields and the geological structure of metallogenic zones, ore fields and deposits.**

***Keywords*—microseismic sounding; high-velocity models; high-low-velocity objects; tectonic zones; Ardon; teib faults**

I. Introduction. Prospects of Using the “Method of Microseismic Sounding”

In the mosaic of the complex geomorphological and tectonic blocking of the Greater Caucasus, prone to varying levels of lateral and vertical amplitude movements without a clear perception of the overall structure as a single geological structure, it is difficult to fully understand its modern structural and tectonic architecture. The high scientific and applied interest in deep investigations in modern conditions and in the past is the need to establish the features of the formation and development of the main structures of the Greater Caucasus, the reconstruction of the geodynamic situation in the collision zone, the morphology definition of the roof and the base of the consolidated crust, stipulating creation of the modern deep model of the Central Caucasus. This makes it possible to establish a hereditary spatial-temporal relationship with near-surface tectonic blocks, metallogenic zones, ore nodes and ore-controlling structures of tectonic nature of higher orders.

In order to solve this most important task, it is necessary to establish deep features of the roof of the consolidated foundation, a full study of which is possible using expensive modifications of seismic prospecting – DSS (Deep Seismic

Sounding), DSP (Deep Seismic Profiling), and ECWM (Earthquake Converted-Wave Method). Methods based on alternative physical fields, such as gravimetry, magnetometry, pulsed electromagnetic fields (the method of telluric profiling, the method of telluric sounding, transient electromagnetic sounding, inductive sounding), are usually inefficient and inaccurate in highlands to the difficulty of providing an appropriate hypsometric data base and their accounting. In addition, the use of appropriate hardware complexes of such methods is often expensive and inaccessible to ordinary scientific and scientific-production organizations. Moreover, in the current socio-political situation, carrying out some methods of “active” seismic prospecting is fraught with the danger of unjustified loss of control over high-explosive substances.

In these conditions the development and use of the so-called “passive” seismic prospecting, based on the use of amplitude-frequency characteristics of comprehensive microseismic motions increases the efficiency, mobility and accessibility of research, significantly reducing the cost of solving deep problems. The resonating of any physical body into a specific radiating standard frequency spectrum, inherent only in the physical parameters of a given body (dimensions, density, elastic properties, etc.), is used in engineering seismology to substantiate differentiation of kinds and types of soils, search for oil deposits, water deposits and etc.

The spectral features of ore deposits, depending on the composition and ores type of certain geological strata of the section, depending on lithology, watering, fracturing, mineral composition, will also be characterized to a certain extent by individual indicators, the correct interpretation of which will eventually allow the identification of many geological objects based on the widespread use of microseismic profiling or sensing.

The microseismic background of the Earth at the observation point is a superposition of a multitude of vibrations generated as natural causes (echoes of remote earthquakes, local micro earthquakes, surface noises, the action of earth tides, storm microseisms, ionospheric phenomena, weather phenomena - rain, hail, strong wind), so technogenic sources (moving vehicles, operation of machinery and mechanics). The use of MMS to isolate the deep structural-tectonic features of the section is due to the presence of a wide range of frequencies of microseismic vibrations and the non-uniform dependence of the intensity distribution on the vibration frequency [1].

Such physical parameter as seismic noise is used in seismic microzonation for taxonomic differentiation of soils, and in seismology in earthquake prognosis. The parameter is also used for lithology differentiation of the upper part of the crustal section, the detection of anomalous zones at depths of up to 10 km and determination of their connection with the tectonic structure and the assessment of the geological environment response to changes in the geodynamic situation [2].

A well-known phenomenon in the form of the presence of anomalies in the low-frequency part of the spectrum of natural microseisms over oil and gas deposits is based on the generation of anomalous microseisms by the oil and gas deposit or on the mechanisms of filtering the microseismic background by a geological environment that includes the oil and gas deposit as reflecting boundary.

One of the main features of a low-frequency anomaly that clearly distinguishes it from random noise spectral maxima is spatial stability, the formation of a meaningful spatial picture characterizing a certain linear anomaly or geometric figure. On the basis of this property of a low-frequency anomaly, series of groupings of parameter values are formed.

The use of seismic noise as a reliable tool in the investigation of earth interior is based on their spatial variability and confinement to zones of tectonic disturbances, geodynamic activity and epicentral zones of potential earthquake sources. The parameters of seismic noise are also widely used in the study of the geodynamic characteristics of the medium and the identification of active tectonic zones [3].

At the stage of modern development of the MMS method [4] it is considered that the informative parameter (useful signal) in the MMS is the distortion of the amplitude field when it interacts with the velocity inhomogeneities of the geological section. The shape and occurrence depth of the inhomogeneity are estimated based on an analysis of the distortion distribution at the surface and the frequency at which this distortion appears. There is a certain critical frequency f of the Rayleigh wave, for which the distortions (shapes, amplitudes, frequencies) of the inhomogeneity lying at a depth H are maximal in comparison with analogous inhomogeneities at other depths (the penetration depth of the Rayleigh wave depends on the wavelength). The indicated frequency f is related to the depth H and the corresponding velocity of the fundamental mode of the Rayleigh wave $V_R(f)$ through the relation: $H \approx 0.4 \cdot V_R(f)/f$. This conclusion, obtained experimentally and theoretically, has been known for a long time. In the MMS method, this ratio is used to solve the inverse procedure for estimating the occurrence depth of an unknown inhomogeneity that forms the amplitude distortions observed at the frequency f. The phase information is not used, although, in our opinion, this would allow the method to be expanded.

The authors of the computer program for processing data of MMS observations based on analysis of the results of conducted numerical experiments concluded that the resolving power of the method when reconstructing the image horizontally can be estimated as (0.25-0.3) λ (where λ is the wavelength), and vertically - (0.3-0.5) λ [5]. This means that objects that are lateral and vertical in size correspond to the detection by means of the method and correspond to the occurrence depth (as it is known $\lambda = V_R(f)/f$). Thus, it turns out that knowing the basic mode of a microseismic wave that resonates with an object, we can determine its position with an permissible error.

The procedure for carrying out the experimental measurements is reduced to the accumulation of the power spectrum of the microseismic signal for some time, depending on the seismic background of the investigated area. In active geodynamic regions, the observation time is 2-3 hours.

Analysis of spectral amplitudes makes it possible to distinguish in the spectra intervals or areas of three types (low-noise, medium noisy and very noisy), the subsequent processing of which, according to a special program, allows quantitative and qualitative assessment of lithologic and structural-tectonic objects.

II. Studies with the Help of MMS and Experimental Parametric Sections

The Greater Caucasus and its meganticlinorium are by now a territory that has been sufficiently well studied in the mapping plan for the depth available to modern technical means. The good exposure of bedrock in the mountainous and high-mountainous parts of the Central Caucasus and the state of exploration of numerous boreholes in applied purposes of foothill and flat areas give grounds to qualify certain intervals as parametric [6]. At the same time, the detailing and feasibility of the deep features of the Central Caucasus, which determines the level and effect of seismic hazard, still needs development [7]. This, unfortunately, was facilitated by the cessation from the end of the 1980s of works on the “System of regional study of the crust and upper mantle along the geotraverses laid through the drilling areas of deep and super deep boreholes” adopted in 1972 [8].

The workers of the GPI VSC RAS conducted field observations with high-precision broadband geophones of Lennartz Electronic GmbH (T = 20s) on the most interesting sections of the region, the results of which were subsequently processed by the MMS method. Deep features of geological sections of the planned profiles could confirm or disprove a number of assumptions and hypotheses of geologists and geophysicists.

Due to the fact that the administrative-territorial borders are derived from the mountainous structure of the Greater Caucasus, and not vice versa, one profile passing through the Roki tunnel, as a regional profile, has emerged across the entire Central Caucasus from the northern boundary of the Ossetian plain (Elhotovo village) in RNO-Alania (in the north) to Tskhinvali RSO (in the south) along the line of the federal highway “Kavkaz”. The length of the profile of “Elhotovo-Tskhinvali” is 152 km (Fig. 1). This profile was planned, if not for the final, then at least for partial confirmation of the underlaying or thrusting nature of the interface between the Southern microplate and the Scythian continental plate.

The second profile was carried out in the structure of the Balkar-Digor tectonic uplift - in the Sadon-Unalsk horst - controlling virtually all known hydrothermal deposits in the region. The profile oriented in latitudinal direction lay in the plane across the proposed stretch in this section of the Ardon deep fault, having a submeridional strike [9; 10].

The observation step on both profiles was 500 m. The known lead-zinc deposits of Verkhny Zgid, Sadon, Dzhimidon are located on the profile line.

Fig. 1. The position of the MMS profile in the plan: I-I profile Tskhinvali-Elhotovo; II-II - profile of V. Zgid-Dzhimidon

Fig. 2 shows the velocity model of the geological section along the observation profile V. Zgid-Dzhimidon. Two local objects are distinctly distinguished on the velocity model, which differ sharply from the enclosing media. The dimensions of objects vertically exceed the horizontal dimensions, while both objects are almost equal. The length of the low-velocity object as a whole in the lateral is about 10-12 km and can reflect the zone of the Ardon deep fault in this area. The vertical range of the anomalously expressed object is 17-18 km.

The eastern boundary of the structure passes through the village of Nizhny Unal, and its western border passes 2.6 km upstream of the Sadon River from its confluence with the Ardon River. The upper part of the zone to a depth of 4.5 km is more heterogeneous and processed by tectonic movements and deformations than the deep horizons. At depths of 4.5-5.3 km between the branches of the fault, a relic of a slightly modified high-velocity environment is noted.

The velocity model of the regional section along the line of observations from Elkhotovo to Tskhinval is shown in Fig. 3. The considered distribution of the relative velocity characteristic is of interest to depths of 30 km in the south and 50 km in the north. The section below these depths has a low confidence level and is not considered here. The tunnel section with a length of 3730 m on the section is indicated by the missed measurements on the profile line due to heavy interference because of traffic.

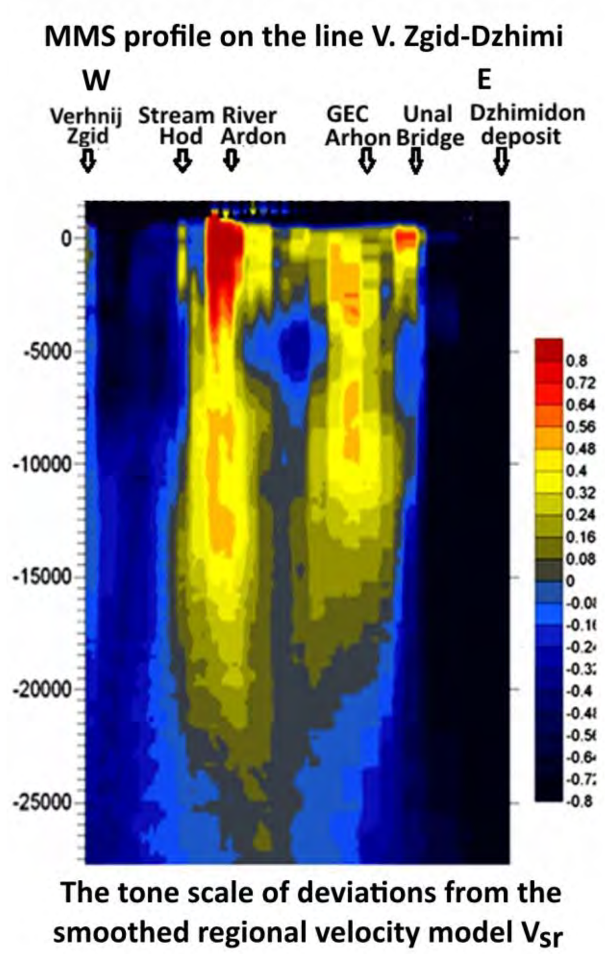


Fig. 2. A high-velocity model of the geological section in the interpretation of MMS.

A joint analysis of the velocity model along the profile of Tskhinvali-Elhotovo (Fig. 3) and the tectonic map of the region makes it possible to make a number of statements. For example, access to the medium-velocity medium in the interval of observation points 108-119 and further to the south, including the interval of the tunnel, to picket 122 was conducted along the strike of a homogeneous flysch, and observations at points 101-108 were conducted in the zone of influence of the Tib fault, the thickness of which is not less than 3.0 km.

The zone of influence of the Adaikom-Kazbek fault is reflected by the velocity model under observation points 134-141. Tectonic processing of the zone of this fault is exposed to a depth of no more than 1.0 km, in contrast to the zone of the Tib fault, representing a weakened cone-expanding zone to depths of the order of 28 km. It is not excluded that a viscous substrate is possible at depths of 7-8 km in the zone of the Tib fault. According to the spatial features of the Tib and Adaikom-Kazbek faults, one can assume their steep dip.

Velocity medium in the interval of points 41-133, having a stable sickness of 8-10 km order is described in detail [11-13]. It should be noted that in positioning of the Main thrust, the authors, in our opinion, admit inaccuracy. The spatial position of the Main thrust corresponds to observation points 124-128, the velocity model under which is identical to the Adaikom-Kazbek zone.

However, one cannot agree with the statement of the authors [4] that “a high-velocity volume is located above the horizontal roof, emerging on the surface in the form of granites, crystalline and metamorphic slates of the Main Ridge”. Indeed, if this refers to the interval of points 133-159, then it should be noted that the site is located on the Southern slope, where the flysch thick dominates. Moreover, such statement should be attributed to a high-velocity medium of stable thickness (8-10 km), located north of the Adaikom-Kazbek, and, of course, the Main thrust. This distinctly prominent object is spatially located in the profile interval between city Alagir and the Adaikom-Kazbek fault, although its not so distinct continuation indeed continues to the Southern slope.

The distribution of the linear size of a high-velocity object begins from the southern boundary of the North Caucasian marginal trough (latitude of city Alagir) and includes the geological structures of the Digora-Osetian zone and the zone of the Main Ridge (Kasar and Makersk subzones). Without going into details of the velocity section below 30 km, we note a low-velocity object underlying a high-velocity and relatively shifted high-velocity object 6 km to the south and confidently traced to the southern boundary of the Tib fault.

It should be noted that the capabilities of the MMS method, in our opinion, can also be quite successfully used in solving other fundamental and scientific-practical problems in the mountain region [14-17].

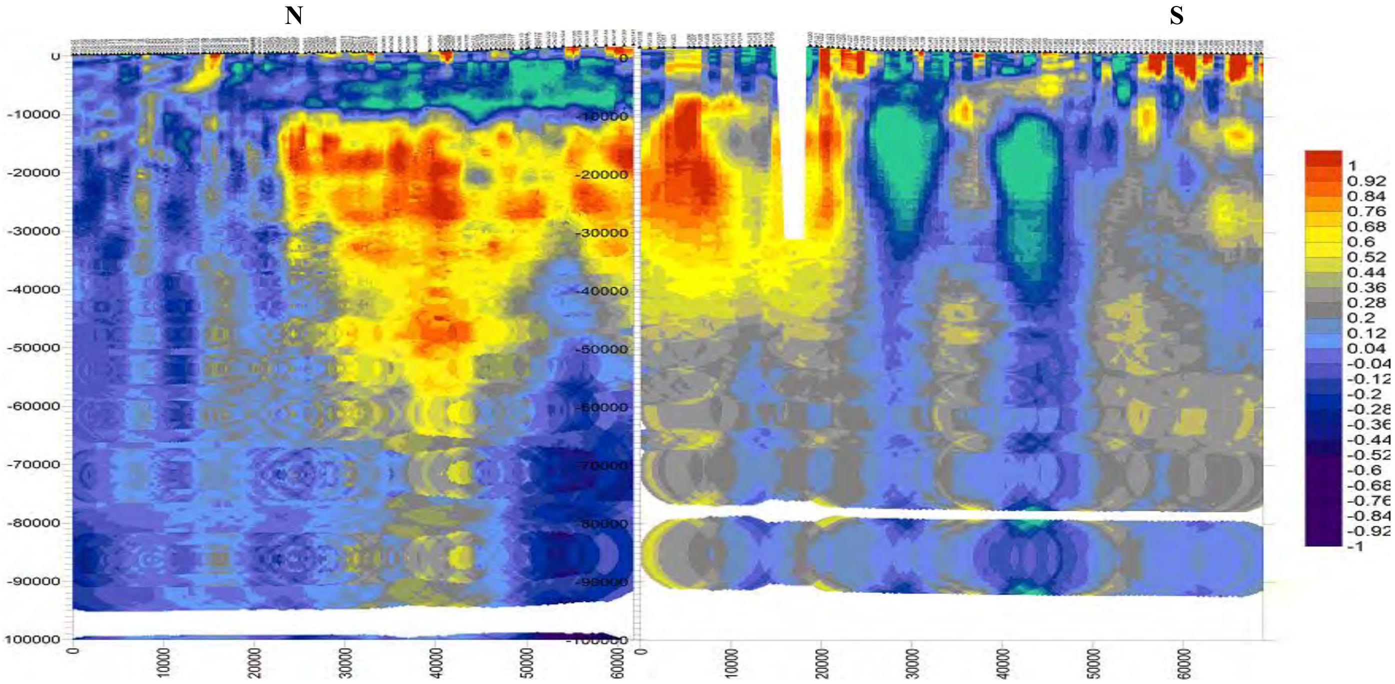
III. Conclusions

The results of the MMS investigations have become the basis for the formation of a large amount of information, the joint analysis of which with the available geological, structural-tectonic and topographical data allows us to find the correlation between the anomalous deviations of the velocity model and real geological structures.

Based on the results of MMS investigations on the “V. Zgid-Dzhimidon deposit”, a low-velocity environment with a swing in the laterals of about 12.5 km and a vertical of at least 15 km is confidently allocated. It is tied to the Ardon deep fault, crossed across the observation profile, which is the first instrumental confirmation of the anomalous heterogeneity of the fault zone.

The main anomalous objects of the high-velocity model of the regional MMS profile “Elhotovo-Tskhinvali” is a high-velocity horizontal environment, over 30km in length and 8-10 km in thickness, underlain by its low-velocity medium, extending from north to south by more than 45 km and having a vertical sweep of up to 40 km. There is also an accurate mapping in the section of the Tib fault, as the main tectonic structure in the Adaikom-Kazbek group, which responded to the velocity model. Despite some remarks, this makes it possible to consider the MMS method as a quite sufficient instrumental structural-mapping method.

MMS profile along the line Elhotovo-Tskhinvali



The tone scale of deviations from the smoothed regional velocity model V_{SR}

Fig. 3. A high-velocity model of the geological section in the interpretation of MMS

The obtained results of the experimental application of MMS are encouraging, and the uselessness of the expensive hardware complex and equipment in combination with efficiency, maneuverability and cheapness make the method an indispensable tool support not only for structural profile investigations, but also for deep-seated ore deposits. For it, the peculiarity of the reaction to microseismic vibrations will be eventually revealed.

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