INVESTIGATIONS OF OIL POLLUTION WITH ELECTRICAL PROSPECTING METHODS

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The most widespread source of pollution in Russia is the oil pollution. It occurs at all stages of oil production, transportation and processing. Outflows, proceeding during decades result to formation of oil secondary deposits. In a near-surface zone, oil pollution becomes especially chemically active and reacts with geological environment, that results in the anomalies of various geophysical methods: SP, IP, GPR and resistivity. The oil pollution is an unusual object due to its ability to oxidation and mobility. The pollution causes processes, occurring with the speed, differed from natural geological processes. Changes of rock properties, caused by oil pollution are inconsistent. A priory, for example, the oil is an isolator, but frequently it causes anomalies of lowered resistivity.

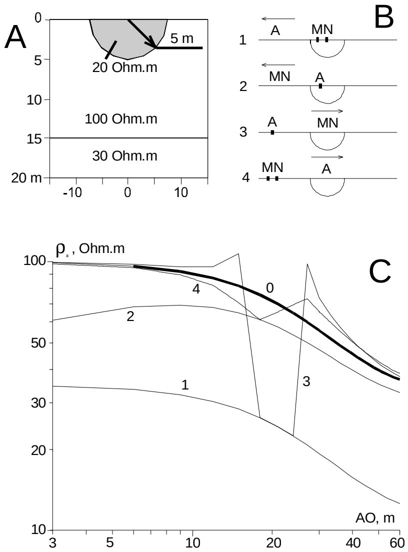

Fig.1. Example of NSI (A), types of survey (B) and sounding curves (C)

For engineering and environmental studies with electrical methods in urban areas (including pollution studies) the main problem is the influence of geological noise. Upper part of cross-section includes many near-surface inhomogeneities (NSI), caused with artificial ground, asphalt cover, trenches, cables, tubes, etc. These inhomogeneities create strong distortions and influence like "the broken glass", preventing from clear seeing deep objects. NSI distorting influence can be canceled by the application of total electric sounding (TES) technology, developed in MSU. In TES technology we apply two-sided pole-dipole array with step of distance growth equal to step between VES sites along profile. NSI creates distortions of four different types (fig.1C), when movable (single or dipole) element crosses the NSI, or unmovable (single or dipole) element is placed in NSI limits (fig.1B). Some distortions of sounding curves are conformable (fig.1C, 1-2), whereas others are non-conformable (fig. 1C, 3-4). On apparent resistivity cross-section distortions display as vertical and inclined strip zones (fig.2,3). For different types of array (Pole-dipole, pole-pole, Schlumberger, Wenner, dipole-dipole, etc.) distortions are different (fig.3). For several NSI (fig.3, 3) interference of distortions appears. We developed software for canceling such distortions. The algorithm of median polishing was offered by J.W.Tukey (1981), and after modification made by E.V.Pervago was applied for processing of Total Electrical Sounding (TES) data. The algorithm's operation is based on regularity of distortion effects and it allows to cancel effectively these effects on apparent resistivity pseudo-cross-section. J.W.Tukey described processing algorithm for data, given in the table as following: at the first step - counting and subtracting median value for each column; at the second step - counting and subtracting median value for every row. Then the 1st and 2nd steps repeat several times.

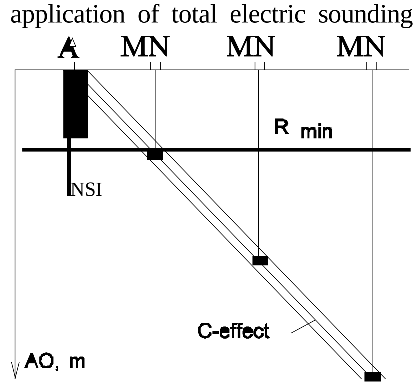

Fig.2. The scheme of non-conformable distorting effect's origin for pole-dipole array.

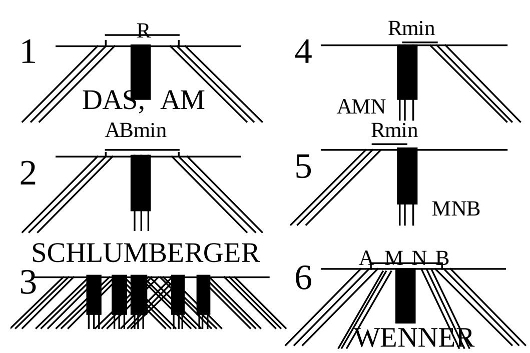

Fig.3. The schemes of distorting effects appearance on ρ_a cross-sections for different arrays.

We present soundings data as the table of ρ_a logarithms, where each spacing corresponds to a row, and each sounding site - to a column. The effect of horizontally layered medium in such table will be displayed simultaneously for all sites, conformable distortion will be displayed simultaneously on all spacings, and non-conformable distortion - as lines, inclined under 45° or another angle to the left or to the right, depending on type of array and sounding technology. To this table we apply algorithm of median polishing, but in addition to rows and columns we shall also include in processing inclined lines, corresponding to non-conformable distortion. The result of algorithm operation is the decomposition of an initial field into several components, connected with: a) position of movable and unmovable electrodes; b) horizontally layered medium and c) some rests. After decomposition each component is filtered from high-frequency noise, connected basically with near-surface inhomogeneities and errors of measurements. Parameters of filtering (width of smoothing window) are get out by user, depending on survey conditions and geological structure. At the last stage the reconstructing process is applied - the smoothed components are united back into ρ_a field.

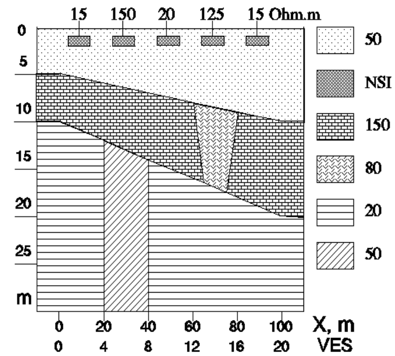

Fig.4. Geoelectrical model with layering, deep objects and NSI.

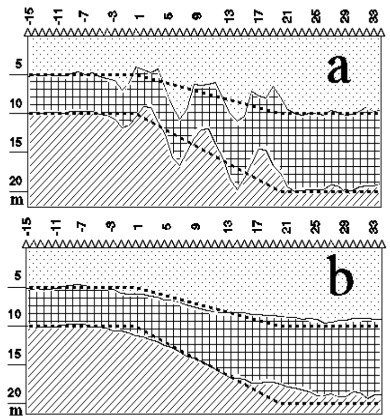

Fig.5. Interpretation results for the model from fig.4 with filtering geological noise (b) and without it (a).

Thus, the technology of processing with the program Median allows to reveal effects of distortions caused by near-surface inhomogeneities and to remove them, to see effects from deep inhomogeneous objects and to separate the influence of horizontally layered medium. Layered medium can be subjected to quantitative 1D interpretation. Deep objects can be interpreted with the help of 2D forward problem account, including inhomogeneities and layered medium.

The role of NSI or geological noise is shown on fig.4-6. Canceling geological noise allows to trace boundaries with greater accuracy (fig.5b) and smaller fitting error (fig.6b). That is true for field data also.

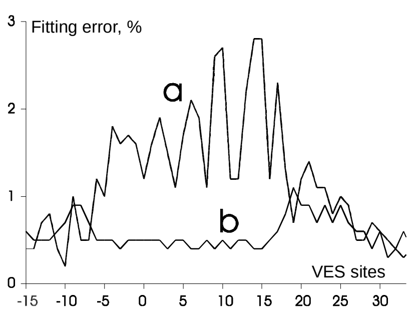

Fig.6. Fitting errors for interpretation results from fig.5 with filtering geological noise (b) and without it (a).

Electrical survey in urban regions can be fulfilled without galvanic contacts with the ground. GPR (georadar) is very useful instrument for that. GPR has small penetration depth and problems with depth estimation. We use GPR together with electrical sounding, which gives reliable depths and has penetration deeper than GPR. At small depth GPR has higher detaility. Traditional electrical sounding needs electrode grounding. In Russia during more than 40 years a non-contact resistivity technology is used. An instrumentation for such measurements is produced in Petersburg. ERA-V instrument can operate without galvanic contacts at frequency 5 and 600 Hz. At 600 Hz we can use non-contact current and measuring lines, at 5 Hz only measuring lines. This modification has two main advantages. 1. In theory the result of measurement with alternating current can be equivalent to DC resistivity, when the dependence of measurements from working frequency is absent. Thus, maximal distance for frequency-independent area is the function of the earth resistivity and working frequency. (it is determined by the near zone condition). On frequency 625 Hz for example, when ρ=1 Ohm.m, this zone limit is at r=10 m, when ρ=10 Ohm.m, it exist up to r=32 m, when ρ=100 Ohm.m, r=100 m. 2. In practice non-contact survey is similar to EM methods with their simplicity in field operations. Electrical sounding results shown on fig.9-10 were measured with non-contact resistivity technology.

Ecological studies of oil pollution on the department of geophysics MSU were carried out for several years, including town Noginsk (1993), on oil refining factories in Moscow (1994), town N (1994-96) and town S (1995-96). The depth of polluted zone was from 0.5 up to 50 m and the time of its formations from several months till 50 years. A typical example is the Moscow oil refining factory in Kapotnya.

On the factory in Kapotnya oil polluted zone is placed at the depth of several meters. For its study a complex of methods VES, SP, IP, GPR was applied (fig.7). A geological situation is typical for Moscow region. On depth about 10 m the waterproof layer of Jurassic clay is situated, and higher of it is sand, the lower part of which is filled with water. The groundwater level is on the depth about 1.5 m. On that boundary the oil pollution is placed, being existed constantly for a long time. The top part of a cross-section with the thickness of 2-3 m is an artificial ground, which is typical for urban areas and has extremely changeable properties. Just in this layer several anomalous zones with intensive oil pollution are located. These zones are confidently mapped on IP, SP, GPR and resistivity methods' data. Polluted object is appeared similar to ore body, because it shows low resistivity, negative SP potential, high IP response. GPR shows low dielectric parameters in polluted area.

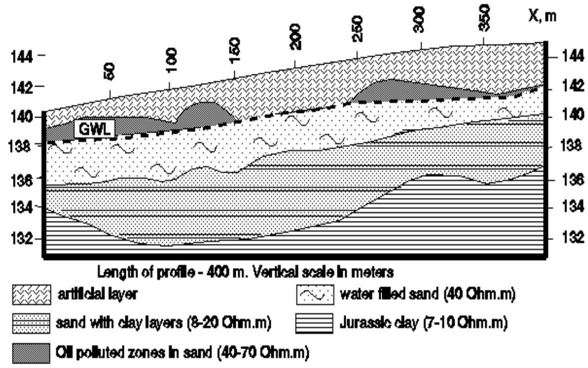

Fig.7. Results of electrical survey above shallow-depth oil pollution in Kapotnja.

Such low-resistive anomalies in the areas of oil pollution were found also by H.Vanhala (Finland)(1994, 1997). Why does oil pollution seem to be low resistive object? In accordance with investigations some scientists: Bailey N.J.L. (1973,1981), Evans C.R. (1977,1981), Rogers M.A. (1973, 1977), Dostalek M. (1975) oil-transforming bacteria are probably responsible for that. In upper part of the cross-section bacteria are very active, they transform upper layer of the oil film into some acids. Acids react with rocks and iron ions in water and result in high groundwater conductivity, karst processes and pyrite creation. Pyrite gives increased IP response.

The GPR data were interpreted independently, and other methods -- in integration. The GPR data only after processing were possible to reveal layered structure and the sites of pollution. The total electrical sounding -- TES was used as a structural method for tracing ground-water level (GWL) and a clayey basement. With the help of an integrated parameter of pollution it became possible to find out its distribution in the area and on the depth. We used a priory information about the thickness and exact places of pollution at the reference profile. To characterize pollution we applied such parameters like the relative thickness of a polluted layer and its bottom's depth. These values were estimated on the regression dependence between these two parameters and some anomalous values of the measured geophysical fields and their dispersions (fig.8). For localization of pollution in plan IP method gave the maximum contribution, about 80% of the all information. SP and resistivity gave less information. GPR information gave wider polluted areas than geological data. We suppose that GPR could see the whole area of pollution whereas the direct geological methods could see only the strongest pollution.

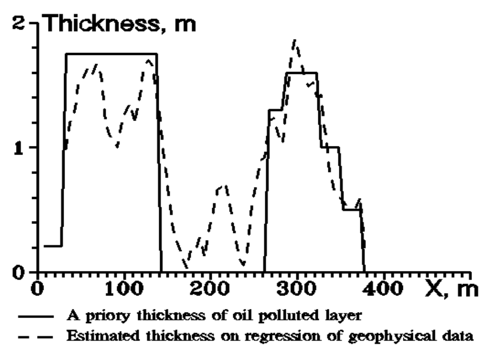

Fig.8. Results of polluted layer thickness estimation on regression with geophysical data.

In town N the study of territory around the oil refining factory was carried out for estimating ecological consequences of this factory activity. In upper part of a geological cross-section on depths up to 50 m during several decades of factory activity in the result of oil leakage from pipelines and storehouses the significant amount of oil

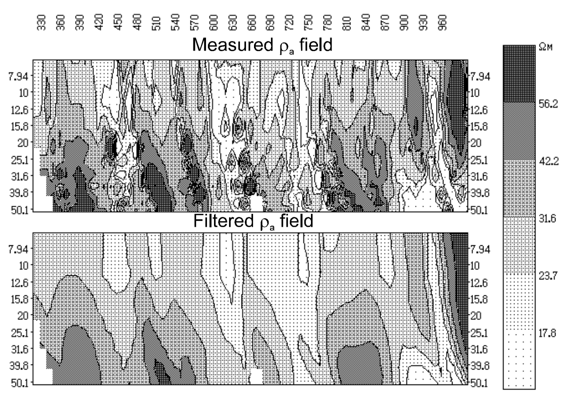

Fig.9. Town N, ρ_a field measured with non-contact electrical sounding technology before and after canceling geological noise

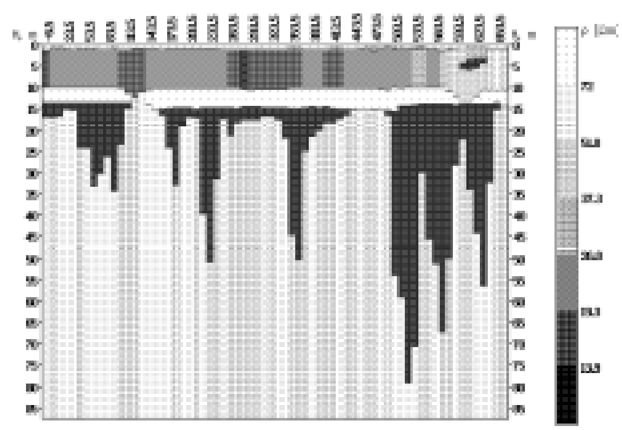
Fig.10. Results of TES interpretation with low resistive traces of oil pollution for data from fig.9.

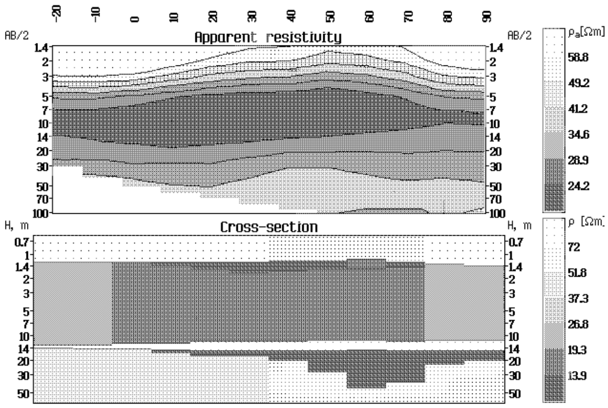

Fig.11. Results of TES interpretation over zone of oil pollution, town N, profile 13

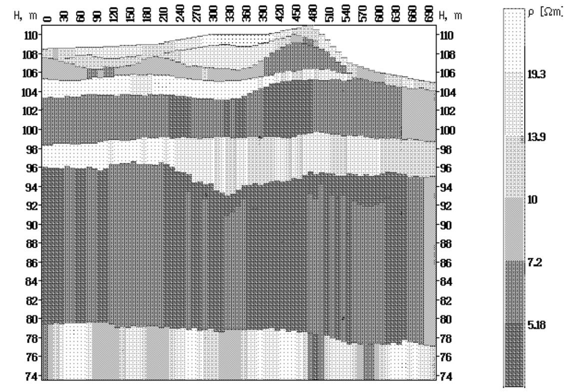

Fig.12. Town S. Profile 4. VES results with traces of oil pollution.

products was collected. That can be considered as a rich secondary oil deposit. The pollution spread to significant distance (several km), despite extremely low values of rock permeability.

The geophysical study in town N was carried out by VES in several stages due to great area for investigation. Each stage included several VES profiles with about 200 VES sites measured on TES (the total electrical sounding) technology with canceling geological noise. The study of the area (taking into account a priory data and results of drilling) has allowed to reveal layered structure of a cross-section and to find out paleovalleys, filled with loose deposits. The system of such paleovalleys serves the most probable ways of oil pollution spreading at significant distances. This example shows that not only background cross-section, but some anomalous features in it play the important role in pollution state and movement. TES is the main method for such pollution study.

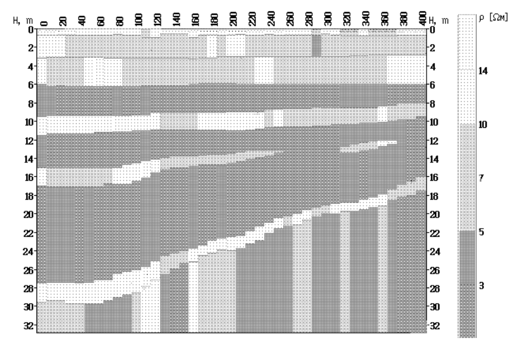

Fig.13. Town S. VES results with traces of oil pollution on profile 2.

Town S. is not far from town N., and oil-refining factory is quite similar. Pollution on the surface is the same or even stronger, but secondary oil deposit is not found yet. Background cross-section is sandy with thin clay layers. We found traces of pollution spreading downward, noticeable on TES method data, but not oil deposits.

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