NEW STEP IN ANISOTROPY STUDIES: ARROW-TYPE ARRAY.

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ABSTRACT

Anisotropy of rocks' resistivity is a weak enough phenomenon in comparison with inhomogeneity influence. That is why we are trying to find an array being the most sensitive to anisotropy and to develop field survey and data processing technology for anisotropy and inhomogeneity influence estimation and separation. New step in this study gives arrow-type array.

At study of anisotropic media with the help of azimuthal resistivity survey prof. A.S.Semenov has recommended to apply dipole equatorial array or any other non-linear array. Arrays with electrodes' position not in one line (non-linear arrays) have higher sensitivity to anisotropy in comparison with linear arrays (Schlumberger, AM, AMN). For separation of anisotropy and inhomogeneity influence we have offered asymmetrical rotation of array and analysis of azimuthal diagrams' spectrum (Bolshakov et al., 1997). Even harmonics of spectrum are the result of anisotropy influence, while odd harmonics are the result of inhomogeneity influence. Dipole equatorial array is not so convenient for asymmetrical rotation, at which one dipole is gone along a circle's arch, while other dipole turns around its center.

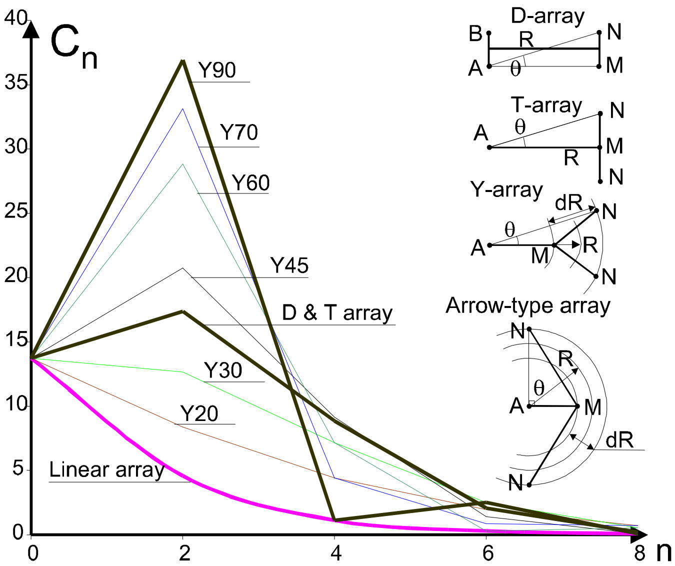

Fig.1. Spectra of arrays. Curves are marked with angle θ value.

For such rotation it is better to use array with one current electrode, for example T-array (fig.1). Only one current electrode is used, the second one is in infinity. Sensitivity of D-array and T-array is the more, the greater ratio R/MN is. But with R/MN growth the level of measured signal decreases and becomes much lower, than for Schlumberger array.

In attempt to connect advantages D(T) and Schlumberger arrays and simultaneously to overcome their lacks the generalized Y-array was invented

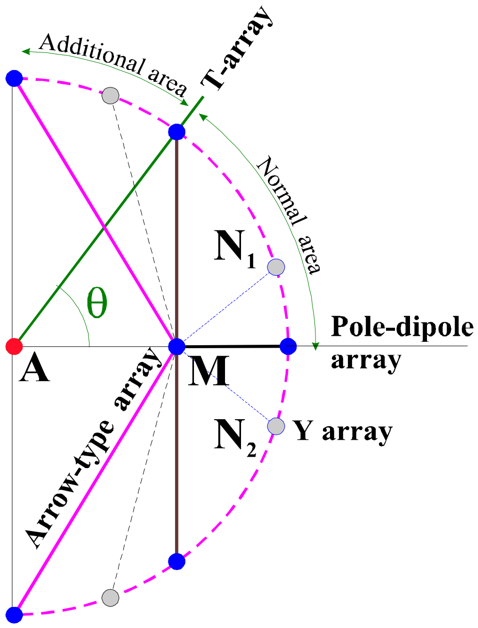

Fig.2. Variants of Y array as functions of angle θ.

(fig.2). As T - array it has two MN lines with one common M electrode. These two MN lines go under equal angles from M electrode position symmetrically from AM direction. But this array has one important feature - two MN lines can influence at level of signal while the radiuses' difference (between A and M, A and N), and on sensitivity to an anisotropy depends on angle between AM and AN azimuths. Really, by joining two MN "wings" we receive low sensitive pole-dipole array, and by flinging them we receive T-array, which is more sensitive. It can be shown with the help of spectra (fig.1). But it has appeared, that the wings can be bent in additional area (fig.2), and in this case sensitivity to an anisotropy continues to grow. So arrow-type array (AT) was revealed. Except higher sensitivity to an anisotropy, it has some interesting and useful properties.

1. It was proved theoretically that the signals in both MN lines of arrow-type array above anisotropic media are completely identical. For T and Y arrays it is not so. This property allows above anisotropic media to measure signal only in one MN line. The measurements in two MN lines help to distinguish inhomogeneous medium from anisotropic one by taking into account the difference of two signals. In inhomogeneous medium the signals in two MN lines are different (fig.3, C) and this difference, like O/E ratio, characterizes a degree of medium inhomogeneity.

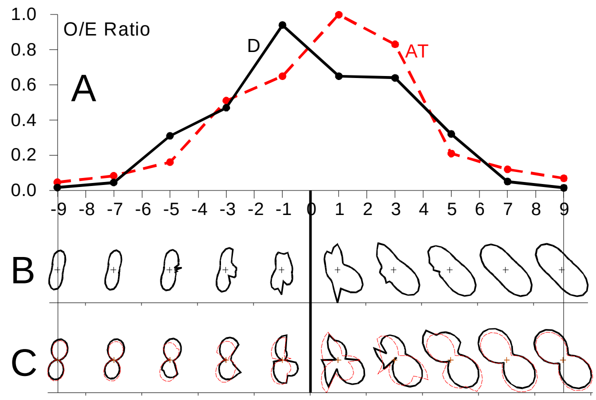

Fig.3. Azimuthal diagrams for dipole (B) and AT (C) arrays and O/E ratio (A) near vertical contact of two anisotropic media.

2. The spectrum of arrow-type array appears very narrow, the harmonics after fourth one can be neglected, and consequently for azimuthal survey the step in 45° is sufficient. The step size is similar to linear array, but sensitivity is higher, than for dipole array (fig.5.). That is because two MN lines are at azimuths with 90° difference. The periodicity of the second harmonic is 180°, i.e. its amplitude for the given array will be maximal, whereas the periodicity of the fourth harmonic is 90° and its amplitude for the given array will be equal to zero. Fourth, eight and some other harmonics are exactly equal to zero, when the radiuses AM and AN are identical. But the possibility of apparent resistivity calculation in this case disappears. If we make these distances different, the fourth harmonic will not be zero, though also small. Arrow-type array is rather convenient for field survey. The scheme of electrodes positions for an azimuth step in 30° is shown in fig.4.

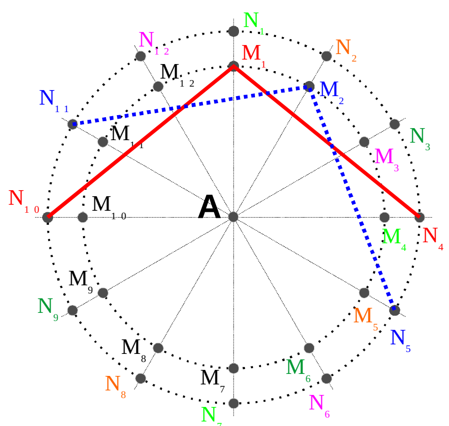

Fig.4. Positions of measuring electrodes for arrow-type array with 30° azimuth step.

Fig.5 shows sensitivity graphs λ_a=f(λ) for linear, dipole equatorial and arrow-type arrays. λ_a value is calculated as axis ratio. This ratio for linear array is exactly equal to λ value. For dipole equatorial array λ_a is proportional to λ^5. For arrow-type array sensitivity is much higher (for small $\lambda < 1.3$). Break in this graph after $\lambda > 1.3$ is connected with appearance of additional negative petals on azimuthal diagram. Sensitivity of array is kept but calculation of λ_a as axis ratio is not valid more. We use another formula for fast calculation of anisotropy factor λ_{eff} to avoid this formal problem: $\lambda_{eff}=1+(\rho max-\rho min) / \rho max$ (fig.6). Full interpretation is made with spectral approach.

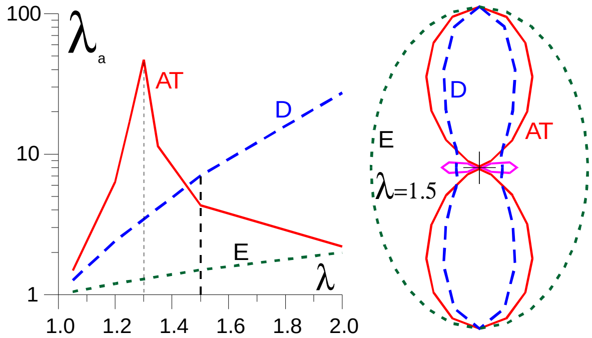

Fig.5. Comparison of linear, dipole equatorial and arrow-type arrays as axis ratio $\lambda_a=f(\lambda)$ and azimuthal diagrams for $\lambda=1.5$.

3. The large axis of ρ_a ellipse is guided along strike of anisotropic formation, when reference azimuth on the nearest measuring electrode will be taken. For that the distance to M electrode (the arrow point), should be smaller, than distances to N electrodes.

The arrow-type array opportunities were checked up with Anis2lw program for two-layer model with arbitrary anisotropy orientation in each layer. In fig.7 the results of comparison of arrow-type and dipole equatorial arrays are submitted. Two-layered model with isotropic top layer with resistivity 400 Ohm.m and thickness 1 m

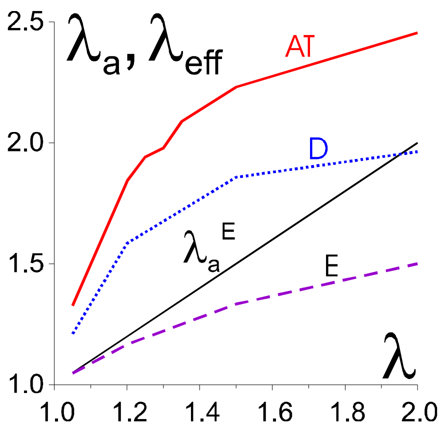

Fig.6. New anisotropy factor λ_{eff} in comparison with old one λ_a^E.

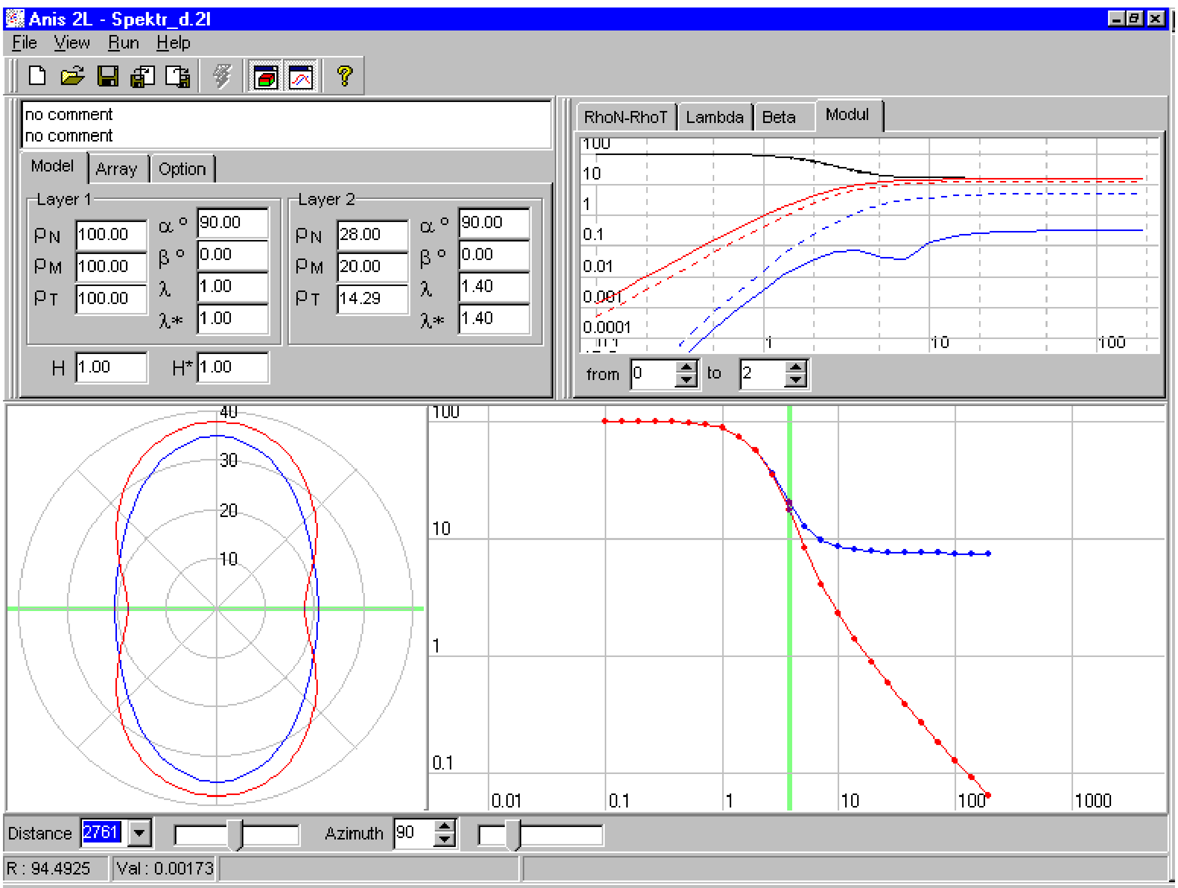

Fig.7. Comparison of D and arrow-type arrays as azimuthal diagrams, VES curves and spectral harmonics.

and anisotropic basement with λ = 1.4, ρ_m = 50 Ohm.m was used. The azimuthal diagrams at this figure are submitted for relative spacing R/h = 3. VES curves are displayed for an azimuth across the strike. Graphs of harmonics at the upper right corner of fig.7 are submitted. The zero harmonics for two arrays coincide, the second harmonics are similar, but that for arrow-type array are a bit greater, and the fourth harmonic is essentially less for AT array, than for D-array. This model approximately corresponds to the situation on plateau Patil in Crimea (Bolshakov et al., 1997), where tavric basement have strong anisotropy. With the help of nonlinear arrays it is possible to estimate its anisotropy even under sandstone layer covering tavric sediments. Before we applied dipole equatorial array. Now we plan to check AT array.

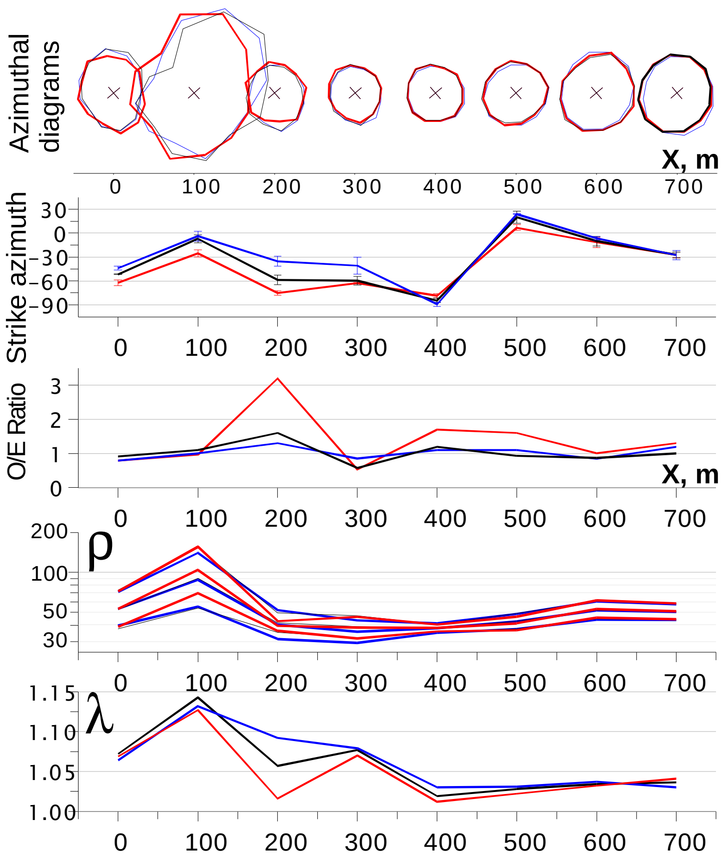

Fig.8. Results of azimuthal resistivity survey of glacial sediments.

After checking high sensitivity of arrow-type array it is possible to apply it for media with weak anisotropy.

Near Alexandrovka place in 200 km from Moscow glacial sediments are widespread. In connection with their origin from horizontal flows it is possible to assume presence of a weak anisotropy in such sediments. Therefore we tried to study their anisotropy with the help of Y-array. The results are shown in fig.8, azimuthal diagrams are displayed here in three forms: for each MN line and as average diagram. Below there are graphs of some interpretational parameters along profile: strike azimuths, ratio of odd to even harmonics (Bolshakov et al., 1997). These allow to estimate relative influence of inhomogeneity and anisotropy when anisotropy of glacial sediments is about λ = 1.05.

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