Program for two-dimensional interpretation of data obtained by resistivity and induced polarization methods

(land, borehole and marine variants)

ZONDRES2D

Program functionality

«ZONDRES2D» is computer program for 2.5D interpretation of electrotomography profile data obtained by resistivity method, induced polarization or excitation-at-the-mass method. Friendly interface and ample opportunities for data presentation allows solving assigned problem with maximum efficiency.

Finite-element method as mathematical apparatus is used to solve forward and inverse problem. It gives best results in comparison with mesh methods [Dey&Morrison, 1979; Lowry, 1989].

For point source field modeling medium is divided into triangle cells grid with different resistivity. Potential behavior inside grid cell is approximated by linear basis function.

$$N(x,z)=\frac{(a+bx+cz)}{2A} \qquad (1)$$

Point source field has 3D structure in 2D medium. Using Fourier transform it is possible to transfer problem solving to spatial frequency domain.

$$\frac{\partial}{\partial x}\left(\sigma\frac{\partial\phi}{\partial x}\right)+\frac{\partial}{\partial z}\left(\sigma\frac{\partial\phi}{\partial z}\right)-\lambda^2\sigma\phi=-I\delta(x)\delta(z) \qquad (2)$$

$$\frac{\partial\phi}{\partial n}+\nu\cdot\phi=0 \qquad (3)$$

where ϕ – spectral potential value, λ – spatial frequency, I - current strength value, σ – medium electroconductivity, δ - Dirac delta function.

Following solution for spatial frequency set and usage of inverse Fourier transform for obtained spectral potential values gives desired values of point source potential in grid nodes [Xu, 2000].

$$U(x,y,z)=\frac{2}{\pi}\int_0^{\infty}\phi(x,\lambda,z)\cos(\lambda\cdot y)d\lambda \qquad (4)$$

Least squares method with regularization is used for inverse problem solution (inversion). Regularization increases solution stability and allows receiving smoother resistivity and potential distribution [Constable, 1987].

$$\left(A^TW^TWA+\mu C^TRC\right)\Delta m=A^TW^T\Delta f-\mu C^TRCm \qquad (5)$$

where A – the Jacobian matrix of partial derivatives, C – smoothing operator, W – relative error matrix, m – section parameters vector, μ - regularizing parameter, Δf – discrepancy vector between observed and calculated values, R – focusing operator.

During inverse problem solution development special attention was devoted to a priori information accounting (data weights, parameters turndown).

«ZONDRES2D» has powerful system of profile data visualization, electrodes editor and system of sensitivity and method resolution analysis.

Two types of graphics are used to display observed and calculated data, their discrepancy or measurement weigths in the program. They are graphics plan and pseudosection.

User can find array parameters, set data weights (relevance) and correct measured values in electrodes editor.

In resolution analysis system user can study model sensitivity function that is level of cell influence on measuring result.

$$S = \sqrt{diag(A^T A)} \qquad (6)$$

Research of sensitivity allows choosing optimal type and parameters of array in order to solve assigned geologic task.

«ZONDRES2D» uses simple and clear data file which allows combining different types of array on one profile. Apparent resistivity, signal to current strength ratio and apparent polarizability can be used as measured characteristics. Program allows importing and visualizing data using other methods which makes data interpretation process more integrated.

«ZONDRES2D» has modeling system that includes all main array types used in resistivity method. Dialog mode is used for array parameters selection and defining number of gage points.

«ZONDRES2D» is easy-to-use instrument for automatic and interactive electrotomography data interpretation and can be used on IBM-PC compatible PC with Windows system.

Resistivity and polarizability of rocks

Electrical resistivity (ER) (units are the ohm*meter (Om*m)) is a measure of how strongly rocks oppose the flow of electric current and is the most universal electromagnetic property. In rocks and ores it varies within wide limits: from 10^{-3} to 10^{15} Om*m. For the most widespread sedimentary, volcanic, and metamorphic rocks ER depends on mineral composition,

physical-mechanical and water properties, salt concentration in groundwater, in a less degree on their chemical composition, and on other factors (temperature, depth of occurrence, metamorphism degree, etc.) [Hmelevskoj, 1997].

Electrical resistivity of minerals depends on their crystal bonds. Dielectric minerals (quartz, micas, feldspars, etc.) which mostly have covalent forces are characterized by very high resistivity (1012 - 1015 Om*m). Semiconductor minerals (carbonates, sulfates, haloids, etc.) which mostly have ionic bonds are characterized by high resistivity (104 - 108 Om*m). Clay minerals (hydromicas, montmorillonite, kaolin, etc.) have ion-covalent bonds and are characterized by quite low resistivity.

Ore minerals (native and some oxides) have electronic conduction and carry current very well. First two groups of minerals create “rigid” matrix solid material. Clay minerals create “plastic” matrix solid material that is able to adsorb bound water whereas rocks with “rigid” minerals can adsorb only solutions and free water (water that can be extracted from rock).

Electrical resistivity of free groundwater changes from Om*m unit fractions in case of high total salt content to 1000 Om*m in case of low one. Chemical composition of dissolved salts does not really matter that is why electrical exploration allows assessing only total salt content. Electrical resistivity of bound water that is adsorbed by solid particles of rocks is very low and does not change greatly (from 1 to 100 Om*m). Its constant mineralization (3-1 g/l) explains this fact. Average mineralization of ocean water is 36 g/l.

Pore water (bound and free) has very low electric resistivity in comparison to matrix of the majority rocks, that is why electric resistivity of rocks is almost independent of their mineral composition but depends on porosity, fracturing, and water saturation. Increase of their values causes decrease of electric resistivity because ion content in groundwater grows. This is the reason why electroconductivity of the majority of rocks is ionic (electrolytic).

Rise of temperature in 40^0 causes resistivity decrease in half. It can be explained by ion mobility increase. Resistivity of rocks increases unevenly at freezing as free water becomes almost dielectric and electroconductivity is determined only by bound water that freezes at very low temperatures (below -50^0 C). Increase of resistivity varies in different rocks: several times in clays, up to 10 times in hard rocks, up to 100 times in clay and sandy loams, and up to 1000 times and more in sands and coarse rocks.

Despite the fact that resistivity depends on numerous factors and varies within wide limits in different rocks, main laws of ER are well determined. Volcanic and metamorphic rocks are characterized by high resistivity (from 500 to 10000 Om*m). Among sedimentary rocks high resistivity (100 – 1000 Om*m) can be found in rock salts, gypsums, limestones, sandstones, and some other rocks. As a rule, in detrital sedimentary rocks the more grain size is the higher resistivity rock has, that is ER depends on clayiness on the first place. In passing from clays to clay and sandy loams and sands resistivity changes from unit fractions and first Om*m to tens and hundreds of Om*m [Hmelevskoj, 1997].

Polarizability coefficient expresses ability of rocks to polarize that is to accumulate charge during passage of current and discharge then after current interruption. Coefficient η is measured in percents as ratio of voltage that remains in potential circuit some time after current interruption (usually 0.5-1 sec.) to voltage in this circuit during passage of current.

Polarization is complex electrochemical process that progresses in rocks during passage of direct or low-frequency alternating (up to 10 Hz) current. Ores with electronic conduction (sulphides, sulphosalts, some native metals, individual oxides, graphite, and anthracite) are characterized by the highest polarizability. These IP potentials' origin is connected with so called concentrated and electron polarization of ore minerals. Polarizability coefficient has up to 2-6 % value above water-encroached loose sedimentary rocks where clay particles are present. Their polarizability is caused by deformation of external plates of double electrical layers which form at solid-liquid contact. The majority of volcanic, metamorphic, and sedimentary rocks saturated with mineral water have low polarizability [Hmelevskoj, 1997].

Program installation and deinstallation

«ZONDRES2D» program is supplied on CD or by internet. Current manual is included in the delivery set. Latest updates of the program can be downloaded from website: www.zond-geo.ru/english

To install the program copy it from CD to necessary directory (for example, Zond). To install updates rewrite previous version of the program with the new one.

Secure key SenseLock driver must be installed before starting the program. To do that open SenseLock folder (the driver can be downloaded from CD or website) and run InstWiz3.exe file. After installation of the driver insert key. If everything is all right, a message announcing that the key is detected will appear in the lower system panel.

To uninstall the program delete work directory of the program.

Program registration

For registration click “Registration file” item of the main menu of the program. When a dialog appears, fill in all the fields, select file name, and save it. Created file is transmitted to specified in the contract address. After that user receives unique password which depends on HDD serial number. Input this password in “Registration” field. The second option is to use the program with supplied SenseLock key inserted in USB-port while working.

System requirements

«ZONDRES2D» can be installed on PC with OS Windows 98 and higher. Recommended system parameters are processor P IV-2 GHz, memory 512 Mb, screen resolution 1024 X 768, colour mode – True colour (screen resolution change is not recommended while working with data).

As far as the program is actively using the registry, it is recommended to launch it as administrator (right click on program shortcut – run as administrator), when using systems higher than Windows XP.

Program start-up, main options

Creation and opening of data file

To start up «ZONDRES2D» it is necessary to create data file of certain format which contains electrodes coordinates, topography and measuring results. «ZONDRES2D» supports also most popular data formats: RES2DINV (Geotomo Software, M.H. Loke), SENSINV2D (Geotomographie, T. Fleschner), ABEM data, and ProfileR (A. Binley).

One profile data usually corresponds to one file. Text data files of «ZONDRES2D» format have «*.z2d» extension (see *«Main data file format»* for more details).

Zond data file	Open Zond data or project file.
ProfileR data file	Open ProfileR data file.
ABEM data file	Open ABEM data file.
Res2dInv	Open Res2dInv data file.
Sens2dInv	Open Sens2dInv data file.
Zond1d file convertion	Import data from Zond-IP 1d file.
Program configuration	Open program parameters file.

For correct running of the program data file must not contain:

- incorrect symbols of records separator (TAB and SPACE use only);
- absurd data values (for example, negative values of apparent resistivity).

Desirably, there must be no more than 5000 observed data values and total unique electrodes position - no more than 500 for one file.

Main Menu Toolbar

The toolbar serves for quick run of the most frequently used functions. It contains the following functional buttons (from left to right):

	Open data file.
	Save data.

	Run inversion parameters setup dialog.
	Run electrodes editor.
	Run forward solution process.
	Start (one click) or cancel (second click) inversion process.
	Run data interpretation mode of resistivity method (DC).
	Run data interpretation mode of induced polarization method (IP).
	Cancel previous step of model changing.

Main Menu Functions

The following table lists items found in the Menu with their corresponding functions:

File/Open file	Open data file.
File/Create survey	Run synthetic measurement system generation dialog.
File/Save file	Save data.
File/Edit data	Open current data file in Notepad editor.
File/Project information	Show downloaded project information.
File/Print preview	Print main window of the program.
File/Recent	Recently used files.
File/Reg file	Create register file.
File/Register	Register program.
File/Exit	Exit program.
Options/Mesh constructor	Run starting model setup dialog.
Options/Program setup	Run inversion parameters setup dialog.
Options/Electrode editor	Run electrodes editor.
Options/Observed graphics	Run graphics parameters setup dialog.
Options/Calculated graphics	Run calculated graphic parameters setup dialog.
Data/Apparent resistivity	Display apparent resistivity values.
Data/Resistance	Display resistance values.
Data/Pseudo-section	Display observed and calculated data in pseudosection.
Data/Graphics-plot	Display observed and calculated data in graphics plan.
Data/Calculated data	Display calculated pseudosection in second part of window.

Data/Data misfit	Display misfit pseudosection in second part of window.
Data/Data weights	Display measurement weights pseudosection in second part of window.
Data/Iso-pole graphics	Run graphics plan feature, where each graphic corresponds to certain source position.
Data/Iso-psZ graphics	Run graphics plan feature, where each graphic corresponds to certain pseudo-depth (array geometric factor).
Data/Display/ Display every N point	Display every N point of pseudosection. This option is used in case of having more than 3000 observed values.
Data/ Display/	Plot data for fixed positions of selected electrodes.
Model/Block section	Display model as blocks.
Model/Smooth section	Display model in smooth interpolated graphic palette.
Model/Contour section	Display model as contour section.
Model/Resistivity	Display resistivity model.
Model/Sensitivity	Display sensitivity function model as contour section.
Model/Extend bottom	If relief is present this option extends bottom cells to maximum depth.
Model/Cutting angle	Specify cutting angle for left and right corner of the model.
Model/Histogram	Display model parameters distribution plot. Minimum and maximum values of parameter's colour scale can be specified in the dialog window.
Advanced/ Inverse procedure/ Length step optimize	Turn on/off automatic step length definition mode. This mode leads to algorithm convergence acceleration but sometimes does not allow avoiding local minimums of the solution.
Advanced/ Inverse procedure/ Display process	Display plots of inversion parameter changes within every iteration and in total selection process (data deviation, model deviation, smoothing factor, data weighted deviation).
Advanced/Inverse procedure/Underwater options/ Resistivity 3.00	Specify water resistivity.
Advanced/Inverse procedure/Underwater	Turn on water resistivity selection.

options/ Invert	
Advanced/Inverse procedure/Underwater options/ Sublayers number 3	Specify number of water layer splits.
Advanced/ Inverse procedure/ Average window 8x4	If this function is turned on window median value is used as m_0 background value for model misfit calculation (in case of smooth inversion Occam).
Advanced/Cells summarization	Run cross-section cells unification dialog (cross-section desensitization or smoothing).
Advanced/Distribution/ Potential distribution	Turn on potential isoline display mode for each source position. Current measurement value is selected in electrodes editor table.
Advanced/Distribution/ Sensitivity isoline	Turn on sensitivity isoline display mode for each measurement value. Current measurement value is selected in electrodes editor table.
Advanced/Distribution/ Sensitivity contour	Turn on sensitivity contour display mode for each measurement value. Current measurement value is selected in electrodes editor table.
Advanced/Display both	Display polarization isolines above resistivity model or vice verse.
Advanced/Isoline setup	Run second parameter's isoline setup dialog.
Advanced/ Reverse pseudosection	Rotate and move for constant value data set when loading.
Advanced/ Open in modeling mode	Open data file in modeling mode.
Advanced/ Real topo coordinates	Display actual profile excess.
Advanced/Extended nodes	Add additional cells to model edges.
Advanced/Electrode RMS	Display relative misfit value for each electrode.
Advanced/Smooth topo	Turn on relief point smoothing interpolation mode
Import/Export/Carotage data	Open logging data and stratigraphic columns file.
Import/Export /	Import random data or model to the program.

Import model/data	
Import/Export /Remove data	Delete imported data plot from the project.
Import/Export / Save selection	Save selected cell parameters.
Import/Export / Load selection	Open selected cell file and insert from current cursor position.
Import/Export / Extract 1d log	Save vertical resistivity and polarizability profile for specified X coordinate.
Import/Export /Load 1d log	Insert vertical resistivity and polarizability profile for specified X coordinate in the model.
Import/Export/Section file	Import SectionCor format file (*.sec).
Import/Export/Remove	Delete imported data.
Import/Export/ Output setting	Exported picture setup.

“Hot” keys

Cursor pad /cursor in model editor	Change active cell of the model.
Delete / cursor in model editor	Clear active cell.
Insert / cursor in model editor	Insert current value to active cell.
F / cursor in model editor	Fix active cell value.
X / cursor in model editor	Use “magic wand” tool to select domain.
V / cursor in model editor	Delete selected.
Up/down / cursor in model editor	Change current value.
Space	Calculate forward problem.

Status bar

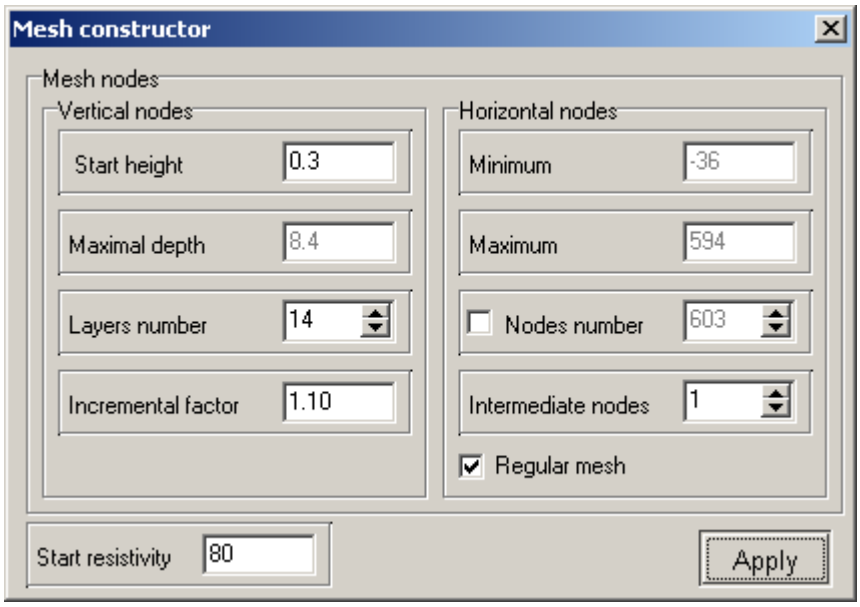
Status bar is located in the lower part of program window and is divided into a few sections which contain different information:

Cursor and active cell coordinates.
Active cell parameters.

Model editor mode.
Calculation progress bar.
Relative misfit.
Additional information. For example, number of observed values and model cells or calculation process status during inversion.

Starting model setup dialog

As soon as data file «*.Z2D» is created, load it by pressing button or using relevant menu item. After successful loading the start up model setup dialog appears. It allows specifying grid parameters, apparent resistivity, and polarizability. This dialog can also be run using **Options/Mesh Constructor** in the main menu of the program (pic.1).



Pic. 1. **Mesh constructor** dialog

The **Vertical nodes** field contains options which set vertical grid parameters of the model. Program automatically selects these parameters using the following rules:

- Depth of bottom layer is equal to half of maximal pseudo-depth for used measurement system.
- Number of layers is equal to double quantity of array unique geometric factors for used measurement system but does not exceed 16.
- The thickness of the next layer is 1.1 times more than the previous one.

Start height – sets thickness of first layer. This value must be approximately equal to the width of the cell and necessary model resolution.

Maximal depth – sets depth of bottom layer. It should be remembered that the maximal depth value must not be too large because influence of geoelectrical section parameters decreases with depth.

Layers number – sets number of model's layers. Usually 12-14 layers are enough for model description. It is not advisable to specify large values for this parameter because computation speed will decrease.

Incremental number – sets ratio between thicknesses of adjacent layers. This parameter value usually ranges from 1 to 2.

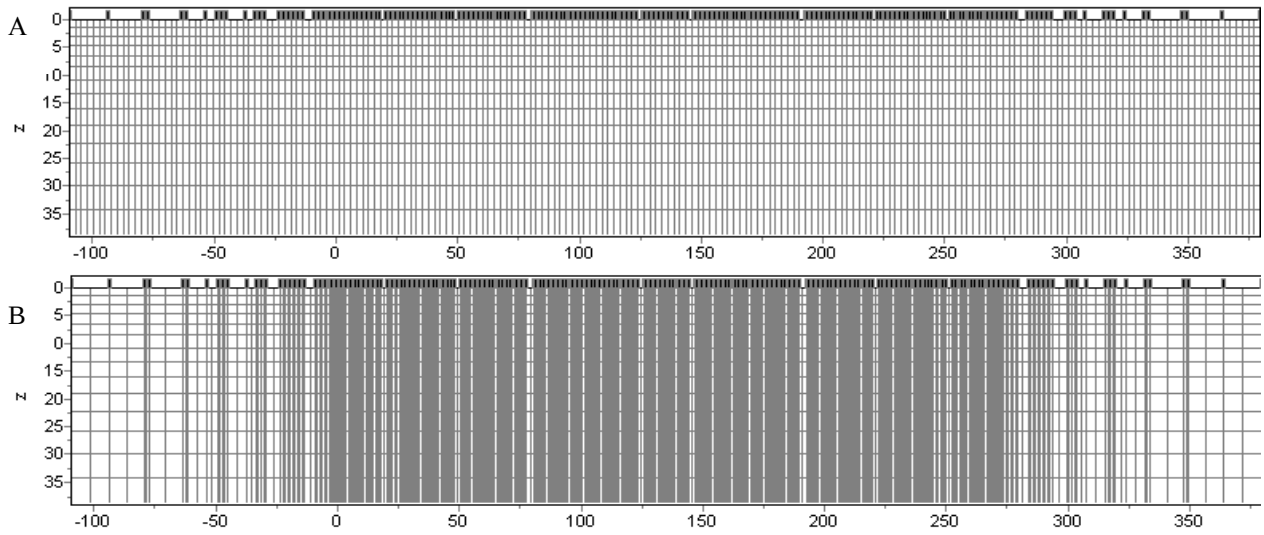
Horizontal nodes field contains options which set horizontal grid parameters.

Minimum – shows (sets) minimal coordinate of the profile.

Maximum - shows (sets) maximum coordinate of the profile.

Intermediate nodes – sets number of complementary nodes between unique electrodes positions on the profile (0 - 4). It is advantageous for the accuracy of the forward problem solution, especially when using total potential calculation scheme.

Nodes number – if this function is ON mesh is created with regular step (on horizontal axis) from **Minimum** to **Maximum** field value. Number of nodes is specified in **Nodes number** field. This function should be used in case of irregular measurement grid. It should be considered that if this function is ON program uses Secondary potential calculation scheme which does not allow taking relief into consideration. It is advisable to use regular mesh to work with non topography measurement systems, for example 2D VES data interpretation (pic.2).



Pic. 2. Regular (A), irregular (B) model mesh

If this function is ON, number of cells considerably decreases but because of nonlinearity of potential function in case of current and potential electrodes getting in one cell the algorithm neglect this data.

Regular mesh – starts horizontal mesh construction algorithm, and complementary nodes are selected from condition of split uniformity. This option should be used if distance between adjacent electrodes is very different (It is advantageous for the accuracy of forward and inverse problem solutions).

If **Nodes number** function is ON, right click on **Regular mesh** panel to specify cells split step on X axis.

Half-space resistivity – sets resistivity of starting model.

Half-space polarizability – sets polarizability of starting model.

Press **Apply** button after mesh setup is finished, and the program starts work mode.

Model editor functions can also be used to correct mesh: add or delete intermediate nodes, level cell height and width (see *«Model editor»* for more details).

The alternative of using data file is creating synthetic observation system that allows constructing various geological situations for the most widely-distributed electrodes arrays (see *«Modeling»* for more details).

Main data file format

Progra presents universal data format which consists of information about current and potential electrodes coordinates and measured values (normalized signal or apparent resistivity and apparent polarization).

ZONDRES2D data file format has *.Z2D extension.

For our purpose data file can be divided into 3 parts: 1) observed data, 2) topography data (if present), 3) model data (saved in file after inversion or modeling).

1st part of data file: Observed data

First line contains control keys which define what kind of data is contained in every column.

Following designations (keys) for electrode coordinates are accepted in «ZONDRES2D»:

Current **C1 C2 C1z C2z C1y C2y**

Potential **P1 P2 P1z P2z P1y P2y**

Y and Z coordinates can be specified if necessary. For example, in case of using plane-table measurement system, downhole source or marine measurements. Sample file –

sample_with_z_source. Distance along Y axis must not exceed 1/3 of maximum separation (distance between current and potential electrodes). Sample file – sample_with_y. When specifying Z coordinates it should be remembered that positive values mean that electrode is below surface. Negative coordinates are only used in case of marine measurements (in this situation measurement surface is bottom).

For measured values:

Apparent resistivity **Ro_a**

Normalized signal modulus (potential to current strength ratio) **Res**

Normalized signal **SRes** (for example, for downhole source measurements, taking sign into account)

It is recommended to ALWAYS use **Res** or **SRes** values while creating data file to avoid mistakes if topography data is present.

Apparent polarizability **Eta_a**

Apparent polarizability, measured in time domain and calculated with the following formula, can be used as Eta_a:

$$\text{Eta\_a}\ (\%) = (\Delta U_{IP} / \Delta U_{CUR}) \cdot 100\%, \qquad (7)$$

where ΔU_{CUR} – potential during current transmission, ΔU_{IP} – during pause. Sample file – sample_with_ip. If charging is used, measured values should be divided by ten first.

In frequency domain apparent polarizability can be measured by phase displacement (φ_{IP}), which is converted to apparent polarizability using the following empiric formula.

$$\text{Eta\_a}\ (\%) = -2.5 \cdot \varphi_{IP}\ (\text{degrees}) \qquad (8)$$

Calculating error or measurement weight is specified in **Weight** column, it defines measurements quality. Measurement weight values should range from 0 to 1. If there is no error data (**Weight** column is absent), weight value is automatically specified as **1** for each measurement.

Second and the following lines contain data corresponding to each measurement, written in the same sequence as control keys in the first line.

In case different (in number of electrodes) arrays are used in one profile * symbol should be written instead of missing coordinate value. Sample-file – sample_with_array_combi.

Then (if necessary) horizontal mesh complementary nodes column is filled. Each new node coordinate is entered after *** symbol. Complementary nodes are usually added for model extension over last electrodes of cable and if there is sharp relief beyond cable. Sample-file – sample_with_ext_nodes.

After file is read data normalization (if necessary) can be performed using the following formula which corresponds to apparent resistivity on direct current.

$$\rho_a = G \cdot \frac{|U|}{C}, \qquad (9)$$

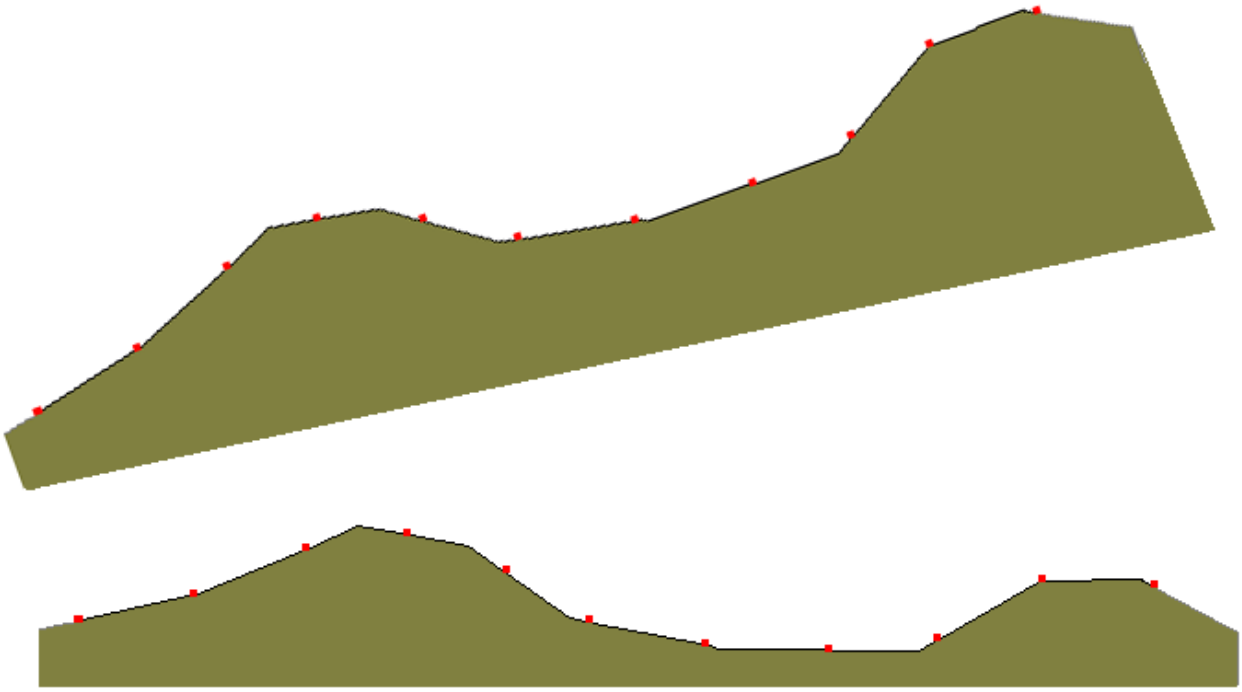
where G - array geometric factor, U – measured value, C – current strength value.

2nd part of data file: Topography data

If topography data is present, the next line contains word **topo** and is followed by list of coordinate and relief excess values. If relief is taken into consideration during interpretation, it is advantageous to use **res** values as initial data. Following additional control keys correspond to different methods of relief specifying.

topo - this key is used if coordinates of electrodes and topographic mapping are given in horizontal projections. Sample-file – topo1.

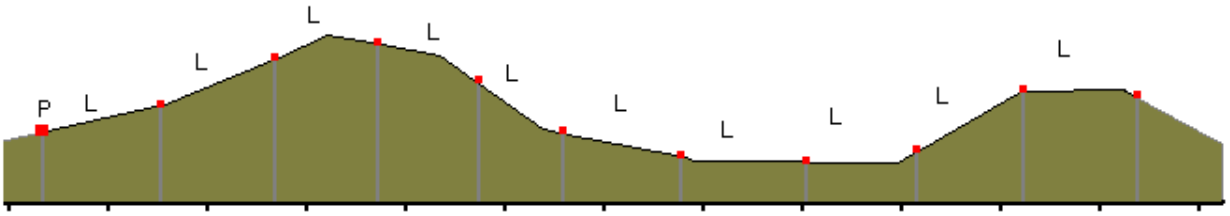
topo~ adjustment to horizontal surface. Relief curve is approximated using least-squares method to line, and then is rotated together with all relief points so that it converges to horizontal axis (pic. 3). This method can be used if measurements are performed along slope with known absolute relief heights. Sample-file – topo2a/topo2b.



Pic. 3. Relief adjustment to horizontal surface

topo# specifies profile coordinates by lengths (“curve”). In this case distance along the cable but not X projection is equal to horizontal coordinate of electrodes (pic. 4). X coordinates of electrodes are recalculated from lengths to horizontal projections. The line that follows the

one with the key must contain tie of one of the cable electrodes **P** to relief point. The second note is electrode coordinate (in lengths), the first one – corresponding to it X coordinate from the list of relief excesses. Sample-file – topo3.



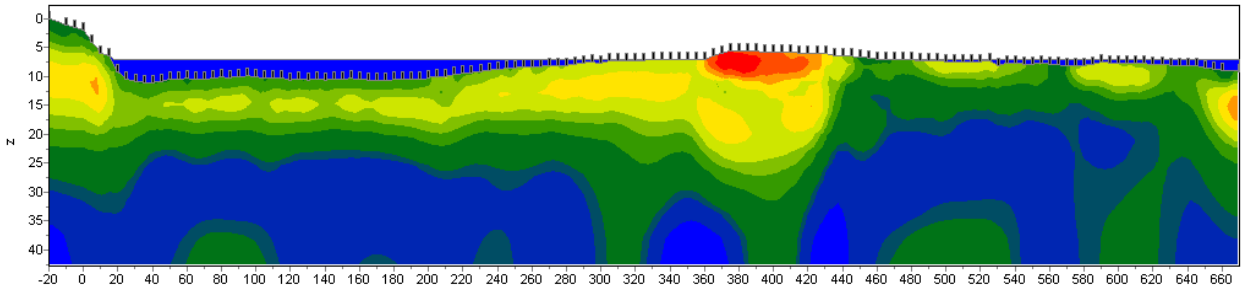
Pic. 4. Electrode positions with shown distance between them adjusted for relief changes (along the cable)

topo% - this key is necessary if **ro_a** values, calculated for projections, are set as initial data, that is distances between electrodes are recalculated from distances along the cable (L) to actual coordinates.

topo^ - this key is necessary if topography data and electrodes coordinates are specified in distances along the cable. Sample-file – topo4.

Keys can be combined, for example, **topo~#**.

topow – this key is used if marine survey data interpretation is performed (on water surface or on the bottom). In this case bottom or bottom going to land (combined measurements) profile is used as relief coordinates (pic. 5). After space in the same line water surface level (relative to fixed below coordinates of profile bottom (in the same coordinate system as the relief)), water resistivity and number of complementary water layer splits (3-10) must be also specified. Main window function **Options/Advanced/Inverse procedure/Underwater options** can be used to change the former two parameters. Sample-file – water1. Combined systems when measurements are performed on the bottom and on water surface can be specified. Sample-file – water3. In order to do that vertical electrode coordinates relative to bottom profile level should be entered.



Pic. 5. Geoelectrical cross-section as a result of combined land and marine measurements

topo* – this key simplifies entering topography data if cable is located on water surface (mobile system). Sample-file – water2.

It is also recommended to become familiar with additional options *described in «Specifics of work with topography data and marine measurements ».*

3d part of data file: Model data

Model description stars with key word **model**. The first line sequentially contains the following parameters: resistivity, minimum and maximum resistivity of colour scale, model to relief distortion coefficient (**topo coefficient**).

The second and the third line contain lists of horizontal and vertical coordinates of mesh nodes (n and m length).

The forth line n lengthways specifies if electrode position corresponds to current node.

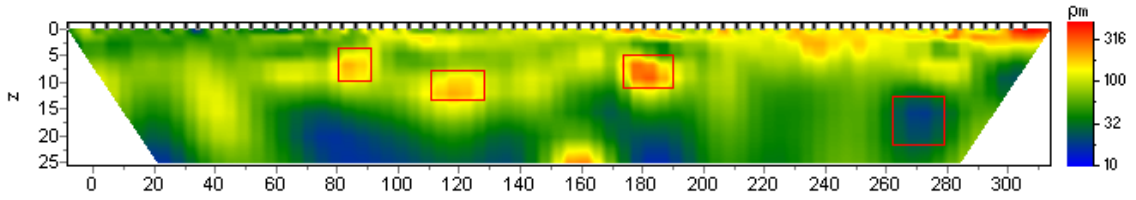
Following n-1 lines m-1 lengthways contain model resistivity matrix.

Following n-1 lines m-1 lengthways contain matrix of model cell fixing.

Then model polarizability is described. The first line sequentially contains the following parameters: resistivity, minimum and maximum polarizability of colour scale. Following n-1 lines m-1 lengthways contain model polarizability matrix.

Preparing data for inversion

Estimation of filed electrotomography data usually comes to analysis of standard statistics received during signal processing. Electrotomography uses much more information in comparison with classic profiling and sounding. For this reason it is acceptable to use data that contains some rejected values for inversion.

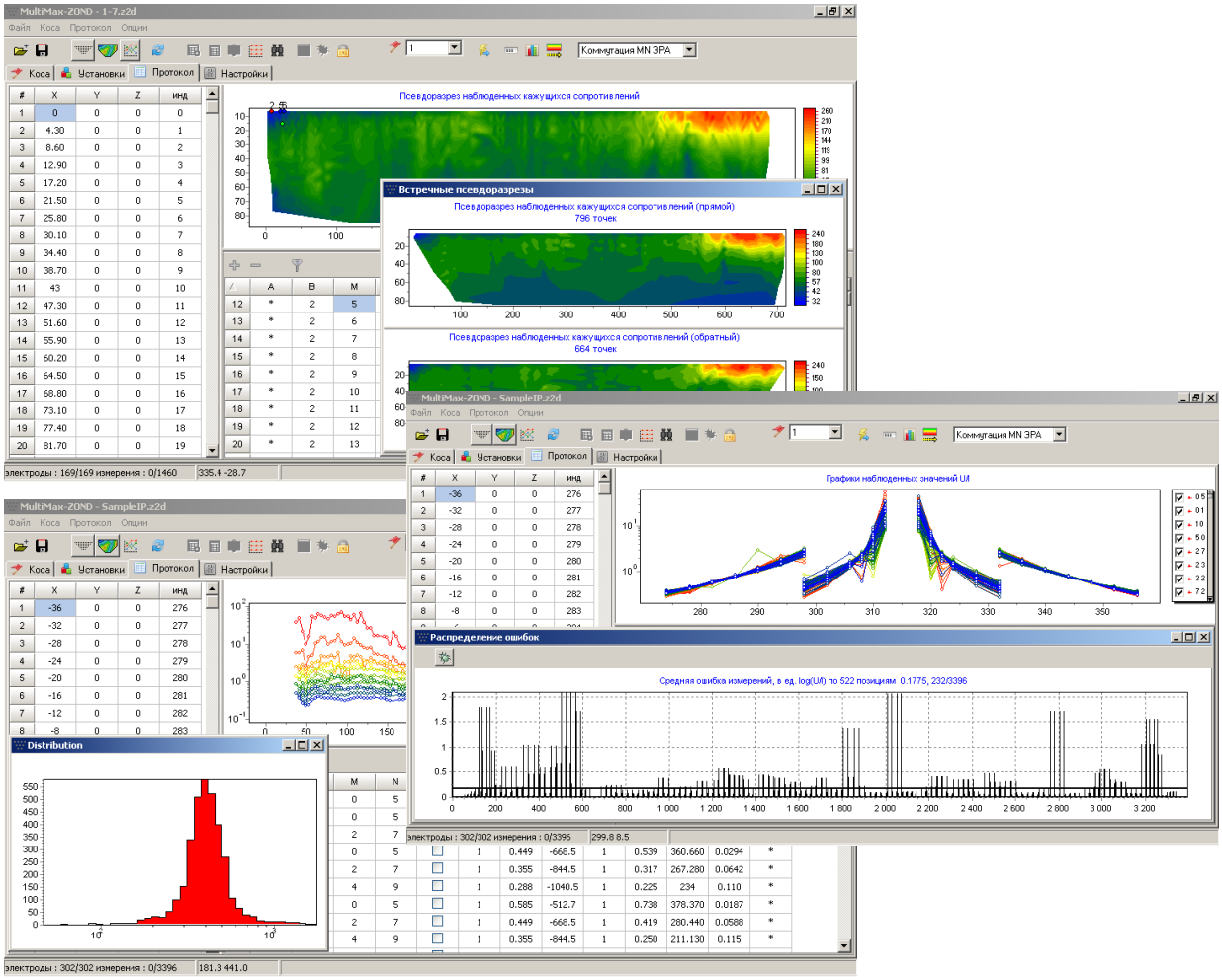


Pic. 6. Resistivity section that contains false anomalies resulted from using poor field data

Poor data can also have no effect on interpretation results (if noise is presented by rare uncorrelated spikes, for example) but sometimes it causes significant model distortion. It was repeatedly noticed that small amount of poor data led to formation of false anomalies as "compensated dipoles" system. It results in interchanging of local anomalies of relatively low

and high resistivity. In this case using adaptive robust systems is not helpful, only total deletion of poor data from inversion is effective.

ZondProtocol program presents ready solution for electrotomography and allows solving wide range of tasks from specifying measurement protocols and measurement process control to data processing and analysis. Due to its usability and compatibility for **ZondRes2d** program it allows receiving good results right on the profile.



Pic 7. **ZondProtocol** program windows

The program solves the following tasks: specify protocols (automatic and interactive), visualize and analyze measurement results, separately display arrays, recalculate data for different arrays, prepare data for inversion.

ZondRez2d program can also perform data rejection. If measurement weights are set 0 values or turned off using electrodes editor they will not be processed (*see «**Ошибка!***

***Источник ссылки не найден.**» for details)*. It is also possible to assign certain weight to measurement value using electrodes editor.

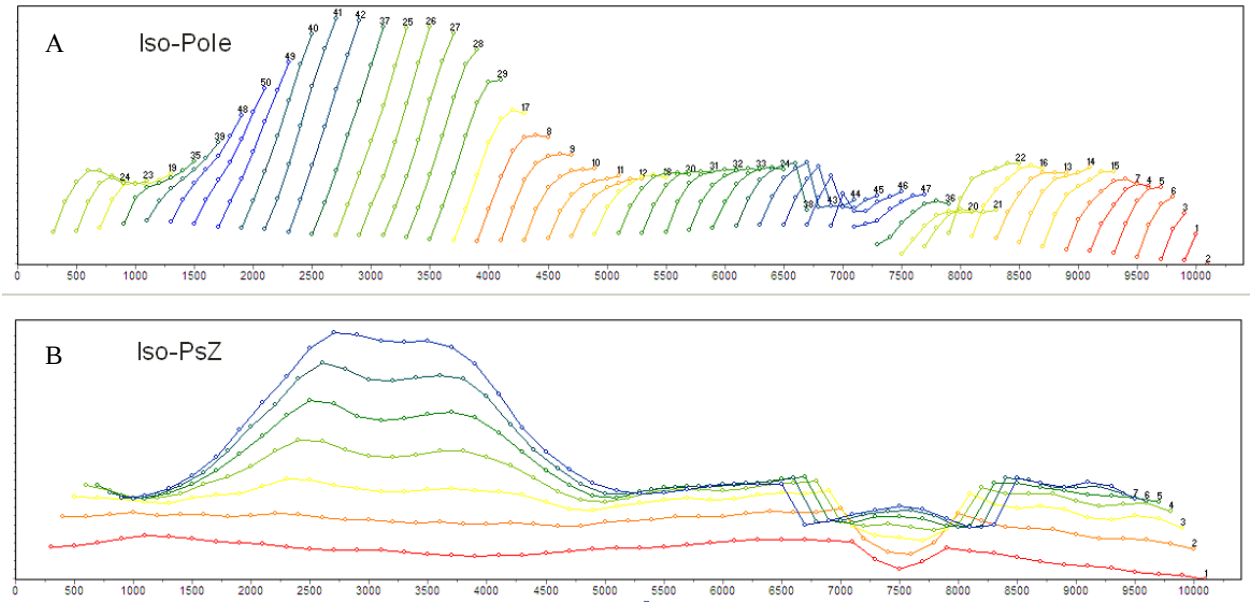
Apparent parameters visualization

There is a possibility to visualize apparent parameters as pseudosection **Options/Data/Pseudo-section** and as graphics plan **Options/Data/Graphics-plot**. In resistivity mode parameter can be represented as normalized signal (**Option/Data/Resistance**) or apparent resistivity (**Option/Data/Apparent resistivity**).

Graphics plan

Graphics plan is used for apparent resistivity values visualization as graphs along profile.

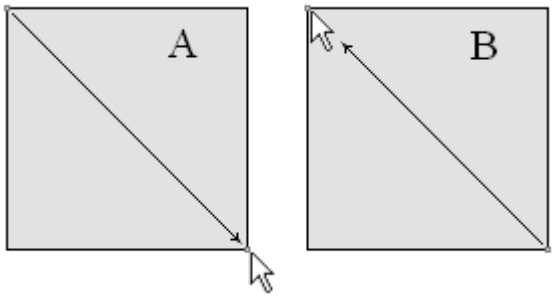
Graphing method can be chosen in the main menu of the program: by certain pseudodepth **Options/Data/Graphics-plot/Iso-PsZ** with different array factor or by certain current circuit position **Options/Data/Graphics-plot/Iso-Pole** (pic. 8).



Pic.8. A. Graphics plan created by certain current circuit position (**Iso-Pole**),
B. Graphics plan created by certain pseudodepth (**Iso-PsZ**).

Mouse clicks are used to work with graphics plan.

Zooming in or dragging some part is performed with pressed button (“rubber rectangular” tool). To zoom in a segment move mouse cursor down and to the right with left button pressed (Pic. 9A). To return to primary zoom do the same but with mouse cursor moving up and to the left (Pic. 9B).



Pic. 9. Mouse cursor navigation to zoom in/out

The following actions are performed by pressing left mouse button on graphic point: all other graphics are hidden and electrodes positions for active point are shown (while the button is pressed). To edit measured values move plot point with right button pressed.

To run graphics plan setup dialog use **Options/Observed graphics Calculated graphics** in the main menu (*see*

Appendix 1: Graphics set editor *for details*). Right click on necessary axis with SHIFT button pressed to run axis editor (*see Appendix 5*:). Right click on legend to the right of the graph with SHIFT button pressed to run legend editor (*see Appendix 5*:).

Click on legend with SHIFT button pressed to select one graph and delete all others. Second click performs inverse operation.

Use mouse wheel to scroll graphs. In order to do that select a few adjacent graphs (on the legend) and scroll mouse wheel with mouse cursor in the centre of the legend. Indices of active graphs will change. Right click on plot point to select value in the table.

Graphics mode allows rejecting some values that will be assigned **0** weights. To reject certain value left click on plot point with ALT button pressed. Right click with ALT button pressed on graphic to set **0** weights to all points of the graph.

Pseudosection

In the first approximation pseudosection visualizes parameter distribution with depth along profile.

Contour graph is created in profile coordinate to pseudodepth axes. Colour scale correlates value to colour.

Double click next to object axes runs context menu which contains the following options:

Log data scale	Use logarithmic scale on colour bar.
Display grid point	Display measurement point ticks.
Display ColourBar	Display colour scale.
Setup	Run pseudosection parameters setup dialog.
Print preview	Print pseudosection.
Save picture	Save pseudosection in graphic file *. emf.
Save XYZ file	Save pseudosection in data-file.
Default	Set pseudosection parameters on default.

Pseudosection parameters setup dialog **Setup** is described in *Appendix 2*: . Right click on necessary axis with SHIFT button pressed to run axis editor (*see Appendix 5*:). Right click on necessary point with SHIFT button pressed to run pseudosection point editor (*see Appendix 5*:).

Zooming in or dragging some part is performed with pressed button ("rubber rectangular" tool). To zoom in a segment move mouse cursor down and to the right with left button pressed (pic. 9A). To return to primary zoom do the same but with mouse cursor moving up and to the left (pic. 9B).

Pseudosection plotting method differs for various arrays. Pseudosection point position:

1. for Wenner array corresponds to array center on X axis and to ¼ of separation between the last electrode and array center on Y axis;
2. for Pole-Dipole array - center between potential electrodes on X axis and separation between current electrode and center of potential electrodes on Y axis;
3. for Dipole-Dipole array - array center on X axis and ½ of distance between dipole centers (for current and potential electrodes) on Y axis;
4. for Gradient array – center between potential electrodes on X axis and ½ of separation between nearest current electrode and center of potential electrodes;
5. for Pole-Pole array – array center on X and Y axes;

6. for VES array – array center on X axis and ¼ of distance between the last electrodes on Y axis.

If data is displayed as pseudosection, use **Options/Data/ Display/** menu option to view certain array data. In case of having more than 3000 observed values **Display every N point** option can be used to subsample pseudosection points.

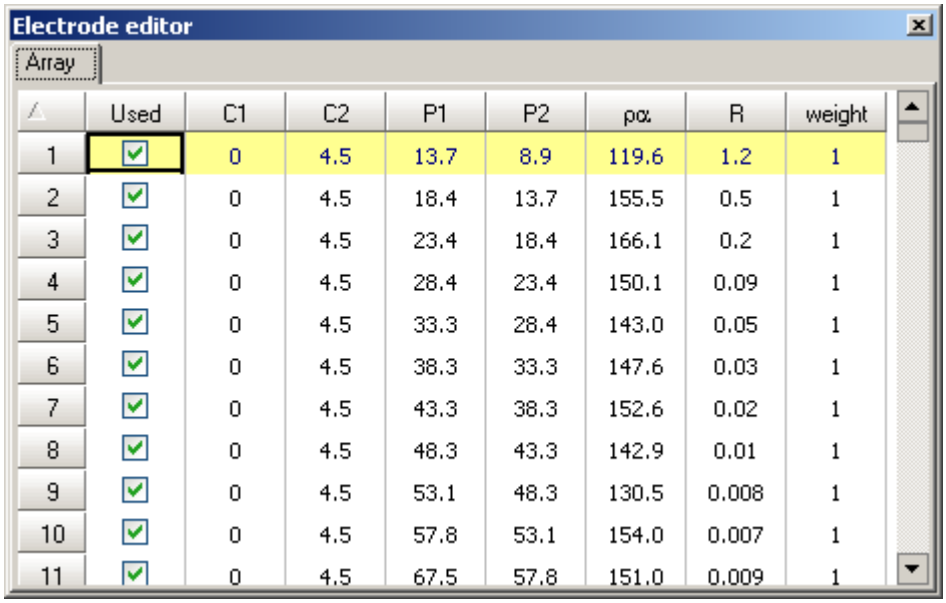
Value weights (**Options/Data/Data Weights**) and relative misfit of every measurement after inversion process finishing (**Options/Data/Data Misfit**) can be displayed as pseudosection in the middle graphic section of the program.

Electrodes editor

Electrodes editor serves for visualization of acquisition geometry and measured values. Window contains table that allows adjusting every measurement parameter (pic 10). The table contains 9 columns:

ID	Measurement index
Used	Indicator specifying whether measurement is used in inversion or not.
C1	Position of the first current electrode on profile.
C2	Position of the second current electrode on profile.
P1	Position of the first potential electrode on profile.
P2	Position of the second potential electrode on profile.
$\rho\alpha$	Measured apparent resistivity value.
R	Measured resistivity (normalized signal) value.
Weight	Measurement weight.

If electrode is absent its coordinate is replaced by symbol *.



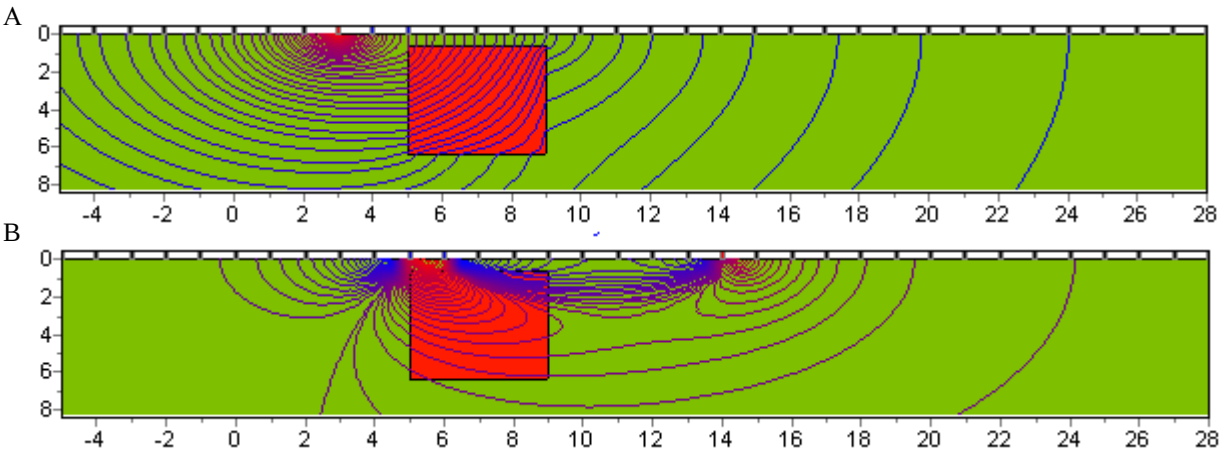
	Used	C1	C2	P1	P2	ρα	R	weight
1	☑	0	4.5	13.7	8.9	119.6	1.2	1
2	☑	0	4.5	18.4	13.7	155.5	0.5	1
3	☑	0	4.5	23.4	18.4	166.1	0.2	1
4	☑	0	4.5	28.4	23.4	150.1	0.09	1
5	☑	0	4.5	33.3	28.4	143.0	0.05	1
6	☑	0	4.5	38.3	33.3	147.6	0.03	1
7	☑	0	4.5	43.3	38.3	152.6	0.02	1
8	☑	0	4.5	48.3	43.3	142.9	0.01	1
9	☑	0	4.5	53.1	48.3	130.5	0.008	1
10	☑	0	4.5	57.8	53.1	154.0	0.007	1
11	☑	0	4.5	67.5	57.8	151.0	0.009	1

Pic. 10. **Electrodes editor** dialog window

The last three columns can be edited using keyboard if necessary. Absurd values of apparent resistivity and normalized signal should not be entered. Measurement weights range from 0 to 1. Table content sorting in current column can be run by clicking column heading.

While moving the cursor through the table, positions of active measurement electrodes are displayed on pseudosection or graphics plan.

Advanced/Distribution option can also be used to run electrodes editor in potential or sensitivity contour display mode. Analysis of potential or sensitivity distribution helps to understand electrotomography principle of operation (pic. 11).



Pic. 11. Potential contours (A) and sensitivity contours (B) of pole-dipole array

While moving the cursor through the table potential and sensitivity contours change for current measurement value.

Data inversion

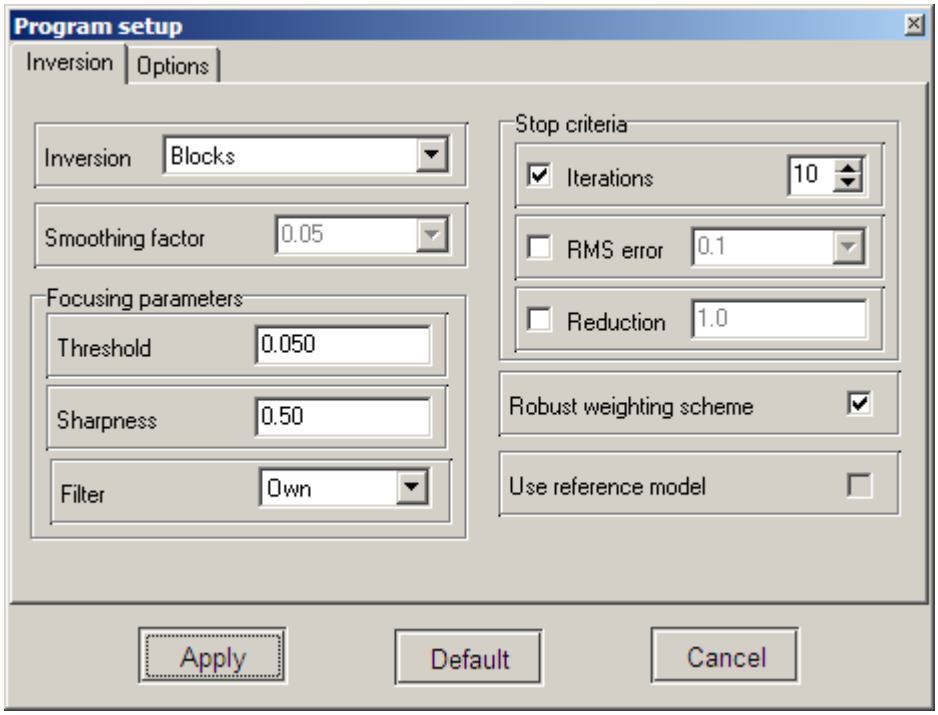
The next step after loading data file and start-up model setup is specifying inversion type and selecting parameters. Use button or **Option/Program setup** menu option to run inversion parameters setup dialog.

Inversion parameters setup dialog

This dialog serves for specifying parameters connected with forward and inverse problem solutions.

Default – set parameters default values.

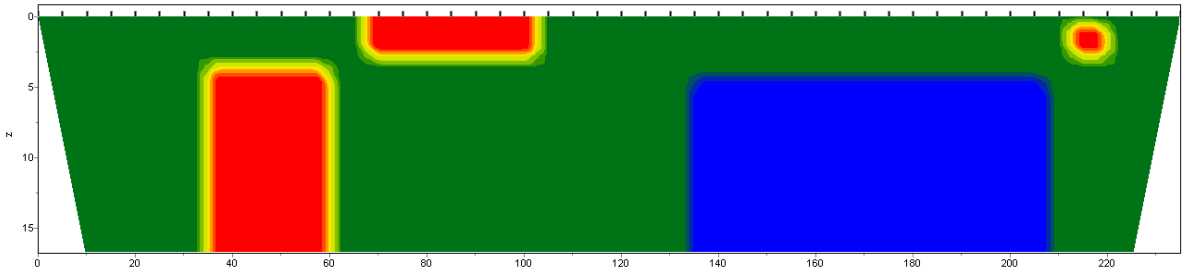
Inversion tab serves for inversion parameters setup (pic.12).



Pic. 12. **Program setup** dialog window, **Inversion** tab

Inversion option defines algorithm that is used for inverse problem solution.

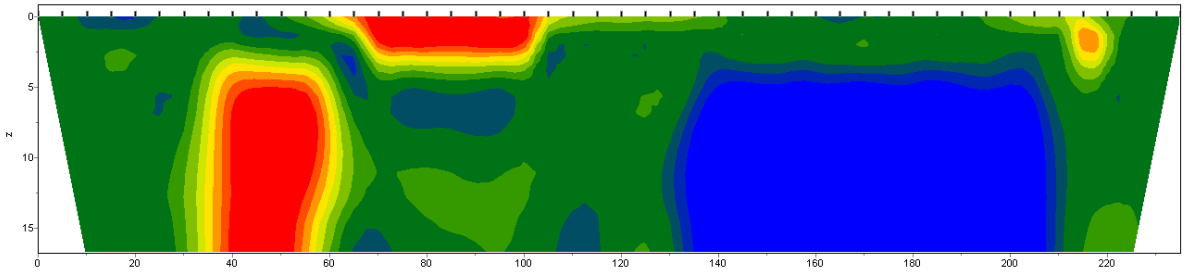
Let us consider inversion algorithms by example of subsurface model that consists of several blocks (pic. 13).



Pic. 13. Test subsurface model

For algorithm testing theoretical response should be calculated and 5 percent Gaussian noise superimposed.

Smoothness constrained is inversion by least-square method with use of smoothing operator. As a result of this algorithm smooth (without sharp boundaries) and stable parameter distribution is received (pic. 13).



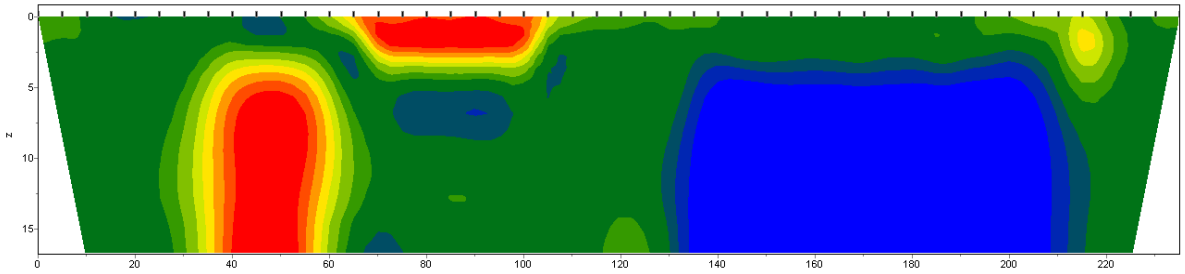
Pic. 14. Regenerated model as a result of ***Smoothness constrained*** inversion

Matrix equation for this kind of inversion is the following:

$$\left(A^T W^T W A + \mu C^T C\right)\Delta m = A^T W^T \Delta f \qquad (10)$$

Judging by the equation it can be said that model contrast is not minimized during inversion. Current algorithm allows receiving minimum misfit values. In the majority of cases it is recommended to use it for initial stages of interpretation.

Occam is inversion by least-square method with use of smoothing operator and additional contrast minimization [Constable, 1987]. As a result of this algorithm the smoothest parameter distribution is received (pic.15).



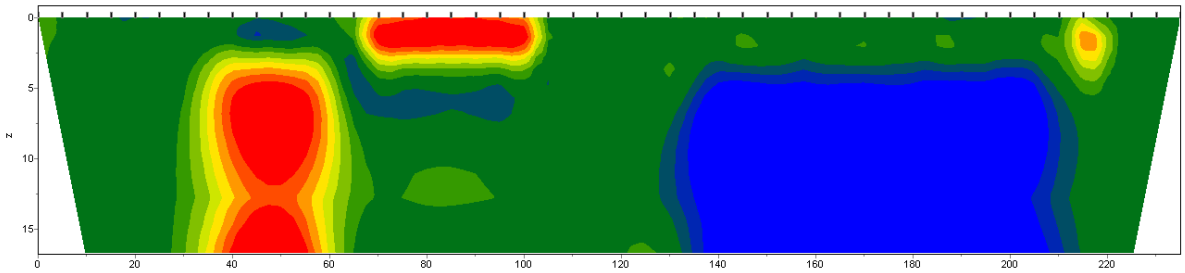
Pic. 15. Regenerated model as a result of ***Occam*** inversion

Matrix equation for this kind of inversion is the following:

$$\left(A^T W^T W A + \mu C^T C\right)\Delta m = A^T W^T \Delta f - \mu C^T C m \qquad (11)$$

Degree of smoothness of received model is in direct proportion to **Smoothness factor** value. It should be noted that high values of this parameter can lead to misfit increase.

Marquardt – classic inversion algorithm by least-square method with regularization by damping parameter (**Ridge regression**) [Marquardt, 1963]. In case of little quantity of section parameters this algorithm allows receiving contrast subsurface model.



Pic. 16. Regenerated model as a result of ***Marquardt*** inversion

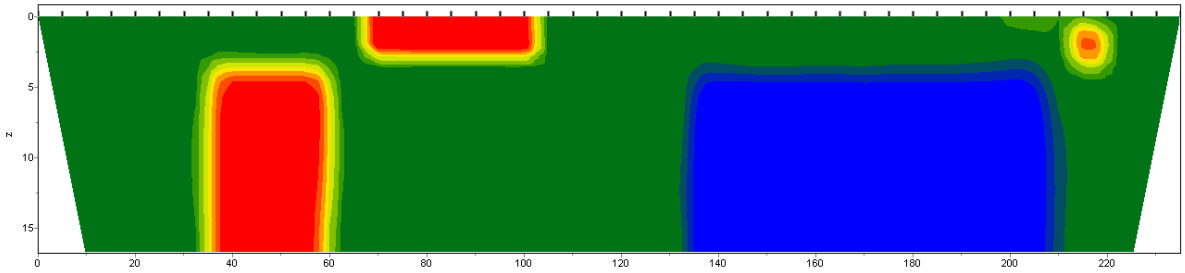
Matrix equation for this kind of inversion is the following:

$$\left(A^T W^T W A + \mu I\right)\Delta m = A^T W^T \Delta f \qquad (12)$$

Unwise usage of this inversion method modification can lead to receiving unstable results and increasing of RMS deviation, that is algorithm discrepancy.

The best option is to use ***Marquardt*** method as specializing (for misfit decrease) after ***Smoothness constrained*** or ***Occam*** inversion is performed.

Focused is inversion by least-square method with use of smoothing operator and additional contrast focusing [Portniaguine, 2000]. As a result of this algorithm piecewise smooth parameters distribution (that is model which consists of blocks with constant resistivity) can be received (pic. 17).



Pic. 17. Regenerated model as a result of ***Focused*** inversion

Matrix equation for this kind of inversion is the following:

$$\left(A^T W^T W A + \mu C^T R C\right)\Delta m = A^T W^T \Delta f - \mu C^T R C m \qquad (13)$$

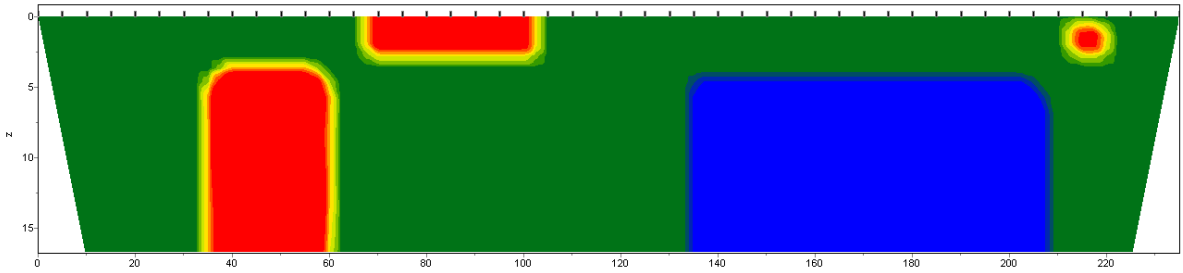
In case of using this type of inversion threshold contrast parameter **Threshhold** should be carefully selected. This parameter defines threshold contrast value for adjacent cells, if it is reached adjacent cells parameters are not averaged (it is considered that there is a boundary between these cells). Dependence of averaging degree (or weight) of two adjacent cells R_i on contrast threshold e and contrast between these cells r_i is the following:

$$R_i = \frac{e^2}{e^2 + r_i^2}. \qquad (14)$$

Blocks – fits parameters for certain domains which differ in resistivity. Domains with equal resistivity consider as single blocks (pic. 18).

Matrix equation for this kind of inversion is the same as for ***Marquardt*** algorithm:

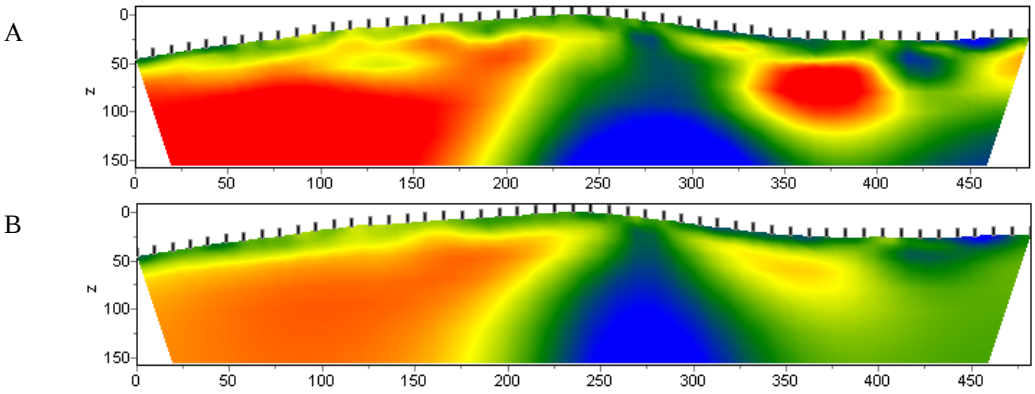
$$\left(A^T W^T W A + \mu I\right)\Delta m = A^T W^T \Delta f \qquad (15)$$



Pic. 18. Regenerated model as a result of ***Blocks*** inversion

It is recommended to use this algorithm for more precise definition of already received results of preceding methods (***Focused*** is the best option) after merging cells in necessary blocks using **Cell summarization** function. Model editor should be used to select certain blocks manually: certain domains should be assigned with different parameters. Certain domains will be highlighted by boundary while working with this dialog window.

Smoothing factor sets dependence of measurement misfit minimization on model misfit. In case of noisy environment or in order to receive smoother and more stable parameters distribution quite high smoothing parameter value is chosen: 0.5 – 2.0; 0.005 – 0.1 values are used for high quality data. High smoothing parameter values mostly lead to high data misfits (pic. 19). Smoothing factor is used in ***Occam*** and ***Focused*** inversion algorithms.



Pic. 19. Geoelectric models as a result of ***Occam*** inversion with **smoothing factor**: 0.01 (A) and 1.0 (B). Resultant misfit for case A – 4.5 %, case B – 6 %.

Robust weighting scheme – this option should be turned on if there are individual high deviations caused by systematic measurement errors. It is possible that current algorithm will not give positive results if amount of rejected data is comparable to amount of high quality data.

Stop criteria field contains inversion stopping criterion.

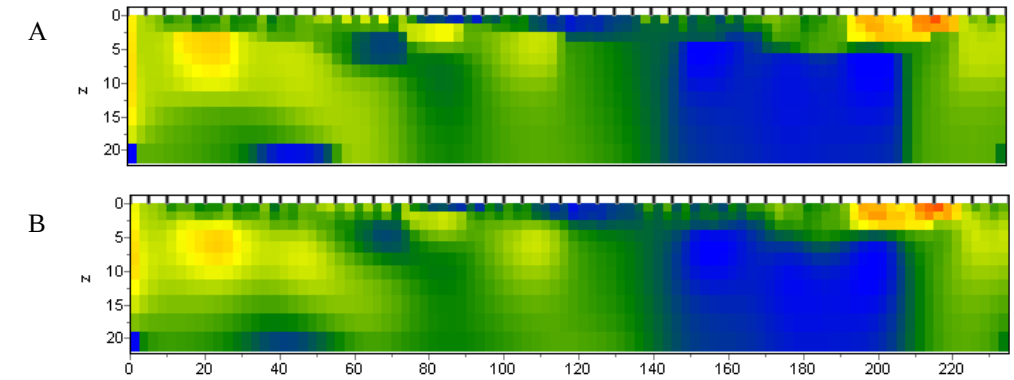
Iterations – if this function is ON inversion process stops as soon as specified iteration number is reached.

RMS error – if this function is ON inversion process stops as soon as specified RMS level is reached.

Reduction – if this function is ON inversion process stops as soon as RMS error increases repeatedly for two sequential iterations (on selected value, in percents).

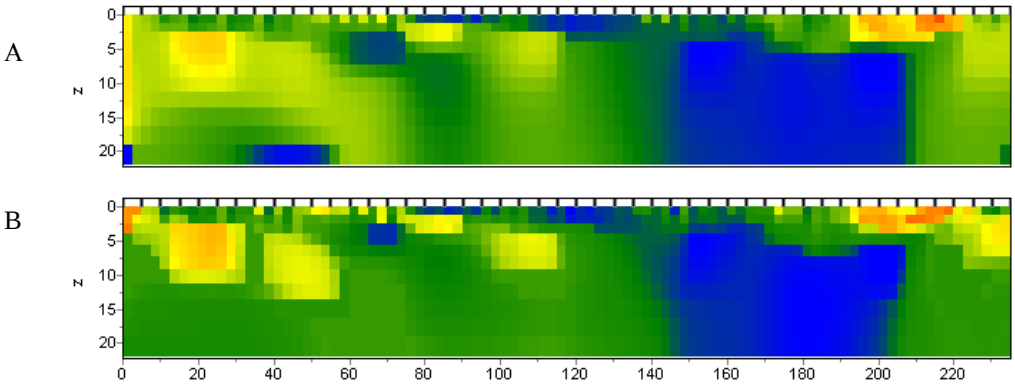
Focusing parameters field

Threshold – defines threshold contrast value for adjacent cells, and if it is reached adjacent cells parameters are not averaged (it is considered that there is a boundary between these cells). This parameter value is chosen empirically (0.001-1) (Pic. 20). Small parameter value can cause algorithm discrepancy (in this case it needs increasing). Large value leads to receiving smooth distribution.



Pic. 20. Geoelectric models as a result of ***Focused*** inversion with **Threshold** parameter: 0.01 (A) and 0.1 (B)

Sharpness – defines ratio between minimization of causative body volume (0) and construction of piecewise-smooth distribution (1) (pic. 21). Value of this parameter is chosen empirically (0.7).

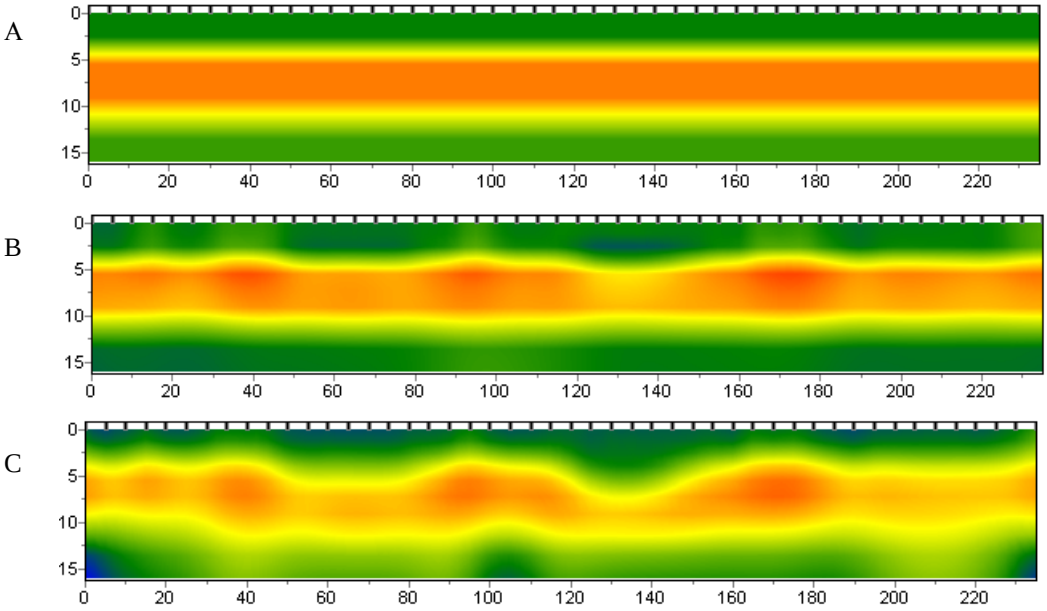


Pic. 21. Geoelectric models as a result of ***Focused*** inversion with **Sharpness** parameter: 0.8 (A) and 0.2 (B)

Focused filter – defines mechanism of focusing filter construction. If **Own** filed is selected, filter is constructed using current parameters (in current interpretation mode). If **Other** is selected, focusing filter based on other medium parameter is used. For example, resistivity model with boundaries which correspond to our idea about medium parameters is received. In order to create polarizability model with the same boundaries go to induced polarization method in data interpretation mode, and choose **Other** and **Threshold** value that corresponds to expected polarizability section specifics.

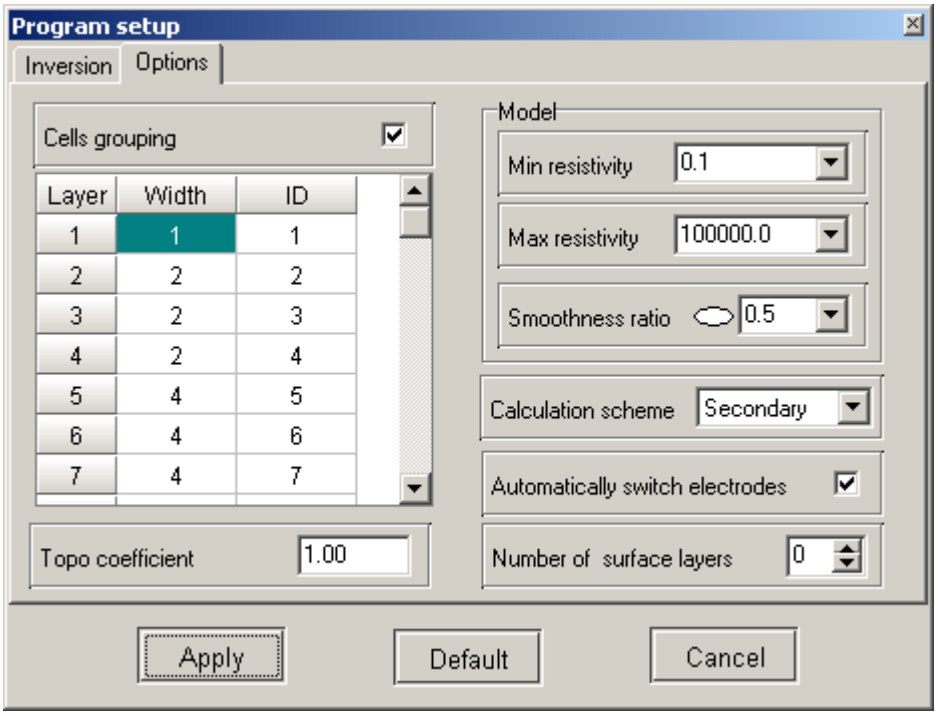
Use reference model – use starting model as a priori. If this function is ON resultant model will not differ much from the starting one (pic. 22). It is possible to use starting model for

inversion using ***Occam*** and ***Focused*** algorithms. Discrepancy between starting and final model can be regulated by changing ratio between minimization value misfit and model misfit. It means that the lower smoothing parameter value is the more significant discrepancy between starting and resultant model may be.



Pic. 22. Starting geoelectric model (A), geolectrical model as a result of ***Occam*** inversion with use of starting model (B) and without it (C)

Second tab **Options** serves for complementary inversion parameters setup (pic. 23).

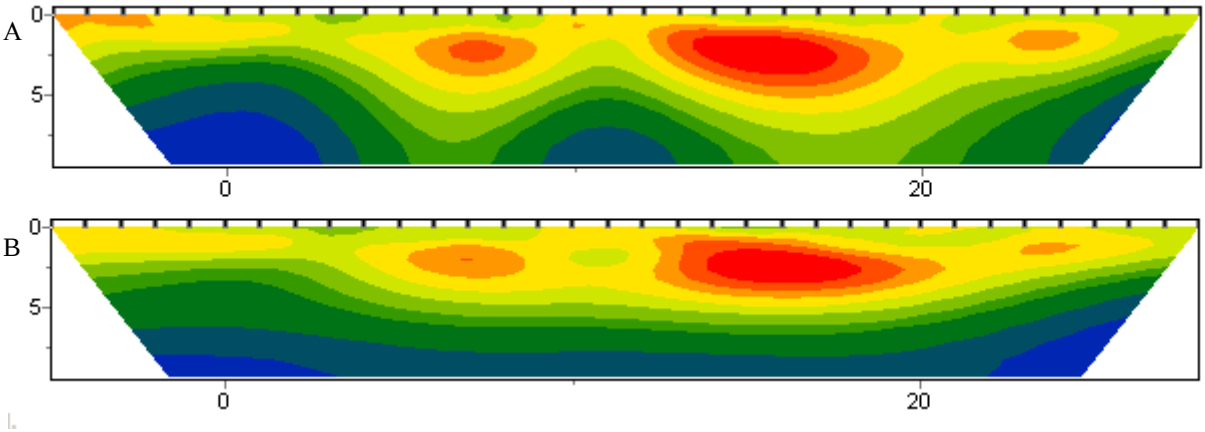


Pic. 23. **Program setup** dialog window, **Options** tab

Model field

Min resistivity, Max resistivity – set model parameters limits of variation for inversion.

Smoothness ratio – specifies smoothness ratio in horizontal and vertical direction. Set this parameter larger than 1 for vertically-layered subsurface and smaller than 1 for horizontally stratified earth. Usually this parameter value ranges from 0.2 to 1 (pic. 24).

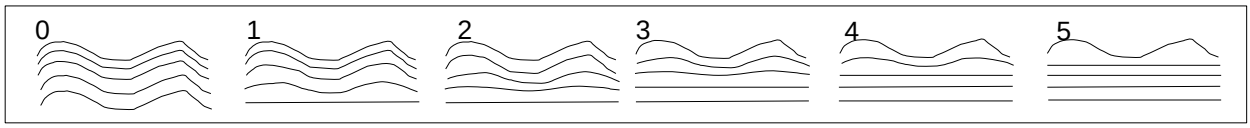


Pic. 24. Geoelectric model as a result of "smooth" inversion with **Smoothness ratio** parameter: 1 (A) and 0.3 (B)

Topo coefficient – sets relief distortion factor with depth (0-5). 0 – relief of next layer duplicates the previous one. 1 – relief is flattening with depth, the last layer is plane (pic. 25). Distorted depth is calculated using the following formula:

$$z^*(x,z) = Topo(x) + z \cdot \left(1 + \frac{\max(Topo) - Topo(x)}{\max(z)} \cdot Tcoeff\right), \qquad (16)$$

where Topo – relief excess, z – depth from surface.



Pic. 25. Model layer distortion with **Topo coefficient** parameter from 1 to 5

Number of surface layers (0-2) – sets number of layers in which strong variation of parameters is possible. Use 1 or 2 layers if near-surface section is very heterogeneous. This option should be used in low contrast mediums where main data anomalous effect is caused by near-surface heterogeneities.

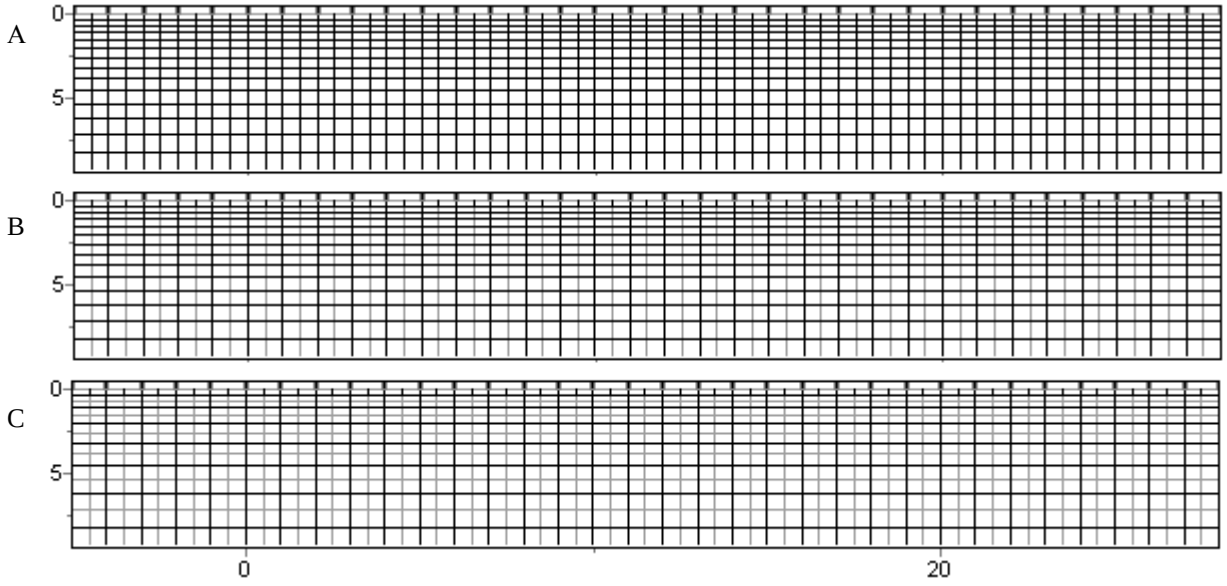
Cell grouping – use this option in the majority of models. It activates table that allows merging adjacent cells and receiving less determinate parameters for inversion. If this option is

used number of cells for forward solution remains the same but number of cells for inversion decreases. Ideally, number of determinate parameters should be close to amount of data.

The table contains three columns. Number of initial model layer is specified in the first column (**Layer**). Number of cells (in horizontal direction) that contain in every cell of inversion mesh for current layer is set in the second column (**Width**). Inversion mesh is displayed in model editor during setup. Double left click on cell in **Width** column to merge cells in horizontal direction for current layer, right click – for current and all underlayers.

Double left click on cell in **ID** column to merge cells in vertical direction for current layer, right click – for current and all underlayers.

There are three examples of inversion meshes below: in the first picture inversion mesh corresponds to model one (pic. 26A); in pic. 26B cells starting from the second layer merge by two; in the third picture cells starting from the second layer merge by four (pic. 26C).



Pic. 26. Examples of inversion meshes

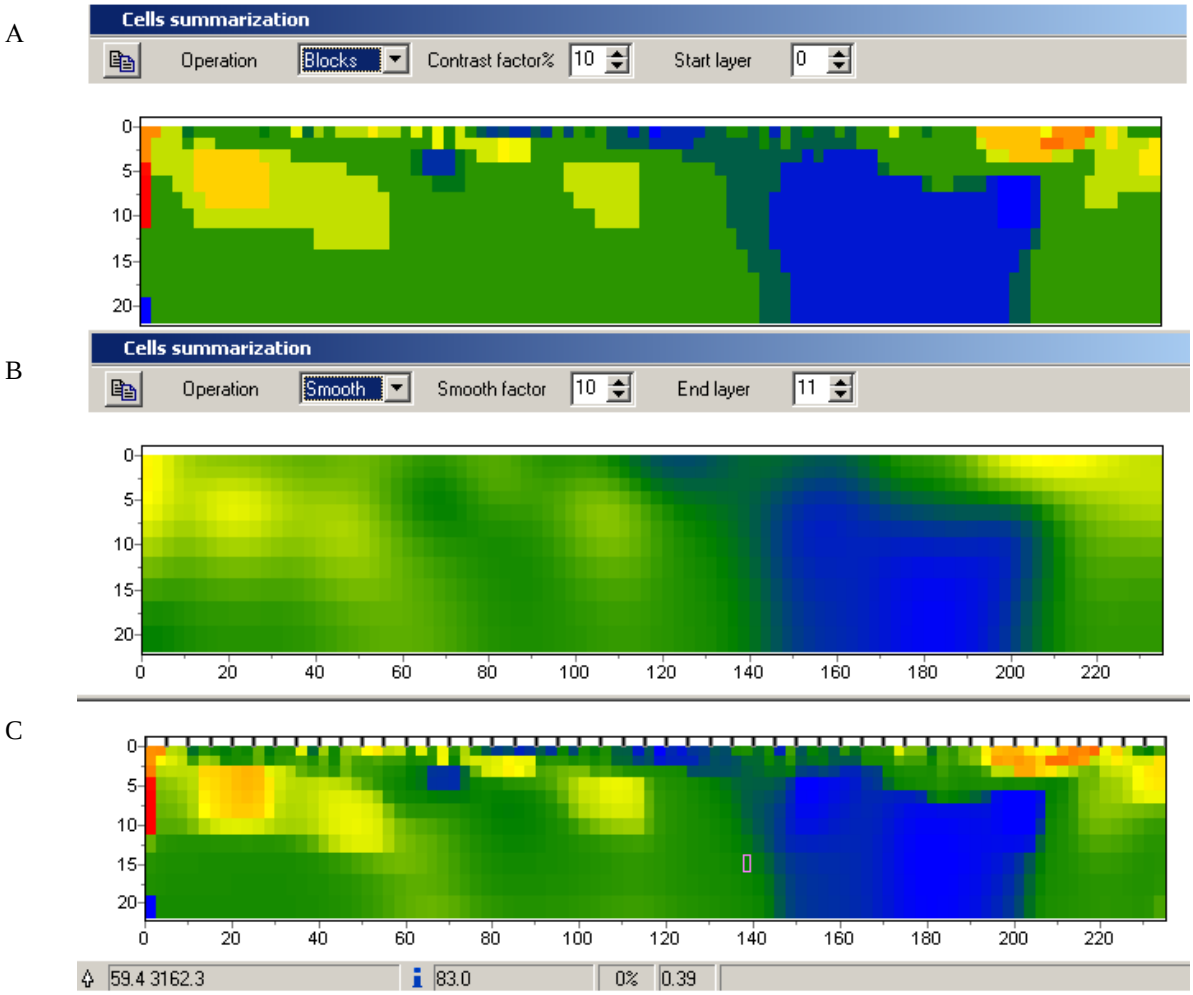
Calculation scheme (**Secondary, Total**) defines algorithm of electric potential calculation. Secondary potential is calculated if **Secondary** is chosen. This method is slower and does not allow taking surface topography into consideration but gives quite exact results if fairly crude mesh is used.

More detailed mesh (1 or 2 nodes between adjacent electrodes) and external model boundary shift further is necessary for total potential calculation (**Total**). It is due to low accuracy of potential determination near current electrode.

Automatically switch electrodes – if this function is ON current electrodes are automatically changed over in order to receive positive values of array factor.

Cell summarization dialog

Cell summarization option serves for smoothing or roughening current model (divide it into blocks). Block model can be used for inversion of ***Blocks*** type. Selecting parameters for each block is necessary then. It is advantageous to use focusing inversion prior to dividing into blocks.



Pic. 27. Example of smoothing (B) and dividing into blocks (A) geoelectric model (C) when **Cell summarization** dialog is used

In **Blocks** mode cells with similar parameters in constant value domain merge depending on **Contrast factor**. **Start layers** option sets layer number starting from which this operation is performed.

In **Smooth** mode cell parameters are averaged depending on **Smooth factor**. **End layers** option sets layer number in which this operation stops.

Button  copies received model to model editor.

Estimation of misfit as a result of inversion

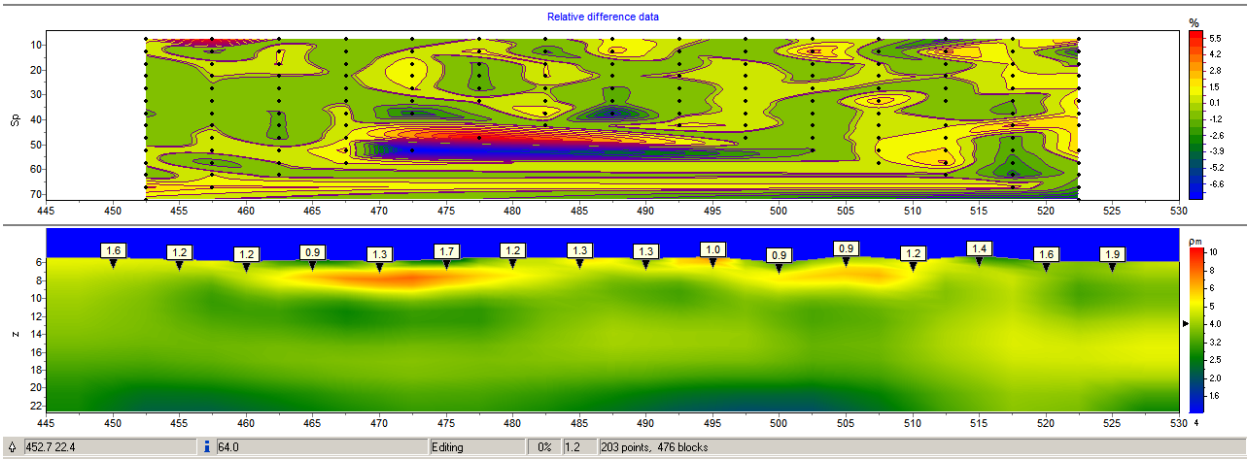
Express-evaluation of inversion result can be made by relative misfit value in the status bar of the program. As a rule the value will not exceed 5% if medium quality data is present.

Relative misfit pseudosection created using **Options/Data/Data Misfit** option can be used to estimate convergence between observed and calculated values for every measurement (pic. 28A).

Option **Options/Advanced/Electrode RMS** is used to view misfit of every electrode (pic.28B).

A

B



Pic. 28. A. Relative misfit pseudosection,

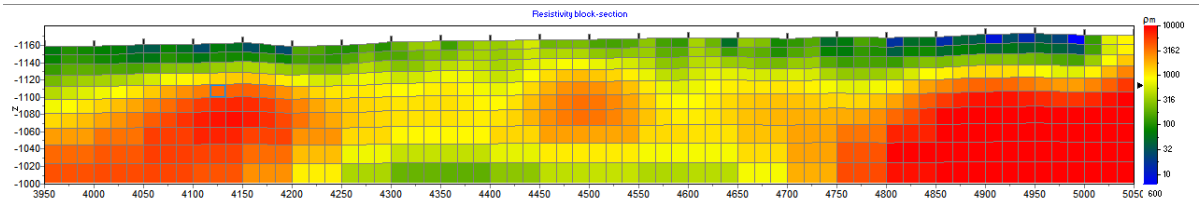
B. Model with displayed misfits of every electrode

In order to eliminate poor and ill-sorted data that leads to appearance of false anomalies after inversion, repeated data rejection based on misfit evaluation can be performed.

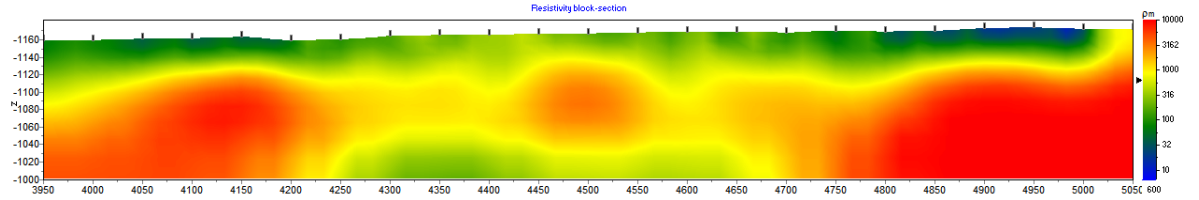
Model visualization modes and parameters

Model can be displayed as cells **Options/Model/Block-section** (pic.29A), in smooth interpolated palette **Options/Model/Smooth-section** (pic.29B) and as contour section **Options/Model/Contour-section** (pic.29C).

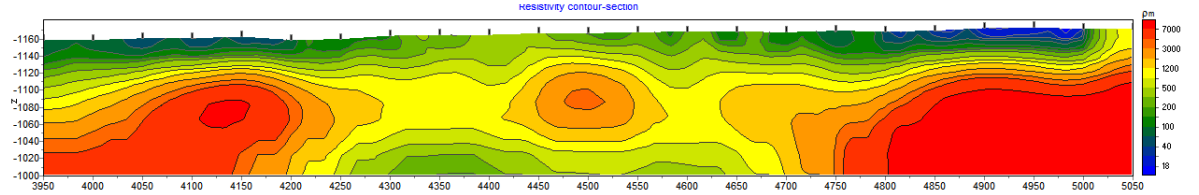
A



B



C



Pic. 29. Model display options:

Block-section (A), **Smooth-section** (Б), **Contour-section** (B).

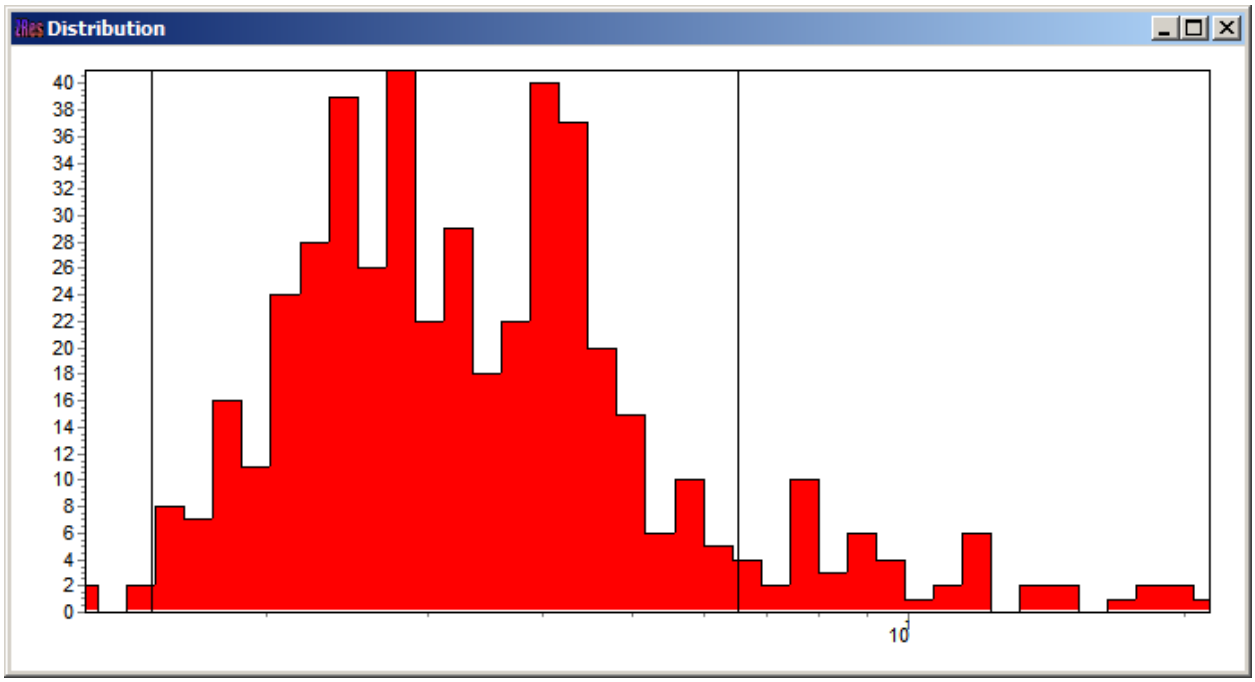
Double click in different domains of model editor to run context menu with the following options:

Top domain	Display model mesh	Display model mesh
	Display objects border	Display objects border
	Display colour bar	Display colour bar
	Setup	Run model parameters setup dialog
	Zoom&Scroll	Turn on zoom and scroll mode
	Print preview	Print model
Colour bar	Set minimum	Set minimum value of colour bar
	Set maximum	Set maximum value of colour bar
	Set incremental factor	Set minimum and maximum value of colour bar relative to value of host medium
	Automatic	Automatically select minimum and maximum value of colour bar
	Log scale	Set logarithmic scale on colour bar
	Set halfspace value	Set halfspace value of host medium

	Set cursor value	Set current value of the parameter

Model parameters setup dialog is described in *Appendix 6*: (for **Block-section** mode) and in *Appendix 4*: Pseudosection parameters setup dialog (for **Contour-section** mode).

To view model parameters distribution graph use **Options/Model/Histogram** dialog (pic. 30). Minimum and maximum of parameter colour scale can be set by changing vertical lines positions.



Pic. 30. **Distribution** dialog

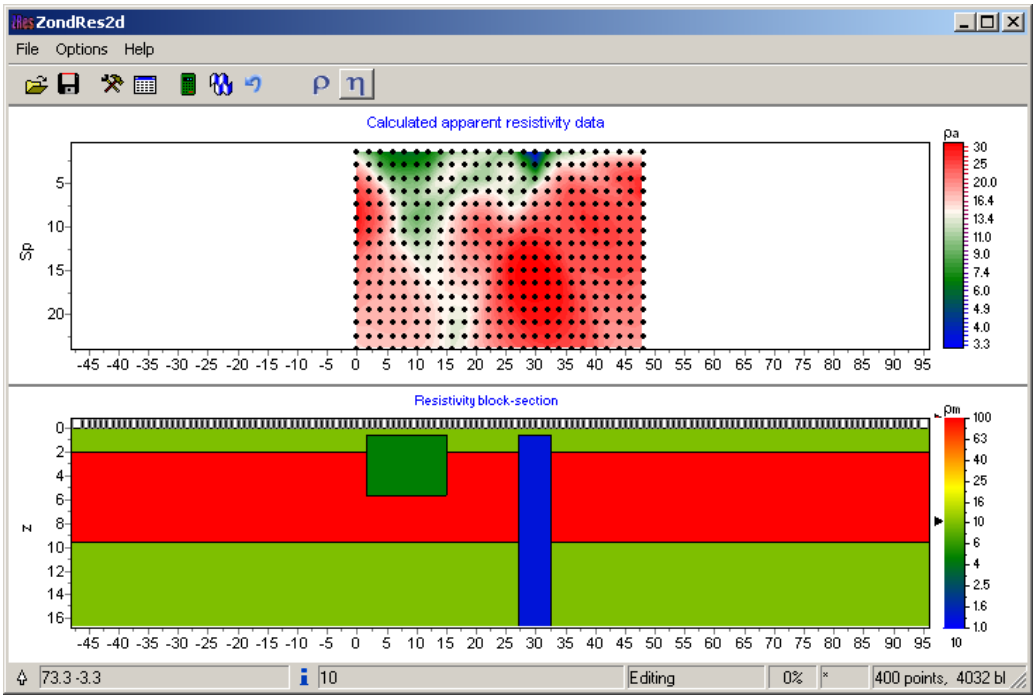
While moving the cursor in created windows coordinates corresponding to current window axes are displayed in left section of status panel of program main window.

Optional features depend on selected model display mode. It is more convenient to perform numerical modeling in **Block-section** mode. Total sensitivity distribution is displayed in **Contour-section** mode (use **Option/Model/Sensitivity** option). Potential and sensitivity distribution is displayed in **Block-section** mode or in interpolated palette in **Smooth-section** mode (see *«Additional features of visualization » for details).*

Border parts of the model are usually characterized by worse resolution. Very often these domains contain numerous false anomalies. **Options/Model/Cutting angle** option allows hiding model borders by specifying cutting angle (in degrees).

Modeling

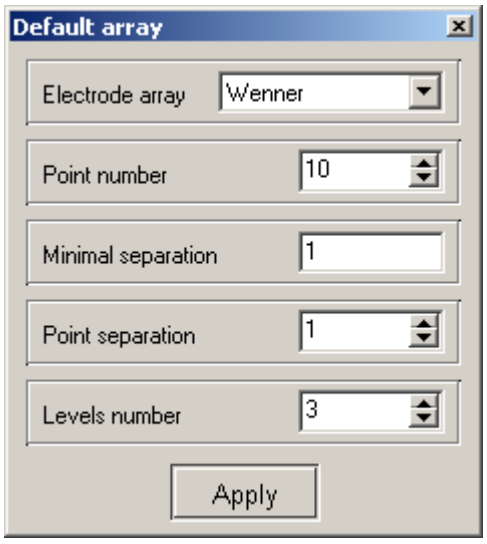
Modeling is an important process prior to field work. It allows choosing optimal parameters for measuring system in order to solve assigned geological task. Using initial information about the lead interpreter can model different geological situations while planning geophysical works.



Pic. 31. Active window of the program in modeling mode

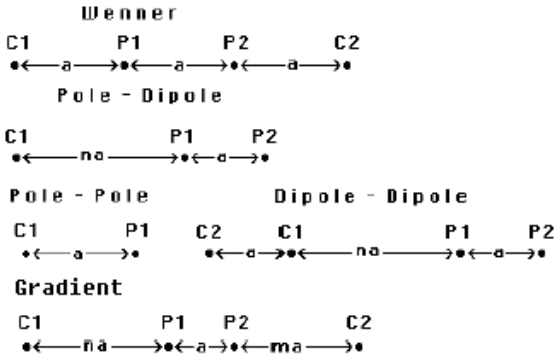
On the first stage measuring system parameters should be selected taking into consideration specifics and depth of burial of the object of interest, work conditions (relief, grounding conditions), and equipment capability. Use **File/Create survey** option to run measuring system parameters setup dialog (pic. 32).

Default array dialog



Pic. 32. **Default array** dialog window

Electrode array – sets array type.



Point number – defines number of source line/point positions on profile (for all array types except Wenner array). For Wenner array this option defines number of sounding points on profile. In this case sounding means set of measurements done by Wenner array whose centers coincide.

Minimal separation (**a**) – defines unit length (in meters) that distances between electrodes will be multiple of.

Point separation – sets distance (in 'a' units) between source line/point positions on profile (for all array types except Wenner/VES array). For Wenner array this option defines distance between adjacent soundings.

Potential line length and minimal distance from potential to current electrode are equal **a** (for all array types except Wenner array). For Wenner array potential line length ranges from **a** to **Levels number* a** value.

Levels number(n) – defines number of potential line positions for current source position (number of unique array geometric factors on profile). For **Gradient** array number of measurements within source-circuit doubles. For **Wenner/VES** array this option sets number of measurements whose centers coincide.

Press **Apply** button when array parameters setup is finished mesh, parameters setup dialog **Mesh constructor** appears then (*see «Starting model setup dialog » for details*). Specify host medium resistivity (and polarizability) in **Half-space resistivity** field (and in **Half-space polarizability** field). After pressing **Apply** button in main window panel functional buttons to work with data activate, and brief information about data and model appears in the right section of status panel.

Model editor

Geoelectric medium creation is performed in model editor (bottom graphic section of program window in **block-section** mode).

Model editor serves for changing certain cell parameters using mouse. To the right of model edit region there is a colour bar that connects colours and resistivity values. Right click on the scale to select current value; this value will be displayed below colour bar.

Work with model cells is similar to raster image editing in graphics editor. When you move cursor in model domain coordinates and parameters of active cell are displayed in the bottom status panel of program main window. Current active cell is highlighted by rectangular – cursor. Selected or fixed cell is marked by white or black dots pattern.

Double click on vertical and horizontal axes and right click in model edit region to run context menu that contains options to edit mesh created in **Mesh constructor** dialog.

Vertical axis	Log scale	Set logarithmic scale on vertical axis
	Set maximum	Set bottom layer depth value
	Redivide	Set equal thickness for all model layers (in current scale)

	Thick mesh	Delete every second node of vertical grid
	Thin mesh	Add intermediate nodes in vertical grid
Horizontal axis	Redivide	Set equal width of cells situated between unique positions of electrodes
	Thick mesh	Delete every second node of horizontal grid (if there is no electrode in this node)
	Thin mesh	Add intermediate nodes in horizontal grid

Right click in model editor domain to run context menu that contains the following options:

Display cell setup	Run cell parameters setup dialog
Cell to cursor value	Use active cell parameter as current value
Edit mode	Run Edit mode
Selection\Free form selection	Highlight set of cells within edit region using mouse. Field is limited by user.
Selection\Rectangular selection	Highlight set of cells within edit region using mouse. Field has rectangular form.
Selection\Elleptical selection	Highlight set of cells within edit region using mouse. Field has elliptic form.
Selection\Magic wand	Highlight set of cells within edit region using mouse. Active cell and adjacent cells whose parameters are close to its parameter are highlighted. Proximity is specified in model parameters setup dialog.
Selection\Remove selection	Delete selected
Mesh options\add column /row	Add new vertical or horizontal boundary. Click in necessary point to creat new boundary there.
Mesh options\remove column /row	Delete selected vertical or horizantal axis
Mesh options\resize column /row	Change row or column thickness using mouse
Clear model	Clear current model

Work with model

Use mouse to work with model.

Left click on cell to set its parameter current value.

Zooming in or dragging some part is performed in **Zoom&Scroll** mode with pressed button. To zoom in a segment move mouse cursor down and to the right with left button pressed. To return to primary zoom do the same but with mouse cursor moving up and to the left

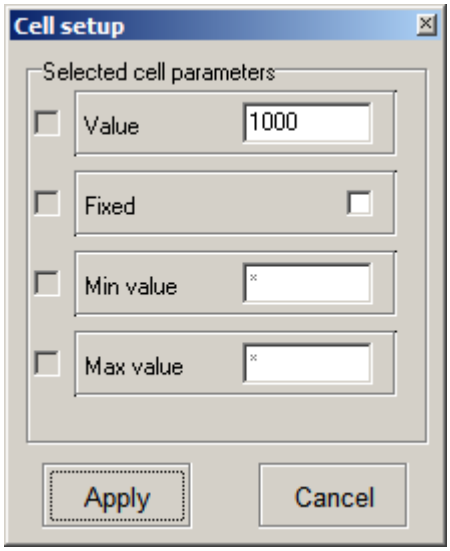
In order to efficiently create a model there are a few cell selection modes in the program: rectangular, elliptical and free form selections or by certain parameter value. Right click in model edit region to run appropriate options (*see* «***Ошибка! Источник ссылки не найден.***» *for details*).

Left click on the cell with SHIFT button pressed to increase cell parameter. Right click on the cell with SHIFT button pressed to decrease it. Percentage of change can be set in model parameters setup dialog. If active cell is included in selection, all changes described above are applied to the whole selection.

Click on the cell with CTRL button pressed to drag selected set of cells within edit range using mouse. While dragging the selection with left button pressed content of selected cells copies to new domain. While dragging the selection with right button pressed content of selected cells is cut and pasted to new domain.

Parameter value can be also assigned to selected cells using cell parameter setup dialog **Cell setup** (pic. 33).

Cell parameter setup dialog



Pic. 33. **Cell setup** dialog window

This dialog serves for selecting cell parameters or highlights it.

Value – sets cell parameter value.

Fixed – fixes or frees cell parameter.

Min value, **Max value** – sets cell parameter size of changing.

Apply to selected – uses current settings for all selected cells if this function is ON.

It should be noted that changing modes (resistivity/polarizability) does not change selected domain.

The main purpose of mathematical modeling is signal level estimation and acquisition geometry resolution evaluation. Press  button in the tool bar to calculate apparent parameters response in specified geoelectric model (forward solution).

It is possible to regenerate starting model, that is to solve inverse problem using calculated from current model data, if theoretical signals are saved with filter - **Zond calculated data**, and then opened as observed data. Use **Import model/data** option (*see «**Ошибка! Источник ссылки не найден.**» for details*) to compare regenerated and starting model but preliminary save starting model with filter - **Zond model with calculated.**

Use **Options/Advanced/Open in modeling mode** option to model geological situation for certain acquisition geometry.

Saving interpretation results

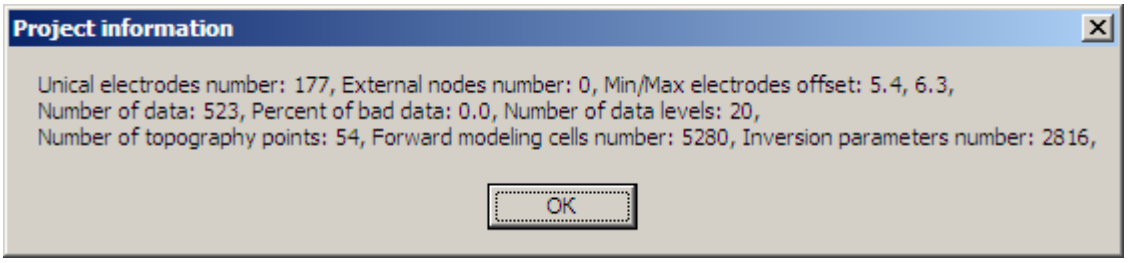
Profile interpretation result is hold in «ZONDRES2D» file format (extension *.z2d) *(see «Main data file format» for details***)**. Field data, relative measurement weights, and current subsurface model is saved in this file. Data from the file is used for further load and subsurface model creation.

Use  button in the tool bar or corresponding menu option **File/Save file** to save interpretation result. This dialog also allows choosing file format to save observed (**Observed**) and calculated for current model (**Calculated**) apparent resistivity and polarizability values and images (**Model**, **WorkSheet**) in *.BMP format in necessary scale. Use **Options/Import/Export/Output settings** dialog (*see «**Ошибка! Источник ссылки не найден.**» for details*) to adjust image scale.

Zond project data	Save observed data and current subsurface model
Zond calculated data	Save calculated data
Zond observed data	Save observed data

ProfileR observed data	Save observed data in ProfileR format
ProfileR calculated data	Save calculated data in ProfileR format
Res2dInv observed data	Save observed data in Res2dInv format
Res2dInv calculated data	Save calculated data in Res2dInv format
Worksheet	Save three graphic section of the window in BMP format
Model	Save bottom graphic section of the window in BMP format. Use **Output settings** dialog to adjust image scale.
Program configuration	Save inversion parameters of the program
Zond model with calculated	Save calculated data and current subsurface model
Grid file	Save data file of the model
Section file	Save current model in SectionCorrector format

Project information



Pic. 34. **Project information** dialog window

Use **File/Project information** option in the main menu to view current project information. The following information is displayed sequentially in the dialog:

- Number of unique current circuit or electrode positions;

- Minimum/ maximum separation;

- Number of measurements;

- Percentage of rejected data (compared to total quantity);

- Number of unique separations;

- Number of topography measurements;

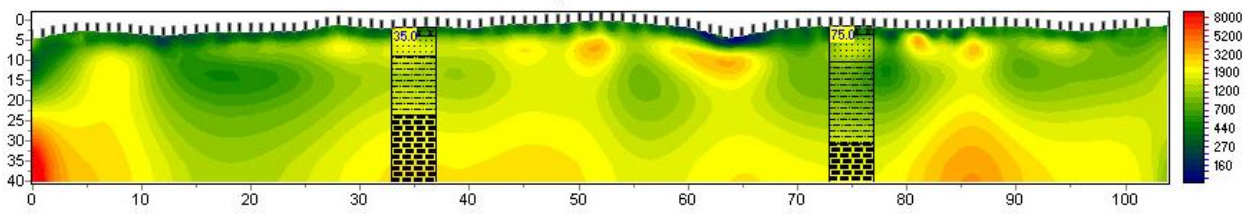
- Number of cells used for forward problem solution;

- Number of cells used for inverse problem solution.

Data import and export

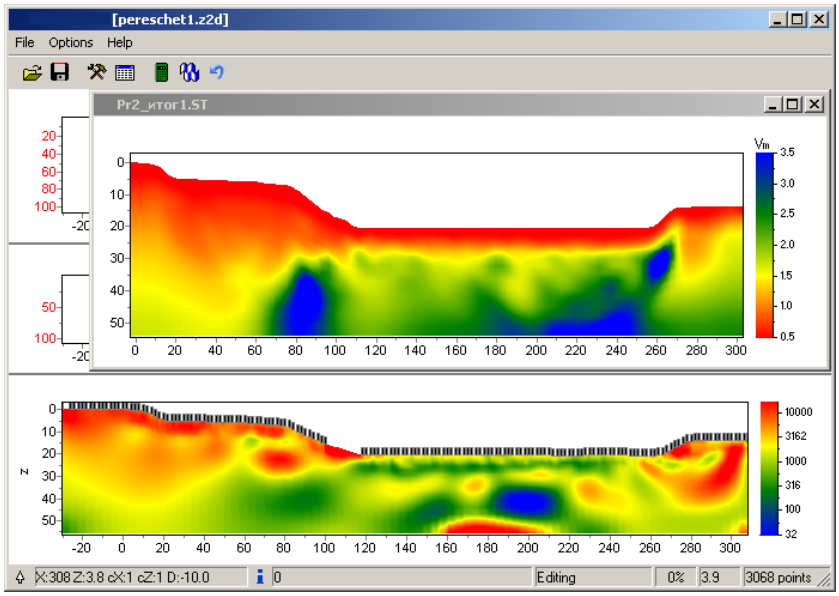
Integration of geophysical methods and accounting a priori information are the best methods to enhance interpretation data quality. There are a few ways of a priori information visualization in the program. **File/Import/Export** option allows loading different geological and geophysical information including lithologic columns, logging data, profile measurements as graphs, models built in other Zond programs, graphic image as base of section (for example, geological or seismic section).

Logging data and lithologic columns if present can be also loaded using **Import/Export/Carotage data** option (pic. 35). *See file format description in «Logging and lithology data file format ».* Sample in folder – sample with_bhdata.



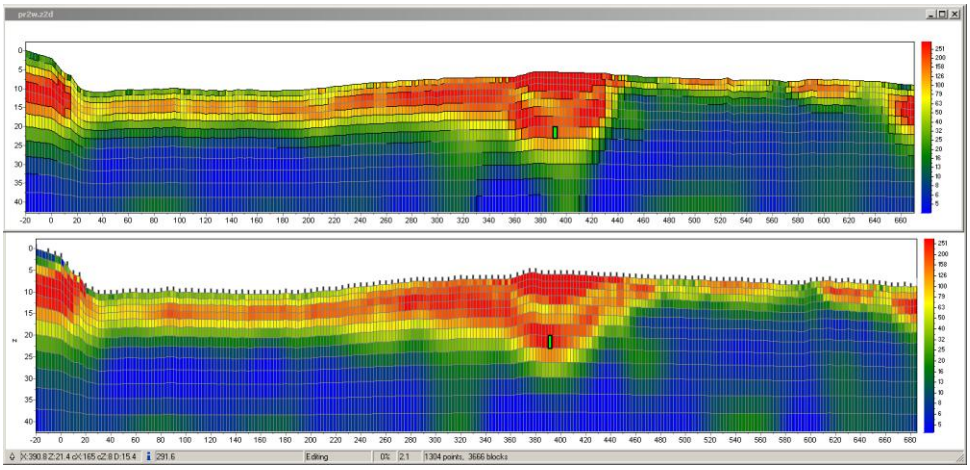
Pic. 35. Resistivity model with plotted lithologic columns

Option **Import/Export/Import/model/data** allows loading model from ZOND software package projects in separate windows (pic. 36). It can be useful to compare interpretation results from adjacent profiles and in case of integrated interpretation of data received from different methods.



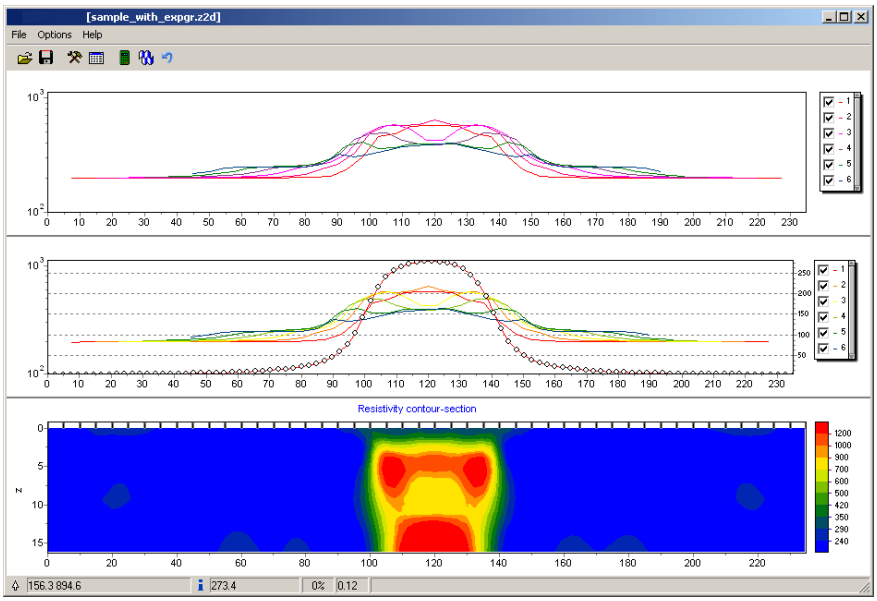
Pic. 36. Active window of the program with imported velocity model

While moving the cursor in model editor it will be displayed in all imported sections in concordance with current cell size in block model (pic. 37).



Pic. 37. Visualization of κesistivity models (both working and imported as blocks) with highlighted cursor

If two-column *.dat file is used as imported file, connected to the right axis plot is displayed in window with calculated data (in **graphics-plot** mode) (pic. 38). Sample in folder – sample_with_exported_graphic.



Pic 38. Active window of the program with imported graph of anomalous magnetic field

First column of *.dat file contains horizontal coordinates of point along profile, the second contains measured values.

Run pop-up menu using right click with SHIFT button pressed on axis or graph to open object parameters setup dialog.

Use **Save/Load selection** option to save or load some part of the model. In block mode (**Blocks-section**) highlight necessary domain using **Selection** options and press **Save selection (Selection** option *is described in «**Ошибка! Источник ссылки не найден.**»*).

To load some part of the model highlight necessary domain of current model. It will be inserted starting from top left border of the selection. Run **Load selection** option and choose file name. If there is no selection, fragment will be inserted starting from top left border of the model.

Use **Extract 1d log / Load 1d log** option to save or load vertical parameter profile to specified horizontal coordinate. Set X coordinate in dialog window to save vertical profile. Select X coordinates range to load vertical profile. This option can be used to take into consideration logging data and to study points of profile intersections.

Run **Import/export/ Section file** option to use a priori information if present as base for model editor. A priori information may include geological, electric or seismic cross-sections and adjacent profile section. In order to do this select **half-space transparency** mode in setup dialog.

After that download graphic image in *.sec format on scale. Sample in folder – sample_with_sectfile.

Fiel *.sec has the following structure:

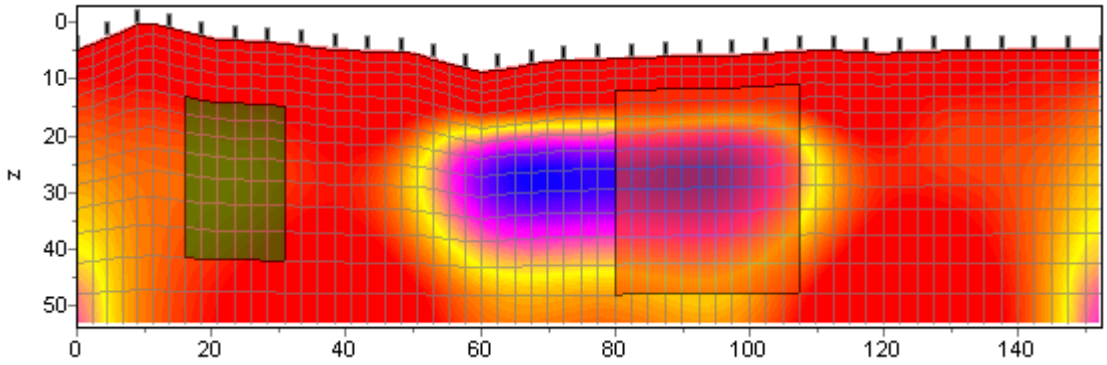
1st line – image file name;

2d line – four coordinates X1 Y1 X2 Y2 of top left and bottom right corner of the image spaced.

sect.emf

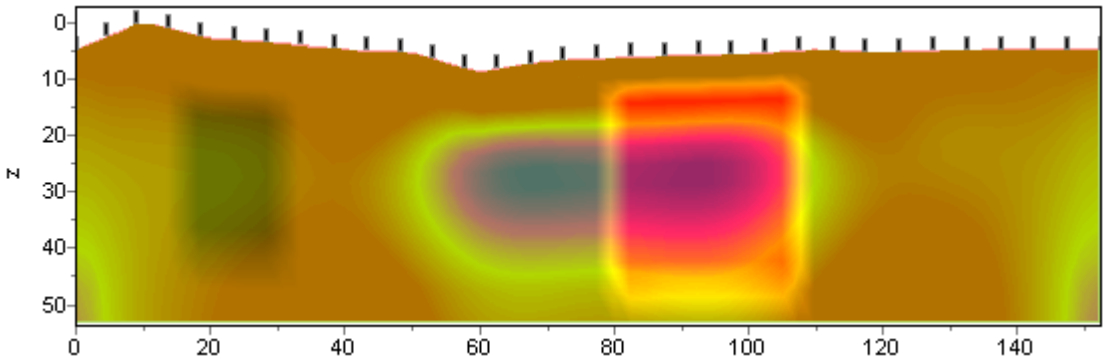
0 0 152.4 53.3

Cells with different from host medium values will be displayed in **Blocks section** mode. Thus it is possible to model anomalies over the base (pic.39).



Pix. 39. Model in **Block-section** mode with base

In **Smooth section** mode colours of base and current model are mixed and thereby specifics of two sections can be seen (pic.40).

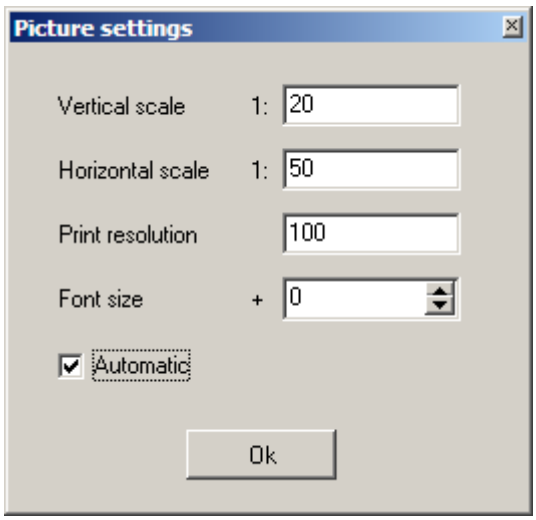


Pic. 40. Model in **Smooth-section** mode with base

Different options for data and resultant model export are *described in «Saving interpretation results »*. Data file can be exported to most popular program formats: RES2DINV (Geotomo Software, M.H. Loke), SENSINV2D (Geotomographie, T. Fleschner), ABEM data and ProfileR (A. Binley). For further geological interpretation and report graphics preparation it is possible to save current model in data file. In order to import model to other Zond programs save it in SectionCorrector program format. **Output settings** dialog allows saving model as raster image of certain resolution and size.

Outbound image setup dialog

Output settings dialog allows adjusting vertical **Vertical scale** (in meters per sm), horizontal scale **Horizontal scale** (in meters per sm), image resolution Print resolution (in DPI) and font size **Font size**.



Pic. 41. **Picture settings** dialog

These settings are applied to model saved in BMP format , only if **Automatic** option is ON. Otherwise the same image that is displayed on the screen will be saved.

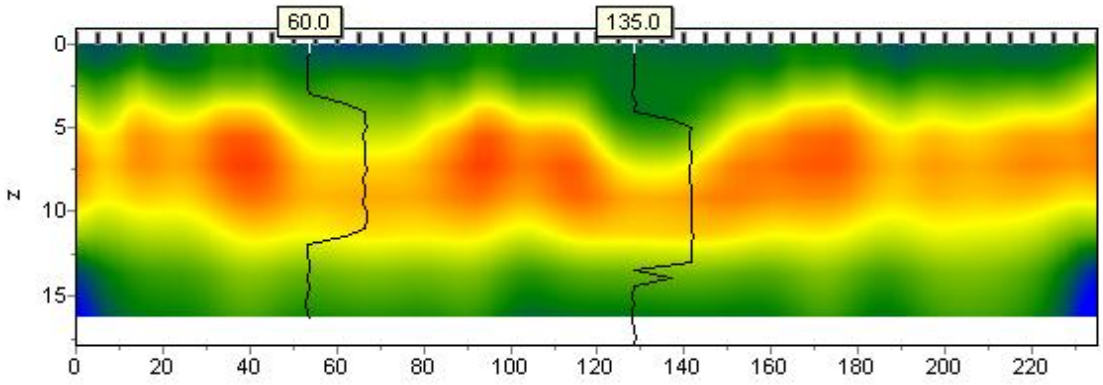
Logging and lithology data file format

Logging data and lithologic columns are hold in certain file formats. First type of files has txt extension; these files contain logging and lithology data. The following structure is used to create logging data file:

First column contains measure point depth (from surface), second column contains well log measurements. Third and forth columns are filled with zeroes.

Logging data sample-file is given below:

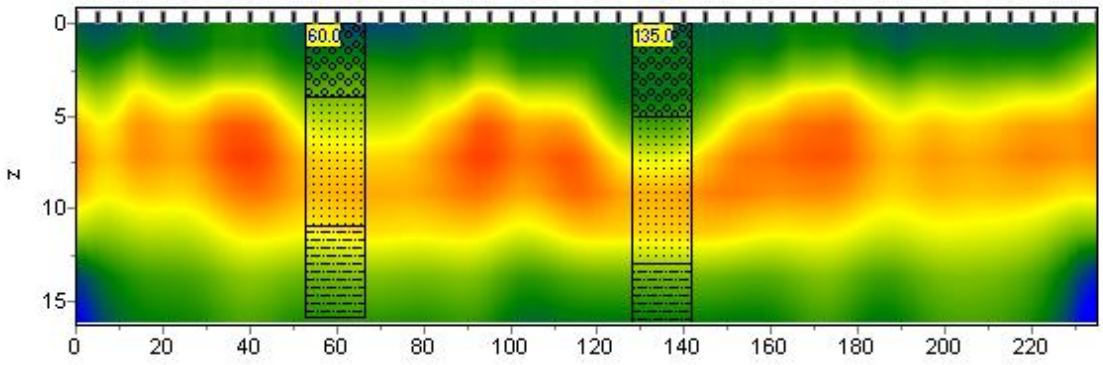
0.5	118.3035394	0	0
1	126.9002384	0	0
1.5	123.4170888	0	0
2	116.1519574	0	0
2.5	117.240884	0	0
3	111.9424174	0	0
3.5	142.0405875	0	0
4	125.3686538	0	0
4.5	521.0730567	0	0
5	735.5232592	0	0
5.5	707.7315998	0	0
6	706.3561614	0	0
6.5	725.9945623	0	0
7	722.433627	0	0
7.5	717.0991126	0	0
8	716.9836552	0	0
8.5	725.5024012	0	0
9	722.3551713	0	0
9.5	731.5717173	0	0
10	723.5097884	0	0
10.5	726.8844987	0	0
11	725.962034	0	0
11.5	743.2485878	0	0
12	726.4061156	0	0
12.5	734.399887	0	0
13	727.9166309	0	0
13.5	116.1921851	0	0
14	517.9613065	0	0
14.5	125.3706264	0	0
15	111.2952478	0	0
15.5	131.911879	0	0
16	107.9217309	0	0
16.5	114.9327361	0	0
17	134.0939196	0	0
17.5	138.4457143	0	0
18	129.1165104	0	0



Pic. 42. Model with plotted well logs

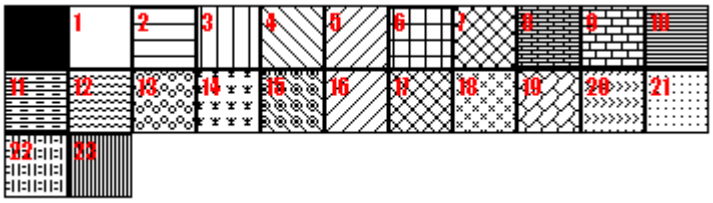
The following structure is used to create lithology data file:

First column contains lithologic layer depth (from surface). Second column is filled with zeroes. Third column defines layer colour for visualization, forth – type of pattern.



Pic. 43. Model with plotted lithologic columns

First 23 patterns for lithologic column creation are given below (pic.44).



Pic. 44. Types of lithologic pattern

Lithologic data sample-file is given below:

0 1 0 13 Top of layer 1

4 1 0 13 Bottom of layer 1

4 1 0 19 Top of layer 2

11 1 0 19 Bottom of layer 2

11 1 0 27 Top of layer 3

16 1 0 27 Bottom of layer 3

Second type of files has *.crt extension; these are control files which specify type of data and way of visualization. Structure of CRT file for lithology and logging data visualization for any quantity of wells is described below.

2280.txt First line – logging or lithology data file

скв2280 Second line – Well name (is displayed on well)

18 2 2 1 0 1 0 0 Third line contains control parameters -

Data record 18 – well coordinate on profile.

2 – image width (in percents to profile length, usually 1 - 20).

2 – type of data visualization 0 - 3.

0 - logging data (as graph); Sample-file - carot1.crt

1 - logging data (interpolated colour column), section colour scale is used for visualization; Sample-file - carot2.crt

2 - lithologic column; Sample-file - strati.crt

3 - logging data (colour column), colours for data visualization correspond to model colour scale, column colours are selected in compliance with model colour scale;

1 – Logging data normalization parameter 0 - 2.

0,1 – the same minimum and maximum is used for all data;

1,2 - subtract average value from every well log;

0 - Logging method index (if different logging methods are displayed indices of all methods should be specified) 0 – n-1, where n – number of methods.

1 – Plot colour.

0 – Data scale is logarithmic 0 or linear 1.

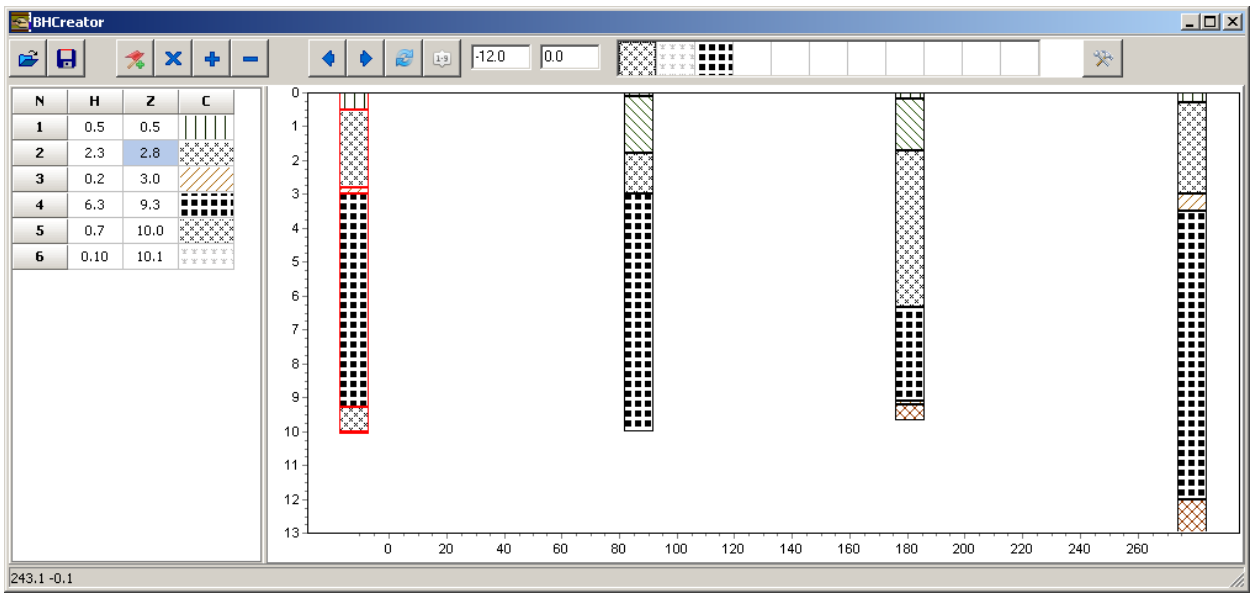
0 – Vertical well shift relative to the earth's surface.

3246.txt Description of the following well on profile

скв3246

102 2 2 1 0 1 0 0

It is recommended to use **BHEeditor** to create lithology data file.



Pic. 45. Active window of **BHEeditor** program

Additional features of visualization

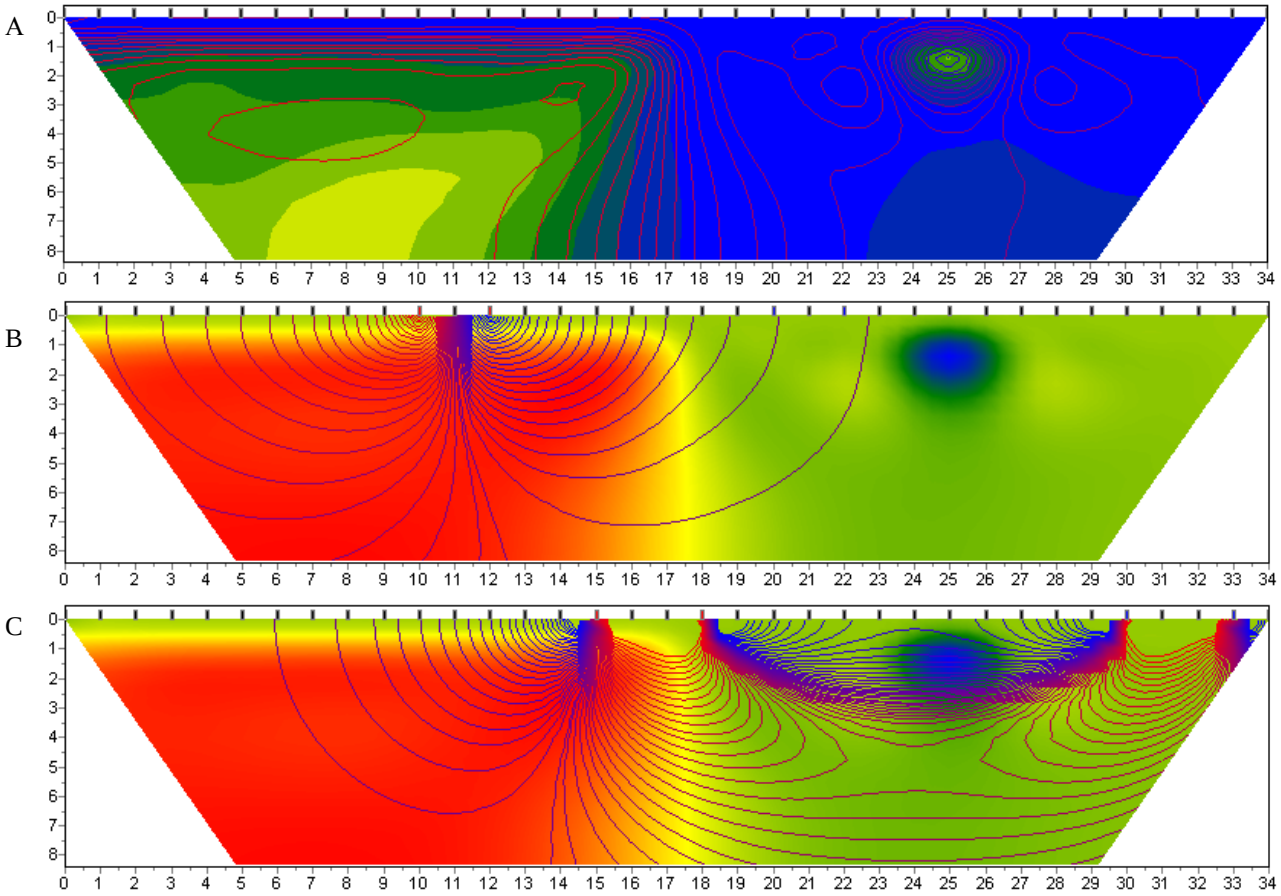
The program operates with the following types of images:

Two parameters simultaneously – resistivity and polarizability. Contours of one parameter overlay contours of another (in **Contour-section** mode) (pic. 46A). To run this option use **Options/Advanced/Display both** in the main menu. Use **Options/Advanced/Isoline setup** dialog to adjust parameters of second parameter contours.

Potential and sensitivity distribution analysis gives better understanding of electrotomography principle of operation.

Potential distribution – potential contours are displayed over section for any source (pic.46B). Source position is selected in electrodes editor. This option works in Block and Smooth section modes. Use **Options/Advanced/Distribution/Potential** in the main menu to run it. Press button in electrodes editor to activate contour parameters setup dialog. This dialog is similar to pseudosection parameters setup dialog (*Appendix 4*: Pseudosection parameters setup dialog).

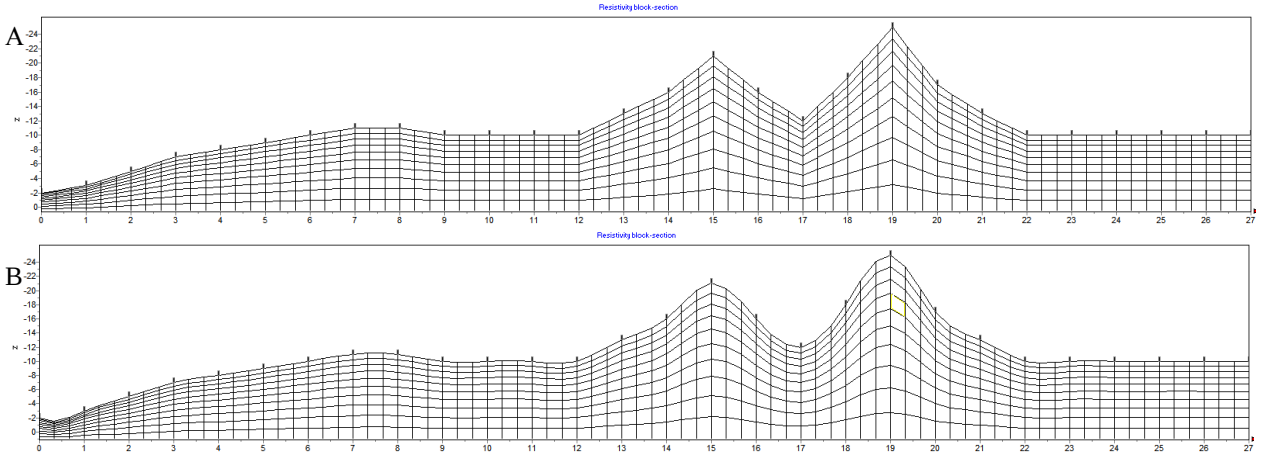
Sensitivity function distribution – sensitivity contours are displayed over section for current measurement (pic.46C). Measurement is selected in electrodes editor table. This option works in Block and Smooth section modes. Use **Options/Advanced/Distribution/Sensitivity isoline** in the main menu to run it. Press button in electrodes editor (**Options/Electrode editor**) to activate contour parameters setup dialog. This dialog is similar to pseudosection parameters setup dialog (*Appendix 4*: Pseudosection parameters setup dialog).



Pic. 46. A. Resistivity section with plotted polarizability contours. B. Resistivity section with plotted potential function contours. C. Resistivity section with plotted sensitivity function contours.

Specifics of work with topography data and marine measurements

It is important to specify model with due account to measurement surface relief [Dahlin, Loke, Oldenburg]. There are different keys in the program for fast and proper relief data entry (*see «2nd part of data file: » for details*). Option for topography smoothing (**Options/Advanced/Smooth topo**) is recommended in case of rough terrain (pic. 47). This option should be turned on before opening data file.



Pic. 47. Model mesh without smoothing (A) and with it (B)

In order to take into account relief beyond model domain complementary nodes should be added on model borders (**Options/Advanced/ Extended node**). This option should be turned on before opening file. Complementary nodes can be also added in the file before topography description, after *** key.

You can find detailed description of **Topo coefficient** option which allows specifying relief distortion with depth in *«Data inversion» chapter.*

Option **Options /Model/Extend bottom** turns on/off extension of bottom cells of the model.

On default relief excesses are plotted relative to zero but if **Options/Advanced/Real topo coordinates** option is used relief excesses specified in file are displayed (with opposite sign).

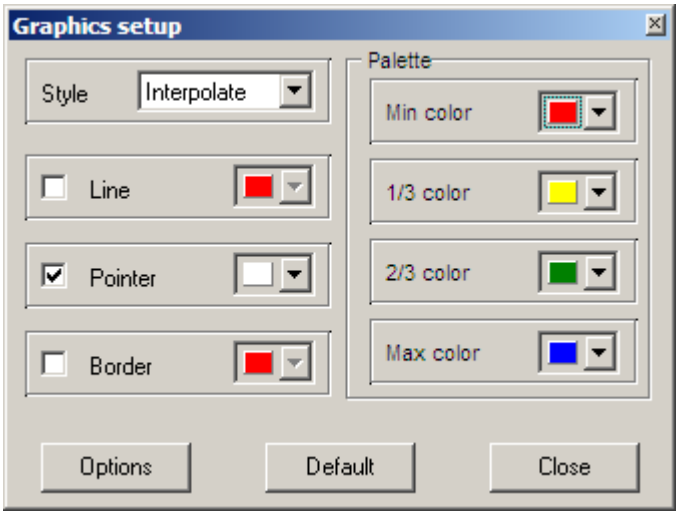
Option **Options/Advanced/Real topo coordinates** should be turned on to save **Grid file** with actual excesses in outbound file.

It is desirable to have water resistivity values for marine survey data interpretation. Use selection option **Options/Advanced/Inverse procedure/Underwater options/ Invert** if water resistivity data is absent.

Water resistivity can be specified using **Options/Advanced/Inverse procedure/Underwater options/ Resistivity** option.

Use **Options/Advanced/Inverse procedure/Underwater options/ Sublayers number** option to specify number of water layer splits. It depends on water layer thickness.

Appendix 1: Graphics set editor



Graphics set editor serves for colour adjustment of graphics set.

Option **Style** defines algorithm of graphic's colour palette specification.

Interpolated palette is used if **Interpolate** is selected. It is created using colours specified in fields **min colour**, **1/3 colour**, **2/3 colour** и **max colour**. Value **const** sets the same colour (option **colour**) for all graphics. Value **random** assigns random colours for all graphics.

Option **Line** sets colour for graphic's connecting lines. If this function is OFF palette colour is used otherwise specified in **Line** field colour is used.

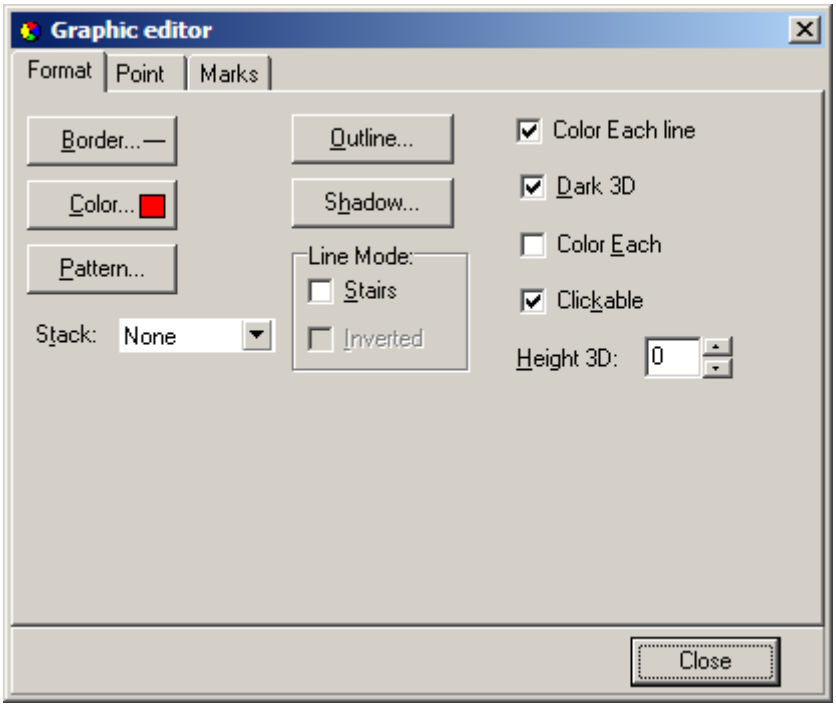
Option **Pointer** sets colour for graphic point's colour fill. If this function is OFF palette colour is used otherwise specified in **Pointer** field colour is used.

Option **Border** sets graphic point's outline color. If this function is OFF palette colour is used otherwise specified in **Border** field colour is used.

Button **Options** runs graphics setup dialog.

Button **Default** returns graphics default settings.

Appendix 2: Graphics editor



Graphics editor serves for graphic interface adjustment. Right click with SHIFT button pressed on graphic to run it.

Tab **Format** contains connecting line settings.

Button **Border** runs connecting line parameters setup dialog.

Button **Colour** runs colour setup dialog.

Button **Pattern** runs filling parameters setup dialog.

Button **Outline** runs graphic's connecting line setup dialog.

Button **Shadow** runs shadows setup dialog.

Tab **Point** contains plot point settings.

Option **Visible** is used to show/hide plot points.

Option **Style** sets point shape.

Option **Width** sets point width in display units.

Option **Height** sets point height in display units.

Option **Inflate margins** defines if image size is zoomed in according to point size or not.

Button **Pattern** runs point's colour fill setup dialog.

Button **Border** runs point's outline parameters setup dialog.

Button **Gradient** runs point's gradient colour fill setup dialog.

Tab **Marks** contains settings of graphic's point marking.

Tab **Style**.

Option **Visible** is used to show/hide plot point marking.

Option **Draw every** allows plotting every second, third and so on marking depending on selected value.

Option **Angle** sets point marking rotation angle.

Option **Clipped** defines whether point marking is plotted or not if it is located beyond graphic borders.

Tab **Arrows** allows adjusting arrow from marking to point.

Button **Border** runs arrow line parameters setup dialog.

Button **Pointer** runs arrowhead shape setup dialog (options in tab Point).

Option **Length** sets arrow length.

Option **Distance** sets distance between arrowhead and plot point.

Option **Arrow head** sets type of arrowhead. **None** – arrowhead specified by **Pointer** button is used. **Line** – classic thin arrowhead is used. **Solid** - classic thick arrowhead is used.

Option **Size** sets arrowhead size if classic arrow is used.

Tab **Format** contains graphic settings of marking frame.

Button **Colour** runs frame background colour selection dialog.

Button **Frame** runs frame line setup dialog.

Button **Pattern** runs background parameters setup dialog.

Option **Bevel** sets frame type: usual, elevated or submerged.

Option **Size** sets elevation or submergence level.

Option **Size** rounds frame corners.

Options **Transparent** and **Transparency** sets frame seamlessness degree.

Tab **Text**:

Button **Font** runs marking font setup dialog.

Button **Outline** runs marking letter outline setup dialog.

Option **Inter-char spacing** sets letter spacing for marking text.

Button **Gradient** runs gradient fill for marking text setup dialog.

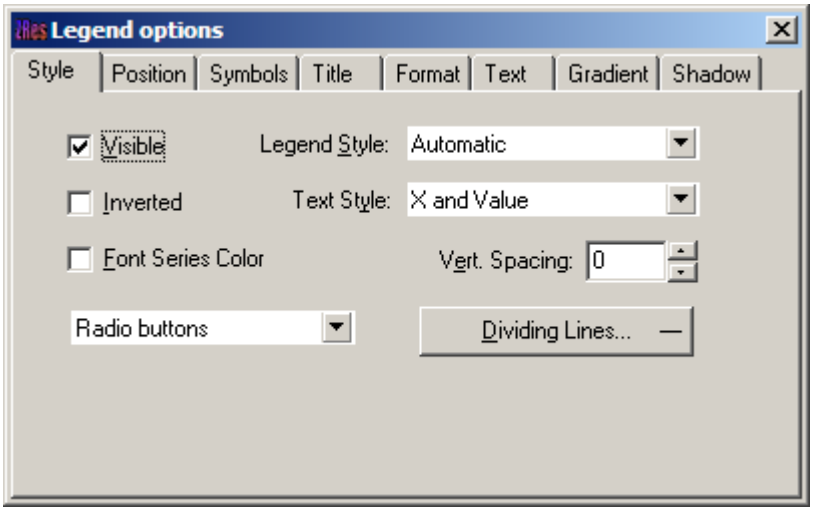
Option **Outline gradient** specifies if gradient fill is used in outline or interior of letters.

Button **Shadow** runs marking text shadow setup dialog.

Tab **Gradient** contains gradient fill settings for frame around markings

Tab **Shadow** contains shadow settings of frame around marking.

Appendix 3: Legend editor



Editor allows adjusting graphic and legend interface. Right click with SHIFT button pressed on legend to the right of the graph to run it. Pop-up window with set of tabs will appear.

Tab **Style** contains settings of legend display, allows choosing data label format and showing boundaries between legend labels and so on.

Tab **Position** serves for choosing legend position relative to graphics plan.

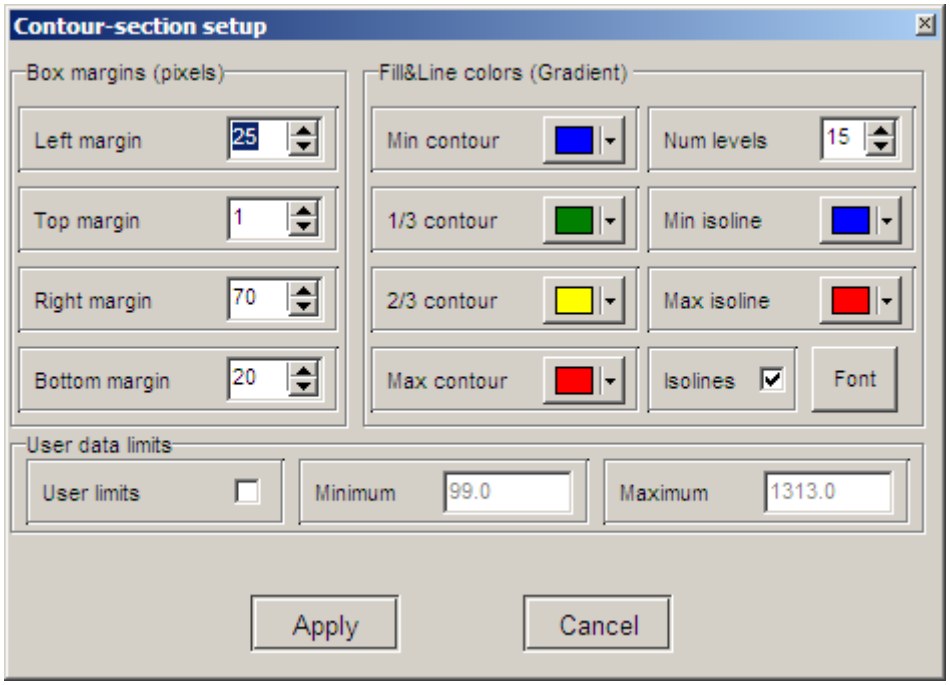
Tab **Symbols** sets legend symbols display parameters.

Tab **Title** specifies legend name and allows adjusting its format.

Tab **Text** serves for adjusting legend label format.

Tabs **Format**, **Gradient** and **Shadow** contain settings of legend window, its gradient fill, and shadow.

Appendix 4: Pseudosection parameters setup dialog



This dialog serves for adjusting pseudosection parameters.

Field **Box margins**

Left margin – sets image indent (in pixels) from window left edge.

Right margin – sets image indent (in pixels) from window right edge.

Top margin – sets image indent (in pixels) from window top edge.

Bottom margin – sets image indent (in pixels) from window bottom edge.

Field **Fill&Line colours**

Options **Min contour**, **1/3 contour**, **2/3 contour** and **Max contour** set interpolation sequence of colours from **Min contour** to **Max contour** via **1/3 contour** or **2/3 contour**. This colour palette is used for filling space between adjacent isolines.

Field **Num levels** defines number of isoline sections. Isoline section is set in uniform linear or logarithmic step depending on data type.

Options **Min isoline** and **Max isoline** set interpolation sequence of colours from **Min isoline** to **Max isoline**. This color palette is used for displaying isolines.

Option **Isolines** specifies whether isolines are created or not.

Field **User data limits**

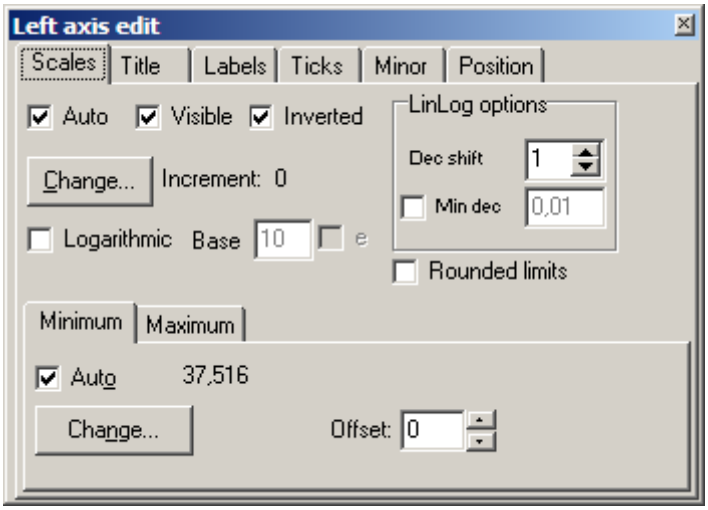
Option **User limits** specifies whether minimum or maximum data values or values from **Minimum** and **Maximum** filed are used for setting isoline sections.

Field **Minimum** sets minimum value to specify isoline sections.

Field **Maximum** sets maximum value to specify isoline sections.

Appendix 5: Axes editor

Many objects have axes. Axes editor is used to adjust appearance and scale axes. Right click on necessary axis with SHIFT button pressed to run it.



Pop-up menu with two fields (**options** and **default**) appears. The first one runs dialog, the second sets values on default.

First tab of **Scales** dialog contains options for axes scale parameters setup.

Option **Auto** defines how minimum and maximum axis values are chosen. If this option is ON axis limits are set automatically otherwise values from Minimum and Maximum filed specified by user are selected.

Option **Visible** shows/hides selected axis.

Option **Inverted** defines axis orientation.

Button **Increment change** runs dialog for axis label step definition.

Option **Logarithmic** selects logarithmic or linear axis scale. In case of sign-changing scale additionally use options from **LinLog options** field.

Option **Base** sets logarithm base for logarithmic axis.

Field **LinLog options** contains options for linear-logarithmic axis adjustment. Linear-logarithmic scale allows representing sign-changing or zero containing data in logarithmic scale.

Option **Dec Shift** sets indent (in logarithmic decades) relative to maximum axis limit modulo to zero. Minimum decade (prezero) has linear scale, others have logarithmic.

Option **Min dec** sets and fixes minimum (prezero) decade value if option is ON.

Option **Rounded limits** defines whether it is necessary to round minimum and maximum axis values or not.

Fields **Minimum** and **Maximum** contain options for axis limits adjustment.

Option **Auto** defines whether axis limit is selected automatically or using **Change** button.

Option **Offset** sets percentage axis limit shift relative to its actual value.

Tab **Title** contains options for axis header adjustment.

Tab **Style**:

Option **Title** sets axis header text.

Option **Angle** sets header text rotation angle.

Option **Size** sets header text indent. If 0 value is specified it is selected automatically.

Option **Visible** shows/hides axis header.

Tab **Text**:

Button **Font** runs header font setup dialog.

Button **Outline** runs dialog for header letters' outline adjustment.

Option **Inter-char spacing** sets letter spacing in axis header.

Button **Gradient** runs gradient fill setup dialog for header text.

Option **Outline gradient** specifies if gradient fill is used in outline or interior of letters.

Button **Shadow** runs axis header shadow setup dialog.

Tab **Labels** contains options for axis label adjustment.

Tab **Style**:

Option **Visible** shows/hides axes labels.

Option **Multiline** is used for setting multiline axes labels.

Option **Round first** rounds first axis label.

Option **Label on axis** hides labels that go beyond axis.

Option **Alternate** arranges labels in two lines.

Option **Size** sets axis label indent. If 0 value is specified it is selected automatically.

Option **Angle** sets label rotation angle.

Option **Min separation %** sets minimum percentage label spacing.

Tab **Text**:

Button **Font** runs label font setup dialog.

Button **Outline** runs dialog for label letters' outline adjustment.

Option **Inter-char spacing** sets letter spacing in label text.

Button **Gradient** runs label gradient fill setup dialog.

Option **Outline gradient** specifies whether gradient fill is used in outline or interior of letters.

Button **Shadow** runs label shadow setup dialog.

Tab **Ticks** contains options for axis main ticks adjustment.

Button **Axis** runs axis line setup dialog.

Button **Grid** runs line setup dialog for main ticks' grid.

Button **Ticks** runs external main axis tick setup dialog. Option **Len** sets its length.

Button **Inner** runs internal main axis tick setup dialog. Option **Len** sets its length.

Option **Centered** centers grid of axis ticks.

Option **At labels only** displays main axis ticks only if axis labels are present.

Tab **Minor** contains options for axis intermediate ticks adjustment.

Button **Grid** runs line setup dialog for intermediate ticks grid.

Button **Ticks** runs external intermediate axis tick line setup dialog. Option **Len** sets its length.

Button **Minor** runs internal intermediate axis tick line setup dialog. Option **Len** sets its length

Option **Count** sets number of intermediate ticks between main ones.

Tab **Position** defines axis size and position.

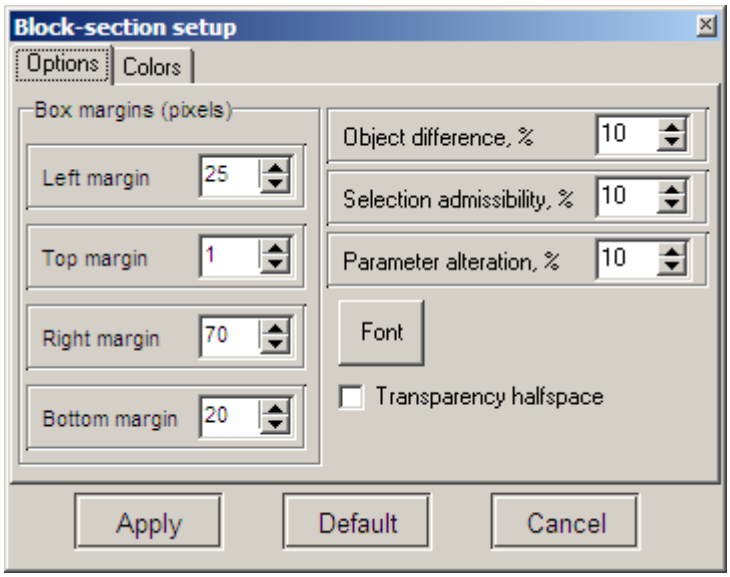
Option **Position %** sets axis indent relative to its standard position on graph (in percent to graph size or in screen units depending on selected option Units).

Option **Start %** sets axis start indent relative to its standard position on graph (in percent to graph size).

Option **End %** sets axis end indent relative to its standard position on graph (in percent to graph size).

Appendix 6: Model parameters setup dialog

Tab **Options**



Field **Box margins**

Left – sets image indent (in pixels) from window left edge.

Right – sets image indent (in pixels) from window right edge.

Top – sets image indent (in pixels) from window top edge.

Bottom – sets image indent (in pixels) from window bottom edge.

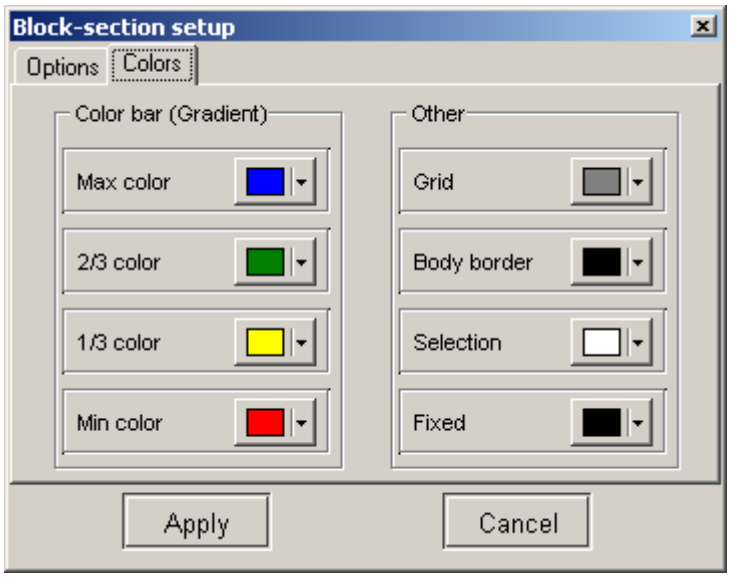
Object difference sets maximum value of adjacent cells parameter ratio, in case of exceeding it boundary between them is drawn.

Selection admissibility sets threshold value of adjacent cells parameter difference which defines their unification and highlighting together (in Magic Wand mode).

Parameter alteration sets value of selected cells parameter increment (in percent to parameter value) in **Edit** mode with SHIFT button pressed.

Button **Font** runs font setup dialog.

Tab **Colours**



Field **Colour bar**

Options **Min colour**, **1/3 colour, 2/3 colour** and **Max colour** set interpolation sequence of colours which define dependence between model parameter value and certain colour.

Field **Others**

Body border sets colour of boundary line between adjacent cells if measure of discrepancy between them exceeds specified in **Parameter alteration** option value.

Grid sets mesh colour.

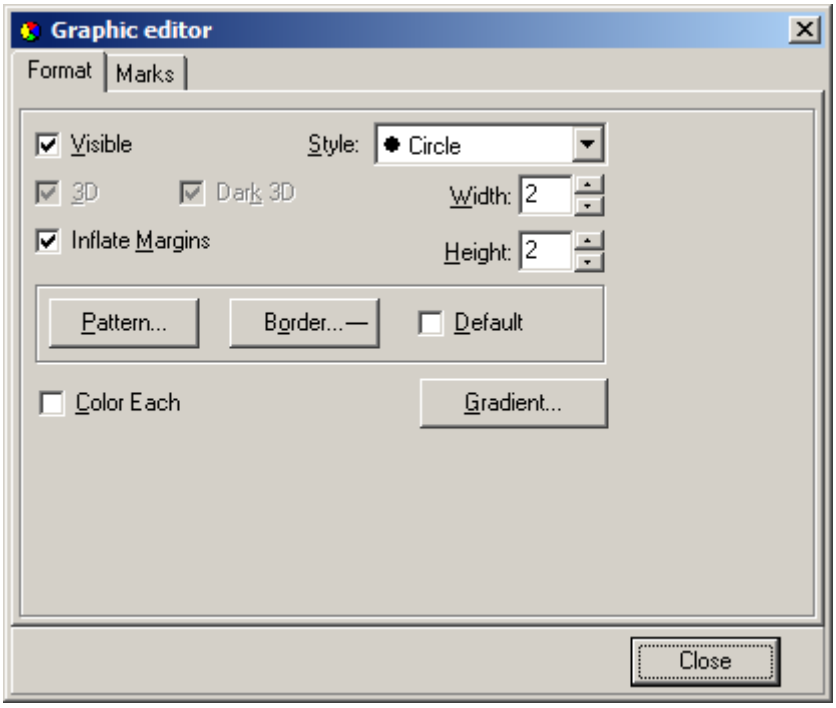
Selection sets mark colour of selected cell.

Fixed sets mark colour of fixed cell.

Transparency halfspace turns cell transparency mode on if parameter value corresponds to host medium value.

If model is edited as contour section, setup dialog is similar to pseudosection parameters setup dialog (*Appendix 4*: Pseudosection parameters setup dialog).

Appendix 7: Pseudosection point editor



Editor serves for adjusting appearance of pseudosection points, electrode position points, and their labels. Right click with SHIFT button pressed on point to run it.

Tab **Format** contains settings of pseudosection and electrode position point appearance. Tab **Marks** contains label settings. Options in these tabs *are described in*

Appendix 1: Graphics set editor .