SOFTWARE FOR 3D INTERPRETATION OF MAGNETIC AND GRAVITY DATA

ZONDGM3D

Program functionality

«ZondGM3D» is a computer program for 3D interpretation areal data obtained from magnetic and gravity surveys. User-friendly interface and rich options for data presentation allows solving existing geological problems with maximum efficiency.

The traditional exploration method for iron-bearing formations is magnetic survey. It studies magnetic fields of objects, which contain ferromagnetic minerals. Physical interrelation between data measured at the surface and magnetic properties at depths allows assuming presence of magnetic bodies.

In magnetic exploration, total magnetic field is measured. It is comprised of the Earth normal field, anomalous fields caused by magnetized bodies and magnetic field variations, mostly related to the solar activity. A useful component associated with a studying area is anomalous field, which can be identified, taking into account the normal field and measuring magnetic variations in the vicinity of a survey area.

The magnetic field on the Earth surface can be represented as a vector sum: $T = T_n + T_a + \delta T_v$, where T_n and T_a are normal and anomalous magnetic fields, δT_v magnetic field variations. The normal field T_n is divided into a dipole (T_d) and non-dipole (T_m) components, that is $T_n = T_d + T_m$.

The dipole field T_d, which, to a first-order approximation, is the magnetic field of the Earth, is a field of a homogeneous magnetized sphere. The difference between the dipole field (calculated) and areal and normal field (measured by satellite) is a non-dipole part $T_m$of the normal field. It is often named as a residual field or a field of continental anomalies (sizes of these anomalies are commensurate with the sizes of the continents). Its maxima does not exceed 30% of a dipole field value.

$T_n$values gradually increase from 33,000 nT at the equator to 68000 nT near the poles, a vertical component of a normal field in the North Pole area reaches 60,000 nT, changes sign to a negative when passing through the equator, and gradually decreases from 0at the equator to -68 000 nT at the south pole of the Earth . Horizontal component has the maximum near the equator (33,000 nT) and decreases to 0 at the poles. A gradient of the normal magnetic field is about 5 nT per kilometer.

Sources of the anomalous magnetic field T_a are magnetized objects, located near the surface of the Earth. Maximum depth of magnetic rocks is about 50 kilometers. At greater depths, magnetic properties of rocks disappear due to high temperatures.

A value of the field T_a is about 10% of T_n , with an exception of the Kursk Magnetic Anomaly, where the field T_a reaches tens of thousands of nT. Anomalies of a magnetic field induced by rocks are divided into regional and local.

A variable part δT_v of the Earth magnetic field is formed by magnetic variations, whose contribution to the total field is less than 1%. The most important variations can be divided into periodic (solar-diurnal and short-periodic variations) and aperiodic (bay disturbance and magnetic storms).

All variations are induced by external (relative to the Earth) sources: interaction of charged particles with the ionosphere; electric currents propagating in stripe areas of high latitude at an altitude of 100-150 km, etc. In general, an accounting for magnetic variations is important in magnetic surveys because they are cause significant distortions in the observed data.

Program «ZondGM3D» allows solving forward and inverse problems of magnetic and gravimetric surveys (recovery of anomalous magnetic susceptibility, density and geometry of magnetic objects).

In the program, magnetic susceptibility is set in SI system (n*10^{-5}), density in g/sm^3, measured values in nanotesla or milligals.

To solve an inverse problem (inversion) various versions of deconvolution methods and Newton's method with focusing regularization are used.

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

where A is the matrix of partial derivatives of measured data with respect to model parameters (Jacobian), C smoothing operator, W matrix of relative measurement errors, m the model parameter vector, μ - regularizing parameter, Δf vector of residuals between the observed and calculated values, R focusing operator.

During the development of inverse problem, special attention was given to a priori information usage (weights of individual measurements, ranges of parameters).

«ZondGM3D» uses a simple and clear data file format.

Program allows importing and visualizing data using other methods which makes data interpretation process more integrated.

«ZondGM3D» is an easy-to-use instrument for automatic and interactive multilevel data interpretation of magnetic and gravity surveys, and can be used on IBM-PC compatible PCs with Windows operating system.

Density of the rocks

It is essential to know rock density σ which is the only physical parameter that gravity survey is based on to perform gravity surveying and especially to interpret results.

Rock density (or volume weight) is defined as its mass per unit volume. Density unit is g/sm^3. Density is usually measured on samples taken from natural outcrop, boreholes or mines. The easiest way to measure density is to weight the sample in the air and in water and then calculate density σ. The most popular and handy device for density measurement is densitometer and it is based on this principle. Densitometer defines density within the accuracy of 0,01 g/sm^3 [Hmelevskoj, 1997].

In order to receive reliable and representative data it is necessary to measure large quantity of samples (up to 50). On the basis of numerous density measurements on samples from the same lithological sequence variation curve or cross-plot of σ values versus number of samples characterized by current density is constructed. Curve maximum corresponds to the most probable density value for current rock. There are gravimetric and other geophysical methods of field and borehole density assessment.

Density of rocks and ores depends on chemical-mineral composition, in other words on bulk density of solid particles, porosity, and pore filler composition (water, solutions, oil, gas). Density of volcanic and metamorphic rocks is mostly defined bytheir mineral composition and increases in going from acidic to base and ultrabasic rocks. Density of sedimentary rocks first of all depends on porosity, water saturation, and to lesser degree on mineral composition. But it strongly depends on deposits consolidation, their age, and depth of burial (their increase leads to density increase as well). Examples of density are given below [Hmelevskoj, 1997].

Rock	**Density (g/sm^3)**
Oil	0,8 -1,0
Coal	1,0
Water	1,1 – 2
Soil	1,13 - 2,0
Sand	1,4 – 2
Clay	2 - 2,2
Sandstone	1,8 - 2,8
Limestone	2,3 - 3,0
Salt	2,1 - 2,4
Granite	2,4 - 2,9
Gneiss	2,6 - 2,9

Gabbro	2,8 - 3,1
Basalt	2,7 - 3,3
Peridotite	2,8 - 3,4
Copperpyrite	4,1 - 4,3
Magnetite, hematite	4,9 - 5,2
Density of the upper parts of the crust (average)	2,67

Magnetic susceptibility of rocks and ores

Magnetic susceptibility χ is the main magnetic property of rocks which characterizes the degree of magnetization of materials and rocks.

It is dimensionless number in SI system. But in practice it is measured in 10^{-5} SI units. It ranges from 0 to 10 units for different rocks. Minerals and rocks are divided in three groups by magnetic susceptibility: diamagnetic, paramagnetic, and ferromagnetic. Diamagnetic rocks have very low magnetic susceptibility (less than 10^{-5} SI units) which has negative value (their magnetization is directed against magnetizing field). Many minerals and rocks such as quartz, mine salt, marble, oil, ice, graphite, gold, silver, lead, copper, etc. are diamagnetic [Hmelevskoj, 1997].

Paramagnetic rocks have positive magnetic susceptibility with low values. The majority of minerals, sedimentary, metamorphic, and volcanic rocks are paramagnetic.

Ferromagnetic minerals (e.g. magnetite, titaniferous magnetite, ilmenite, pyrrhotite) have very large χ values (up to several millions of 10^{-5} SI units).

Magnetic susceptibility of the majority of rocks depends largely on the presence and percentage of ferromagnetic minerals in their composition.

Table below gives χ values of some rock-forming minerals and rocks. It can be seen from the table that ferromagnetic minerals are strongly magnetic. Ultrabasic and base rocks are characterized by the highest magnetic susceptibility values among other volcanic rocks, acidic rocks are magnetic and weakly magnetic. Magnetic susceptibility of metamorphic rocks is lower than the one of volcanic rocks. Sedimentary rocks with the exception of some sandstones and clays are almost non-magnetic.

Mineral, rock	$\chi 10^{-5}$ (SI units)	
	range	average
Quartz	-	10
Calcite	7 – 12	-
Gypsum	-	12
Coal	-	25
Sphalerite	-	750
Hematite	500 - 50000	6000
Pyrrhotine	10^3-10^7	150000
Ilmenite	$5*10^5$ -$5*10^6$	10^6
Magnetite	10^6-10^7	$5*10^6$
Limestone	25 - 3500	300
Sandstone	0 - 20000	400
Gneiss	100 - 20000	-
Granite	0 - 40000	2000
Diabase	1000 - 15000	5000
Gabbro	1000 - 100000	60000
Basalt	30 - 150000	60000
Peridotite	90000 - 200000	150000
Sedimentary (average)	0 - 5000	1000
Metamorphic (average)	0 - 75000	50000
Acidic volcanic (average)	50 - 80000	8000
Base volcanic (average)	60 - 120000	30000

To convert χ values in CGS system which is used in the program, magnetic susceptibility in SI units is divided by 4π.

Magnetic susceptibility of para- and ferromagnetic rocks decrease with increasing temperature and almost disappears at Curie temperature which ranges from +400 to +700C for different minerals. Maximum depth of magnetic survey investigation is approximately 25-50 km.

Temperature is higher than Curie point at greater depths and all occurring there rocks become essentially non-magnetic.

Prospecting geological structures and ores with magnetic susceptibility κ are embedded by rocks with magnetic susceptibility χ. This is the reason why similarly to gravity survey redundant or effective magnetic susceptibility $\Delta\chi$ is of interest. Value of $\Delta\chi$ can vary and be positive or negative. Magnetic anomalies appear due to variation of $\Delta\chi$ from zero [Hmelevskoj, 1997].

System requirements

«ZondGM3D» can be installed on a PC with OS Windows 98 and higher. Recommended system parameters are processor P IV-2 GHz, memory 2 Gb, screen resolution 1024 X 768, color mode – True color (screen resolution change is not recommended while working with data).

Program installation and deinstallation

«ZONDGM3D» program is supplied by internet. Current manual is included in the delivery set. Latest updates of the program can be downloaded from website: www.zond-geo.com/english

To install the program copy it 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 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 start-up, main options

Preparing and opening a data file

To begin working with « ZONDGM3D», it is necessary to have a data file of specific format which contains information about measurement positions and measured values.

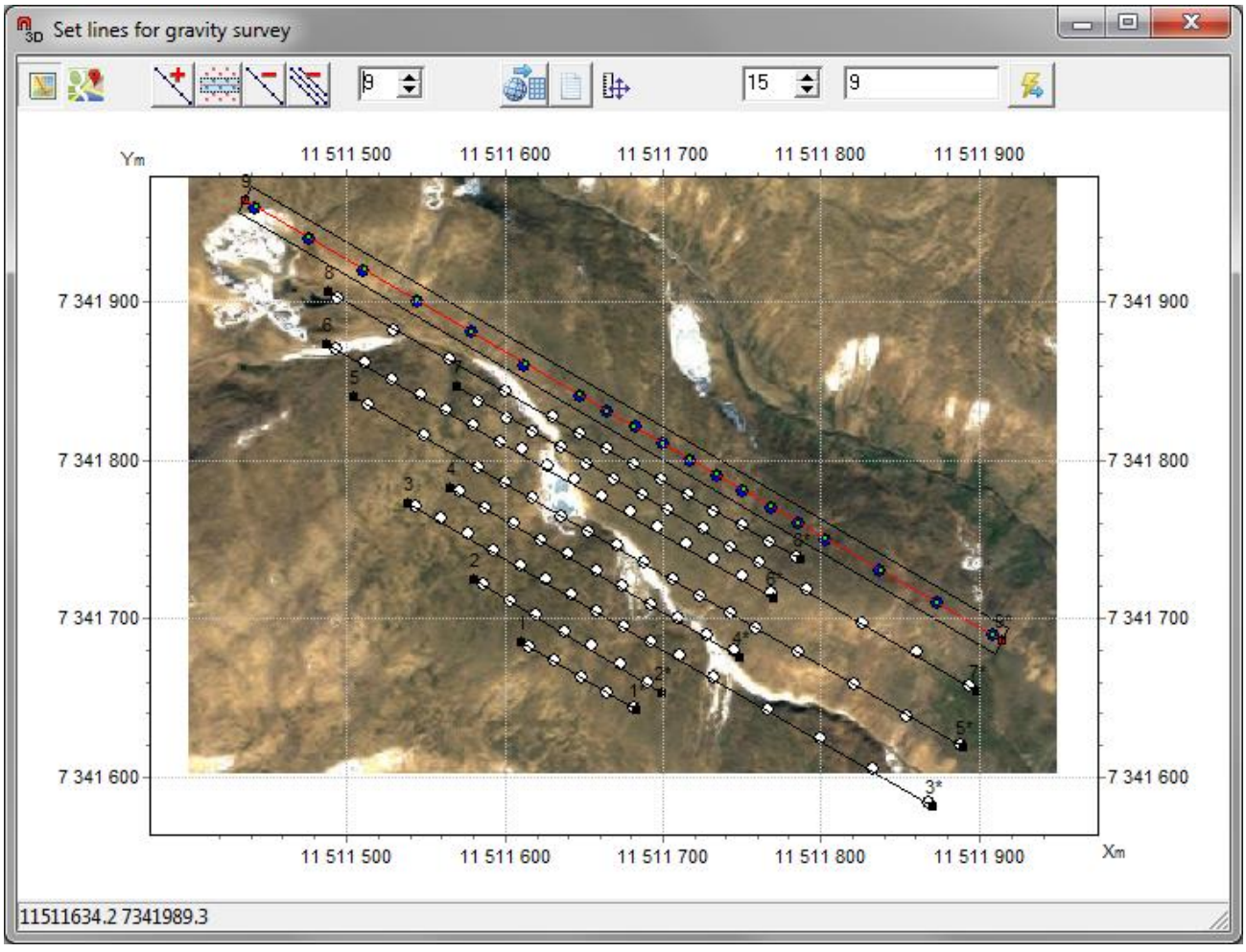
One file usually contains data obtained from one profile. Text data files created in «ZONDGM3D» format have «*.GM3» extension. See **data file format** section for more details.

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

- unconventional separation symbols (use TABs and SPACEs only);
- invalid values of measured data
- It is desirable to not have more than 50000 observed data values in a single file.

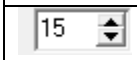
Setting and modifying topography profiles and data

After uploading data file, setting profiles dialog **Set lines for gravity (magnetic) survey** appears (pic. 1). This dialog lets you set, delete and modify profile lines, change coordinates of observation sites as well as upload picture or map as a base layer for the site plan. The dialog is available in the program main menu Options/ Set survey lines.

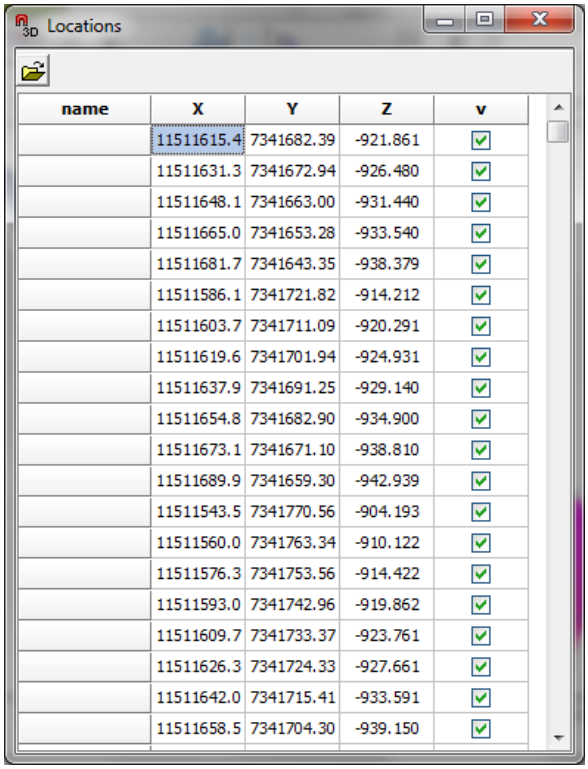


Pic. 1. Customization dialog for profile lines **Set lines for gravity (magnetic) survey**

The main dialog panel contains the following options:

	**Map -** load and display raster map file (pic. 1) **Topography -** display the relief isolines **Obs data –** display observed data
	Load Google map
	Add profile line. To set profile lines click the left mouse button; to set the last point click the right mouse button
	Include measurement points in profile automatically. The points contained in a rectangular area around the specified line.
	Remove current profile
	Remove all profiles.
	Set the current profile number
	Convert from geographic coordinates to rectangle. If it is known a priori geographic coordinates (latitude and longitude) were in the file, it is necessary to convert them to rectangular using this button.
	Set coordinates in a table (**Locations** dialog)
	Select equal axes image scale or maximum window area filling.
	Set size of automatic selection measured points area in a profile
	Set the current profile name
	Go to the data inversion mode for selected profiles system

To change coordinates of observation sites, use the  button, which activates **Locations** dialog (pic. 2). Coordinates of sites can be uploaded from text file containing columns with site number, two horizontal and vertical coordinates and height of sensor (negative value), or they can be copied straight from any table file.



Pic. 2. Setting dialog **Locations** for coordinates of observation sites

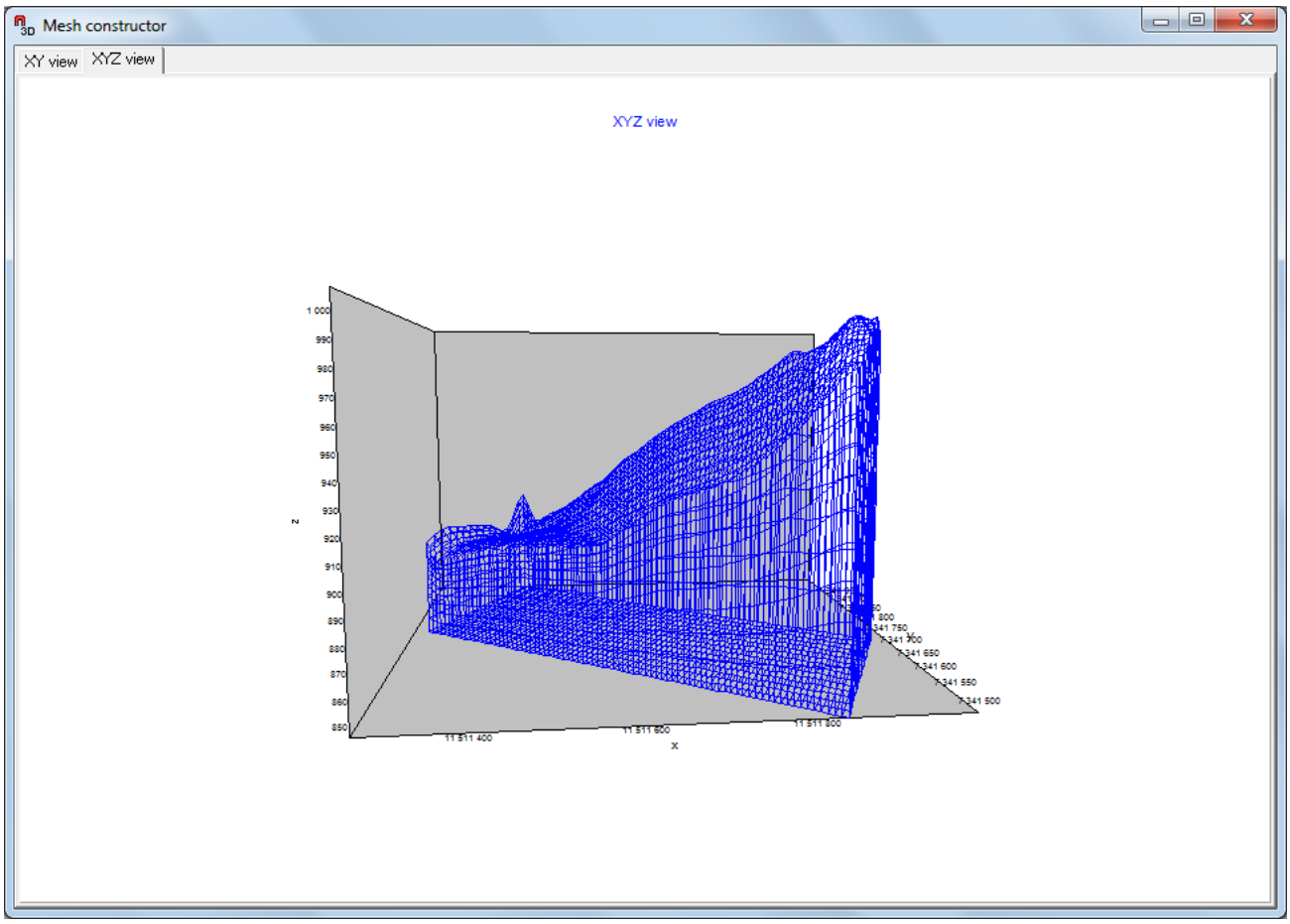
To finish operating with profiles editor and go to inversion, press the  button.

Customization dialog for the start model

Customization dialog for the start model Mesh constructor appears after setting profile lines and pressing the  button. This dialog is also available in program main menu Options/Mesh constructor.

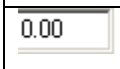
The window includes two tabs - **XY view** and **XYZ view**.

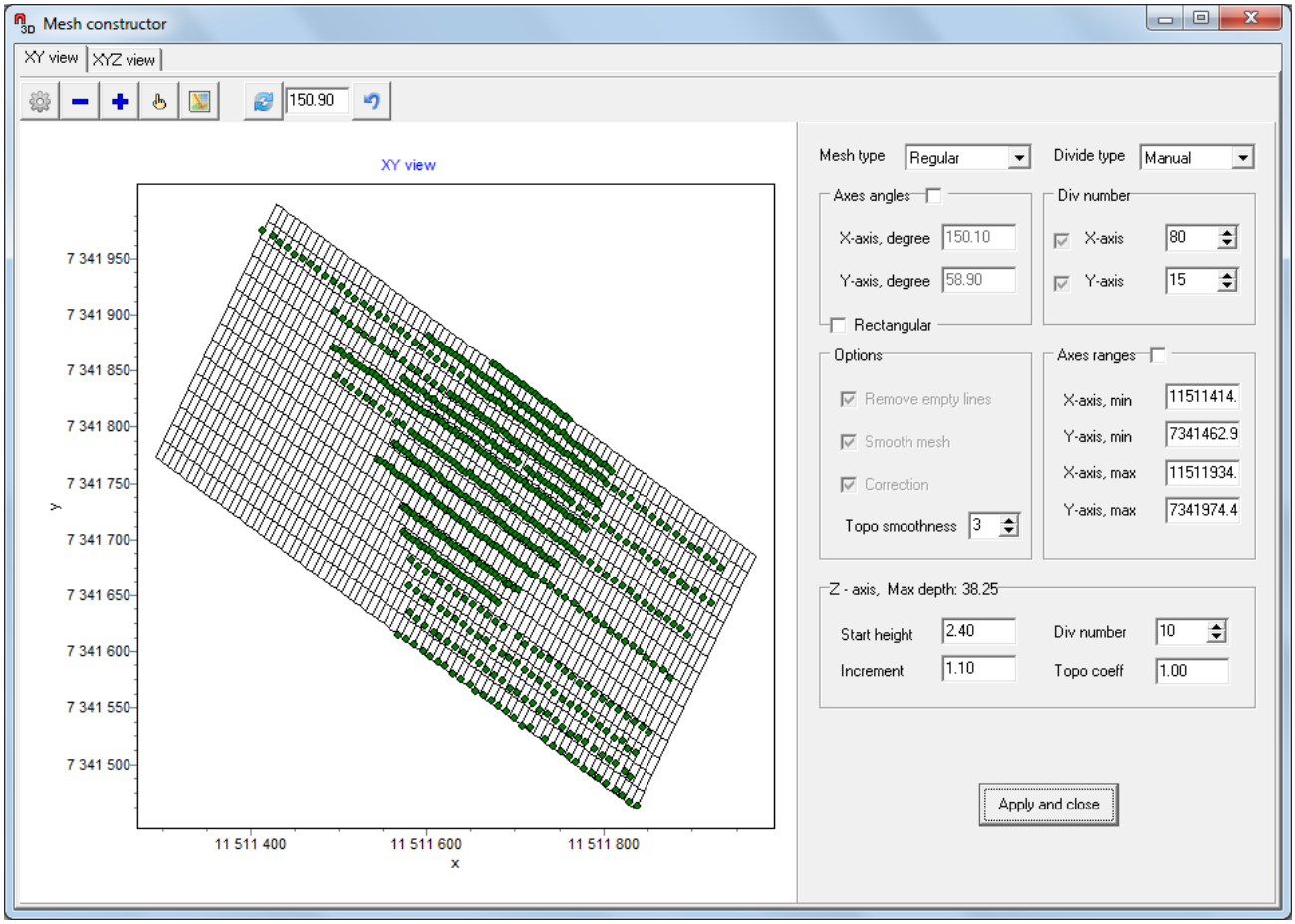
XYZ view tab contains three-dimensional image of created mesh (pic. 3). To rotate the image, use the left mouse button. To scale the image, use scroll wheel. To move along the axes, use the right mouse button. Press Shift and hold it while right-clicking the axis to enable axes editor (more).



Pic. 3 **Mesh constructor** window**, XYZ view** tab**.**

In **XY view** tab setting of all mesh partition parameters is accomplished. The tab consists of two sections (pic. 4). In the left section there is a horizontal plan, the right section contains mesh partition settings. Toolbar contains the following buttons:

	Build a model in accordance with defined parameters
	Remove line. Hold the mouse pointer over needed line and click the left mouse button
	Add line. Hold the mouse pointer over the place where you want to create a line and click the left mouse button
	
	Show relief map as a base layer
	Rotate observation area by a defined angle
	Define rotation angle
	Undo rotation



Pic. 4 **Mesh constructor** window**, XY view** tab.

Settings of mesh partition consist of:

Drop-down menu **Mesh type** sets mesh type. The following mesh types are available: *Regular* – fits for the majority of standard observing systems when observation sites are situated quite regularly, *General* – for relatively irregular observing systems, *One line* – in cases when observing system is considerably elongated in one direction (one or two long profiles). Program will add cells automatically.

Section **Axes angles** sets angles for X and Y axes (X-axis, degree and Y-axis, degree respectively). If Rectangular check box is selected, the value of rotation angle for second axis will change so that their mutual orthogonality remains.

Section **Div. number** lets you set a number of cells along X and Y axes.

Drop-down menu **Divide type** allows to choose automatic or manual mode for mesh setting.

If you choose **Divide type** – *Automatic*, the following sections are available:

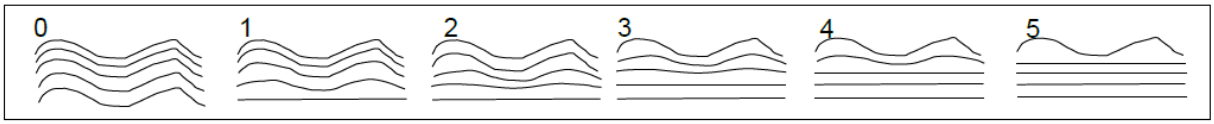
Section **Options,** including the following check boxes: *Remove empty line* – remove empty cells (without measurement points), *Smooth mesh* - program will remove vertexes offset

towards observation sites, *Correction* – program will find the optimal mesh increment if distance between profiles/observation sites is not constant, *Topo smoothness* – set the degree of relief smoothing (values from 1 to 5, where 5 – maximum smoothing degree).

Section **Extra div** allows to set a number of intermediate cells for X and Y axes respectively.

If you choose **Divide type** – *Manual,* section **Axes Range** becomes available, there you can set the minimum and the maximum coordinates values along X and Y axes respectively.

Section **Z-axis, Max.depth** is intended for setting partition along vertical axis. **Max. depth** – determines the depth of the lower layer. It should be borne in mind that the maximum depth value must not be too large because there is a decreasing with depth in the influence of magnetic and density section parameters. **Start height** – sets thickness of the first layer. This value must comply with the required resolution. **Increment** – sets ratio of abutting layers thickness. This parameter is usually in the range of 1 to 2. **Div number** – sets a number of layers in the model. It is usually enough to have 12-14 layers to describe model. Setting too large values of this parameter is not desirable because it will lower computing speed. **Topo coeff –** set coefficient of topographic form distortion with the depth (0-5). 0 – relief of each next layer repeats the previous one. 1 – relief flattens out with the depth, the last layer is flat (pic. 5).



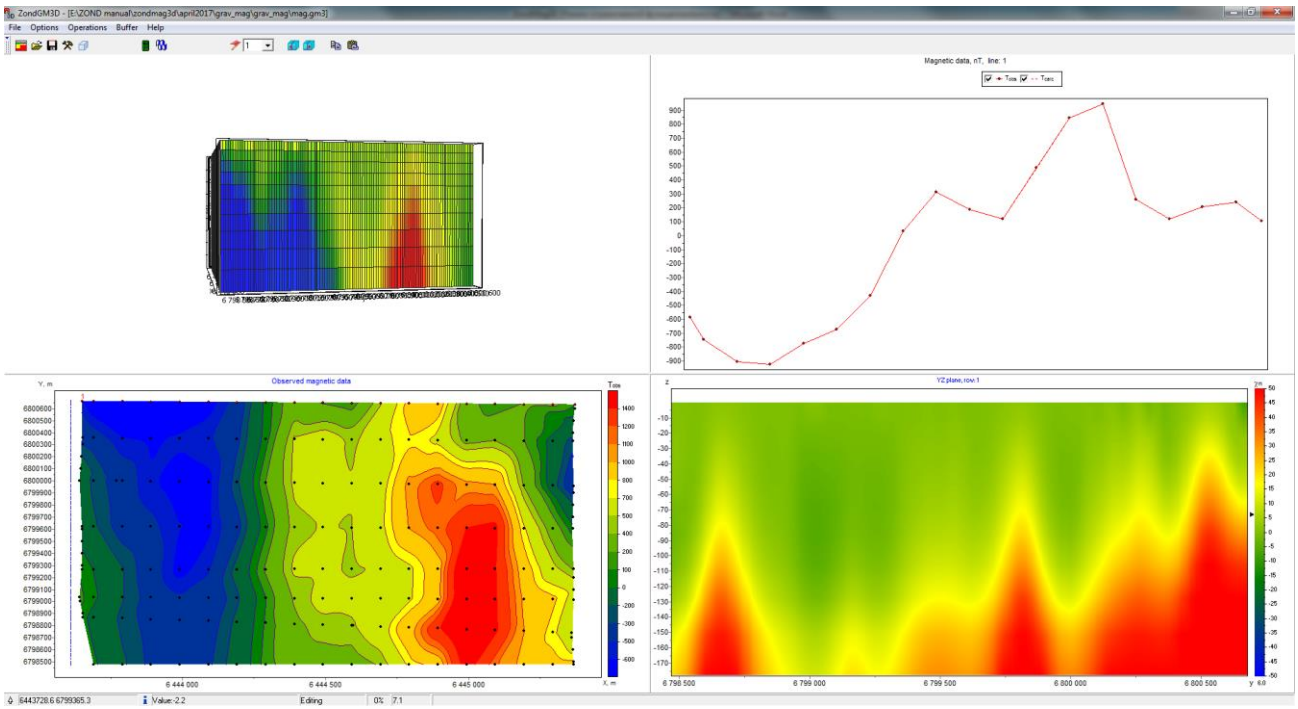
Pic. 5. Model layers distortion using **Topo coefficient** parameter from 1 to 5

To finish operating with mesh constructor and go to inversion, press the 

button.

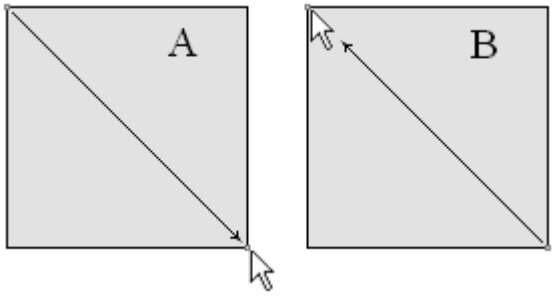
Main Window

ZondGM3D main window is divided into 4 sections (pic. 6). In the top left corner there is a 3D model section. In the top right corner observed and calculated graphs of magnetic or gravity field for selected profile are displayed. In the bottom left corner there is a plan of graphs or plan of contours for all the profiles. In the bottom right corner there is a 2D plan of model in the selected direction. Click the right mouse button in one or another section to see settings menu for this section. Settings are described in more details in corresponding parts of the guidance.



Pic. 6. Main Window of ZondGM3D

For all sections but 3D model 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. 7A). To return to primary zoom do the same but with mouse cursor moving up and to the left (Pic. 7B).

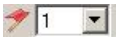


Pic. 7. Mouse cursor navigation to zoom in/out

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):

	Go to modelling regime
	Open data file.

	Save data.
	Run inversion parameters setup dialog.
	Run dialog for settings of 3D model image parameters. (more).
	Run forward solution process.
	Start (one click) or cancel (second click) inversion process.
	Work with magnetic measurements.
	Work with gravity measurements.
	Select profile.
	Go to previous slice of the model.
	Go to next slice of the model.
	Copy current slice of the model to clipboard.
	Paste data into current slice of the model. If right-click the button, there will be menu of options for filling the model: Current – paste model for selected parameter into current slice Current&+ – paste model for selected parameter into current and all next slices Current&- – paste model for selected parameter into current and all previous slices All params – apply selected paste regime to all parameters

Functions of the main window menu

The following table lists menu items with their corresponding functions:

File/Create survey	Call the dialog of synthetic survey system creation (more).
File/Open file	Run synthetic measurement system generation dialog.
File/ Import from text/excel	Import a data file in text or Microsoft Excel format (more)
File/Save file	Save data.
File/Edit data	Open current data file in Notepad editor.
File/Print preview	Print main window of the program.
File/Reg file	Create register file.
File/Registration	Register program.

File/Recent	Recently used files.
File/Exit	Exit program.
Options/Mesh constructor	Run starting model setup dialog. (more)
Options/Set survey line	Call survey line setup window (more)
Options/Observation setup	Run normal gravity setting dialog (more).
Options/Program setup	Run inversion parameters setup dialog. (more).
Options/Data/Contour map	Display data as a contour section (more)
Options/Data/Graphics map	Display data as graphs (more)
Options/Data/Points map	Display data as points (more)
Options/Data/Calculated data	Display calculated pseudosection in second part of window.
Options/Data/Observed data	Display observed pseudosection in second part of window.
Options/Data/Data misfit	Display misfit pseudosection in second part of window.
Options/Model/Block section	Display model as blocks.
Options/Model/Smooth section	Display model in smooth interpolated graphic palette.
Options/Model/Infinite borders	Increase length (height) of outermost model cells.
Options/Model/Plane	Choose model slice orientation.
Options/Model/Model histogram	Display model parameters distribution plot. Minimum and maximum values of parameter's colour scale can be specified in the dialog window.
Options/Inversion/Smoothness	Definition of a level, relative to which smoothness of a calculated model is determined. Available values: Median - from data average; "0" - from zero level Start model - from a starting model (useful when a priori information is available) Previous - from the previous iteration. Diagonal filter – include diagonal smoothing component (use not only adjoining cells but also diagonal cells).
Options/Inversion/Resolution	Set sensibility parameter value. Increasing of sensibility leads to increasing of the bottom model cells influence. Log norm option allows to use loglinear norm of parameters for inversion. Log barrier option sets the minimum threshold of loglinear norm (usually it is a level of minimum parameter values for the section).

Options/Inversion/Damping optimization	Regime of an additional optimization of regularizer at each iteration. This regime allows to speed up the process algorithm convergence but several times increases time of each iteration. Since time of inversion for large models is estimated at hours, in some cases it is recommended to disable this regime.
Options/Inversion/Groups blank cells	Combine corner cut cells under inversion.
Options/Import/Export/Background 2D	Load background – load image file as a base layer for 2D plan (more) Remove current – remove current base layer.
Options/Import/Export/Background 3D	Load background – load image file as a base layer for 3D plan Remove current – remove current base layer.
Options/Import/Export/Import mod3D	Import current 3D model in Zond3D format .
Options/Import/Export/Export mod3D	Export current 3D model in Zond3D format.
Options/Import/Export/Import mod2D's	Import current 2D model in Zond2D format.
Options/Import/Export/Export mod2D	Export current 2D model in Zond2D format.
Options/Import/Export/Save rotations	Save 3D model as a set of images for different rotation angles.
Options/Import/Export/Save slides	Save 3D model as a set of images for different positions of slice plane.
Options/Import/Export/Output settings	Exported picture setup.
Options/ Boreholes/Load borehole data	Open and display a file with borehole log data and stratigraphic columns
Options/ Boreholes/ Create/Edit borehole data	Create/edit borehole data (more)
Options/ Boreholes/ Remove borehole data	Remove borehole data.

Options/ Boreholes/ Set column's width	Set width of borehole columns.
Options/ Boreholes/ Edit positions	Edit positions of boreholes and corresponding lithology columns.
Operations/ Bouguer&Free Air	Set density value for the intermediate layer
Operations/ Subtract median field	Subtract median value.
Operations/ Subtract user value	Subtract user-specified value.
Operations/ Return to original data	Back to the raw data, cancel all transformation and operations.
Buffer/ Model 1, 2….	Save the current model to clipboard (more)
Buffer/ Open	Open saved to clipboard models and compare.
Help/ About	About the program.
Help/ Context	Run manual.
Help/ Check for updates	Check for updates.

"Hot" keys

Cursor pad /cursor in the model editor	Change of the model active cell
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 an area.
V / cursor in model editor	Delete selection.
Up/down / cursor in color scale	Change current value.
Space	Calculate forward problem.
Enter	Switch to Euler or Objects mode and back.

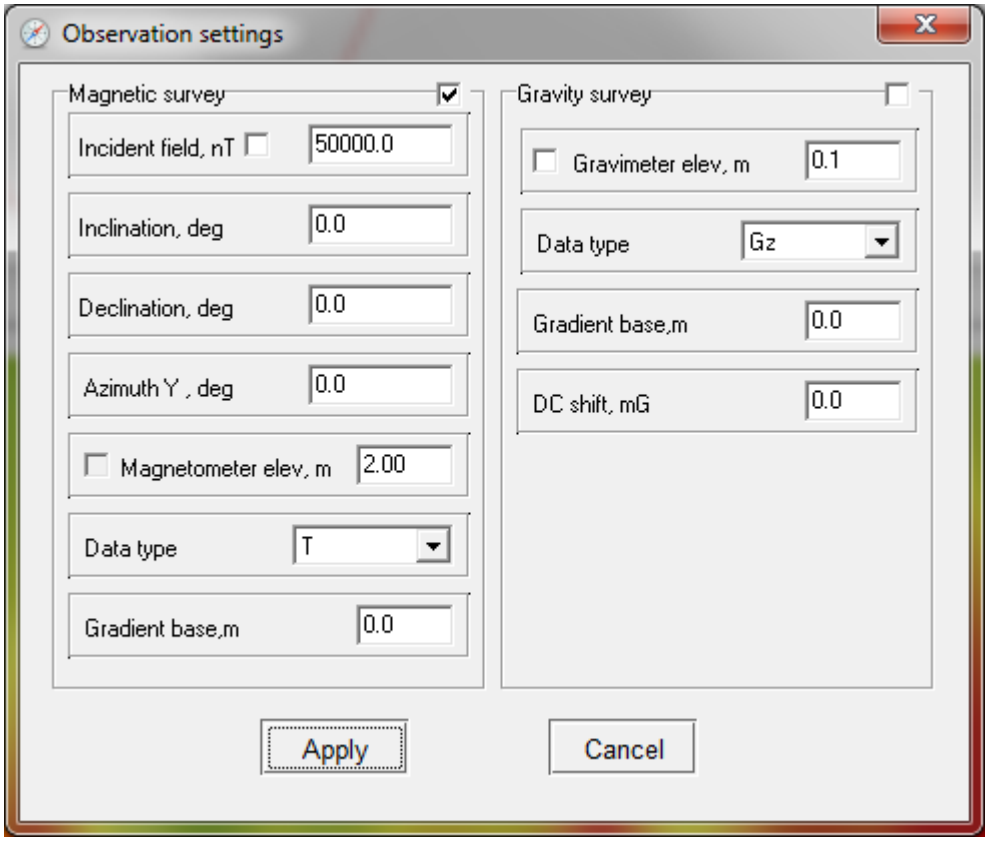
Status bar

Status panel is divided into a few sections which contain different information:

Coordinates of cursor and active cell.
Parameters of active cell
Additional information.

Measurement parameters setting dialog

Upon successful file loading, the window measurement parameters selection appears and dialog of initial model settings, in which it is possible to select survey layout parameters (pic. 8). This dialog is also available in the Options/Observation settings item of the main menu. Window of measurement parameters selection is divided into two parts: **Magnetic survey** and **Gravity survey**, corresponding to settings for the magnetic and gravity fields.



Pic.8 Measurement parameters setting dialog (Observation settings)

Magnetic survey part:

Incident field – – magnitude of the normal magnetic field vector (T_0), in nT..

Inclination, deg – a value of the normal magnetic field inclination, in degrees (I_0). It is counted down from horizontal.

Declination, deg – a value of the normal magnetic field declination, in degrees (D_0). It is counted clockwise from north.

Azimuth Y– azimuth of Y azis in degrees.

Magnetometer elev – magnetic sensor height in meters relative to relief.

Data type –a type of measured data. T is the magnetic field, GrZ - magnetic field gradient

Gradient base, m –a height of a sensor above the earth's surface

Gravity survey part:

Gravimeter elev, m – a gravimetric observations height, in meters, relative to the relief.

Data type – a type of measured data. Gz – vertical component of gravity force, Grz gradient of Gz.

Gradient base, m – a sensor height above the earth's surface.

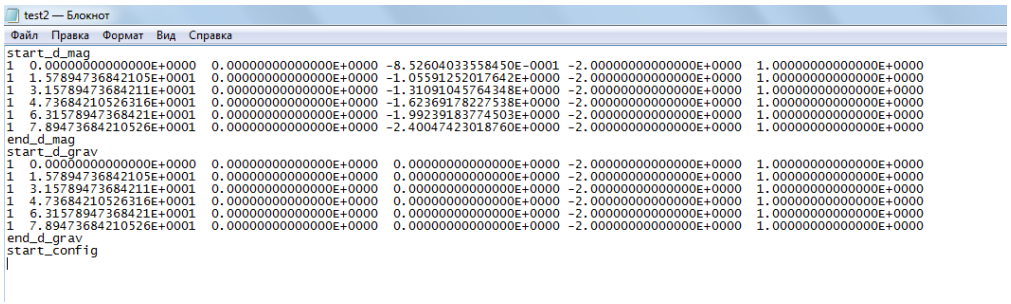
Data file format

Text file consists of two main blocks containing information about gravity and magnetic measurements.

Block of the gravity data description must start with *start_d_grav* string. Strings containing information about measurements coordinates and field data then follows. The first writing is a number of measurement profile, the second and the third – coordinates of measurement site (in meters), the fourth – measured values of gravity field (in mGals), the fifth – gravity sensor height (in meters, negative value), the sixth – weight of the measurement (can be missing). The gravity data description block must end with *end_d_grav* string.

Block of the magnetic data description must start with *start_d_mag* string. Strings containing information about measurements coordinates and field data then follows. The first writing is a number of measurement profile, the second and the third – coordinates of measurement site (in meters), the fourth – measured values of magnetic field (in nT), the fifth – magnetic sensor height (in meters, negative value), the sixth – weight of the measurement (can be missing). The gravity data description block must end with *end_d_mag* string. Each of the blocks described above can be missing.

An example of a text file of data for 6 observing sites is shown in picture 9.

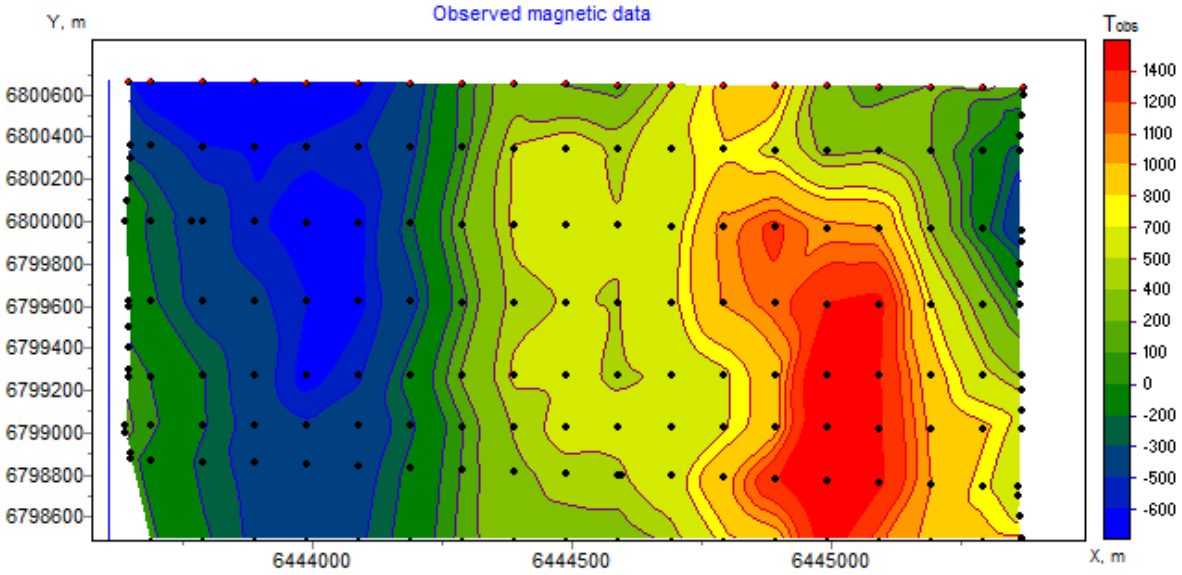


Pic. 9. An example of data file

Data visualization

Contour plan

In the program operating window when the chosen type of data displaying is **Options/Data/Contour map,** contour plan is displayed in the bottom left corner. Observed parameter (**Options/Data/Observed**), theoretically calculated parameter (**Options/Data/Calculated data**) or misfits values for the area (**Options/Data/Misfit)** can be displayed (pic.10).



Pic. 10. Contour plan of magnetic field observed values.

Red line shows the position of the current profile for which there are graphs of observed and calculated parameter (top right corner section), blue dotted line shows the current position of model slice.

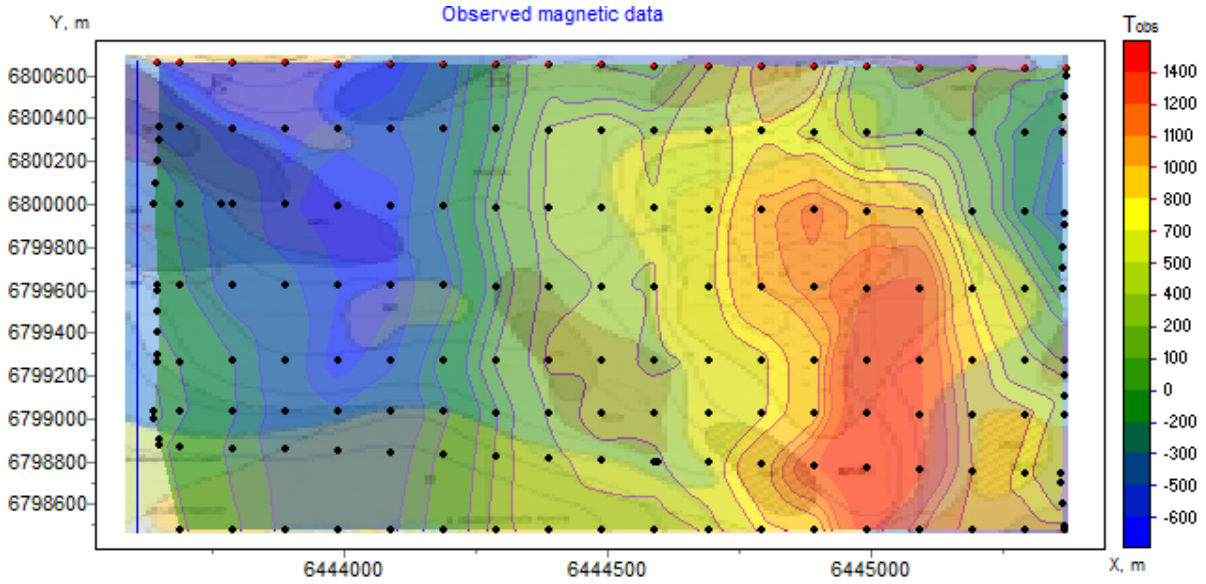
Right mouse button click on object section calls up the context menu with the following options:

Log data scale	Use logarithmic scale on color bar.
Smooth mode	Smooth pseudosection
Display grid point	Display measurement point ticks.
Display ColorBar	Display colour scale.
Setup	Run parameters setup dialog (more).
Print preview	Print contour plan (more).
Save picture	Save contour plan to image file.
Save XYZ file	Save contour plan to Surfer format.

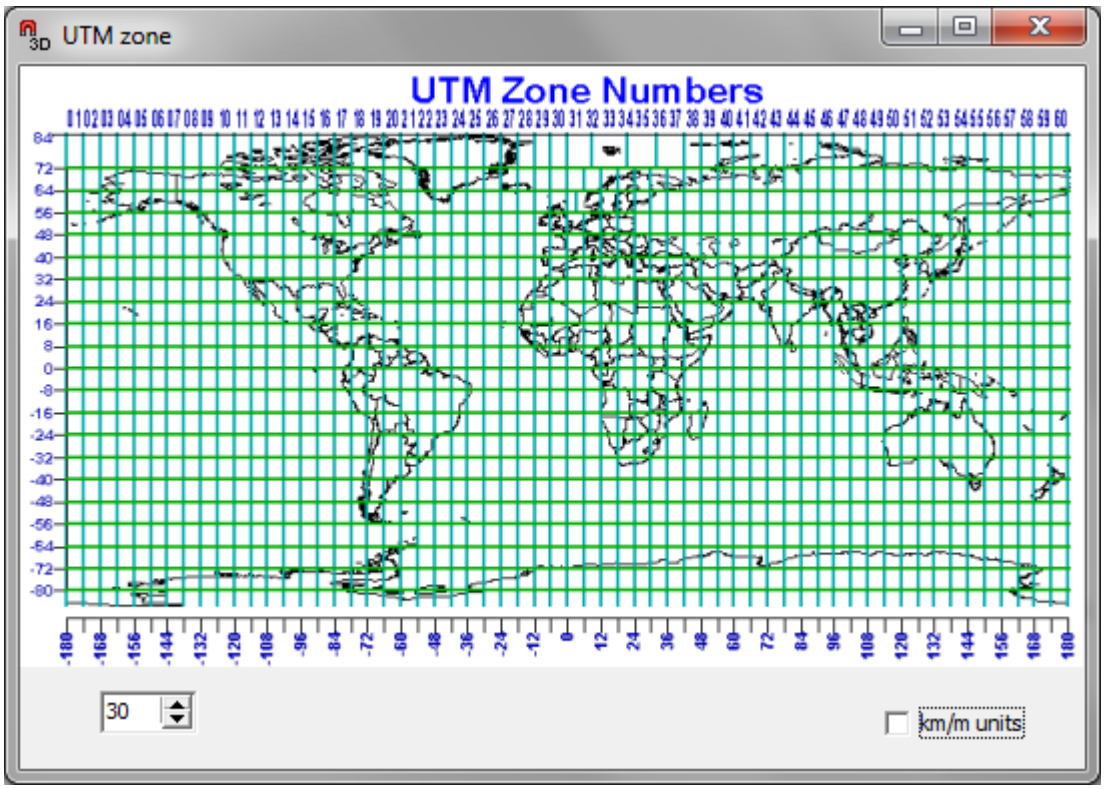
X:Y=1:1	Make scales along the vertical and horizontal axes the same.
Load background	Load image as a base layer (image file).
Load googlemap	Load Google map as a base layer.
Remove background	Remove current base layer.
Draw in Surfer	Export to Golden Software Surfer

Load background option allows to upload any bitmap file as a base layer whilst the picture becomes semitransparent. This option is very useful for comparing measured data with topographic maps, plots, geological maps and tectonic maps as well as with another methods data (geophysical, geochemical, etc.) which are performed in graphical format. There is an example of usage geological map as a base layer in the picture 11.

Load googlemap option allows to upload Google map in accordance with set points coordinates. After choosing this option the UTM zone window where you have to select zone number will appear (pic. 12).



Pic. 11 An example of adjustment of the measured data contour plan and a geological map for the survey area.



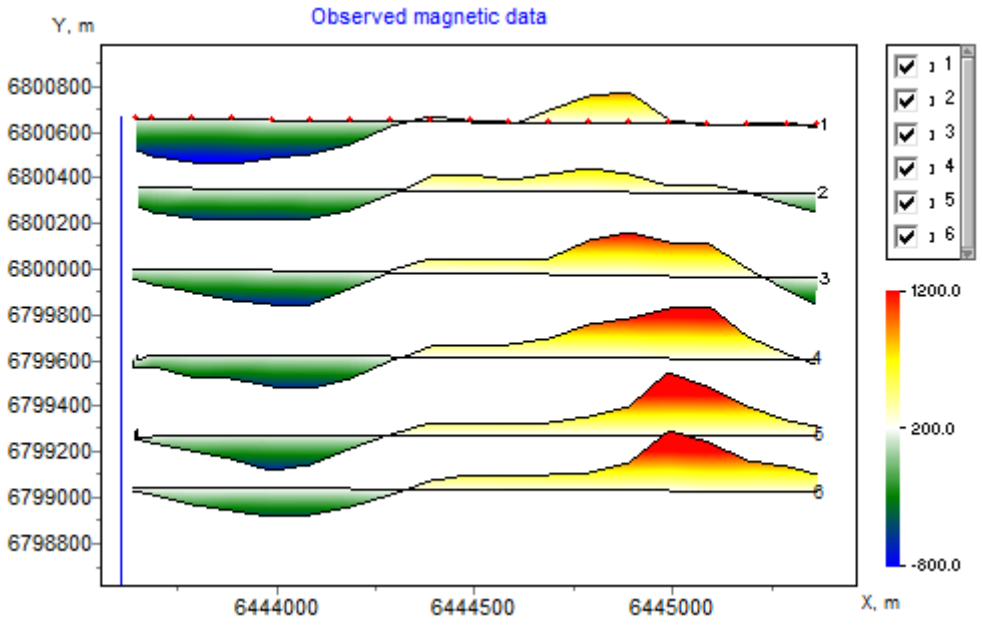
Pic. 12 Choosing UTM zone dialog.

Right click on necessary axis with Shift pressed and the axes editor will appear. (more).

Profiling plots

This object is used to plot theoretical and experimental parameters along profiles.

Object is introduced in the bottom left corner of the program operating window when the chosen type of data displaying is **Options/Data/Graphics map**. Observed parameter (**Options/Data/Observed**), theoretically calculated parameter (**Options/Data/Calculated data**) or misfits values for the area (**Options/Data/Misfit)** can be displayed. If misfits displaying (**Options/Data/Misfit) (**pic.13) is chosen, observed graphs are shown as curves with filling, calculated – as solid red curves. To change graphs scale, use mouse scroll wheel. To activate or deactivate graphs for one or another profile, use legend in the right part of the object.



Pic. 13 Profiling plots window.

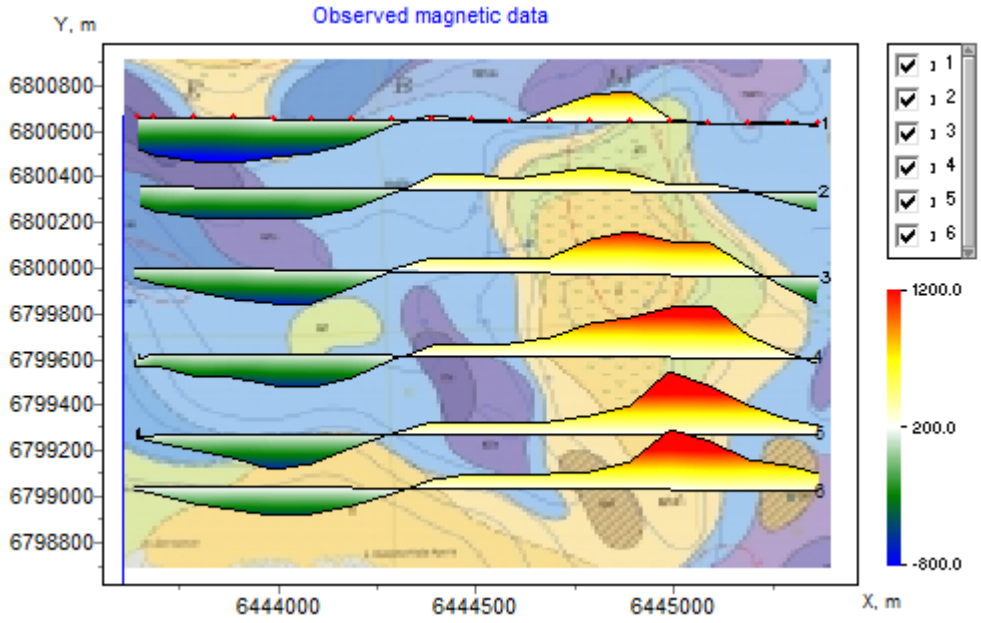
The red line with crosses shows the position of the current profile which's observed and calculated parameter graphs are shown (section in the top right corner), blue dotted line shows the current position of the model slice.

Right-clicking on the object section runs the context menu with the following options:

Setup	Run parameters setup dialog (more).
Print preview	Print (more).
Save picture	Save profiling plots in an image file.
X:Y=1:1	Make scales along the vertical and horizontal axes the same.
Load background	Upload a picture as a base layer (image file)
Load googlemap	Upload Google map as a base layer
Remove background	Remove current base layer

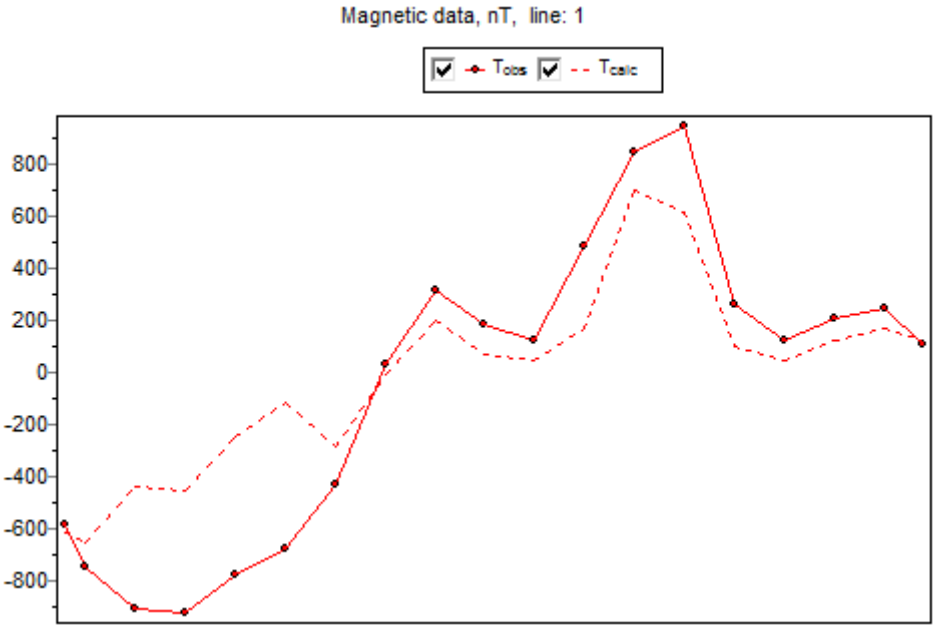
Axis parameters can be set in the axis editor (right mouse click and pressed Shift on an axis).

As for the contour plan, you can upload any image file or Google map as a base layer. In the picture 14 there is an example of profiling plots with a fragment of a geological map as a base layer.



Pic. 14. Profiling plots with a fragment of a geological map as a base layer.

Profiling plot for the current profile is displayed in the window above the model (pic. 15).

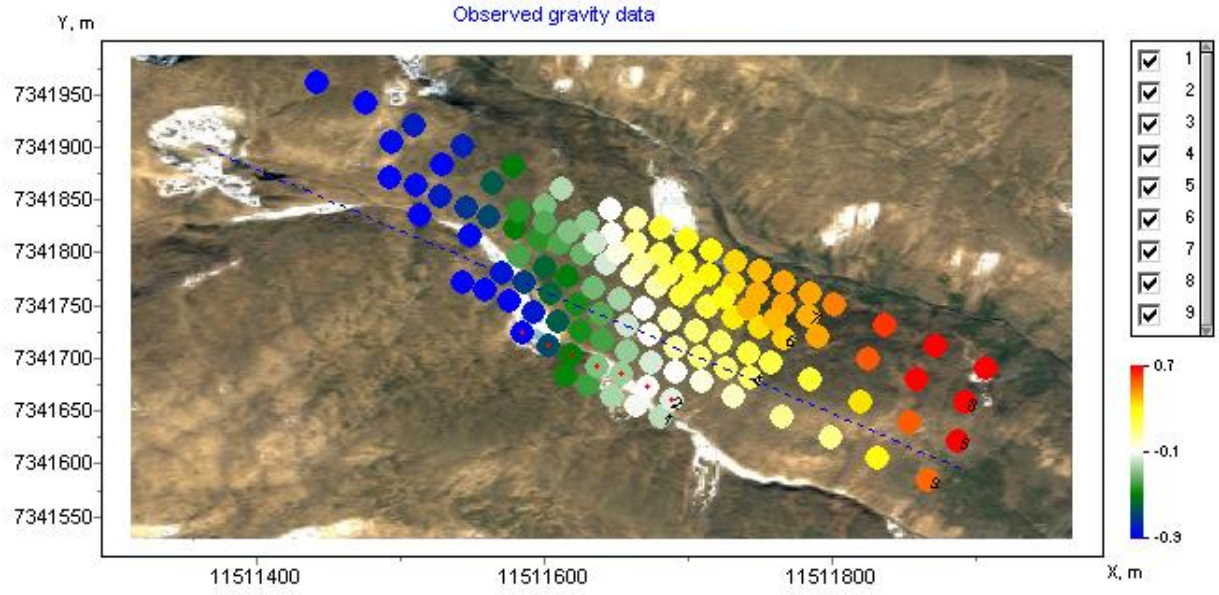


Pic.15. Calculated (dotted line) and observed (solid line) profiling plots.

By default, measured curves are shown with solid curves with circles at measurement points, calculated curves - with dotted lines. Graphical parameters of observed and calculated graphs can be set in the graph setting dialog which is run by right-clicking on the graph with pressed Shift (more). Axis parameters can be set in the axis editor (right mouse click + Shift on the axis).

Data displaying in a form of points

Data displaying in a form of points is useful when using base layer. Object can be situated in the bottom left corner of the operating window when the chosen type of data displaying is **Options/Data/Points map**. Observed parameter (**Options/Data/Observed**), theoretically calculated parameter (**Options/Data/Calculated data**). To change the points size, use mouse scroll wheel. To activate or deactivate points for one or another profile, use legend in the right part of the object.



Pic. 16 Data window displayed in a form of points.

The red line with crosses shows the position of the current profile which's observed and calculated parameter graphs are shown (section in the top right corner), blue dotted line shows the current position of the model slice.

Right mouse click on the object section runs the context menu with the following options.

Setup	Run parameters setup dialog (more).
Print preview	Print (more).
Save picture	Save data in a form of points in an image file
X:Y=1:1	Make scales along the vertical and horizontal axes the same.
Load background	Upload a picture as a base layer (image file)
Load googlemap	Upload Google map as a base layer
Remove background	Remove current base layer

Axis parameters can be set in the axis editor (right mouse click and pressed Shift on an axis).

As for the contour plan, for points you can upload any image file or Google map as a base layer.

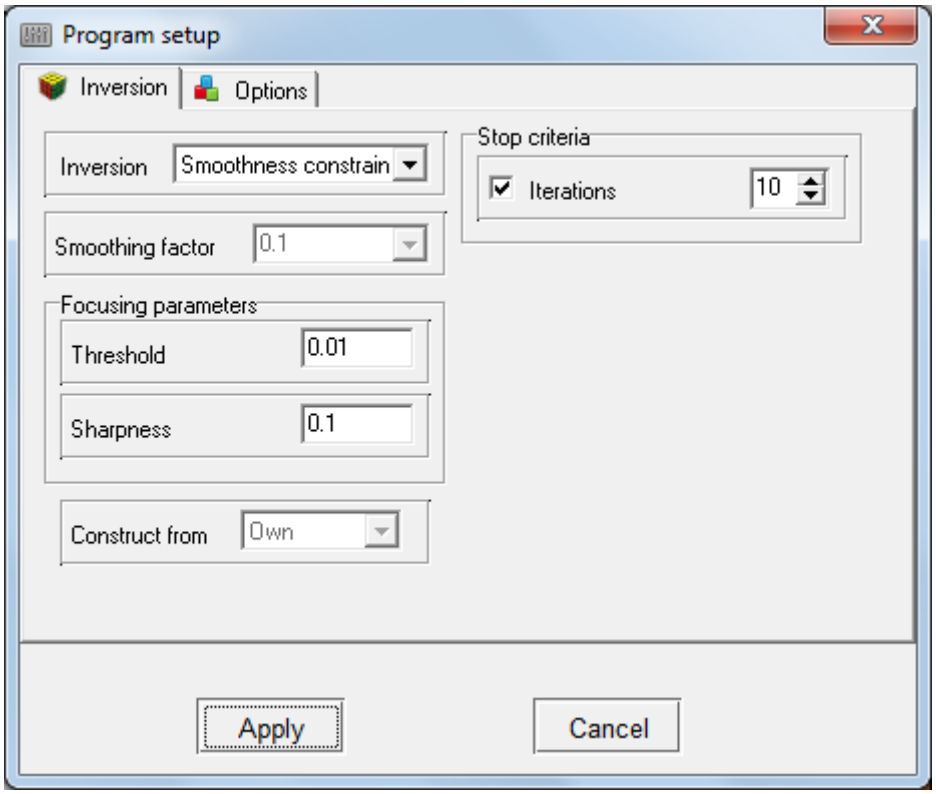
Data inversion

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.

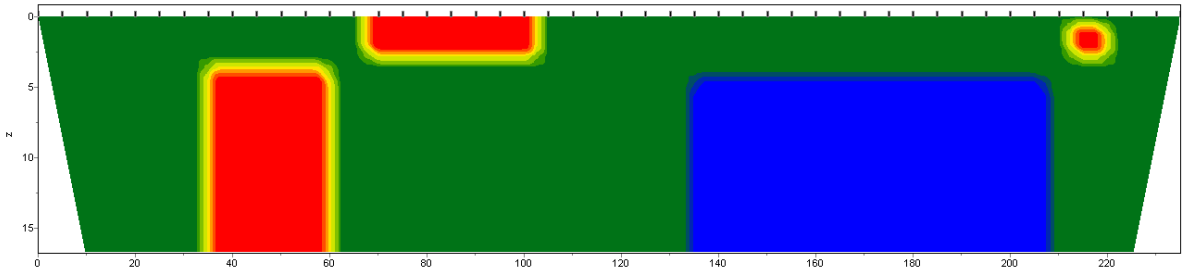
Inversion tab serves for inversion parameters setup (pic.17).



Pic. 17. **Program setup** dialog window, **Inversion** tab

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

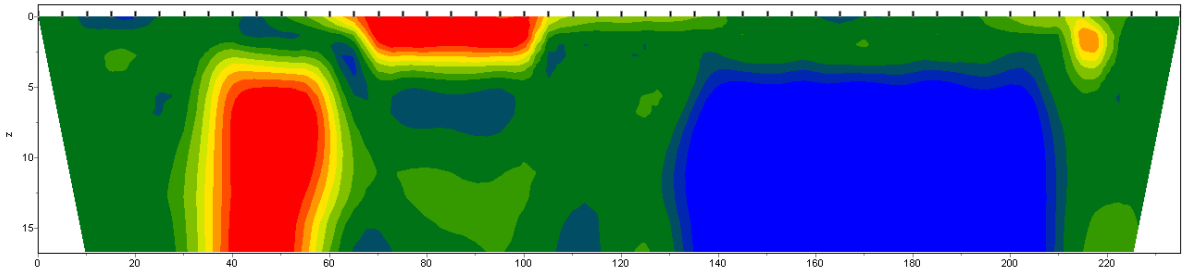
Let us consider inversion algorithms by example of subsurface model that consists of several blocks (pic. 18).



Pic. 18. 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.19).



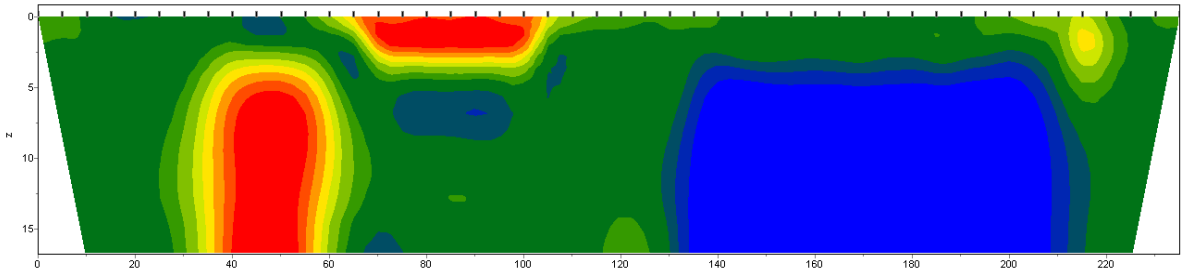
Pic. 19. Regenerated model as a result of ***Smoothness constrained*** inversion

Matrix equation for this kind of inversion is the following:

$$\left(A^T W^T W A + \mu C^T C\right)\Delta m = A^T W^T \Delta f \qquad (1)$$

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.20).



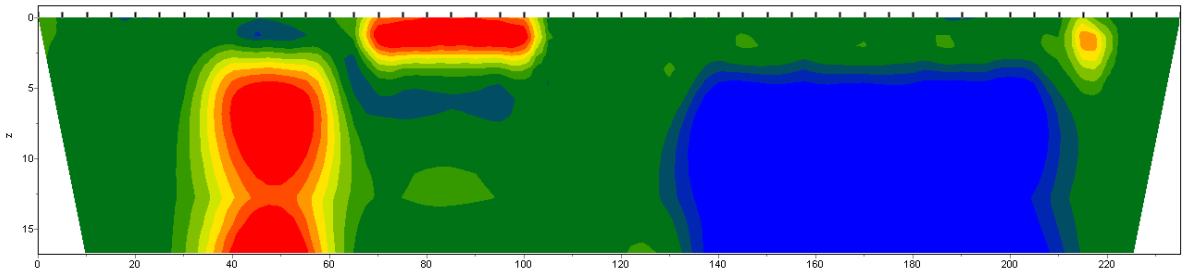
Pic. 20 Regenerated model as a result of ***Occam*** inversion.

Matrix equation for this kind of inversion is the following:

$$\left(A^T W^T WA + \mu C^T C\right)\Delta m = A^T W^T \Delta f - \mu C^T Cm \qquad (2)$$

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.21).



Pic. 21. Regenerated model as a result of ***Marquardt*** inversion

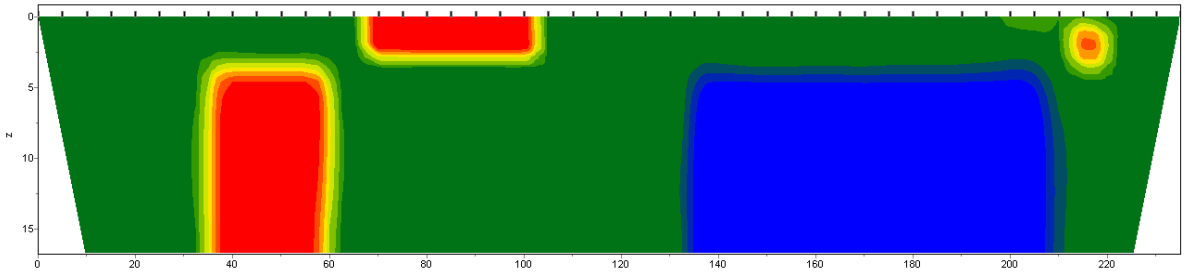
Matrix equation for this kind of inversion is the following:

$$\left(A^T W^T WA + \mu I\right)\Delta m = A^T W^T \Delta f \qquad (3)$$

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 parameter) can be received (pic.22).



Pic. 22. Regenerated model as a result of ***Focused*** inversion

Matrix equation for this kind of inversion is the following:

$$\left(A^T W^T WA + \mu C^T RC\right)\Delta m = A^T W^T \Delta f - \mu C^T RCm \qquad (4)$$

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

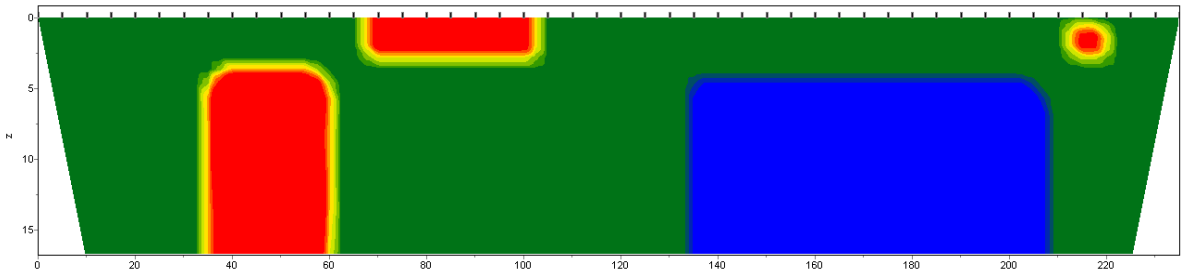
between these cells). Dependence of averaging degree (or weight) of two adjacent cells R_i on contrast threshold e and contrast between these cells r_i is the following:

$$R_i = \frac{e^2}{e^2 + r_i^2}. \qquad (5)$$

Blocks – fits parameters for certain domains which differ in values. Domains with equal values consider as single blocks (pic.23).

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

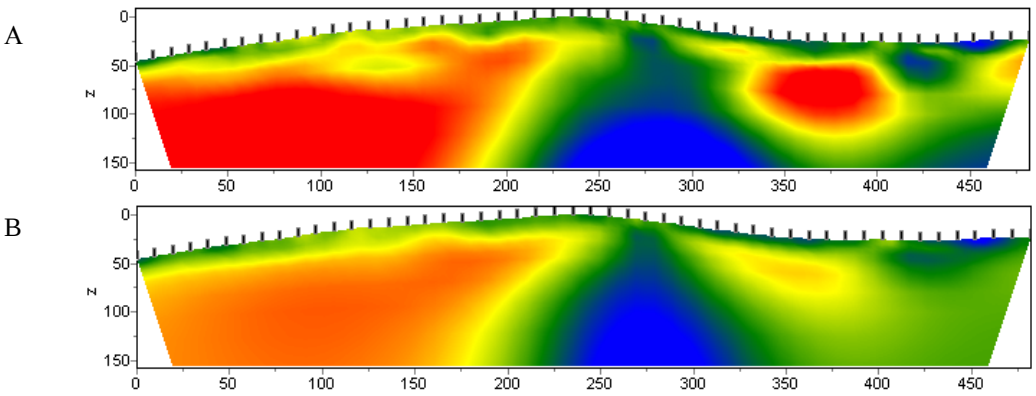
$$\left(A^T W^T W A + \mu l\right)\Delta m = A^T W^T \Delta f \qquad (6)$$



Pic. 23. 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. 24). Smoothing factor is used in ***Occam*** and ***Focused*** inversion algorithms.



Pic. 24. 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 %.

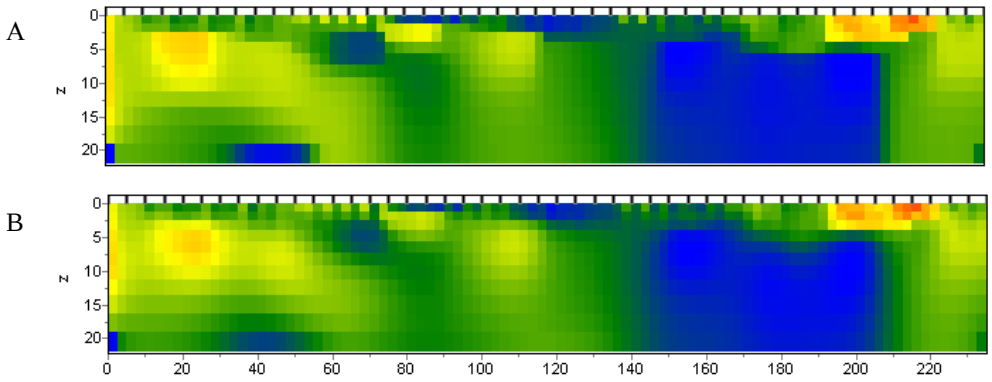
Robust weighting scheme – this option should be turned on if there are individual high deviations caused by systematic measurement errors. It is possible that current algorithm will not give positive results if amount of rejected data is comparable to amount of high quality data.

Stop criteria field contains inversion stopping criterion.

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

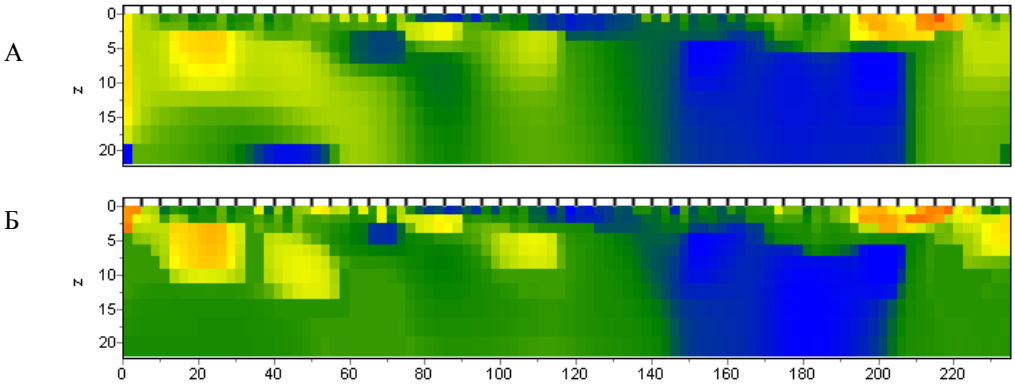
Focusing parameters field

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. 25). Small parameter value can cause algorithm discrepancy (in this case it needs increasing). Large value leads to receiving smooth distribution.



Pic. 25. Geoelectric models as a result of ***Focused*** inversion with **Threshold** parameter: 0.01 (A) and 0.1 (B)

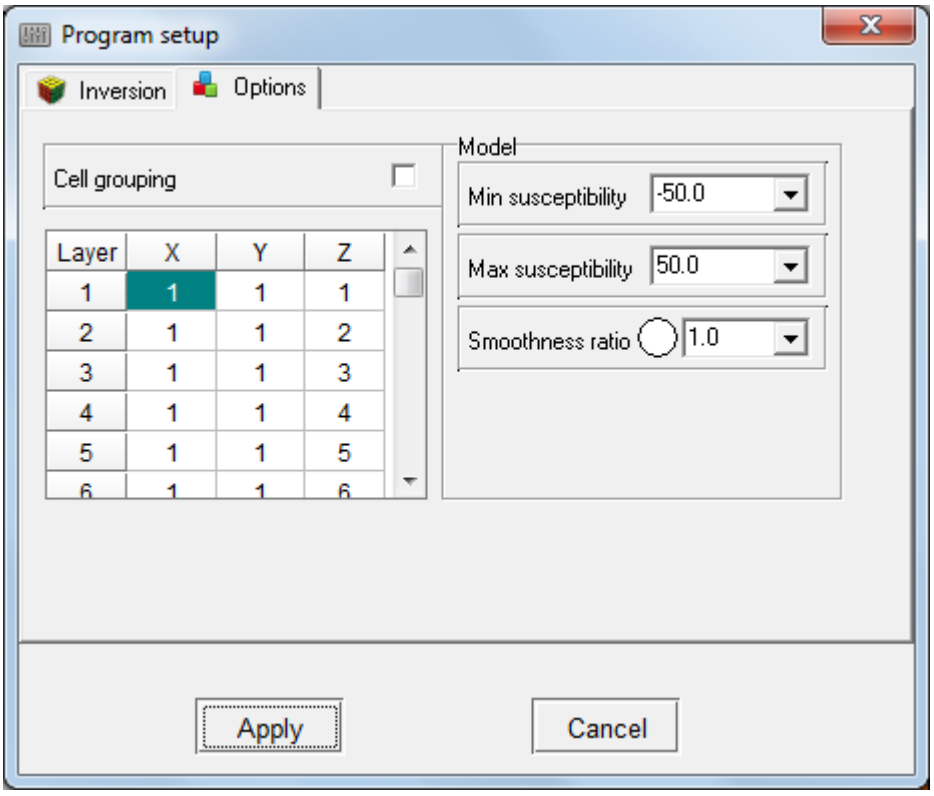
Sharpness – defines ratio between minimization of causative body volume (0) and construction of piecewise-smooth distribution (1) (pic. 26). Value of this parameter is chosen empirically (0.7).



Pic. 26. Geoelectric models as a result of ***Focused***
inversion with **Sharpness** parameter: 0.8 (A) and 0.2 (B)

Construct from – 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, 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.

The second inlay **Options** is used for adjustment of additional inversion parameters. (pic.27).

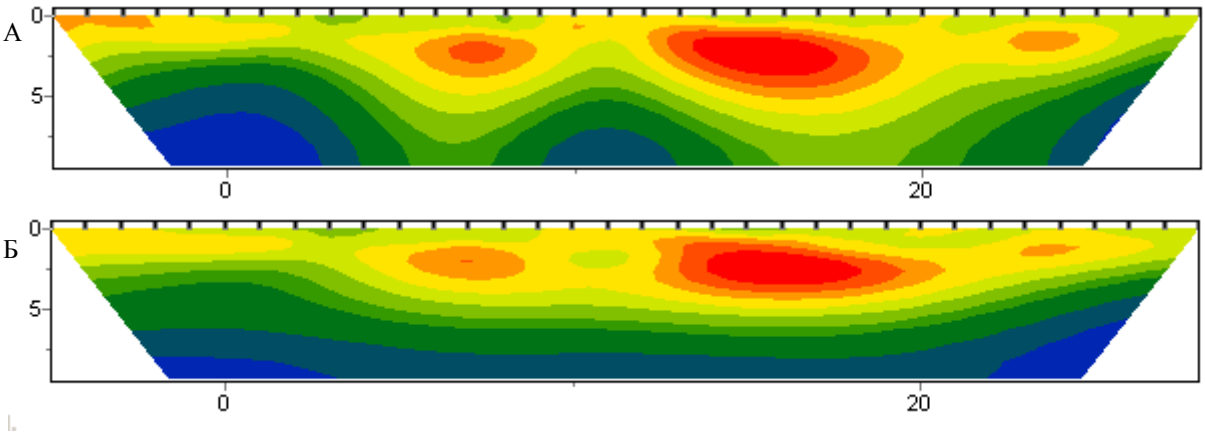


Pic. 27. **Program setup** dialog window, **Options** tab

Model field:

Min susceptibility, Max susceptibility, **Min. Density, Max.density**– sets the limits of model parameters variation for inversion. The values of the magnetic susceptibility need to be specified in the GHS system ($n*10^{-5}$).

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.28).

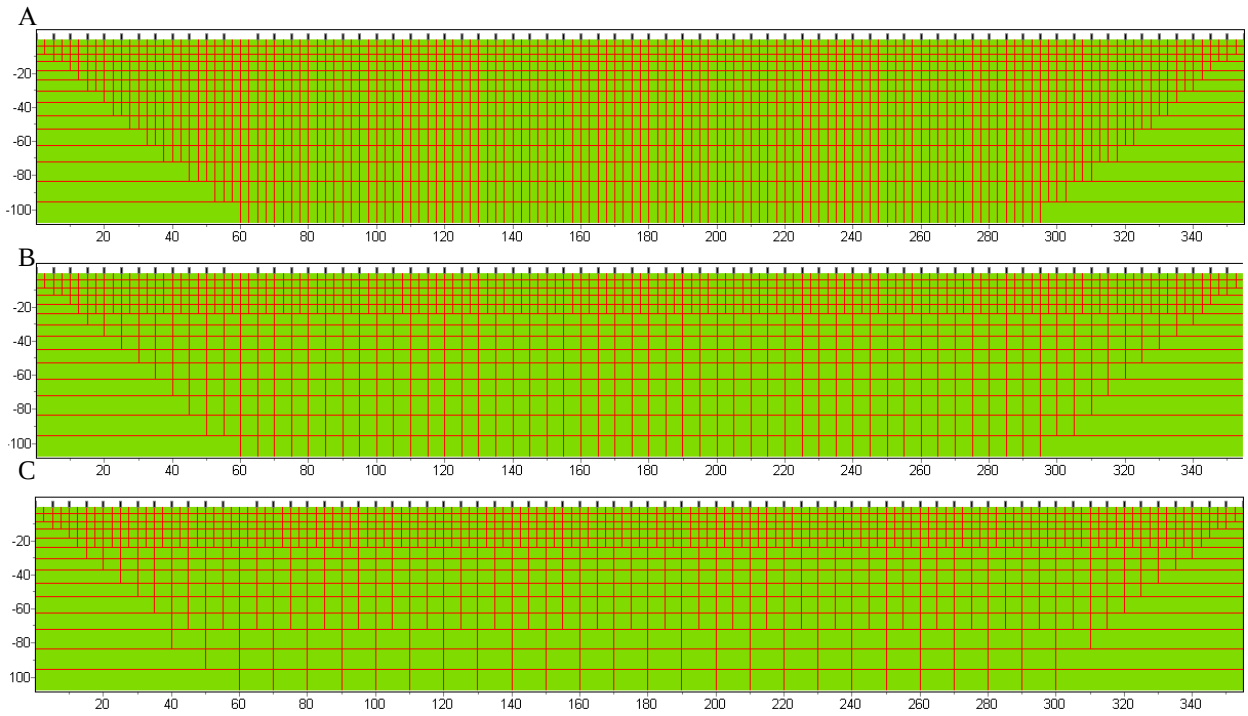


Pic. 28. Geoelectric model as a result of "smooth" inversion with **Smoothness ratio** parameter: 1 (A) and 0.3 (B).

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 four columns: in the first (**Layer**) there is a layer number for the initial model; in the following three columns (**X, Y, Z)** you can set a number of cells (in the corresponding direction) which are contained in every cell of the inversion mesh for this layer. The inversion mesh will be displayed in the model editor, while it is being customized. Double click on the cells in the X and Y columns allows to unite cells in the horizontal direction for this and all the underlying layers.

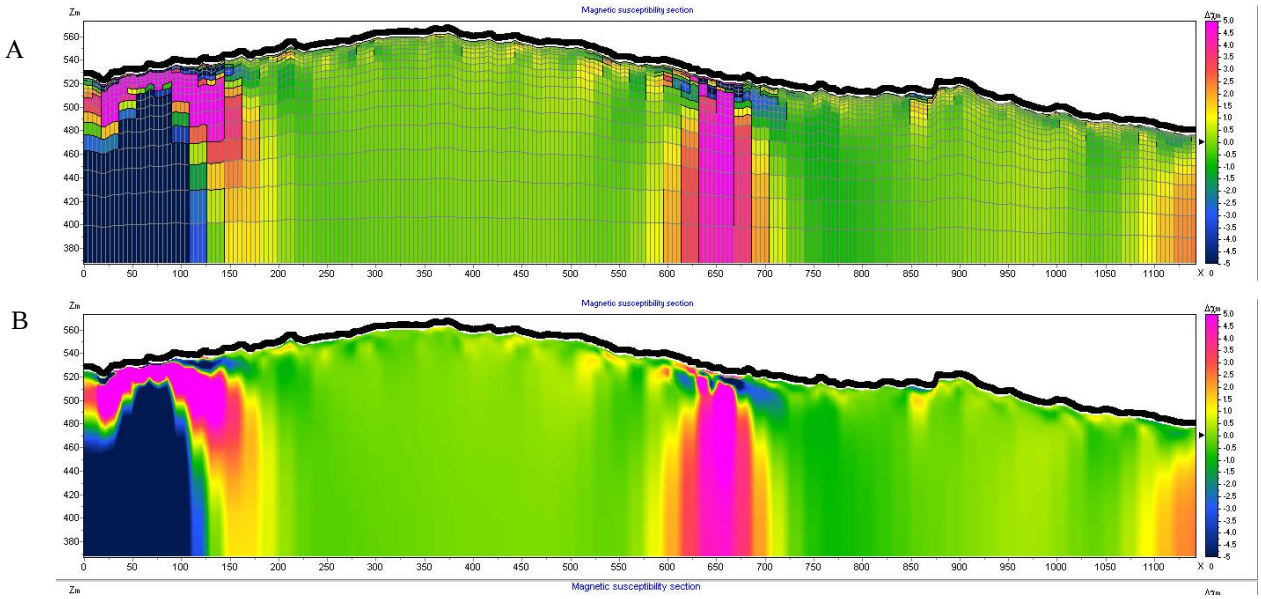
Examples of three inversion meshes are shown below. First one corresponds to model (pic. 29A), in the second one cells are united into groups of two, starting with second layer (pic. 29B), in the third one cells are united into groups of four, starting with second layer (pic. 29C).



Pic. 29. Examples of inversion meshes.

Model visualization modes and parameters

Model can be displayed as cells **Options/Model/Block-section** (pic.30A) or in smooth interpolated palette **Options/Model/Smooth-section** (pic.30B)



Pic. 30. Model display options:

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

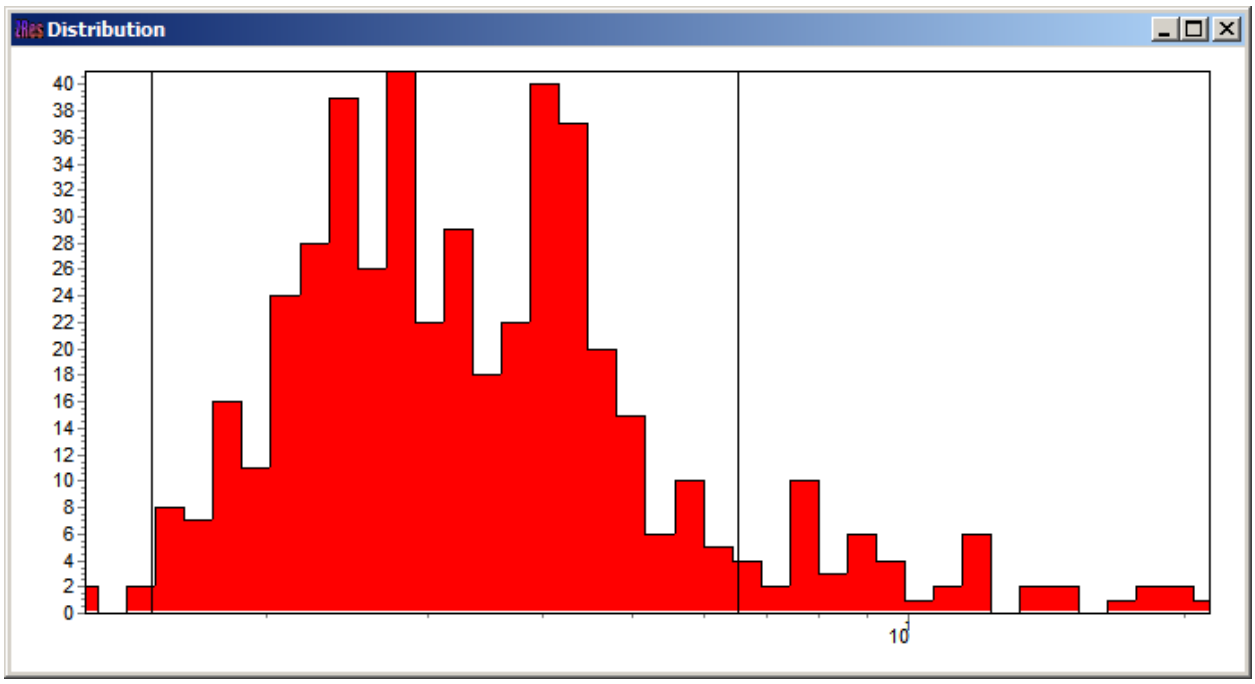
You can choose the model slice orientation (XZ, YZ, XY) using **Options/Model/Plane** option.

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 color bar	Display colour bar
	Setup	Run model parameters setup dialog (more).
	Zoom&Scroll	Turn on zoom and scroll mode
	Print preview	Print model
	X:Y=1:1	Make scales along the vertical and horizontal axes the same.
Colour bar	Set minimum	Set minimum value of colour bar
	Set maximum	Set maximum value of colour bar
	Automatic	Automatically select minimum and maximum value of colour bar
	Smooth image	Set logarithmic scale on colour bar
	Set cursor value	Smooth image contours

When right-clicking on model cells, the dialog for operating with the model will appear, it is described below.

To view model parameters use **Options/Model/Model Histogram** dialog (pic. 31). Minimum and maximum of parameter colour scale can be set by changing vertical lines positions.



Pic. 31. **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.

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

3D model parameters setting dialog

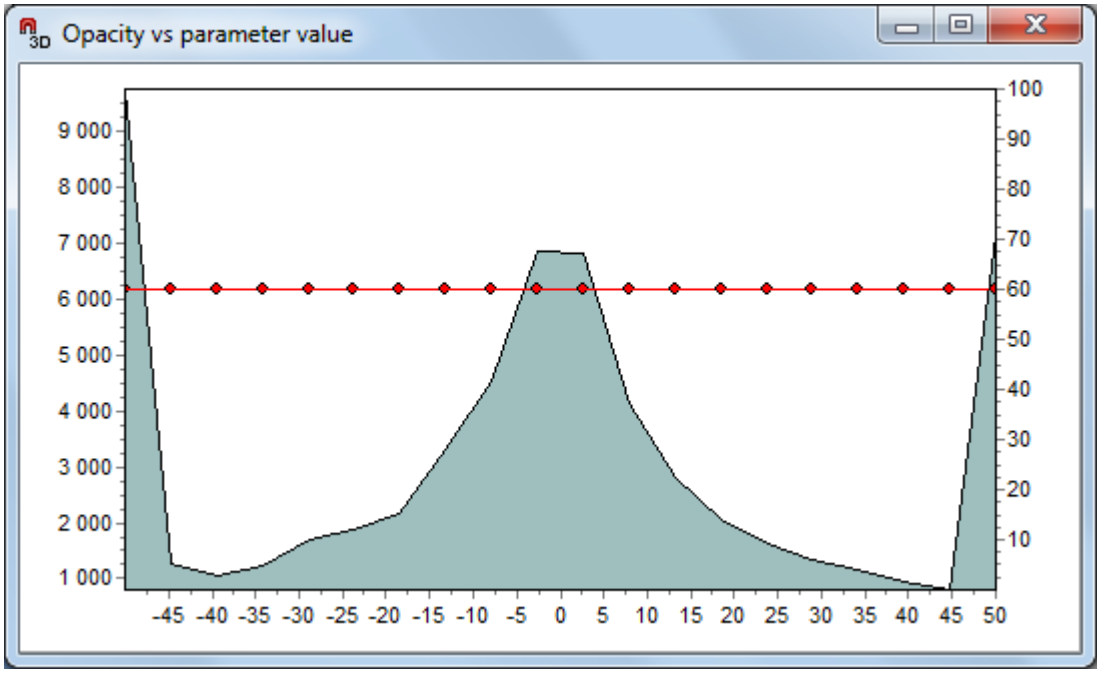
3D model serves to display the section in 3D view. The image size is controlled with the mouse wheel. To rotate model use pressed left mouse button. The  button on the toolbar of the program main window serves to set the 3D image parameters, the settings are also available on right mouse button click in the 3D model section, whereupon the **3D Options** appears.

When the  button is held down, the following options are available:

3D view settings	Call the 3D model parameters setting dialog
OpenGL settings	3D image editor (more)
Print preview	3D model print setting dialog (more)
Plane cut	Choose the model slice orientation.
Model	Set the start model parameters Half-space value – set the value of the parameter for the half-space

	Clear model – clear the current model Clear limits – clear the current parameters limits MinMax auto – set the parameters limits automatically Smooth/raster model – smooth/raster the model
Axes settings	Call the axis parameters setting dialog (more).
Show	Choose the displayed objects (to choose check the boxes opposite to the needed objects): Cutting plane – show the model borders Survey points – show the measurement points Boreholes – show well log and stratigraphy data Background – show the base layer
Synchronous cut	Change the slice position on the 3D model synchronously with changing the 2D plan using the  buttons.
X:Y:Z 1:1:1	Set the same scale for all the axes

The 3D image parameters setting dialog consists of five tabs. The **Opacity** (0-100) option is situated in the bottom part that allows to set the general model transparency. For more delicate model transparency parameter settings use the  button (pic.32).



Pic. 32. **Opacity vs parameter value** dialog window.

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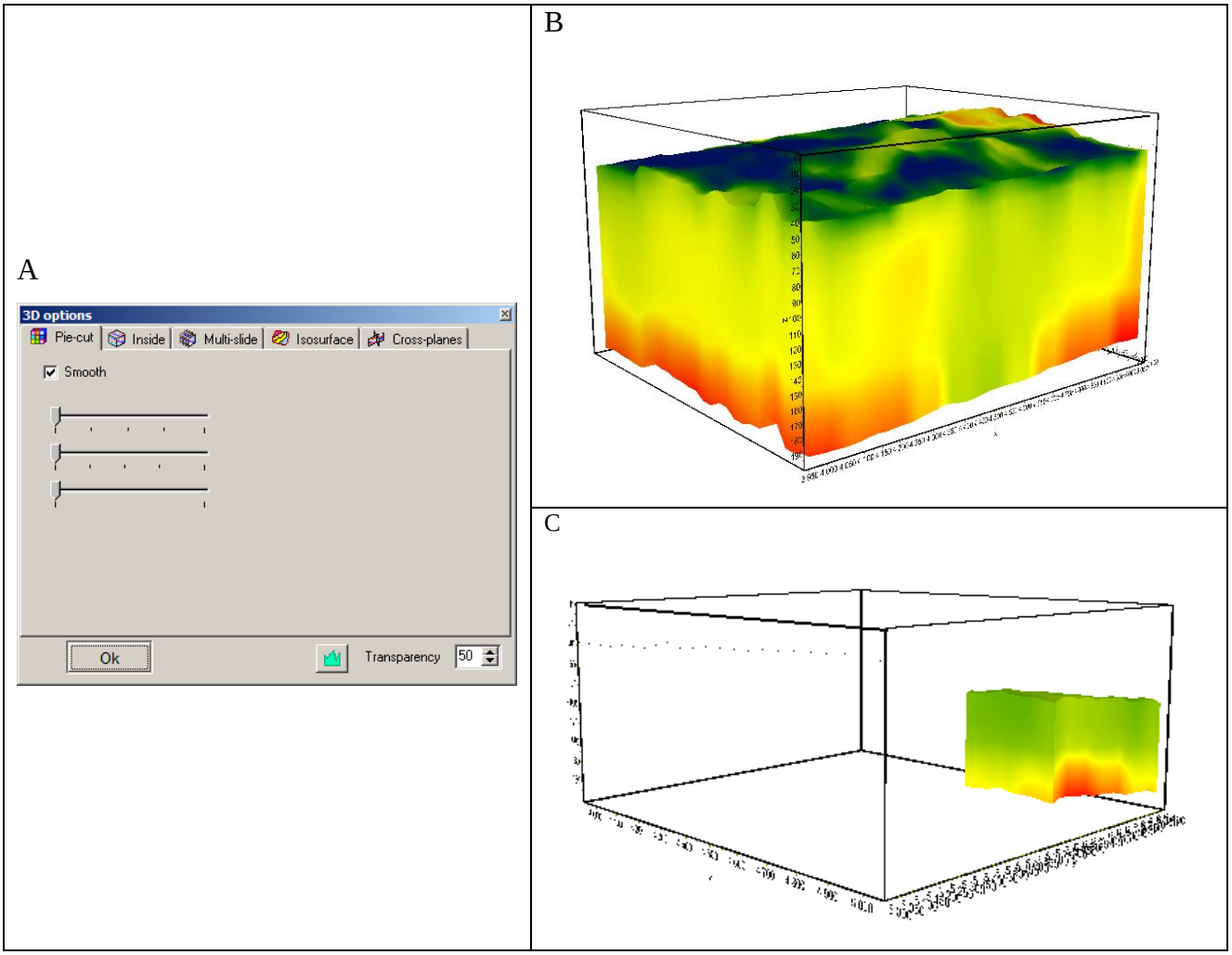
There is a filled graph in the **Opacity vs parameter value** window which shows the current parameter distribution. Red graph shows the transparency value depending on the parameter. The background medium parameter value is usually a maximum on the distribution graph. If it must be shown only anomalous objects, the transparency of those which are close to background medium is being decreased. Use mouse to change the transparency profile.

The **Pie-cut** tab – construct a model in the form of opaque parallelogram limited by user-selected cross-sections (pic.39).

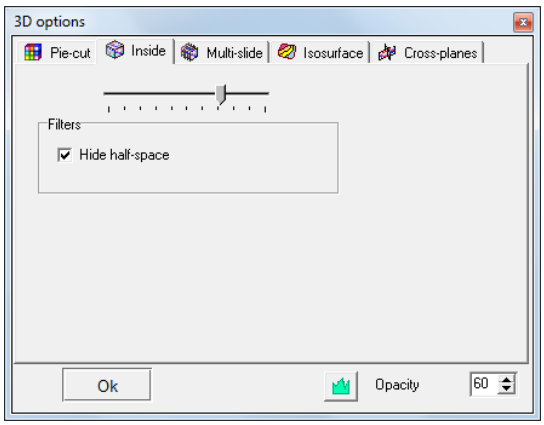
The **Smooth** option activates the model constructing regime with continuous interpolative filling. Three sliders set the positions of cutting-off borders for the model.



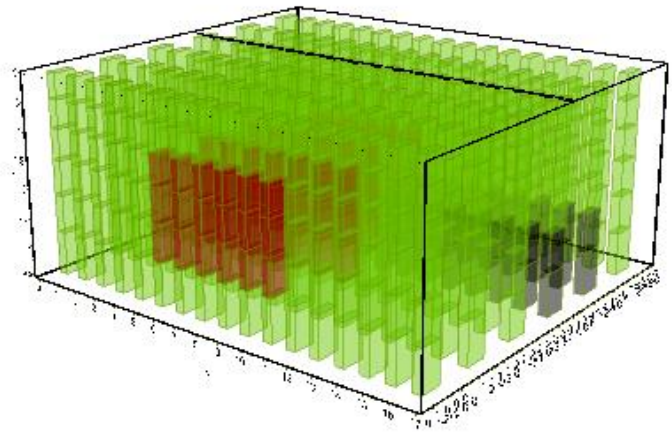
Pic. 33. Dialog window **3D options**, **Pie-cut** tab (A) and examples of the corresponding model visualization (B, C).

Inside tab – fully built the model of semi-transparent blocks (pic. 34). The slider in the top part sets relative cell size from 0 to 100 percent. The unnecessary blocks are cut off in the **Filters** section. **Hide half-space** option forbids drawing of the blocks which's values are equal to those of the half-space (convenient to use in the modelling regime). In case of inversion results displaying it is more suitable to use **Opacity** dialog settings.

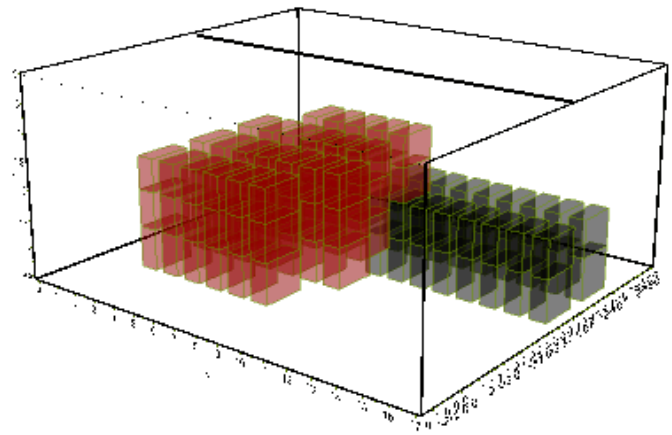
A



B



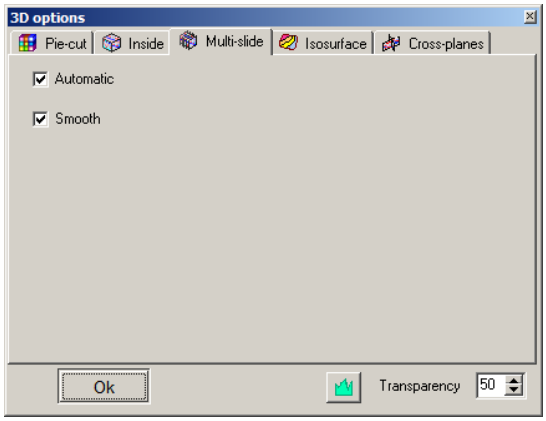
C



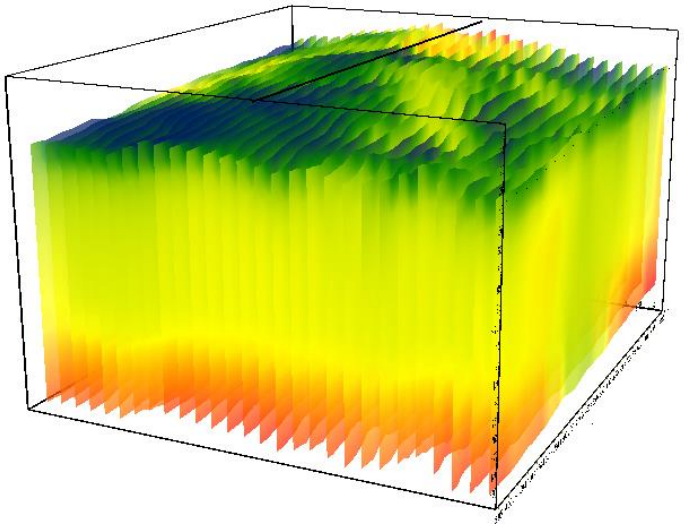
Pic. 34. Dialog window **3D options**, **Inside** tab (A) and examples of the corresponding model visualization (B, C).

Multi-slide tab – shows a stand of semi-transparent model slices along one of the directions (pic. 35). **Smooth** option includes regime of the model graphical construction with a continuous interpolative filling. **Automatic** option includes an automatic selection of the stand direction depending on the angle of vision.

A



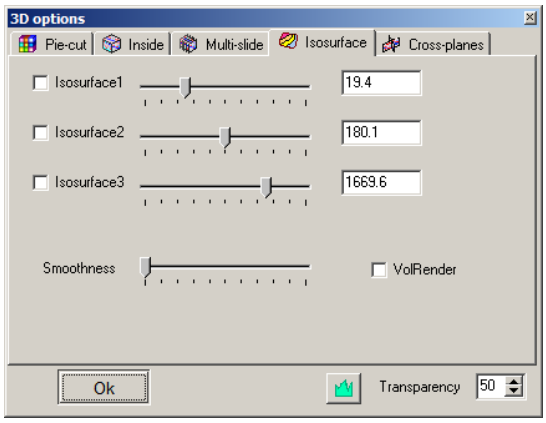
B



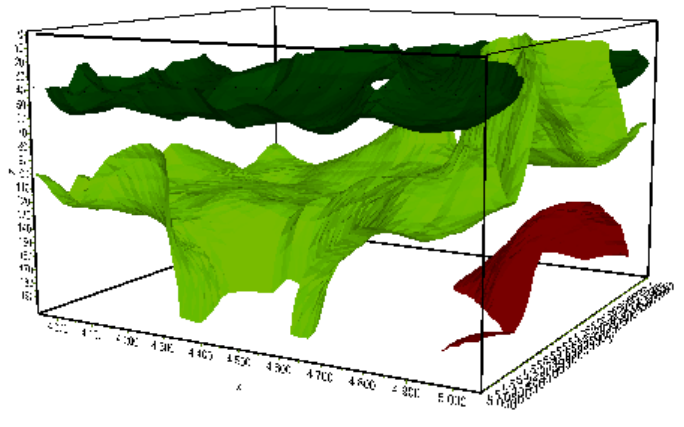
Pic. 35. Dialog window **3D options**, **Multi-slide** tab (A) and an example of the corresponding model visualization (B).

Isosurface tab – displays three-dimensional isosurfaces of the section parameters (pic. 36). Three sliders determine the values upon which the isosurfaces will be built. The **Smoothness** slider determines a smoothness degree of the isosurface. **VolRender** option activates the displaying regime for a semi-transparent fog which's colour is determined by the model parameters.

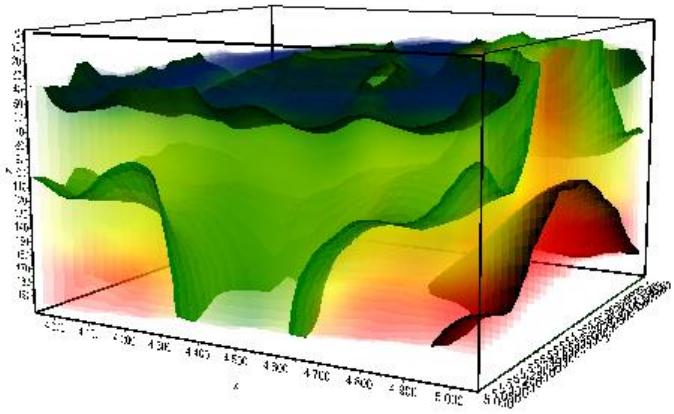
A



B



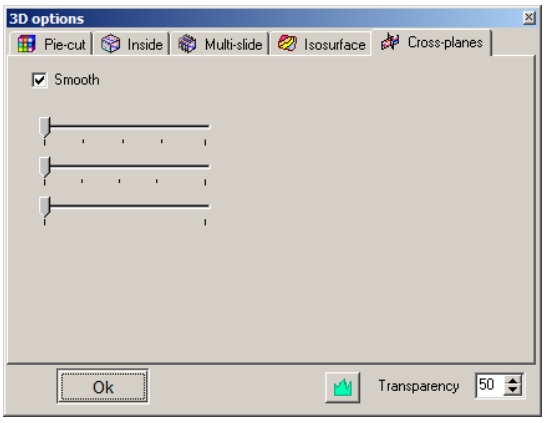
C



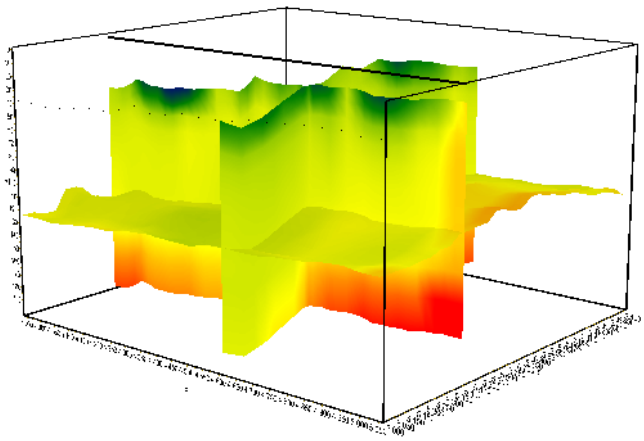
Pic. 36. Dialog window **3D options**, **Isosurface** tab (A) and examples of the corresponding model visualization (B, C).

Cross-planes tab – displays three semi-transparent mutually intersecting planes (pic. 37). **Smooth** option activates the model graphical construction regime with a continuous interpolative filling. Three sliders determine the position of the model intersection planes.

A



B



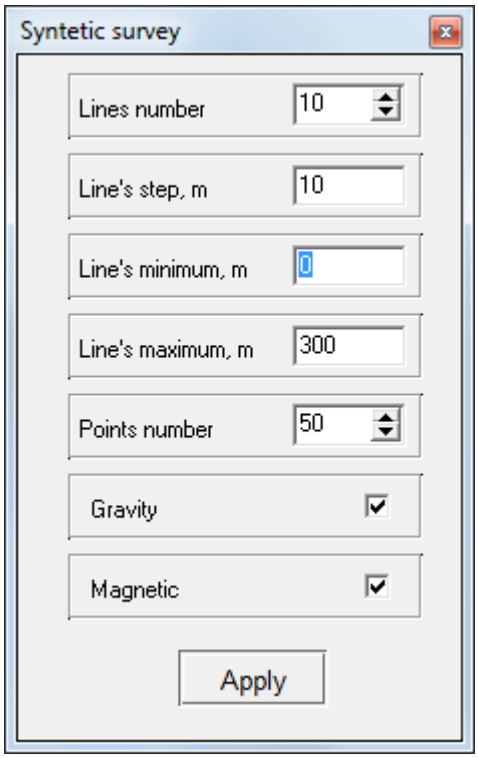
Pic. 37. Dialog window **3D options**, **Cross-planes** tab (A) and an example of the corresponding model visualization (B).

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.

To go to modelling regime, choose **File/Create survey** in the program main menu or press the  on the program main window toolbar.

Dialog Create survey



Pic. 38. Dialog window **Create survey**.

Dialog contains settings of synthetic model:

Lines number – a number of profiles

Line's step, m – distance between profiles in meters

Line's minimum, m - position of the first measurement point on profile

Line's maximum, m - position of the last measurement point on profile

Points number - number of profile points

Gravity and **Magnetic** options allow switching on or off calculation of the magnetic or gravity fields.

After setting the model parameters, the **Mesh constructor** dialog window will appear (more), where you can set mesh partitioning parameters. Then you need to create a model.

Model editor

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 parameter 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.

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
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.

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.

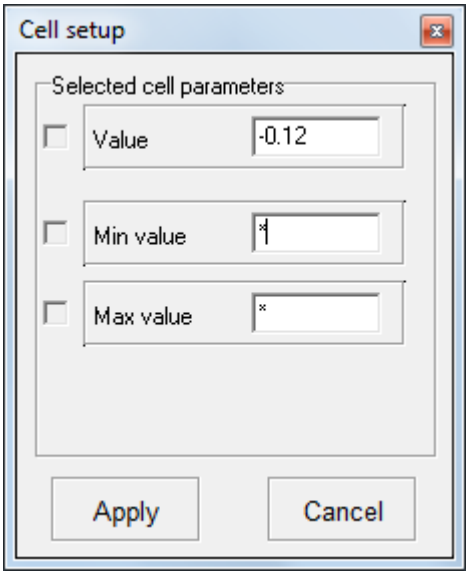
Parameter value can be also assigned to selected cells using cell parameter setup dialog **Cell setup** (pic. 39).

Cell parameter setup dialog

This dialog serves for selecting cell parameters or highlights it.

Value – sets cell parameter value.

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



Pic. 39. **Cell setup** dialog window

Interpretation results saving

Profile interpretation result is hold in «ZONDGM3D» file format (extension *.gm3) 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.

You can save result of the interpretation by clicking the button on the toolbar or the corresponding menu item **File/Save file**.

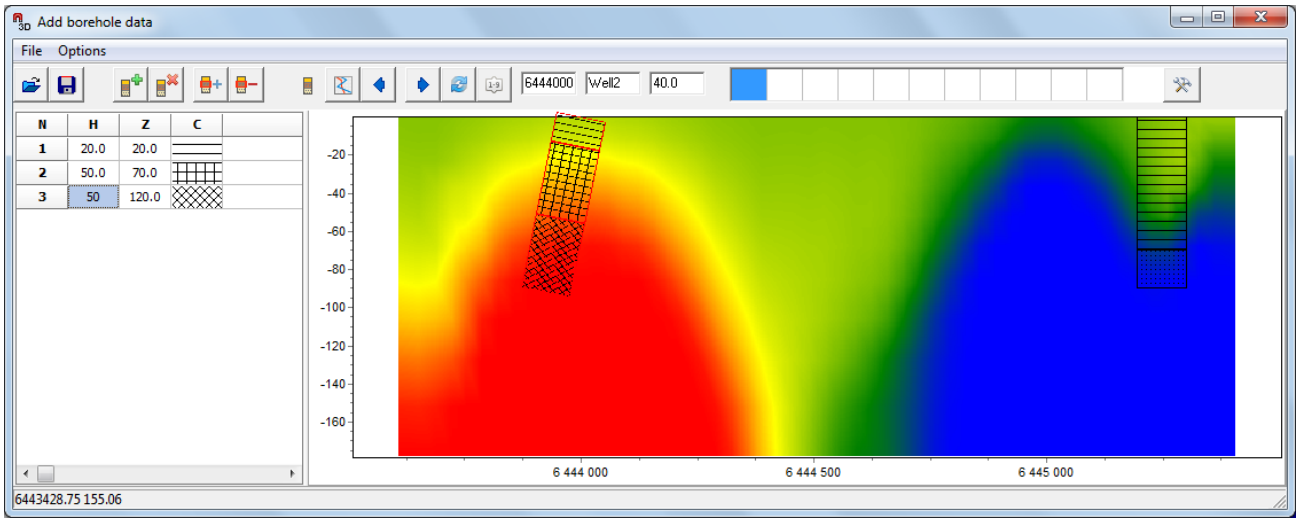
Project file	Save observed data and current subsurface model
Project with calculated data	Save calculated data and current subsurface model
Observed	Save observed data
Calculated data	Save calculated data
XYZV	Save table file *.dat with observing sites coordinates and parameter calculated values
XYZ	Save table file *.dat with observing sites coordinates

A priori information input

Existence of a priori information (borehole data) allows getting more reliable inversion results. Program «ZONDGM3D» has a built in module, which allows displaying a priori data in graphical form on sections.

Creation borehole data

To create a stratigraphy file select **Options/Boreholes/Create/Edit borehole data** in the main program menu. The dialog box **Add borehole data** appears (pic. 40).

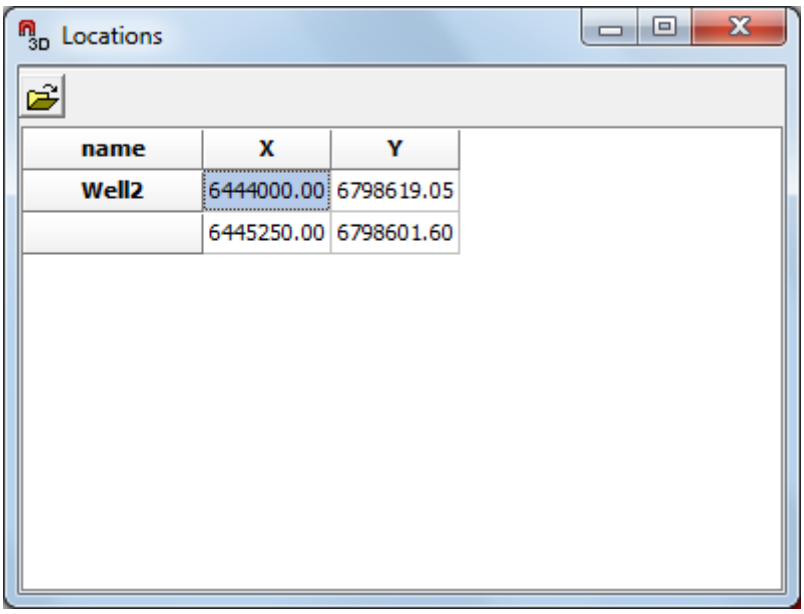


Pic. 40 Lithology file creation dialog **Add borehole data**

Dialog box toolbar contains the following buttons:

	Open lithology file
	Save lithology file
	Create a new borehole
	Remove borehole
	Add layer in borehole
	Remove layer in borehole
	The lithology column mode
	The logging data mode
	Go to the previous borehole
	Go to the next borehole
	Update data window
	Sort boreholes by coordinate
	Select fill color of window displaying boreholes (red in the example).
	Additional options

On the main panel there are also horizontal coordinate setting windows for borehole (the profile beginning distance) - **horizontal position,** borehole name – **Name** and an angle of inclination - **Angle**. Horizontal coordinates of boreholes are set in meters. The empty square windows are intended to create set of fillings. To change horizontal coordinates, use the program main menu function **Options/Boreholes/Edit position,** then dialog window **Locations** will appear (pic. 41), where you can set or upload coordinates.



Pic. 41 Dialog of borehole coordinates creating **Locations.**

The module contains two main windows. On the left is **Data window**, containing a table with the following columns: N - layer index, H - layer thickness in meters, Z – layer bottom depth in meters, C – filling type. Borehole data are displaying on the right window in graphical form.

To begin creating a lithology file click the button  on the toolbar. Then a new table appears in the **Data Window**. To set number of layers, click the button  . Then it is necessary to edit the table: set thickness or bottom depth for every layer, and also choose the filling type according to the lithology. To call filling dialog Pattern Color Editor, click double the left mouse button in column C of the data window (Pic. 42). The program offers a rich variety of lithology fills. The option **Color** allows choosing the fill color.

Pic. 42 Fill editor window

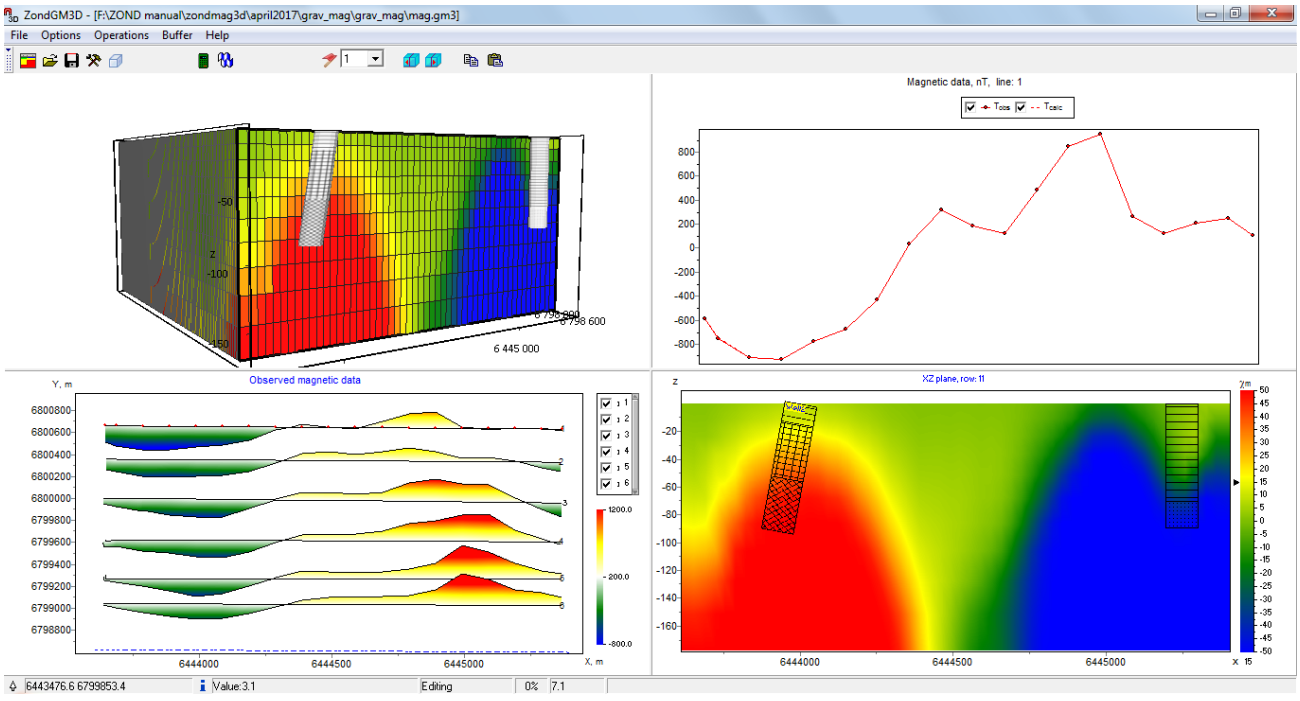
After completing entering borehole data, press a button  and the borehole appears in the graphics window. After that it is necessary to set the horizontal and vertical borehole coordinates on the toolbar in kilometers, after that the borehole will be displayed in accordance with its coordinates. In the graphics window active borehole is displayed in red.

For comfortable working with a large number of boreholes it is possible to create a palette in the program. To create a palette, select a fill on the fills column of the **Data window** and then click the right mouse button within fills area in the main program panel. In this way, fills set can be created and saved. To do this, click the button  and choose **Save default palette**. Saved fills set can be used when creating a new data file of lithology and logging ( - **Load default palette**).

The option **Set percent** is called by clicking the button  and can be used for changing scale of borehole data in graphical form.

After saving the data file, multiple auxiliary files will be created: ***.crt** - module project that can be loaded into the program «ZONDGM3D» and ***.txt** - file for each borehole, the names correspond to the horizontal and vertical coordinate. More about the format of lithology file.

To add borehole data, use **Options/ Borehole/Load borehole data.** Borehole data will be displayed on both model section and in the 3D model area (pic. 43).



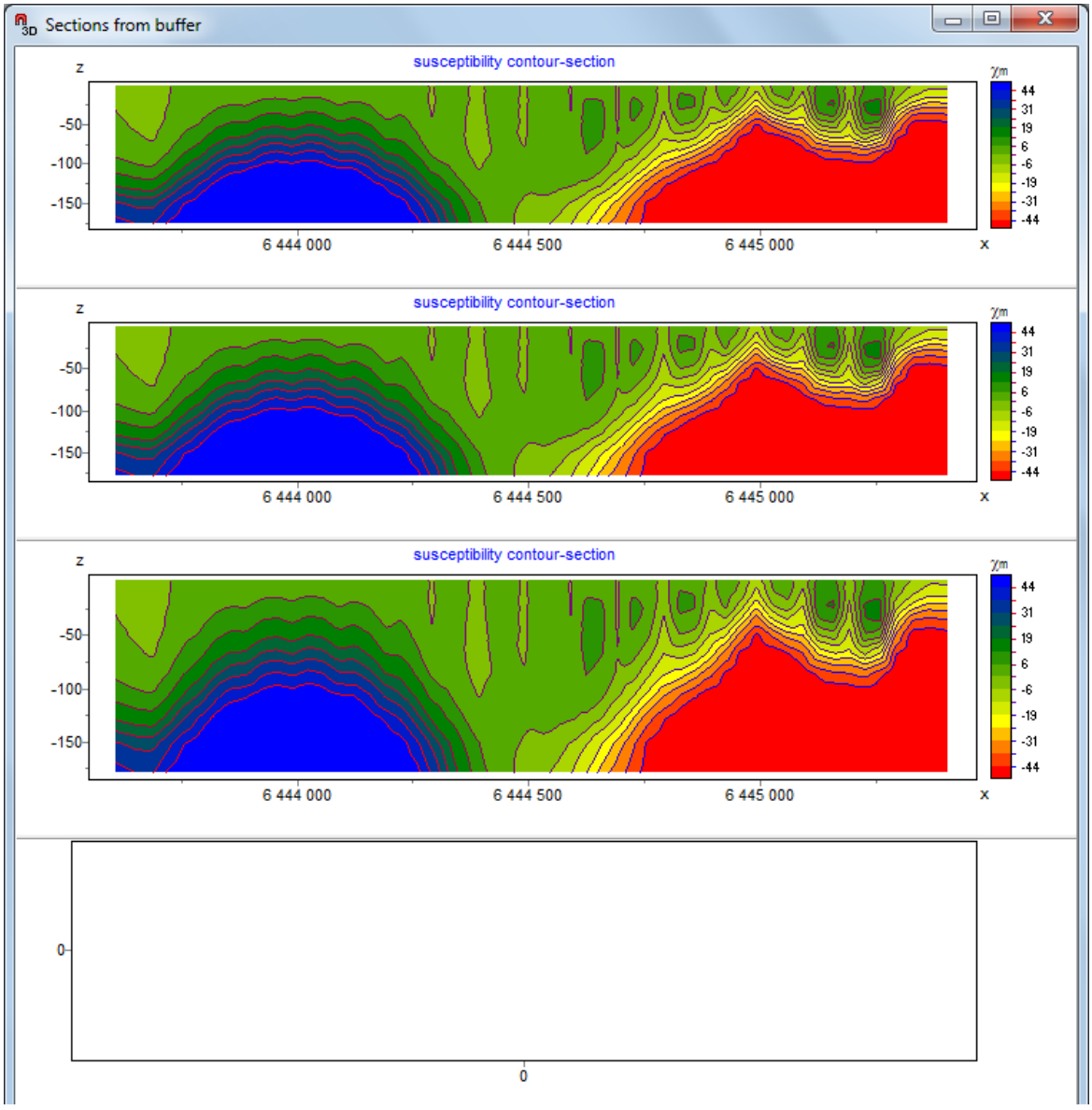
Pic. 43 Lithology data displaying in the section editor.

To load the available logging data of boreholes prepare a file format described in the part «Logging and lithology data file format» and load it using the button  .

Option «Buffer» of the main menu

Buffer option of the program main menu allows comparing models, obtained with different inversion parameters and program settings (when using additional geological data, filter data, etc.). When using this option, all obtained models are displayed in using the same color palette, and scales.

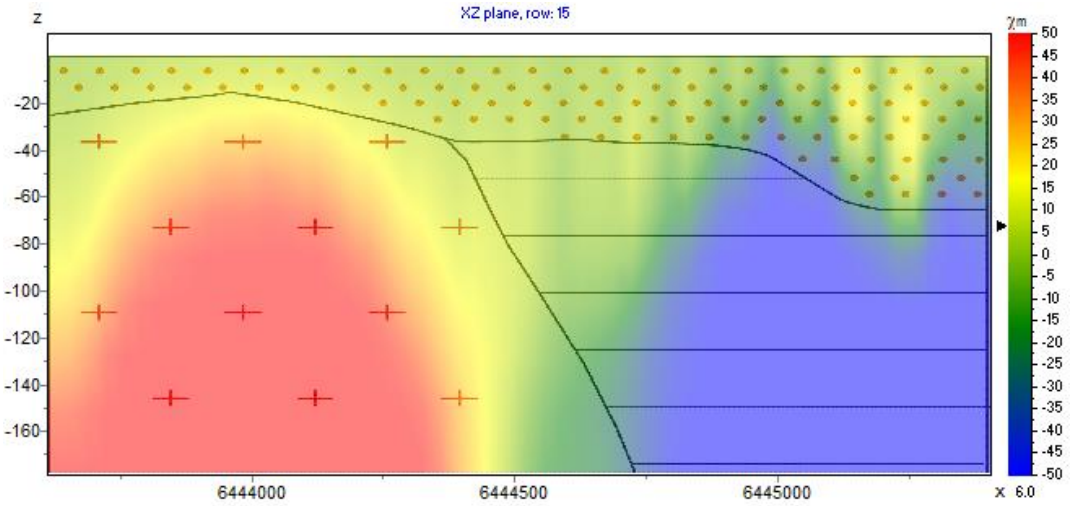
After getting one of models, click on the Buffer tab of the main menu and select Model 1. The program offers to set name of a current model, in which different parameters can be stored. Then, the current model will be saved, and a new inversion can be done with different program settings and save as a Model 2. It is possible to save up to five different models. To open the window of saved models, select **Buffer/Open** in the program main menu.



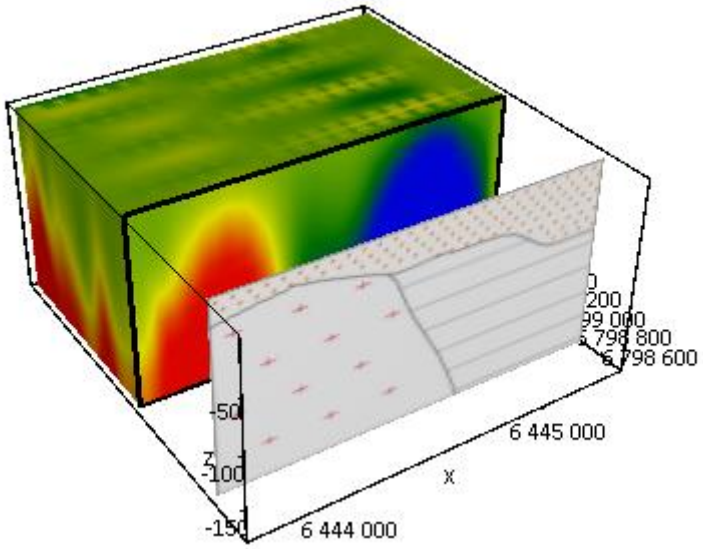
Pic. 44. Dialog window Sections from Buffer

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. **Options/Import/Export** option allows loading different geological and geophysical information including profile measurements as graphs, models built in other Zond programs, graphic image as base of section (for example, geological or seismic section) (pic. 45).



Pic. 45 An example of **Background 2D** function usage



Pic. 46 An example of **Background 3D** function usage

Using option **Save rotations,** you can save shots of the model rotation about Y axis in the «camera» chosen direction.

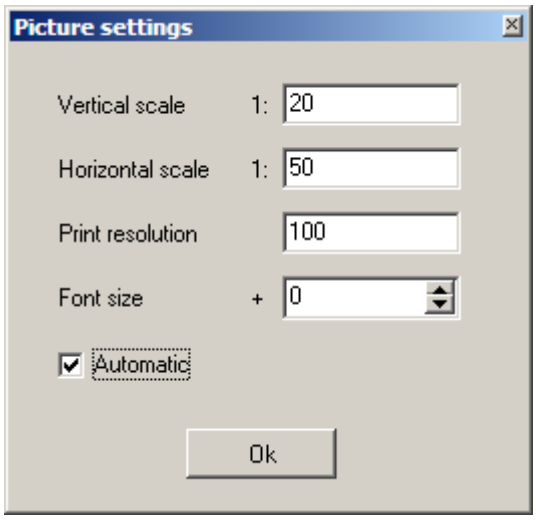
The pictures of model sections in the XZ plane in the chosen direction of the «camera» can be saved using **Save slides** in the model displaying regime **Multi-planes.**

To compare the results of different methods, it is convenient to use **Import Mod2D's** and **Import mod3d** functions. These options allow to upload models saved in other Zond programs as MOD3D and MOD2D files into the current model as a current model.

Different options for data and resultant model export are described in *«Saving interpretation results».* For the further geological interpretation and preparation of report graphics there is an opportunity to save the model into three-dimensional dat-file or the model slices in the XZ plane into 2D dat-files. The model can be saved as a bitmap (**Save slides)** of definite resolution and size using the **Output settings** dialog.

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. 47. **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.

Survey data import from external files

There is an ability to import text files or Excel files. To do this, choose the item **File/Import from text/excel**. After selecting the file, a dialog box will appear (Fig. 48). There you can specify columns containing the following information: profile distances (ProfPos), horizontal coordinates (X/Latitude и Y/Longitude), measuring point altitude (Z), gravity (Grav) and magnetic (Mag) data, profile number (Line) in the Type string. You can also set units for every value in the Units string. Start and End buttons allows to set string of the beginning and the end of the data. Choose the required string and click the corresponding button. String of the beginning is highlighted in green, the end is in red colour.

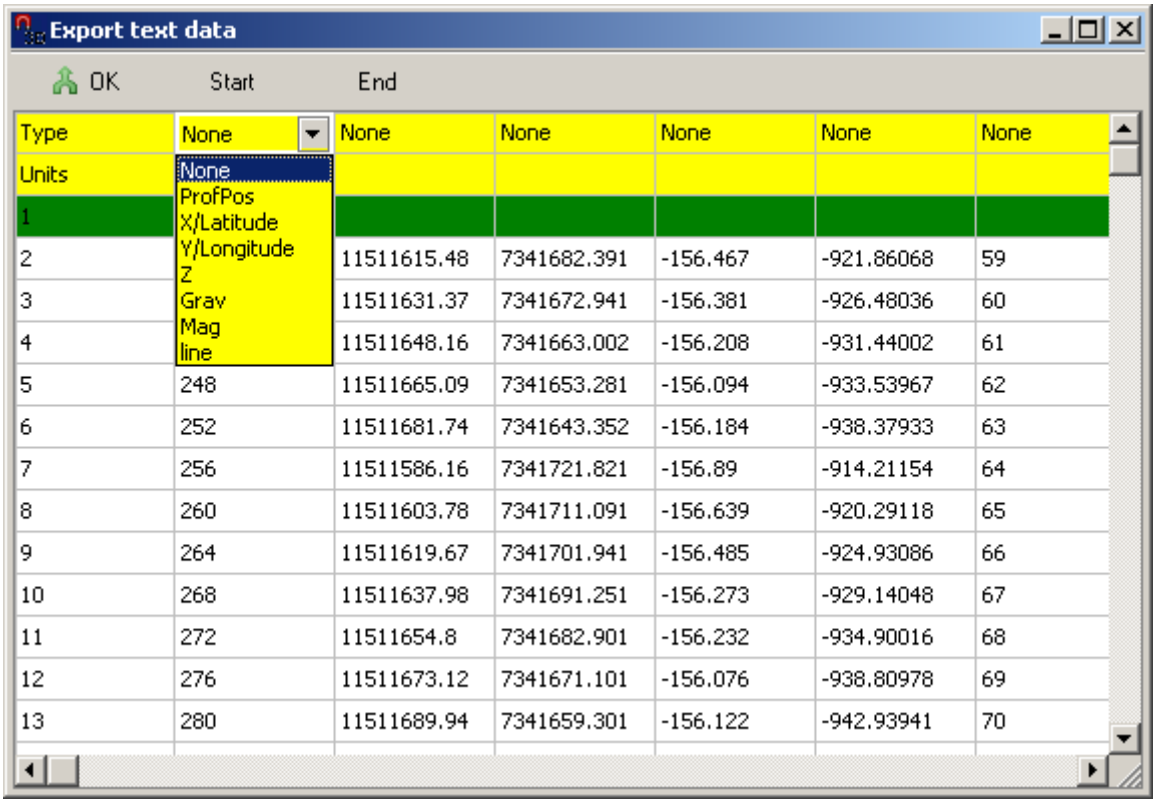


Fig.48 **Import from text/excel** dialog box.

After clicking **OK** button, all the data will be uploaded and the measurements parameters setting window will appear (more).

Logging and lithology data file format

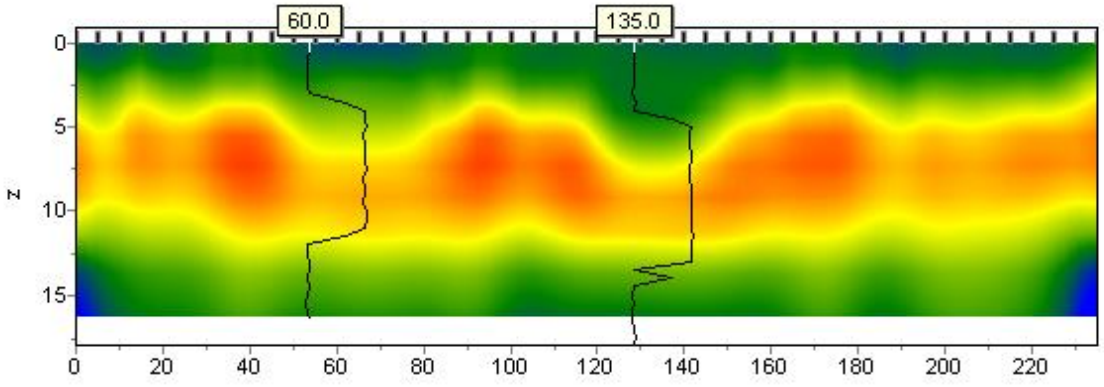
Logging data and lithologic columns are hold in certain file formats. First type of files has txt extension; these files contain logging and lithology data. The following structure is used to create logging data file:

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

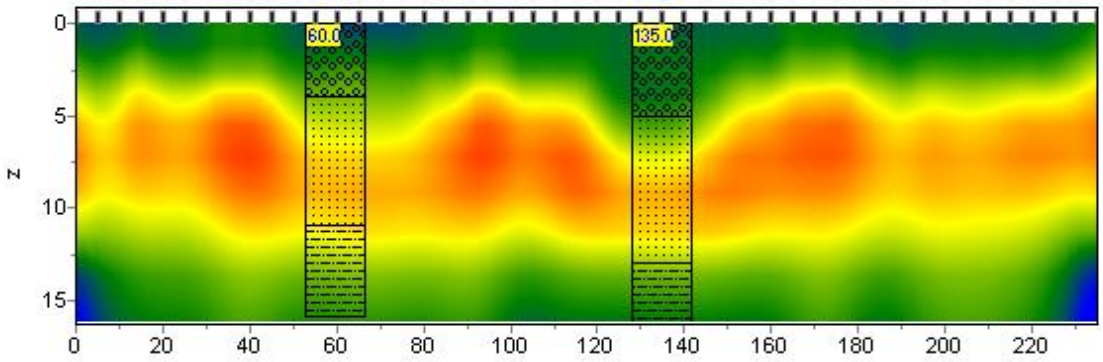
3.5	142.0405875	0	0
4	125.3686538	0	0
4.5	521.0730567	0	0
5	735.5232592	0	0
5.5	707.7315998	0	0
6	706.3561614	0	0
6.5	725.9945623	0	0
7	722.433627	0	0
7.5	717.0991126	0	0
8	716.9836552	0	0
8.5	725.5024012	0	0
9	722.3551713	0	0
9.5	731.5717173	0	0
10	723.5097884	0	0
10.5	726.8844987	0	0
11	725.962034	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. 49. Model with plotted well logs.

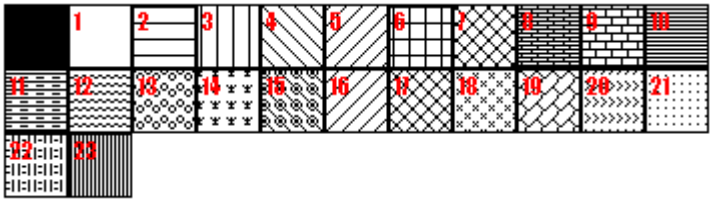
The following structure is used to create lithology data file:

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. 50. Model with plotted lithologic columns

First 23 patterns for lithologic column creation are given below (pic.51).



Pic. 51. 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);

1 - logging data (interpolated colour column), section colour scale is used for visualization;

2 - lithologic column;

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.

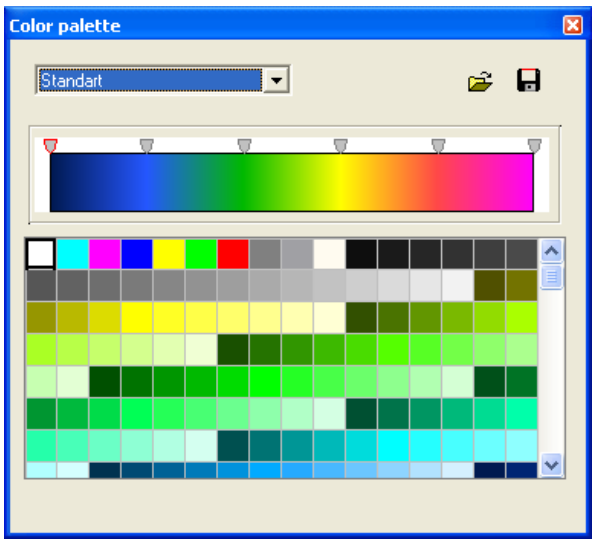
3246.txt Description of the following well on profile

скв3246

102 2 2 1 0 1 0 0

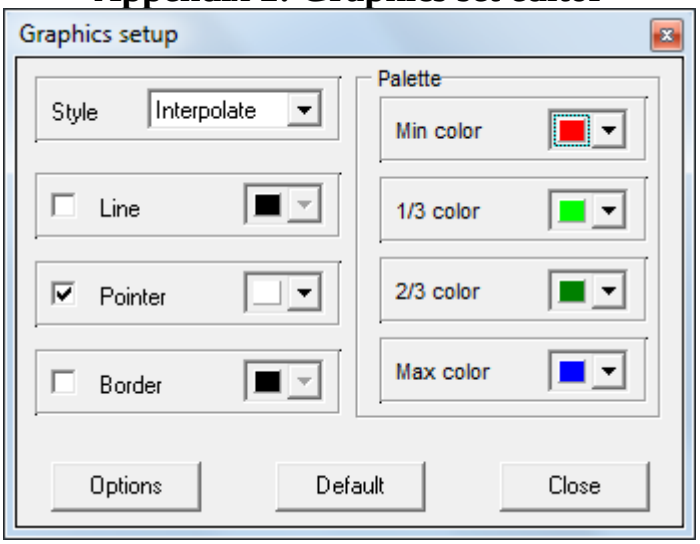
Appendix 1. Palette settings

Dialog can be used for setting object palette of the program and is called by clicking the button **Palette** (Fig. 52). Dialog allows selecting one of the default palettes (forward and inverse rainbow, grayscale, etc.) or create a custom scale. To add a slider on the scale, click the right mouse button with pressing Ctrl. To remove a slider, press the key Delete. It is also possible to save a custom palette. To do this, click the button  . To load existing ones, click the button  .



Pic. 52 Palette settings dialog.

Appendix 2: Graphics set editor



Pic. 53 Graph set editor dialog.

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.

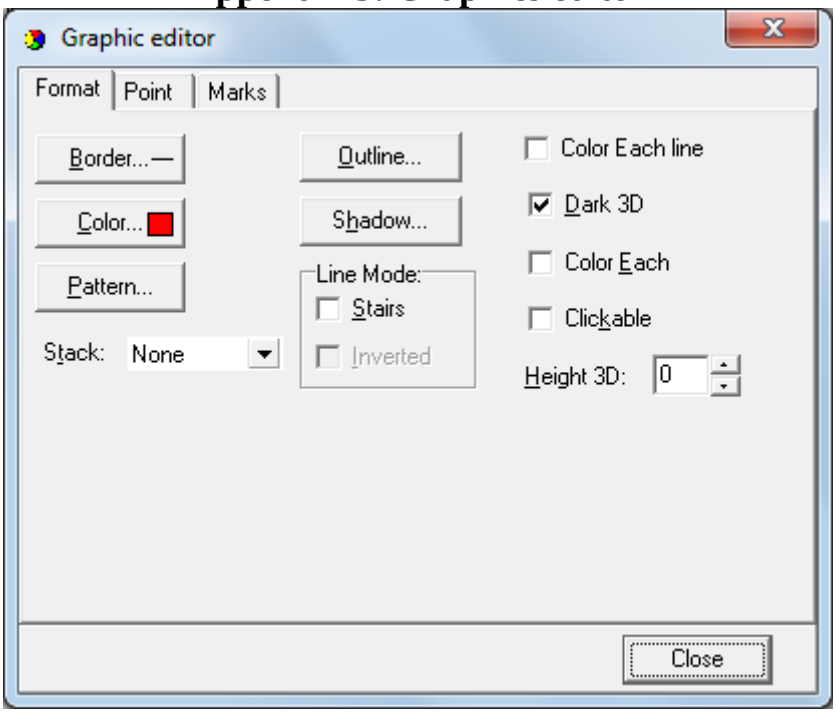
Option **Pointer** sets colour for graphic point's colour fill. If this function is OFF palette colour is used otherwise specified in **Pointer** field colour is used.

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 3: Graphics editor



Pic. 54 Graph editor dialog.

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.

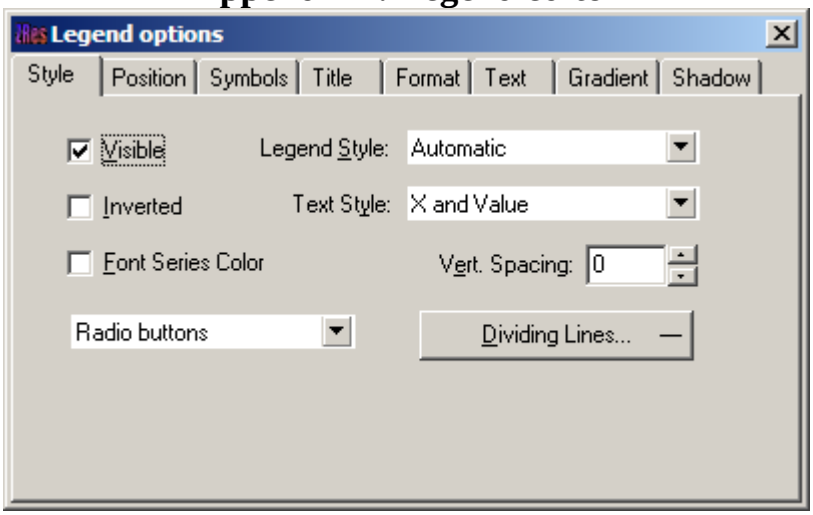
Option **Outline gradient** specifies if gradient fill is used in outline or interior of letters.

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 4: Legend editor



Pic. 55 Graph legend editor dialog.

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.

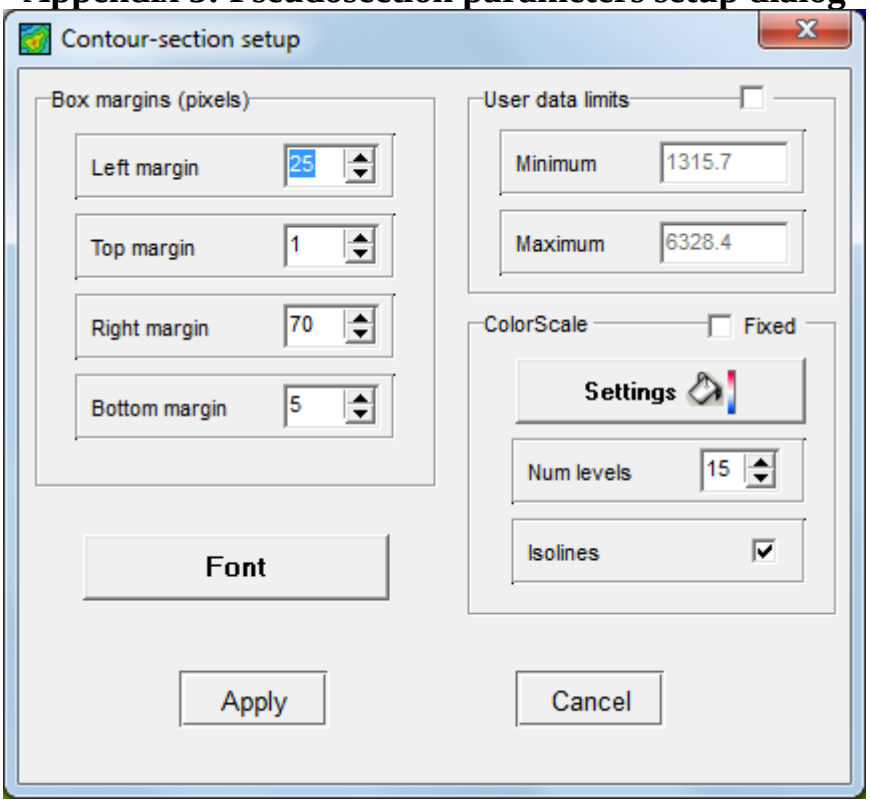
Tab **Symbols** sets legend symbols display parameters.

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 5: Pseudosection parameters setup dialog



Pic. 56. Contour plan parameters setting dialog.

Dialog serves to set contour plan parameters setting.

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 **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.

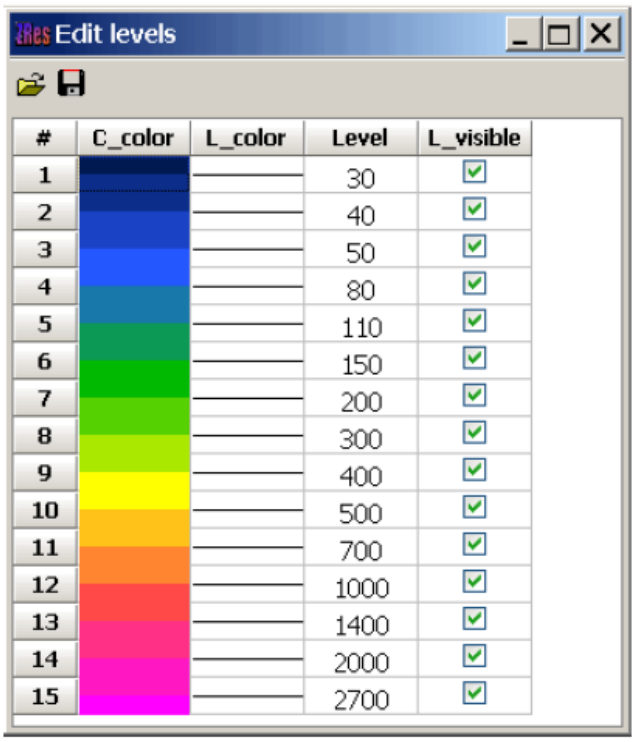
Field **Maximum** sets maximum value to specify isoline sections.

ColorScale section allows operator of creating palette (check the box to use these settings).

Num levels section – sets a number of contour intervals. Contour intervals are set with uniform linear or logarithmic spacing depending on the data type.

Isolines option – tell the program whether to draw contours.

To configure filling parameters, use the **Settings** button. After clicking this button there will be the **Edit Levels** dialog (pic. 57). The dialog is presented as a table with the following columns. *C_color* – colour scale for filling. To edit the colour scale, right-click on the name of the column and you will see the Color palette dialog (more). To edit a certain colour, right-click on this colour. *L_color* – colour scale for contours. Editing is conducted similarly to the colour scale for filling. When right-clicking on the column name, the Automatic dialog appears, there you can set maximum and minimum value for the contours and also specify logarithmic contour spacing. Column *L_visible* – allows to deactivate one or more contours, deselect the check box of the corresponding value.



Pic. 57 Dialog window Edit levels

The **Font** button is intended for the setting of the filling legend font parameters. After clicking the **TeeFont Editor** dialog will appear.

The **Font** button calls the font setting dialog for the filling legend.

The **Outline** button runs the setting dialog for the letters outline.

The **Inter-char** spacing option sets the letter spacing for text.

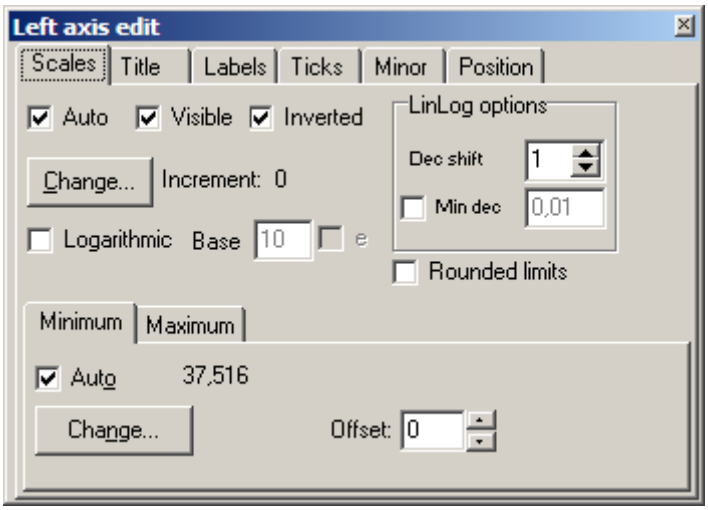
The **Gradient** button runs the setting dialog for gradient text filling.

The **Outline gradient** option specifies where to apply gradient text filling, on the outlines or the letters interior.

The **Shadow** button runs the setting dialog for the look of the text dropping shadow.

Appendix 6: 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.



Pic. 58 Axes editor window

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.

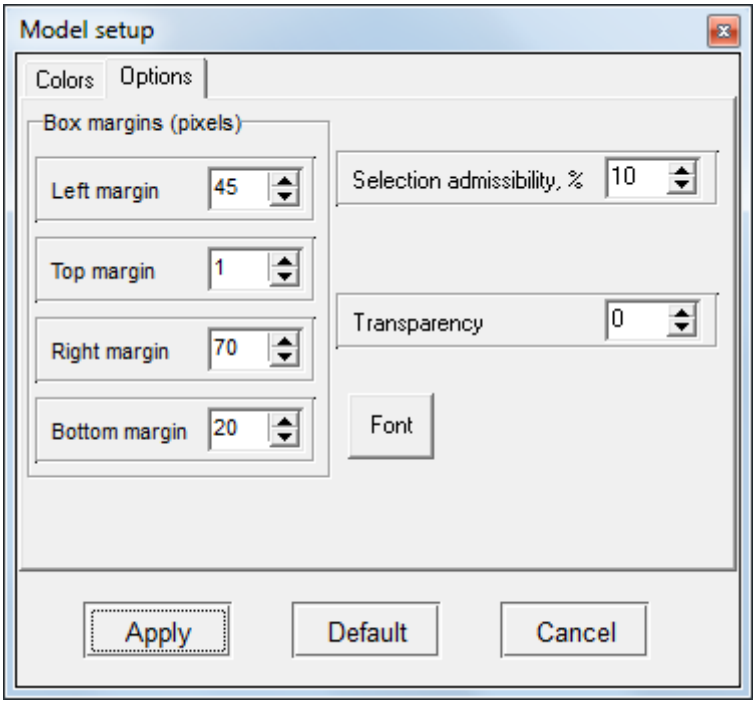
Option **Position %** sets axis indent relative to its standard position on graph (in percent to graph size or in screen units depending on selected option Units).

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 7: Model parameters setup dialog

Options tab



Pic. 59 Setting dialog for the model parameters, **Options** tab.

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.

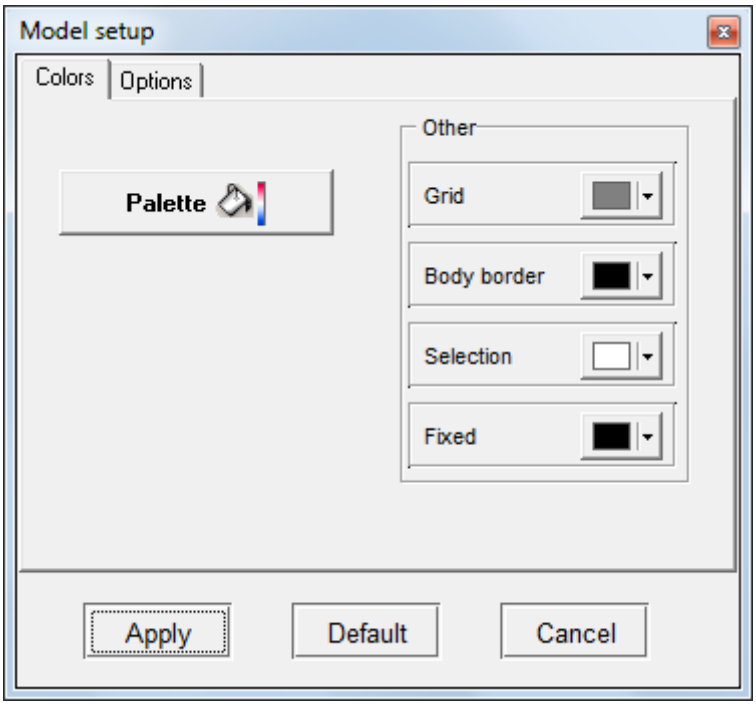
Bottom – sets image indent (in pixels) from window bottom edge.

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

Transparency – sets the transparency values.

The **Font** button runs font setting dialog.

Colors tab.



Pic. 60 Setting dialog for the model parameters, **Colors** tab.

The **Palette** button runs the palette setting dialog (more).

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.

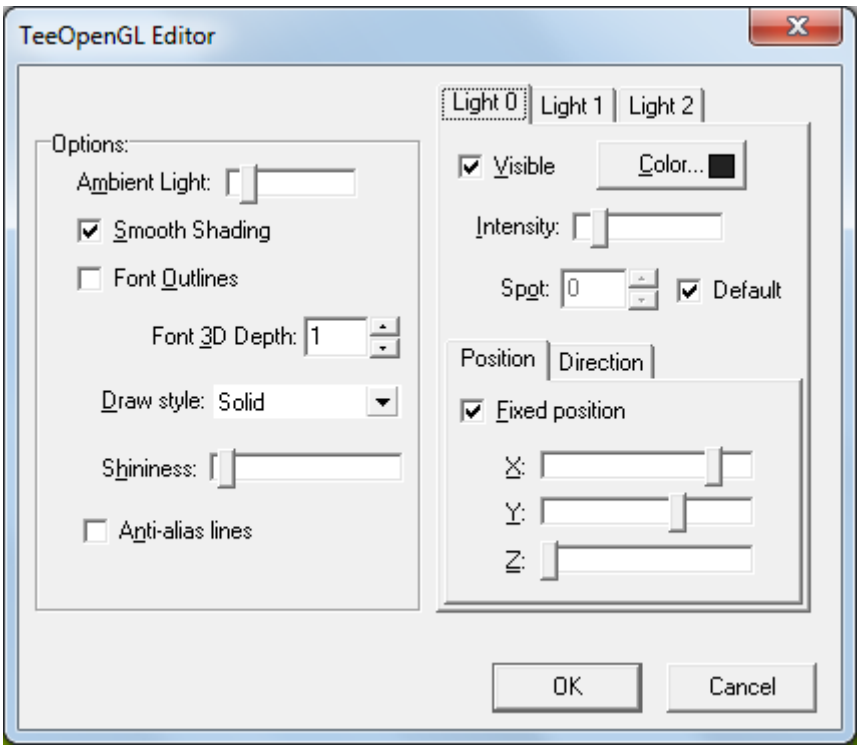
Grid sets mesh colour.

Selection sets mark colour of selected cell.

Fixed sets mark colour of fixed cell.

Appendix 8: 3D model editor

Dialog is available when clicking the button, then you can choose **OpenGL settings** option. The dialog window **TeeOpenGL Editor** will appear (pic. 61).



Pic. 61. 3D model editor **TeeOpenGL Editor**

The **Options** section is intended to set general image parameters.

Ambient Light – sets brightness of external backlighting.

Smooth Shading – smooths shadows.

Font Outlines – highlights axes titles.

Font 3D Depth – sets font depth.

Draw style – chooses 3D model rendering style (Solid – solid filling, Wireframe – show only frame, Points – show as points).

Shininess – sets brightness.

Anti-alias lines – activates/deactivates smoothing lines.

Light 0, 1 и **2** tabs set the light source parameters.

Visible – activates/deactivates the chosen source.

Color… - sets colour of light source.

Intensity – sets intensity of light source.

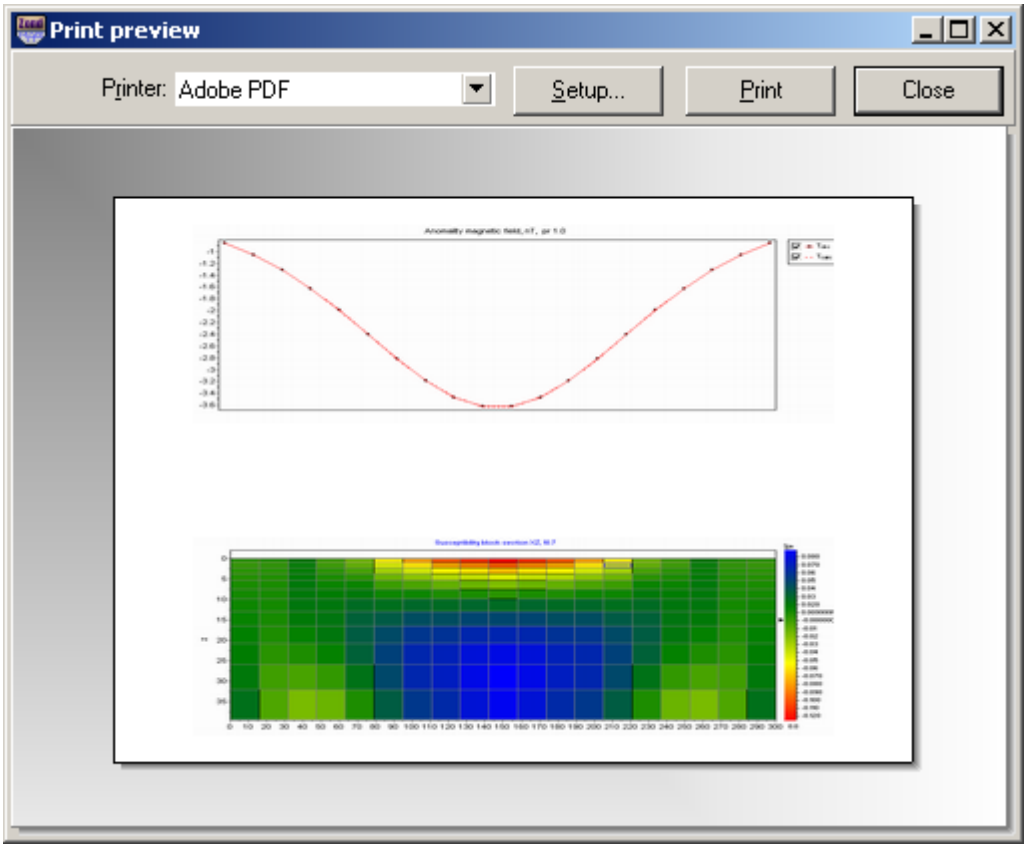
Spot – size of source, Default – sets the default value.

Fixed position – sets position of source along axes.

Set direction – sets light direction along axes.

Appendix 9: Print preview dialog

Print preview dialog is called in the main program menu **File/Print preview.** It is also available by double-clicking on any object in the program. When choosing this option by right-clicking on any object of the program, only this object will be printed.

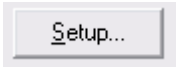


Pic. 62 **Print preview** window

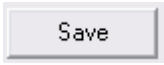
To move a printing object on a sheet click the left mouse button.

In the main menu of the **Print Preview** window the following buttons are:

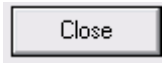
- Select Printer. In the pop-up menu it is possible to select one of the configured printers.



- The button prints settings. In the opening window, it is possible to choose the size and orientation of the sheet, the print properties, the number of pages per sheet and other parameters.



- сохранение в bitmap files.



- закрытие окна Print preview.