Program for one-dimensional data interpretation of transient electromagnetic method using arbitrary source-receiver configuration (loop/line/dipole)

ZONDTEM1D

User manual

Contents

Program functionality

«ZONDTEM1D» is a computer program for 1D interpretation of profile data obtained by transient method. Friendly interface and ample opportunities for data presentation allows solving assigned geological problem with maximum efficiency.

«ZONDTEM1D» is an easy-to-use instrument for automatic and interactive profile data interpretation and can be used on IBM-PC compatible PC with Windows system.

Electrical resistivity (ER) (units are the ohm*meter (Om*m)) is a measure of how strongly rocks oppose the flow of electric current and is the most universal electromagnetic property. In rocks and ores it varies within wide limits: from 10^{-3} to 10^{15} Om*m. For the most widespread sedimentary, volcanic, and metamorphic rocks ER depends on mineral composition, physical-mechanical and water properties, salt concentration in groundwater, in a less degree on their chemical composition, and on other factors (temperature, depth of occurrence, metamorphism degree, etc.) [Hmelevskoj, 1997].

Electrical resistivity of minerals depends on their crystal bonds. Dielectric minerals (quartz, micas, feldspars, etc.) which mostly have covalent forces are characterized by very high resistivity (10^{12} - 10^{15} Om*m). Semiconductor minerals (carbonates, sulfates, haloids, etc.) which mostly have ionic bonds are characterized by high resistivity (10^4 - 10^8 Om*m). Clay minerals (hydromicas, montmorillonite, kaolin, etc.) have ion-covalent bonds and are characterized by quite low resistivity.

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

Electrical resistivity of free groundwater changes from Om*m unit fractions in case of high total salt content to 1000 Om*m in case of low one. Chemical composition of dissolved salts does not really matter that is why electrical exploration allows assessing only total salt content. Electrical resistivity of bound water that is adsorbed by solid particles of rocks is very

low and does not change greatly (from 1 to 100 Om*m). Its constant mineralization (3-1 g/l) explains this fact. Average mineralization of ocean water is 36 g/l.

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

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

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

ZondTEM1D program allows to perform a one-dimensional data interpretation of the data obtained by using transient electromagnetic method (TEM) using various observation systems, both ground, marine and airborne modifications. The program supports both conventional setups (coincident loop, in-loop, distant loops, line loop, loop-line, line-line), and exotic layouts with arbitrary orientation. It is possible to set multiple receivers of any type for each source (thus the inversion is performed for all data simultaneously). The geometry of the source and receiver can be arbitrary in the plane with a fixed height (for aerogeophysics). The geometrical parameters and the time mode of measurements can be edited "on the fly" for all or individual sense points. The values of electromagnetic fields and their time derivatives are calculated. The option of setting arbitrary source pulse is implemented.

In the extended version of ZondTEM1D in addition to electrical resistivity, the parameters of the Cole-Cole formula and magnetic permittivity of rocks can also be used as the medium parameters. Carrying out TEM data inversion taking into account IP parameters can give more reliable results.

From the end of 70s to early 80s of the last century, many publications about TEM surveys reported measurement results where registered transients violate monotonicity and change polarity. These effects were observed in the range from a few tens to a few hundreds of microseconds and at first were considered only as a noise. Researchers relatively quickly understood that the cause of these processes is quickly established induction-induced polarization, the effect which (at least formally) can be accounted for by using of a complex, frequency-dependent conductivity $\sigma * (\omega)$, described by the Cole-Cole formula [Waite, 1987]:

$$\rho'(\omega) = \rho_0 \cdot \left(1 - \frac{\eta}{100} \left(1 - \frac{1}{1 + (i\omega\tau)^C} \right) \right)$$

where ω - angular frequency, C; ρ_0 - the resistivity, η - polarizability ($0 \leq \eta \leq 1$); c - the exponent; τ - relaxation time.

System requirements

«ZONDTEM1D» can be installed on PC with OS Windows 98 and higher. Recommended system parameters are processor P IV-2 GHz, memory 512 Mb, screen resolution 1024 X 768, color mode – True color (screen resolution change is not recommended while working with data).

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

Program installation and deinstallation

«ZONDTEM1D» program is supplied on CD or by internet. Current manual is included in the delivery set. Latest updates of the program can be downloaded from website: www.zond-geo.ru.

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

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

To uninstall the program delete work directory of the program.

Program registration

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

Adopted definitions

Ro_a – apparent resistivity.

U_t – time derivative of the signal.

Pseudodepth – approximate investigation depth connected with skin-layer thickness.

All geometric values are specified in meters.

Creation and opening of data file

To start up «ZONDTEM1D» it is necessary to create data file of certain format which contains information on measurement times, acquisition geometry, and EMF values. One profile data usually corresponds to one file.

EMF versus time curve is considered as data element in «ZONDTEM1D»program. That's why data should be represented as a set of sounding curves.

Field data file	Open Zond data file(s).
Project data file	Open Zond project file.
Model data file	Open model data file.
TEMFAST/AMIRA TEM data files	Open Amira-TEM or TEM-FAST data file.
ERA data files	OpenERA data file.
Podbor data files	Open Podbor data file.
Interpex TEM data files	Open Interprex TEM data file.
Emma TEM data files	Open Emma TEM data file.
Geonix gx7 data files	Open Geonix gx7 data file.
Equator database files	Open file of the Equator database
Nemfis files	Open data file of Nemfis equipment
GEM-2 csv files	Open csv file of GEM-2 equipment
SmartEM files	Open TEM-file of SmartEM equipment
ORG files	Open ORG database file
BEM files	Open AIE-2 equipment file(s)

Text data files of « ZONDTEM1D » format have «*.tdf» and «*.tdp» extension. See **Data file format** for more details.

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

- curves with less than 3 time values;
- incorrect symbols of records separator (TAB and SPACE use only);
- absurd data values.

Desirably, total record number should be no more than 5000 in one file.

Previous interpretation model loads together with field data while opening «*.tdp» file.

In case initial file does not contain point coordinates, **Stations locations** window (fig. 1) appears at file opening. User can specify point coordinates manually, copy data from Excel or load text file with coordinates via 📂 button in this window.
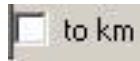
Toolbar buttons allow performing the following coordinate transformation:
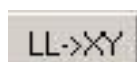
LL->XY - convert the geographical coordinates in rectangular

UTM - convert geographic coordinates to UTM system

 - specify the units. By default, the coordinates and height are set in meters, after using this option - in kilometers.

Fig. 1 Stations locations window. Setting of sense points coordinates.

Table of measurement points contains the following columns: Name - the name of the source file, X, Y, Z - coordinates and height of the point, v - included or excluded points.

Data file format

Program presents universal data format which consists of information on coordinates and relative elevations of sounding points and array configuration. In addition the program contains the following formats: GEONICS, EMMA, USF, Podbor, Amira, ERA, Nemfis Equator, SmartTem, Gem-2.

ZONDTEM1D data file format (*.tdf extension).

#	Text	Comment
1	zondtem3.0	
2	title: station1	

Data for Station1 point

#	Text	Comment
3	1	!number of sounding
4	3.00000000000000E+0002 1.00000000000000E+0003 0.00000000000000E+0000	!XYZ coordinates
5	3	!type of transmitter/Loop
6	0.00000000000000E+0000 0.00000000000000E+0000 0.00000000000000E+0000	!center of transmitter, XYZ
7	-100 -100 100 -100 100 100 -100 100	!XY nodes of loop/line or center XY and dircos of dipoles
8	3	!number of receivers
9	2	!type of the first receiver/Loop

Data for first receiver

#	Text	Comment
10	0.00000000000000E+0000 0.00000000000000E+0000 0.00000000000000E+0000	!center of the first receiver, XYZ
11	-10 -10 10 -10 10 10 -10 10	!XY nodes of loop/line or center XY and dircos of dipoles
12	1	!number of sweep
13	1	!type of sweep1/finite impulse
14	8.33330000000000E-0003 8.33330000000000E-0003 8.60000000000000E-0005 0.00000000000000E+0000	!tpulse, tpause, ramp front, rmp back (sec)
15	30	!number of points

….Data section

Data for the second receiver….

Fig. 2 Example of a *.tdf data file format. In this example, as a source the loop of 200x200 m was used. Three receivers, the first is 20x20 m loop. Single time mode was used, the type of pulse - the pulse of the finite length.

First line contains identifier of data format **ZondTem3.0** (Current version of data format)**.** When working with data obtained in the frequency domain, the string should contain key "frequency domain" (ZondTem3.0 frequency domain).

Second line contains number of sounding stations.

Set of lines describing each sounding point follows. Number of sounding description blocks must be equal to value in the second line.

Sounding station description block

First line contains word **Title,** followed by name of sounding station (preferably no longer than 8 symbols).

Second line contains three numbers: X Y Z – sounding station coordinates. It is recommended to input in UTM system.

Third line – type of transmitter:

   0   - vertical magnetic dipole (VMD),

   1 – horizontal electric dipole (HED), 2 – line of finite length, 3 - loop, 4 - horizontal magnetic dipole (HMD).

Forth line – coordinates of transmitter center X Y Z. It is important to specify only the third coordinate which is source elevation above ground surface (for magnetic dipoles only (aerogephysics)). In all other cases the line contains 0 0 0.

Fifth line – description of source nodes. (!XY nodes of loop/line or center XY and dircos of dipoles) Nodes are specified differently for various sources.

   0- vertical magnetic dipole: 2 numbers, X and Y coordinates of dipole center.

   1- horizontal electric dipole: 4 numbers, X Y coordinates of dipole center and X Y direction cosines (1 0 – means that dipole is positioned along X axis).

   2- line of finite length: 4 numbers, X1 Y1 X2 Y2 coordinates of the beginning and the end of current circuit.

   > If control word **length** is specified then circuit is set using one number only. *Length 100* means that current circuit of 100 meters length is positioned along X axis with its center in point (0 0).

   3- loop: 2*N numbers, where N – number of nodes (>2). Four nodes are used for square loop (8 records). X1 Y1 X2 Y2 X3 Y3 X4 Y4.

   > If control word **side** is specified then loop is set using one or two numbers. Line side 100 means that a square loop with a side of 100 meters is set, centered at the point (0, 0).

   > *Side 100 50* means that square loop 100x50 meters is specified with its center in point (0 0).

   > If control word **circle** is specified then loop is set using one number only. *Circle 100* means that round loop with 100 meters radius is specified with its center in point (0 0).

4- horizontal magnetic dipole: 4 numbers, X Y coordinates of dipole center and X Y direction cosines (1 0 – means that dipole is positioned along X axis).

Source center is recommended to be used as origin of coordinates when describing array geometry.

Sixth line – number of receivers. Any number of receivers of different types can be used. Set of lines describing each receiver follows.

First line – receiver type:
   0 – electrical antenna (horizontal component), 1 – electrical circuit of finite length, 2 – loop (vertical component), 3 - magnetic antenna (vertical component), 4 - magnetic antenna (horizontal component).

Second line – coordinates X Y Z of receiver center. It important to specify only the third coordinate which is receiver elevation above ground surface (for magnetic dipoles only). In all other cases the line contains 0 0 0. Last, Z coordinate - determines the height of the receiver above the ground.

Third line – description of receiver nodes. Nodes are specified differently for various receivers. One coordinate system must be used to describe receivers and sources.

   0 - electrical antenna: 4 numbers, X Y coordinates of dipole center and X Y direction cosines (1 0 – means that dipole is positioned along X axis).
   1 - electrical line of finite length: 4 numbers, X1 Y1 X2 Y2 coordinates of the beginning and the end of receiving line.
   2 - loop: 8 numbers, coordinates of loop nodes X1 Y1 X2 Y2 X3 Y3 X4 Y4.
      If control word **side** is specified then loop is set using one or two numbers. *Side 100* means that square loop with side 100 meters is specified with its center in point (0 0). *Side 100 50* means that square loop with sides 100x50 meters is specified with its center in point (0 0).
   3 - magnetic antenna (vertical component): 2 numbers, X and Y coordinates of dipole center.

4 - magnetic antenna (horizontal component): 4 numbers, X Y dipole center coordinate and X Y direction cosines (1 0 – means that dipole is positioned along X axis).

Other types of receivers (components ratio, full magnetic field vector (triaxial loop), space derivatives) are available in the full version of the program.

Forth line – number of time modes (SWEEP). It is usually 1.

 The description of each of the successive time mode is following (2 lines).

First line – pulse type. 0 – step, 1 – rectangular finite pulse, 2 – free-form pulse (fig. 3).
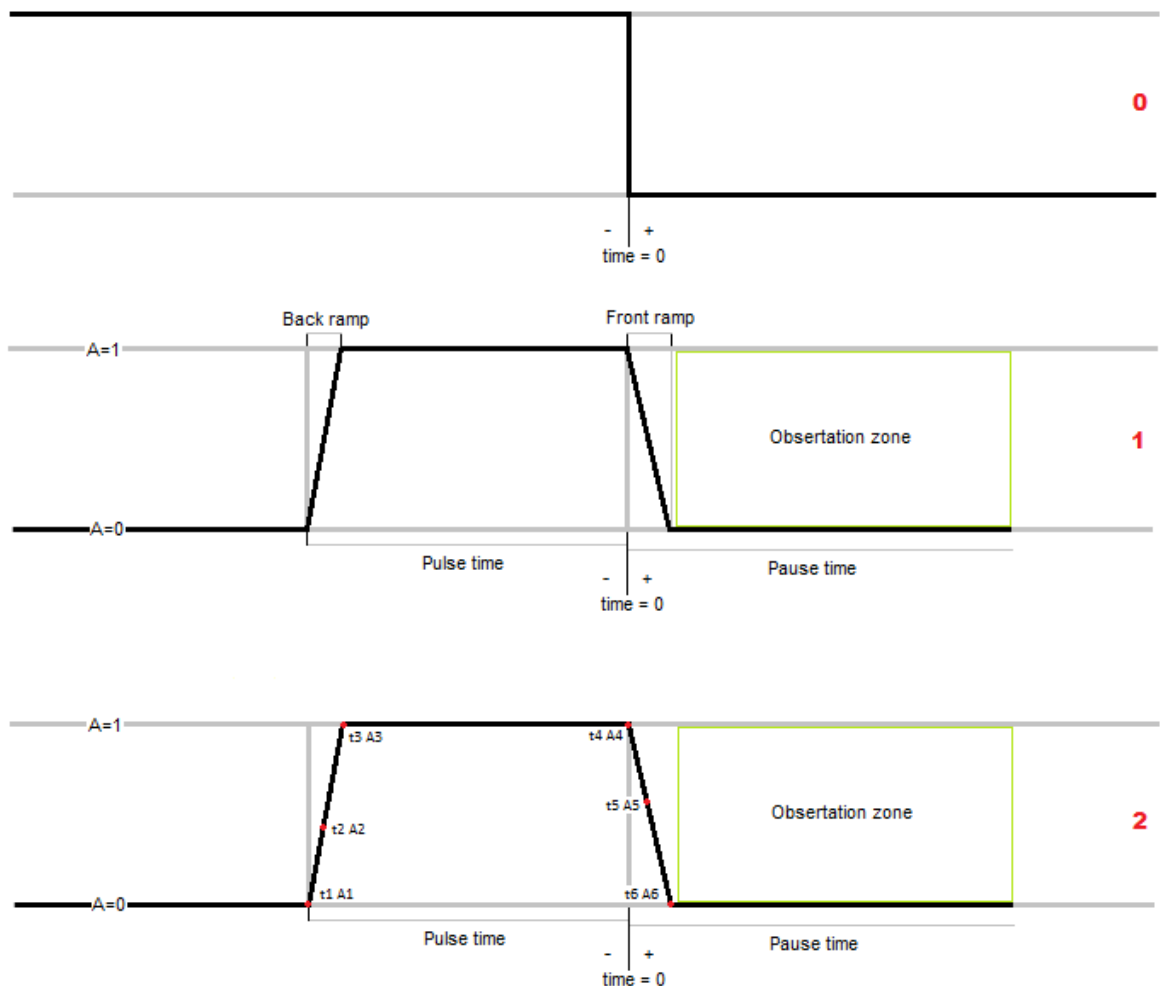
Fig. 3 Time characteristic of used pulses: 0 – step, 1 – rectangular pulse finite length, 2 – free-form pulse

– set of time mode parameters.

For pulses of 0 and 1 type set of parameters is as follows (4 numbers): pulse time, pause time, leading edge time, trailing edge time (all specified in seconds).

For pulses of 2 type nodes describing form of current pulse are sequentially specified: tN AN tN-1 AN-1 …. t1 A1 (N –number of nodes). While describing set of nodes act on the premise that zero time point is pulse leading edge and all times are specified with negative sign. List is filled downwards time. Maximum pulse amplitude is 1.

Fifth line – number of measurements (time delays) for current receiver.

Sixth line – "heading", which shows the program what type of data is stored in each column. Usually the line is as follows.

 # t(sec) sweep U(uV) weight

- measurement number.

t(sec) – measurement time (in seconds) from leading edge of pulse. In the frequency domain, amounts inversely proportional to frequency are specified in this column.

Sweep – index of time mode for current measurement (must be less than or equal to number of specified time modes).

U(uV) - value of measured EMF or electrical field, specified in microvolts and preliminarily normalized to current (Volt/Ampere*10^6). If dipole (frame) is used for measurements, observed values must be normalized (divided) by receiver frame area. In the frequency domain, use the following keys *mod* - means column modulus values of the signal from frequency and *phas* - description of the phase (in degrees).

Weight – point weight, inverse proportional to the variance. Set in a range from 0 to 1. *mod_w* and *phas_w* are used respectively in the frequency domain.

Then follows the description of the second receiver (if applicable), etc.

```
zondtem3.0
1 !number of sounding
title: Ceibita.TEM
 2.73388000000000E+0005  1.04729700000000E+0006  0.00000000000000E+0000 !XYZ
coordinates
```

```
3 !type of transmitter/Loop
 0.00000000000000E+0000        0.00000000000000E+0000        0.00000000000000E+0000
!center of transmitter, XYZ
-20 -20 20 -20 20 20 -20 20  !XY nodes of loop/line or center XY and dircos of dipoles
1 !number of receivers
3 !type of receiver/Hz dipole
 0.00000000000000E+0000     -4.00000000000000E+0001        0.00000000000000E+0000
!center of receiver, XYZ
0 -40  !XY nodes of loop/line or center XY and dircos of dipoles
3 !number of sweep
1 !sweep1 Pulse 0 - step, 1 - finite, 2 - user
 8.33333333333333E-0003        8.33333333333333E-0003        2.60000000000000E-0005
0.00000000000000E+0000 !tpulse, tpause, ramp front, rmp back (sec)
1 !sweep2 Pulse 0 - step, 1 - finite, 2 - user
 3.33333333333333E-0002        3.33333333333333E-0002        2.60000000000000E-0005
0.00000000000000E+0000 !tpulse, tpause, ramp front, rmp back (sec)
1 !sweep3 Pulse 0 - step, 1 - finite, 2 - user
 8.33333333333333E-0002        8.33333333333333E-0002        2.60000000000000E-0005
0.00000000000000E+0000 !tpulse, tpause, ramp front, rmp back (sec)
60 !number of points
#  t(sec) sweep  U(uV) weight
1  8.81250000000000E-0005 1  4.78964858050746E-0001   1.00000000000000E+0000
2  1.09430000000000E-0004 1  2.60055881336580E-0001   1.00000000000000E+0000
….
```

Fig.4 Example of the *.tdf data file format. In this example, as the source the loop of 40x40 m was used. One receiver - a vertical magnetic dipole centered at the point (0, 40). Three time modes were used. Type of pulse - the pulse of finite length. Pulses of different characteristics.

```
zondtem3.0
1 !number of sounging
title: TEM14.tem
 0.00000000000000E+0000        0.00000000000000E+0000        0.00000000000000E+0000  !XYZ
```

```
coordinates
3 !type of transmitter/Loop
 0.00000000000000E+0000  0.00000000000000E+0000  0.00000000000000E+0000 !center of
transmitter, XYZ
-25 -25 25 -25 25 25 -25 25  !XY nodes of loop/line or center XY and dircos of dipoles
1 !numer of receivers
3 !type of receiver/Hz dipole
 0.00000000000000E+0000  5.00000000000000E+0001  0.00000000000000E+0000 !center of
receiver, XYZ
0 50  !XY nodes of loop/line or center XY and dircos of dipoles
2 !number of sweep
2 !sweep1 Pulse 0 - step, 1 - finite, 2 - user
-0.0100000   0   -0.00813110   0.630000   -0.00616500   1   0   1   0.0000228570   0.0712200
0.0000231010 0.0619600 0.0000236680 0 !nodes of pulse shape t1 A1, t2 A2... tn An,  t(sec)
2 !sweep2 Pulse 0 - step, 1 - finite, 2 - user
-0.0400000 0 -0.0381310 0.630000 -0.0361650 1 0 1 0.0000234570 0.0695200 0.0000237020
0.0604900 0.0000242680 0 !nodes of pulse shape t1 A1, t2 A2... tn An,  t(sec)
40 !number of points
#  t(sec) sweep  U(uV) weight
1  1.38700000000000E-0004 1  1.99982520494646E-0001  9.99798526090574E-0001
2  1.60000000000000E-0004 1  1.37363612643888E-0001  9.99807868777242E-0001
3  1.90000000000000E-0004 1  8.77733435283546E-0002  9.99811806878011E-0001
…..
```

Fig. 5 Example of the *.tdf data file format. In this example, the loop of 50x50 m was used as the source. One receiver - a vertical magnetic dipole centered at the point (0, 50). Three time modes were used. Pulse type - defined by the user, the pulses have different characteristics, which are specified by nodes.
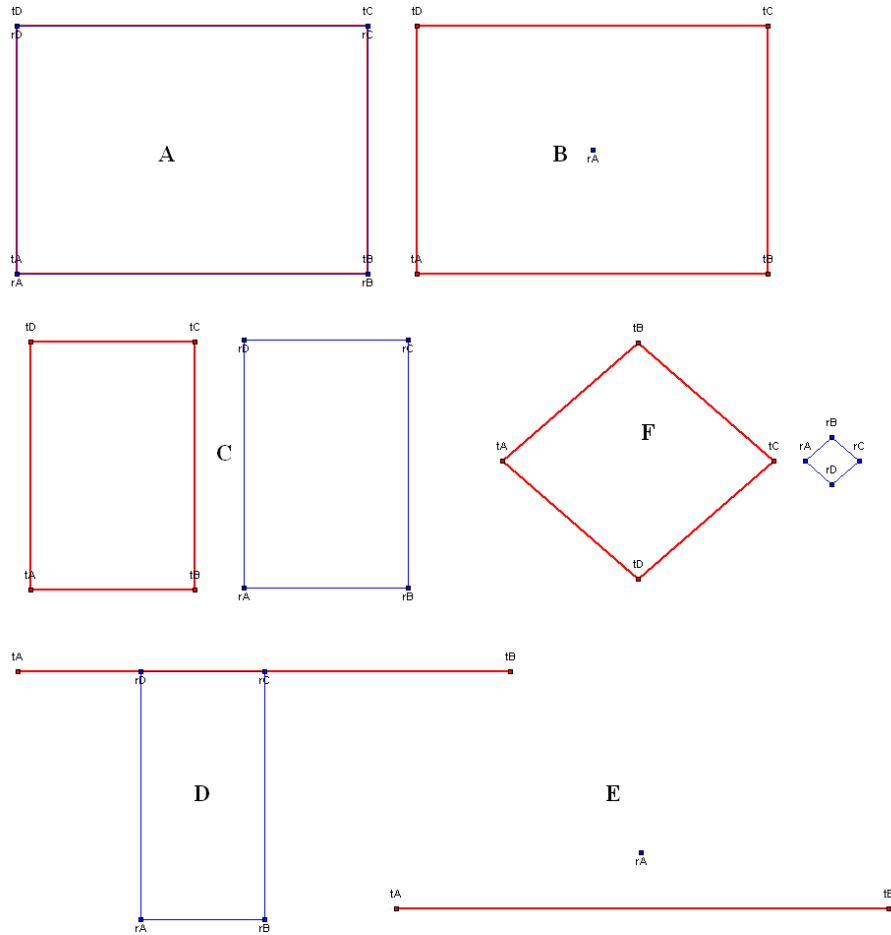
Fig. 6 Schemes of soundings when working with EMF induction measurements. A, B, C, D, E, F
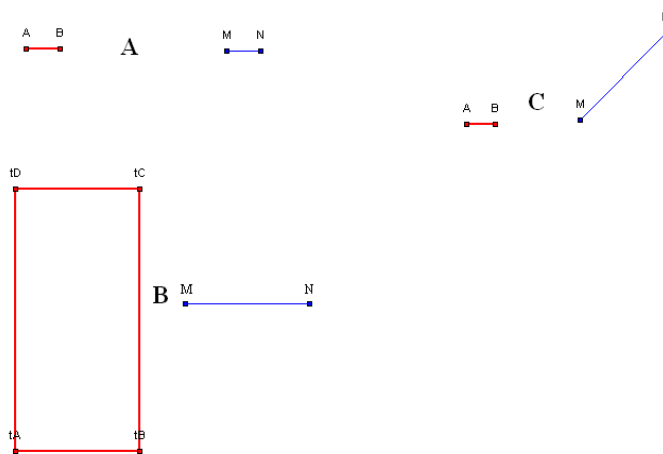
Fig. 7 Schemes of soundings when working with the electrical component of the field. A, B, C

Dialog of field data entry (TEM Notepad)

The dialog is meant for new data entry and can be found in the main menu of the program **File/TEM Notepad (New data)**. Figure 8 shows dialog window of **TEM Notepad** function.
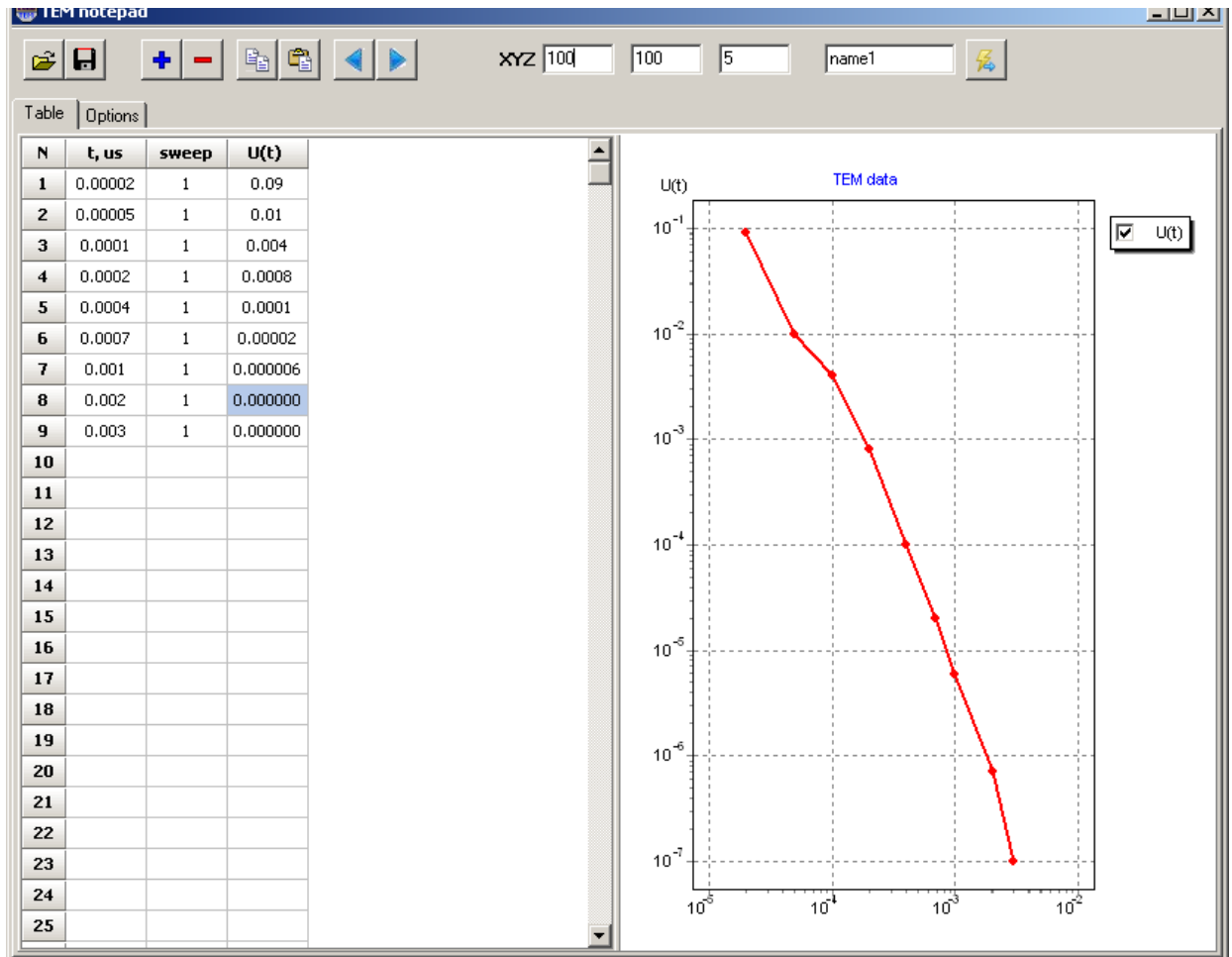
Fig. 8 Dialog window **TEM Notepad** (tab **Table**)

Main menu of the window contains the following buttons:

	Open *.txt data file
	Save file as *.txt
	Add sounding point.
	Delete sounding point.
	Copy

	Paste
	Proceed to next point.
	Proceed to inversion.

Use XYZ field to specify coordinates of sounding station and its name (field «name1» in fig. 8).

Tab **Table** (fig. 8) contains sounding data. There is a table in the left part of the window which contains the following columns: t,us – time in milliseconds, sweep – configuration of pulse mode (pulse length, pauses, time of pulse fronts; usually one configuration is used for one sounding but some systems use a few configurations (Geonics)), U(t) – value of measured field component. Data is represented graphically in the right part of the window.

Tab **Options** (fig. 9) is used to change array geometry and time mode. It contains three tabs **Transmitter**, **Receiver**, **Time mode** – which are used to specify parameters of source and receiver or a set of receivers, and time mode.
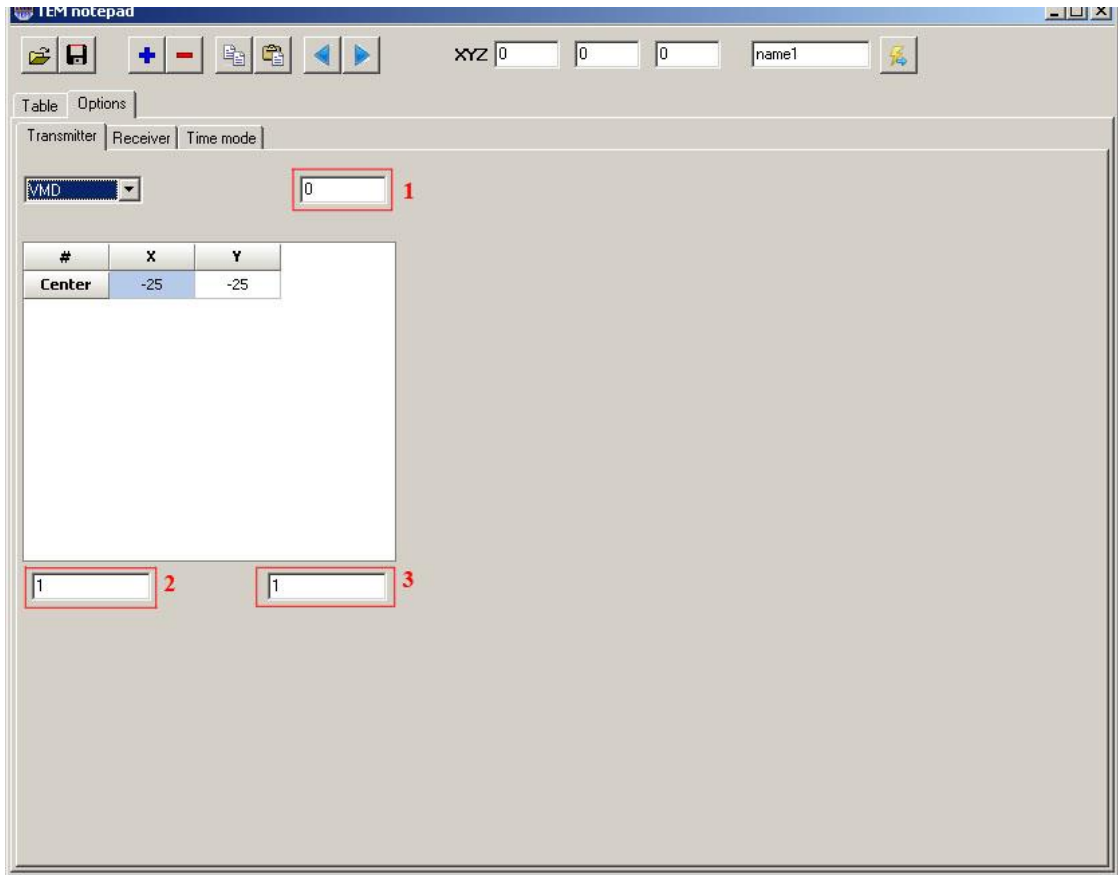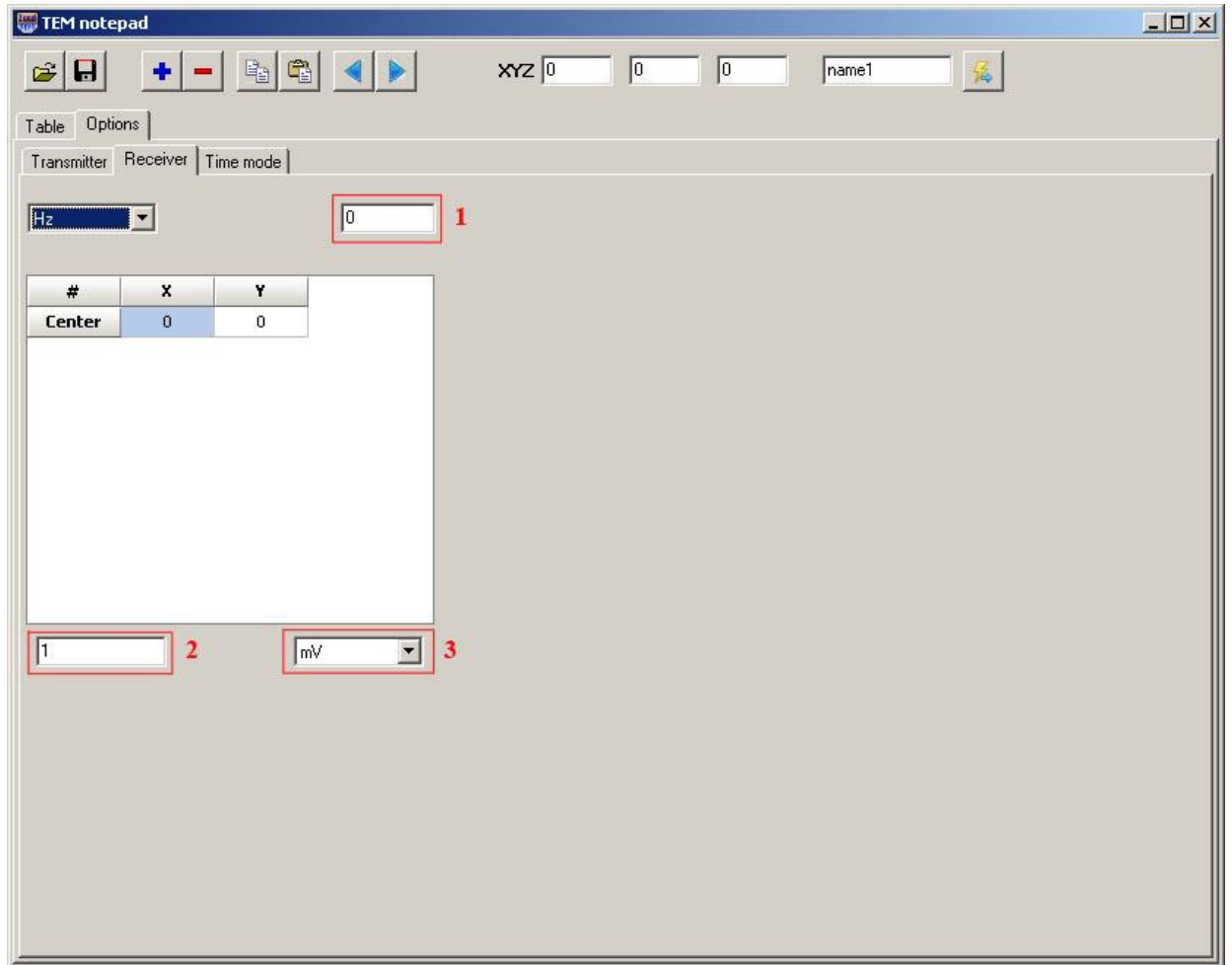
Fig. 9 Dialog window **TEM Notepad** (tab **Options/Transmitters**). Fields marked by numbers serve to specify the following parameters: 1 – the height of the source above the surface, 2 – current strength, 3 – effective length of line/number of turns in the loop

Type of source can be changed in **Transmitters** tab: *VMD* – vertical magnetic dipole, *HED* – horizontal electric dipole, *Line* – line of finite length, *Loop* – free-form loop, *HMD* – horizontal magnetic dipole. Source elevation above ground surface can be specified (for magnetic dipoles only) in the field situated to the right of drop-down list. Source geometry (relative XY coordinates of nodes for sources of finite length (loop, line) or relative center coordinates and direction cosine (for dipole)) are specified in the table. The best option is to enter nodes coordinates of source and receiver considering source center as origin of coordinates.

Fields below the table are used to specify current strength in Amperes (if measured values were not normalized to current) and effective area/length of dipole, but again only if data has not been normalized (for dipole sources only).

Type of receiver can be chosen in tab **Receiver** (for each source): *Exy* – horizontal electric dipole with arbitrary XY orientation, *Line Exy* - arbitrary electric line of finite length, Loop Hz -

an arbitrary loop with the measurement of the magnetic component, Hz - the vertical component of the magnetic field (dipole), Hxy – horizontal component of magnetic field (dipole). Other, "exotic" types of receivers can be used in the full version of the program: components ratio, full magnetic field vector or space derivatives.

Fig. 10 Dialog window **TEM Notepad** (tab **Options/Receiver**). Fields marked by numbers serve to specify the following parameters: 1 – the height of the receiver above the ground (for magnetic dipoles only), 2 – effective antenna area (for magnetic dipoles only), 3 – units

Receiver elevation above ground surface can be specified (for magnetic dipoles only) in the field situated to the right of drop-down list with types of receivers.

Index of current receiver (if there is more than one receiver) is chosen in the drop-down list to the right of the table. Number of receivers can not be changed.

Source geometry (relative XY coordinates of nodes for receivers of finite length (loop, line) or relative center coordinates and direction cosine (for dipole)) are specified in the table. Coordinates are defined relative to chosen origin of coordinates.

Time mode parameters are specified in tab **Time mode** (fig. 11). Use this tab to choose type of current pulse (*Step* – step, *Finite pulse* – pulse of finite length, User – user-specified free-form pulse), define pulse length (field *Pulse*), pauses (field *Pause*), leading edge (field *Ramp Front*) and trailing edge (field *Ramp Back*) in microseconds; select number of pulses taken into account (field *N Pulses*) and its polarity (options *Unipolar/ heteropolar*).

All settings of time mode are specified for each time configuration (Sweep). According to the above-mentioned, one sounding usually corresponds to one sweep.
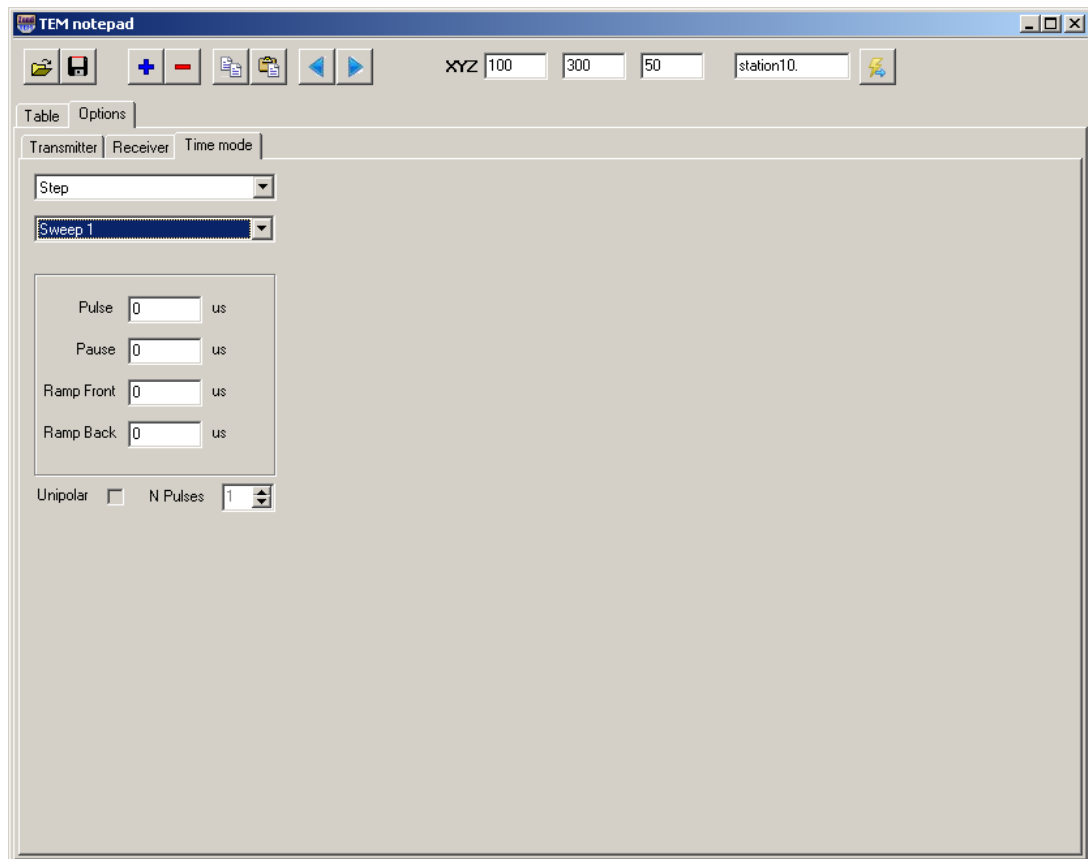
Fig. 11 Dialog window **TEM Notepad** (tab **Options/Time mode**)

Use ➕ button to create next sounding points. When all parameters are set, press ⚡ button to start inversion.

Interpretation results saving

Profile interpretation result is hold in *ZONDTEM1D project files* (extension *.tdp). This file contains name of file with field data, selected parameters and parameters variation limits for each sounding. Use 💾 button in the tool bar or corresponding menu option to save interpretation result. If autosave option is on interpretation result is saved automatically in selected periods of time. Theoretical curves can be also saved in tdf format.

Possible options for saving data:

Project data file	Save the measured values and the current medium model
Calculated as observed files	Save the calculated values
Observed files	Save the observed data file taking into account performed editing.
Grid file	Save medium model in a tabular file
Section file	Save the current model in the section format. This file can be used as a background.
Project with calculated	Replace the observed data in the project with calculated

Data export

«ZONDTEM1D» program allows exporting data to MS Excel and Auto CAD format, and also creating files for using in other Zond program. This function can be found in **File/Export to**.

The following options to export data are available:

Excel report	Create a file containing information about every measurement point, information about frequency distribution of measured and calculated values of apparent resistivity and impedance phase, measurement point coordinates, etc.
Excel map	Create a file containing stations name, their coordinates and

	resistivity values (calculated) and background position of each layers on each observation point (useful when creating area maps of parameter distribution).
CAD section	Export models in AutoCad file format *.dxf.
MOD1D file	Save model file with extension *.mod1d for later use in other Zond programs

To compare results of different methods it is also possible to use the export function MOD1D file. When using the file in another Zond program or for other profile within the area survey saved in such a way model will be loaded as a new model (Fig. 12).
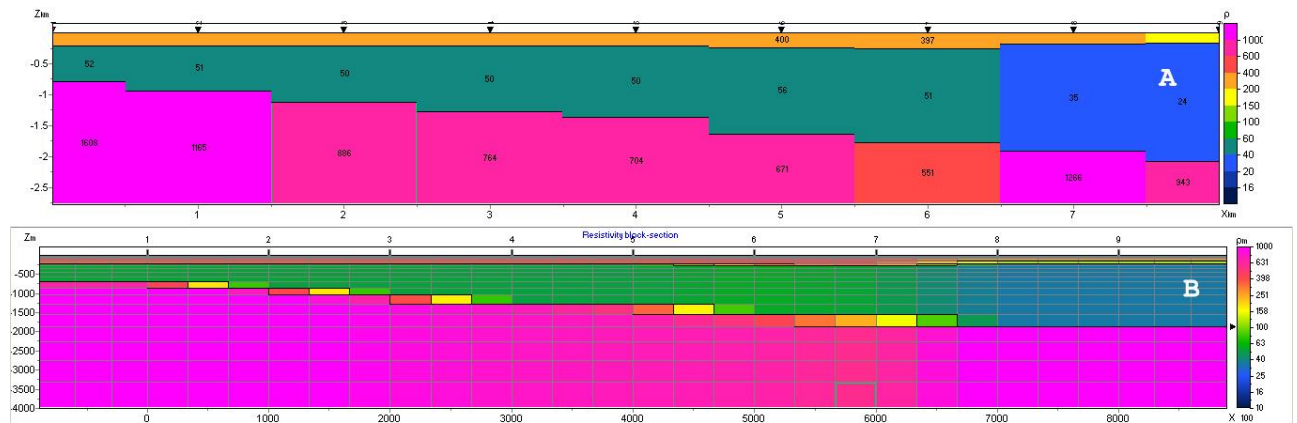
Fig. 12 An example of using the option Export/MOD1D file. A - the original model, B - the result of importing *.MOD1D file in ZondMT2D program

Working guidelines
Program main window

When «*.tdf» file is created, load it using 📂 button or corresponding menu item. If file is successfully loaded, functional buttons to work with data are activated in the main window toolbar (fig. 13) and short information on first sounding station appears in the right section of status panel. While moving the cursor in created windows, coordinates which correspond to axes in every window are displayed in the left section of status panel. Use the first system button

![objects setup icon] of the window, marked in plan as "**objects setup**", to open context menu which allows running setup dialog for each object in the window. Methods of editing are described in detail in the following chapters (**Model editor**, **Section**, **Model table**, **Pseudosection**, **Profile plot**, **Data editor**).

Second ◀ and third ▶ buttons serve to proceed from one sounding station to another.
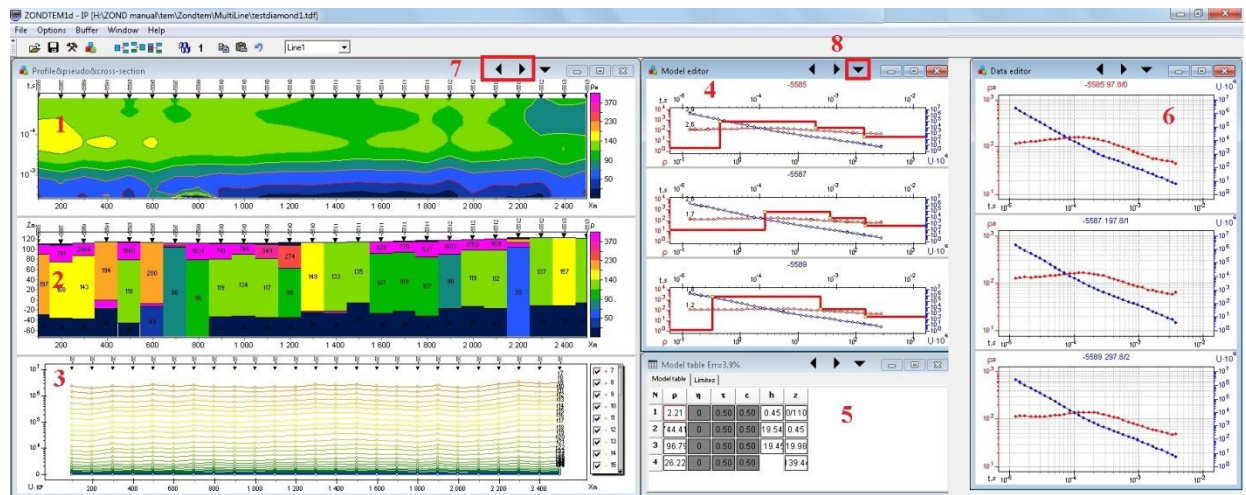
Fig. 13 Program main window. The following windows are marked by numbers: 1 – pseudosection, 2 – section, 3 – profile plot, 4 – model editor, 5 – parameters table, 6 – graph of theoretical and observed curves; 7 – button for proceeding from one station to another, 8 – button for object setup

Style sheet library

Use tab **Widow** in program main window to select style. Library has three options of objects configuration.

Vision style (fig. 9) – user simultaneously operates with three windows: first one contains pseudosection, section and profiling plots (displayed parameter can be chosen), spaced by floating slider; the second one contains graphs (from one to three) of model setup; the third window contains parameters table. Graph of theoretical and observed curves is absent in this style.

Graph of theoretical and observed curves and profile plot window are absent in **Interpretation** style.

Graph of theoretical and observed curves and profile plot window are present in **Editing** style. This style is used to edit field data.

Main window toolbar

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

	Open «*.tdf» or «*.tdp» data file
	Save interpretation result or calculated curves.
	Run parameters setup dialog (more).
	Run sounding parameters setup dialog (more)
	Merge two layers with summary thickness.
	Add layer. User-selected layer is divided into two layers with equal thicknesses (in logarithmic scale).
	Delete selected layer.
	When clicking the **right** mouse button: display a pop-up menu in which it is necessary to choose for which items will be performed inversion: *current* - for current point, *to end* - from the current point to the profile end, *to start* - from the current point to the profile beginning. When clicking the **left** mouse button: to run inversion for the selected profile area or the current point
	Run single iteration for current point
	Copy model at current stake to buffer.
	Read model from buffer and use it at current station (left click) or at all following stations (right click).
	Cancel previous step.
	Select profile (when working with areal data).

Main menu functions

The following table lists items contain their corresponding functions:

File	Open data	Open «*.tdf» or «*.tdp» data file.
File	Save data	Save interpretation result or calculated curves.
File	TEM Notepad (new data)	Create new sounding file (more)
File	Project information	Display and/or create information on current project.

File	Edit data	Open currently used data file in Notepad.
File	Program setup	Run parameters setup dialog (more).
File	Export to	Export field data or calculated data (more)
File	Print preview	Run print dialog of model and data (more).
File	Registration file	Create registration file.
File	Registration	Enter registration key.
File	Recent	Open one of recently opened projects.
File	Exit	Exit program.
Options	Set lines survey	Set profile line (when working with areal data).
Options	Visualization of areal data	Display isolines map of selected parameter (more). Recommended for areal data.
Options	Visualization of 3D section	Run dialog of 3D model visualization (more)
Options	Sounding settings	Run setup dialog of sounding station (more)
Options	Load borehole data	Load lithology file.
Options	Create/Edit borehole data	Create/edit lithology file (more)
Options	Remove borehole data	Delete lithology file.
Options	Insert apriori boundaries	Set geological boundaries (more)
Options	Smooth model	Smooth model (more)
Options	Set positive data at load	Set all data positive at load file.
Options	Invert visible data	Invert only visible graphs (more)
Options	Fixed noise level	Fix the noise from 10^{-7} to 10^{-1} mV
Options	BiLog equal scale	Set the same logarithmic scale for the axes in the display windows of sounding curves
Options	Set positive data	Set all data positive for current point.
Options	Multiply data to "-1"	Multiply data with «-1» for current point.
Options	Denoise data	Remove data (more)
Options	2D smoothing	Remove noise using 2D filtering (more)
Options	Digital filter/app. res	Calculate exact apparent resistivity to any source-receiver systems, taking into account all the parameters of the setup, including line-line systems. By default, apparent resistivity is calculated only for systems with magnetic source-receiver according to the formula for the late stage.
Options	VES data	Joint interpretation with VES data (more)
Options	MT data	Joint interpretation with MT soundings data (more)

Buffer	Model 1,2…5	Save 1 to 5 calculated models to the clipboard for further comparisons
Buffer	Open	Open saved models in a single window ([more])
Window	Tile vertical	Order windows vertically.
Window	Tile horizontal	Order windows horizontally.
Window	"Editing" style	Load "Editing" style.
Window	"Interpretation" style	Load "Interpretation" style.
Window	"Vision" style	Load "Vision" style.
Window	Default	Order windows on default for current style.
Help	About	About program.
Help	Context	Load manual file
Help	Check for updates	Check for updates.
Help	Error! Clear setting	Reload the program when an error occurs

"Hot" keys

[Space]	Run the automatic inversion for this item
[S]	Add layer. User-selected layer is divided into two layers with equal thicknesses (in logarithmic scale).
[M]	Merge two layers with summary thickness.
[D]	Delete selected layer.
->	Proceed to next station.
<-	Return to previous station.
[Escape]	Stop inversion process.

Program setup dialog

The dialog serves to adjust autosaving options and specifics of starting model definition, set default values and inversion parameters. Use [button] button in the toolbar or corresponding menu item (**File/Program setup**) to run it.

Tab Options
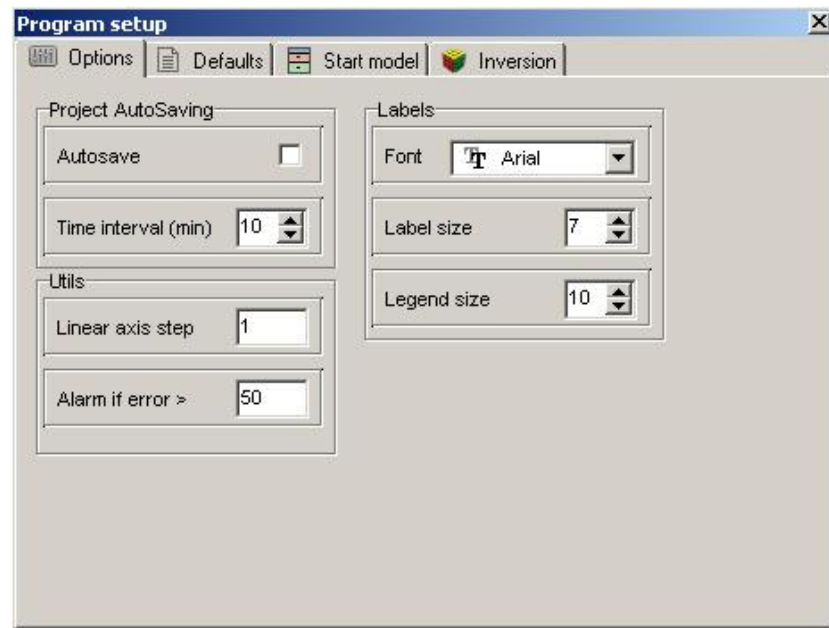
Fig. 14 Window **Program Setup**, tab **Options**

Field Project AutoSaving sets autosaving mode for open project.

Option *Autosave* enables autosaving for open project in certain time intervals.

Field *Time interval* sets time interval (in minutes) for autosaving (file is saved with the same name but with "Temp" added).

Field Labels sets parameters of used fonts.

Field *Font* sets font style for marks on axes, curves, etc.

Field *Label size* sets font size for marks on axes, curves, etc.

Field *Legend size* sets font size used to display parameters names.

Field Utils sets additional parameters.

Field *Linear axis step* sets necessary step for axes. This option is used for axes scaling.

Field *Alarm if error >* runs confirmation dialog of profile inversion if station value of RMS error exceeds specified in the field value.

Tab Defaults

This tab serves to set different parameters used while working with model. Rows correspond to types of layer parameters (properties and thickness), columns correspond to options (fig. 14).

The program includes the following notation of model parameters: ρ - apparent resistivity, η - polarizability, τ - relaxation time c - the exponent.

First row *Value* – default values (used for starting model).

><	Value	Minimum	Maximum	Fixed	Invert
ρ	10	1	10000	☐	☑
η	0	0	60	☑	☐
τ	0.5	0	10	☑	☐
c	0.5	0	1	☑	☐
h	1	0.5	1000	☐	☑

Fig. 15 Window **Program Setup**, tab **Defaults**

Second column *Minimum* – smallest extreme of default parameters (used for parameters fixing).

Third column *Maximum* – superior limit of default parameters (used for parameters fixing).

Forth column *Fixed* – defines if parameter of specified type should be fixed after file reading or not. This option is not available in case of loading project file.

Fifth column *Invert* – defines if parameter is corrected during inversion or not.

Tab Start model
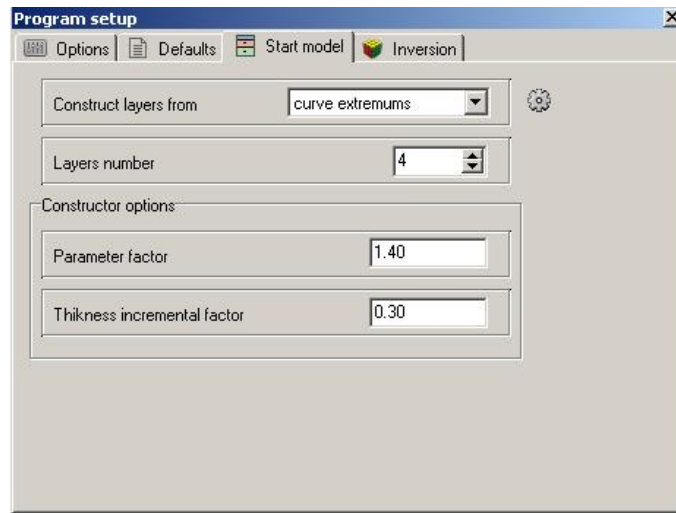
Fig. 16 Window **Program Setup**, tab **Start model**

Current tab is used as starting model constructor during field data reading.

Field **Construct layers from** – sets algorithm which determines positions of layer boundaries.

Value *Curve extremums* – boundary positions are determined by field curves (from extremum analysis). Maximum number of layers is specified in *Layers number* field.

Value *incremental factor* – default values are used to specify thickness of layers. Thickness of each layer is equal to thickness of the previous one multiplied by *Thickness incremental factor*. Number of layers is specified in *Layers number* field.

Field Constructor options – contains options used to specify starting model parameters. Field *Parameter factor* sets coefficient which maximums are multiplied by and minimums are divided by (ranges from 1 to 4). This coefficient increases starting model contrast which is very important if curves do not have asymptotes.

Field *Thickness incremental factor* – sets coefficient which layer thicknesses are multiplied by (ranges from 0.2 to 1) or coefficient of thickness increase for each following layer in *incremental factor* mode (ranges from 1 to 2).

When starting model parameters are set use ⚙ button to apply them to current project without closing parameters setup window.

Tab Inversion
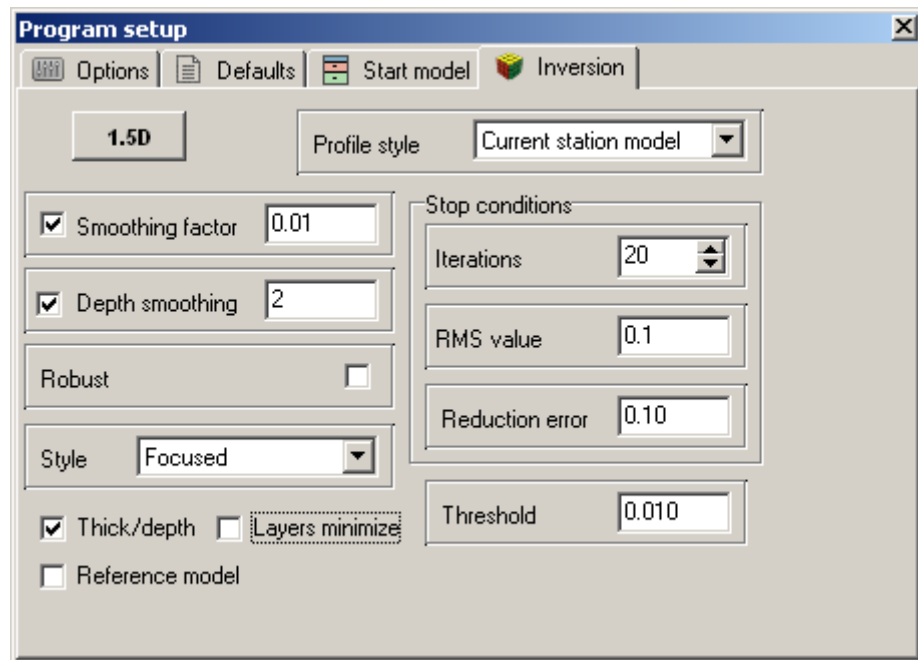
Fig. 17 Window **Program Setup**, tab **Inversion**

Field **Profile style** – sets inversion style of profile inversion.

Value *Current station's model* – current station model is used as starting model for inversion.

Value *Start station's model* – model of inversion start station is considered to be starting model for inversion for all other points.

Value *Previous station's model* – previous station model is used as starting model for inversion.

Field **Smoothing factor** – sets staring value of smoothing parameter. It depends on many factors: condition number of Jacobian matrix, signal to noise ratio of data, and number of model parameters definitions. It is an empiric value. For noisy data or for smooth parameters distribution greater values of smoothing factor are chosen: 0.05 – 10; for precise measurements it ranges from 0.005 to 0.01.

Models created using three different values of smoothing factor (0.01 – blue, 0.1 – red, 1 – black) are shown below (fig. 18).
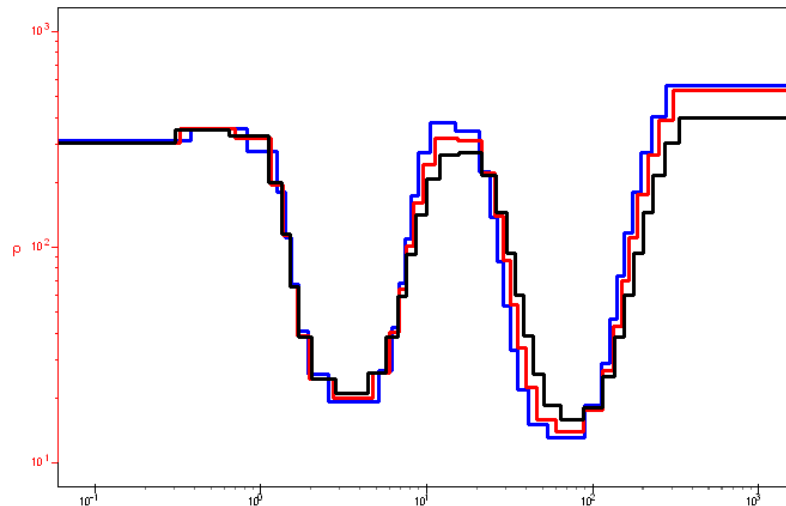
Fig. 18 Models with different values of **Smoothing factor** (0.01 – blue, 0.1 – red, 1 – black)

Field **Stop conditions** – sets rules which stops inversion.

Field *Iteration's number* – sets maximum number of iterations. Automatic interpretation process stops when it's achieved.

Field *RMS value* – sets minimum RMS error. Automatic interpretation process stops when it's achieved.

Field *Reduction error* – sets discrepancy value. Inversion process stops if this value repeatedly increases (in specified value (%)) for three sequential iterations.

Option **Depth smoothing** – sets degree of model depth smoothing (if this option is on). The greater its value is (1 – 10) the more parameters of adjacent layers are averaged with depth. This option is used if *Smooth* field is chosen in procedures of section parameters recovery window **Style**.

Option **Robust** – this option is used if data contain certain significant errors, connected with systematic measurement errors.

Option **Style** – sets type of procedure for section parameters recovery.

Value *Smooth* – inversion by least-square method using smoothing operator and complementary contrast minimization. This algorithm results in the smoothest parameters distribution. This type of inversion is recommended for initial stages of interpretation. But number of model layers must significantly exceed number of layers in real model. It is preferable to have more than 10 layers of fixed thickness.

Value *Standard* – inversion by least-square method using damping factor regularization. It results in model with sharp boundaries. Careless usage of this algorithm leads to results instability and increase of RMS increase. The best option is to consider this algorithm specifying and use it after inversion by *Smooth* algorithm.

Value *Focused* – inversion by least-square method using smoothing operator and additional contrast focusing. It results in piecewise smooth parameters distribution, that is model consists of layers with equal resistivity. This type of inversion is recommended for initial stages of interpretation. But number of model layers must significantly exceed number of layers in real model. It is preferable to have more than 10 layers of fixed thickness.

Careless usage of this algorithm leads to algorithm discrepancy and model instability. Figure 19 shows models created using three different inversion algorithms (standard – black, focused – blue, smooth – red).
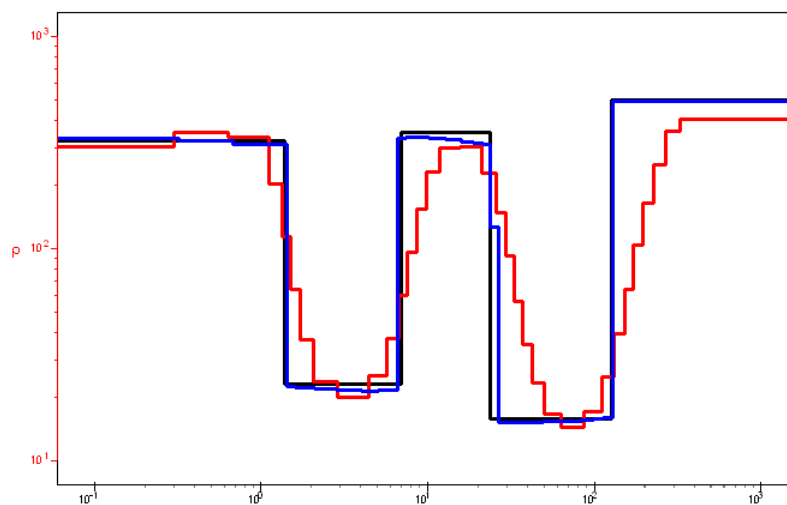
Fig. 19 Models created using different inversion algorithms (standard – black, focused – blue, smooth – red)

Option **Threshold** – sets maximum contrast value of adjacent layers. When this value is achieved parameters of adjacent layers are not averaged (thus boundary is considered to exist between layers). It's an empiric value (0.001-1). Low values of this parameter lead to algorithm discrepancy (it's recommended to increase it). High values result in smooth distribution.

Figure 20 shows models created using two different values of parameter ***Threshold*** (0.01 – black, 0.1 – red).
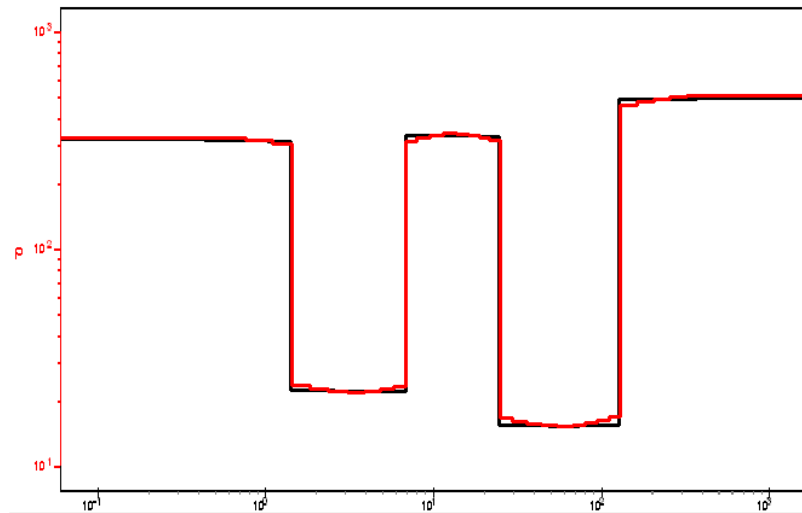
Fig. 20 Models created using two different values of contrast parameter ***Threshold*** (0.01 – black, 0.1 – red)

Option **Layers minimize** sets minimum number of layers. It is used combined with multilayered section and focusing inversion. This algorithm minimizes number of layers. Multilayered (10-15 layers) model and focusing inversion are chosen (smoothing factor~0.1). During inversion layers with similar parameter are merged and inversion process continues with lower number of layers.

Option ***Thick/depth*** sets thickness (if this option is active) or depth (if not) fitting. Depth fitting is useful if depths of boundaries are known and fixed. It is recommended to assign depth default values for profile inversion with depth fitting.

Option ***Reference model*** sets the model selection using the start model as a referent.

Button **1.5D** runs dialog of special profile inversion algorithm.

For this algorithm subsurface model is considered to be horizontally layered or quasi-horizontally layered (with smooth boundaries) at the bottom. Top part of the section can change greatly from point to point (fig. 21). A few adjacent soundings which have common bottom part and variable top part are used for inverse solution. Fitting is conducted simultaneously for all

curves in the window and central point has the greatest weight for discrepancy calculation. (fig. 22).

$\mathbf{\rho}_5$	$\mathbf{\rho}_1$	$\mathbf{\rho}_6$
$\mathbf{\rho}_2$		
$\mathbf{\rho}_3$		
$\mathbf{\rho}_4$		
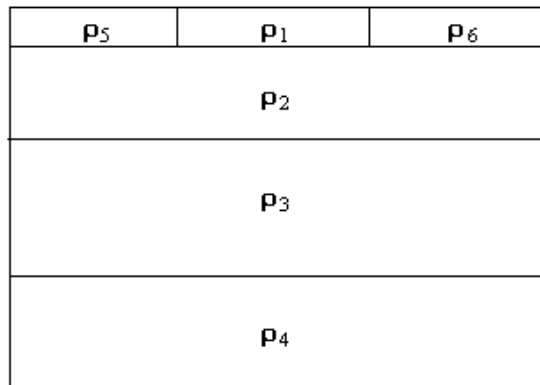
Fig.21. Subsurface model for 1.5D inversion
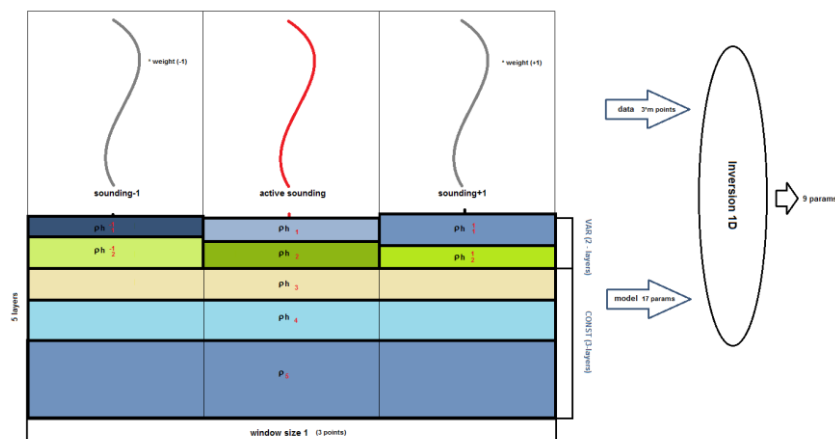
Fig.22. Scheme of 1.5D inversion

Additional parameter - offset to prevent P-effect is assigned to each curve in the window. This parameter is minimized for all curves during fitting and thus it significantly decreases P-effect influence.

Current algorithm differs from standard inversion in additional parameters and construction of smoothing operator. Parameters which model P-effect have less weight compared to the others. Main characteristics of the algorithm are given below.

- Fitting is conducted simultaneously for all curves in the window and central point has the greatest weight for discrepancy calculation.
- P-effect of each curve is selected during inversion process.
- Own model with common bottom part and variable top part corresponds to each curve.
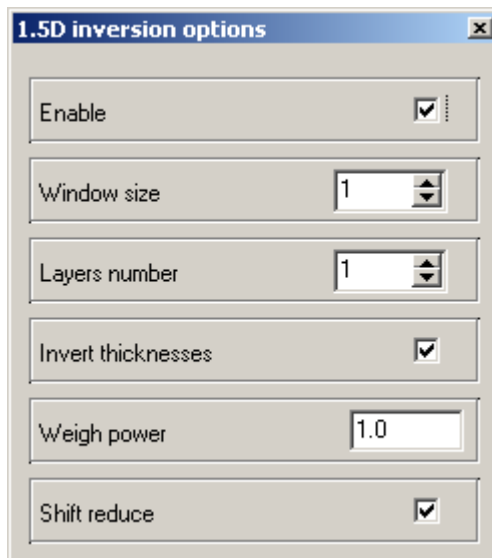
Fig. 23 Parameters window of 1.5D inversion

Option **Enabled** enables current algorithm.

Option **Window size** sets window size for the algorithm. Value 1 means three soundings in the window, 2 - five soundings in the window.

Option **Layers number** sets number of layers which model top (heterogeneous) part of the section.

Option **Inverse thickness** indicates if thicknesses of first layers which model top (heterogeneous) part of the section are fitted or not.

Option **Weight power thickness** sets coefficient of curve weight decrease depending on the distance from the central curve in the window (0 – all curves in the window have the same weight).

Option **Shift reduce** indicates if P-effect is taken into account during inversion or not.

Figure 24 shows results of this algorithm (A) compared to results obtained by standard procedure (B).
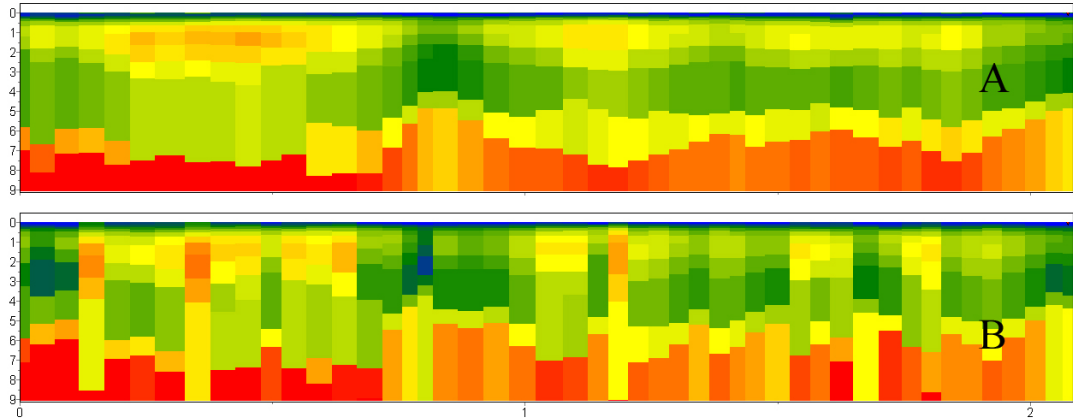
Fig. 24 Results compare of standard 1D inversion (B) and application 1.5D inversion algorithm (A)

Sounding settings

Main menu option **Options/Sounding setting** or button in the toolbar of program main window are used to browse or edit sounding point parameters. Press Apply button to use specified parameters for selected station. Apply to all button serves to use specified parameters for all points on profile.

Tab **Survey** (fig. 25) contains information on station coordinates and name (top field of data). Map of profile points is displayed in the right graphic window, editing point is highlighted in red. Source (red color) is displayed in the left graphic window according to specified in data file geometry (loop or line). Receiver (blue color) is also displayed in the left graphic window.
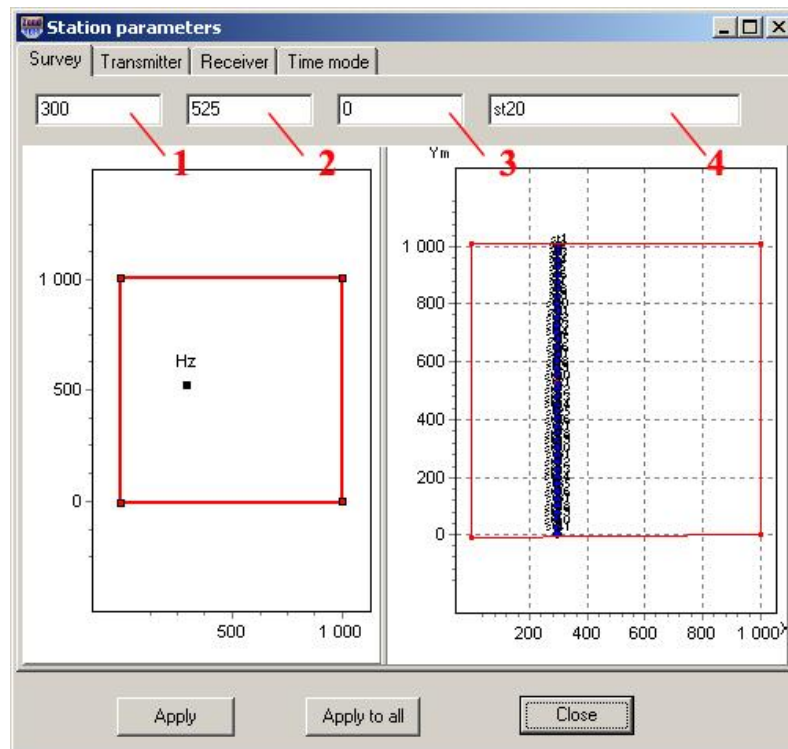
Fig. 25 Window **Station parameters,** tab **Survey.** 1-3 – X, Y and Z coordinates respectively, 4 – station name

Tab **Transmitters** (fig. 26) allows choosing type of source: *VMD* – vertical magnetic dipole, *HED* – horizontal electric dipole, *Line* – line of finite length, *Loop* – free-form loop, *HMD* – horizontal magnetic dipole. Source elevation above ground surface can be specified (for magnetic dipoles only) in the field situated to the right of drop-down list. Source geometry (relative XY coordinates of nodes for sources of finite length (loop, line) or relative center coordinates and direction cosine (for dipole)) are specified in the table. The best option is to enter nodes coordinates of source and receiver considering source center as origin of coordinates.
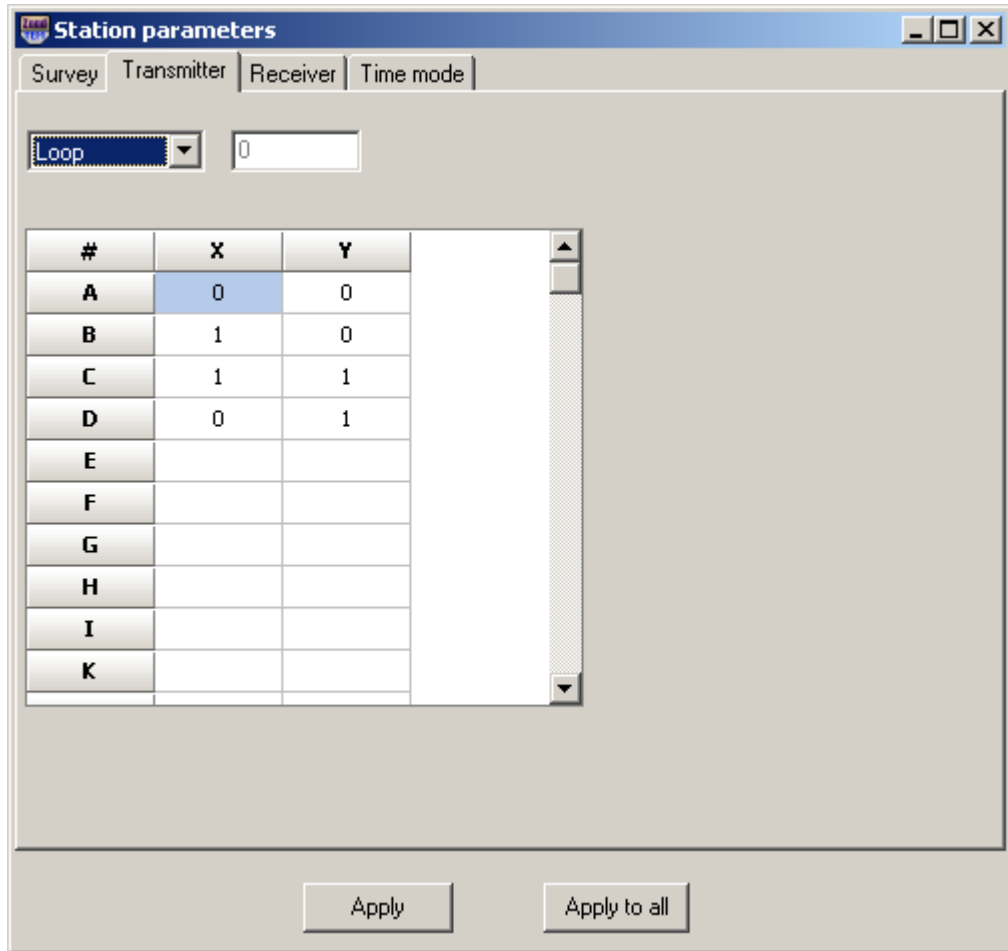
Fig. 26 Dialog window **Station parameters** (tab **Transmitters**)

Tab **Receiver** is used to choose receiver type and its geometry (fig. 27). Factor in Multiplier field is necessary for complementary user's data normalization. For a loop additionally vertical coordinate of sounding station must be specified in the field to the right of receiver type selection.

Same center - coaxial installation (center of the source and receiver are the same).

dF / dT - set derivative calculation of the field in time.
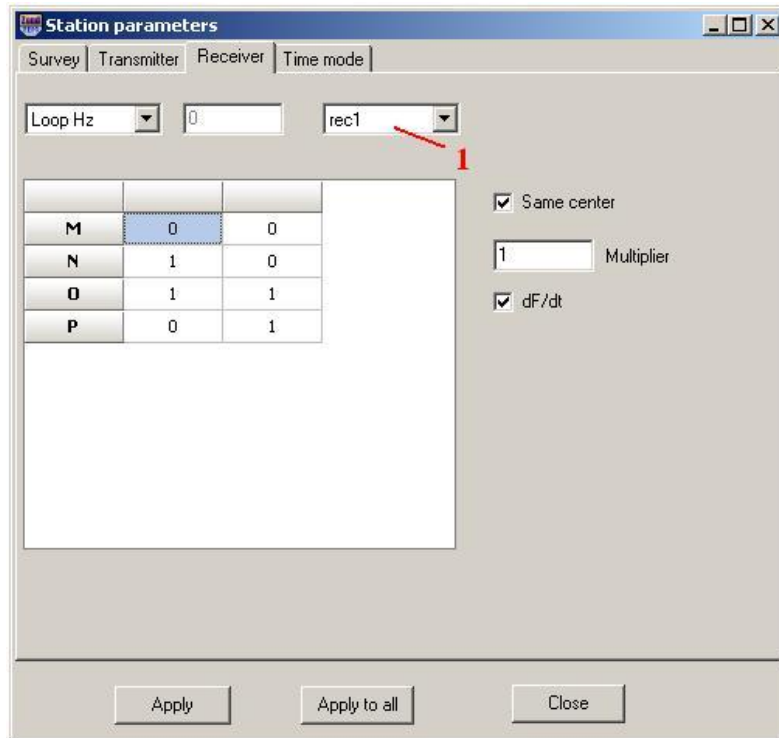
Fig. 27 Window **Station parameters**, tab **Receiver** 1- window of receiver number selection (active when using multiple receivers)

Tab **Time mode** serves to specify signal parameters (fig. 28). In Signal type field user can choose: *Step*, *Finite pulse*, *User defined*. Current tab also allows specifying pulse time (field *Pulse*), pause time (field *Pause*), leading edge (field *Ramp Front*), trailing edge (field *Ramp Back*), and number of pulses (field *N Pulses*). If *Unipolar* is ticked then pulse is unipolar.

Current mode is displayed graphically at the bottom of the window.
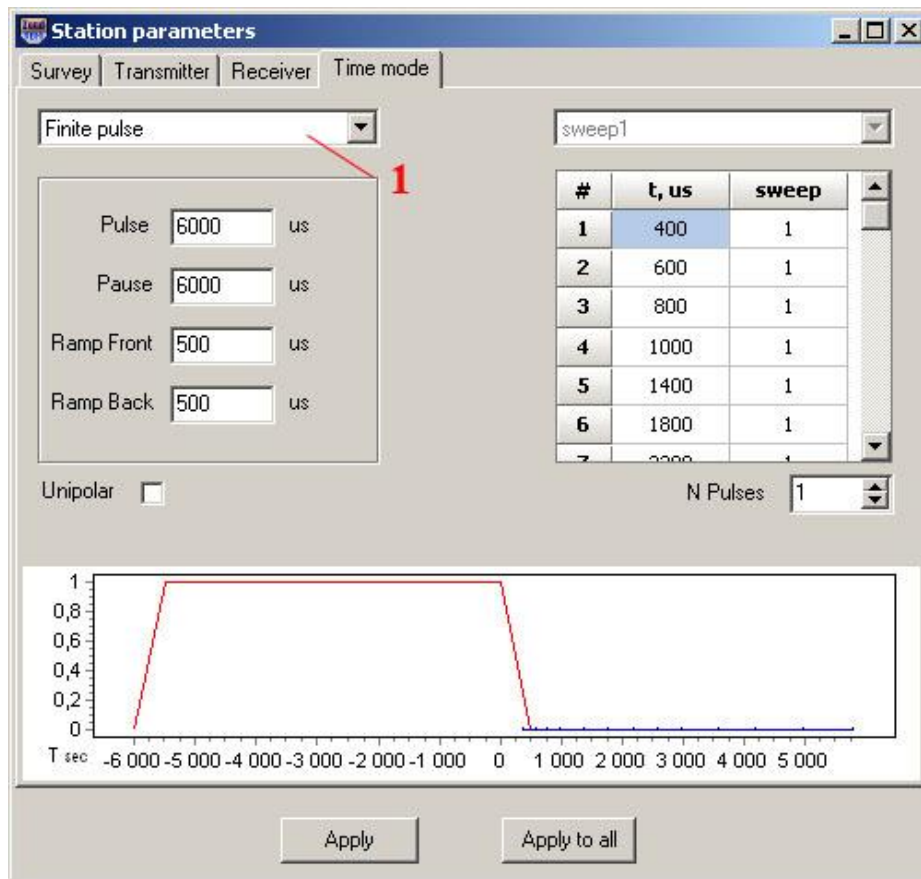
Fig. 28 Window **Station parameters**, tab **Time mode.** 1 –pulse type choice

Field data interpretation

«ZONDTEM1D» program allows solving 1D forward and inverse problems of transient method. Program automatically selects resistivity values and layer thicknesses. It is also possible to fix parameters and specify their variation limits and define weights of certain measurements.

Interpretation mode becomes available after reading data from a file.

Data inversion

This option is used for quick data inversion of one or all profile stations. Newton's method is used for minimization of least-square deviation between calculated and observed curves. Right-click the button 🔧 on the toolbar. A pop-up menu will be shown, where it is necessary to choose for which items inversion will be performed: *current* - the current point, *to end* - from the

current point to the end, *to start* - from the current point to the beginning of the profile. After selecting points, left-click the button . Information on current relative misfit between calculated and observed curves is shown in the status bar. Inversion stops when current relative misfit between calculated and observed curves or number of iterations reach predefined values. (for more information read Program properties window)

Inversion gives a non-unique solution since calculated curves can be identical for different models. So it is necessary to take into account a-priori information on geoelectrical section when specifying starting model. If a-priori information is reliable it is advisable to fix known parameters or limit their value ranges in starting model and also add geological boundaries.

Program objects

Interactive interpretation is made in the following objects: **Model editor, Section, Parameters table**, visualization is made in the following objects: **Pseudosection, Profile plot, Calculated and observed curves plot.** These objects appear automatically as soon as data is loaded.

Model editor

It serves to display observed and calculated sounding curves and to visualize and edit parameters curve of calculated model.

Model editor window is shown in figure 29. Curves with the filled circles - experimental curves of apparent resistivity (left red axis) and the transients (right blue axis) versus time (upper axis). The lower horizontal axis shows the depth (in meters) of the calculated model, which shows a continuous red line. The calculated curves are shown by not empty circles. In the example, for apparent resistivity and formation it shows three curves that correspond to the three sources used in the measurements. The numbers in the left side of the graph contains a misfit error (RMS) for of each curve inversion.
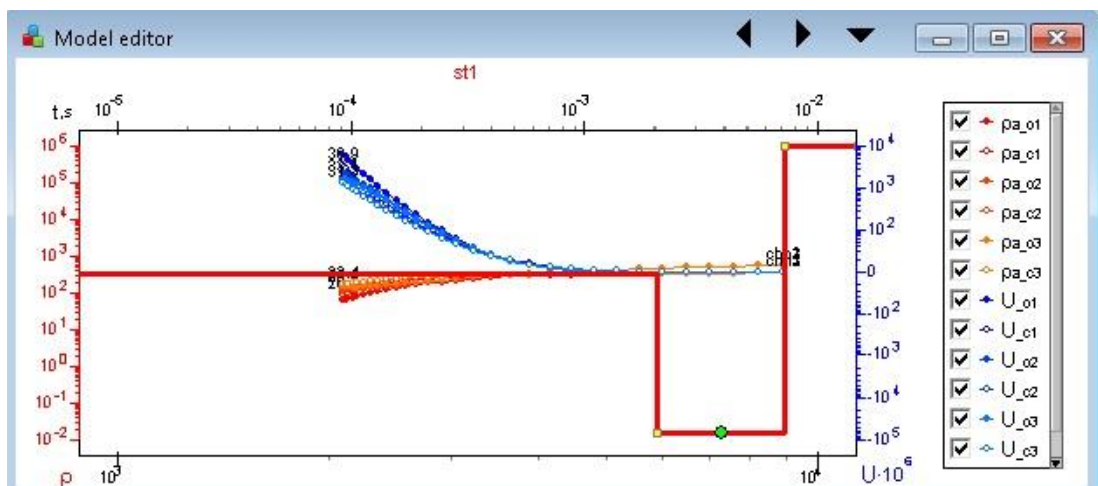
Fig. 29 Model editor window

When working with the data in the frequency domain the curves of apparent resistivity (module) and phase are displayed in the model editor (Fig. 30).
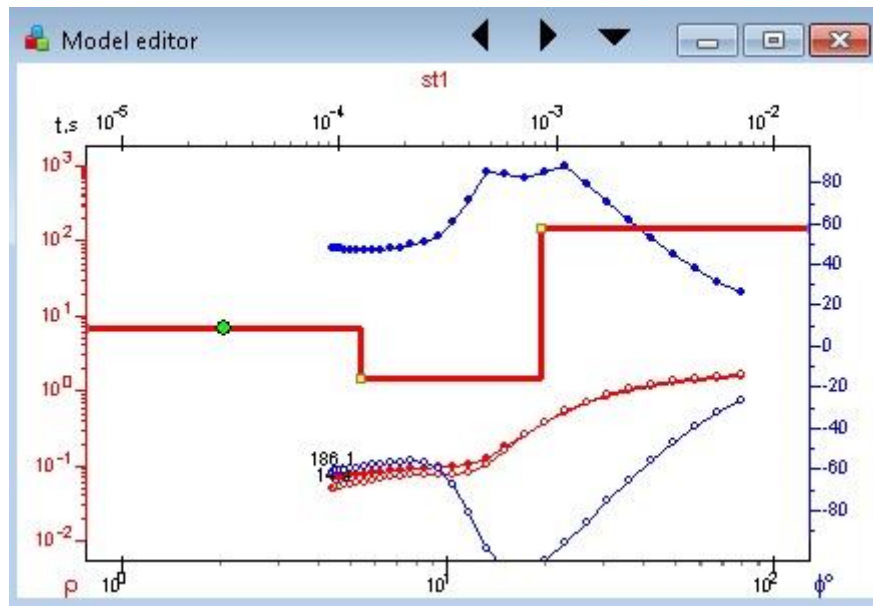
Fig. 30 Plots of amplitude and phase for data in the frequency domain.

Graphical parameters of observed, calculated and model plots are specified in graphs editor dialog (right click+SHIFT on plot). Axis parameters are specified in axes editor (right click+SHIFT on axis).

Window can contain one, two or three similar graphs which allow editing models at three neighboring stations at once.

Model parameters can be changed via mouse. In order to do that place mouse cursor on model curve (cursor shape must change at that moment) and with left button pressed drag selected part of curve. Green circle on selected curve indicates active layer.

Alteration of vertical curve pieces positions corresponds to alteration of model geometry (that is thicknesses [right click] and depths of layers tops [left button]).

Alteration of horizontal curve pieces positions corresponds to alteration of model layer parameters.

Double click in object area to run context menu which contains the following options:

Print preview	Run graph print dialog.
Display legend	Display/hide graphics legend.
Setup	Run object parameters setup dialog.
Left axis Resistivity	Display apparent resistivity on the left axis
Left axis Polarizability	Display polarisability on the left axis
Left axis Time constant	Display relaxation time on the left axis
Left axis C exponent	Display exponent on left the axis

Right axis Resistivity	Display apparent resistivity on the right axis
Right axis Polarizability	Display polarisability on the right axis
Right axis Time constant	Display relaxation time on the right axis
Right axis C exponent	Display exponent on the right axis

To show the plot legend on the right, select Display legend option. If there are multiple receivers for one sounding point it is possible to display graphs for each receiver individually. At the same time, option *Invert visible,* which inverts visible graphics, is active for displaying graphs.

Setup option runs *curve parameters setup dialog* (fig. 31).
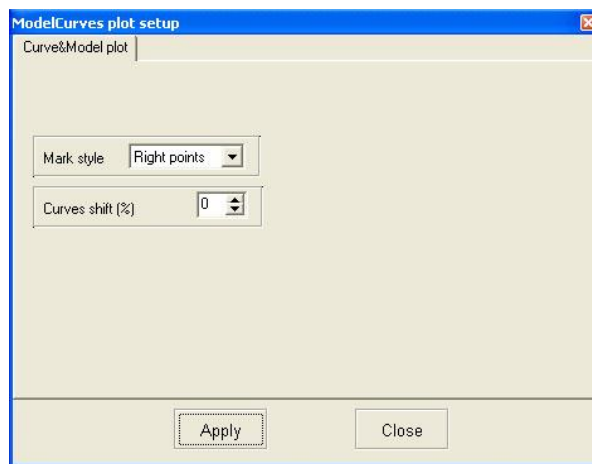
Fig. 31. Curve parameters setup dialog

Field **Marks Style** – defines how to draw graph's marks.

Value *Left points* – to the left of graph.

Value *All points* – from point to point.

Value *Right points* – to the right of graph.

Field **Curves shift** – sets shift (in percent of logarithmic decade) between adjacent curves (is used in ZondTEM and ZondVMD programs).

Data Editor

It is displayed if **Editing** style is selected (tab **Window**).
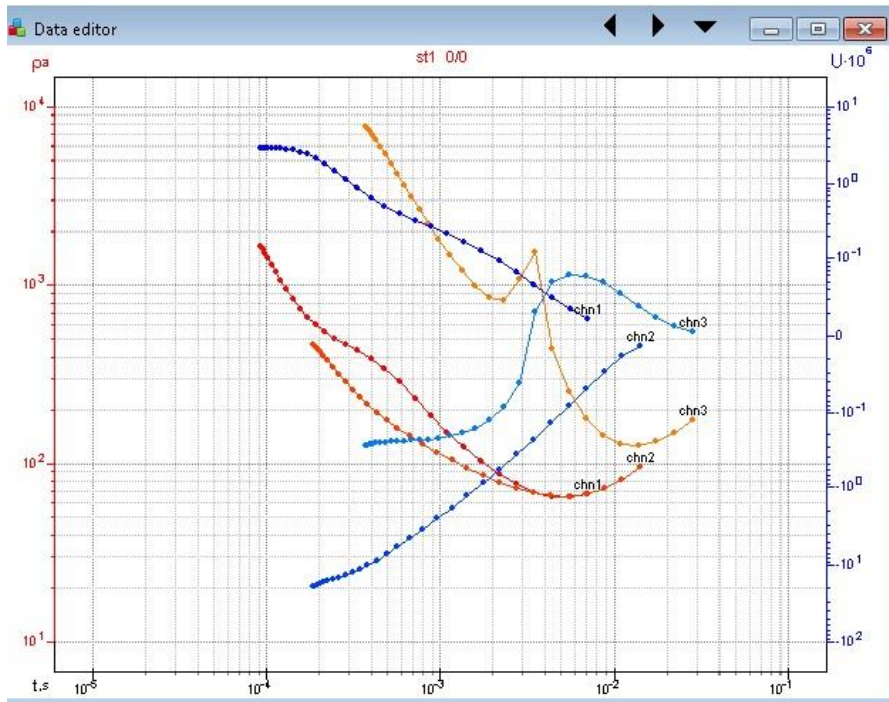
Fig. 32 Data editor window

Double click in object area to run context menu which contains the following options:

Print preview	Run graph print dialog.
Display weights	Display/hide point weight.
Display legend	Display/hide graphs legend.
Setup	Run object parameters setup dialog.

Setup option runs curve parameters setup dialog (fig. 33).
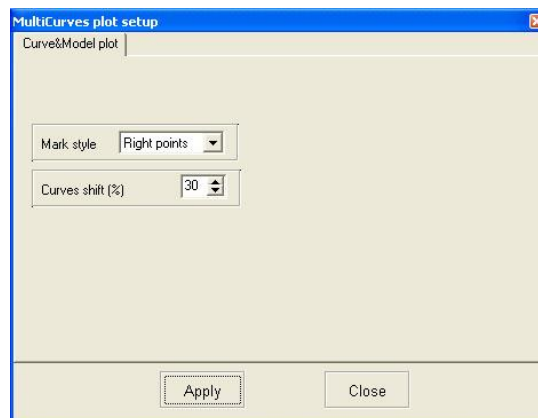
Fig. 33 Curve parameters setup dialog

Field **Marks Style** – sets positions of graph's marks.

Value *Left points* – to the left of graph.

Value *All points* – from point to point.

Value *Right points* – to the right of graph.

Field **Curves shift** – sets shift (in percent of logarithmic decade) between adjacent curves.

Options button ▼ runs complementary context menu.

Change orientation option changes positions of sounding curves for adjacent points: top-down and left-right.

MultiCurves Plot Setup option (fig. 33) runs curve parameters setup dalog described above.

Set MultiCurves Plot number option sets number of adjacent sounding stations to display their curves simultaneously (from 1 to 3).

Right click in points of observed curves to run context menu which allows specifying weights of observed data:

Good point	Set weight 1 to active point.
Bad point	Set weight 0.5 to active point.
Very bad point	Set weight 0 to active point.
Good points >>	Set weight 1 to active point and to all points to the right of it.
Bad points >>	Set weight 0.5 to active point and to all points to the right of it.
Very bad points >>	Set weight 0 to active point and to all points to the right of it.
Good points <<	Set weight 1 to active point and to all points to the left of it.
Bad points <<	Set weight 0.5 to active point and to all points to the left of it.
Very bad points <<	Set weight 0.5 to active point and to all points to the left of it.
Delete point	Delete point.
Delete point>>	Delete point and all points to the right of it.
Delete point<<	Delete point and all points to the left of it.
Edit data	Edit curves.

Right or left click with ALT button pressed to increase or decrease point weight respectively.

Use scroll wheel with ALT button pressed to delete points. Change limits of deletion using scroll wheel.

Point weights are very important for model parameters inversion. Points with weight equal to 0 are not taken into account. Weight is calculated in the following way: = 1-dispesion/(observed value). Data weight can be specified in data file and is saved in project file.

Edit data option is used to edit sounding curves manually. When this option is selected dialog window **Edit data** appears (fig. 34).
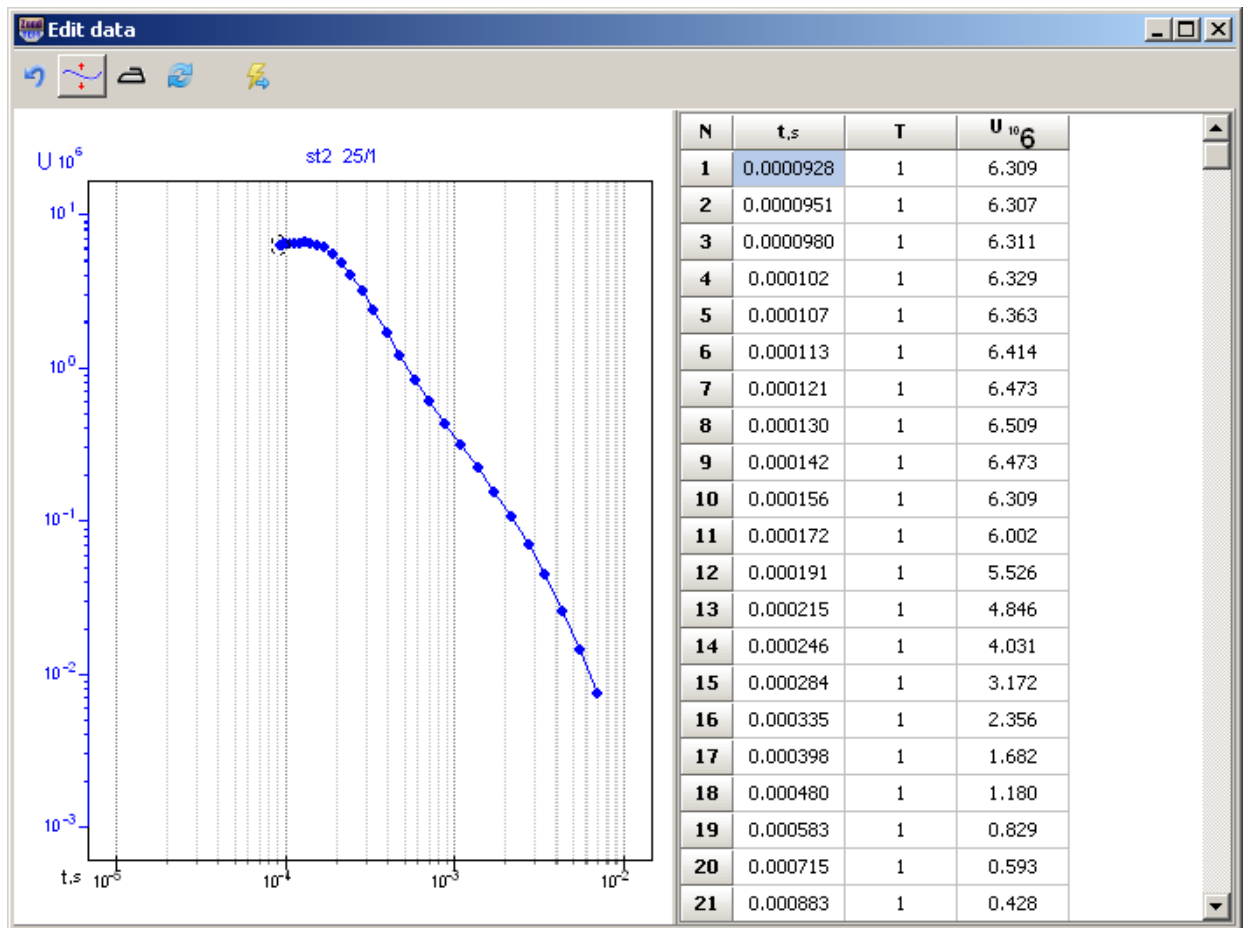
Fig. 34 Sounding curves setup window **Edit data**

Window toolbar contains the following buttons:

	Return to previous curve.
	Move the whole curve or its piece.
	Smooth curve
	Redraw curve in other windows.
	Exit editing mode with saving.

The window consists of two parts. Editing curve is displayed in the left part. Table, times and values of editing parameter are shown in the right one. Right click to delete point on the curve. Deleted point will be highlighted in grey in the table then. Left click to recover point. Use scroll wheel with ALT button pressed to delete points. Change limits of deletion using scroll wheel. After editing, press button in the toolbar to start inversion.

Model table

Tab Model table

Window with editing table is used to change model parameters via keyboard. Table contains 5 columns. Each table row contains properties of one layer only.

First column contains resistivity values of the layers, the second one − polarisability values, the third one − time constant, the fourth one − thickness, and the fifth one − depth to layer top with sounding station elevation taken into account. The cell is light grey by default (color can be specified) if parameter variation limit is set. The cell is dark grey by default (color can be specified) if layer parameter is fixed.

Right click on table cells to run context menu (fig. 35). If you right click on the first row (table heading) then selected menu option will be applied to specified parameter of all layers (cell is changed into col then). If you right click on the first column then selected menu option will be applied to all parameters of specified layer.
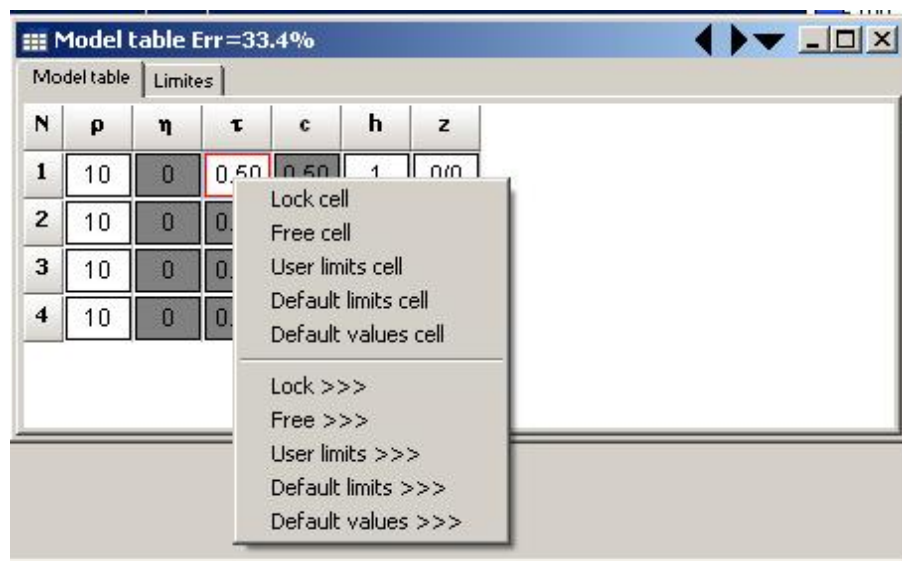
Fig. 35 Model parameters editing window in table.

Lock	Fix parameter.
Free	Unfix parameter.
User limits	Set user-specified variation limits.
Default limits	Set variation limits (on default).
Default values	Set default values.
Lock >>>	Fix parameter in current model and in all following points' models.
Free >>>	Unfix parameter in current model and in all following point models.
User limits >>>	Set user-specified parameter variation limits in current model and in all following models.
Default limits >>>	Set default parameter variation limits in current model and in all following models.
Default values >>>	Set parameter default values in current model and in all following models.

Tab Limites

This tab serves to set parameter variation limits (fig. 36). Toolbar buttons are used to select parameter type (resistivity, any parameter from cole-cole formula or layer thickness) to specify limits to. **Auto** button sets limits to all parameters of selected type automatically, according to their values and specified divergence percent. Model of selected parameter (black), its lower (red) and upper (blue) variation limits are shown in the graph.
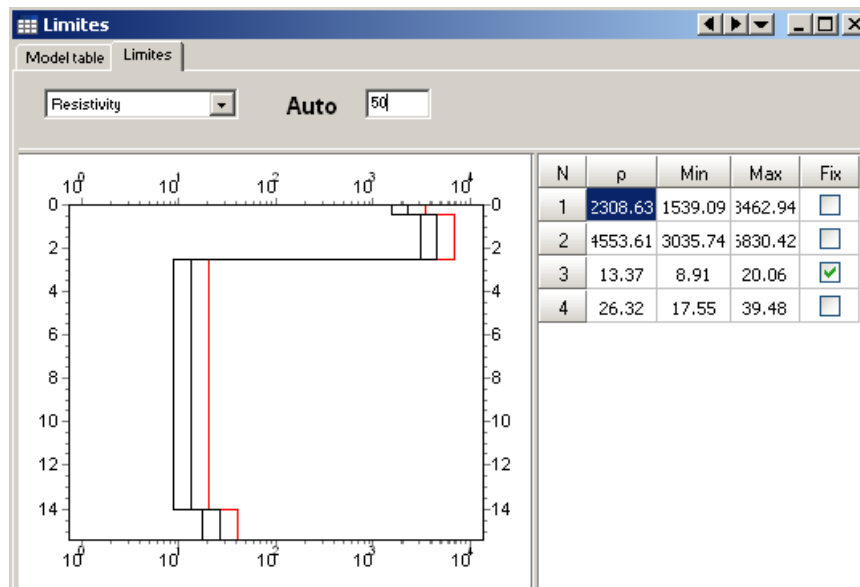
Fig. 36 Tab **Limites** of model parameters table

Lower and upper limits of model parameters are edited via mouse. Variation limits can be edited in the table situated to the left of the graph.

Use ▼ button in the top right corner of the window to run complementary context menu (fig. 37).
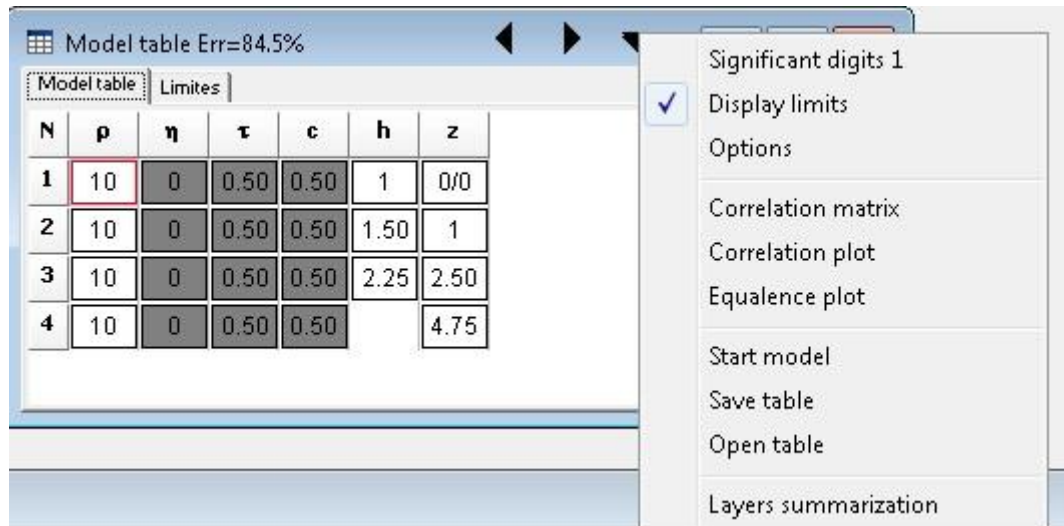
Fig. 37 Model parameters table menu

Significant digits	Set parameter accuracy with which parameters will be displayed.
Display limits	Display/hide range of parameter values.
Options	Run graphic parameters setup dialog.
Correlation matrix	Display correlation matrix and confidence limits of model parameters.
Correlation plot	Run drawing map window of correlation plot for two parameters.
Equivalence plot	Run equivalent models cloud plot window.
Start model	Return to starting model.
Save table	Save current model as *.MDL file.
Open table	Load model from *.MDL file.
Layers summarization	Run layer merging dialog.

Layers summarization dialog is used to convert multilayered models obtained by Smooth or Focused inversion into simpler geological models which contain less layers. Multilayered model which consists of 14-20 layers is convenient at the beginning of interpretation (fig. 38).
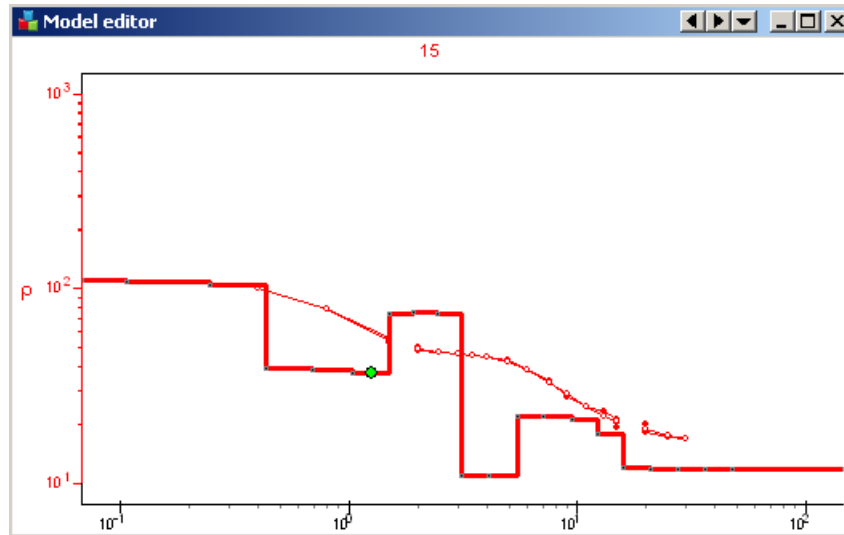
Fig. 38 Example of multilayered model

It is advisable to consider results of Smooth and Focused inversion as starting approximation for further more conscious interpretation. They give an idea about approximate geoelectrical section structure. Then Layer summarization dialog helps to obtains simpler model (fig. 39) which is displayed on top of an old one using black line.
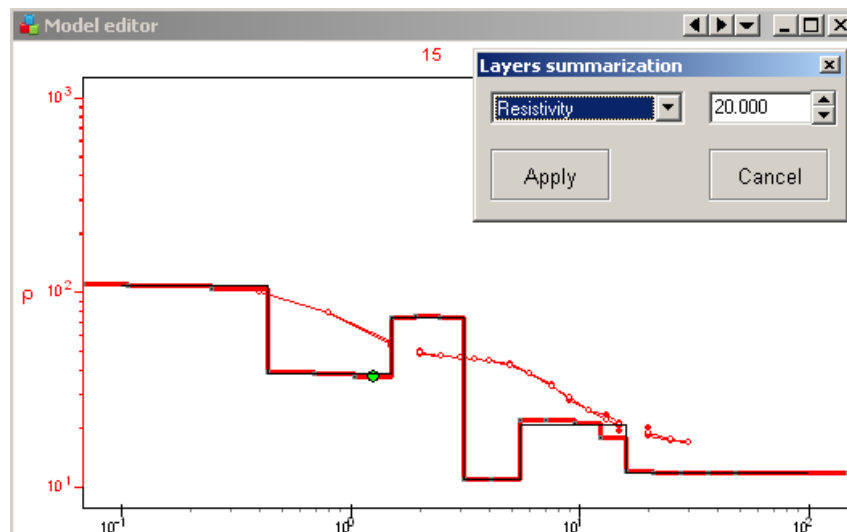
Fig. 39 Dialog **Layers summarization** (red line – multilayered model, black line – integrated model)

When specified in the field contrast parameter is achieved, two layers are merged.

After that some parameters can be fixed and Standard inversion or manual fitting is performed (fig. 40).
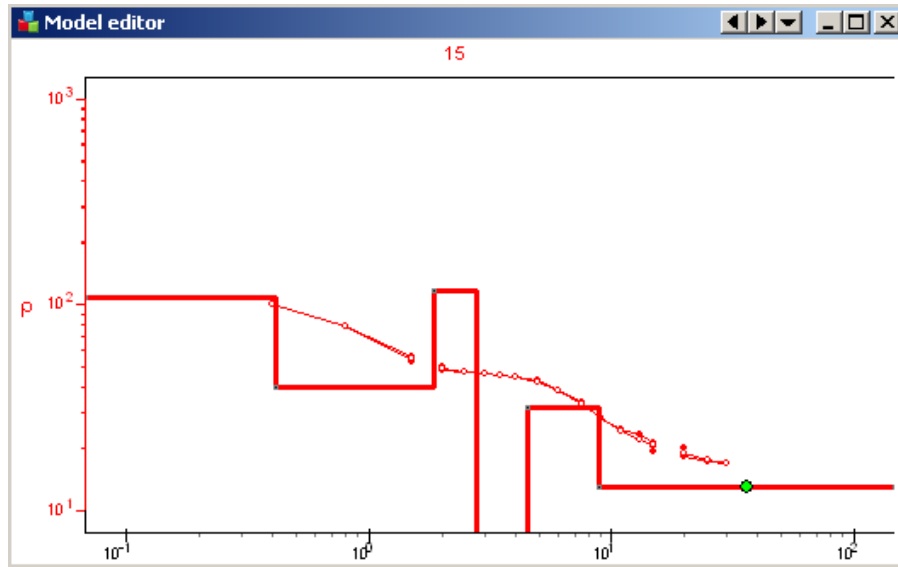
Fig. 40 Example of inversion results after usage of Layers summarization function

Equivalence analysis. In electrical exploration uniqueness theorem of inverse problem is proved if there are no mistakes in continuous measurements. In practice measurements are conducted within finite intervals with certain discretization and besides they contain mistakes. Presence of mistakes and incomplete data turn theoretical solution unicity into practical solution non-uniqueness which means equivalence of different inverse problem solutions. Two geoelectrical sections are considered equivalent if relative data discrepancy does not exceed accuracy of field measurements or inversion misfit. Practically equivalence principle means that some section parameters cannot be defined during interpretation if some other section parameters are not known. Equivalence principle effect complicates data interpretation. Fixing certain parameters (on the basis of apriori data) can solve the problem.

Equivalence principle analysis is based on two approaches – information-statistical for all model parameters by means of correlation matrix of coupling creation and direct calculation of equivalence domain for couple of section parameters with visualization.

One more option of equivalence analysis is creation of equivalent models cloud that is set of model curves which give similar theoretical curves.

Usually statistical estimation of equivalence for all parameters is performed first, then certain pairs of parameters with high correlation coefficients are studied.

Use **Correlation matrix** (fig. 41) option to run correlation matrix. Main diagonal of correlation matrix contains ones. If correlation coefficient modulo is significantly less than unity

then section parameters which were used to calculate it influence data differently and are defined with high accuracy. Thus their separate estimation is made possible.

If correlation coefficient modulo of parameters is close to 1 then these parameters are jointly indefinable. In this case it is recommended to fix one of equivalent parameters if it is possible to receive independent information on it. In case of strong parameter correlation of adjacent layers it is advisable to fix one of correlative parameters or merge these two layers in one that is to simplify the model.

Correlation matrix	ρ1	ρ2	ρ3	ρ4	ρ5	h1	h2	h3	h4
ρ1	1.00	0.15	-0.014	0.0039	-0.000	-0.61	0.14	0.0087	0.0024
ρ2	0.15	1.00	-0.063	0.011	-0.002	-0.63	0.94	0.031	0.0066
ρ3	-0.014	-0.063	1.00	-0.086	0.010	0.050	0.057	-0.92	-0.060
ρ4	0.0039	0.011	-0.086	1.00	-0.063	-0.012	-0.025	-0.089	0.94
ρ5	-0.000	-0.002	0.010	-0.063	1.00	0.0026	0.0055	0.015	0.077
h1	-0.61	-0.63	0.050	-0.012	0.0026	1.00	-0.57	-0.029	-0.007
h2	0.14	0.94	0.057	-0.025	0.0055	-0.57	1.00	-0.072	-0.016
h3	0.0087	0.031	-0.92	-0.089	0.015	-0.029	-0.072	1.00	-0.075
h4	0.0024	0.0066	-0.060	0.94	0.077	-0.007	-0.016	-0.075	1.00
par	324.26	22.91	351.17	15.82	503.38	1.39	5.50	16.85	104.55
min	308.90	20.28	307.90	13.91	419.39	1.34	4.84	14.76	91.52
max	340.38	25.89	400.52	18.00	604.19	1.44	6.26	19.25	119.43

Fig. 41. Window **Correlation matrix**

Last two columns of the table show confidence intervals for each parameter. Confidence intervals are considered reliability criterion for parameters definition and are connected with summarized sensitivity of section parameters. In case of large confidence interval parameter value is considered unreliable. When assessing the confidence interval width should be considered the absolute values of the resistivity and thickness of the layers. In this example, the confidence interval for ρ1 is about 30 Om*m with the absolute value being 300 Om*m. It means, value is determined with an error about 5%, which is quite acceptable. For ρ5 confidence interval width is about 200 Om*m at absolute value 500 Om*m. It means, error is enough large and is about 25%.

Double click on a matrix cell to run correlation dependency map (**Correlation plot**) of selected pair of parameters (fig. 37).

Correlation map of parameters pair represents contour map of discrepancy between theoretical data of current and calculated model. Assuming that current parameter values are centers of equivalence field, a few more forward solutions for parameters close to current point

are calculated and maximum error of discrepancy between them and central point is estimated. In order to create correlation map for two parameters they are assigned set of values in certain range, data discrepancy with current model is estimated and contour map is generated. If parameter distribution is logarithmic then all above-mentioned actions are performed using parameters logarithms. Contours of maximum error values which represent equivalence principle domain geometry and range validity are shown in the equivalence map. Isometric equivalence domains indicate that there is no correlation between parameters estimations, oblong domains mean the opposite. Correlation analysis promotes successful revealing of equivalence between two parameters.
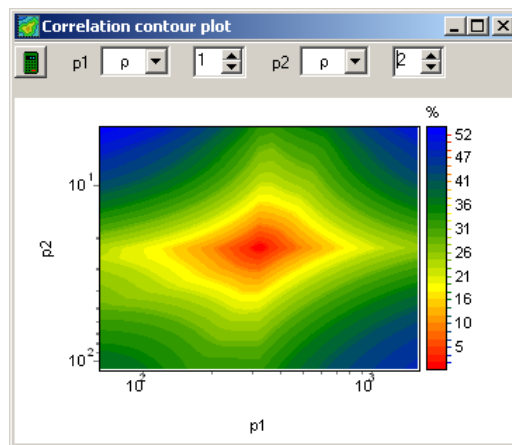
Fig. 42 Window **Correlation contour plot**

Color bar represents discrepancy to color ratio.

Field *p1* - sets type of first parameter for correlation analysis performance.

Field *p2* - sets type of second parameter for correlation analysis performance.

Following fields specify indexes of these first and second layers parameters, for which Field *p1* sets type of first parameter for correlation analysis performance.

 - create correlation map.

Use **Equivalence plot** option to run equivalence model cloud plot window. It implements quite resource-intensive algorithm of equivalence model access scan within specified error range (fig. 43).
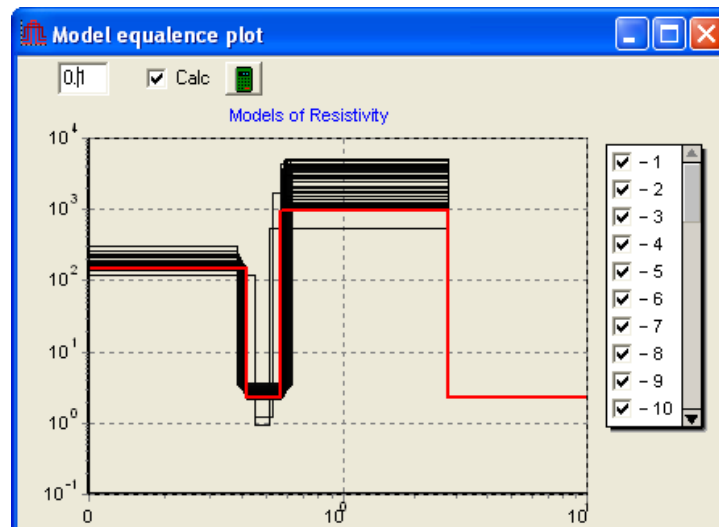
Fig. 43. Window **Equivalence plot**

Minimum error values to consider model equivalent to current (field 0.1) must be specified. If Calc option is not ticked then equivalence models are calculated for model inversion error. Usually, this value is chosen slightly larger than the current inversion error. Parameter for calculation is chosen then (Resistivity). After that access scan can be started ▮. Algorithm result in set of model curves. Use scrolling to proceed from one curve to another.

Table graphical parameters setup dialog (**Options**)

Option **Lock** sets fixed parameter cell color.

Option **Range** sets cell color for parameter with specified variation limits.

Option **Free** sets cell color for parameter without specified variation limits.

Option **Min** sets color of parameter minimum limit.

Option **Max** sets color of parameter maximum limit.

Option **Active** sets frame color of active cell.

Option **Font** sets cell font.

Option **Cell height** sets cell height.

Section

Current object visualizes geoelectrical section variations along profile. Graph is created in profile coordinate to depth axes. Color bar represents correlation between displayed parameter value and color (fig. 44).

If mouse cursor is located within geological section then use slider to select and highlight layer which is located below it. Cursor shape changes when it is reaching boundary of layers which can be edited then. To do that drag selected boundary with left button being pressed. If right button is pressed then selected boundary along with underlying boundaries are dragged. Double click on layer to run its parameter setup window.
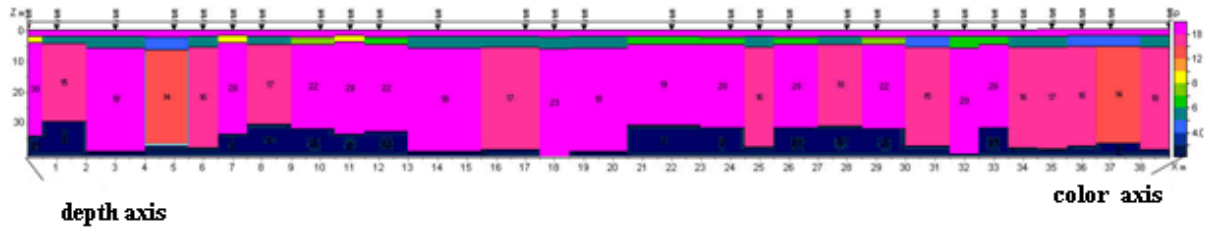
Fig. 44 Geoelectrical section window

Right click in the top (to decrease) or in the bottom (to increase) part of the axis changes maximum vertical axis value.

Double click on the object area runs context menu with the following options:

Log data scale	Use logarithmic scale in color bar.
Display labels	Display labels (parameter values) on axes.
Display ColorBar	Display color bar.
Refresh section	Update section.
Setup	Run object setup dialog.
Print preview	Print section.
Save picture	Save section as graphics file.
Output settings	Run output graphics scale parameters setup dialog.
Layered section	Display section as layers.
Layered section [topo]	Display section as layers with topography.
Contour section	Display section as contours.
Smooth section	Display smooth section.
Add background	Add background image.
Remove background	Delete background image.
Increase bottom	Increase maximum vertical axis value.
Decrease bottom	Decrease maximum vertical axis value.
Set bottom	Set maximum vertical axis value manually.
Model interpolation	Interpolate all models between two selected sounding stations.
Bad data interpolation	Interpolate models (with large fitting error) between two selected sounding stations.
Column percent	Set column size for each point
Resistivity display	Display resistivity section
Polarizability display	Display polarisability section
Time constant display	Display relaxation time section
C exponent display	Display power exponent section

Figure 45 shows four versions of geoelectrical section visualization.
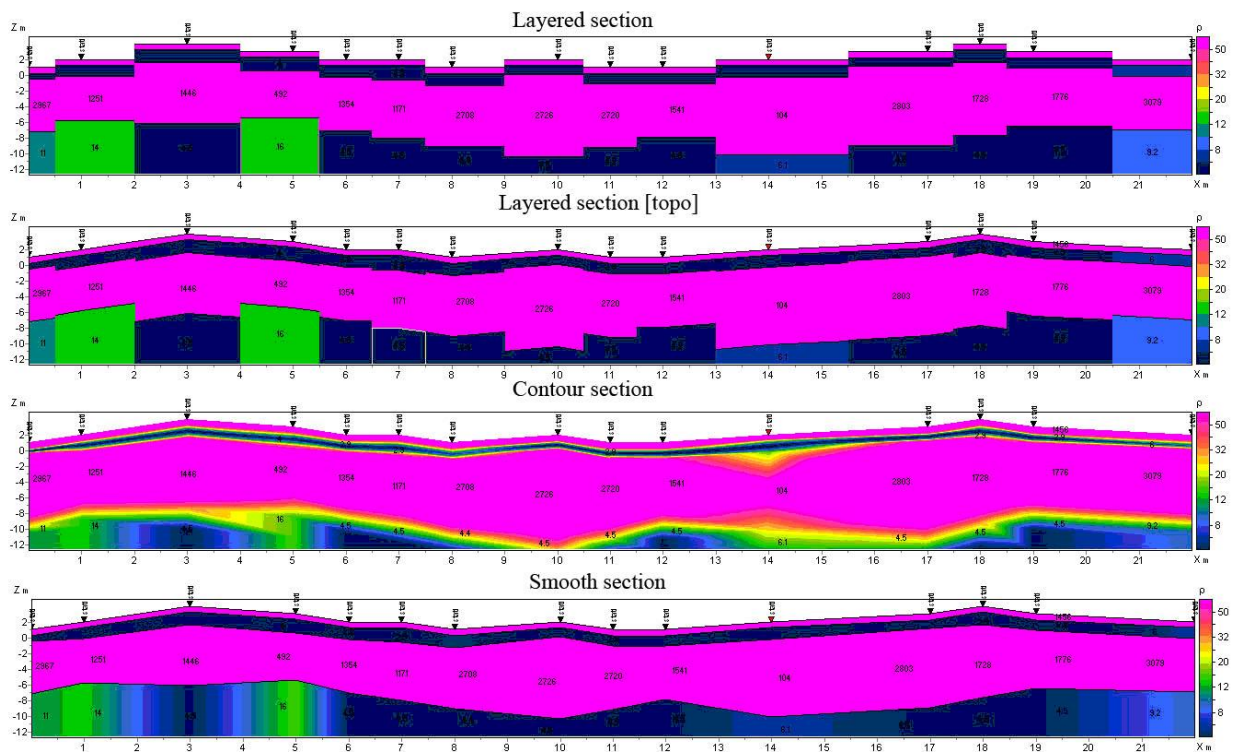
Fig. 45 Options of geoelectrical section visualization

Option **Setup** runs section parameter setup dialog (fig. 46).
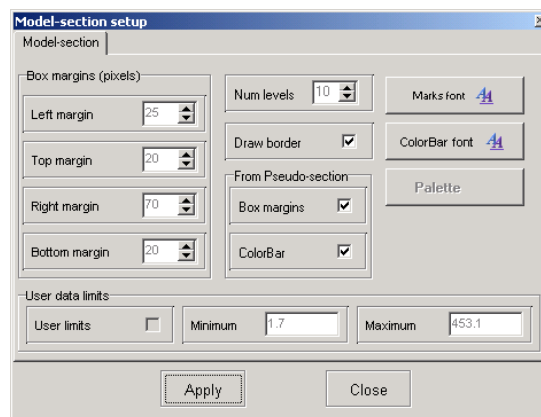
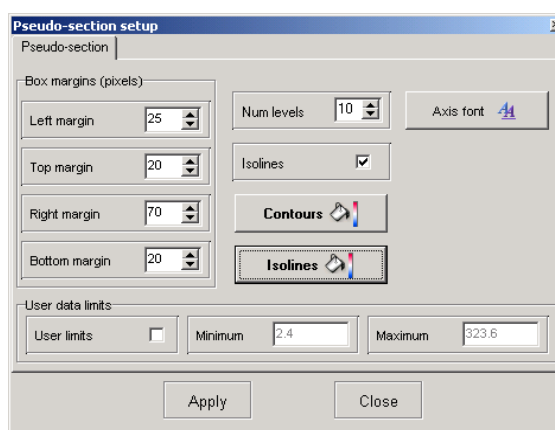Fig. 46. Geoelectrical section parameter setup dialog

Field Box margins

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

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

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

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

Field *Num levels* – sets number of colors. Levels are set using uniform linear or logarithmic step depending on data type.

Button **Palette** – runs section layers color setup dialog ([more](#)).

Button **ColorBar font** – runs color bar font setup dialog.

Button **Marks font** – runs layer marks font setup dialog.

Field User data limits

Option *User limits* – specifies whether to use minimum and maximum data values or specified in [*Minimum*] and [*Maximum*] fields values for color bar definition.

Field *Minimum* – sets minimum value for color bar definition.

Field *Maximum* – sets maximum value for color bar definition.

Field *From pseudosection*

Option *Box margins* – specifies to use *Box margins* field values which correspond to pseudosection.

Option *ColorBar* – specifies to use corresponding to pseudosection color bar.

Dialog **Output settings** allows specifying Vertical scale, Horizontal scale, Print resolution in dpi and Font size if Automatic box is not ticked (fig. 47).
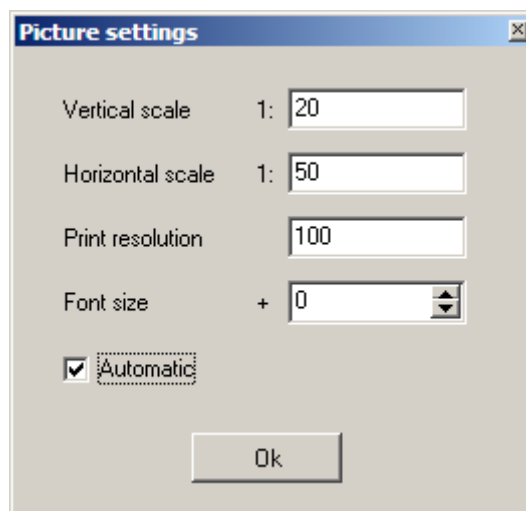
Fig. 47 Output picture settings window

Option **Add background** is used to insert background in model field. This function can be useful if apriori information (geological section along profile) or data obtained by other

methods are present or to compare inversion results at different stages. Background picture file must be in bmp format. When this option is selected, window appears to specify position of output file. Background is displayed above model and background layer is transparent (fig. 48, 49).
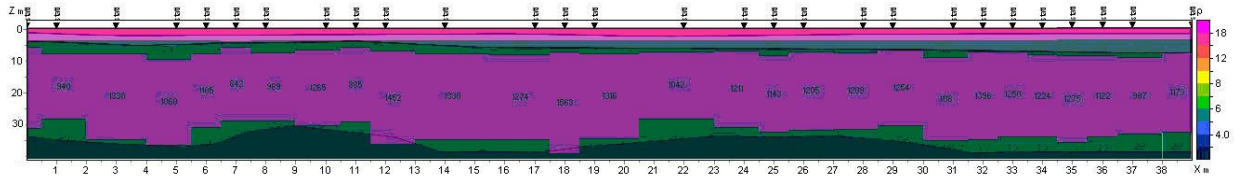
Fig. 48 Example of geological section background
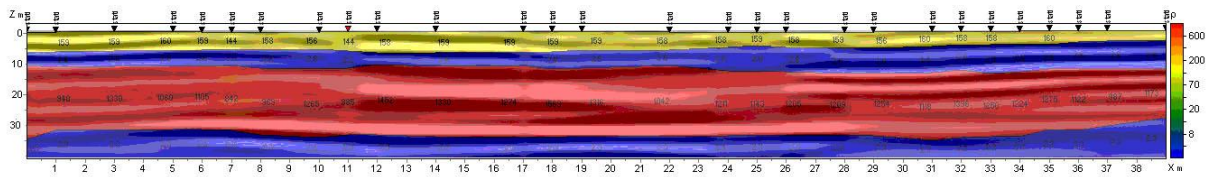
Fig. 49 Example of seismic section background

Pseudosection

Current object visualizes observed values along profile as isolines (fig. 50).
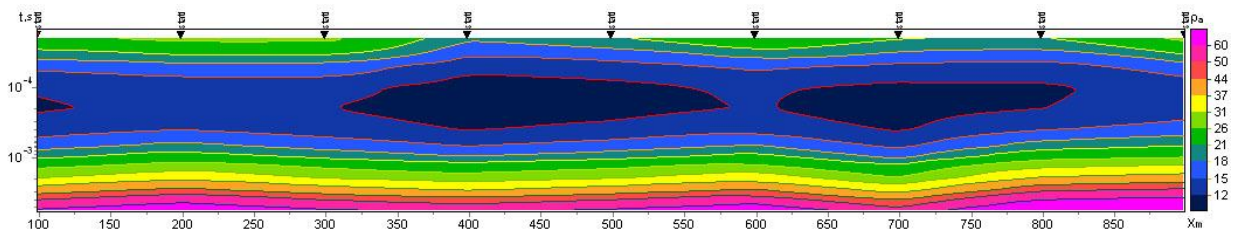
Fig. 50 Example of apparent resistivity pseudosection

Graph is created in the axes: profile coordinate, time. Color bar represents correlation between displayed parameter value and color.

Double click on object area runs context menu with the following options:

Setup	Run object parameters setup dialog.
Print preview	Print pseudosection.
Log data scale	Use logarithmic scale for color bar.
Smooth image	Smooth pseudosection.
Display labels	Display labels of measurement points.
Display ColorBar	Display color bar.

Save picture	Save pseudosection as graphics file.
Save XYZ file	Save pseudosection as Surfer file.
Apparent resistivity display	Display apparent resistivity pseudosection.
Voltage display	Display EMF pseudosection.
Set active chn	Select receiver for which data is displayed

Tab **Setup** is used to adjust pseudosection parameters (fig. 51).

Fig. 51. Pseudosection parameters setup window

Field **Box margins***:*

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

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

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

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

Field **Num levels** – sets number of isoline sections. Sections are set using uniform linear or logarithmic step depending on data type.

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

Button **Contours** – runs contour filling color setup dialog (more).

Button **Isolines** – runs isoline colors setup dialog.

Button **Axis font** – runs color bar font setup dialog.

Field **User data limits**

Option **User limits** – specifies whether to use minimum and maximum data values or specified in *Minimum* and *Maximum* fields values for color bar definition.

Field *Minimum* – sets minimum value for color bar definition.

Field *Maximum* – sets maximum value for color bar definition.

Profile plot

Current object visualizes profile graphs (theoretical and experimental) for different times (fig. 52) (available for **Editing** and **Vision** styles only).
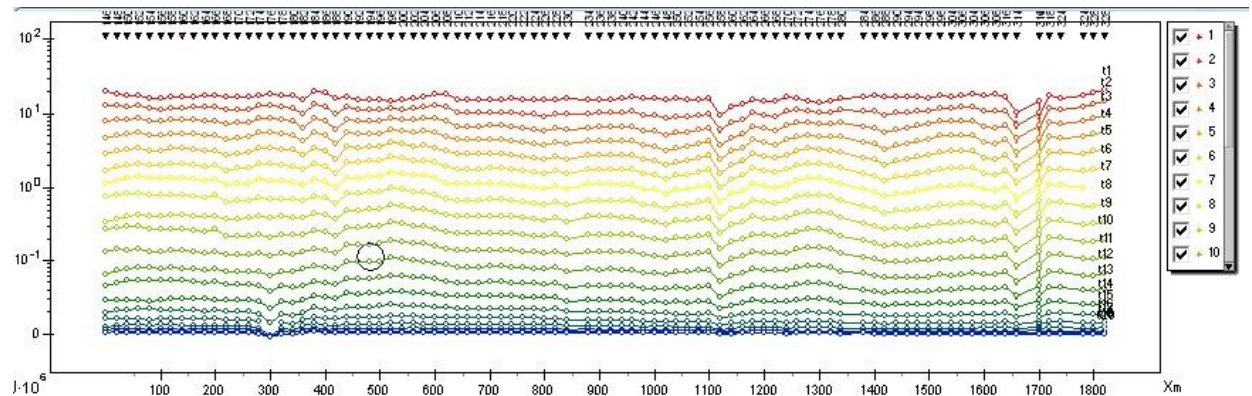
Fig. 52 Profile graph window

Curve color corresponds to certain period. Indexes on the right correspond to the number of the curve.

On default theoretical curves are displayed by solid curves, experimental curves – by solid curves with circles in measurement points. Color specified in current object setup dialog corresponds to each curve. Labels on experimental curves mean values of pseudodepth for which curves are created.

Graphical parameters of observed and calculated curves can be specified in setup dialog. Axis parameters can be set in axes editor (right click+SHIFT on the axis).

When you left click on curve, curves for other periods disappear until you release the button. Plots can be shifted vertically by mouse dragging with right button pressed. Left click on curves list with SHIFT button pressed to display one curve only. Use scroll wheel to proceed to the next plots. Use again left click on curves list with SHIFT button pressed to display all curves.

Right and left clicks with ALT button pressed are used to increase or decrease points weight.

To delete points use scroll wheel with ALT button pressed. Deletion domain is changed via scroll wheel.

Double click on object area runs context menu with the following options:

Setup	Run object parameters setup dialog.
Print preview	Print graphics plan.
Display calculated	Display theoretical curves.
Delete invisible	Delete invisible graphs.
Apparent resistivity display	Display apparent resistivity graphs.
Voltage display	Display EMF pseudosection.
Set active chn	Select receiver for which data is displayed

Option **Setup** is used for profile plot setup (fig. 53).
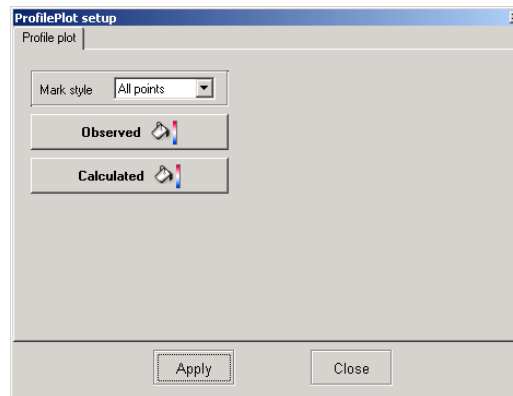
Fig. 53 Profile plot parameters setup dialog

Option **Marks style** – specifies how to draw graph labels.

Value *Left points* – to the left of the plot.

Value *All points* – from point to point.

Value *Right points* – to the right of the plot.

Buttons **Observed** and **Calculated** – runs graphics parameters setup dialog for observed and calculated curves.

Advanced program options
Work with areal data and 3D visualization

Select **Options/Set lines survey** in the main menu to set a number of profile lines. **Line settings** window (fig. 54) appears. It represents areal positions of sounding stations.
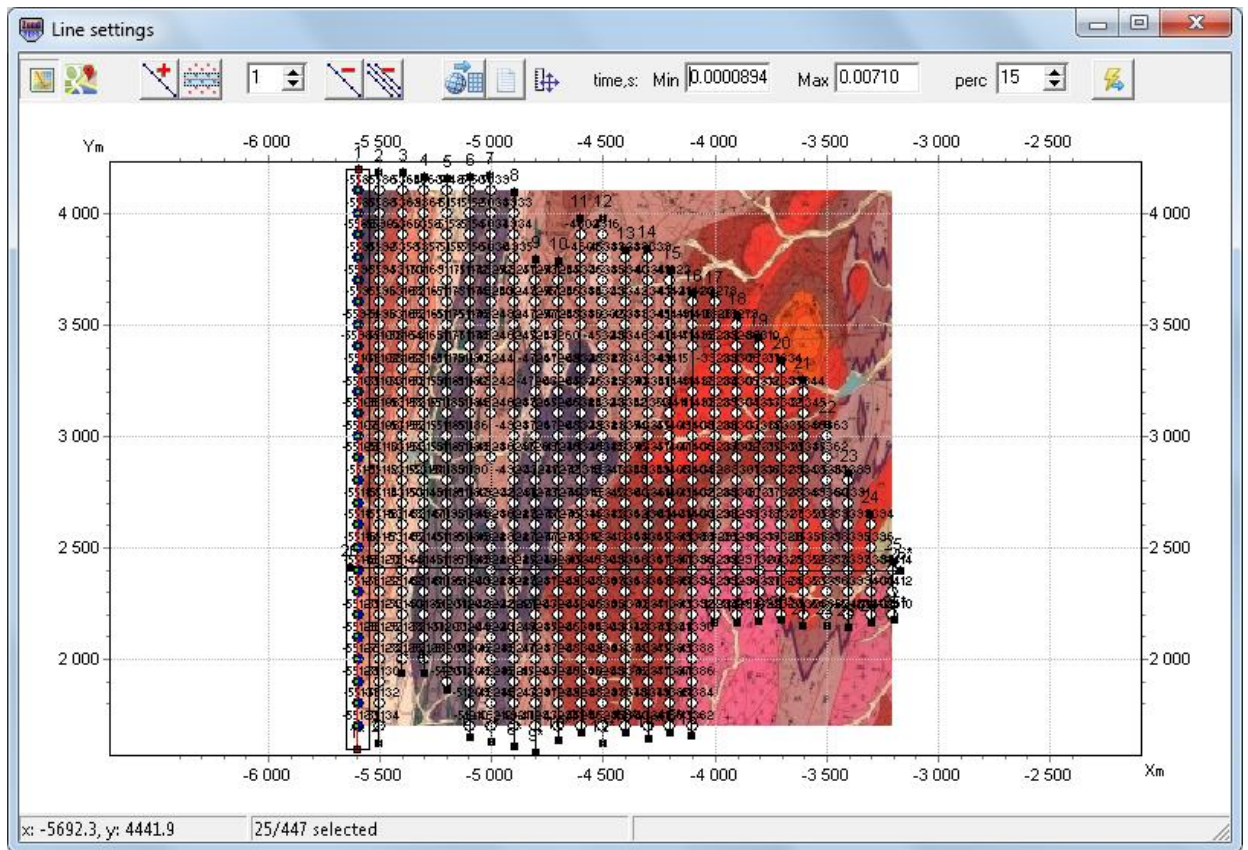
Fig. 54 **Line settings** dialog window for areal data

The main toolbar contains the following functions:

	Load raster file of map.
	Load Google map.
	Add profile line. Left click to set profile points, right click to specify the last point.
	Delete all profiles.
	Include sounding stations (located within rectangular area around selected line) in profile automatically.
	Delete current profile.
	Recalculate geographical coordinates to rectangular. When EDI files are loaded they are recalculated automatically. If beforehand file is known to contain geographical coordinates (latitude and longitude) then prior to interpretation they must be recalculated to rectangular coordinates using this button.
Time: Min-Max	Set minimum and maximum sounding time respectively. Out-of-range measurements are not loaded to the program.
	Select image scale: equiaxial or maximum window filling.
perc	Set size of sounding station automatic selection domain for profile.
	Start data inversion for selected profile set.

A few profile lines can be specified in the program simultaneously. When profile and all points around it are set, all included in profile points are displayed in blue. Left click to

include/exclude profile point. If profile line does not cross points then position of sounding station projection is displayed in green.

Right click on necessary point to view and edit sounding station coordinates. Coordinates which can be edited are displayed in opening window.

Press ⚡ button to start data interpretation when profile is set. Main window of the program appears then. Use [Line1 ▼] window in the main window toolbar to switch profiles.

Option **Visualization of areal data** (**Options/ Visualization of areal data)** is used to create areal distribution maps of selected parameter (resistivity, apparent resistivity, heights, etc.) depending on depth or time area. Figure 55 shows example of apparent resistivity areal distribution map.
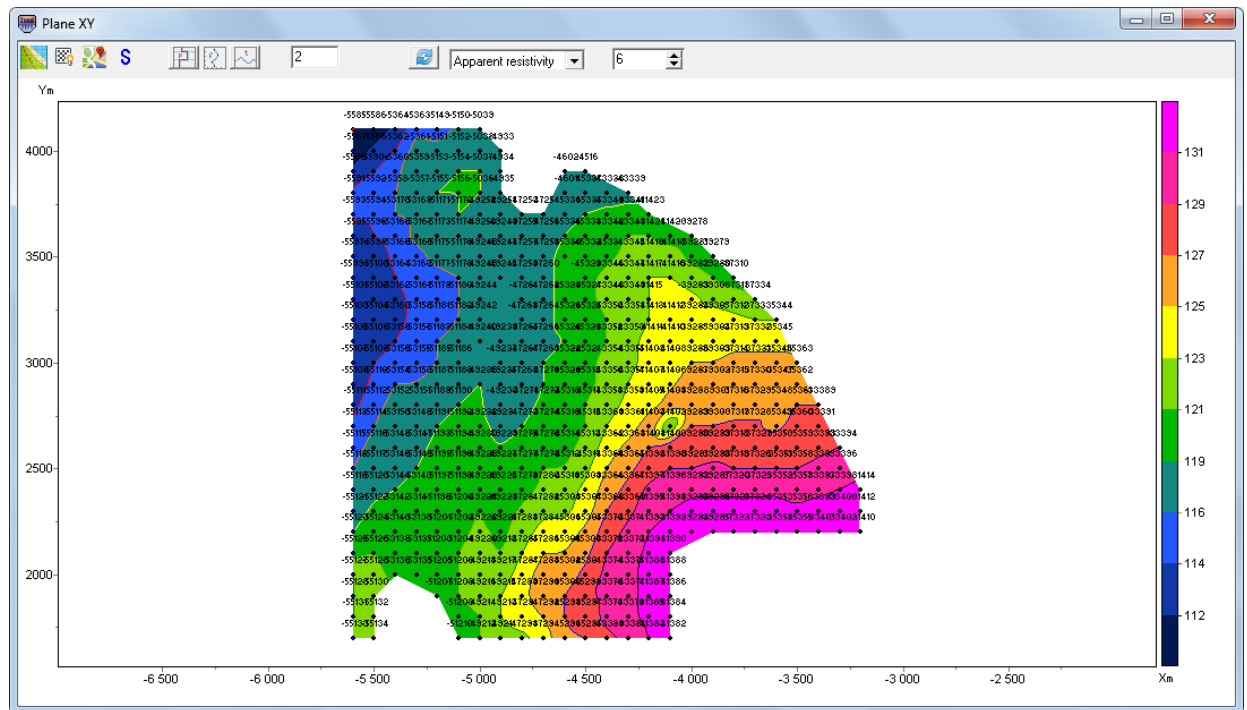
Fig. 55 Window **PlaneXY**. Apparent resistivity contour map

Window toolbar contains the following buttons:

	Load map raster file as background.
	Create a map of shady relief. It allows visualizing two parameters simultaneously.

	Load Google map.
	Create isolines for model parameters (resistivity, conductivity or thickness).
	Create isolines for measured parameters (apparent resistivity or EMF).
	Create isolines for elevation values.
	Redraw current plan.

When plotting model parameters there are two windows in the toolbar which are used to select one of parameters and specify depth to display it at. Depth counting method is specified in the right window: Depth from topo – depth values are counted off the ground, Absolute depth – absolute depth values are used, Layer index – isolines map is generated for specified layer.

When plotting isolines of measured parameters, layer number corresponds to initial data time grid.

Option **Visualization 3D section (Options/ Visualization 3D section)**

Current option is meant for 3D visualization of profile interpretation results. If this option is selected **3D sections viewer** window appears. Window toolbar contains the following buttons:

	Print preview.
	Rotate 3D model.
	Display horizontal map. Plan depth from the surface is set in kilometers in the window to the right 5.0.
	Press this button to set equal scale for all axes. Window to the right appears then. It allows specifying scale ratio for each axis.
	Vertical axis Z setup.
Resistivity ▼	Visualized parameter selection window

Window **3D section viewer** contains three tabs:

Tab *Lines* (fig. 56) is used to edit coordinates of profile beginning and end and to set profile for 3D visualization. There is a table to the left which contains profile names and coordinates of profile beginning and end. Tick box in the last column (V – visible) to display profile in 3D. Profile plan is displayed in the right window. Active profile is highlighted in red.

Axes properties can be edited by right click with Shift button pressed. See Axes editor for details of axes parameters setup.
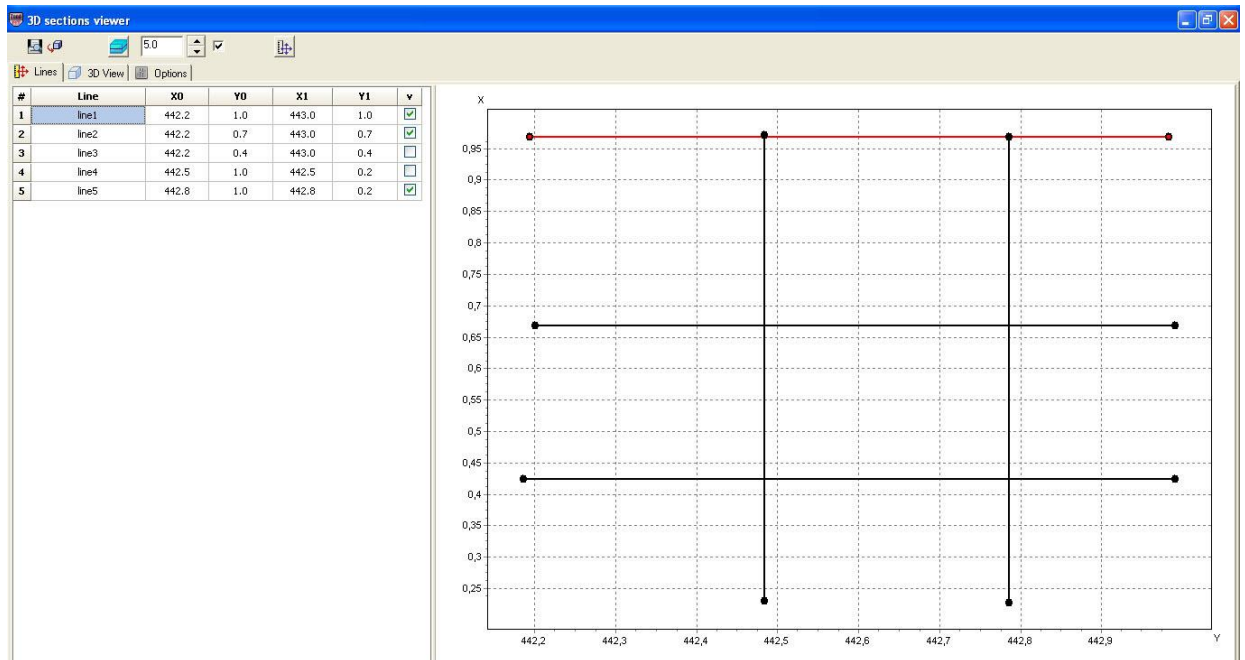

Fig. 56 Window **3D section viewer**, tab **Lines**

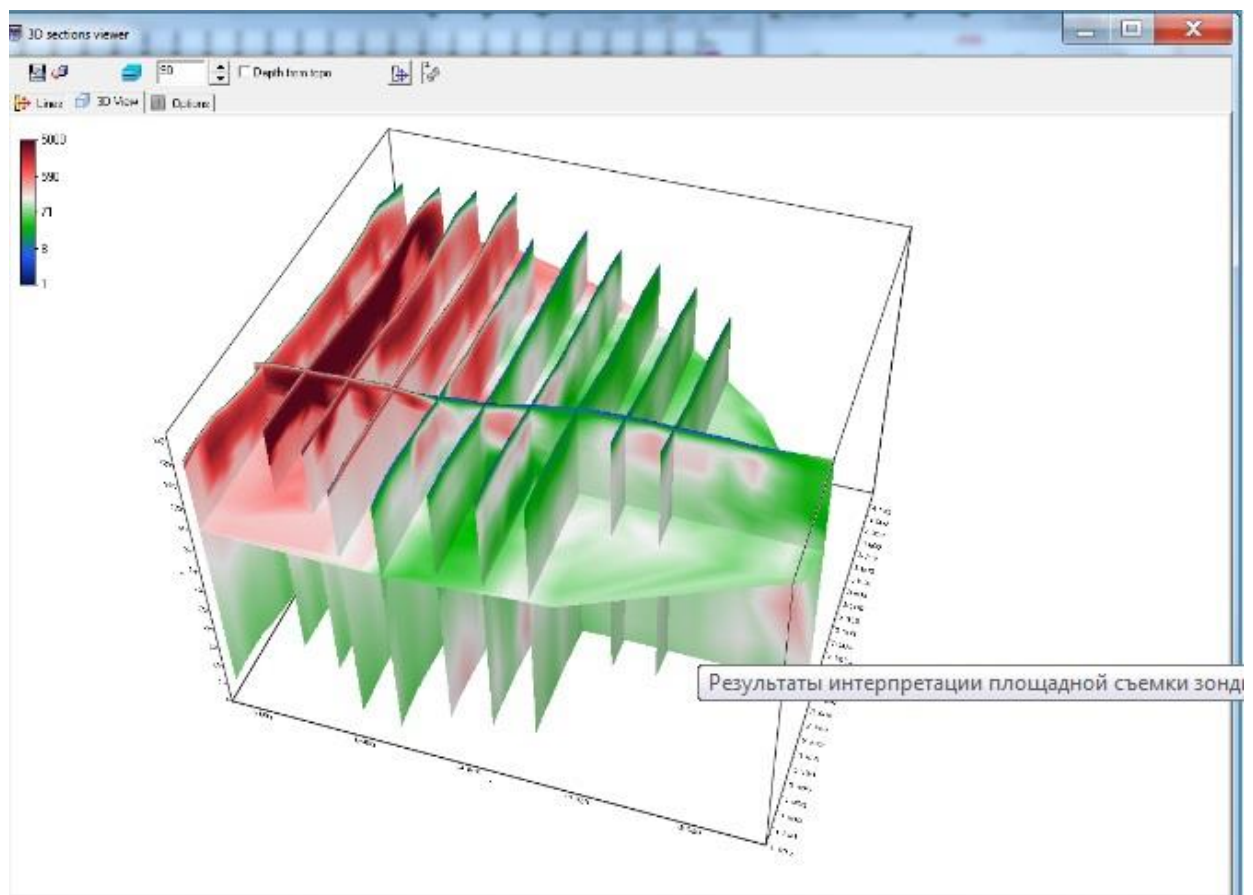Tab *3D view* (fig. 57) is used to view 3D model.

Fig. 57 Window **3D section viewer**, tab **3D view**

Tab **Options** (fig. 58) is meant for image parameters setup.

Field *Color scale* allows specifying filling parameters. **Palette** button runs filling setup dialog ([more](#)). Field *Color scale limits* is used to specify color bar minimum and maximum values manually or select automatic mode of range definition by ticking certain box.
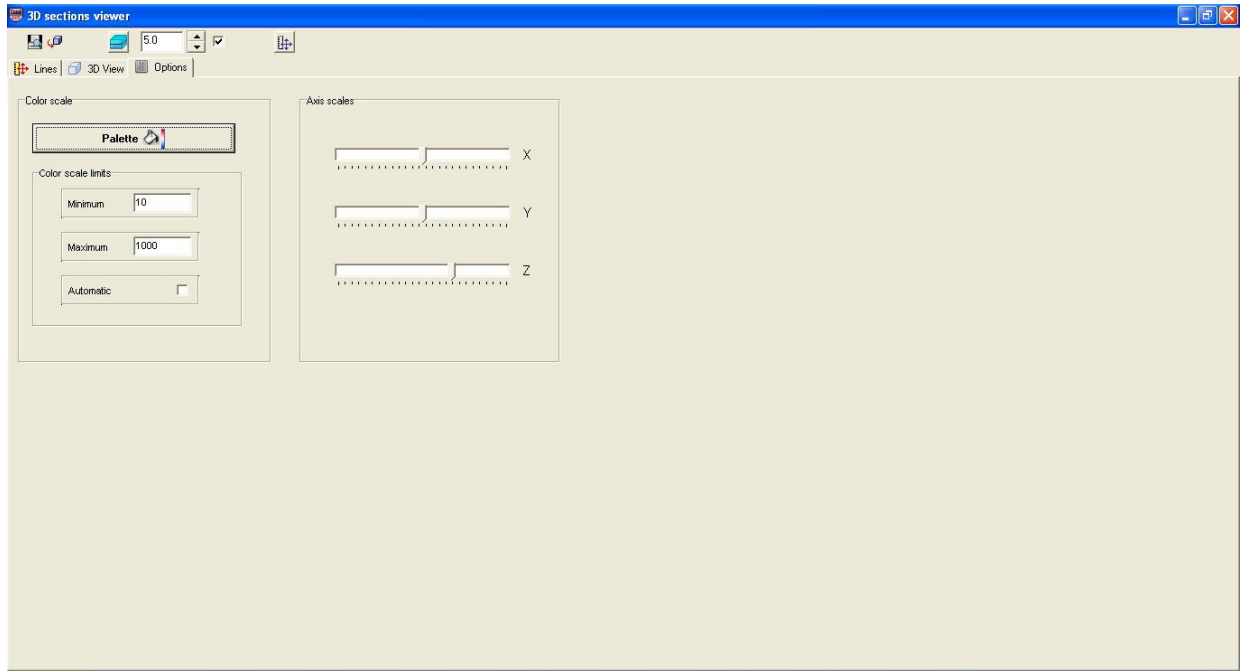
Fig. 58 Window **3D section viewer**, tab **Options**

Field *Axis scales is* meant for axes scale definition. Scales can only be set with pressed button ▦ in window toolbar.

Input of apriori information

Apriori data (borehole data) availability helps to increase reliability of received geoelectrical sections significantly. «ZONDTEM1D» program has integral module which is used to visualize apriori data graphically in sections.

Lithology file creation and insertion

Choose **Options/Create/Edit borehole data** option in the main menu to create lithology file. Dialog window of the module **Add borehole data** (fig. 59) appears.
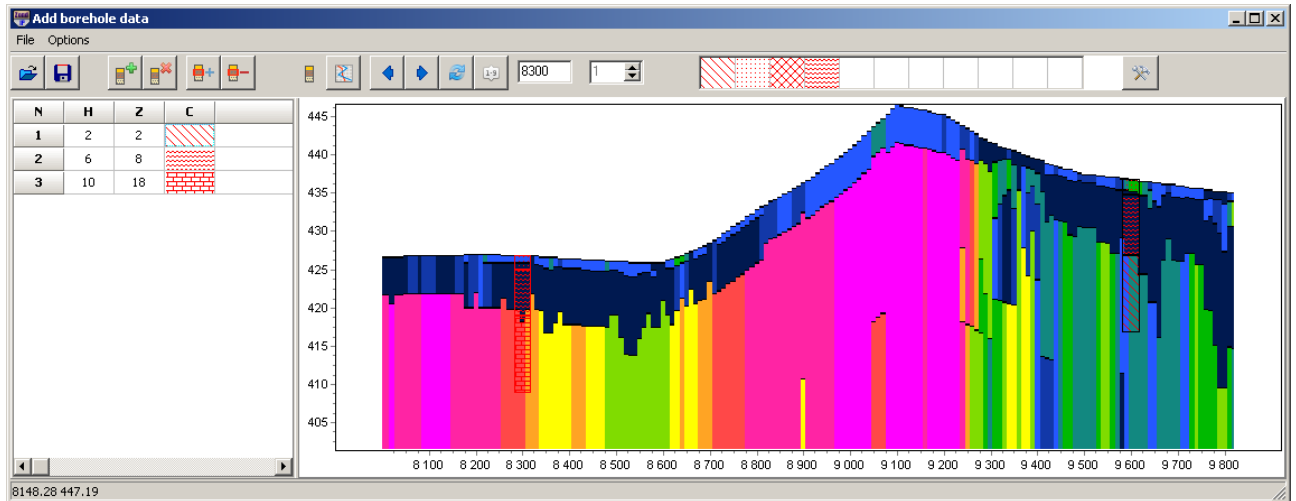
Fig. 59 Dialog window of lithology file creation **Add borehole data**

Dialog window toolbar contains the following buttons:

	Open lithology file.
	Save lithology file.
	Create new borehole.
	Delete borehole.
	Add new layer to borehole.
	Delete layer from borehole.
	Load logging data
	Return to previous borehole.
	Proceed to next borehole.
	Refresh drawing data window.
	Sort out boreholes by coordinate.
	Select fill color of borehole display window (red in example).
	Additional options.

The main toolbar also contains fields used to specify horizontal coordinate of borehole (offset from profile beginning) - **horizontal position** and elevation - **Position from surface**.

Vertical and horizontal coordinates are set in kilometers. Empty square windows are used to create set of filling patterns.

The module consists of two windows. **Data window** is located on the left. It contains table with the following columns: **N** – number of layer, **H** – layer thickness in meters, **Z** – layer bottom depth in meters, **C** – type of pattern. Borehole data is displayed graphically in the right window.

Press ⬛ button in the toolbar to start creating lithology file. New table appears in **Data window**. Use ⬛ button to set number of layers, then edit table by specifying thickness or layer bottom depth for each layer and select pattern type according to lithology. Double left click on **C** column to run pattern setup dialog **Pattern Color Editor** (fig. 60). The program offers a rich variety of lithology fillings. The **Color** option, allows selecting a filling color.

Fig. 60 Filling editor window

When borehole data is entered, press 🔁 button to display borehole in graphical window. Then it is necessary to specify horizontal and vertical borehole coordinate in kilometers in the toolbar and after that borehole is displayed according to its coordinates. Active borehole is displayed in red in graphics window.

Palette can be created to make work with large number of boreholes more convenient. In order to create palette select pattern in pattern column of **Data window**, then right click on pattern domain in the main toolbar. Set of patterns can be created in this way. To save it press

![button icon] button and select **Save default palette.** Saved set of patterns can be used while creating new lithology and logging data file (![icon] - **Load default palette**).

Function **Set percent,** run via button ![icon], serves to change scale of borehole data graphical representation.

When data file is saved a few files are created: ***.crt** – module project that can be loaded in «ZONDMT1D» program and ***.txt** – file for each borehole, file names correspond to horizontal and vertical coordinate. See [Appendix 1](#). for details of lithology data file format. .

Use **Options/Load borehole data** function to add borehole data. Borehole data is displayed in geoelectrical section and in model editor window (fig. 61).
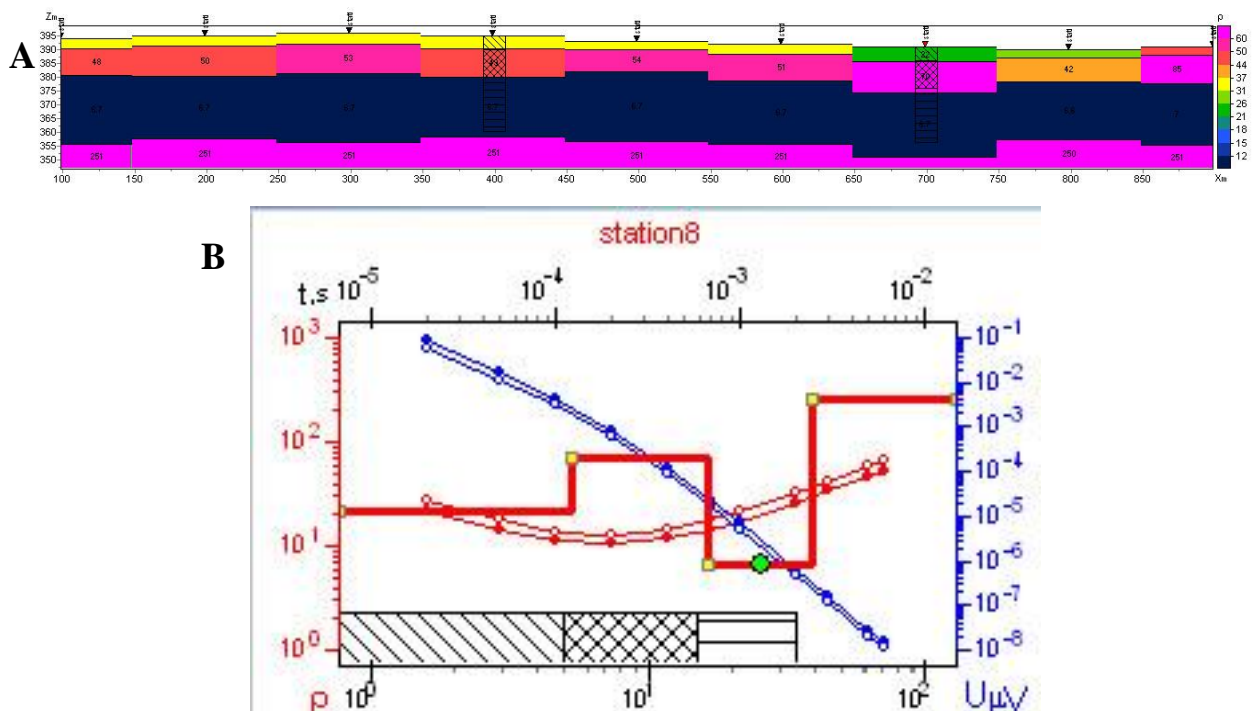
Fig. 61 Display of lithology data in geoelectrical section (A) and in model editor (B)

Insert apriori boundaries dialog

Use **Options** menu to run boundaries setup dialog **Insert apriori boundaries**. It allows taking into account apriori geological information. Menu with the following buttons appear when this tab is selected:

![icon]	Enable/Disable editing boundaries mode	Enable/Disable editing boundaries mode.
![icon]	Add new boundary	Add new boundary.
![icon]	Delete boundary	Delete all boundaries.

💾	Save boundaries to file	Save boundaries to file.
📂	Load boundaries from file	Load boundaries from file.

Apriori data entry to inverse problem is extremely important to increase interpretation quality. On one hand it increases problem stability and on the other – decreases equivalence field and allows receiving more consistent structure. This is almost the only way to receive acceptable result in models with low-sensitive parameters.

Prior to boundaries specification it is recommended to perform **Smooth** inversion (selecting type of inversion (**Style**) in **Inversion** tab of program setup window) with enabled depth fitting (tick **Thick/depth**). Program setup window. for details of inversion parameters.

Boundaries must be plotted in the geoelectrical section according to borehole data or on the assumption of a priori conception of geological structure. Use left mouse button with enabled boundaries editing mode to set boundaries. Right click to close boundary. It is not recommended to use many nodes in boundaries. It is preferable to have as smooth boundaries as possible.

When boundaries are set run inversion again. It will take specified boundaries into account (fig. 62B).
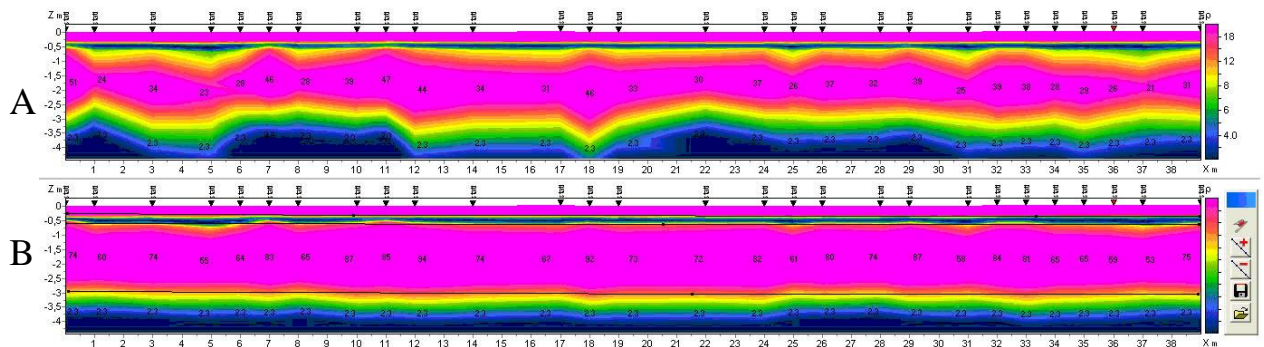

Fig. 62 Example of geoelectrical section after inversion without (A) and with (B) regard to geological boundaries

Raw data filtering

ZondTEM1D allows smoothing raw data. In the menu Options two functions are available: Denoise data and 2D smoothing. Use these functions with care, because too strong data smoothing and filtering may lead to the substantial useful information losses.

Function *Denoise data* smooths automatically source curves for the currently selected receiver, removing individual spikes on sounding curves. Fig. 63 shows an example of apparent resistivity data before and after denoising.
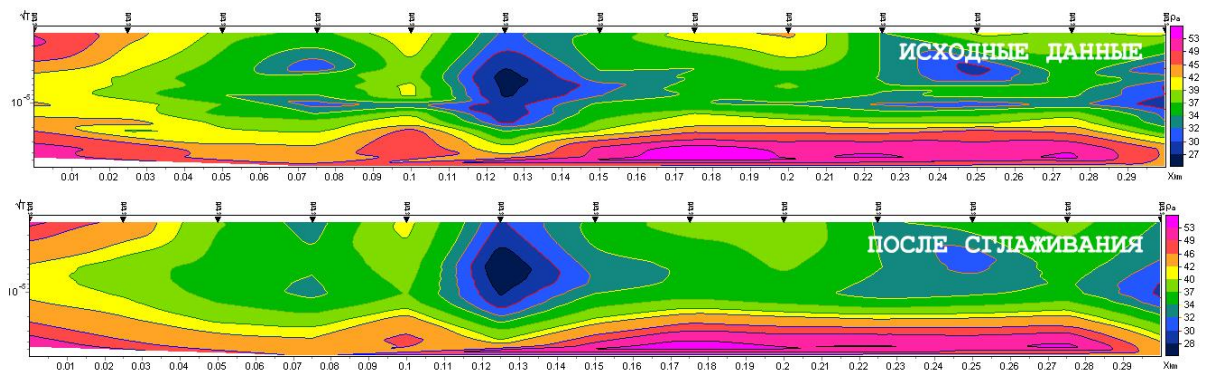
Fig. 63 Example of using *Denoise data* function for apparent resistivity data. Top - the initial data below - data after smoothing.

2D smoothing function performs two-dimensional data smoothing. This function, unlike the previous one, allows data smoothing in the horizontal and/or vertical direction rather than removing of certain spikes. After selecting this option, a dialog Options (Fig. 64) appears with the following settings:
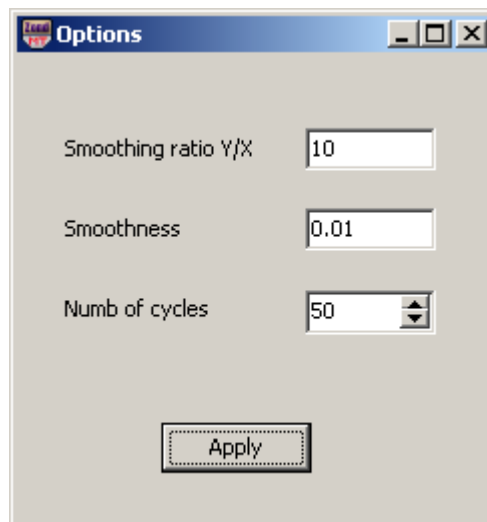
Fig. 64 Setting smoothing 2D smoothing

Smoothing ratio Y/X - smoothness ratio on the axis X and Y. When the value of this parameter is greater than zero, the main smoothing is conducted by the vertical axis, it means on the time axis. For large values of this parameter, the result of applying function is similar to the

results after using Denoise data. For parameter values less than zero, the main smoothing is conducted on the horizontal axis. (fig. 65)

Smoothness – data smoothness degree. The larger the parameter value, the more smoothing is applied to the data.

Numb of cycles - number of calculation cycles.
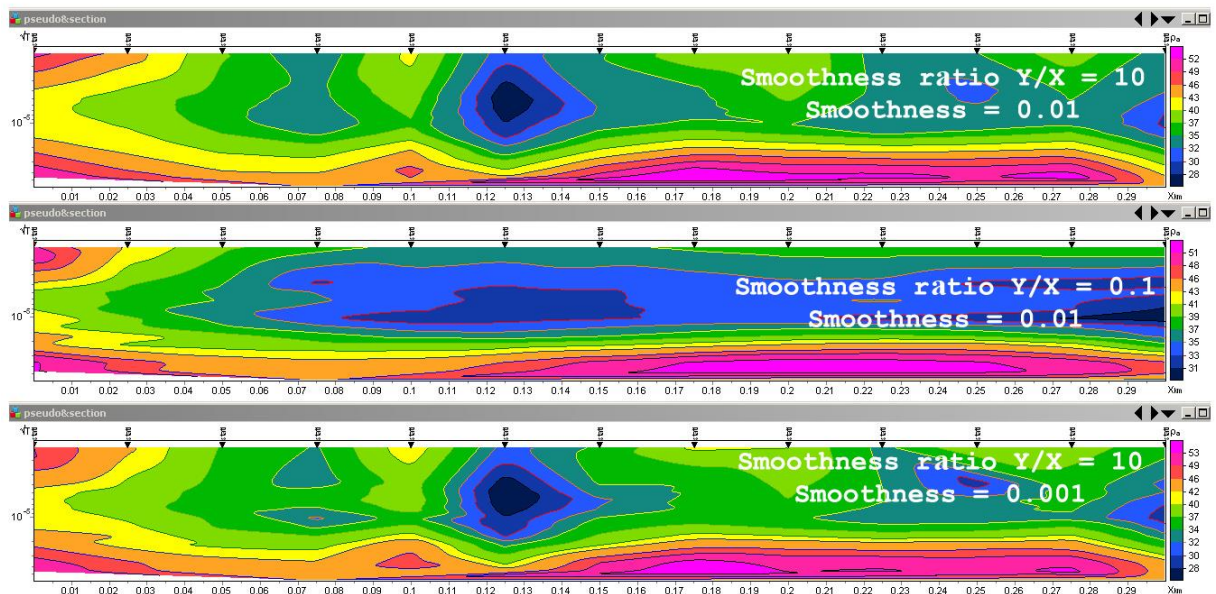
Fig. 65 Example of applying 2D smoothing function with different settings.

Model smoothing

The program ZondTEM1D allows smoothing calculated geoelectrical sections (Fig. 66). To do it, select Smooth model in the menu Option. Smoothing is done automatically. During smoothing, layer boundaries and resistivity values (or other parameters used) change.
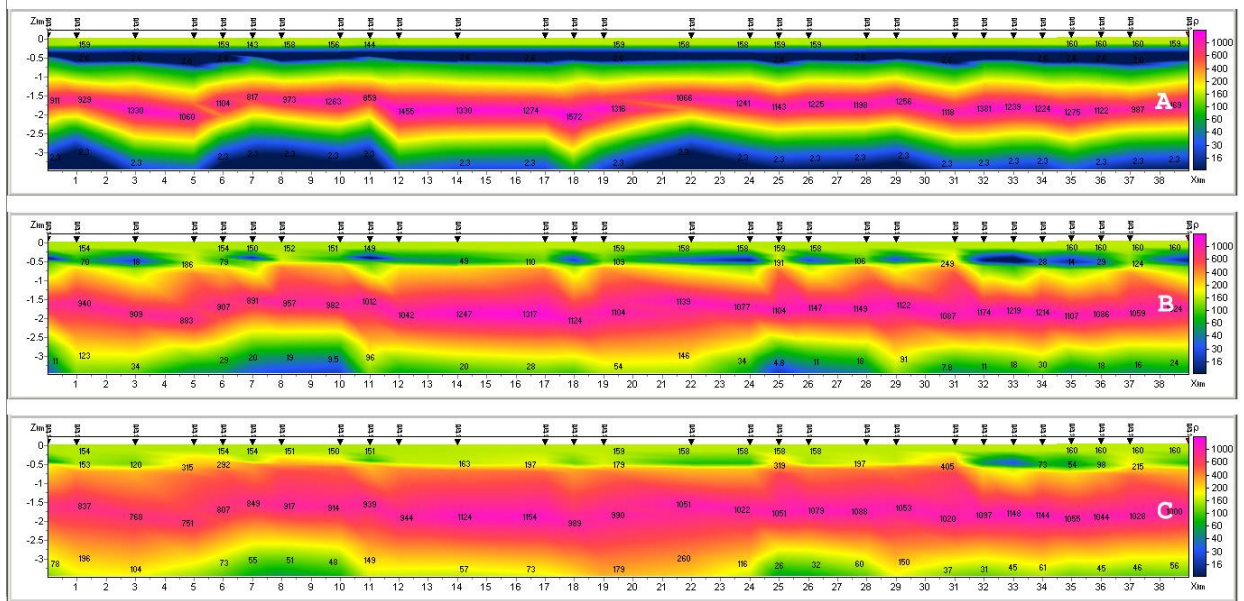
Fig. 66 Example of applying the function Smooth model. A - initial model, B - after applying the option Smooth model, C - after applying the option Smooth model twice.

Buffer menu for comparison inversion results

Menu **Buffer** of the main window allows comparing inversion results using different parameters. After calculating the first model, go to the menu and select **Buffer Model 1**. In the appeared dialog, it is possible to specify model name, reflecting, for example, used parameters in the inversion. In this way, 1 to 5 models may be saved.

A tick will appear in front of a saved model. When clicking on the saved model, appeared dialog allows loading selected model as the current (button **From Buffer**), or saving the current model as selected (Button **To Buffer**).

The option Open from the Buffer menu opens all saved models for the current measurement point in one window. (Fig. 67)
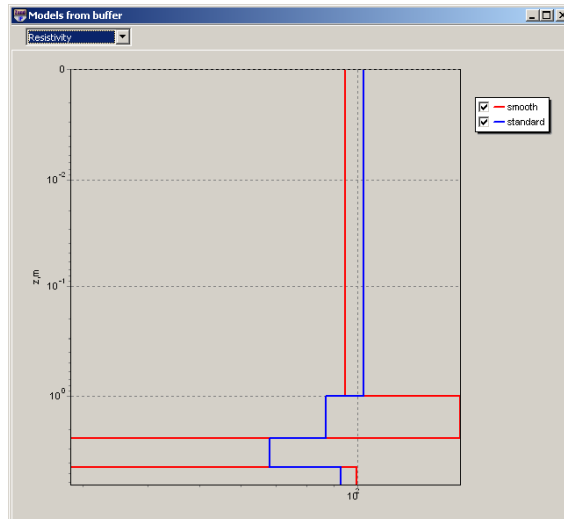
Fig. 67 Two models opened in one window for one measurement point.

Module of join TEM and VES data interpretation

This module is intended for joint interpretation TEM and VES soundings data.

The module is available in the main menu Options/VES Data. The following options are available in menu:

Load VES data	Load VES data in format TXT (file format is described below).
Remove VES data	Delete VES sounding data.
Joint inversion	Joint inversion of VES and TEM data
Display VES plot	Display VES graph window.

Text file of data VES should contain the following values are recorded in the lines:

ab/2 - half length of the source line, in meters

mn - receiver line length, in meters

app.res – apparent resistivity

In the window VES Plot graphs of apparent resistivity display (Fig. 68). The red color shows the measured curve, blue - selected as a result of the joint inversion. It is possible to edit axes properties. To run editor, right-click button with pressed Shift button. For details on setting axis parameters, see Axes editor.
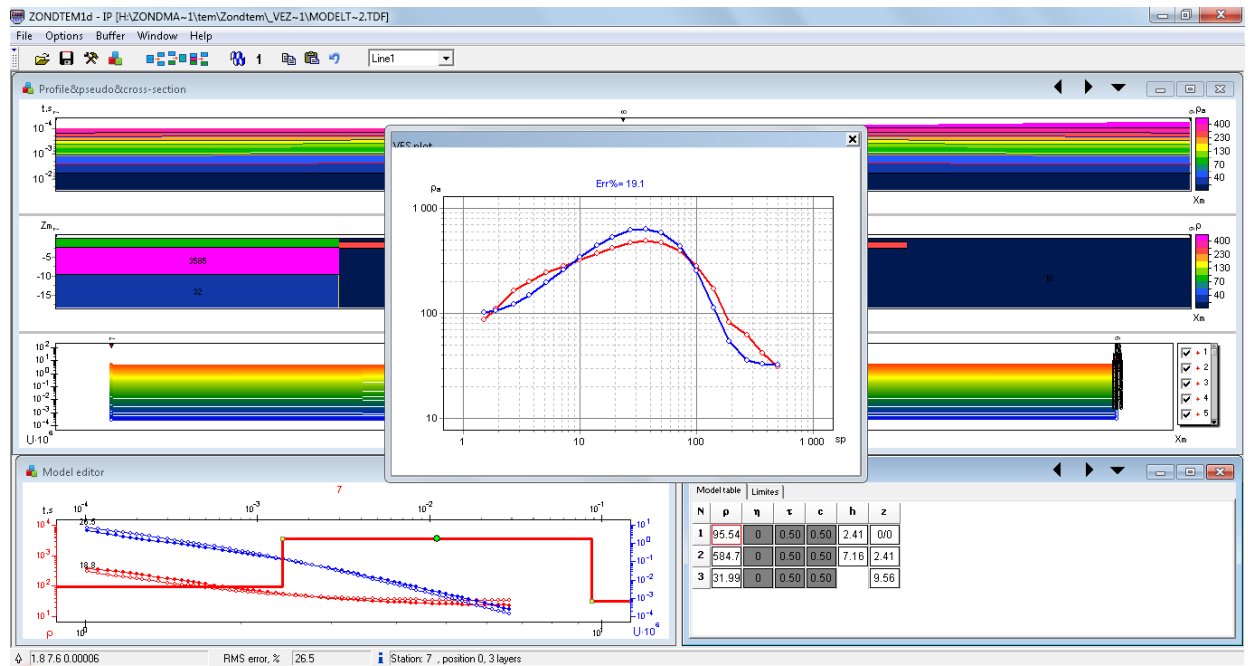
Fig. 68 Displaying of curve graphs VES. The joint inversion results of TEM and VES data.

Module of joint interpretation of TEM and MT (AMT, RMT) sounding data.

This module is intended for joint interpretation of TEM data, and such sensing frequency modifications as MT, AMT, RMT, CSAMT, CSAMT. All modifications difference by emitted frequency range and penetration depth. In what follows, we will use MT to abbreviate all these methods.

The module is available in the **Options/MT Data** menu. The following options are available in the menu:

Load MT data	Load MT data in TXT file (file format is described follow).
Load MDF data	Load MDF format data file, created by ZondMT1D program or ZondMT2D
Remove MT data	Remove MT sensing data
Joint inversion	Joint inversion of MT and TEM sensing data
Display MT plot	Display MT curves graphs window.

Text file of MT data must contain the following values (are recorded in lines):

per - periods set

app.res - apparent resistivity corresponding values

pha - impedance phase corresponding values.

The MT curves graphs window MT Plot shows graphs of apparent resistivity and impedance phase (Fig. 69). Curves with circles show the measured parameters, solid lines - selected as a result of the joint inversion. It is possible to edit axes properties. To run the editor, right-click with pressed Shift button For details of setting axis parameters, see Axes editor.
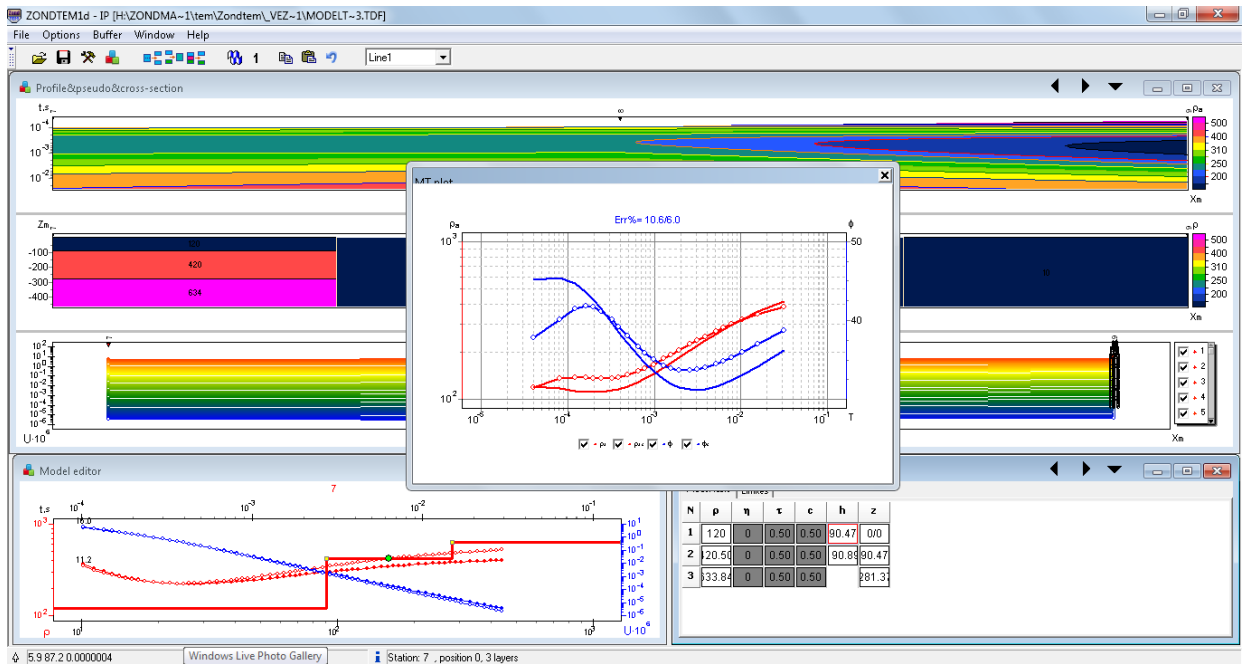

Fig. 69 Displaying of MT curves graphs. The joint inversion results of TEM and AMT data.

Program graphic objects setup

Color palette setup dialog

The dialog is meant for object palette setup and can be run using **Palette** button (fig. 70). The dialog allows choosing one of default palettes (forward and inverse rainbow, grey scale, etc.) or creating own one. Right click with Ctrl button pressed to add slider to the scale. Use Delete button to remove slider. Use ⊟ button to save scale or load already existent scale using ⊡ button.
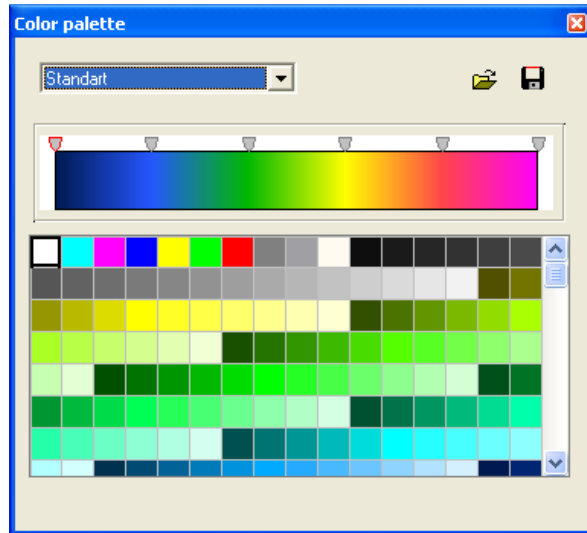
Fig. 70 Color palette parameters setup dialog

Axes editor
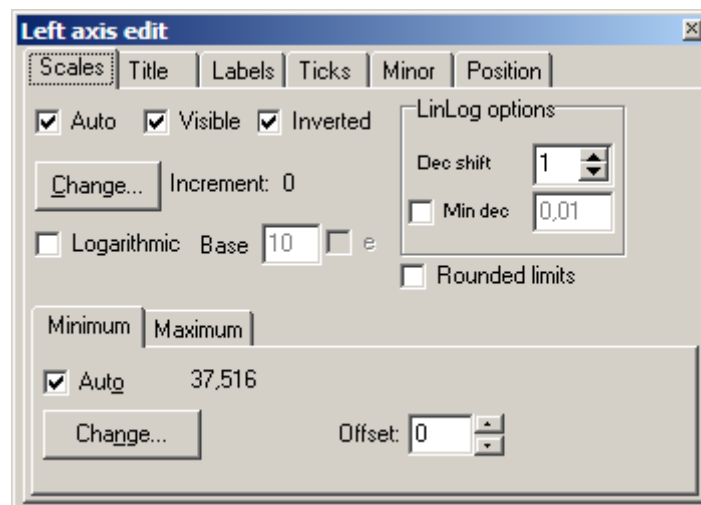
Fig. 71 Axes editor window

Axes editor is used to set graphic and scale axes parameters. Right click on necessary axis with SHIFT button pressed to run it. Pop-up menu with two fields (**options** and **default**) appears. The first one runs dialog, the second sets values on default.

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

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

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

Option **Inverted** defines axis orientation.

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

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

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

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

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

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

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

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

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

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

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

Tab **Style**:

Option **Title** sets axis header text.

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

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

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

Tab **Text**:

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

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

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

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

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

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

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

Tab **Style**:

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

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

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

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

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

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

Option **Angle** sets label rotation angle.

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

Tab **Text**:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Button **Ticks** runs external intermediate axis tick line setup dialog. Option **Length** 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).
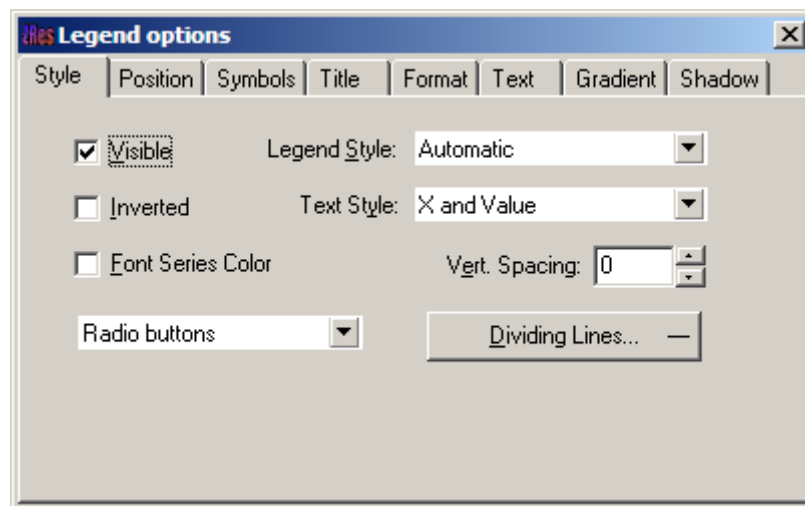
Legend editor

Fig. 72 Legend editor window

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.
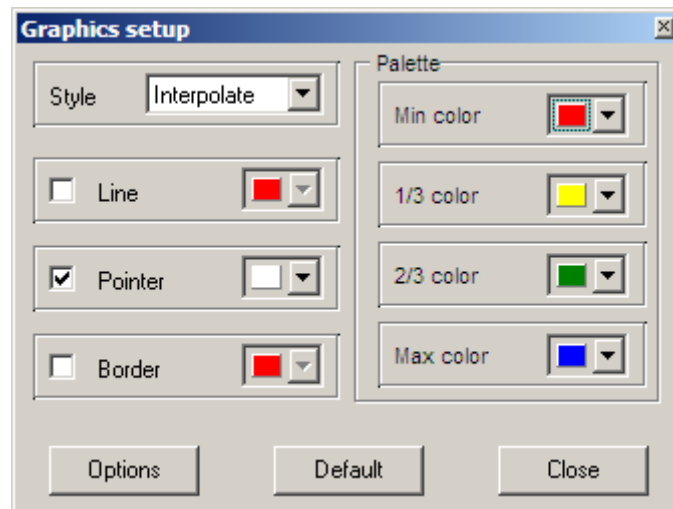
Graphics set editor

Fig. 73 Graphics set editor window

Graphics set editor serves for color adjustment of graphics set.

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

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

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

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

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

Button **Options** runs graphics setup dialog.
Button **Default** sets graphic settings equal to default settings.
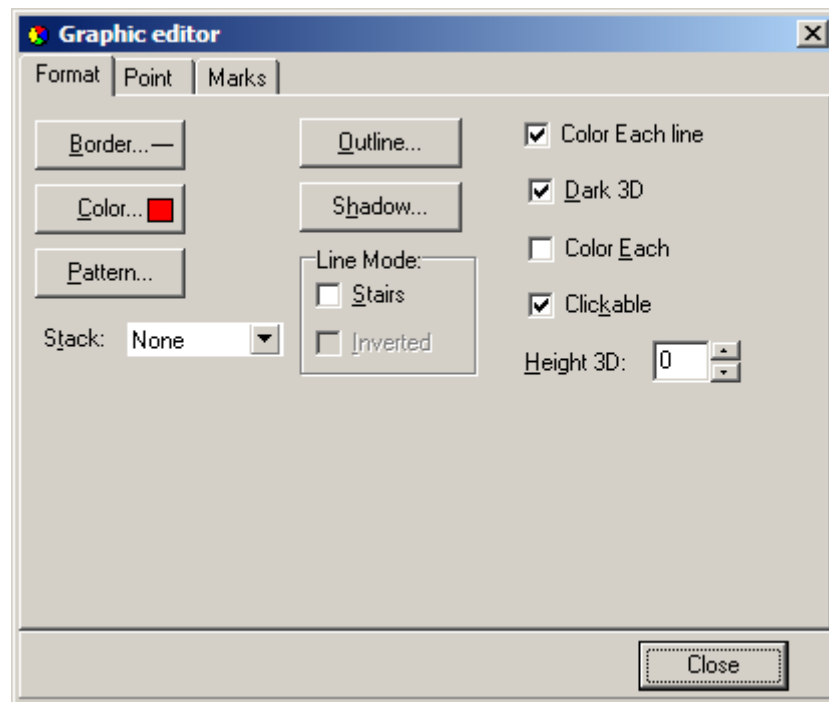
Graphics editor

Fig. 74 Graphics editor window

Graphics editor is used for graphic interface setup. 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 **Color** runs color setup dialog.

Button **Pattern** runs graph 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 color fill setup dialog.

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

Button **Gradient** runs point's gradient color 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 **Color** runs frame background color 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.

Print preview dialog

Use **File/Print preview** function of the program main menu to run print preview dialog. Double click on any program object also runs it. Two options are available when running via main menu:

Option **Station** serves to print sense curves and current station model (fig. 75). Model parameters are displayed as table which contains number, resistivity value and depth of top layer boundary.
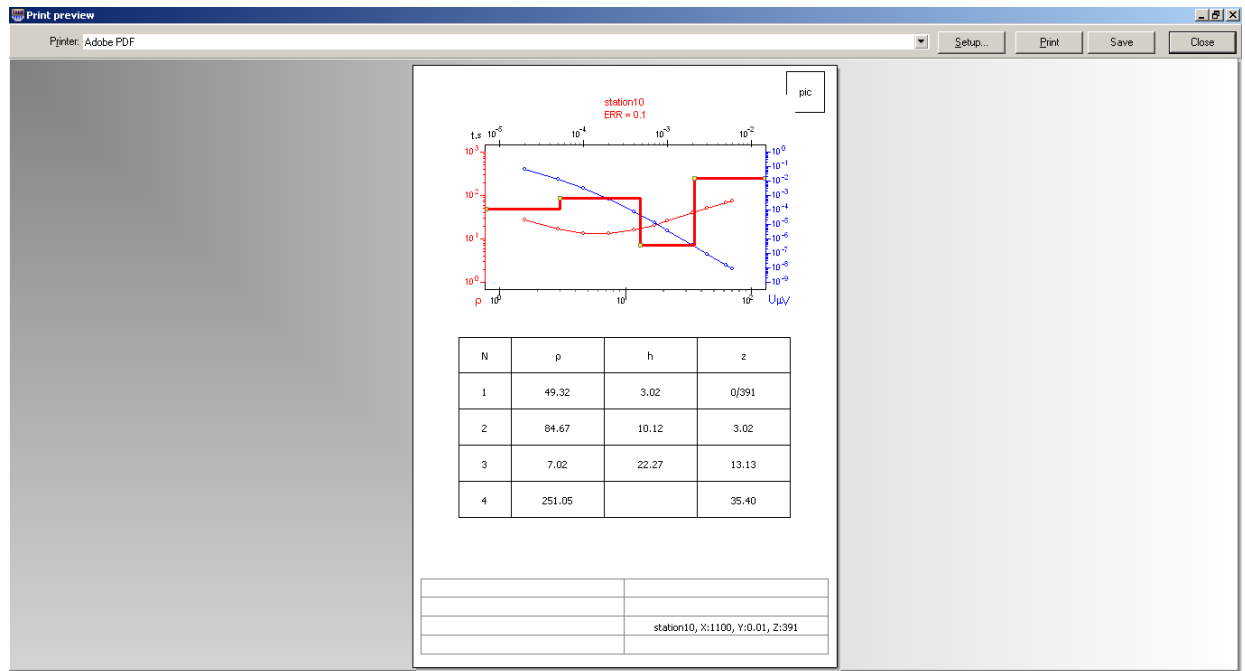

Fig. 75 Window **Print preview/Station**

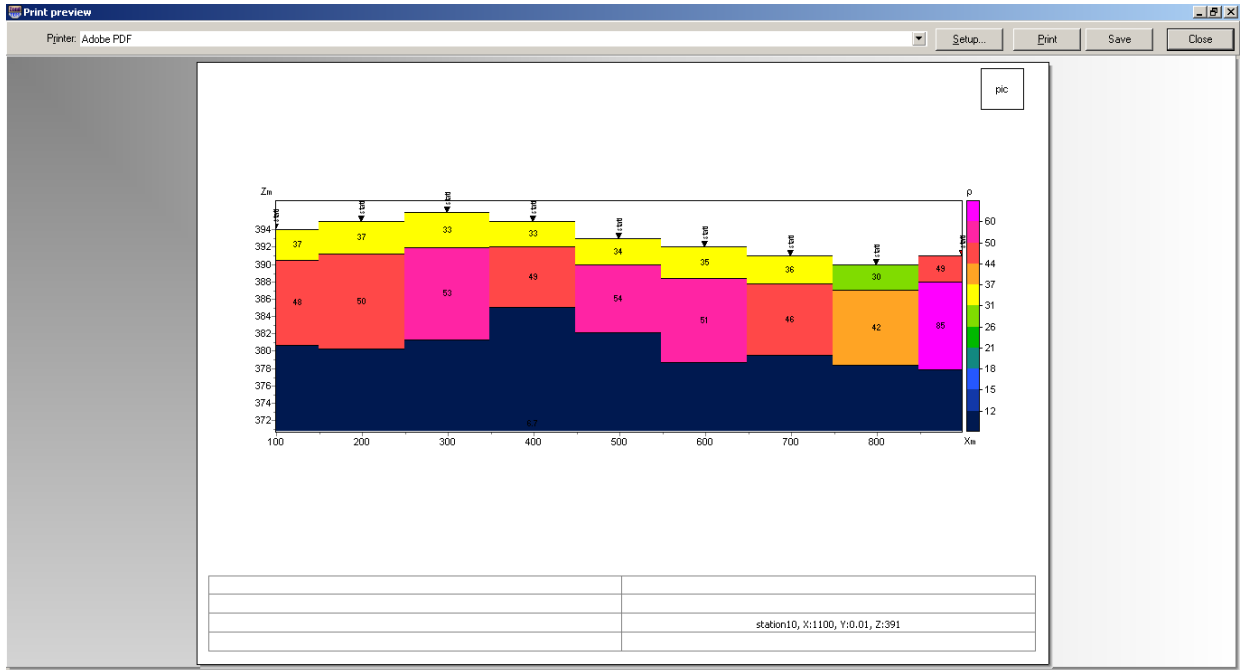Option **Section** serves to print geoelectrical section (fig. 76).

Fig. 76 Window **Print preview/Section**

Use left button to move print object in the page.

Print Preview window of the main menu contain the following buttons.

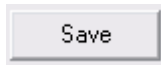 - select printer. One of adapted printers can be chosen in opening menu.

 - print setup button. Size and page orientation, print properties, number of pages per sheet and other parameters can be set in opening window.

 - press this button to start printing when necessary parameters are specified.

 - save in bitmap files.

 - close Print preview window.

Squares in the top part of the page are intended for company seals, stamps and symbols. Right click on the square and choose raster image which you would like to insert in to opening window. Use mouse to change square size.

Editing table is located at the bottom of the page. In order to add text, right-click on the table and type in necessary text in opening window. Comments can be also saved in table files using ![save icon] button or already saved comments can be loaded using ![open icon] button.

Appendix 1. Lithology data file format

Lithologic columns are hold in certain file formats. First type of files has txt extension.

The following file structure is used to create lithology data file:

First column contains depth (from ground surface) of layer boundary. Second column contains zeros. Third column defines layer color for visualization, forth – type of pattern

Lift of first 23 patterns which can be used for lithologic column creation is given below.
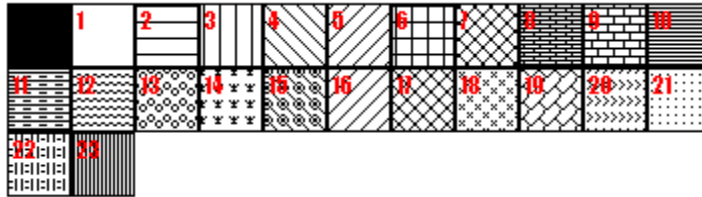
Lithologic data sample-file is given below:

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 data visualization for any number of wells is described below.

2280.txt	First line – file name with logging or lithology data
brhl2280	Second line – Borehole name (is displayed on borehole)
18 2 2 1 0 1 0 0	Third line contains control parameters -

Data record 18 – borehole 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 color column), section color scale is used for visualization;

2 - lithologic column;

3 - logging data (color column), colors for data visualization correspond to model color scale, column colors are selected in compliance with model color 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 borehole 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 color.

0 – Data scale is logarithmic 0 or linear 1.

0 – Vertical borehole shift relative to ground surface.

3246.txt   Description of the next borehole on profile

brhl3246

102 2 2 1 0 1 0 0