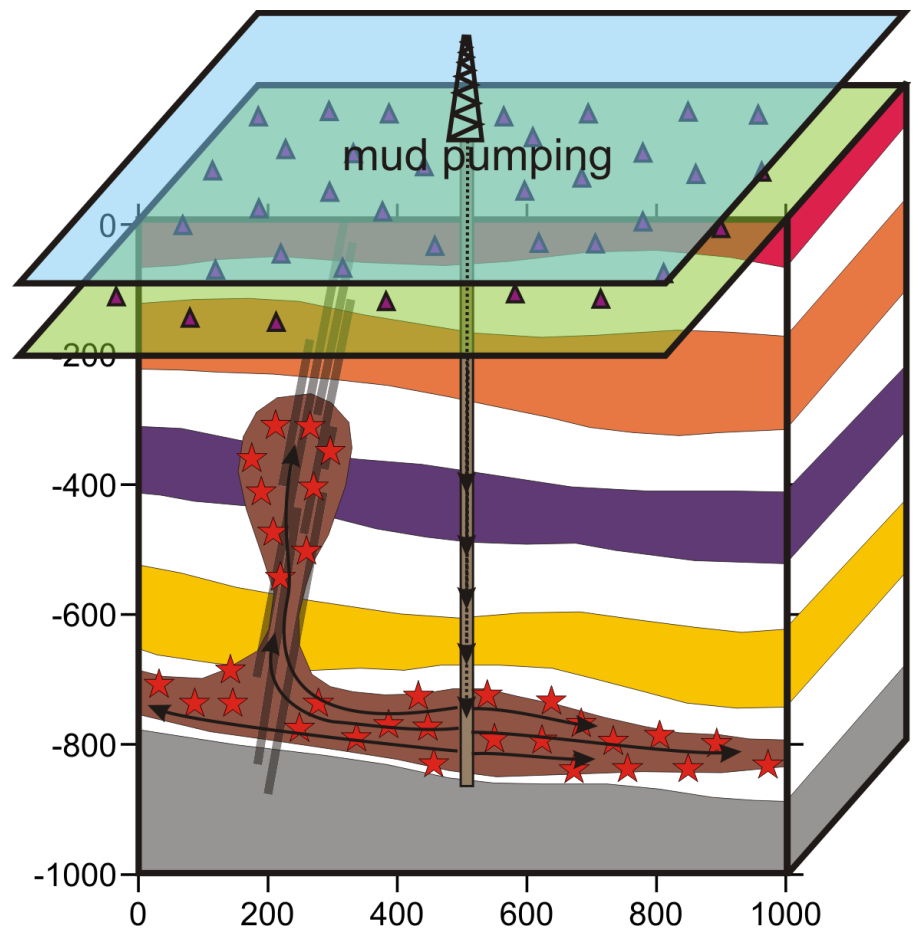
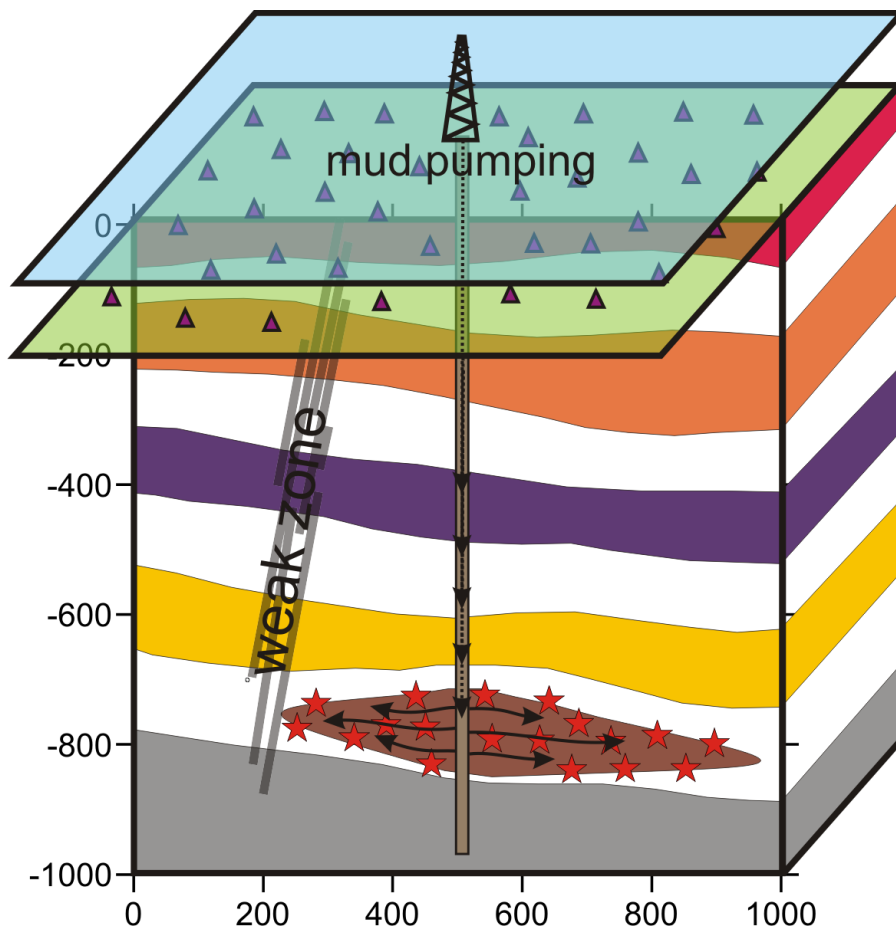


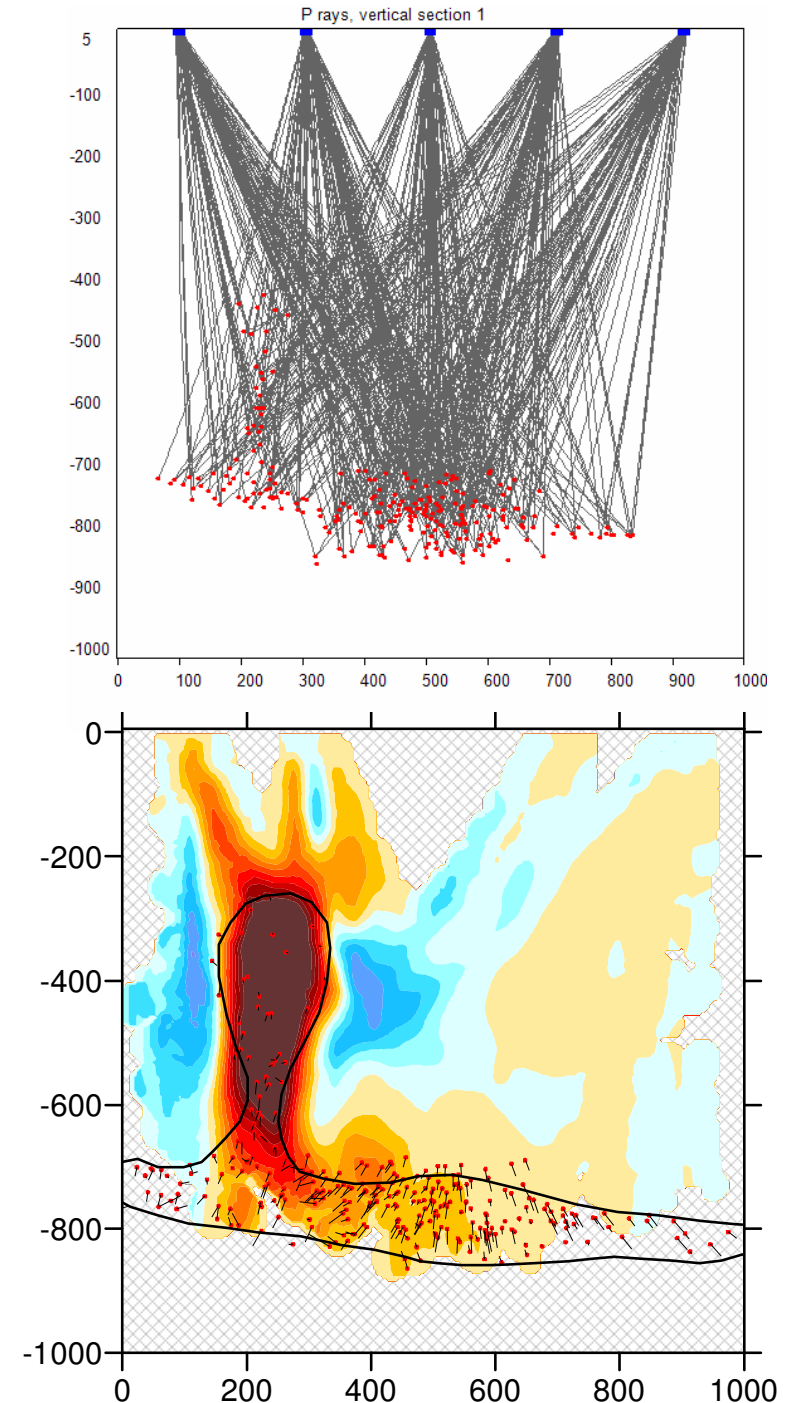
# User instruction

for performing synthetic modeling in XYZ using the LOTOS code for passive source tomography



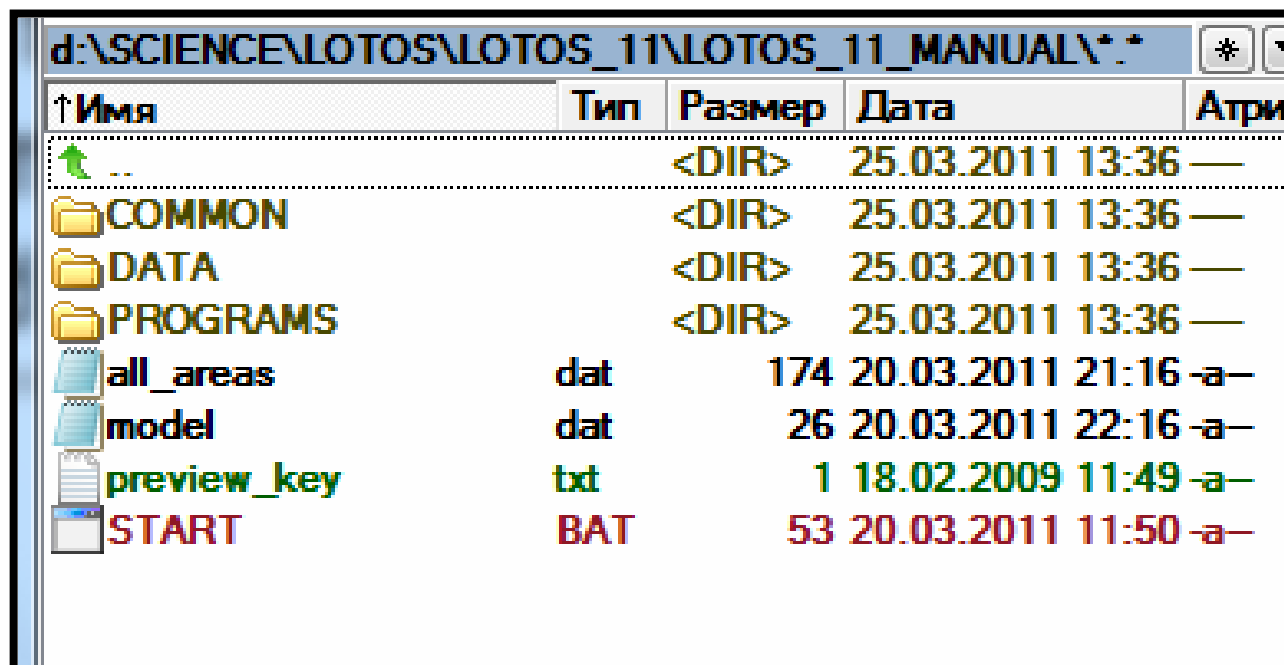
# General workflow:

1. Defining configuration of sources and receivers in 3D; fixing the source-receiver pairs
2. Defining the synthetic model (reference 1D model + P and S anomalies)
3. Computing synthetic times
4. Performing inversion using the LOTOS code
5. Visualization of the results



## Preparation stage:

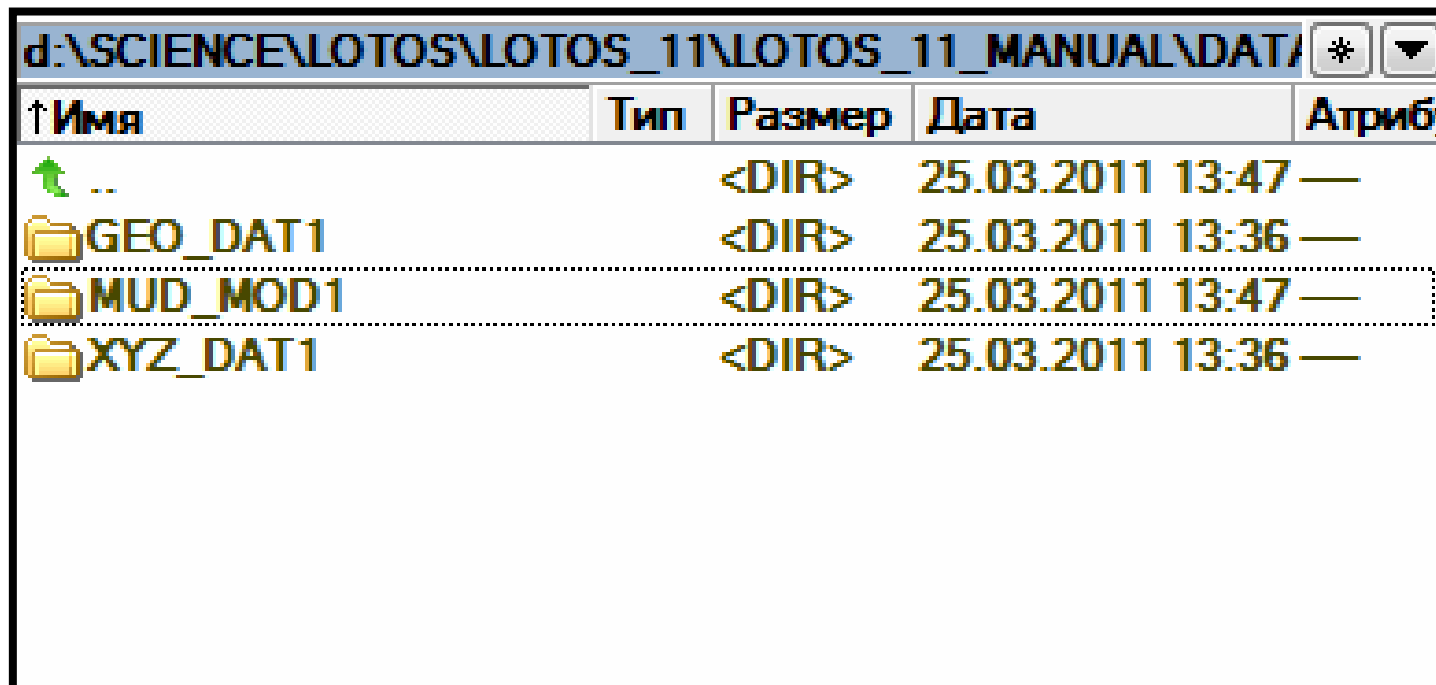
1. In this manual, the SURFER software will be used as a basic tool for digitizing and visualization. Alternatively, other free tools are available in the code.
2. Copy the folder “LOTOS\_11\_release” to any location of the computer. The structure of the root folder is presented below:



Имя	Тип	Размер	Дата	Атри
..	<DIR>		25.03.2011 13:36	—
COMMON	<DIR>		25.03.2011 13:36	—
DATA	<DIR>		25.03.2011 13:36	—
PROGRAMS	<DIR>		25.03.2011 13:36	—
all_areas	dat	174	20.03.2011 21:16	-a-
model	dat	26	20.03.2011 22:16	-a-
preview_key	txt	1	18.02.2009 11:49	-a-
START	BAT	53	20.03.2011 11:50	-a-

## Preparation of a new model:

1. Open the DATA folder
2. Create a clone of the area folder XYZ\_DAT1 using the CTRL+C and CTRL+V keys.
3. Rename this new folder (for example, MUD\_MOD1). Note that the folder name should contain 8 characters.

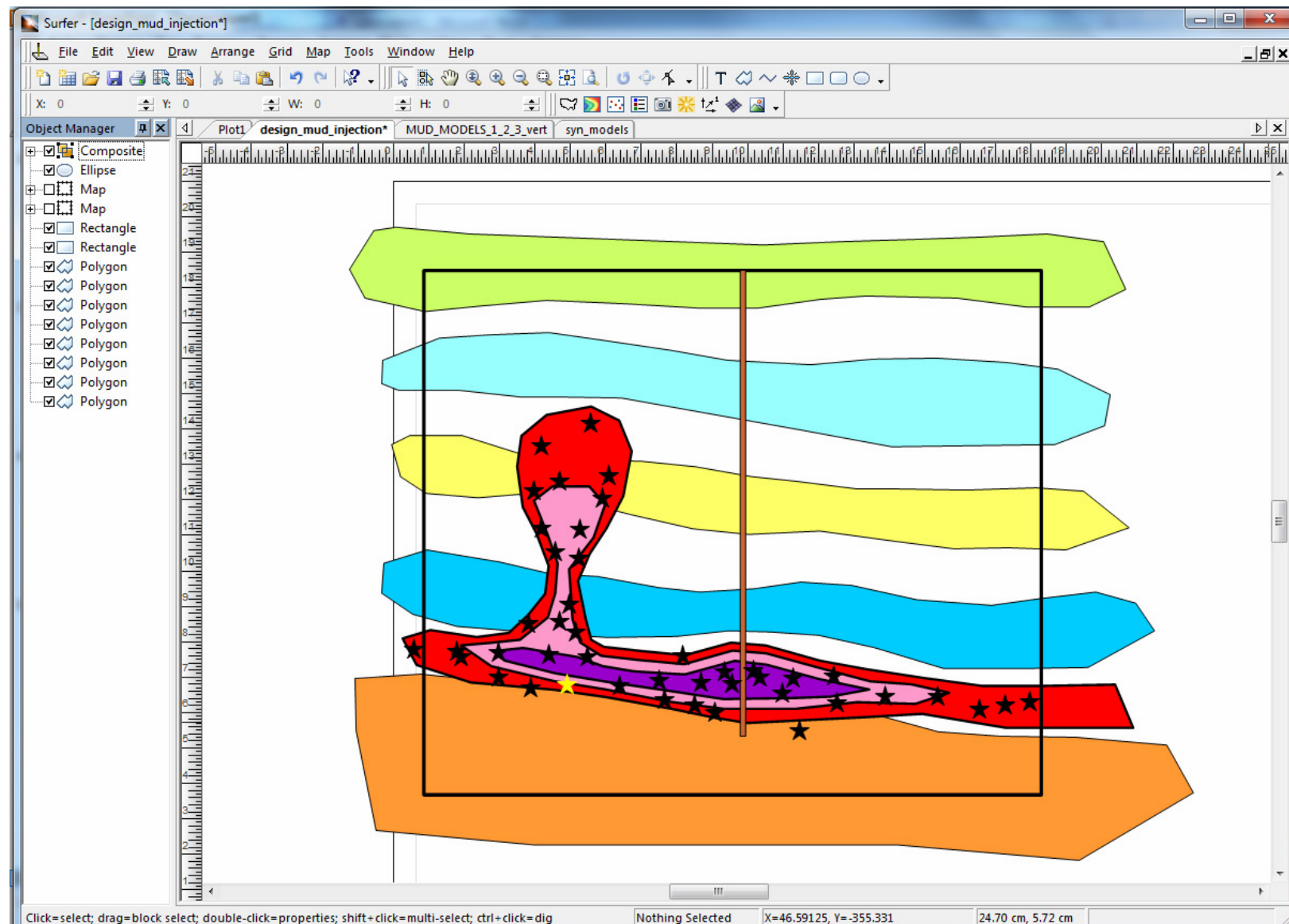


d:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\DATA				
Имя	Тип	Размер	Дата	Атриб
..	<DIR>		25.03.2011 13:47	—
GEO_DAT1	<DIR>		25.03.2011 13:36	—
MUD_MOD1	<DIR>		25.03.2011 13:47	—
XYZ_DAT1	<DIR>		25.03.2011 13:36	—



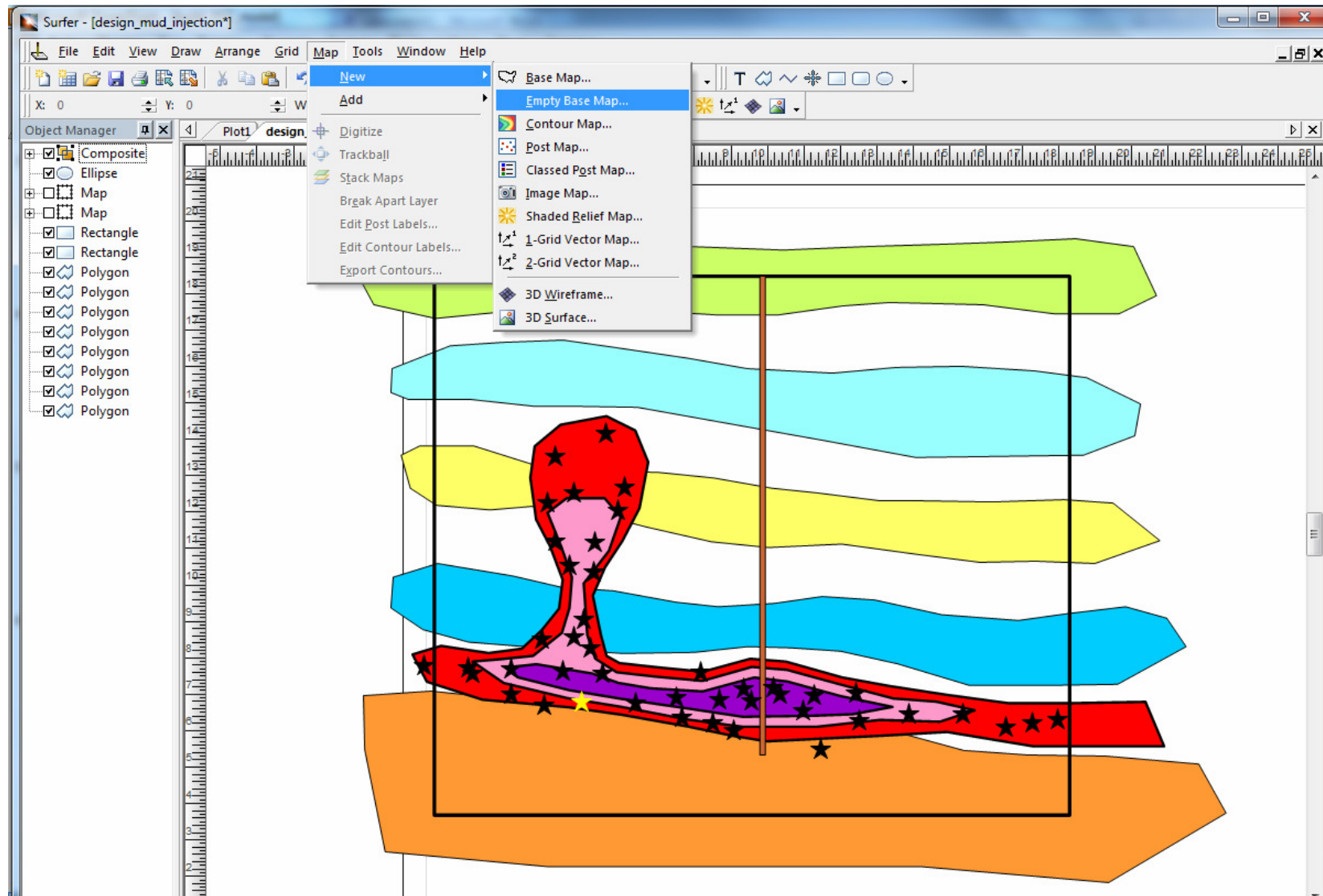
# Design of the model:

The model can be drawn manually and scanned or designed in any graphical editor (Corel, Surfer). Then it should be imported to Surfer as shown below:



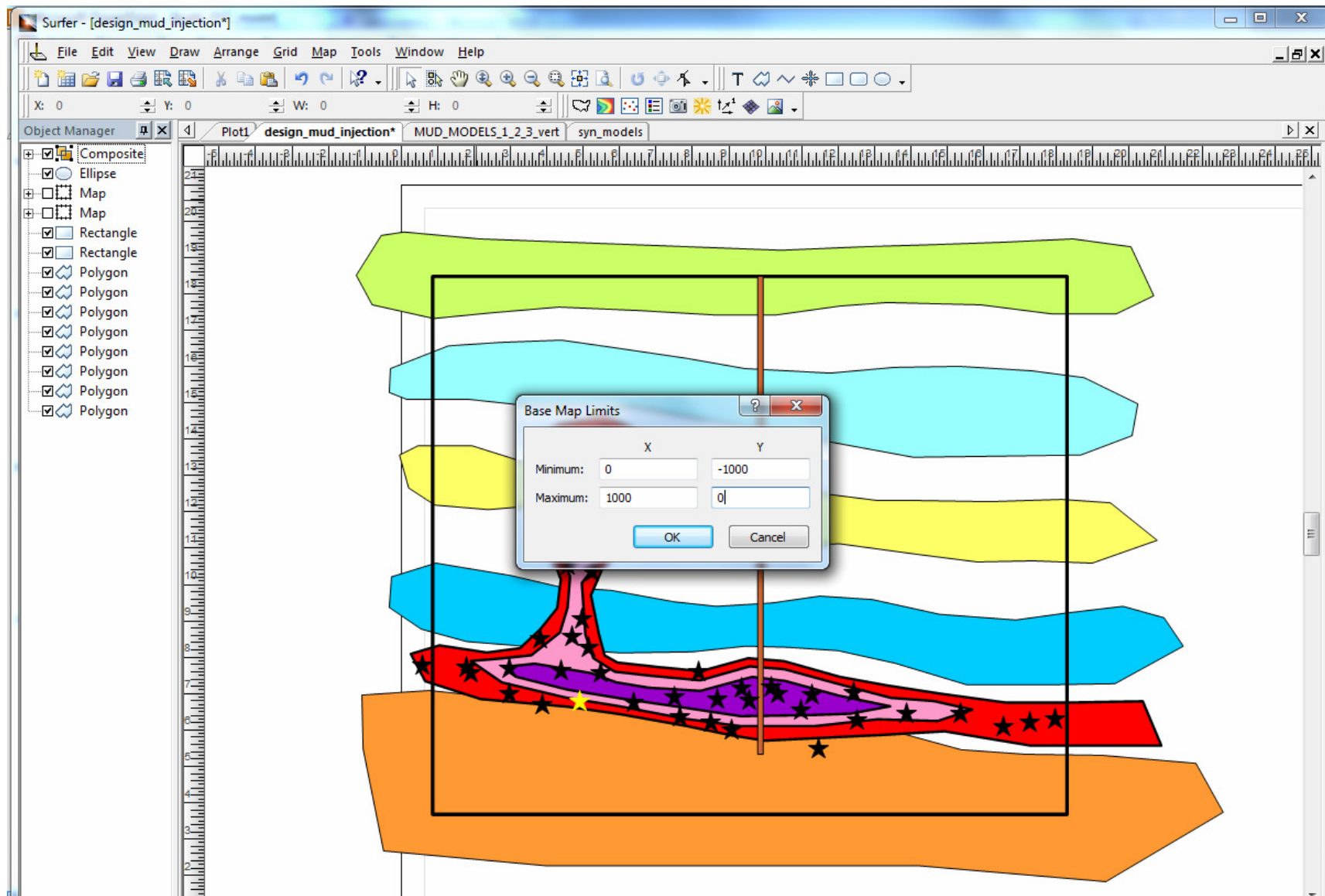
# Digitizing the synthetic model:

First, define the coordinate system. Keys Map – New – Empty Base Map :



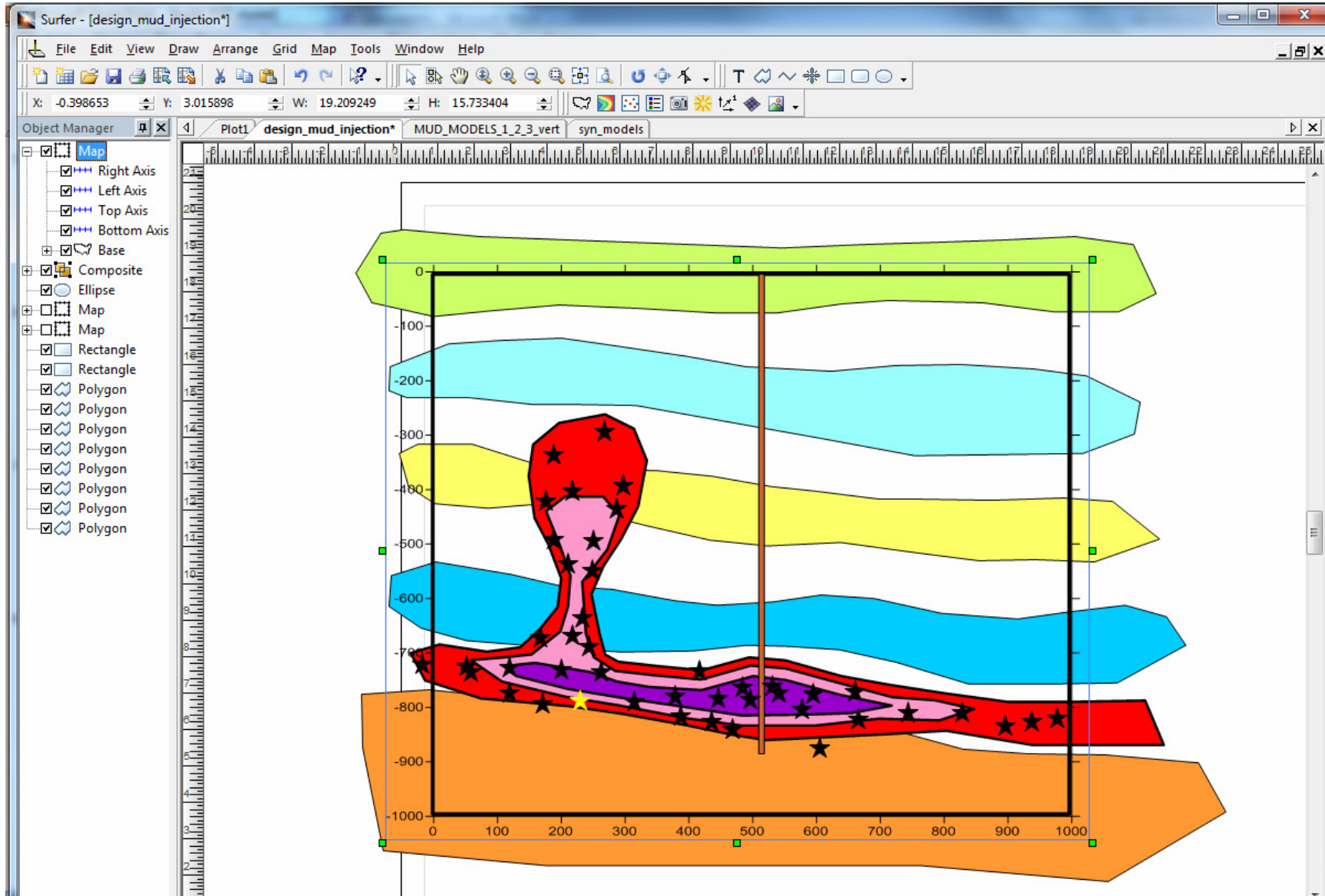
# Digitizing the synthetic model:

Define the coordinate limits of your system. Note that here, the underground area is negative, and positive direction is up. :



# Digitizing the synthetic model:

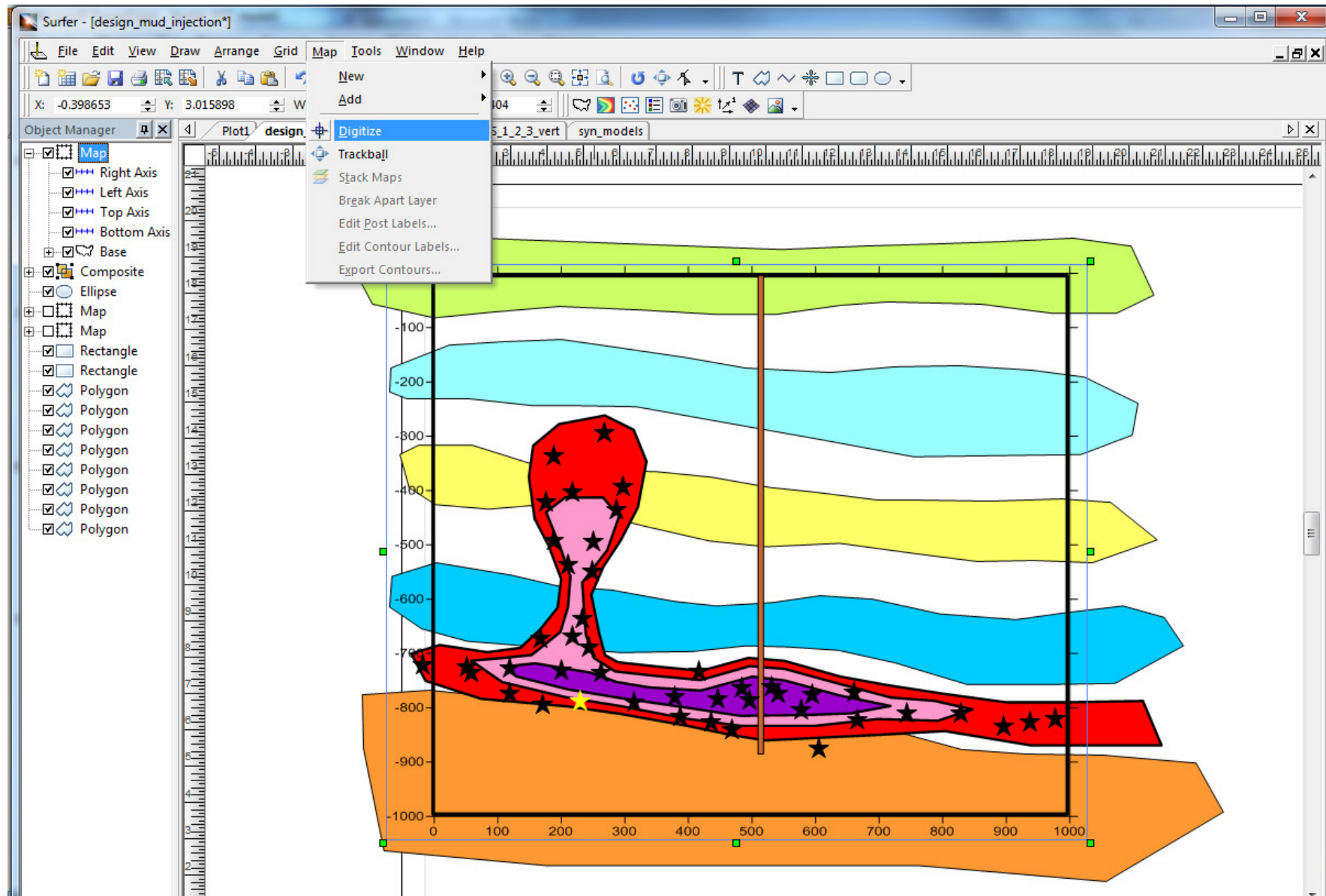
Scale the appeared coordinate system to the limits of the model :





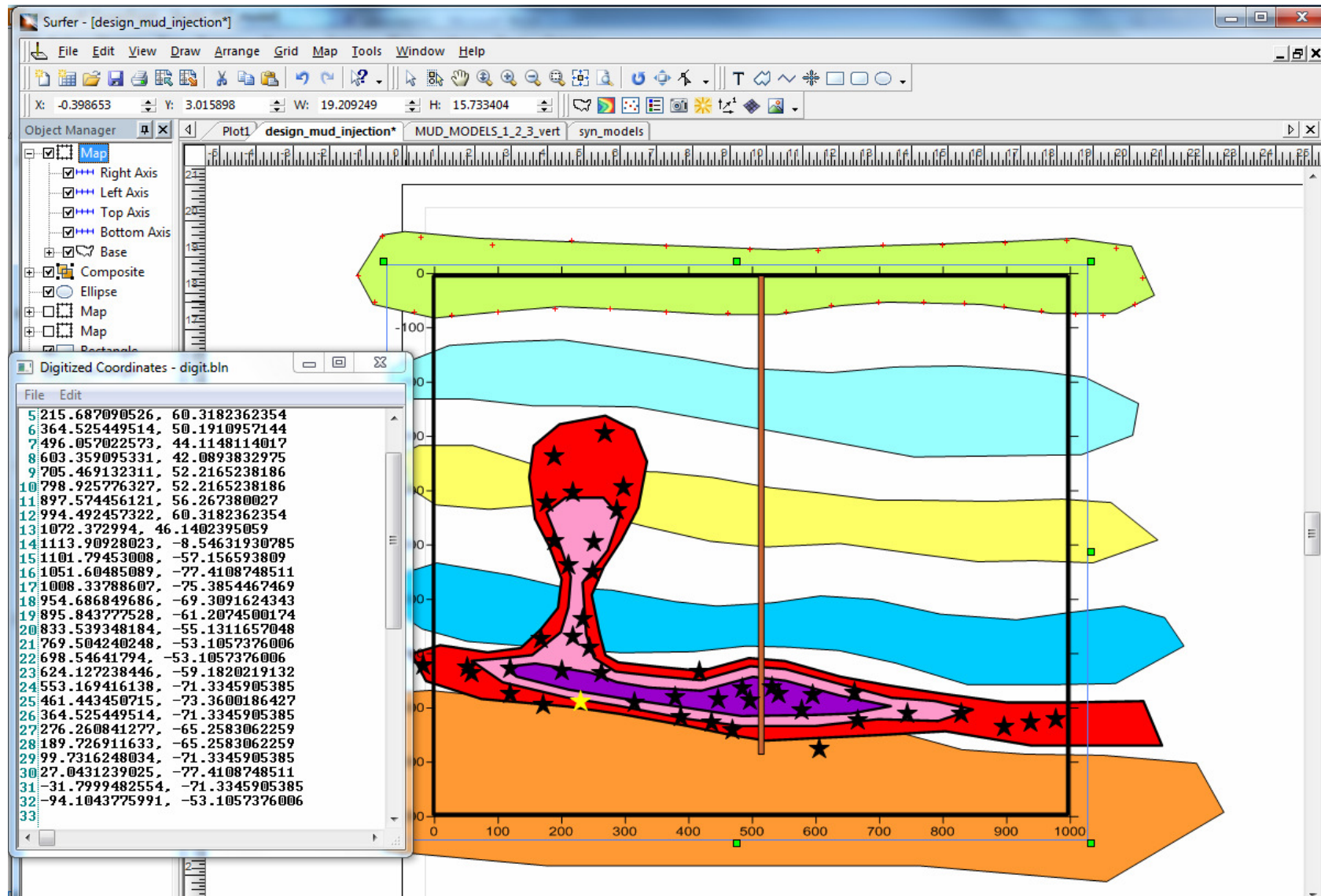
# Digitizing the synthetic model:

Select the new coordinate system and use menu Map - Digitize:



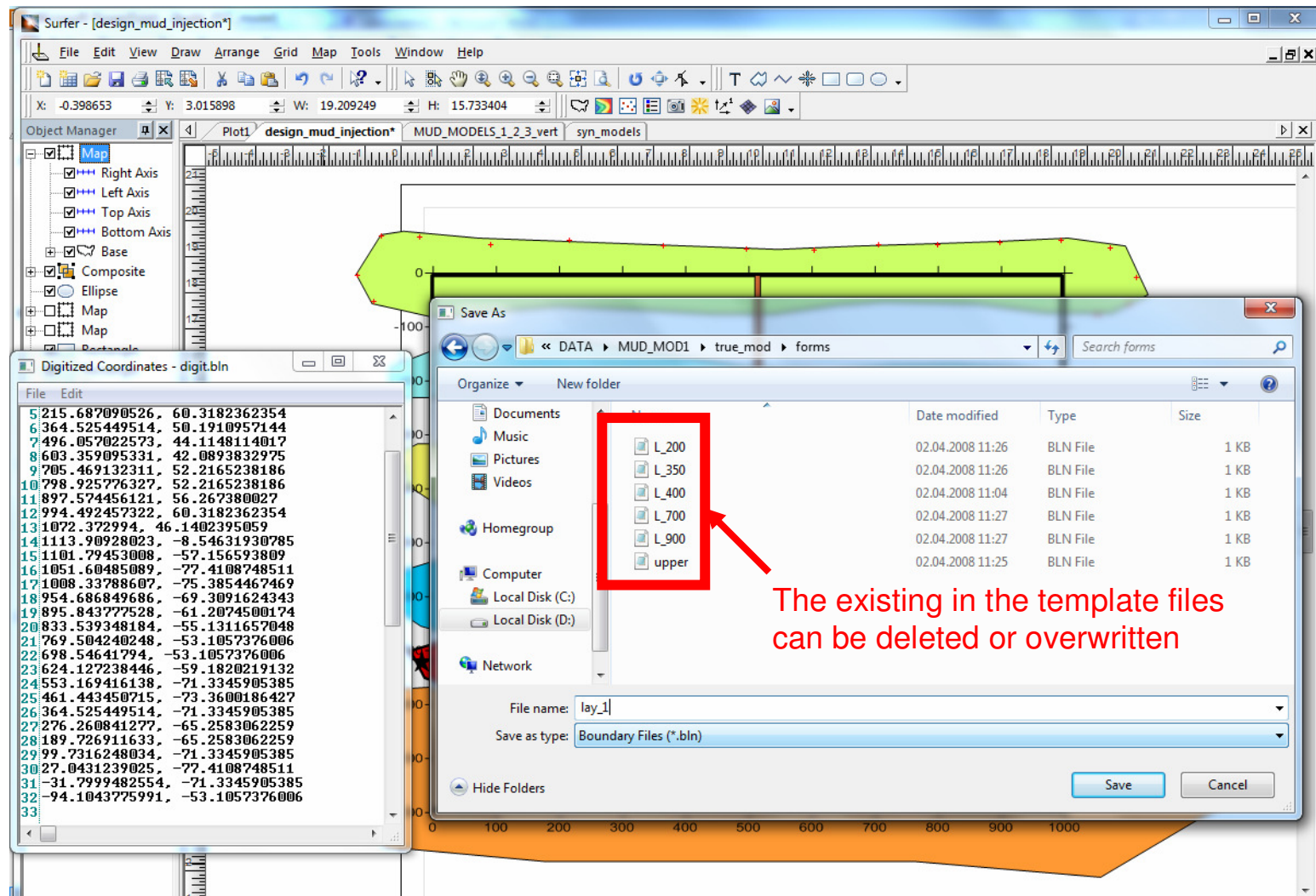
# Digitizing the synthetic model:

Then click along boundary of one of the object. A window with digitized coordinates appears:



# Digitizing the synthetic model:

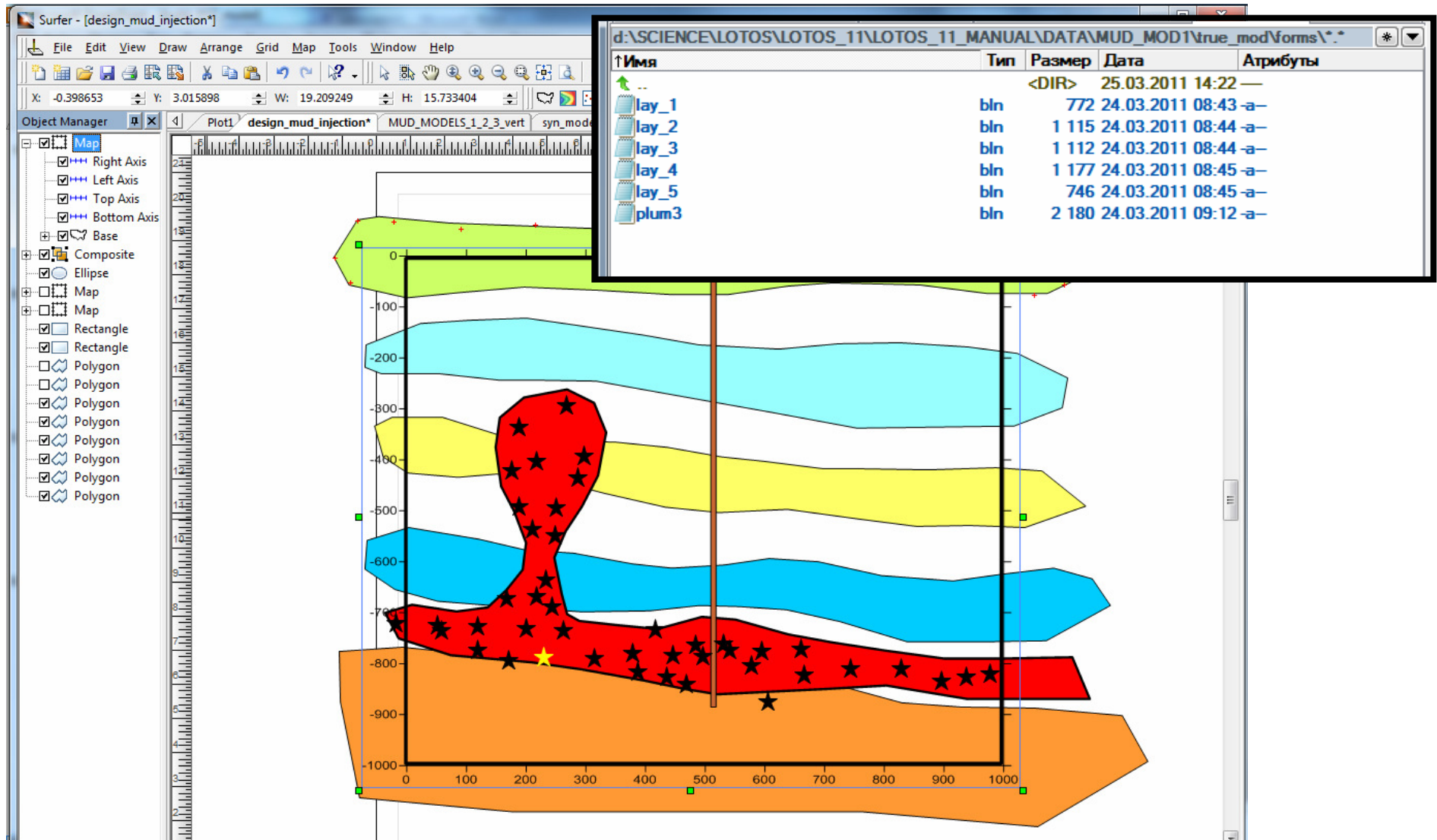
In the “digitized coordinates” window click menu File – Save As and save the file with the current polygon to the true synthetic model folder: DATA/MUD\_MOD1/true\_mod/forms. Note that the length of these files should be 5 symbols. Before starting digitizing a new polygon, do not forget to close the previous window.





# Digitizing the synthetic model:

In the presented case, after digitizing all features, the folder “forms” will contain six BLN files :





# Creating and visualizing the synthetic model:

Folder “true\_mod” contains the synthetic model which is used to generate the synthetic data. Open file “DATA/MUD\_MOD1/true\_mod/anomaly.dat”. Make the changes as shown below:

The image shows a Total Commander window on the left and an AkelPad window on the right. The Total Commander window displays the directory structure of 'd:\SCIENCE\LOTOS\LOTOS\_11\LOTOS\_11\_MANUAL\DATA\MUD\_MOD1\true\_mod'. The AkelPad window shows the content of 'anomaly.dat'.

**anomaly.dat - AkelPad**

Файл Правка Поиск Кодировки Настройки Справка

3 1 - board, 2 - horiz. anom, 3 - vert. anom

6 number of anomalies

\*\*\*\*\*

0. 0. 1000. 0. lay\_1 Figure

0. 0. 0. 0. -5 -9 -600. 600.

\*\*\*\*\*

0. 0. 1000. 0. lay\_2 Figure

0. 0. 0. 0. -3 -5 -600. 600.

\*\*\*\*\*

0. 0. 1000. 0. lay\_3 Figure

0. 0. 0. 0. 5 7 -600. 600.

\*\*\*\*\*

0. 0. 1000. 0. lay\_4 Figure

0. 0. 0. 0. -3 -4 -600. 600.

\*\*\*\*\*

0. 0. 1000. 0. lay\_5 Figure

0. 0. 0. 0. 3 4 -600. 600.

\*\*\*\*\*

0. 0. 1000. 0. plum3 Figure

0. 0. 0. 0. -5 -13 -150. 150.

Annotations:

- Coordinates of the vertical section:  $x_a, y_a - x_b - y_b$
- Name of the polygon which exists in “forms”
- Not important in this case
- P and S anomalies in %
- Thickness of the anomaly across the section (in both directions)

# Creating and visualizing the synthetic model:

Change parameters of visualization in vertical and horizontal sections. Open files “DATA/MUD\_MOD1/setver.dat” and “DATA/MUD\_MOD1/sethor.dat”. Make the changes as shown below:

The image shows a Total Commander window displaying the directory structure of a synthetic model. The file list includes folders like 'inidata', 'inimodel', 'MODEL\_01', and 'true\_mod', along with files 'config.txt', 'INFO.TXT', 'sethor.dat', and 'setver.dat'. The status bar at the bottom indicates '0 KB из 1 KB, файлов: 0 из 4' and the path 'OS\LOTOS 11\LOTOS 11 MANUAL\DATA\MUD MOD1>'. Overlaid on the right are two AkelPad text editors. The top editor, 'setver.dat', contains parameters for vertical sections, including the number of sections, limits, distance from section, and smoothing factor. The bottom editor, 'sethor.dat', contains parameters for horizontal sections, including the number of depth slices, depths, limits of maps, distance from nearest node, and smoothing factor.

**setver.dat - AkelPad**

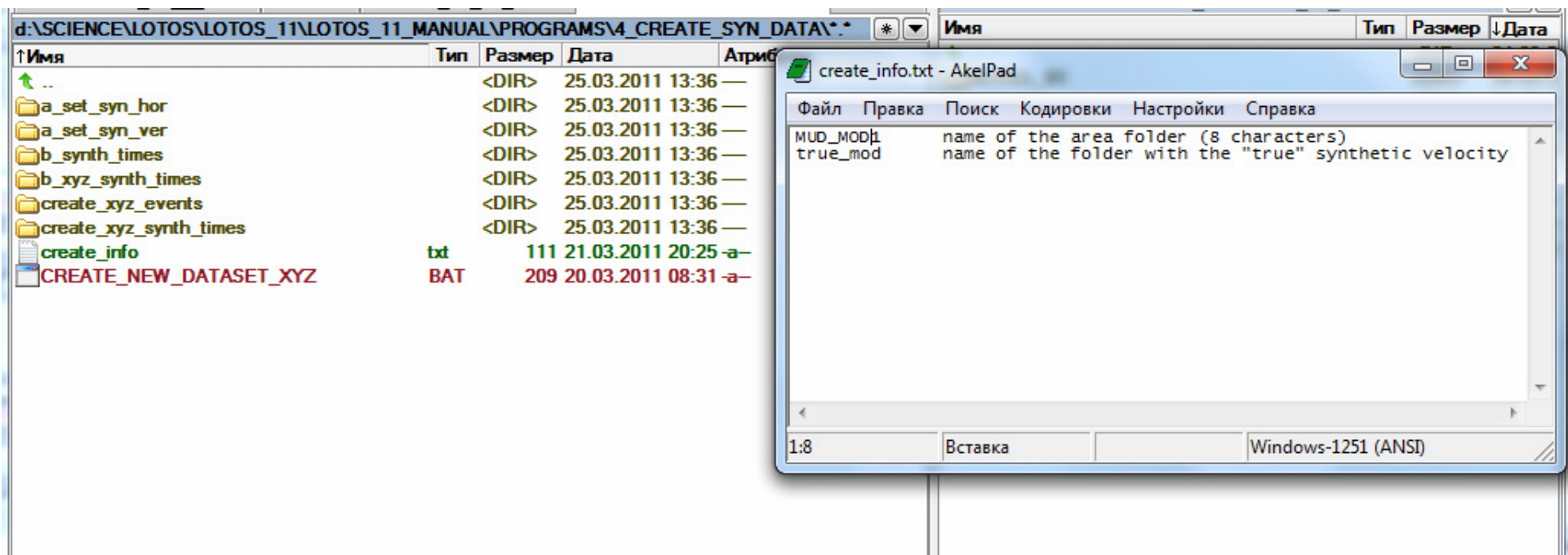
```
1      Number of different sections
0 0. 1000. 0. XA,YA - XB,YB
40 distance from section for visualization of events
4      -500 dx
-5 1000 4 zmin,zmax,dz
100      Marks for indication of position of section
20      Distance to the nearest node
0      Smoothing factor
0      If 0, no sources are visualized
```

**sethor.dat - AkelPad**

```
3      Number of depth slices
300 500 700      Depths of sections
0. 1000. 5 -500 500 5 Limits of maps: X1,X2,dx, Y1,Y2,dY
20      distance from nearest node
0      Smoothing factor1      Number of summary
```

# Creating and visualizing the synthetic model:

Go to the folder “PROGRAMS/4\_CREATE\_SYN\_DATA”. Open file “create\_info.txt” and define the name of the area folder and a folder of a model used as a true one.





# Creating and visualizing the synthetic model:

In the folder “PROGRAMS/4\_CREATE\_SYN\_DATA” click on file “VISUALIZE\_SYN\_MODEL.BAT” and it will run the console:

The image shows two windows side-by-side. The left window is Total Commander 6.03a, displaying the directory structure of 'D:\SCIENCE\LOTOS\LOTOS\_11\LOTOS\_11\_MANUAL\PROGRAMS\4\_CREATE\_SYN\_DATA'. The file 'VISUALIZE\_SYN\_MODEL.BAT' is highlighted with a red box. A red arrow points from this box to the command prompt window on the right. The command prompt window shows the execution of the batch file, which copies files and runs a program to create and visualize a synthetic model. The output includes file names, sizes, and dates, as well as a list of parameters for the model.

**Total Commander 6.03a - ISS GmbH Heidelberg**

Файл Выделение Навигация Сеть FTP Вид Вкладки Конфигурация Инструменты

[d-] [нет\_] 141 157 420 КБ из 304 650 236 КБ свободно

Имя	Тип	Размер	Дата	Атрибуты
..	<DIR>		25.03.2011 17:13	—
a_set_syn_hor	<DIR>		25.03.2011 13:36	—
a_set_syn_ver	<DIR>		25.03.2011 13:36	—
b_synth_times	<DIR>		25.03.2011 13:36	—
b_xyz_synth_times	<DIR>		25.03.2011 13:36	—
create_xyz_events	<DIR>		25.03.2011 13:36	—
create_xyz_synth_times	<DIR>		25.03.2011 13:36	—
create_info	txt	111	25.03.2011 14:54	-a-
CREATE_NEW_DATASET_XYZ	BAT	209	20.03.2011 08:31	-a-
VISUALIZE_SYN_MODEL	BAT	119	25.03.2011 17:13	-a-

0 КБ из 0 КБ, файлов: 0 из 3

OTOS\_11\_MANUAL\PROGRAMS\4\_CREATE\_SYN\_DATA>

F3 Просмотр F4 Правка F5 Копия F6 Перемещ

**C:\windows\system32\cmd.exe**

```
D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\4_CREATE_SYN_DATA>copy cre
l.dat
1 file(s) copied.

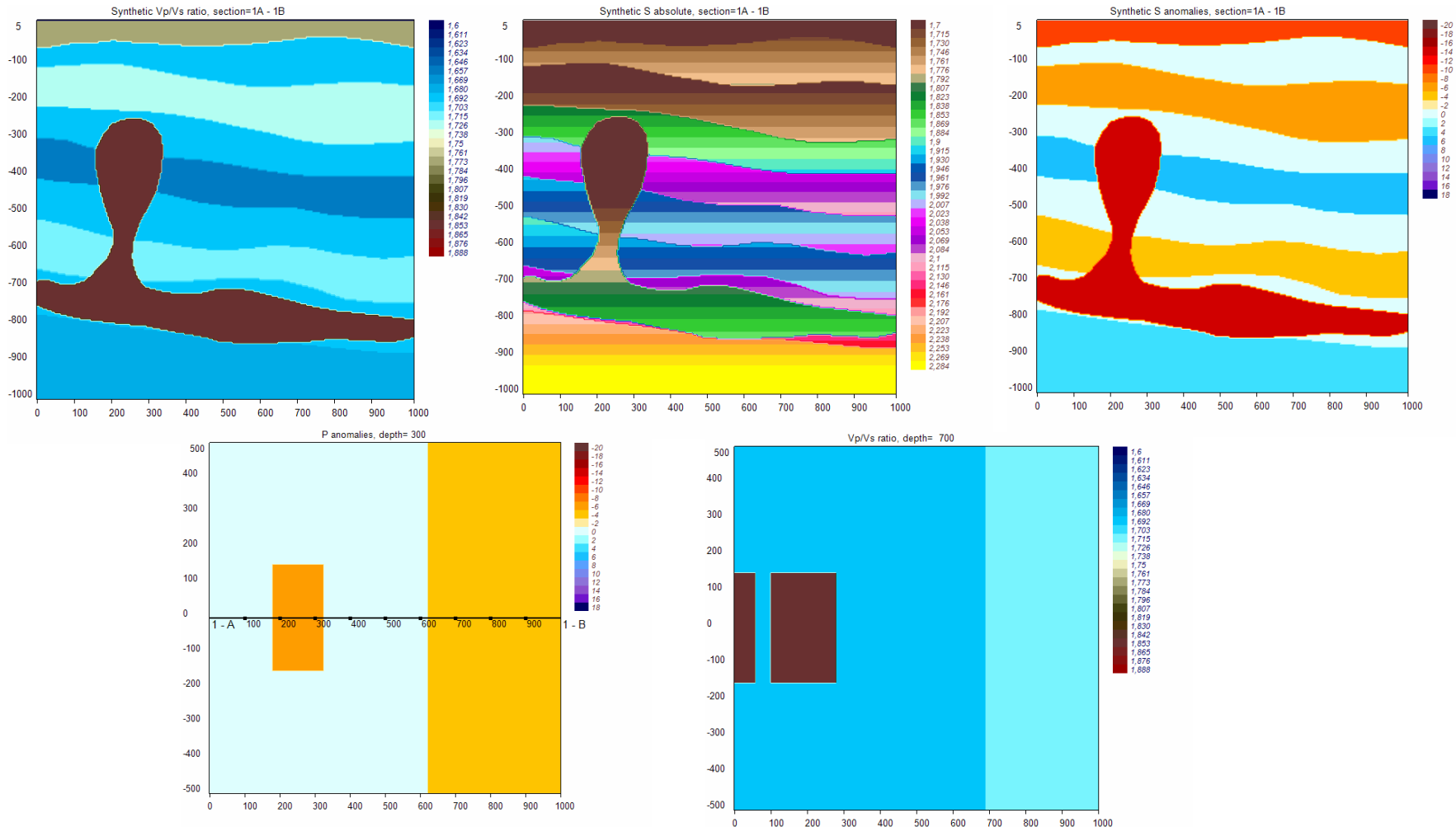
D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\4_CREATE_SYN_DATA>cd a_set
D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\4_CREATE_SYN_DATA\
A subdirectory or file ..\..\..\TMP_files\hor already exists.
Synthetic model in horizontal sections
ar=MUD_MOD1 md=true_mod
A subdirectory or file ..\..\..\PICS\MUD_MOD1\true_mod\SYN already exists.
1 file(s) copied.
1 file(s) copied.
1 file(s) copied.
nref=2
ar=MUD_MOD1 kod of anom.=3
n_anomaly=3, : FREE VERTICAL ANOMALIES
npix_x=500 npix_y=500
nfnap=401 ntmap=401
ilev=1 zzz=300.0000
ilev=2 zzz=500.0000
ilev=3 zzz=700.0000

D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\4_CREATE_SYN_DATA\
D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\4_CREATE_SYN_DATA>cd a_set
D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\4_CREATE_SYN_DATA\
A subdirectory or file ..\..\..\TMP_files\vert already exists.
ar=MUD_MOD1 md=true_mod
A subdirectory or file ..\..\..\PICS\MUD_MOD1\true_mod\SYN already exists.
1 file(s) copied.
1 file(s) copied.
1 file(s) copied.
1 file(s) copied.
1 file(s) copied.
nref=2
ar=MUD_MOD1 kod of anom.=3
n_anomaly=3, : FREE VERTICAL ANOMALIES
section: 1 dist=1000.000 nxsec=251 nzsec=252
npix_x=500 npix_y=500

D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\4_CREATE_SYN_DATA\
D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\4_CREATE_SYN_DATA>pause
Press any key to continue . . .
```

# Creating and visualizing the synthetic model:

In the folder “PROGRAMS/4\_CREATE\_SYN\_DATA” click on file “VISUALIZE\_SYN\_MODEL.BAT” and it will run the console:



After finishing calculations, check pictures in PICS/MUD\_MOD1/true\_mod/SYN

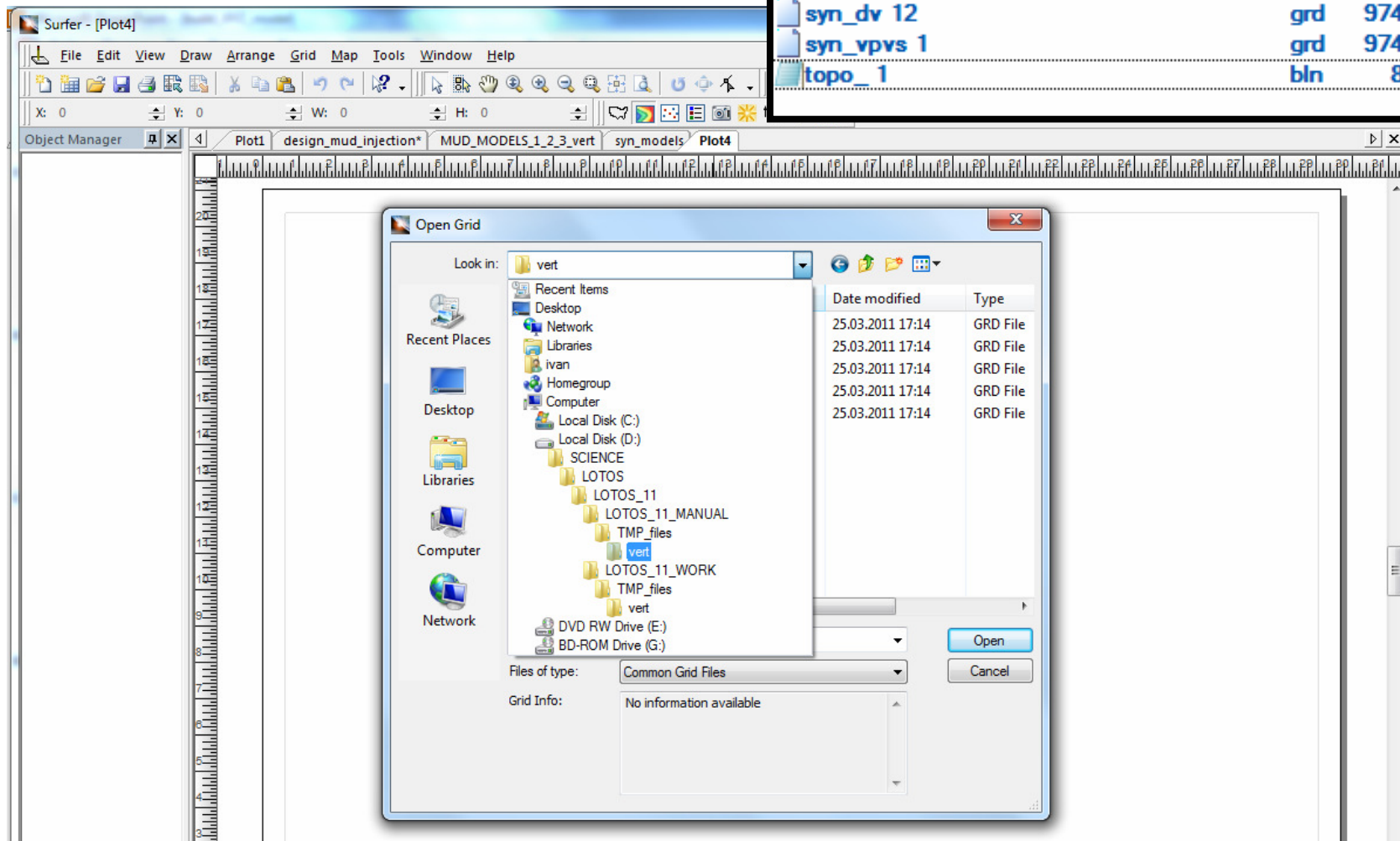
Plots with the configuration of the synthetic model in hor and ver sections are presented

# Creating and visualizing the synthetic model:

Same pictures can be created in Surfer:

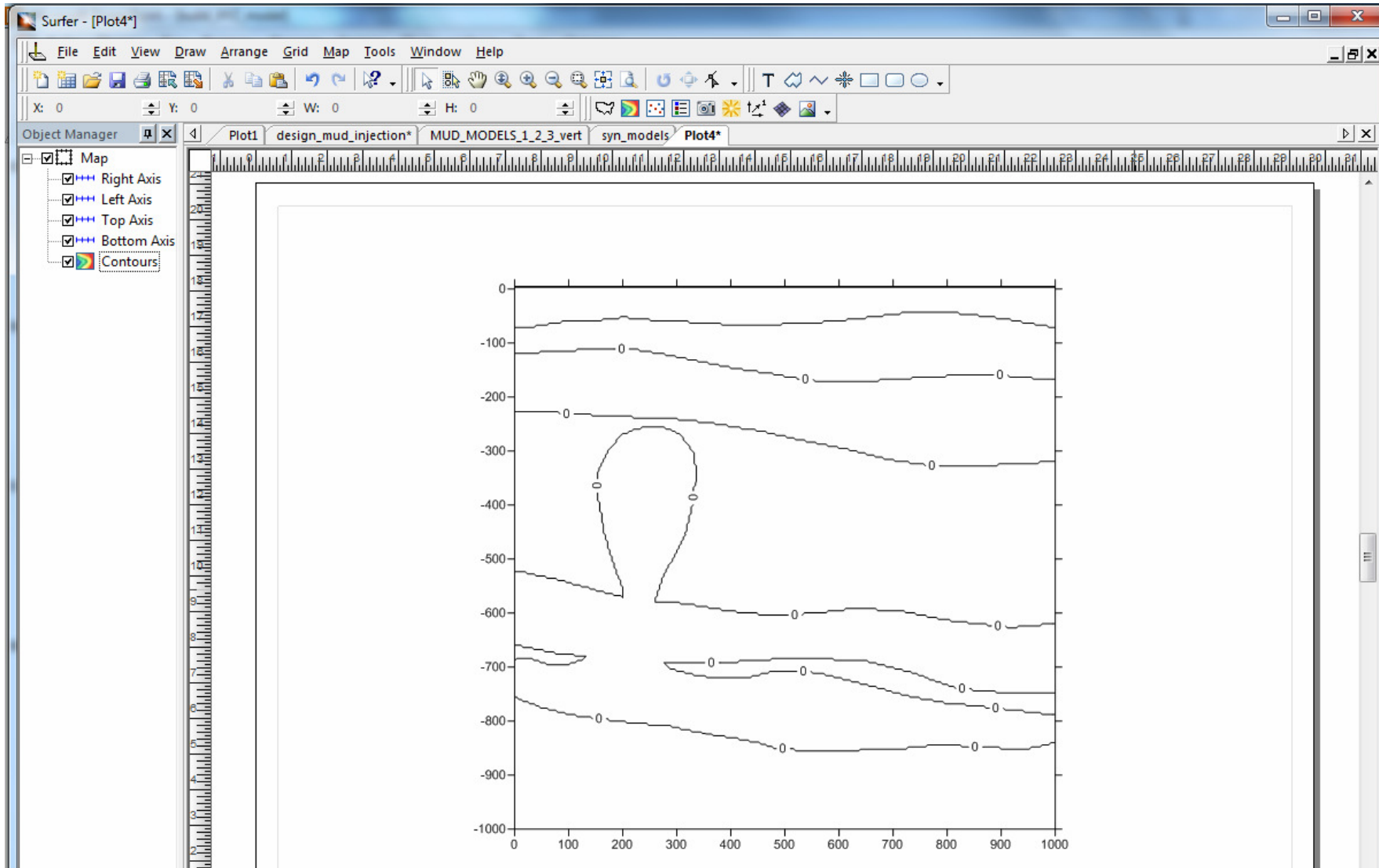
1. open a new plot;
2. Open grid in: TMP\_files/vert

Имя	Тип	Размер	Дата
<DIR>			25.03.2011 17
mark_1	bln	398	25.03.2011 17
mark_1	dat	517	25.03.2011 17
syn_abs 11	grd	974 603	25.03.2011 17
syn_abs 12	grd	974 603	25.03.2011 17
syn_dv 11	grd	974 603	25.03.2011 17
syn_dv 12	grd	974 603	25.03.2011 17
syn_vpvs 1	grd	974 603	25.03.2011 17
topo_1	bln	8 046	25.03.2011 17



# Creating and visualizing the synthetic model:

Select one of the grd files (syn\_dv 12.grd which correspond to velocity anomalies in 1<sup>st</sup> vertical section for the S model). Initially it does not look nice. Apply a standard palette and switch on the option “fill contours”:

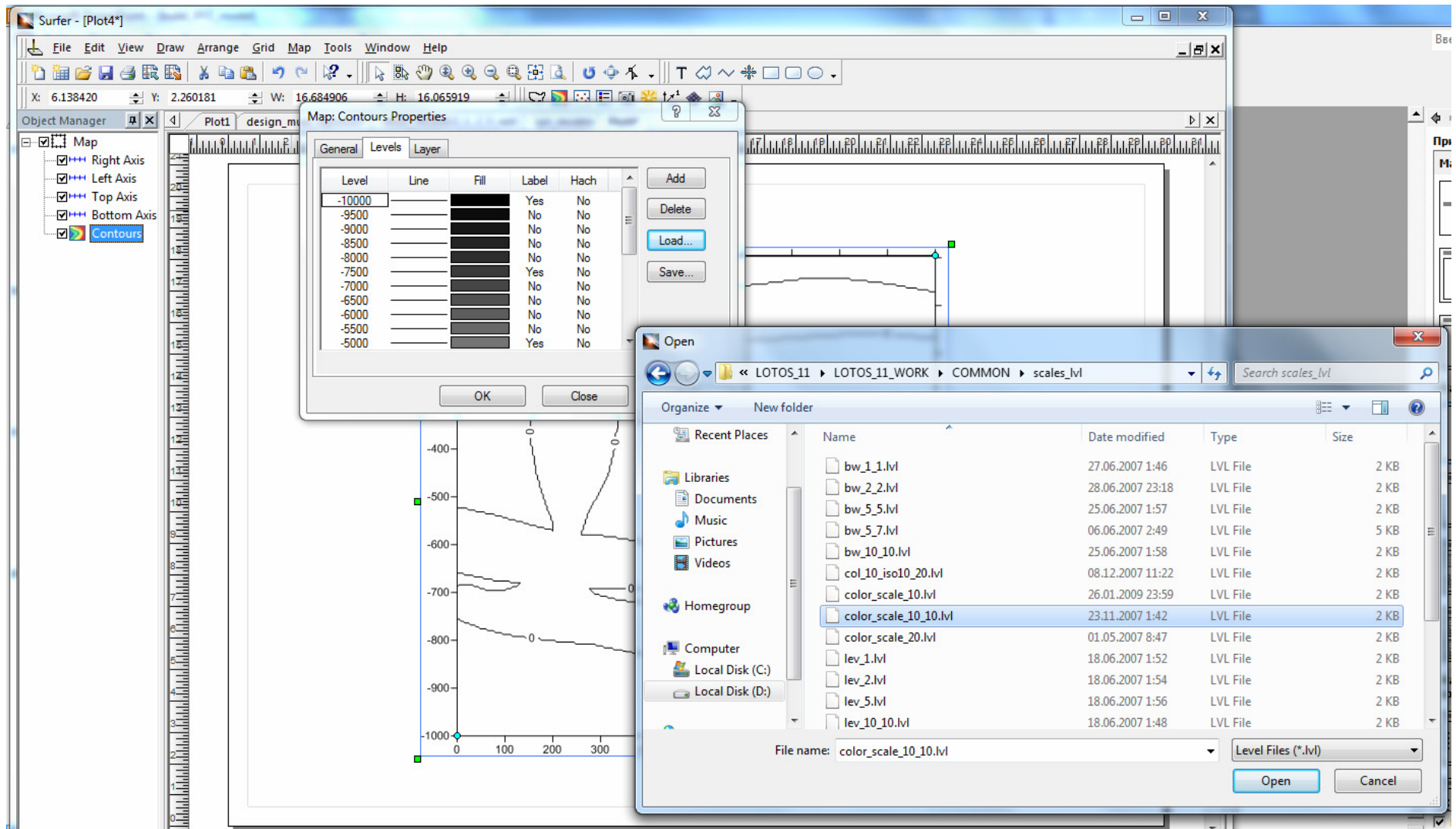




# Creating and visualizing the synthetic model:

Click on contours in left menu. Menu Levels: Load. Chose the lvl file in COMMON/scales\_lvl.

To fill contours: Menu General – mark the option “fill contours”

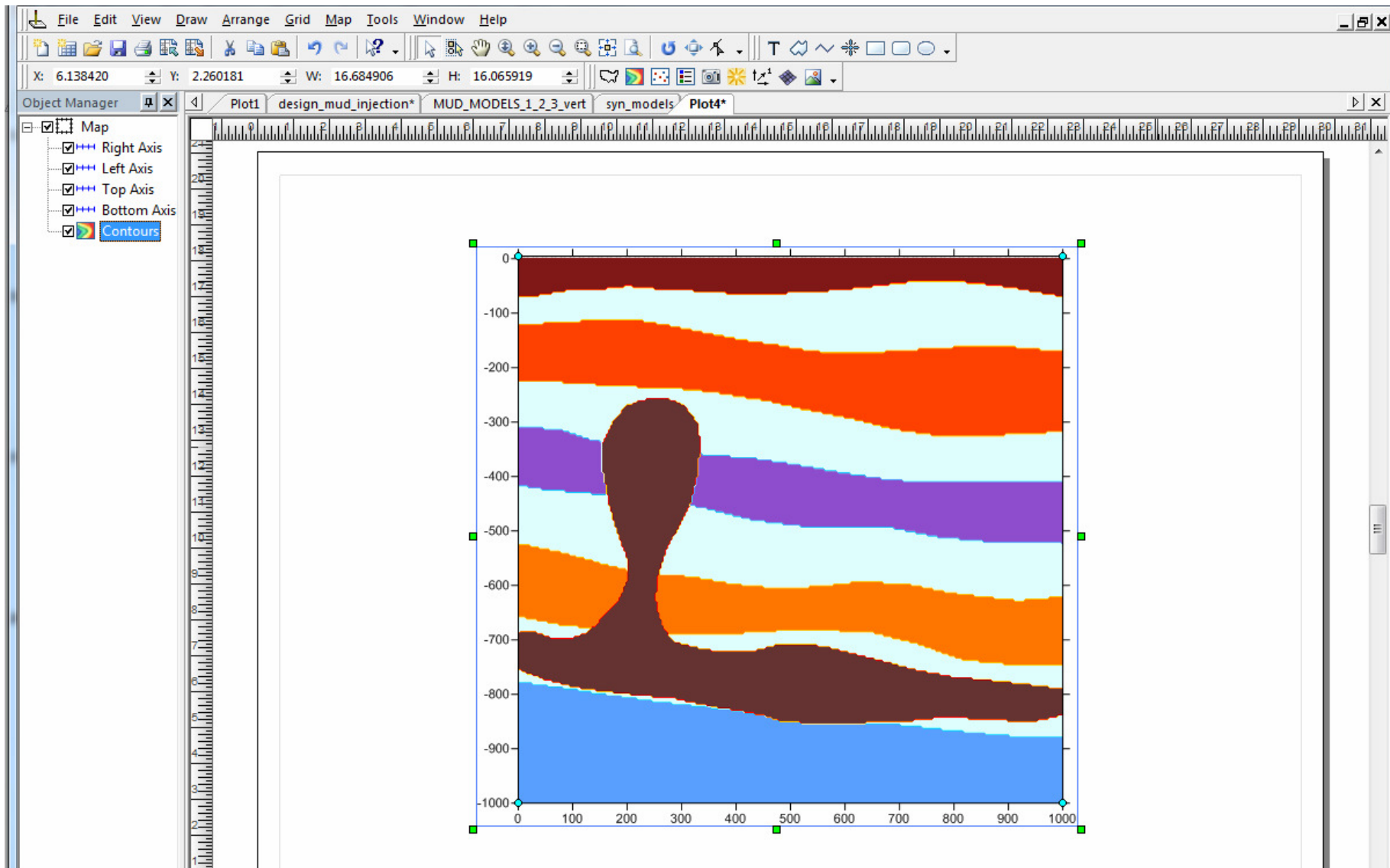




# Creating and visualizing the synthetic model:

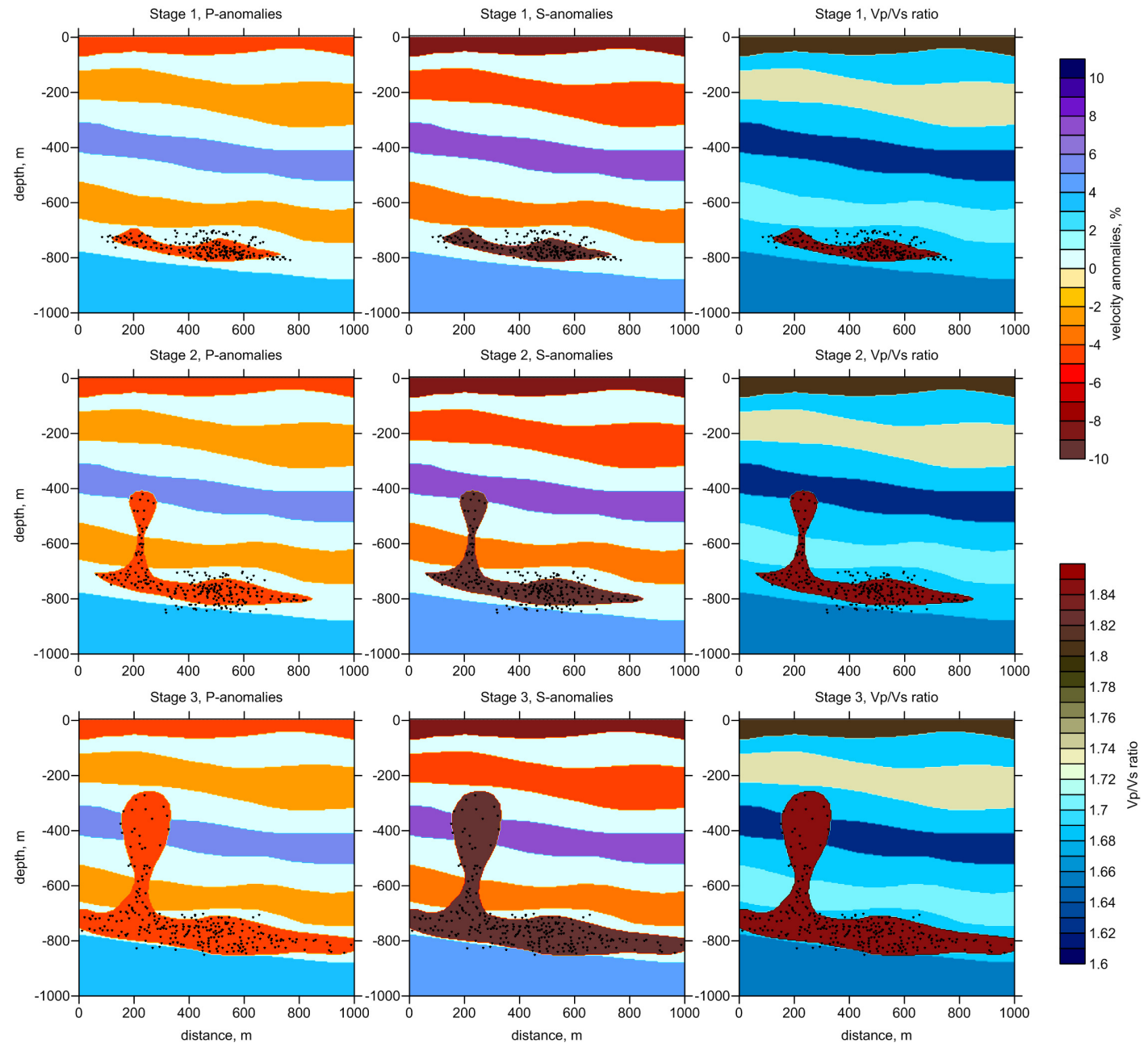
The result is presented below:

The other grids can be presented in a similar way.



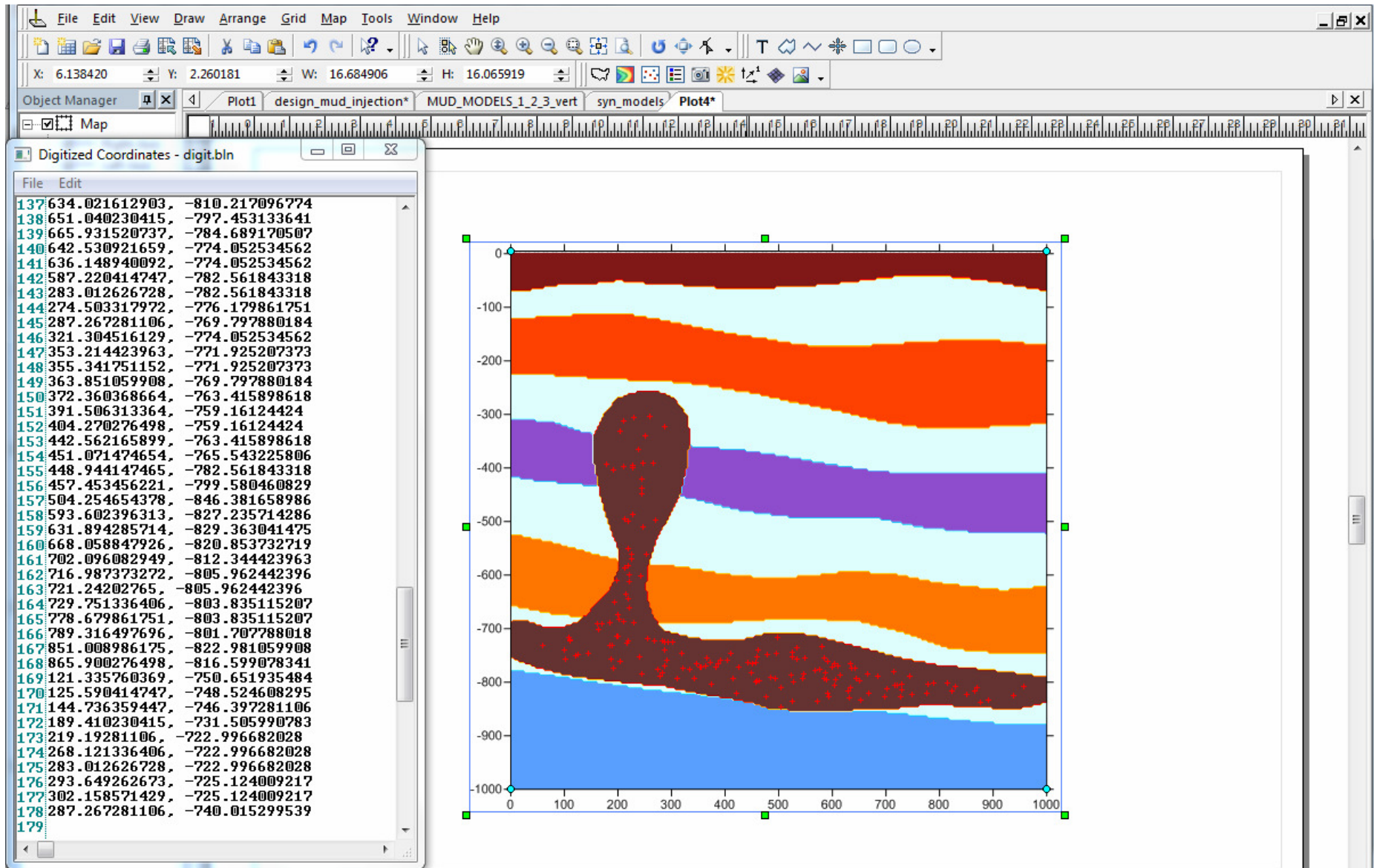
# Creating and visualizing the synthetic model:

Here is the examples of three models designed and presented in Surfer



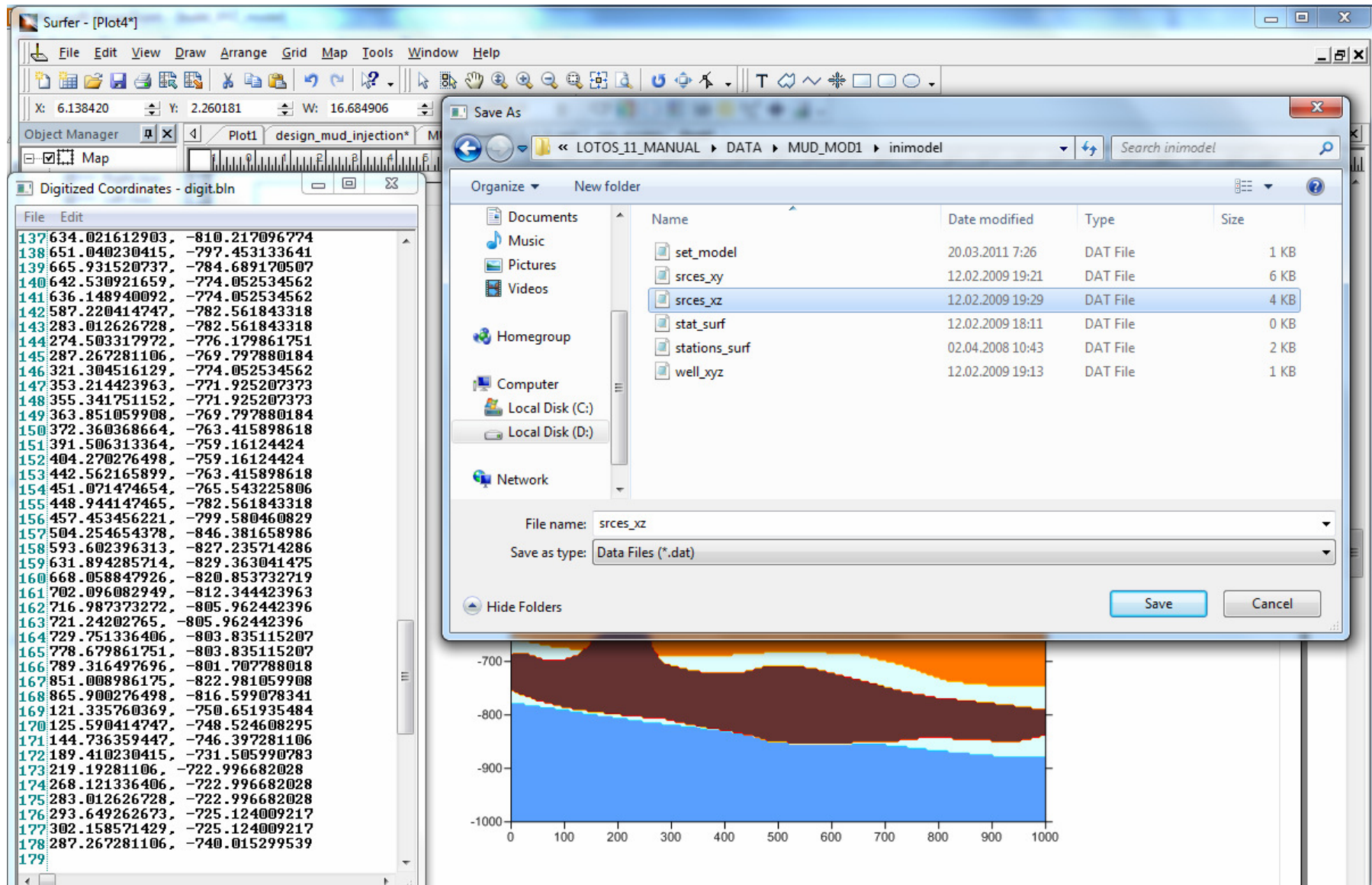
# Creating and visualizing the events and stations:

**Definition of events in the vertical section:** (1) select a vertical section with the model; (2) select menu: Map – Digitize; (3) start digitizing events



# Creating and visualizing the events and stations:

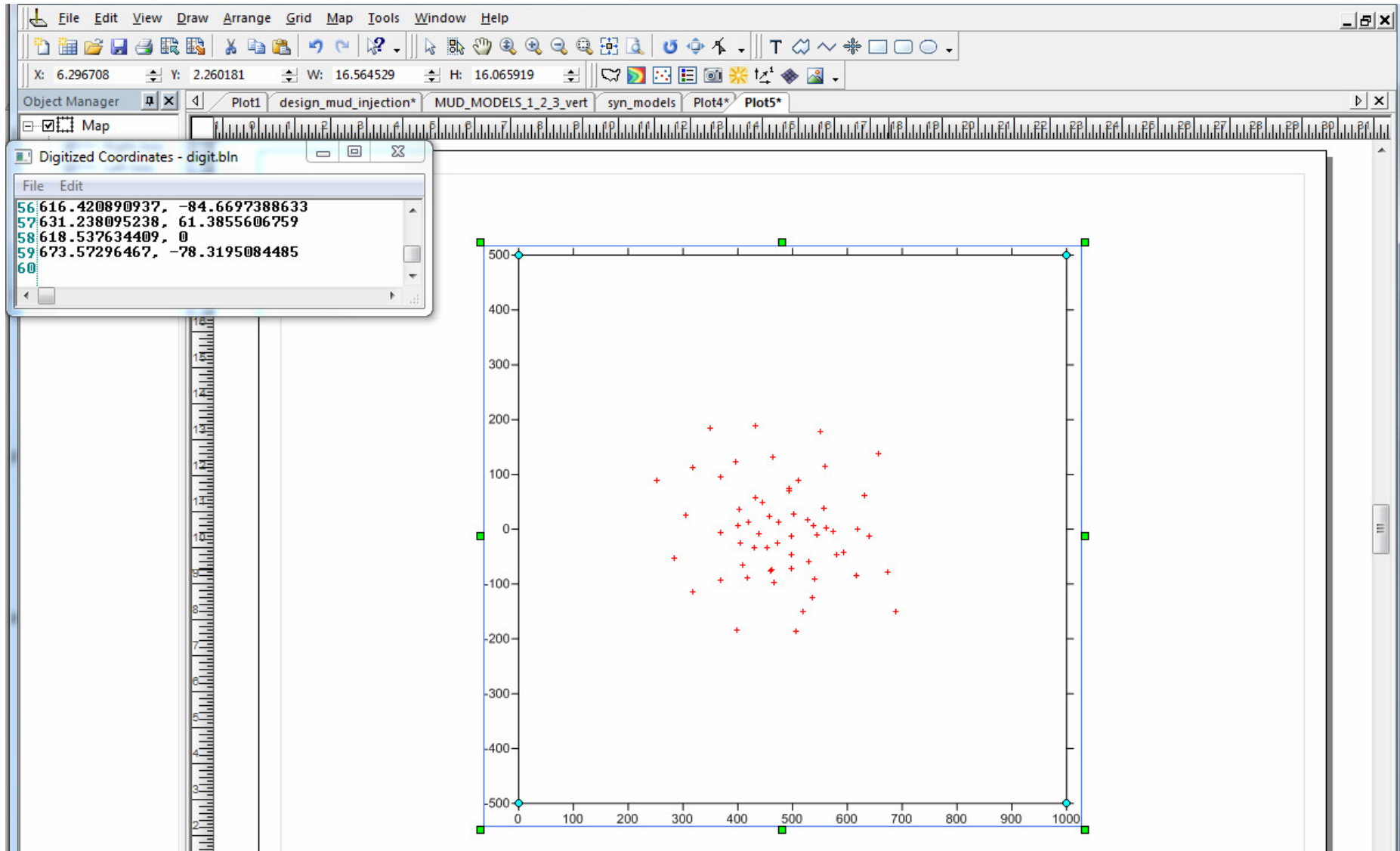
Save the points as: DATA/MUD\_MOD1/inimodel/srces\_xz.dat





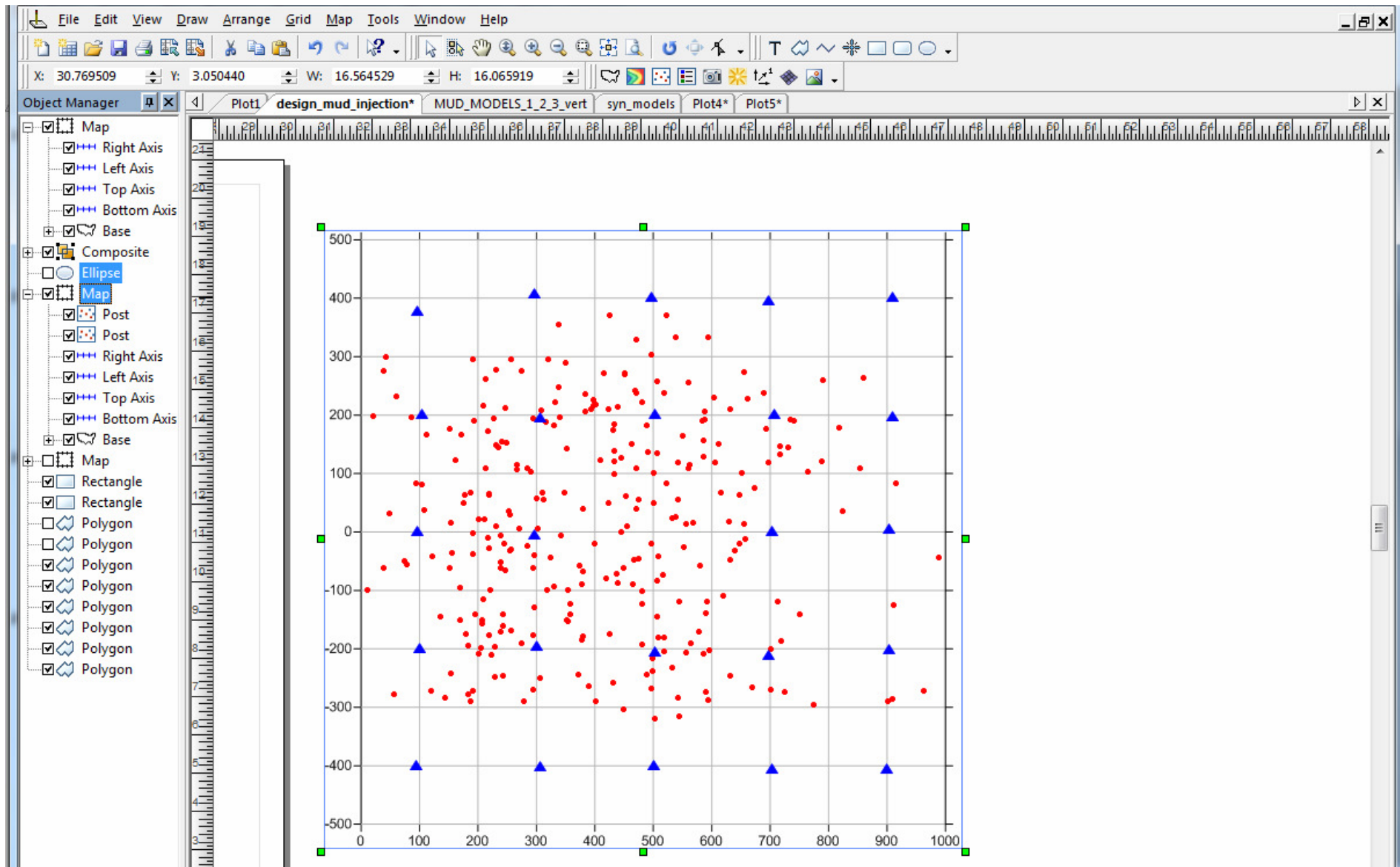
# Creating and visualizing the events and stations:

**Defining events in map view:** (1) create a new plot; (2) define an empty base map (menu: Map – New – Empty Basemap); (3) define necessary limits; (4) select the map; (5) digitize the events; (6) save them as DATA/MUD\_MOD1/inimodel/srcses\_xy.dat



# Creating and visualizing the events and stations:

In a same way define location of receivers in map view: save them as DATA/MUD\_MOD1/inimodel/stations\_surf.dat



# Creating and visualizing the events and stations:

Define the parameters of data generating in file  
DATA/MUD\_MOD1/inimodel/set\_model.dat

No receivers in the  
borehole are installed

events picked in map  
view are randomly  
distributed between 700  
and 850 m depth

events picked in  
vertical section are  
randomly  
distributed in  
distance interval of  
-300 to 300 m from  
section

randomly from 50%  
to 100% of stations  
record P picks

For randomly distributed P picks  
(50 to 100%) we define S picks

No events in the  
YZ section are  
picked

```
Listser - [D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\DATA\MUD_MOD1\inimodel\set_model.dat]
Файл  Правка  Вид  Справка
1      Index for stations on day surface
0      Index for stations in the well
40     spacing between stations in the well
0.5    step for finding stations
1      kod_ztr_xy
700 850 diapazon for z
1      kod_ztr_xz
-300 300 diapazon for y
0      kod_ztr_yz
-300 300 diapazon for x
50 prmin_p=50
100 prmax_p=100
50 prmin_s=40
100 prmax_s=80
```

station block

source block

S-R pair definition

## Creating and visualizing the events and stations:

In the folder “PROGRAMS/4\_CREATE\_SYN\_DATA” click on file “CREATE\_NEW\_DATASET\_XYZ.BAT” and it will run the console:

Number of events

Number of rays

Number of S rays

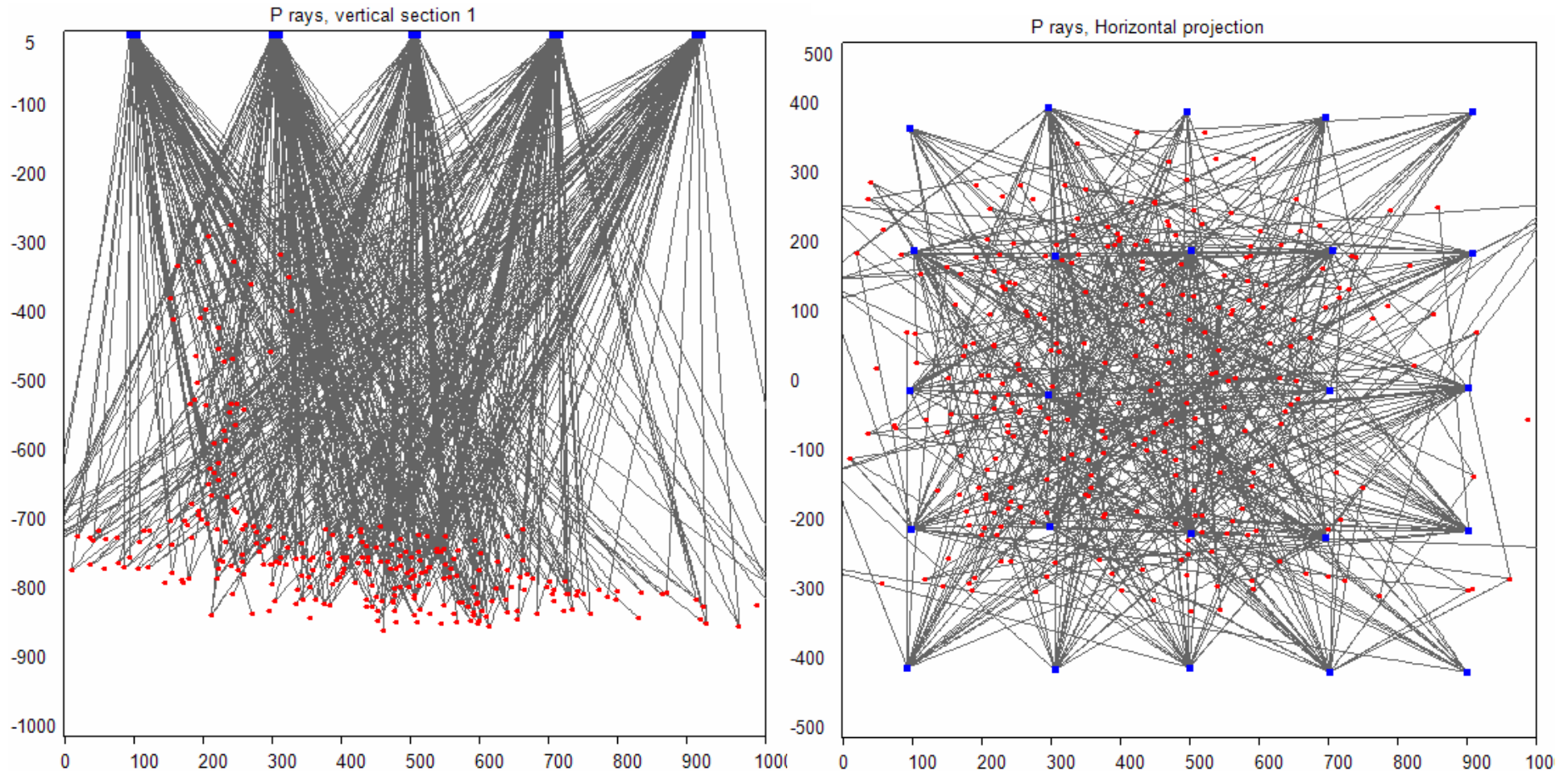
Number of P rays

The program asks for confirmation because it may overwrite a relevant data file



# Creating and visualizing the events and stations:

After finishing calculation, the program generates the plots with sources, receivers and synthetic ray paths in horizontal and vertical sections in PICS/MUD\_MOD1/obs\_system



In the DATA/MUD\_MOD1/initata folder, the files are properly organized. They represent the case of real data

# Preparing the model for the tomographic inversion:

Be sure that a model folder with the name of 8 characters is created. It should contain two files ref\_start.dat and MAJOR\_PARAM.DAT. Be especially careful with parameters highlighted in blocks. They should correspond to limits of the model:

The screenshot displays three windows from a Windows operating system. On the left is the 'Total Commander 6.03a' file manager, showing a directory tree with files like 'MAJOR\_PARAM' and 'ref\_start'. In the center and right are two instances of 'AkelPad' editing the 'MAJOR\_PARAM.DAT' file. The file contains a series of parameters for tomographic inversion, organized into sections. Several parameters are highlighted in yellow boxes, indicating they are critical for the model's limits. These include parameters for 1D model parameters, inversion parameters, 3D model parameters, and location parameters. The parameters are listed with their values and descriptions, such as 'KEY 1: REAL; KEY 2: SYNTHETIC', 'Iterations for 1D inversions', 'weight of the station corrections (P and S)', 'grid for ray density calculation (X)', 'grid for ray density calculation (Y)', 'min and max levels for grid', 'Grid type: 1: nodes, 2: blocks', 'min distance between nodes in vert. direction', 'plotmin, plotmax= maximal ray density, relative to average', 'Uppermost level for the nodes', 'step of movement along x', 'step of movement along z', 'Parameters for location in 3D model using bending tracing', 'Parameters for BENDING', 'Parameters for location', 'within this distance the weight is', 'power for decreasing of W with distance', 'lower limit for location (for LT residuals)', 'upper limit for location (for GT residuals)', and 'causes better coherency of P and S'.

```
*****
GENERAL INFORMATION :
1 KEY 1: REAL; KEY 2: SYNTHETIC
1 KEY 1: Vp and Vs; KEY 2: Vp and Vp/Vs
0 KEY 0: all data, KEY 1: odd events, KEY 2: even events
0 Ref. model optimization (0-no; 1-yes)
2 KEY 1: geographic coordinates; 2: Cartesian coordinates
1 KEY 1: True locations of events are available; KEY 0: Real

*****
ORIENTATIONS OF GRIDS :
4 number of grids
0 22 45 67 orientations

*****
1D MODEL PARAMETERS :
2 Iterations for 1D inversions
-10 3. 5 zmin, dzstep depth step for finding the best
1 1 300 dsmn, dzlay,zgrmax : parameters for 1D trace
5 dz_par, step for parameterization
0.2
6. 9. sm_p,sm_s
0.0 0.0 rg_p,rg_s
10 10 1 w_hor,w_ver,w_time
300 LSQR iterations
0 nsharp
27 27 z_sharp

*****
INVERSION PARAMETERS :
40 1 LSQR iterations, iter_max
1 1. Weights for P and S models in the upper part
25.0 25.0 level of smoothing (P, S and crust)
25.0 25.0 regularization level (P, S and crust)

0.0001 0.0001 weight of the station corrections (P and S)
10.0 wzt_hor
10.0 wzt_ver
5.0 wzt_time

*****
Coordinates of the start point for the location in 1D model
START_POINT:
500 0 700 xcoord, ycoord, zcoord

*****
Parameters for location in 1D model using reference table
and data selection:
*****
LIN_LOC_PARAM :
9 Minimal number of records
100 km, maximum distance to nearest station
1.7 S max resid with respect to P max resid
100 dist_limit=100 : within this distance the weight
1 n_pwr_dist=1 : power for decreasing of W with distance
30 ncyc_av=10

! For output:
30 bad_max=30 : maximal number of outliers
0.05 maximal dt/distance
30 distance limit

10 Frequency for output printing
3 Number of different grids

50 50 50 dx,dy,dz
0.0 res_loc1=0.2 : lower limit for location (for LT residuals)
40. res_loc2=1.5 : upper limit for location (for GT residuals)
2. w_P_S_diff=2 (+ causes better coherency of P and S)

*****
Parameters for 3D model with regular grid
*****
3D MODEL PARAMETERS:
0. 1000. 20 xx1, xx2, dxx,
-500. 500. 20 yy1, yy2, dyy,
-0 1000. 20 zz1, zz2, dzz
20 distance from nearest node
0 Smoothing factor1

*****
Depth limits for the source locations
*****
SRCE_LIMITS:
1100 Max allowed depth of earthquake

*****
Parameters for grid construction
*****
GRID PARAMETERS:
-1500. 1500. 30. grid for ray density calculation (X)
-1500. 1500. 30. grid for ray density calculation (Y)
-5. 1000. 20. min and max levels for grid
1 ! Grid type: 1: nodes, 2: blocks
20. !min distance between nodes in vert. direction
0.05 100.0 !plotmin, plotmax= maximal ray density, relative to average
-3. !zupper: Uppermost level for the nodes

1.0 !dx= step of movement along x
1.0 !dz= step of movement along z

*****
Parameters for location in 3D model using bending tracing
*****
LOC_PARAMETERS: Parameters for location in 3D
! Parameters for BENDING:
5 ds_ini: basic step along the rays
50 min step for bending
0.4 min value of bending
100 max value for bending in 1 step

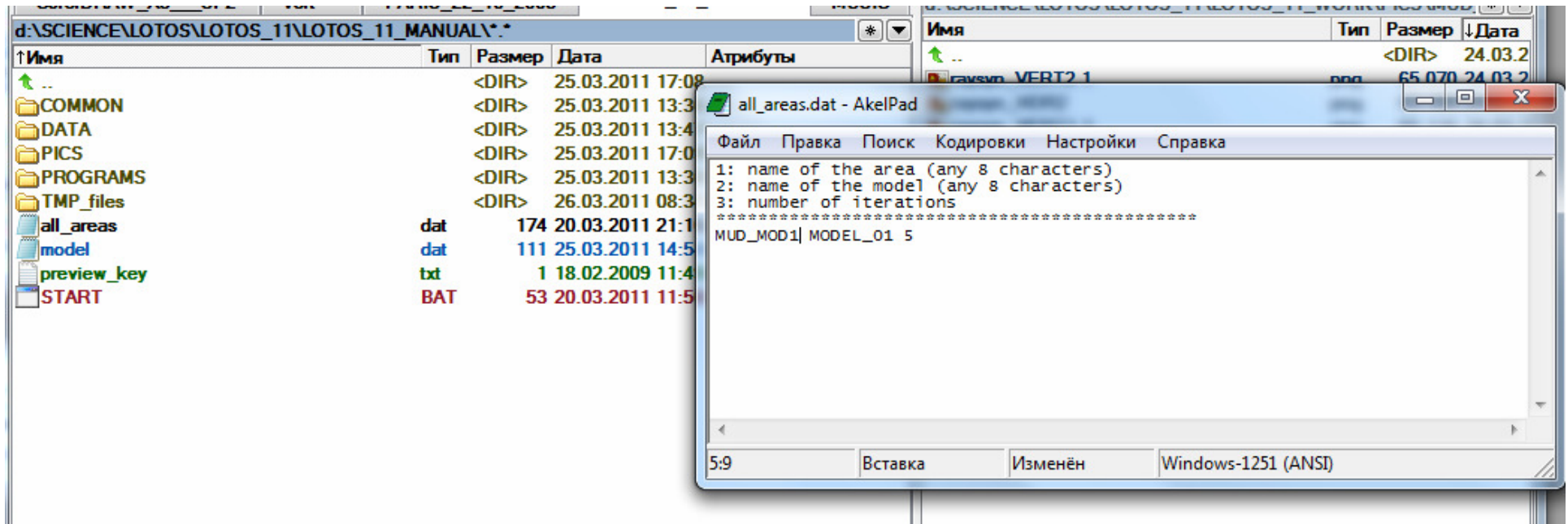
! Parameters for location
100 dist_limit=100 : within this distance the weight is
1 n_pwr_dist=1 : power for decreasing of W with distance
30 ncyc_av=10

0. res_loc1=0.2 : lower limit for location (for LT residuals)
10. res_loc2=1.5 : upper limit for location (for GT residuals)
2. w_P_S_diff=2 (+ causes better coherency of P and S)
50. stepmax
10. stepmin
```



# Running the tomographic inversion:

In the root folder in file “all\_areas.dat” define the name of the area and model that will be processed:



Then click on START.BAT and it will run the console

# Running the tomographic inversion:

Calculations start with preliminary source locations using straight lines as the ray paths

Start source locations using the 3D ray tracing code

```
C:\windows\system32\cmd.exe
A subdirectory or file ..\..\..\TMP_files\rays already exists.
A subdirectory or file ..\..\..\TMP_files\1D_mod already exists.
A subdirectory or file ..\..\..\TMP_files\vert already exists.
n_ar=
1
DATASET:MUD_MOD1 MODEL:MODEL_01
key_ft1_xy2= 2 kref= 0
1 file(s) copied.

PRELIMINARY LOCALIZATION OF SOURCES USING STRAIGHT RAYS
Preliminary location of sources using straight lines in the starting model
ar=MUD_MOD1 md=MODEL_01
nref= 2
nst= 24
10 goal= 0.9385806 err= 11.79056
20 goal= 0.8534636 err= 20.97158
30 goal= 0.8333189 err= 23.36870
40 goal= 0.8992980 err= 16.60365
50 goal= 0.9263662 err= 22.68051
60 goal= 0.9221687 err= 19.49776
70 goal= 0.9133840 err= 14.11797
80 goal= 0.8745198 err= 14.59564
90 goal= 0.8714378 err= 24.82930
100 goal= 0.8618082 err= 12.11483
110 goal= 0.7242336 err= 17.14297
120 goal= 0.8701032 err= 10.50032
130 goal= 0.7567356 err= 11.18670
140 goal= 0.7819677 err= 19.07337
150 goal= 0.8673593 err= 37.95326
160 goal= 0.8199968 err= 23.52433
170 goal= 0.9298037 err= 19.54255
180 goal= 0.9515170 err= 15.97040
190 goal= 0.9583993 err= 19.38873
200 goal= 0.9269031 err= 8.369435
210 goal= 0.8846579 err= 20.87315
220 goal= 0.8044080 err= 16.85744
230 goal= 0.8489386 err= 23.82999
240 goal= 0.9691785 err= 0.9896887
250 goal= 0.8948867 err= 23.95334
260 goal= 0.8675178 err= 24.50414
270 goal= 0.9398813 err= 24.79888
280 goal= 0.8782298 err= 22.92866
290 goal= 0.9313650 err= 25.02690
Average error of source location = 19.44132
A subdirectory or file ..\..\..\PICS\MUD_MOD1\MODEL_01 already exists.
1 file(s) copied.
Vertical: 1 dist= 1000.000 npix_x= 497 npix_z= 500
Horizontal: npix_x= 500 npix_y= 500

LOCATE THE SOURCES USING THE 3D RAY TRACING
SOURCE LOCATION: ar=MUD_MOD1 md=MODEL_01 it=1
A subdirectory or file ..\..\..\TMP_files\tmp already exists.
cannot find REF_PARAM in MAJOR_PARAM.DAT!!!
ar=MUD_MOD1 md=MODEL_01
nan= 0
nref= 4
536.0000 26.000000 727.0000 44
536.0000 26.000000 727.0000
old resid= 1.114701 new_resid= 1.146966 red= -2.894452
10 317 ds= 0.0000000E+00 G= 0.9413223
*****
383.0000 -59.000000 686.0000 33
383.0000 -59.000000 686.0000
old resid= 1.237800 new_resid= 1.268019 red= -2.441392
20 607 ds= 0.0000000E+00 G= 0.8482091
*****
```

Error of source location in respect to true ones

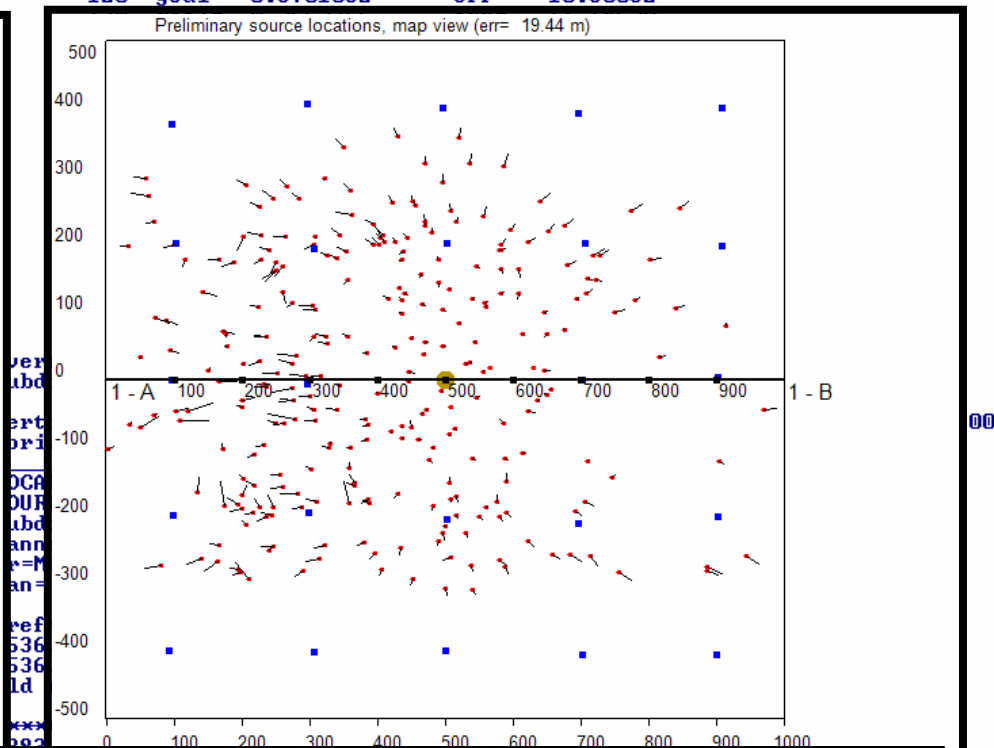
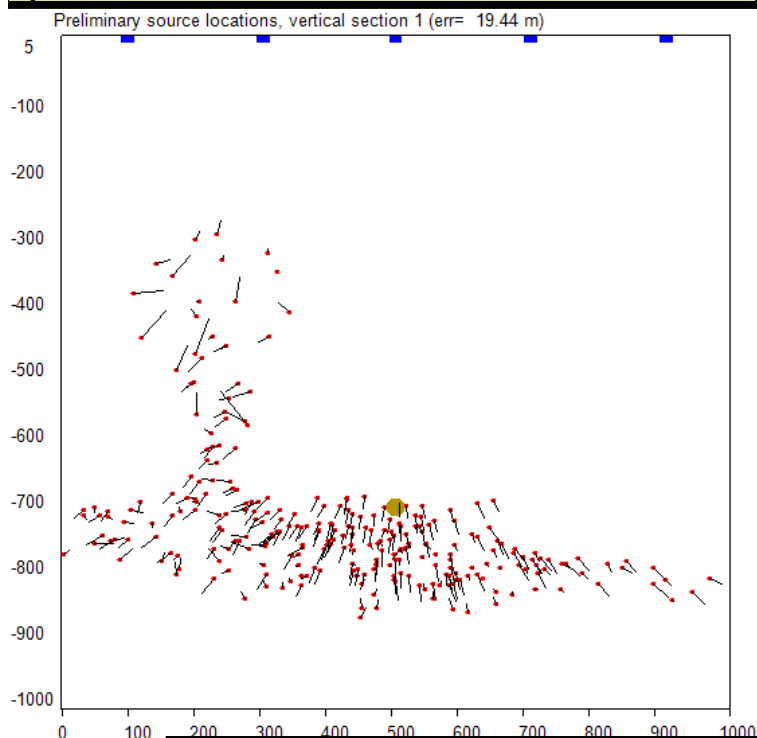
# Running the tomographic inversion:

Calculations start with preliminary source locations using straight lines as the ray paths

```
C:\windows\system32\cmd.exe
A subdirectory or file ..\..\..\TMP_files\rays already exists.
A subdirectory or file ..\..\..\TMP_files\1D_mod already exists.
A subdirectory or file ..\..\..\TMP_files\vert already exists.
n_ar=
1
DATASET:MUD_MOD1 MODEL:MODEL_01
key_ft1_xy2= 2 kref= 0
1 file(s) copied.

PRELIMINARY LOCALIZATION OF SOURCES USING STRAIGHT RAYS
Preliminary location of sources using straight lines in the starting model
ar=MUD_MOD1 md=MODEL_01
nref=
2
nst=
24
10 goal= 0.9385806 err= 11.79056
20 goal= 0.8534636 err= 20.97158
30 goal= 0.8333189 err= 23.36870
40 goal= 0.8992980 err= 16.60365
50 goal= 0.9263662 err= 22.68051
60 goal= 0.9221687 err= 19.49776
70 goal= 0.9133840 err= 14.11797
80 goal= 0.8745198 err= 14.59564
90 goal= 0.8714378 err= 24.82930
100 goal= 0.8618082 err= 12.11483
110 goal= 0.7242336 err= 17.14297
120 goal= 0.8701032 err= 10.50032
```

Error of source location in respect to true ones



In this stage we can see the results of source locations in ver and hor sections in folder PICS/MUD\_MOD1/MODEL\_01/LOC

# Running the tomographic inversion:

Compute the ray density and construct the grid

```
*****
err_loc@= 19.44132 err_loc= 19.32629
nzt= 291 nray= 9032
A subdirectory or file ..\..\..\PICS\MUD_MOD1\MODEL_01\LOC already exists.
1 file(s) copied.
Vertical: 1 dist= 1000.000 npix_x= 497 npix_z= 500
Horizontal: npix_x= 500 npix_y= 500
nst= 24

COMPUTE THE RAY DENSITY
Computing ray density
ar=MUD_MOD1 md=MODEL_01 it=1 gr=1
orient= 0.0000000E+00
nx= 100 ny= 100 nz= 50
nzt= 100 nray= 1792 1267
nzt= 200 nray= 3543 2474
total number of rays: 5183 3637

DEFINE THE PARAMETERIZATION GRID
execution grid
ar=MUD_MOD1 md=MODEL_01 it=1 gr=1
nx= 100 ny= 100 nz= 50
nmax_p= 100000
aver ray length in one block= 182.3893
iy= 40 node= 416 yy= -315.0000
iy= 45 node= 544 yy= -165.0000
iy= 50 node= 478 yy= -15.00000
iy= 55 node= 551 yy= 135.0000
iy= 60 node= 453 yy= 285.0000
number of valuable velocity parameters: 10220
aver ray length in one block= 135.7987
iy= 40 node= 397 yy= -315.0000
iy= 45 node= 519 yy= -165.0000
iy= 50 node= 458 yy= -15.00000
iy= 55 node= 523 yy= 135.0000
iy= 60 node= 408 yy= 285.0000
number of valuable velocity parameters: 9591
execution of Tetrad
ar=MUD_MOD1 md=MODEL_01 it=1 gr=1
nur= 5 ntet= 2457 ntop= 416
nur= 10 ntet= 2997 ntop= 544
nur= 15 ntet= 2853 ntop= 478
nur= 20 ntet= 2994 ntop= 551
nur= 25 ntet= 2259 ntop= 453
nur= 5 ntet= 2347 ntop= 397
nur= 10 ntet= 2837 ntop= 519
nur= 15 ntet= 2694 ntop= 458
nur= 20 ntet= 2844 ntop= 523
nur= 25 ntet= 2049 ntop= 408
execution of sosed1
ar=MUD_MOD1 md=MODEL_01 it= gr=
ilev= 5 notr<ilev>= 2592 total= 7380
ilev= 10 notr<ilev>= 3100 total= 21897
ilev= 15 notr<ilev>= 3052 total= 36749
ilev= 20 notr<ilev>= 3037 total= 52111
ilev= 25 notr<ilev>= 2169 total= 65419
ilev= 5 notr<ilev>= 2468 total= 6964
ilev= 10 notr<ilev>= 2905 total= 20694
ilev= 15 notr<ilev>= 2851 total= 34547
ilev= 20 notr<ilev>= 2868 total= 49003
ilev= 25 notr<ilev>= 1954 total= 61285

VISUALIZE THE RAY PATHS AND GRID IN HORIZONTAL AND VERTICAL SECTIONS
A subdirectory or file ..\..\..\TMP_files\rays already exists.
ar=MUD_MOD1 md=MODEL_01 iter= 1
1 dist= 1000.000 nrtot= 9032 nptot= 237484
```

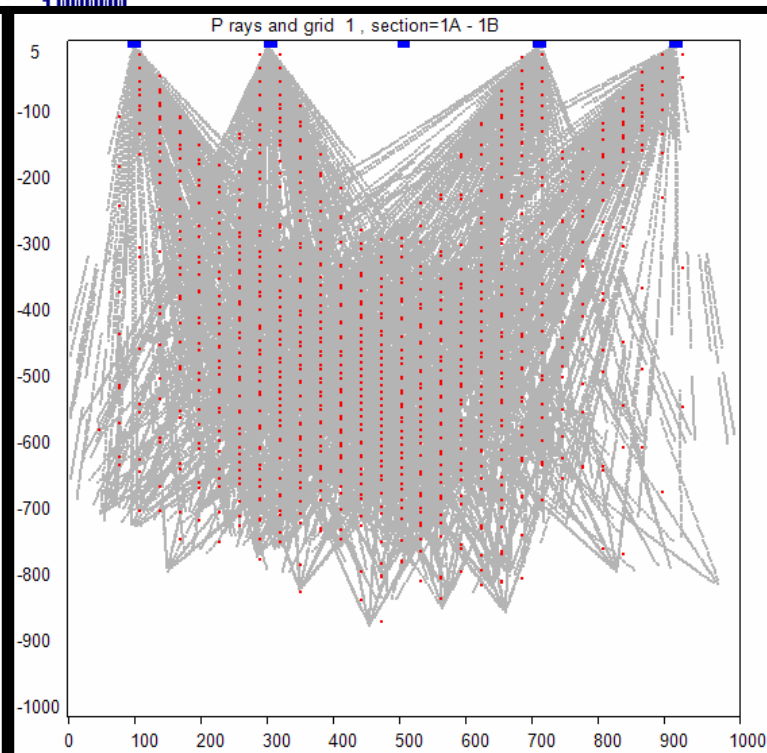
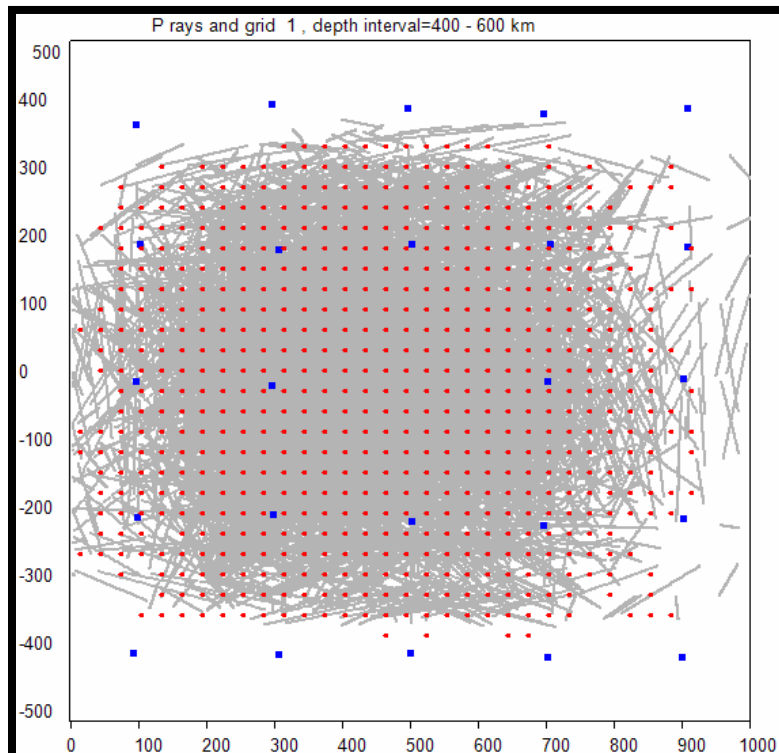
# Running the tomographic inversion:

Compute the ray density and construct the grid

```
*****
err_loc@= 19.44132 err_loc= 19.32629
nzt= 291 nray= 9032
A subdirectory or file ..\..\..\PICS\MUD_MOD1\MODEL_01\LOC already exists.
1 file(s) copied.
Vertical: 1 dist= 1000.000 npix_x= 497 npix_z= 500
Horizontal: npix_x= 500 npix_y= 500
nzt= 24

COMPUTE THE RAY DENSITY
Computing ray density
ar=MUD_MOD1 md=MODEL_01 it=1 gr=1
orient= 0.0000000E+00
nx= 100 ny= 100 nz= 50
nzt= 100 nray= 1792 1267
nzt= 200 nray= 3543 2474
total number of rays: 5183 3637

DEFINE THE PARAMETERIZATION GRID
execution grid
ar=MUD_MOD1 md=MODEL_01 it=1 gr=1
nx= 100 ny= 100 nz= 50
nray= 100000
```



ilev= 25 ntr(ilev)= 1954 total= 61285

In this stage we can see the results of grid construction in ver and hor sections in folder PICS/MUD\_MOD1/MODEL\_01/RAYS\_GRID

# Running the tomographic inversion:

```

ilev=      15  notr(ilev)=      3052  total=      36749
ilev=      20  notr(ilev)=      3037  total=      52111
ilev=      25  notr(ilev)=      2169  total=      65419
ilev=       5  notr(ilev)=      2468  total=       6964
ilev=      10  notr(ilev)=      2905  total=      20694
ilev=      15  notr(ilev)=      2851  total=      34547
ilev=      20  notr(ilev)=      2868  total=      49003
ilev=      25  notr(ilev)=      1954  total=      61285

VISUALIZE T
A subdirector ar=MUD_MOD1 IN HORIZONTAL AND VERTICAL SECTIONS
P_files\rays already exists.
1 dist= 1000.000 nrtot= 9032 nptot= 237484
ilev= 1 z1= -10.0 z2= 400.0 nrtot= 18064 nptot= 1100777
ilev= 2 z1= 400.0 z2= 600.0 nrtot= 27096 nptot= 1514700
ilev= 3 z1= 600.0 z2= 800.0 nrtot= 36128 nptot= 1815400
1 file(s) copied.
Horizontal: npix_x= 500 npix_y= 500
section:1 dist= 1000.000 npix_x_ver= 497

COMPUTE THE 1ST DERIVATIVE MATRIX <UP-US SCHEME>
execution of matr
ar=MUD_MOD1 md=MODEL_01 it=1 gr=1
orient= 0.00000000E+00
nref= 2
nymax= 29 ntnmax= 10220
nmax= 551 otr nmax= 1582
number of velocity parameters= 10220
number of velocity parameters= 9591
1000 33 1 121 -0.788
2000 64 2 176 -2.352
3000 97 1 145 0.090
4000 128 1 143 0.863
5000 162 1 73 0.060
6000 195 1 166 1.158
7000 227 2 126 -0.019
8000 257 1 129 3.398
9000 290 1 182 -0.543
nray= 9032 nzt= 291
nabr= 10220 nonzer= 1128272
nrs= 5183 nonz_p= 654718
nrs= 3849 nonz_s= 473554

PERFORM THE INVERSION <UP-US SCHEME>
execution of invers
ar=MUD_MOD1 md=MODEL_01 it=1
nref= 2
nan= 0
nst= 24
Number of rays = 9032 9032 nzt= 291
nst_p= 24 nst_s= 24
Preliminary values: N rows= 159193 N nonzer= 1453943
N rows= 159193 N columns= 21023 N nonzer= 1453943
iter= 20
iter= 40
nray= 9032
avres0= 1.571272 avres= 0.8861332 red= 43.60410
nrps= 5183 3637
total avdv_p= 0.1906749 avdv_s= 0.5518757
avstat_p= 3.5689014E-09 avstat_s= 1.4389984E-09
source corrections:
av1= 4.848230 av2= 1.818011 av3= 0.3398348

```

numbers of  
nodes in P and  
S models

number of non-  
zero elements  
in the main  
matrix

total number of  
unknown

variance  
reduction in  
matrix  
inversion

Compute the first derivative  
matrix

Perform the inversion

This loop is repeated for four  
differently oriented grids



# Running the tomographic inversion:

After computing results in four grids, we create one average model

Visualize the result in horizontal and vertical sections

Next iteration starts with source location in the updated velocity model

```
izz=      20  zzz= 380.0000
izz=      25  zzz= 480.0000
izz=      30  zzz= 580.0000
izz=      35  zzz= 680.0000
izz=      40  zzz= 780.0000
izz=      45  zzz= 880.0000
izz=      50  zzz= 980.0000
nx=      51  ny=      51  nz=      51

VISUALIZE THE RESULT IN HORIZONTAL SECTIONS <UP-US SCHEME>
A subdirectory or file ..\..\..\TMP_files\hor already exists.
  1 file(s) copied.
  1 file(s) copied.
  1 file(s) copied.
ar=MUD_MOD1 md=MODEL_01
npix_x=      500  npix_y=      500
nmap=      201  nmap=      201
nref=      2
ilev=      1  nzst=      10
ilev=      2  nzst=      21
ilev=      3  nzst=      210
ilev=      1  zzz= 300.0000
ilev=      2  zzz= 500.0000
ilev=      3  zzz= 700.0000

VISUALIZE THE RESULT IN VERTICAL SECTIONS <UP-US SCHEME>
ar=MUD_MOD1 md=MODEL_01 iter=      1
A subdirectory or file ..\..\..\TMP_files\vert already exists.
A subdirectory or file ..\..\..\PICS\MUD_MOD1\MODEL_01\IT1 already exists
  1 file(s) copied.
  1 file(s) copied.
  1 file(s) copied.
  1 file(s) copied.
  1 file(s) copied.
nref=      2
nst1=      4  nzt1=      35
section: 1 dist= 1000.000  npix_x=      4
section: 1 dist= 1000.000  npix_x=      4
npix_x=      500  npix_y=      500

LOCATE THE SOURCES USING THE 3D RAY TRACING
SOURCE LOCATION: ar=MUD_MOD1 md=MODEL_01 it=2
A subdirectory or file ..\..\..\TMP_files\tmp already exists
cannot find REF_PARAM in MAJOR_PARAM.DAT!!!
ar=MUD_MOD1 md=MODEL_01
nan=      0
nref=      4
  538.4921  25.07332  726.1299  44
  538.4921  25.07332  726.1299
old resid= 1.146966  new_resid= 0.7013815  red= 38.84897
  10  317  ds= 2.797594  G= 0.9747321
*****
  387.1138  -61.09050  689.2866  33
  387.2022  -61.59073  693.0360
old resid= 1.268019  new_resid= 0.7894025  red= 37.74523
  20  607  ds= 8.595094  G= 0.8813775
*****
  441.3703  180.8618  784.7817  30
  441.7571  180.6161  787.7507
old resid= 1.159297  new_resid= 0.7419356  red= 36.00125
  30  912  ds= 8.293923  G= 0.8567482
*****
  451.3696  -70.14542  848.0112  19
  451.3696  -70.14542  848.0112
old resid= 1.171009  new_resid= 0.7300680  red= 37.65480
  40  1242  ds= 2.419172  G= 0.9358814
```

reduction of  
the residuals in  
respect to  
previous  
iteration, in%

# Running the tomographic inversion:

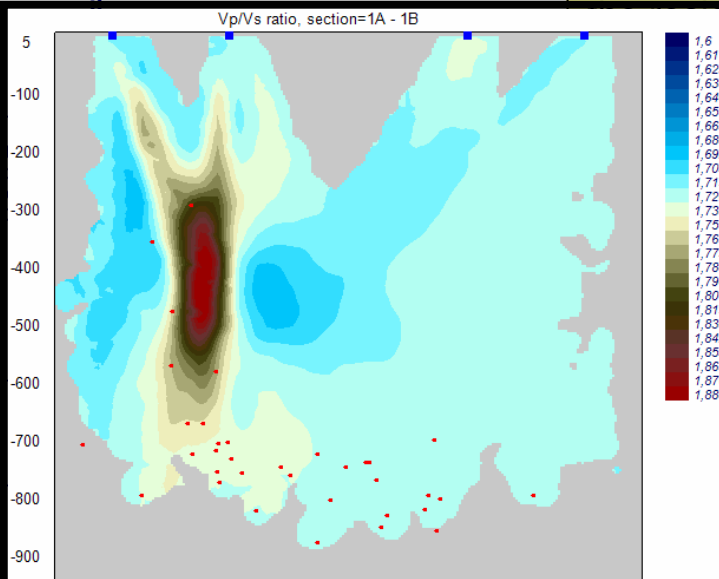
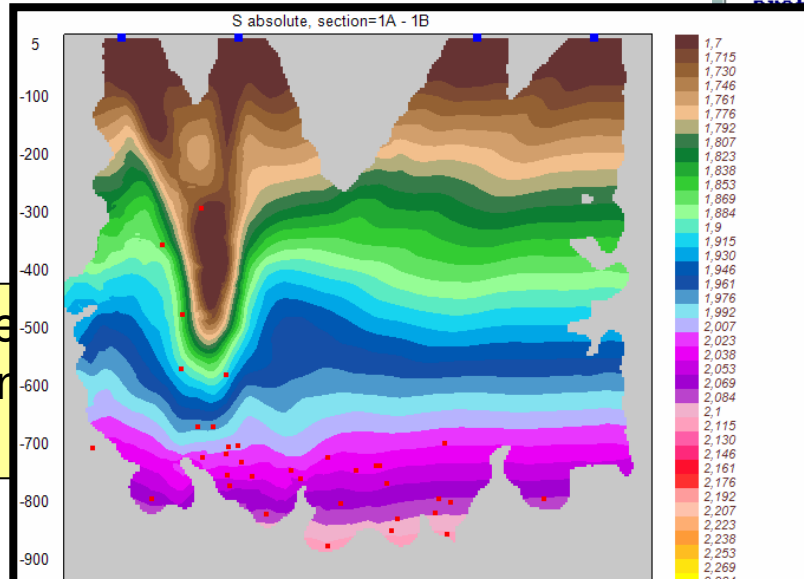
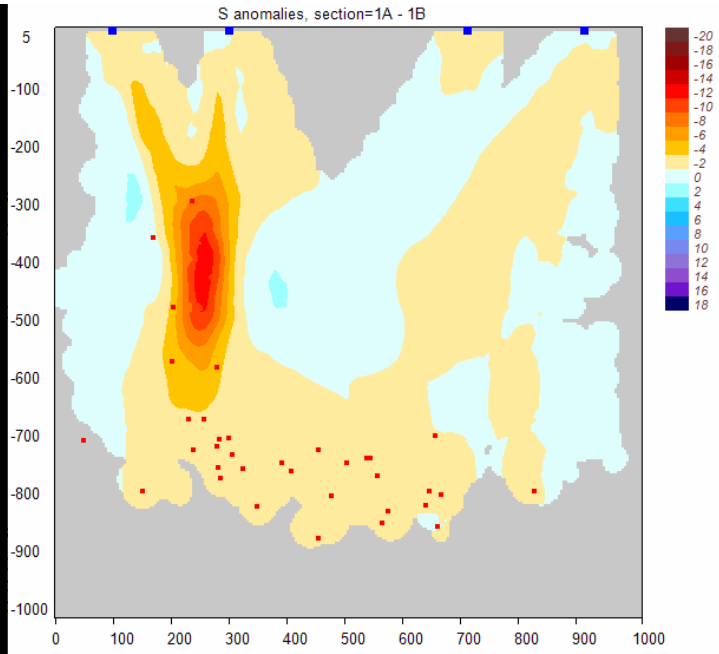
After computing results in four grids, we create one average model

Visualize the result in horizontal and vertical sections

```
izz=  
izz=  
izz=  
izz=  
izz=  
nx=
```

```
VISUALIZE  
A subdirect  
1 f  
1 f  
1 f  
ar=MUD_MOI  
npix_x=  
nfmap=  
nref=  
ilev=  
ilev=  
ilev=  
ilev=  
ilev=
```

```
VISUALIZE  
ar=MUD_MOI  
A subdirect  
A subdirect  
1 f  
1 f  
1 f  
1 f  
1 f  
1 file(s) copied.
```



Next iteration  
location  
model

After each iteration we can see the inversion results presented in vertical and horizontal sections in folder PICS/MUD\_MOD1/MODEL\_01/IT1

# Running the tomographic inversion:

```

C:\windows\system32\cmd.exe

izz=      20   zzz= 380.0000
izz=      25   zzz= 480.0000
izz=      30   zzz= 580.0000
izz=      35   zzz= 680.0000
izz=      40   zzz= 780.0000
izz=      45   zzz= 880.0000
izz=      50   zzz= 980.0000
nx=       51   ny=       51   nz=       51

VISUALIZE THE RESULT IN HORIZONTAL SECTIONS <UP-US SCHEME>
A subdirectory or file ..\..\..\TMP_files\hor already exists.
  1 file(s) copied.
  1 file(s) copied.
  1 file(s) copied.
ar=MUD_MOD1 md=MODEL_01
npix_x=      500   npix_y=      500
nfmap=      201   ntmap=      201
nref=        2
ilev=        1   nzst=        12
ilev=        2   nzst=        20
ilev=        3   nzst=       212
ilev=        1   zzz=   300.0000
ilev=        2   zzz=   500.0000
ilev=        3   zzz=   700.0000

VISUALIZE THE RESULT IN VERTICAL SECTIONS <UP-US SCHEME>
ar=MUD_MOD1 md=MODEL_01 iter=      5
A subdirectory or file ..\..\..\TMP_files\vert already exists.
A subdirectory or file ..\..\..\PICS\MUD_MOD1\MODEL_01\IT5 already exists.
  1 file(s) copied.
  1 file(s) copied.
  1 file(s) copied.
  1 file(s) copied.
  1 file(s) copied.
nref=        2
nst1=        4   nzt1=        35
section: 1 dist= 1000.000   npix_x=      497
section: 1 dist= 1000.000   npix_x=      497
npix_x=      500   npix_y=      500

CREATING THE REPORT ABOUT THE VARIANCE REDUCTION
ar=MUD_MOD1 md=MODEL_01 niter=      5
nbad=        0
iter=        1   dtot_p=  0.9701900   red=  0.00000000E+00
iter=        1   dtot_s=  2.380682   red=  0.00000000E+00
Source mislocation: 19.32629

iter=        2   dtot_p=  0.7188722   red=  25.90397
iter=        2   dtot_s=  1.400773   red=  41.16088
Source mislocation: 17.27818

iter=        3   dtot_p=  0.5913971   red=  39.04316
iter=        3   dtot_s=  1.108027   red=  53.45761
Source mislocation: 16.49232

iter=        4   dtot_p=  0.5190980   red=  46.49522
iter=        4   dtot_s=  0.9876495   red=  58.51402
Source mislocation: 16.12297

iter=        5   dtot_p=  0.4692164   red=  51.63665
iter=        5   dtot_s=  0.9166359   red=  61.49692
Source mislocation: 16.00161

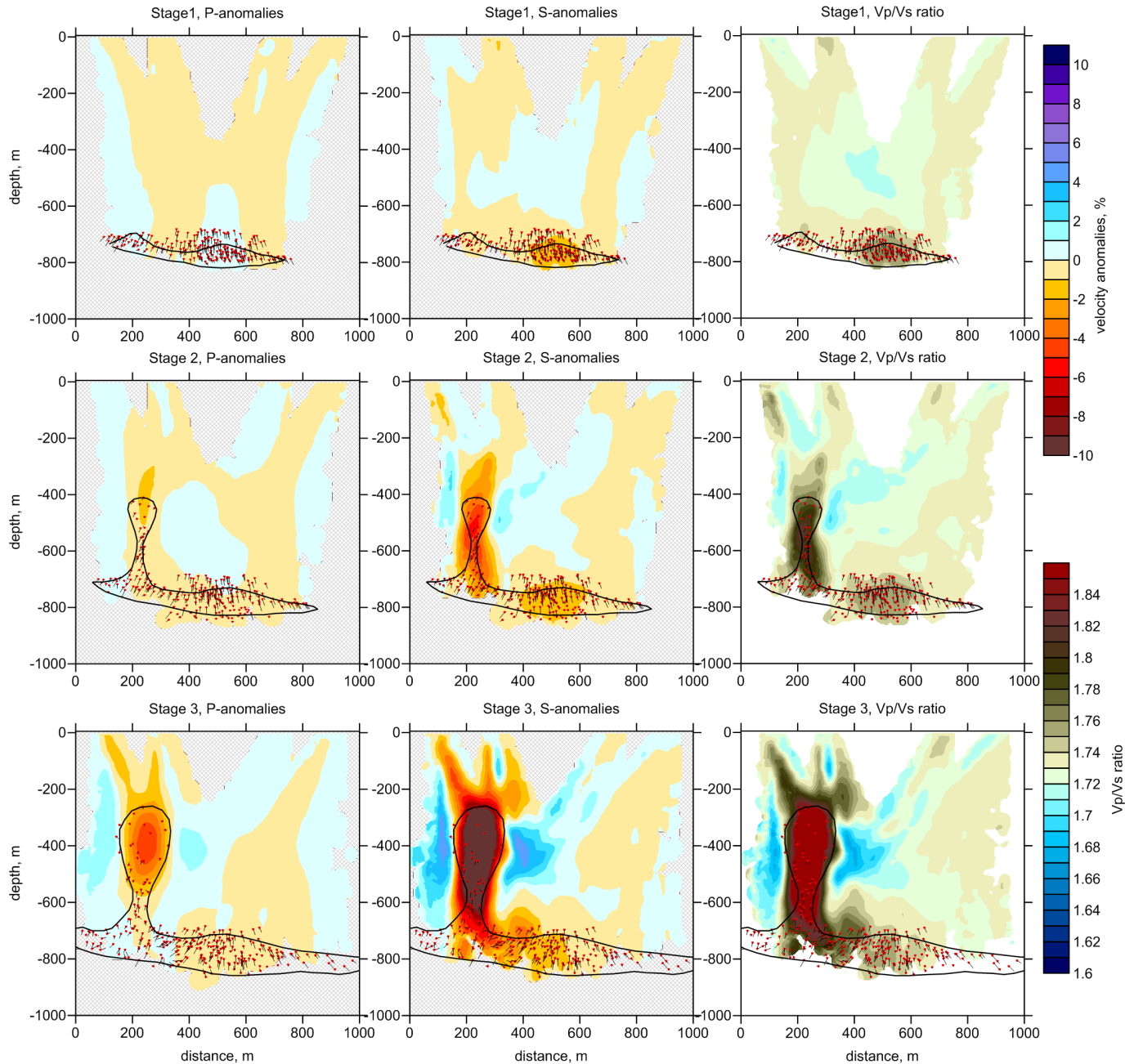
nsrcs=      291   nray_p=      5183   nray_s=      3849

D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\@_START\START>pause
Press any key to continue . . .

```

Calculations end with the report on the accuracy of source locations and mean residuals in iterations

# Presenting the inversion results in Surfer:



Files for  
visualization in  
Surfer (5<sup>th</sup> iteration,  
1<sup>st</sup> section)

Located events in vertical section:  
TMP\_files\loc\srces\_ver5 1.dat

Event mislocations:  
TMP\_files\loc\shift\_ver5 1.bl

P-velocity anomalies:  
TMP\_files\vert\ver\_15 1.grd

S-velocity anomalies:  
TMP\_files\vert\ver\_25 1.grd

P-absolute velocity:  
TMP\_files\vert\abs\_15 1.grd

**S-absolute velocity:**  
**TMP\_files\vert\abs\_25 1.grd**

Vp/Vs ratio:  
TMP\_files\vert\vpvs\_5 1.grd

Running a new model  
will overwrite these  
files!