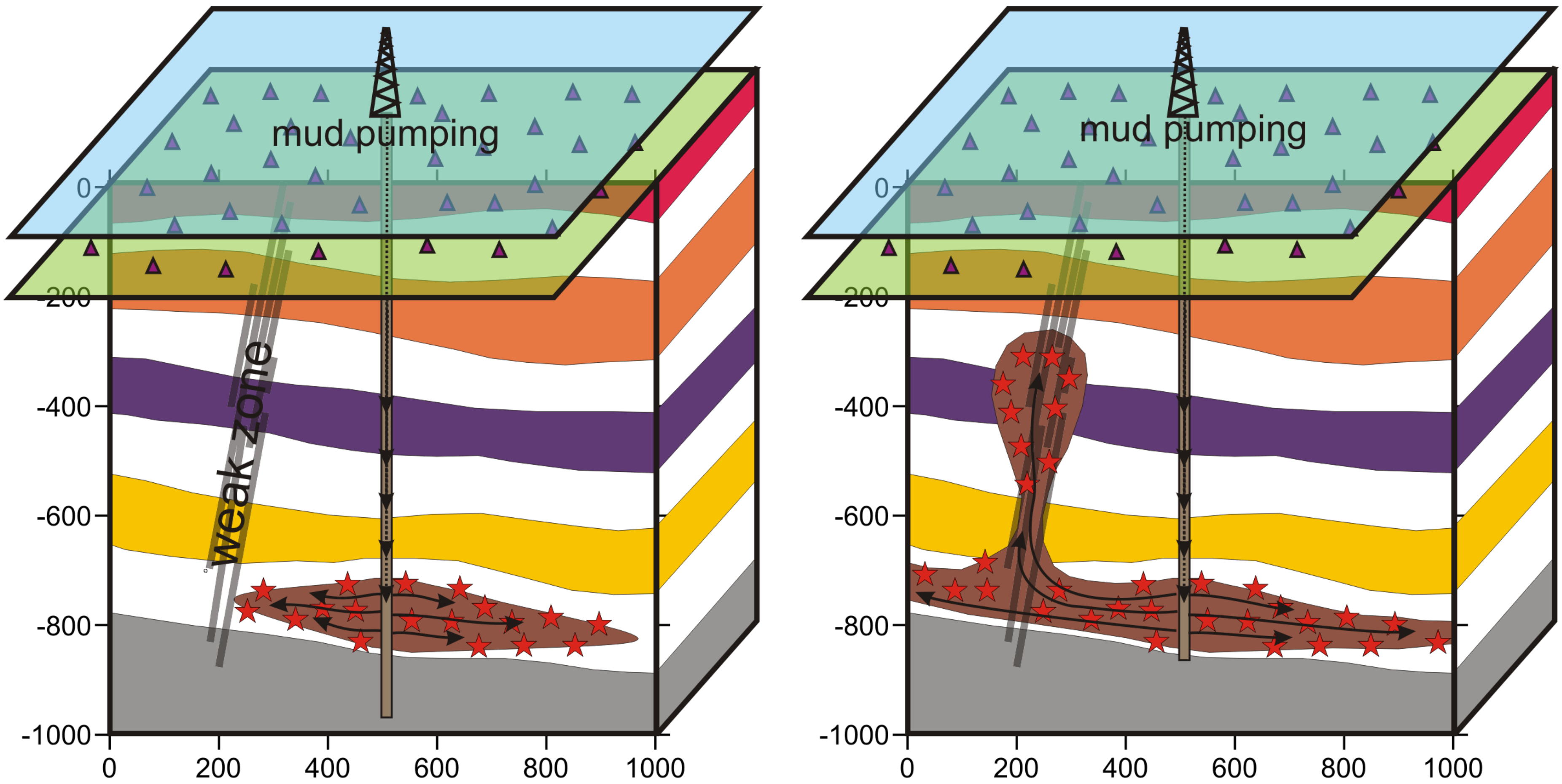
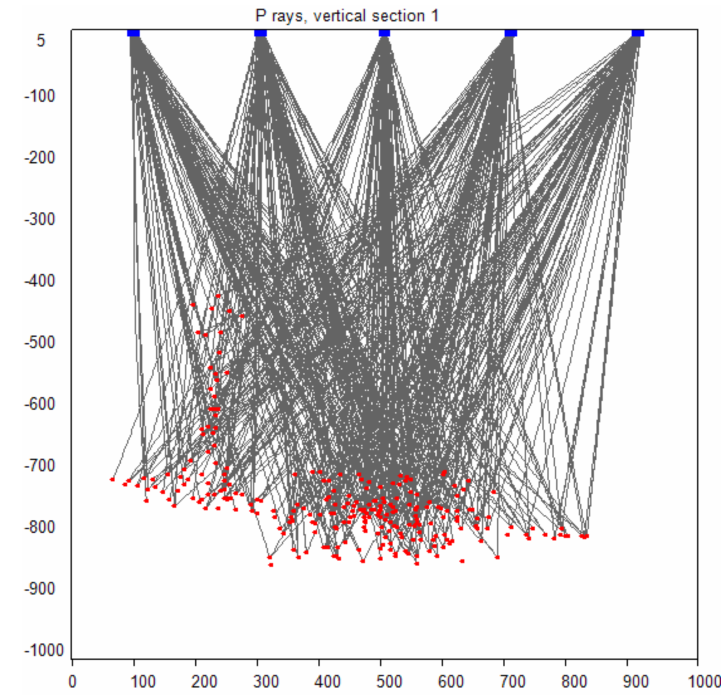
User instruction

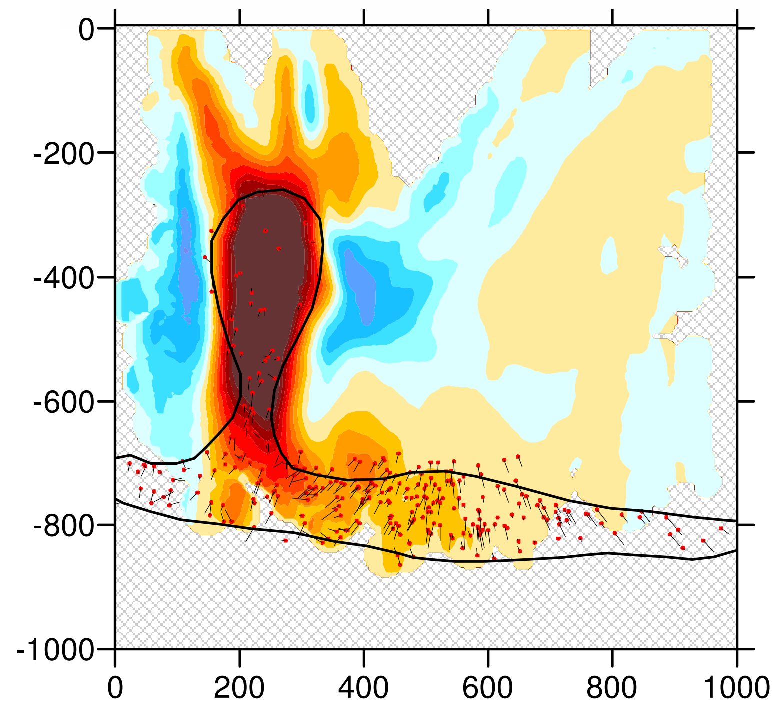
for performing synthetic modeling in XYZ using the LOTOS code for passive source tomography



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

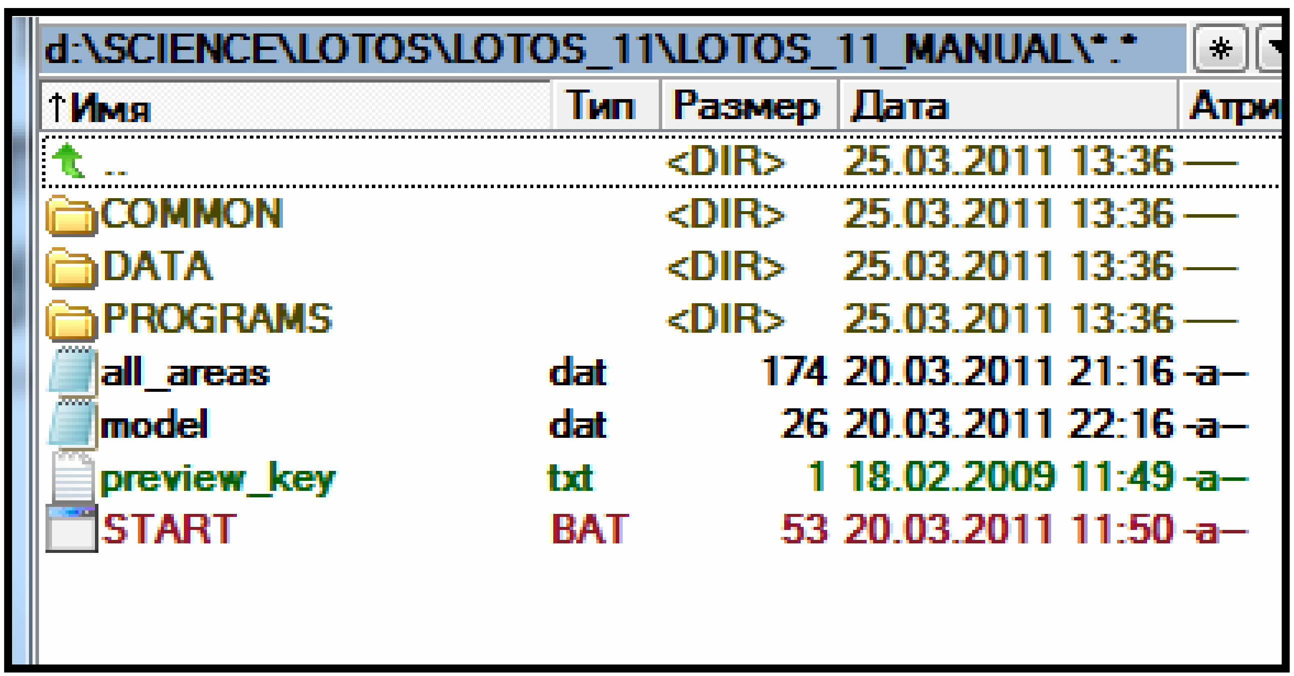




Preparation stage:

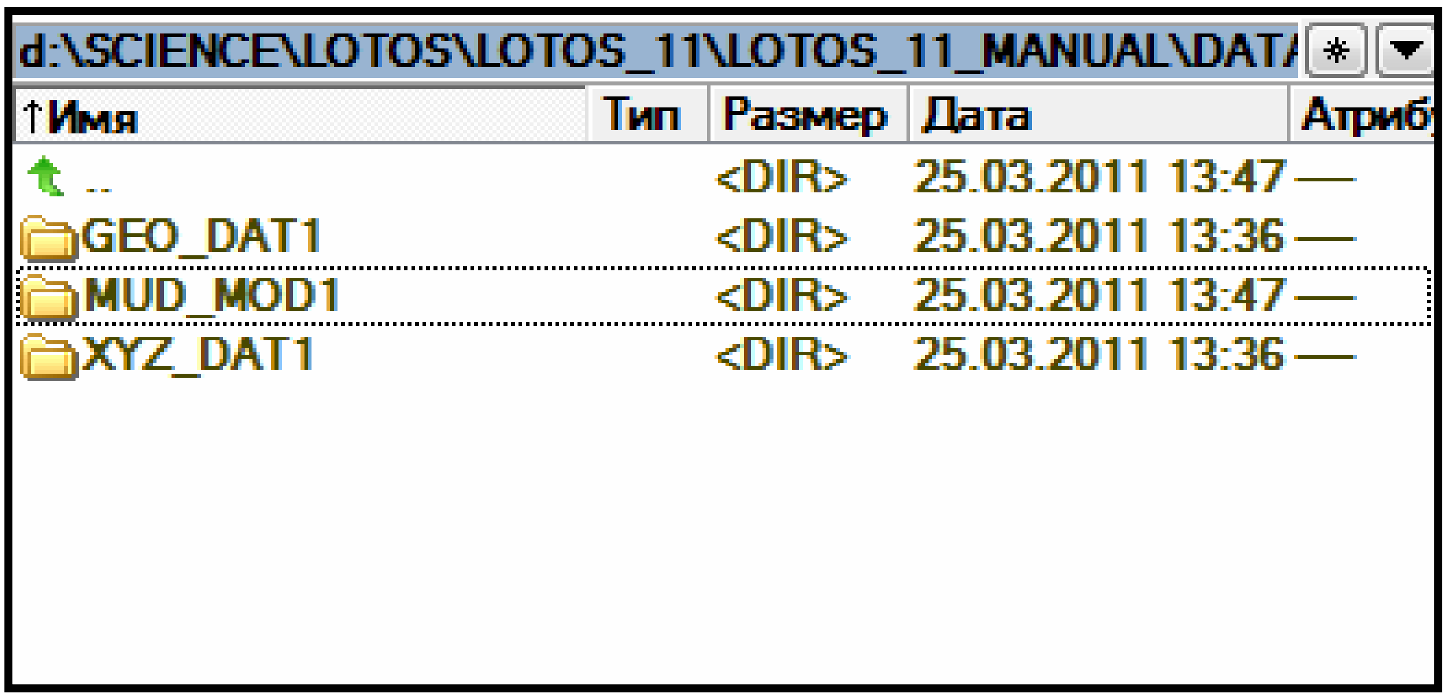
1. In this manual, the SURFER software will be used as a basic tool for digitizing and visualization. Alternatively, other free tools are available in the code.

2. Copy the folder “LOTOS_11_release” to any location of the computer. The structure of the root folder is presented below:



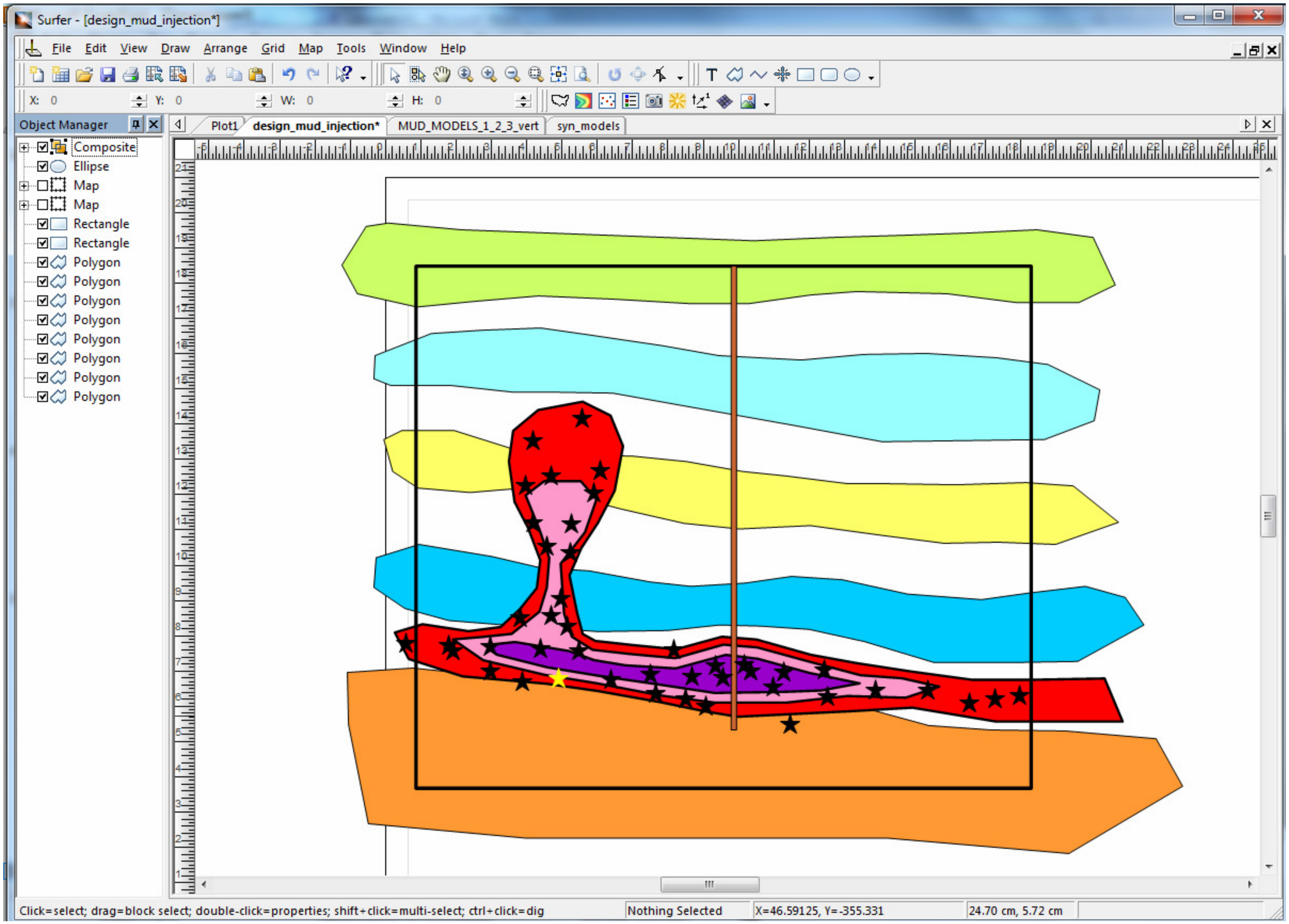
Preparation of a new model:

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.



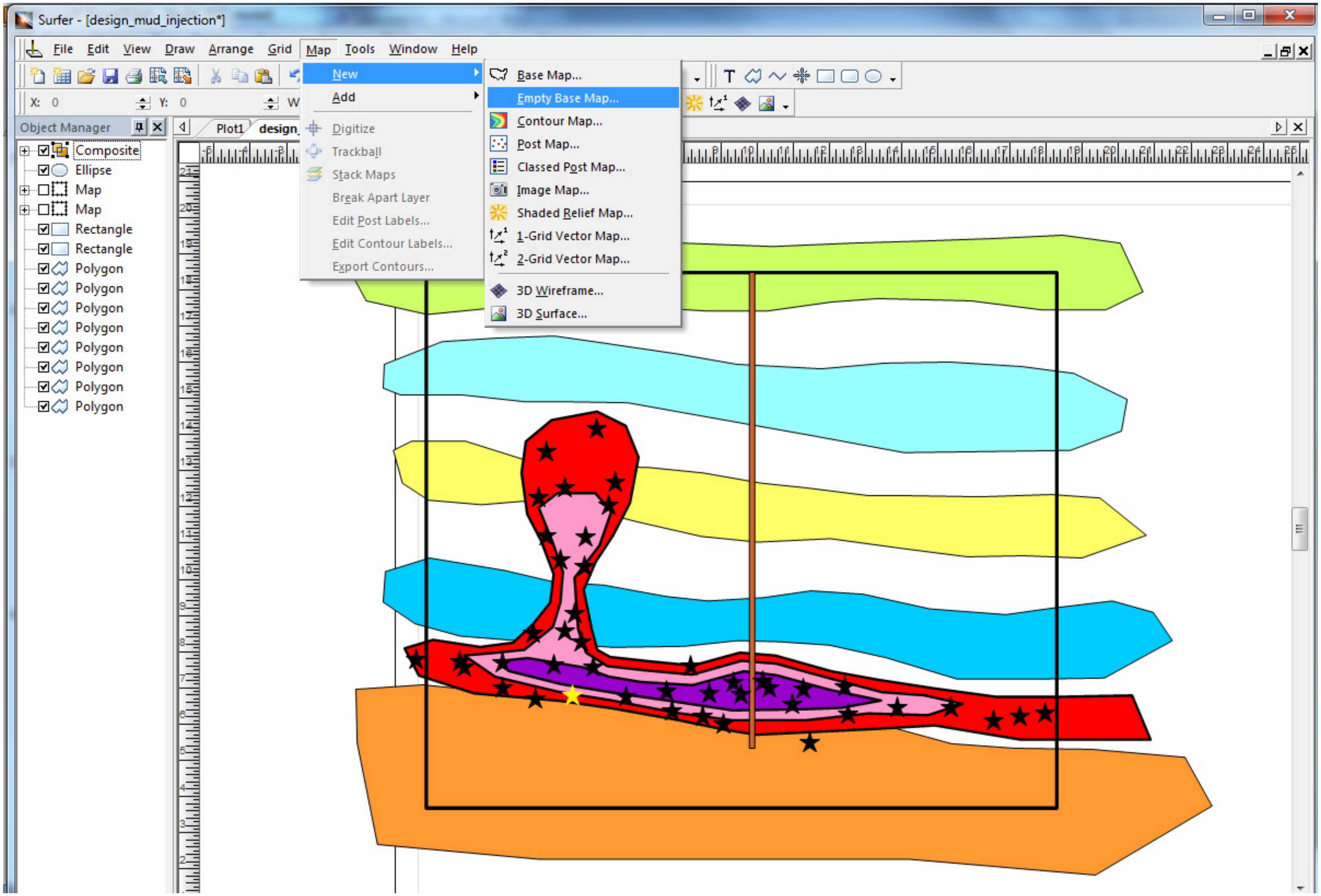
Design of the model:

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:



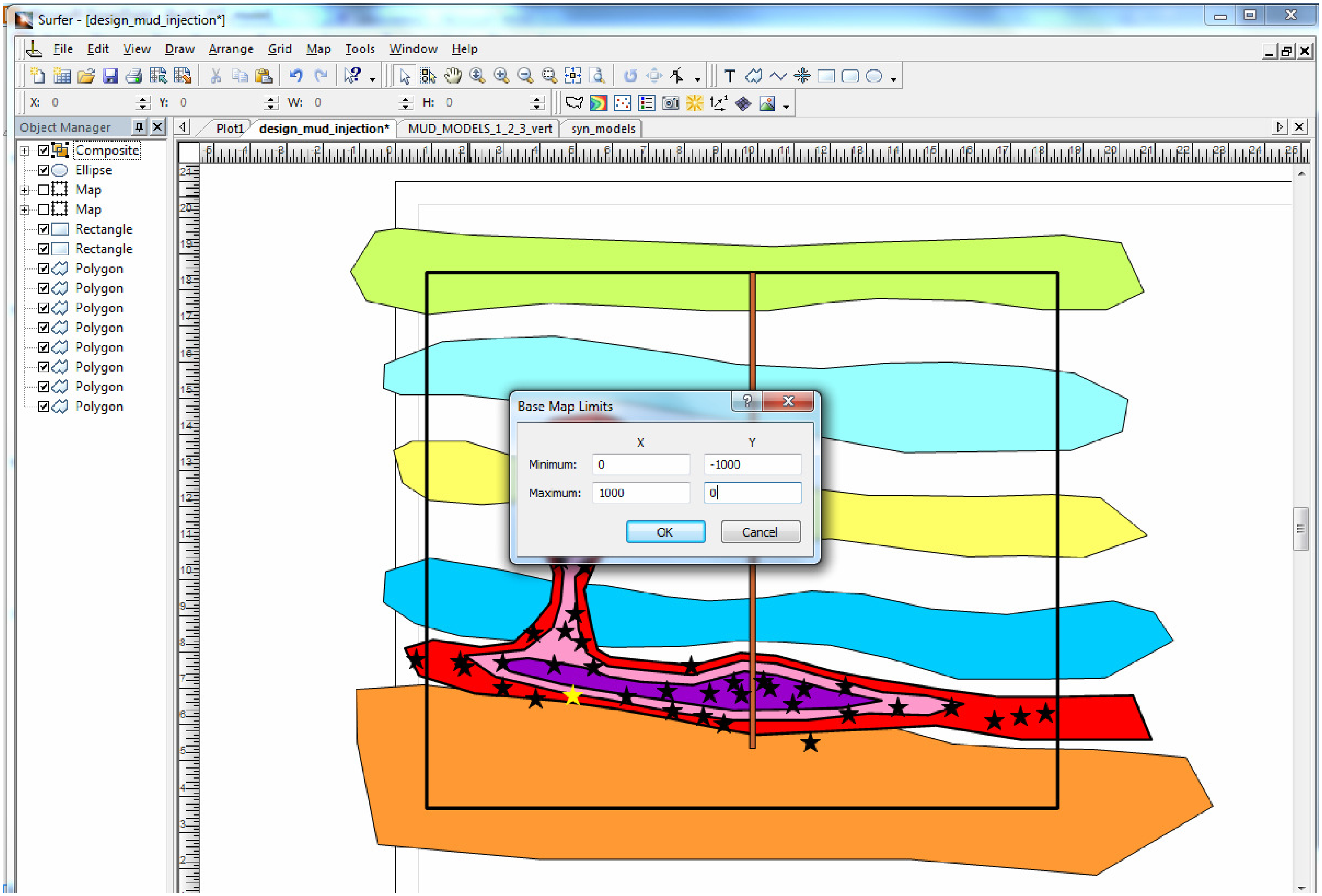
Digitizing the synthetic model:

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



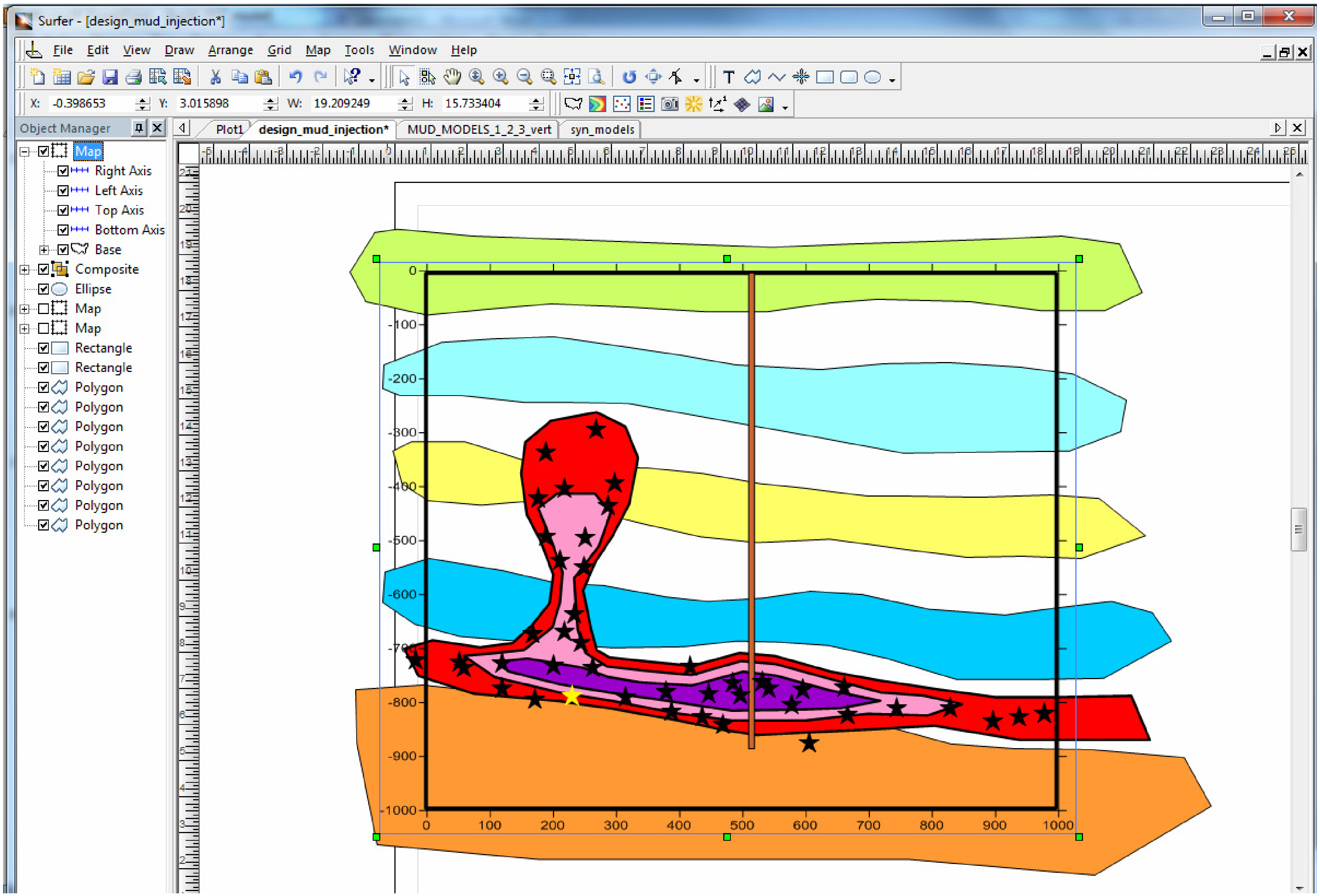
Digitizing the synthetic model:

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



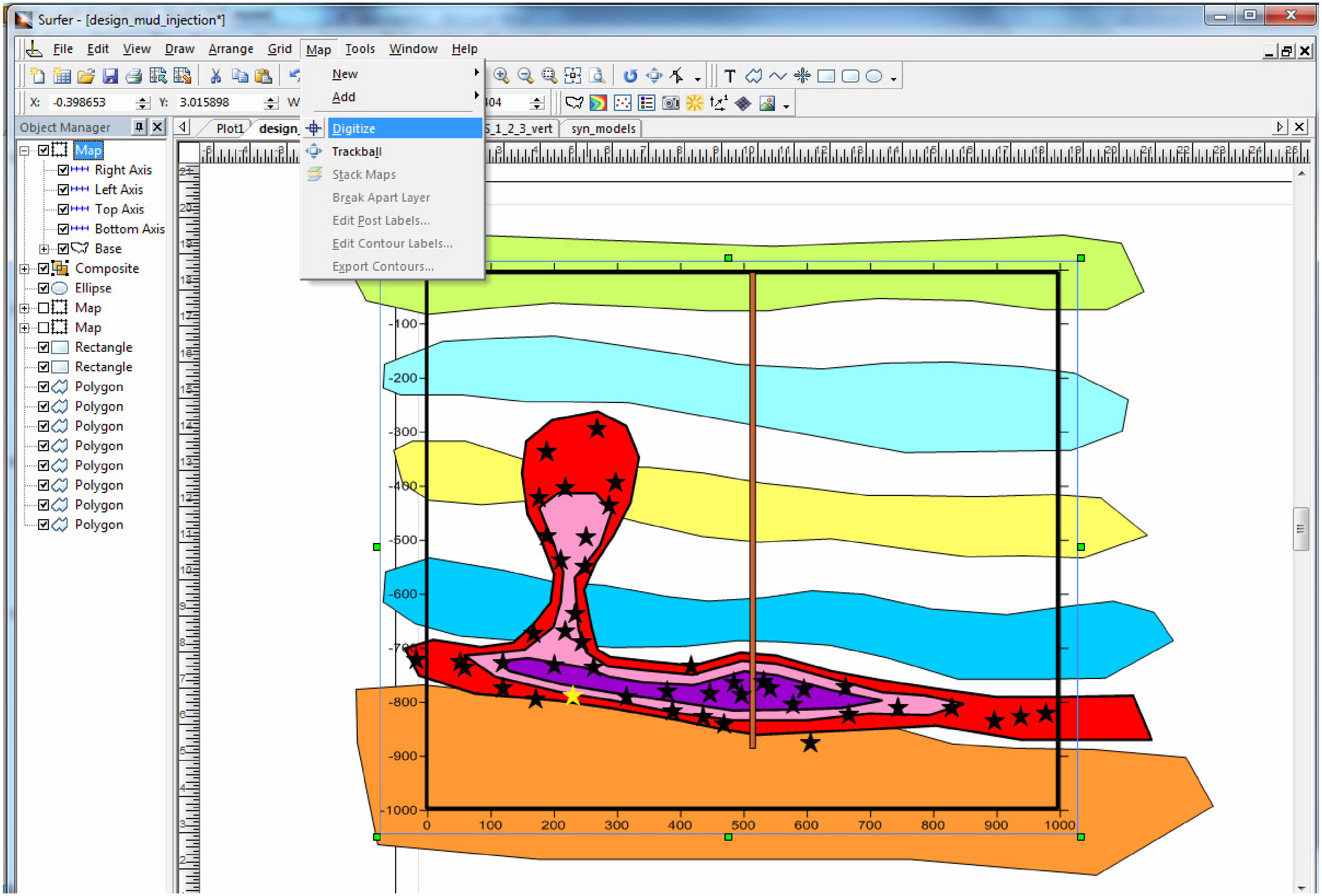
Digitizing the synthetic model:

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



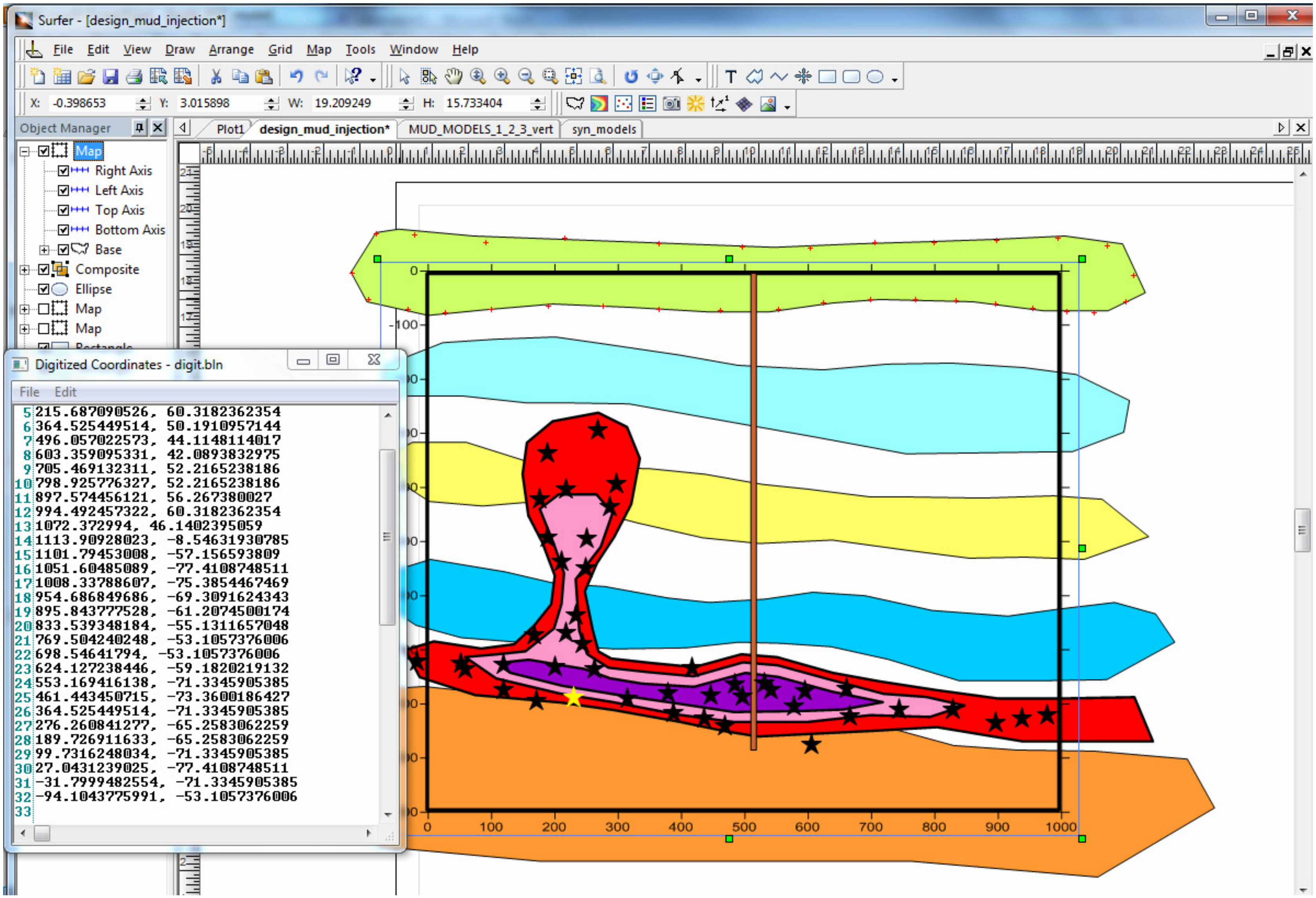
Digitizing the synthetic model:

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



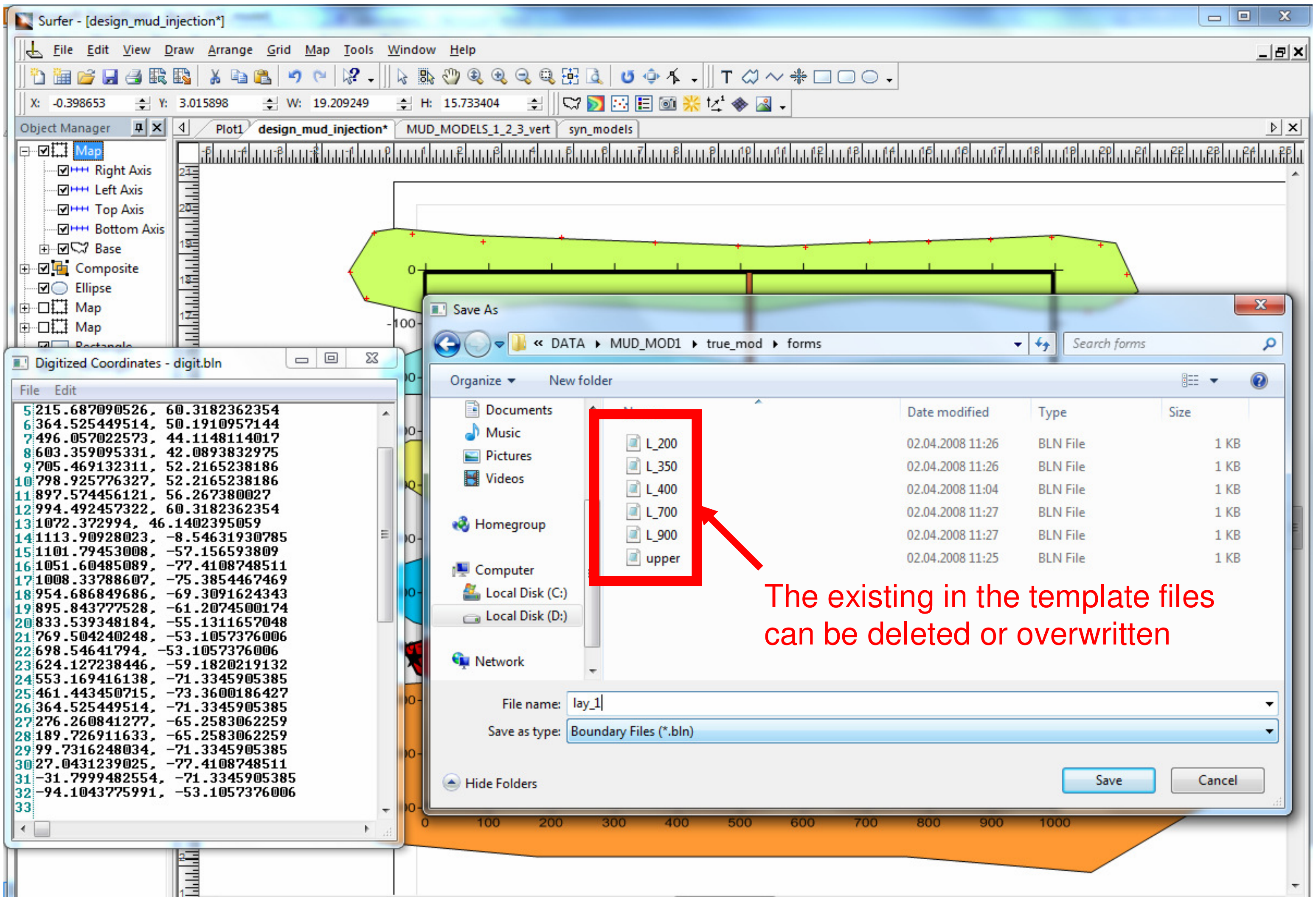
Digitizing the synthetic model:

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



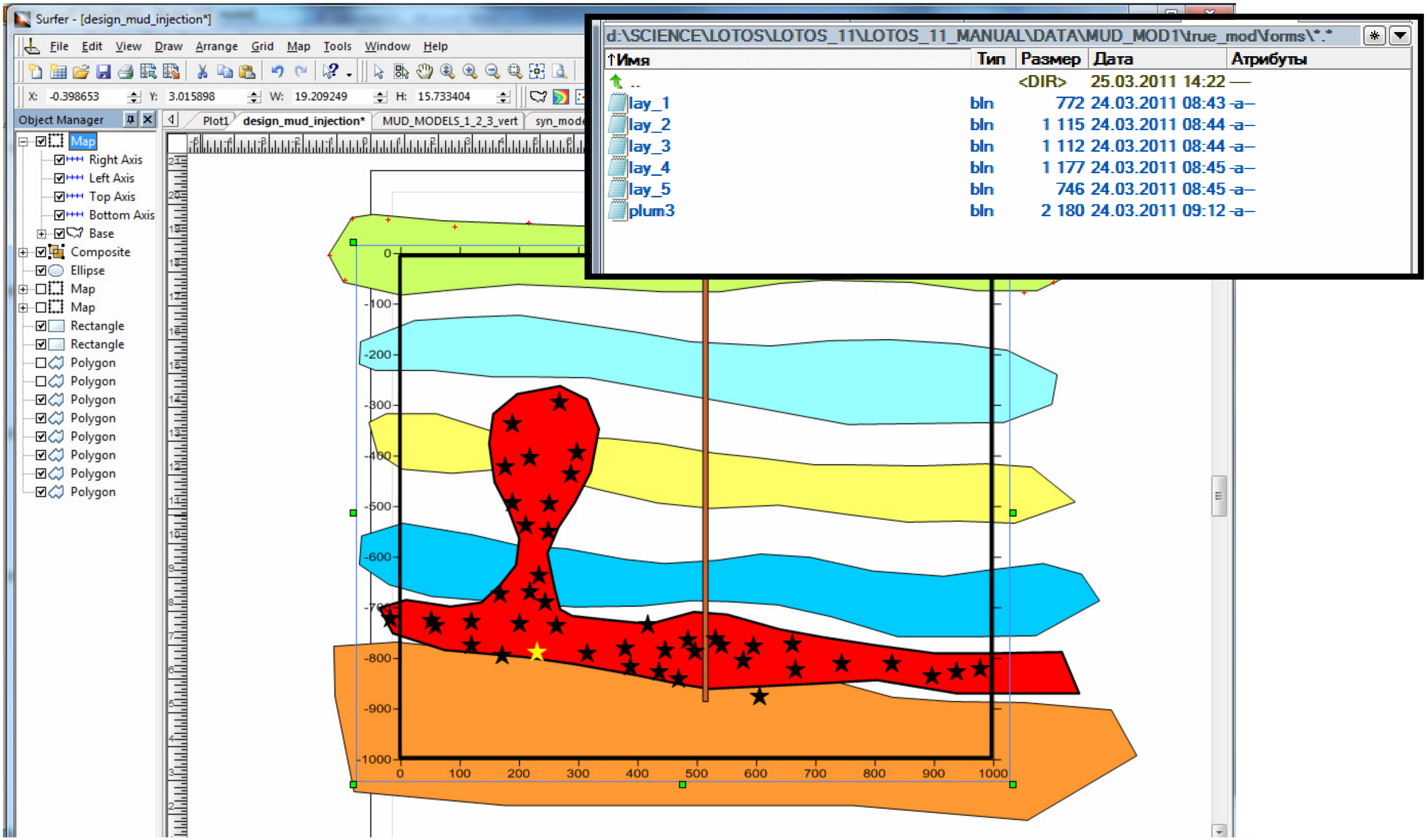
Digitizing the synthetic model:

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.



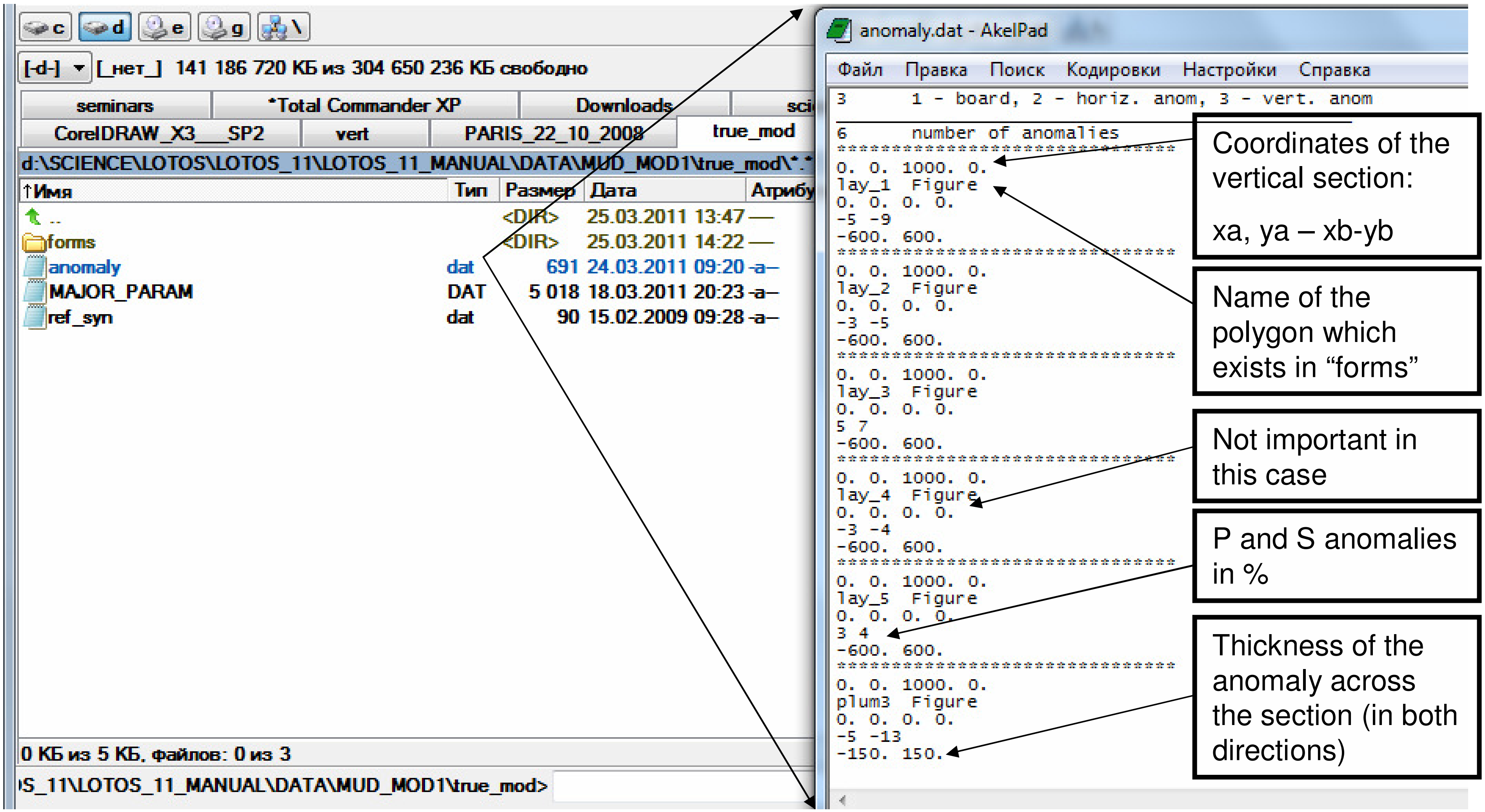
Digitizing the synthetic model:

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



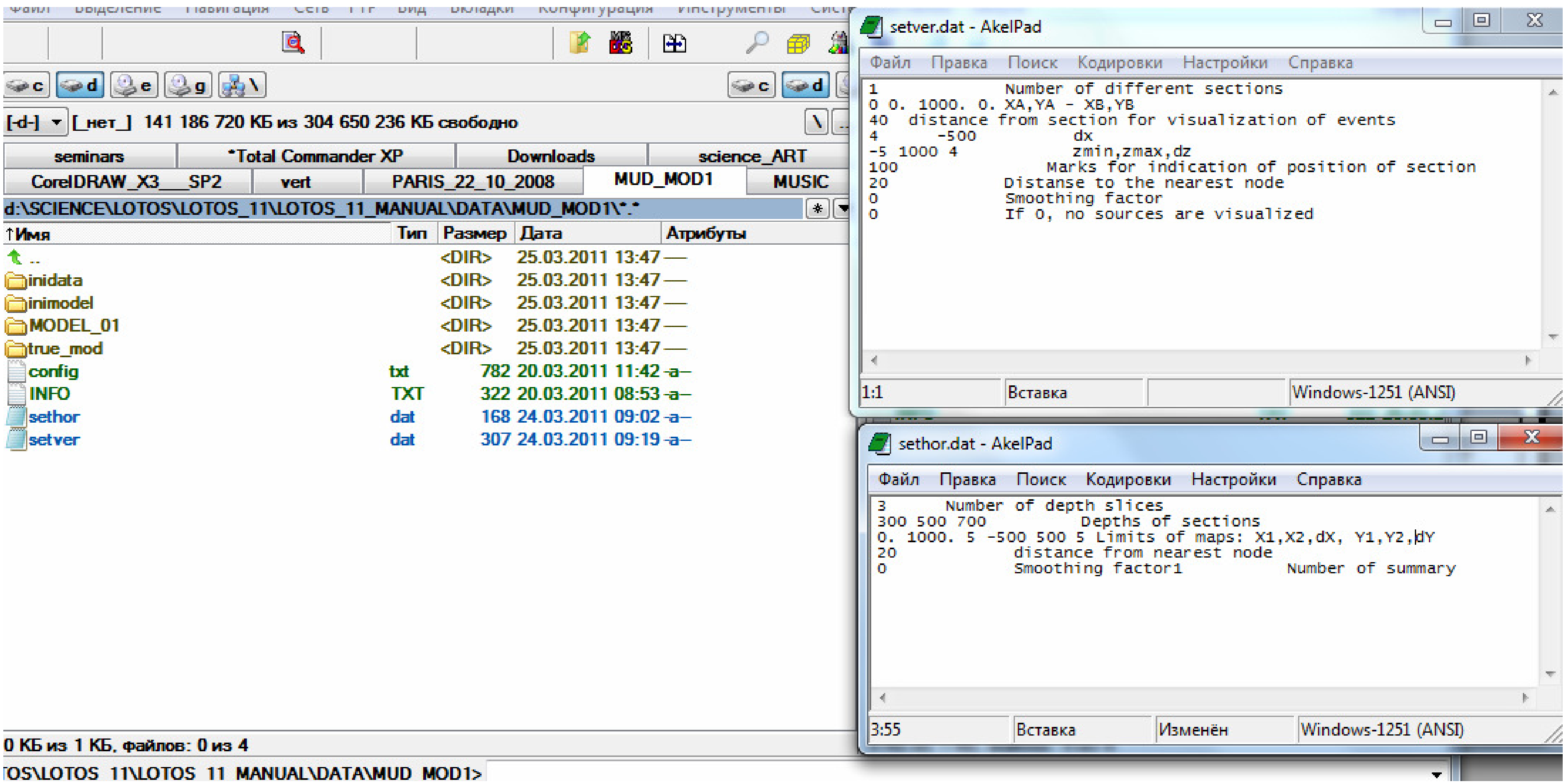
Creating and visualizing the synthetic model:

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:



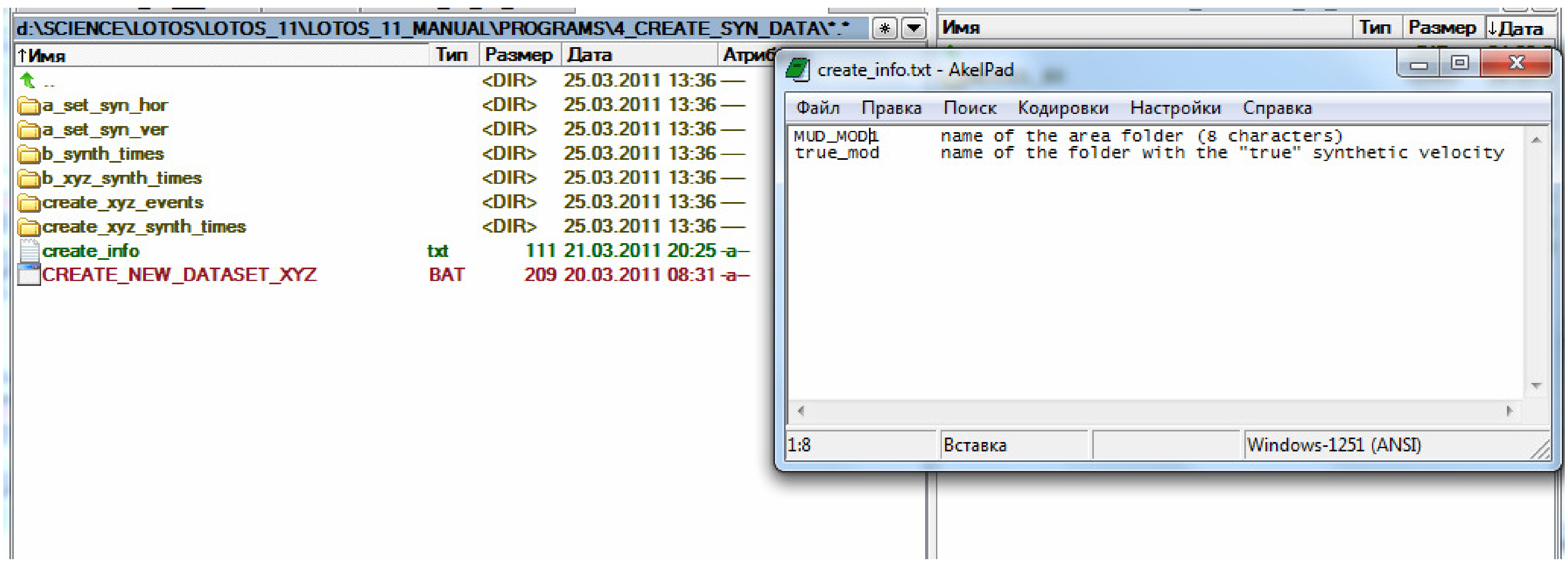
Creating and visualizing the synthetic model:

Change parameters of visualization in vertical and horizontal sections. Open files “DATA/MUD_MOD1/setver.dat” and “DATA/MUD_MOD1/setver.dat”. Make the changes as shown below:



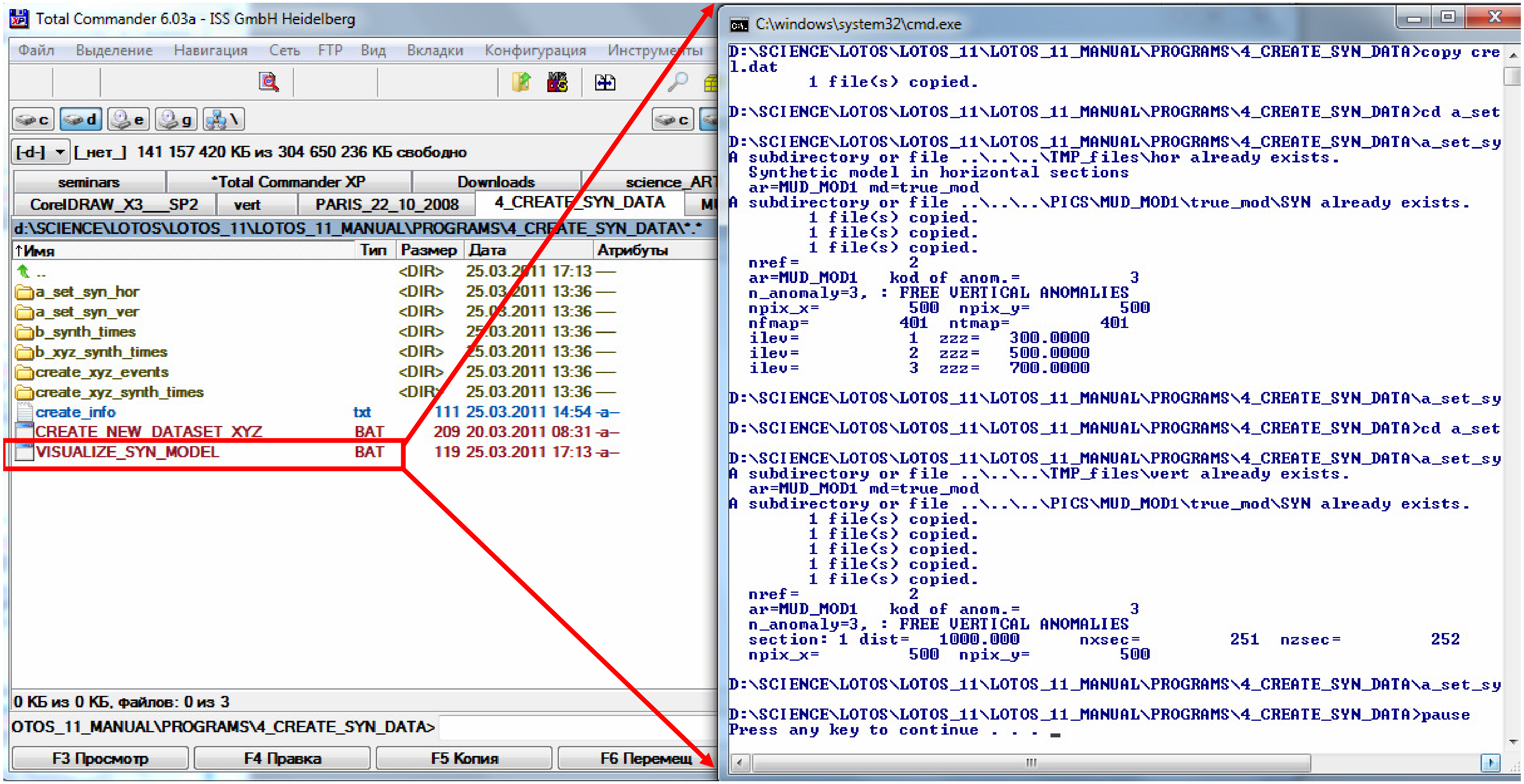
Creating and visualizing the synthetic model:

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.



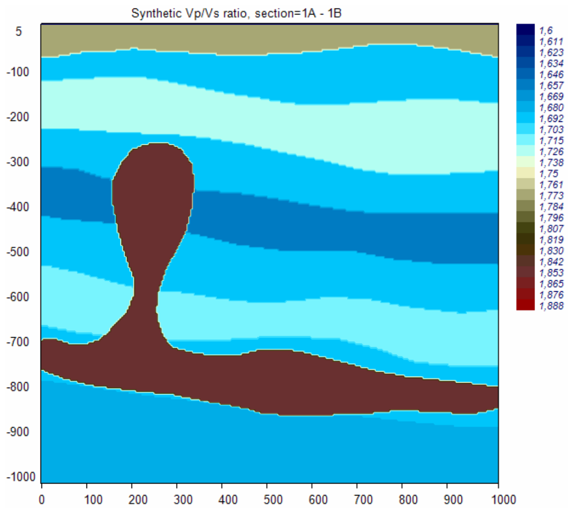
Creating and visualizing the synthetic model:

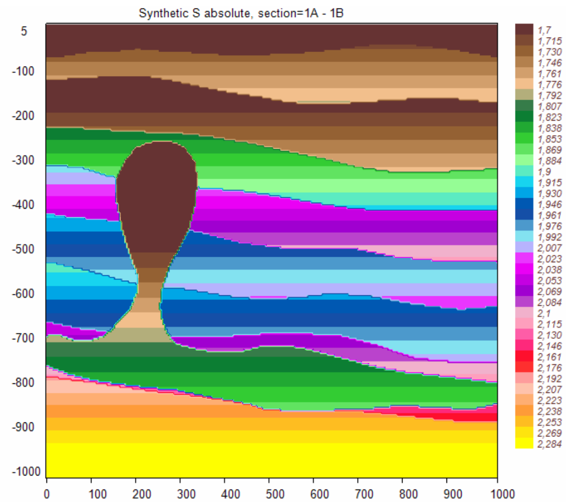
In the folder “PROGRAMS/4_CREATE_SYN_DATA” click on file “VISUALIZE_SYN_MODEL.BAT” and it will run the console:

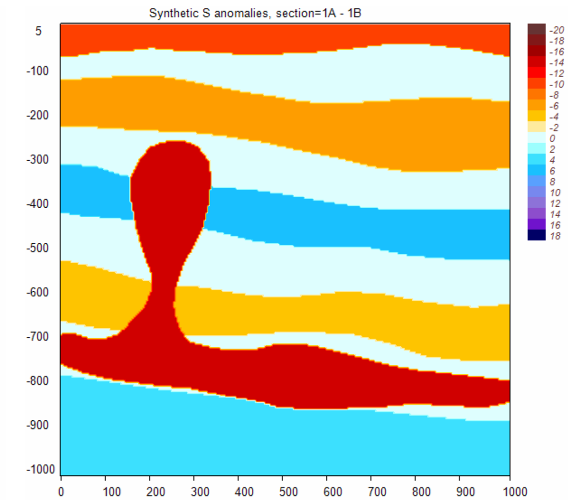


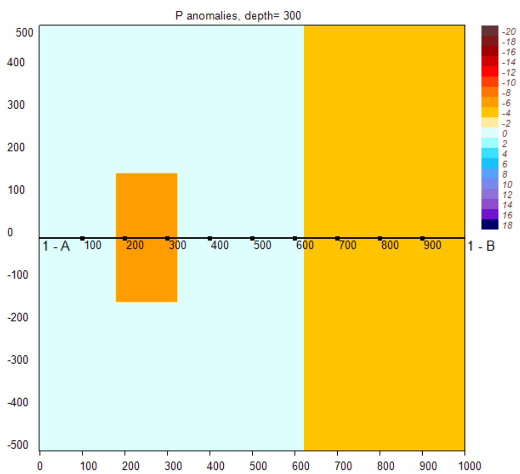
Creating and visualizing the synthetic model:

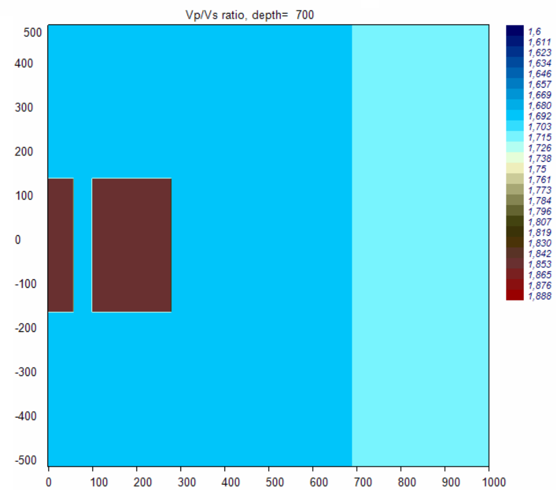
In the folder “PROGRAMS/4_CREATE_SYN_DATA” click on file “VISUALIZE_SYN_MODEL.BAT” and it will run the console:











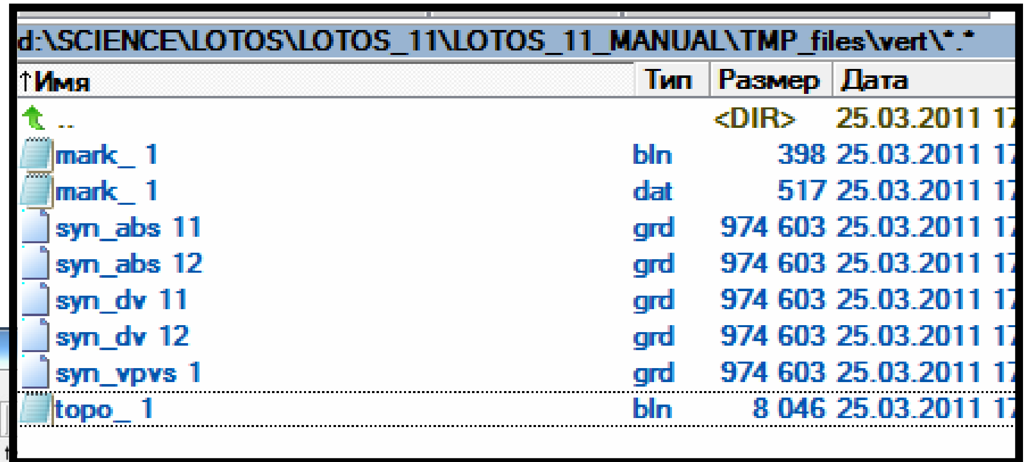
After finishing calculations, check pictures in PICS/MUD_MOD1/true_mod/SYN

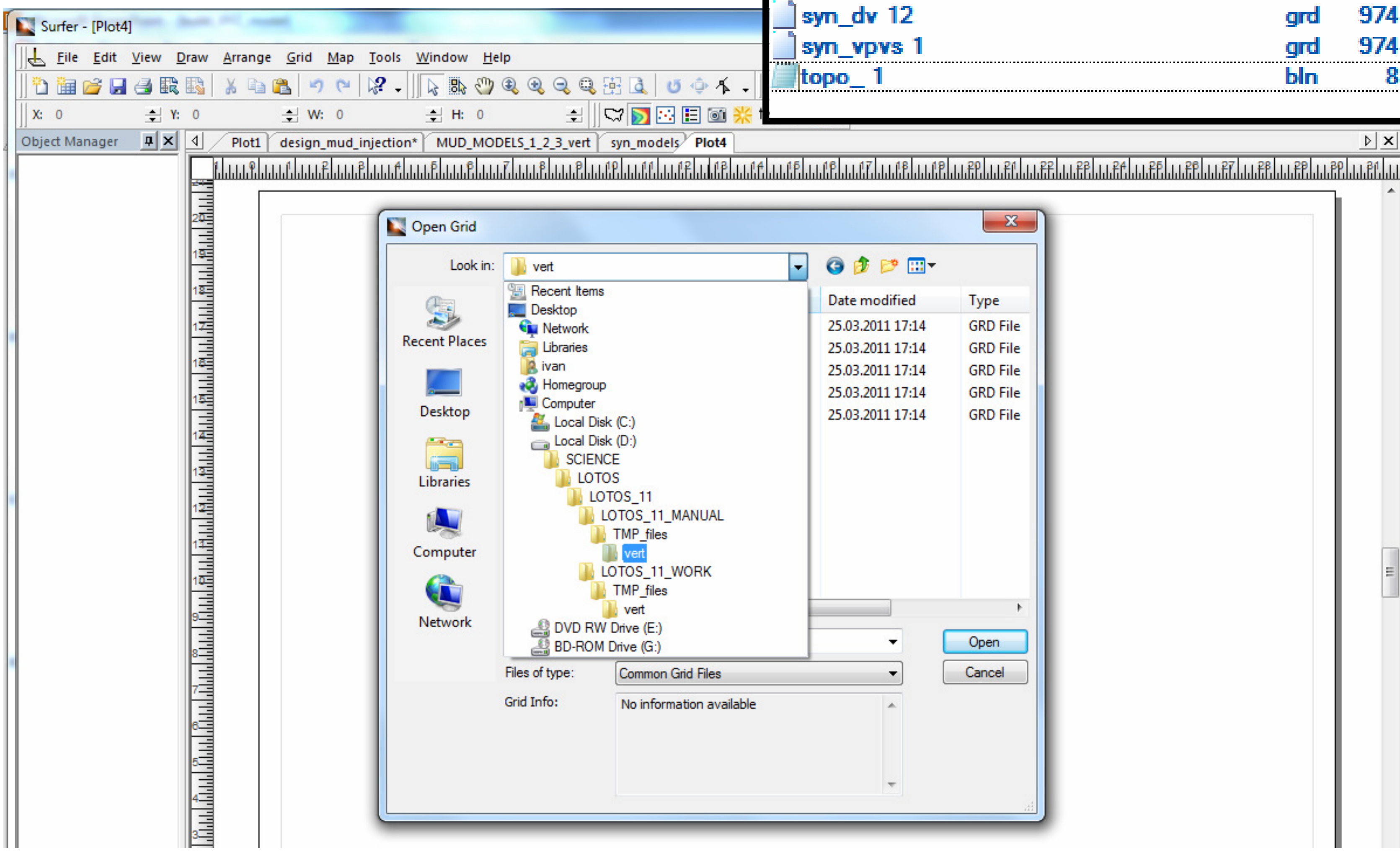
Plots with the configuration of the synthetic model in hor and ver sections are presented

Creating and visualizing the synthetic model:

Same pictures can be created in Surfer:

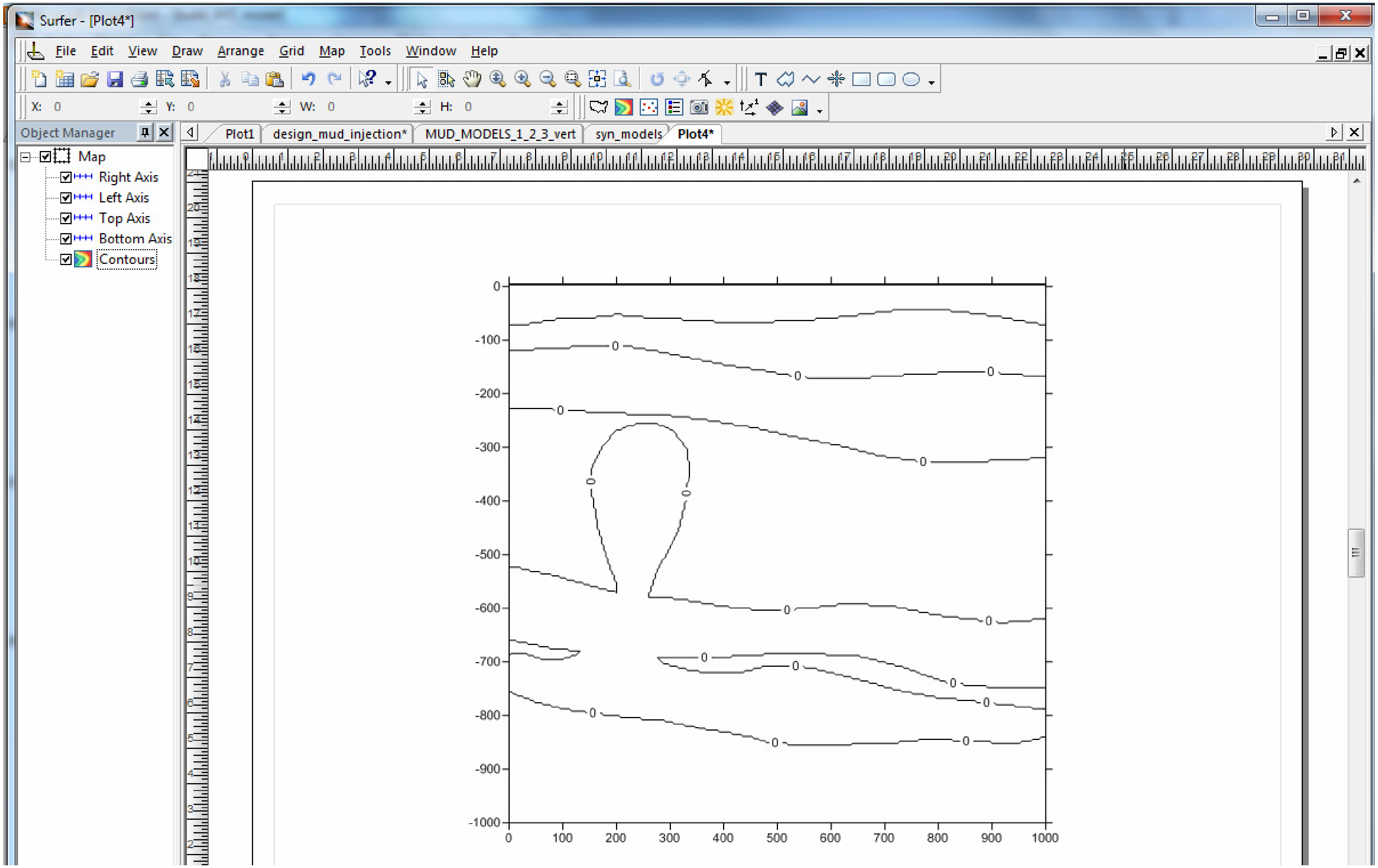
1. open a new plot;
2. Open grid in: TMP_files/vert





Creating and visualizing the synthetic model:

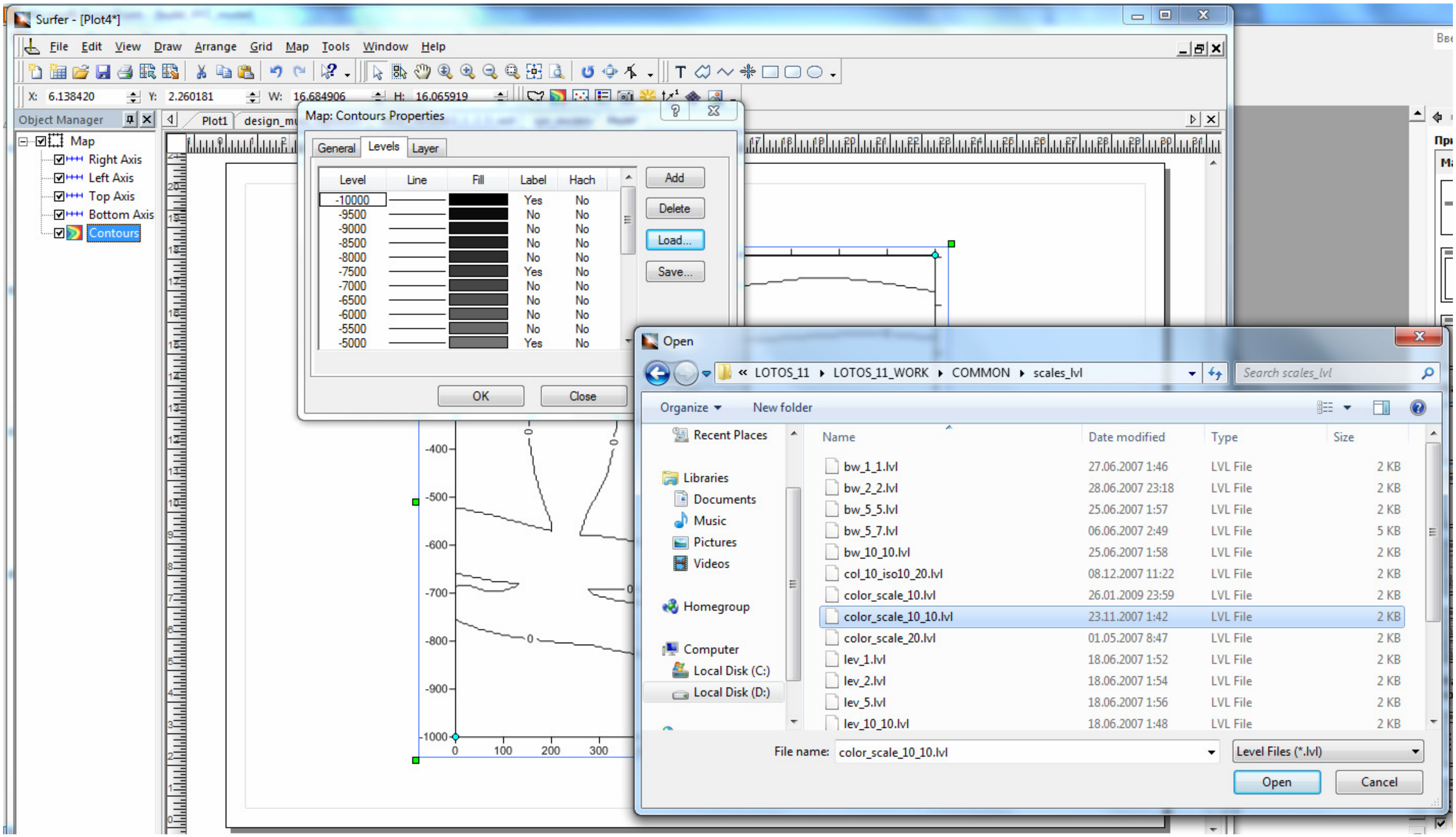
Select one of the grd files (syn_dv 12.grd which correspond to velocity anomalies in 1st vertical section for the S model). Initially it does not look nice. Apply a standard palette and switch on the option “fill contours”:



Creating and visualizing the synthetic model:

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

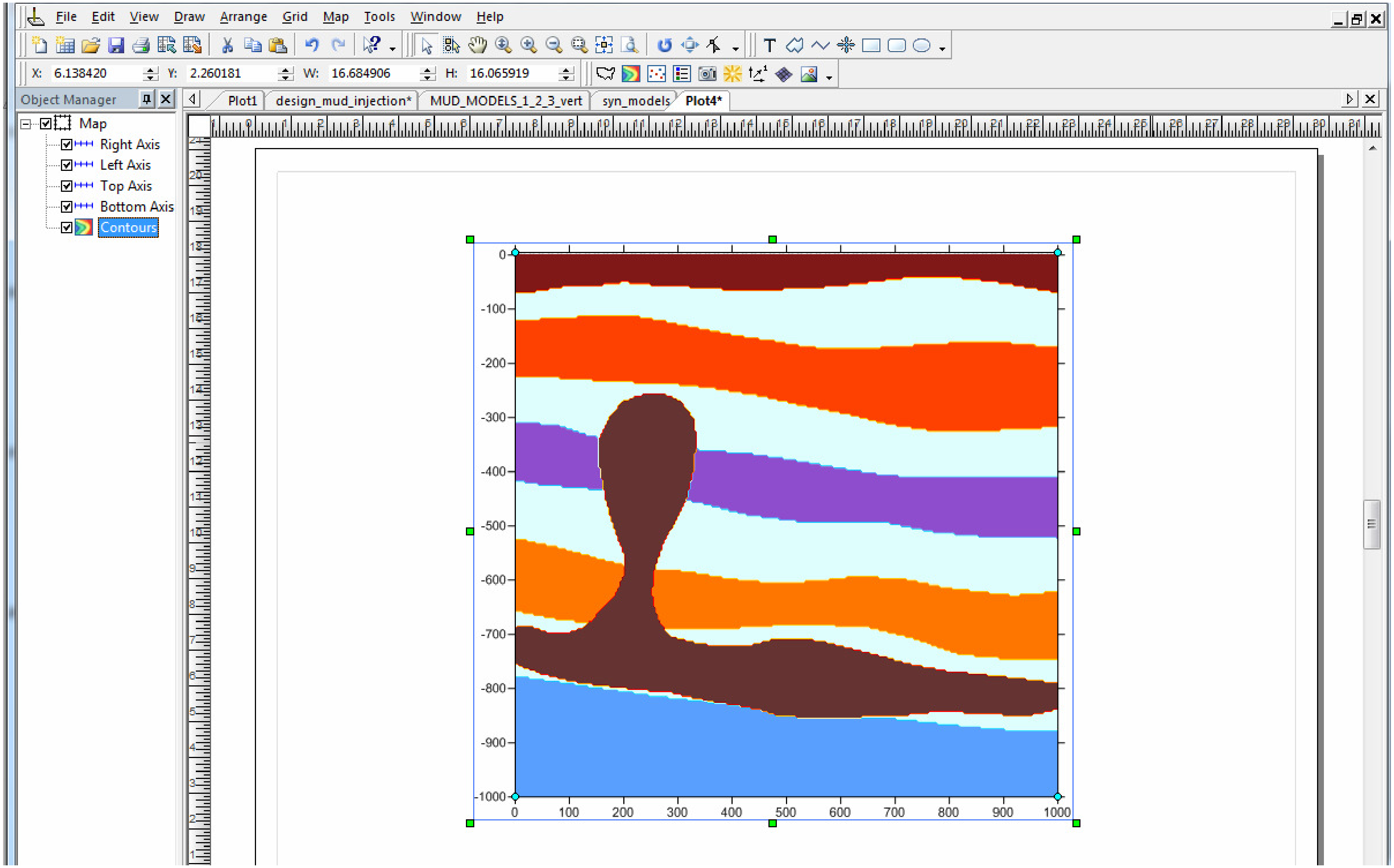
To fill contours: Menu General – mark the option “fill contours”



Creating and visualizing the synthetic model:

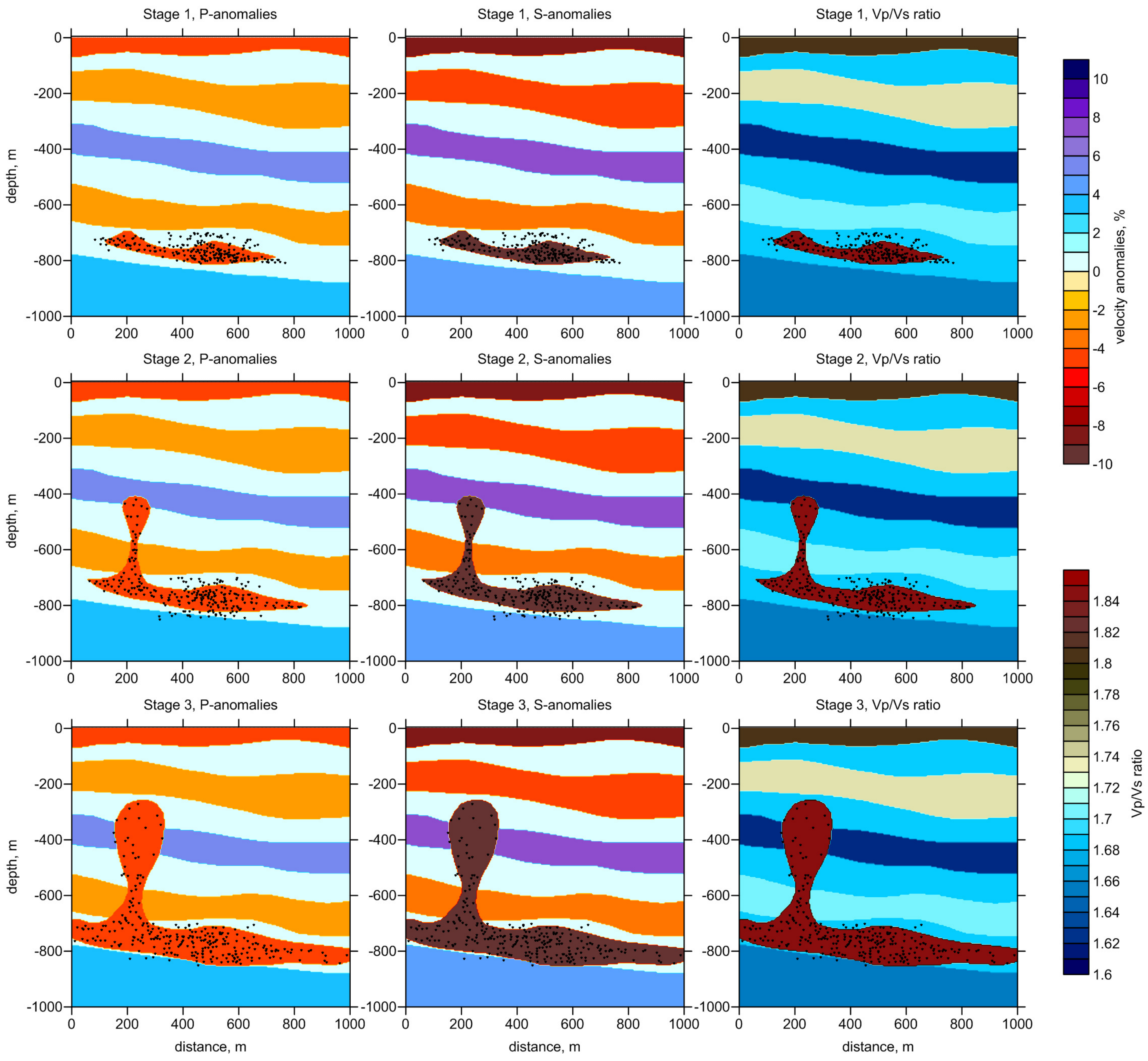
The result is presented below:

The other grids can be presented in a similar way.



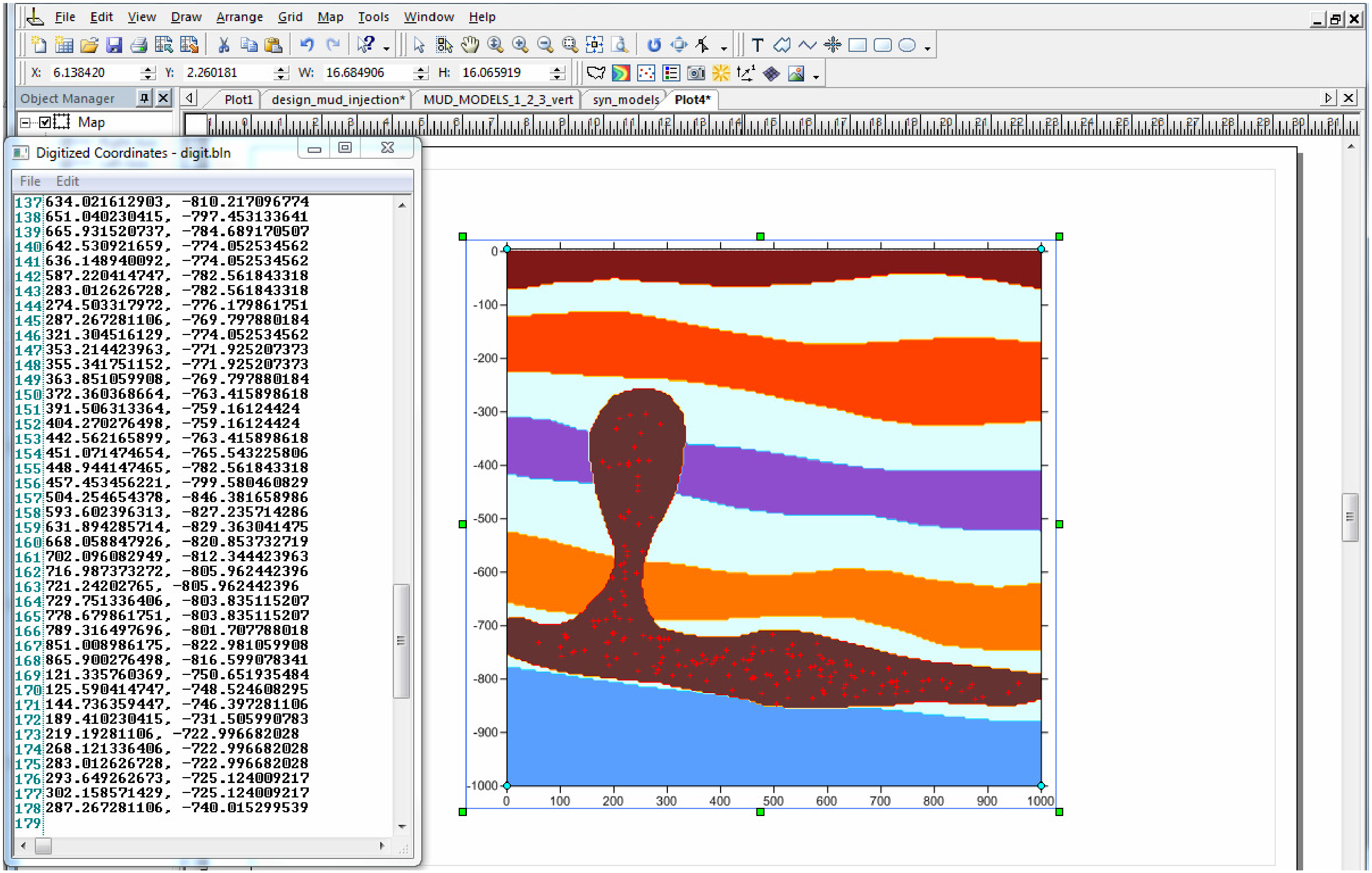
Creating and visualizing the synthetic model:

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



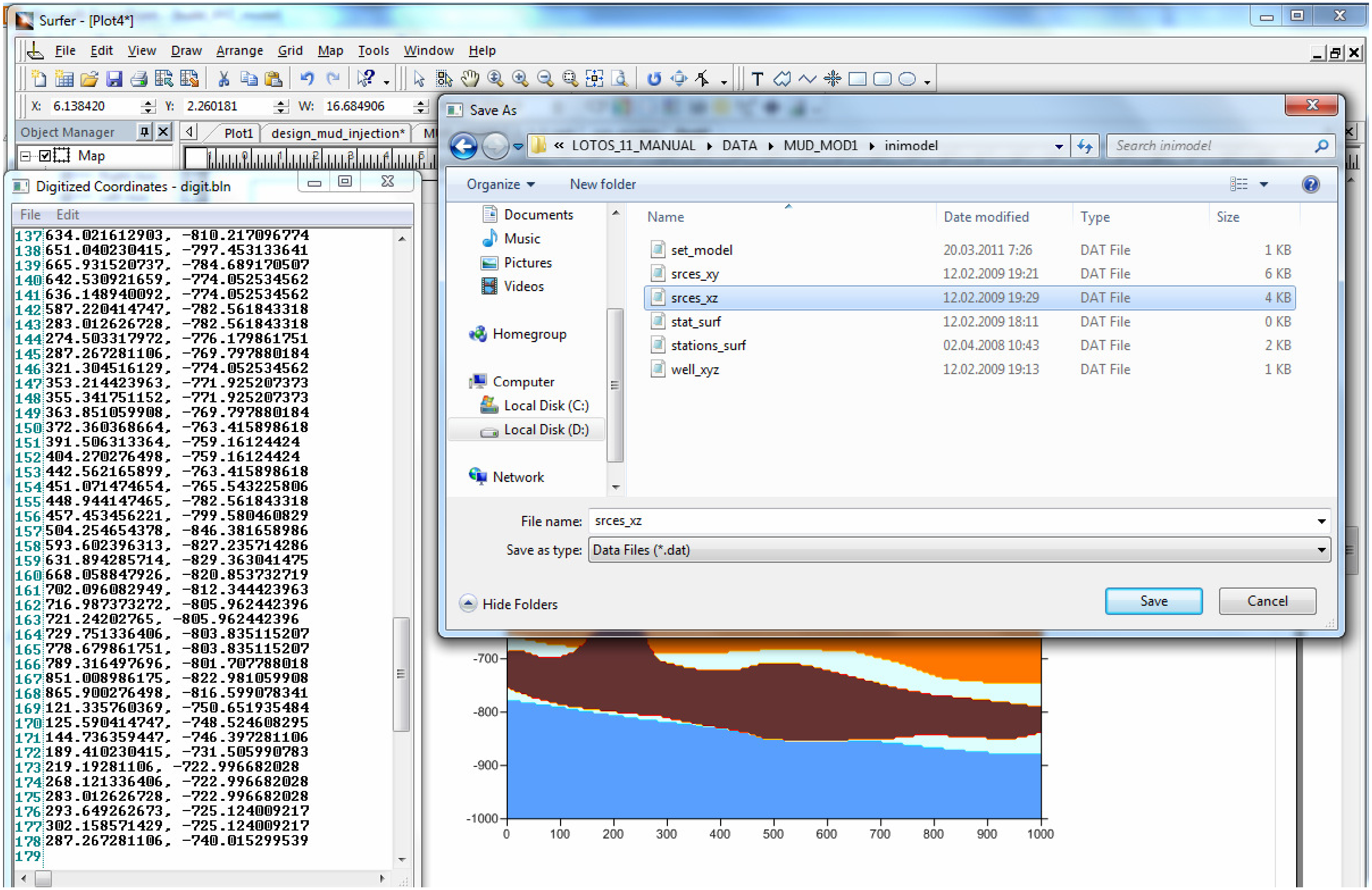
Creating and visualizing the events and stations:

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



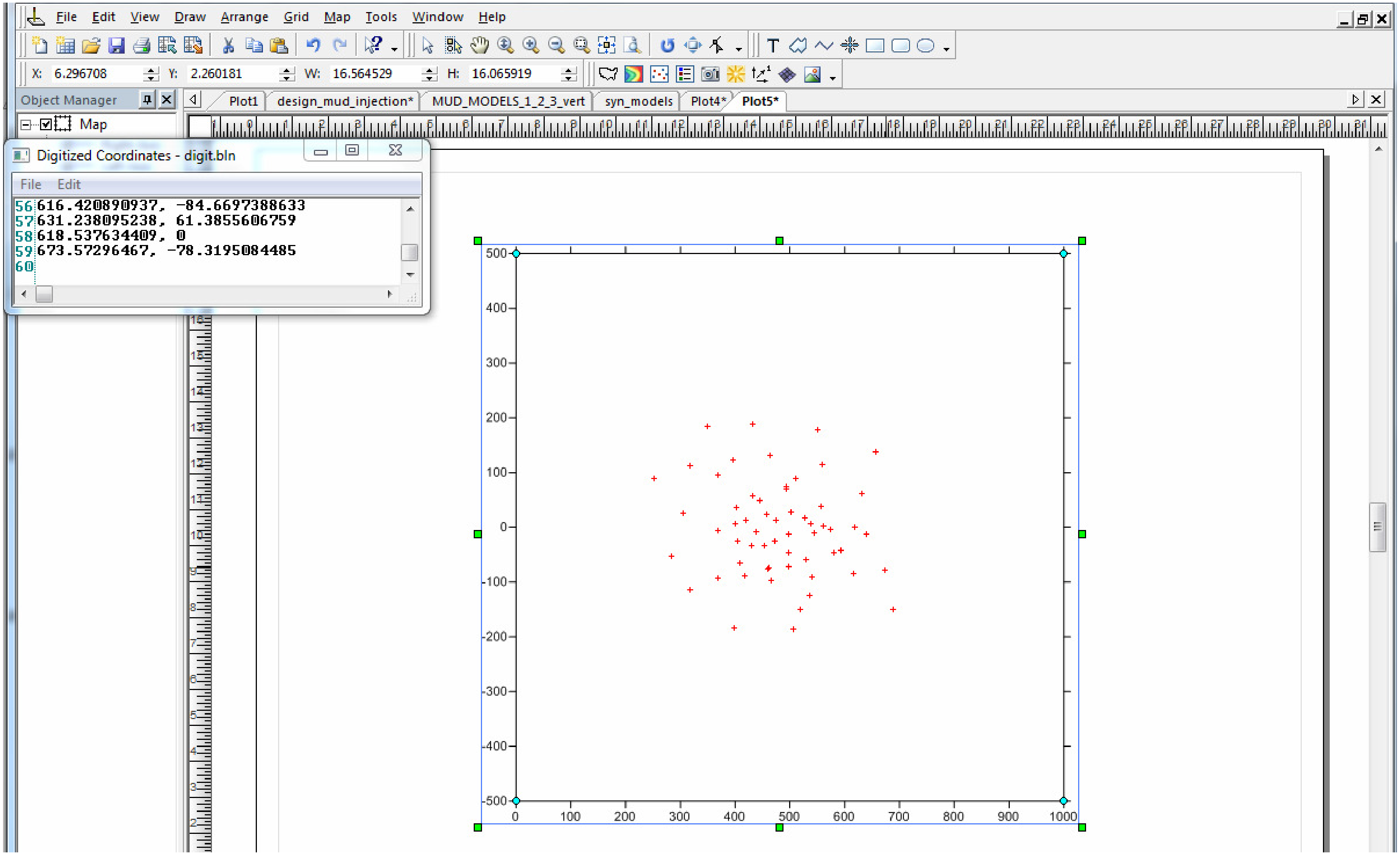
Creating and visualizing the events and stations:

Save the points as: DATA/MUD_MOD1/inimodel/srces_xz.dat



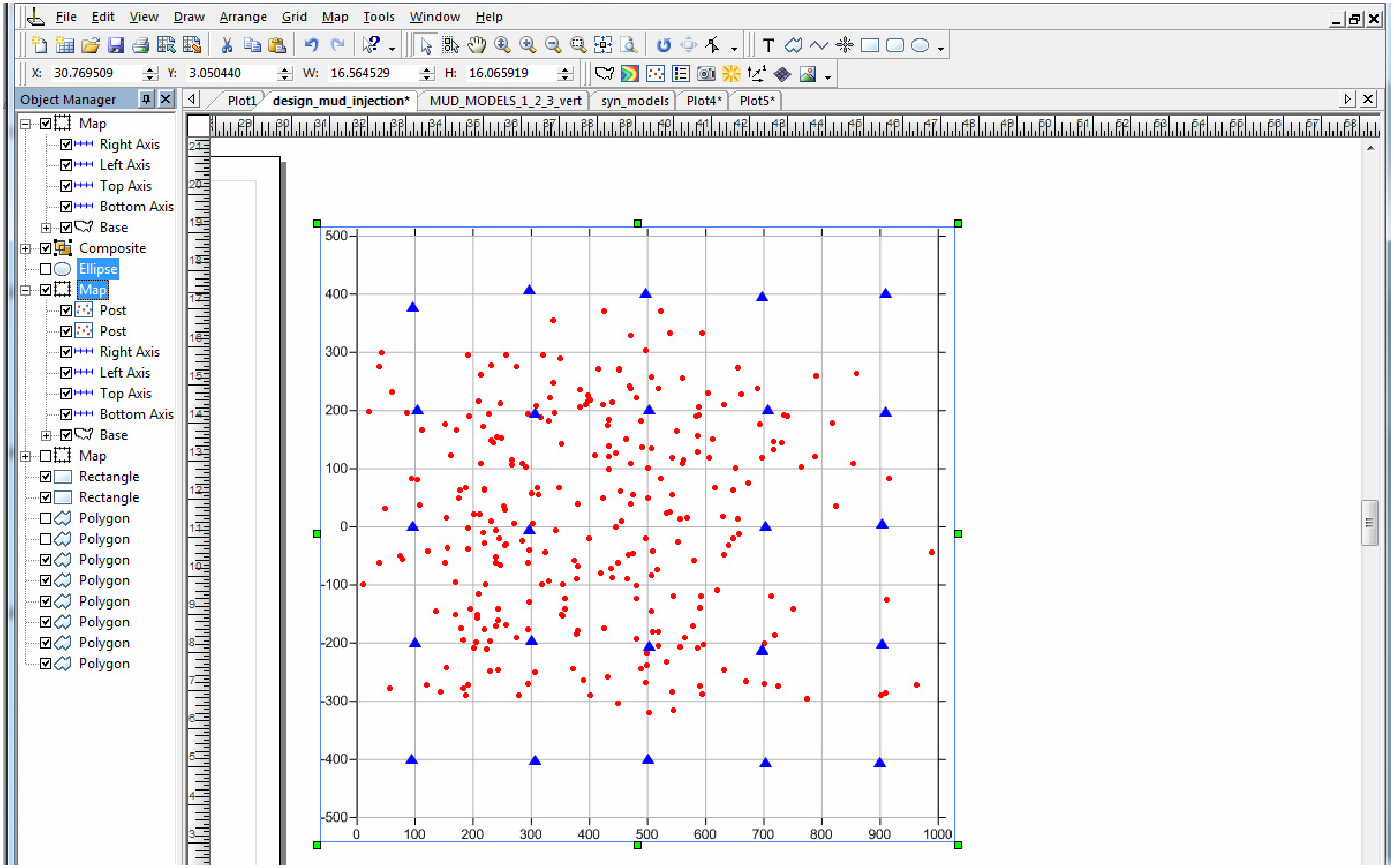
Creating and visualizing the events and stations:

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/srces_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

Lister - [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

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

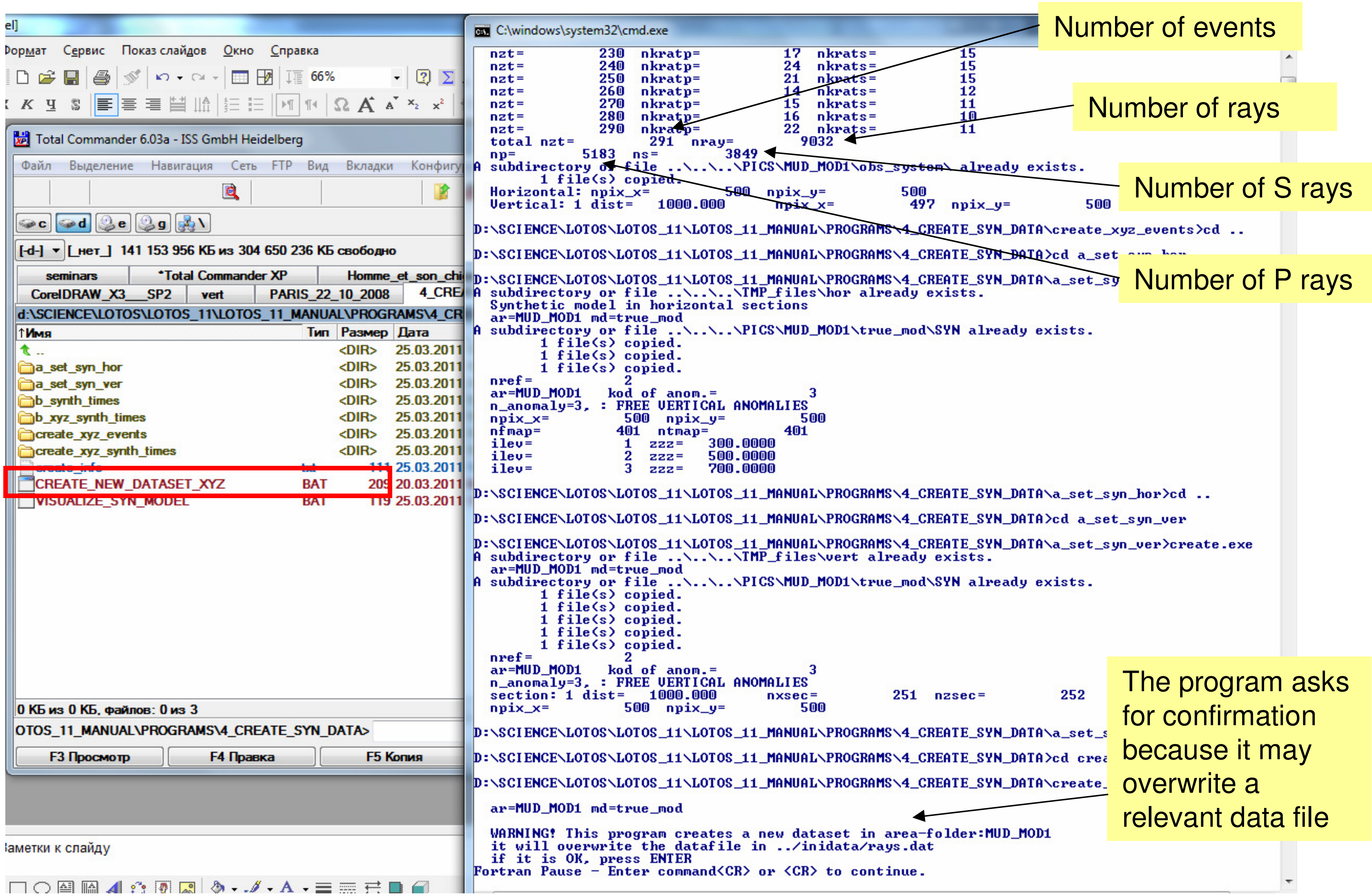
No events in the YZ section are picked

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

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

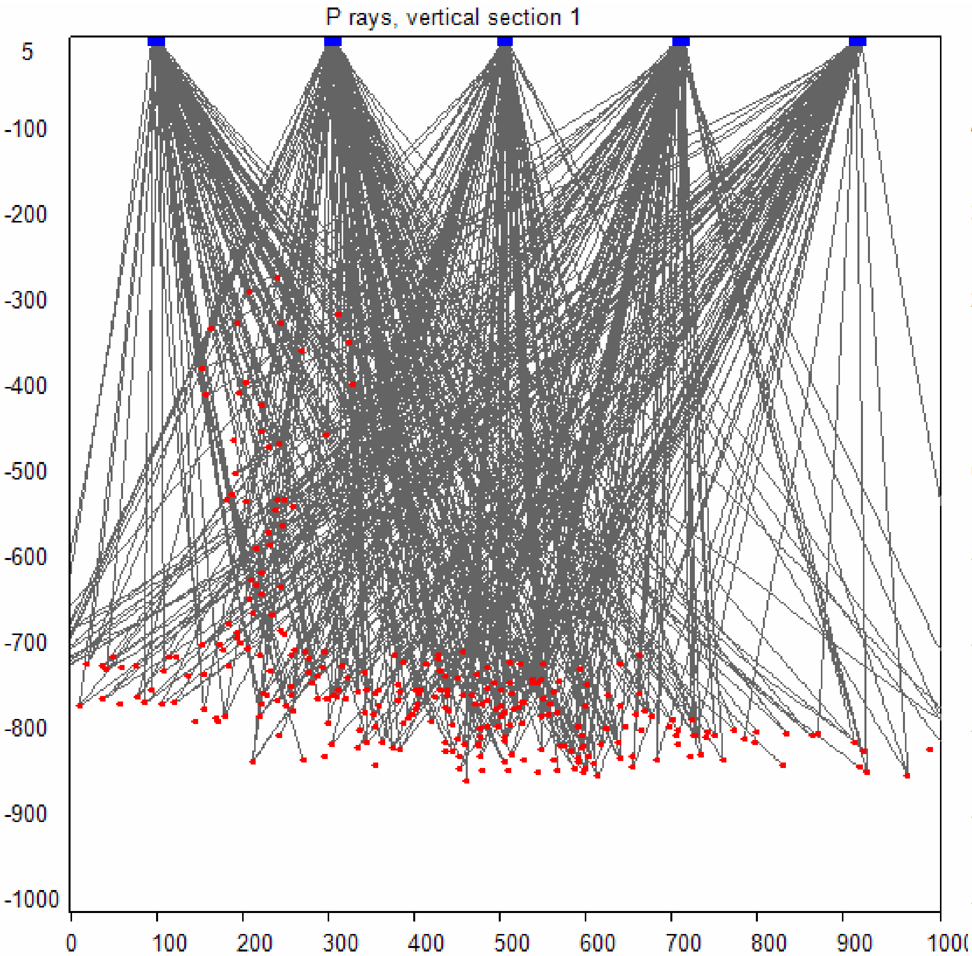
Creating and visualizing the events and stations:

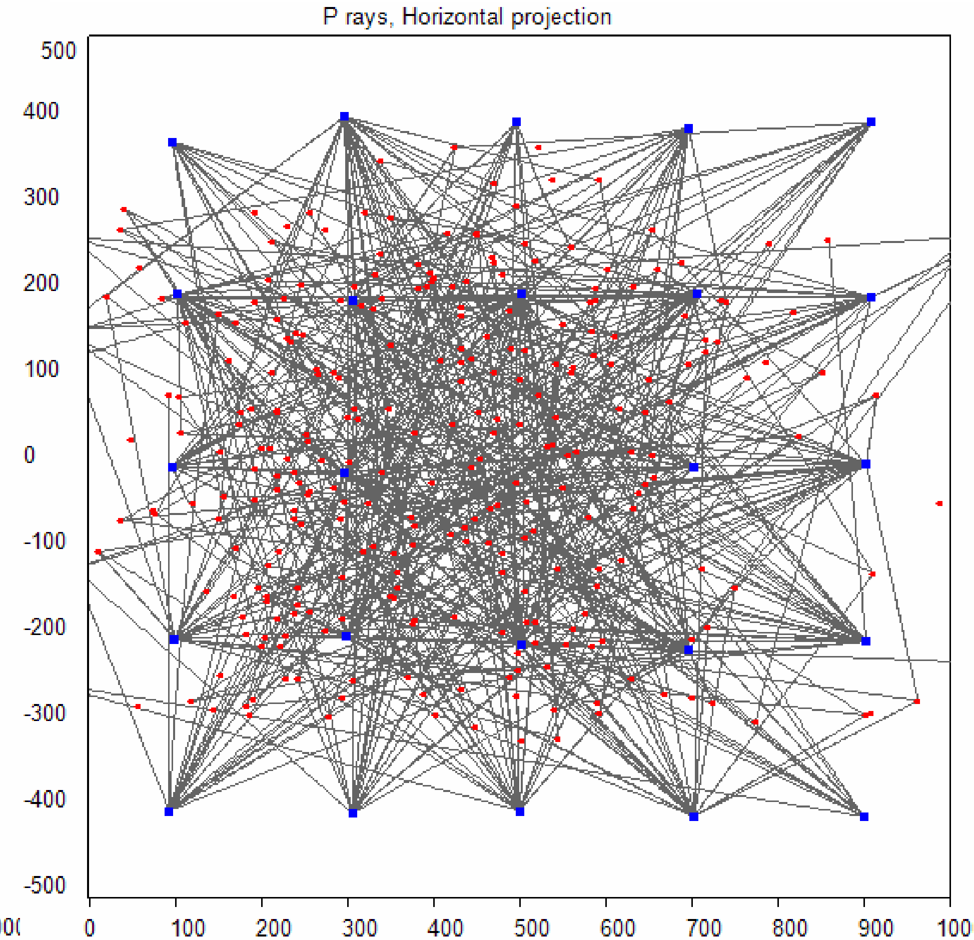
In the folder “PROGRAMS/4_CREATE_SYN_DATA” click on file “CREATE_NEW_DATASET_XYZ.BAT” and it will run the console:



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

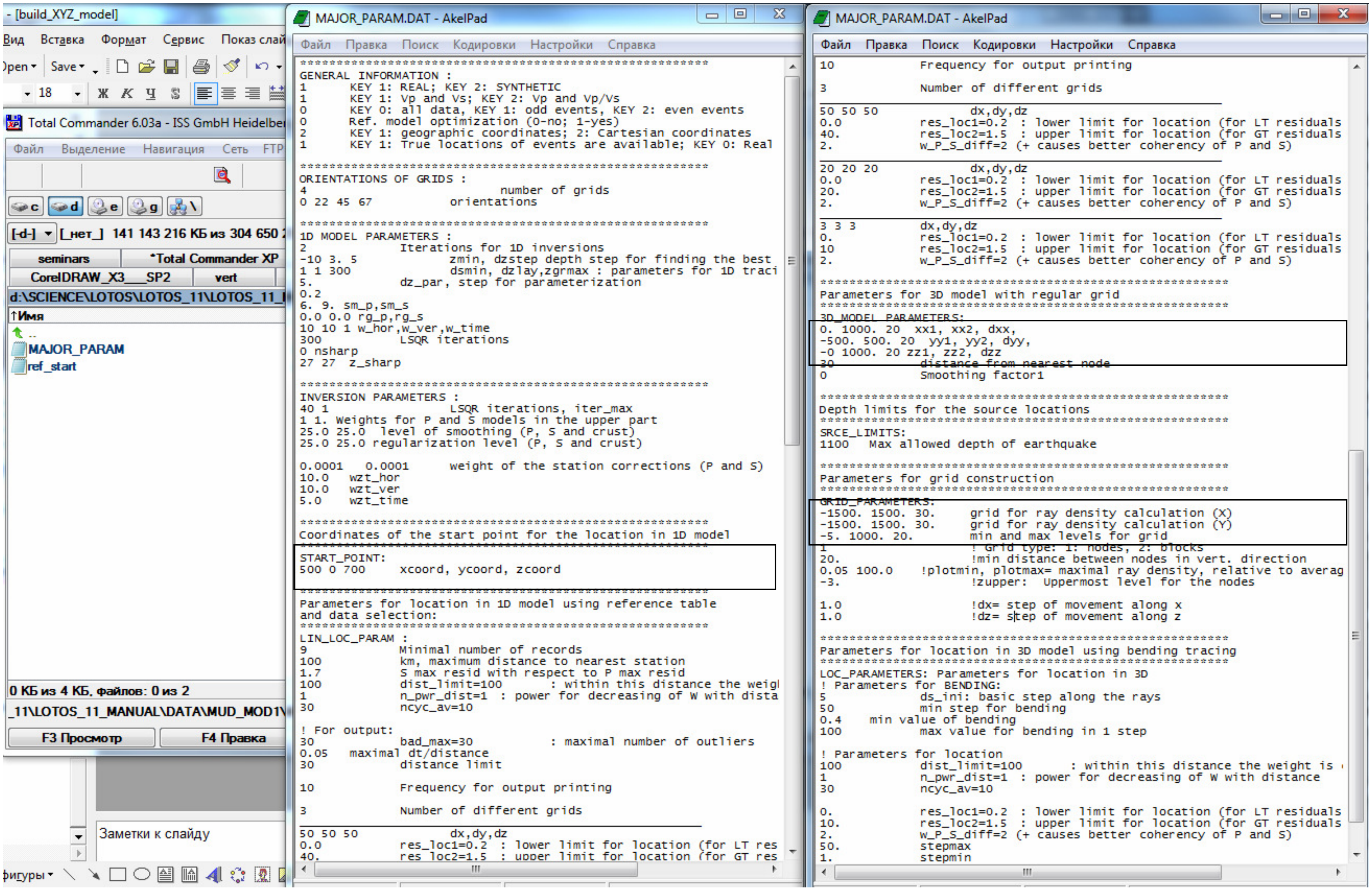




In the DATA/MUD_MOD1/initata folder, the files are properly organized. They represent the case of real data

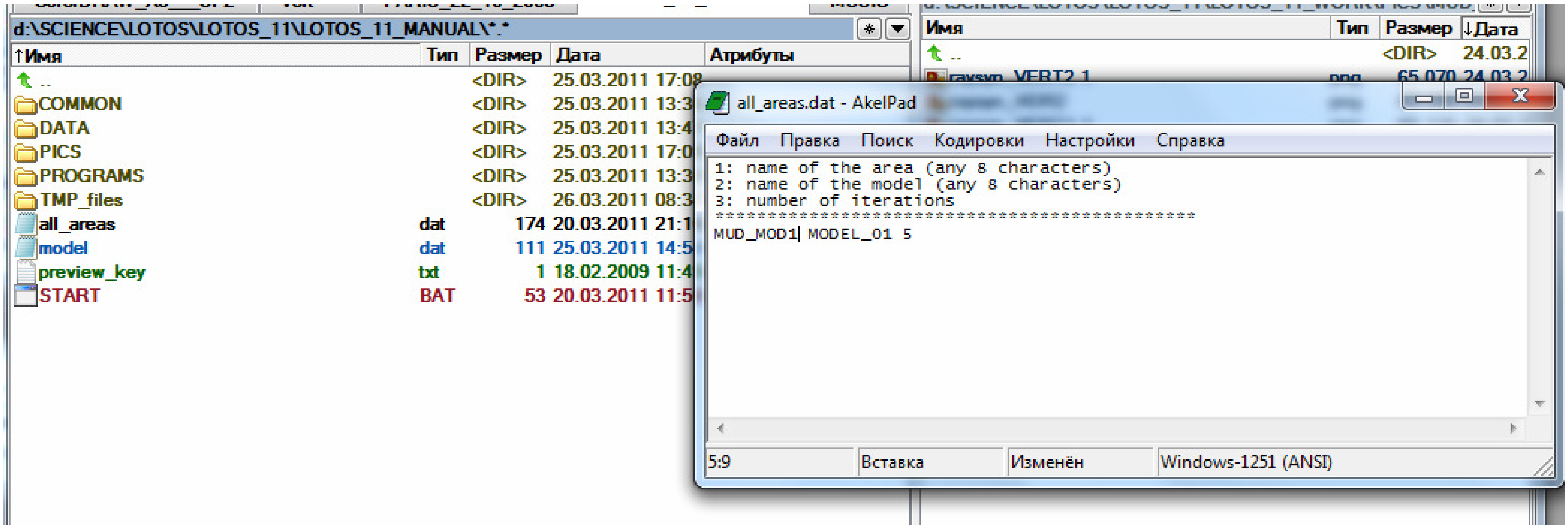
Preparing the model for the tomographic inversion:

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:



Running the tomographic inversion:

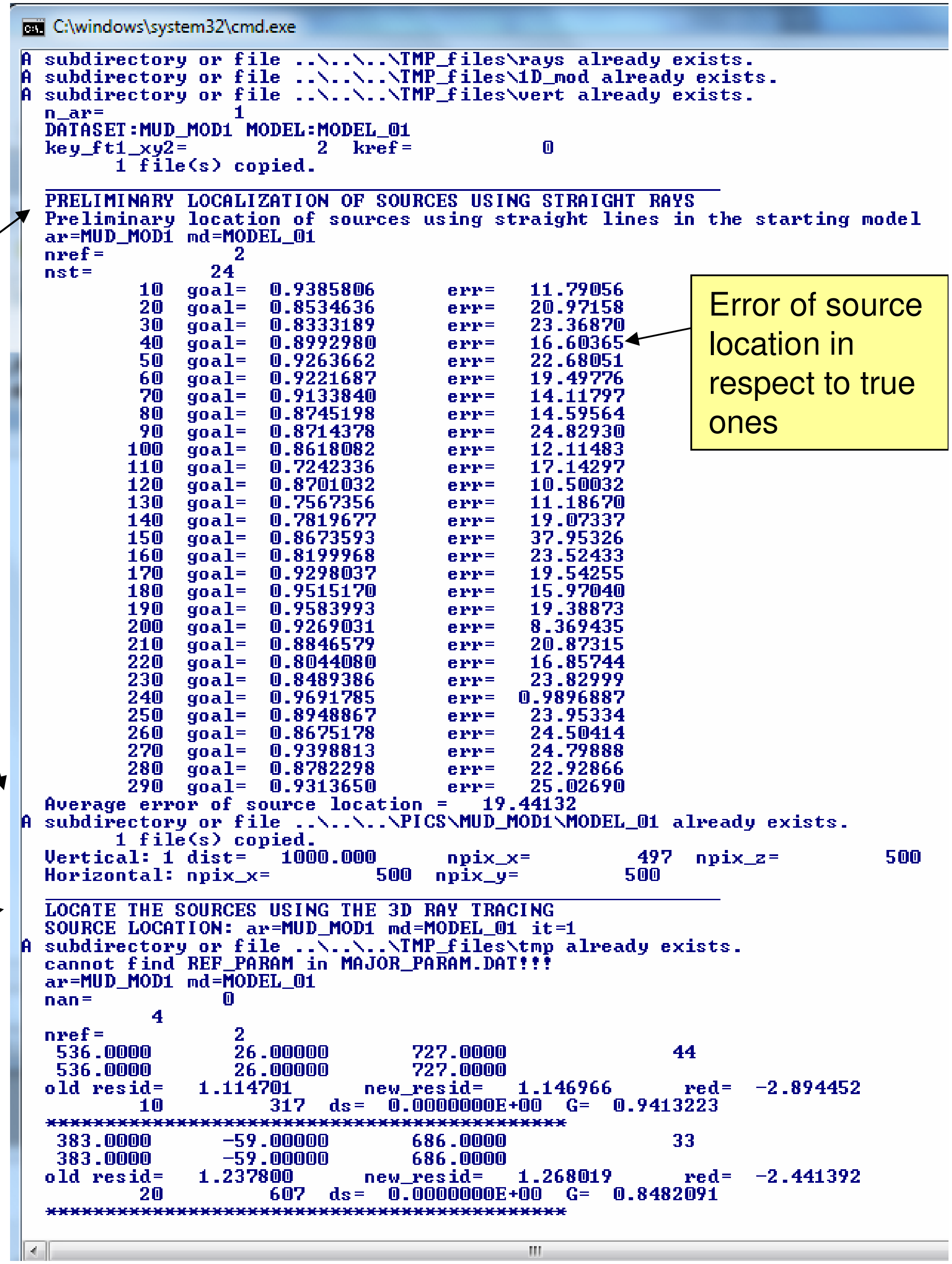
In the root folder in file “all_areas.dat” define the name of the area and model that will be processed:



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



Error of source location in respect to true ones

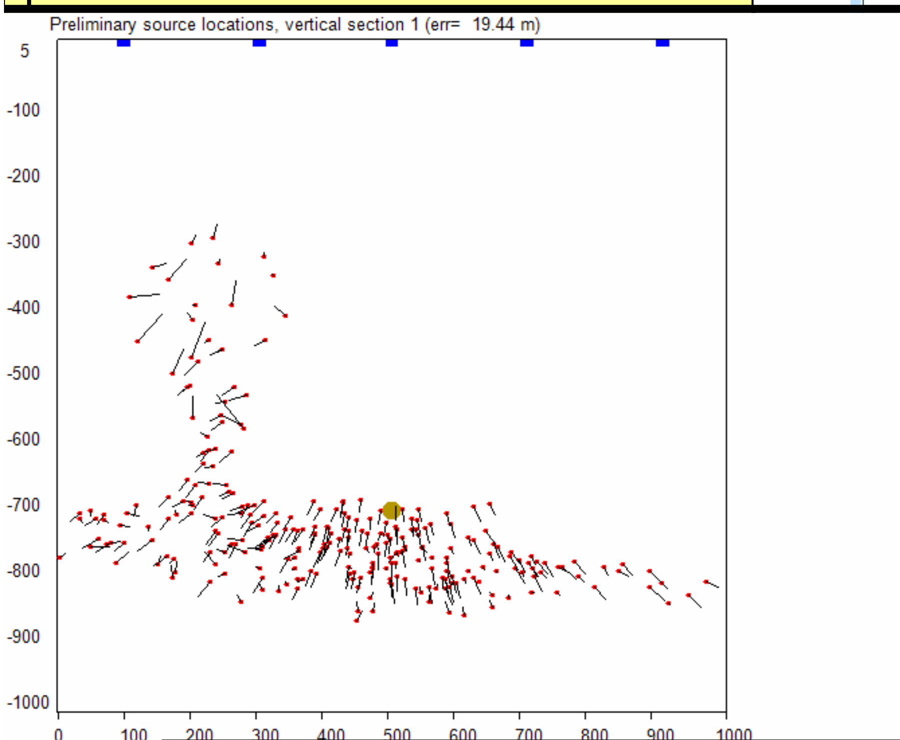
Start source locations using the 3D ray tracing code

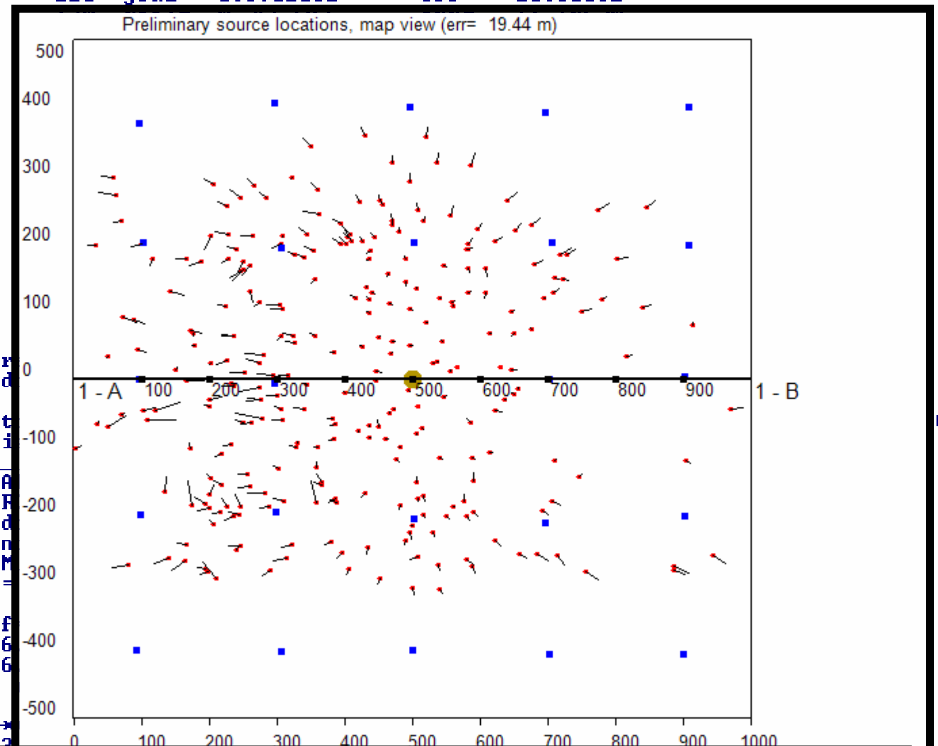
Running the tomographic inversion:

```
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
```

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

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:

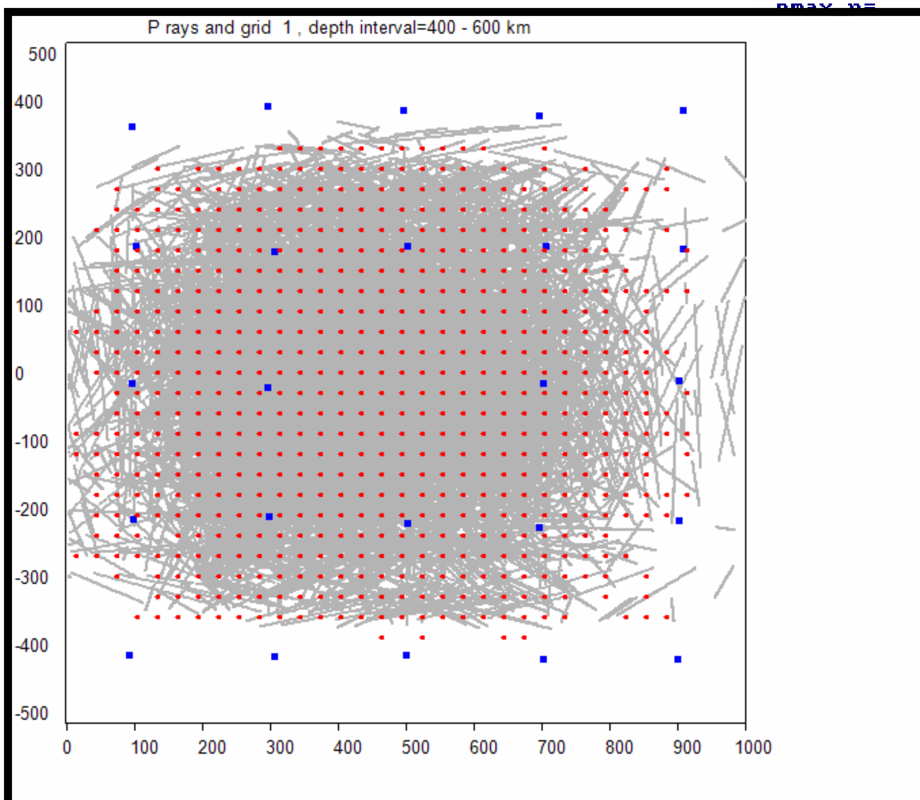
Compute the ray density and construct the grid

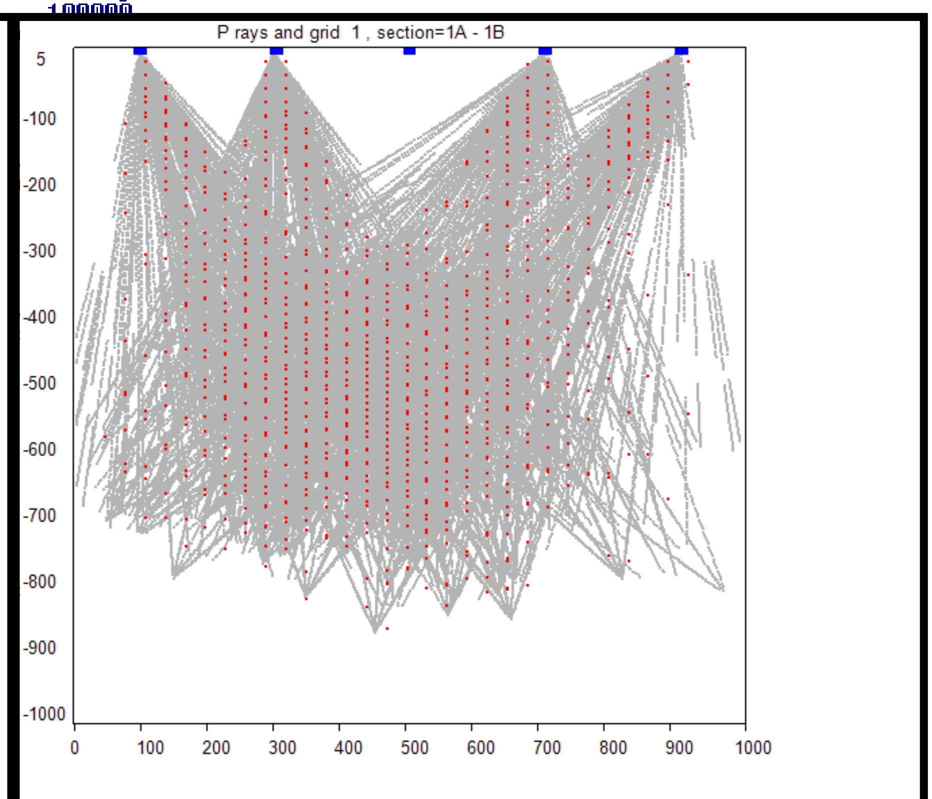
```
*********************************************
err_loc0=   19.44132       err_loc=   19.32629
nzt=          291  nray=          9032
A subdirectory or file ..\..\..\PICS\MUD_MOD1\MODEL_01\LOC already exists.
        1 file(s) copied.
Vertical: 1 dist=   1000.000      npix_x=          497  npix_z=          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 lenght 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 lenght 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 sosedi
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_loc0=   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
```






```
ilev=          25  notr(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=                                  2905  total=        20694
 ilev=                                  2851  total=        34547
 ilev=                                  2868  total=        49003
 ilev=                                  1954  total=        61285

 VISUALIZE TI                  IN HORIZONTAL AND VERTICAL SECTIONS
A subdirector                 P_files\rays already exists.
 ar=MUD_MOD1                                1
          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= 15147
ilev= 3 z1=  600.0 z2=  800.0 nrtot=  36128 nptot= 18154
        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 (VP-VS SCHEME)
 execution of matr
 ar=MUD_MOD1 md=MODEL_01 it=1 gr=1
 orient=  0.0000000E+00
 nref=            2
 nymax=           29  ntmax=       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
 nobr=         10220          9591  nonzer=      1128272
 nrp=          5183  nonz_p=       654718
 nrs=          3849  nonz_s=       473554

 PERFORM THE INVERSION (VP-VS 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

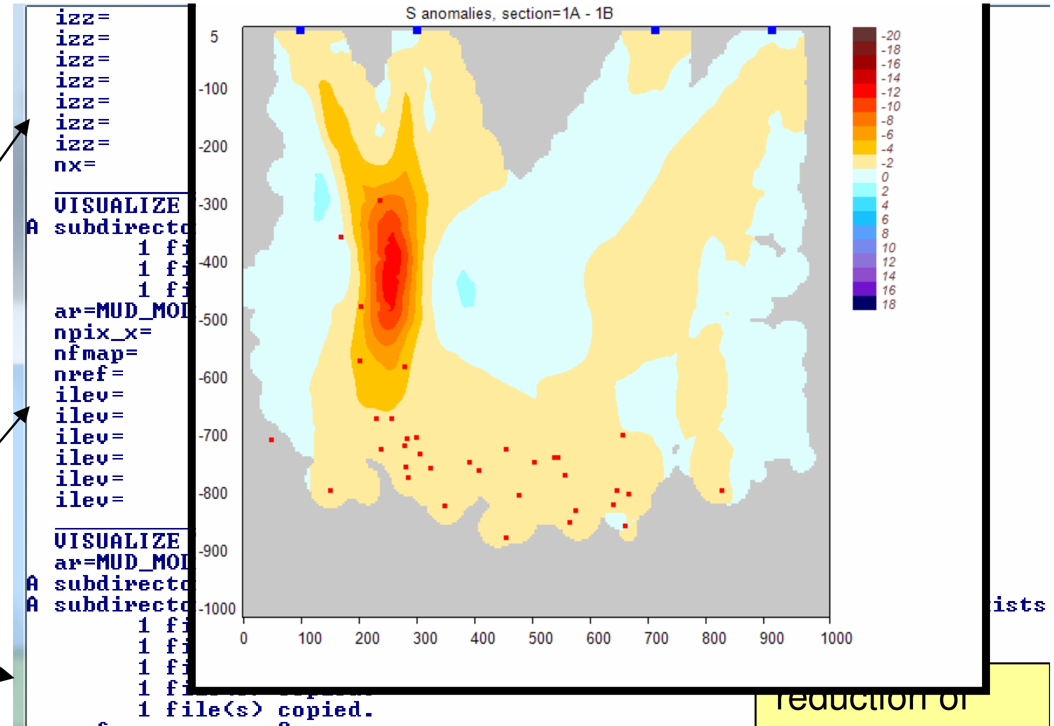
reduction of the residuals in respect to previous iteration, in%

```
 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 (VP-VS 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  nzzt=           10
 ilev=            2  nzzt=           21
 ilev=            3  nzzt=          210
 ilev=            1  zzz=    300.0000
 ilev=            2  zzz=    500.0000
 ilev=            3  zzz=    700.0000

 VISUALIZE THE RESULT IN VERTICAL SECTIONS (VP-VS 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 alread
 cannot find REF_PARAM in MAJOR_PARAM.DAT!!!
 ar=MUD_MOD1 md=MODEL_01
 nan=            0
           4
 nref=            2
  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
```

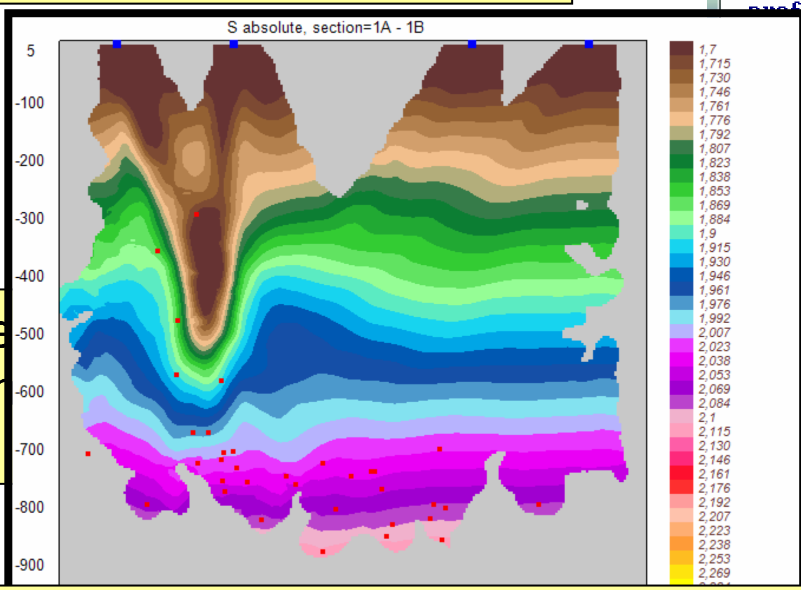
Running the tomographic inversion:

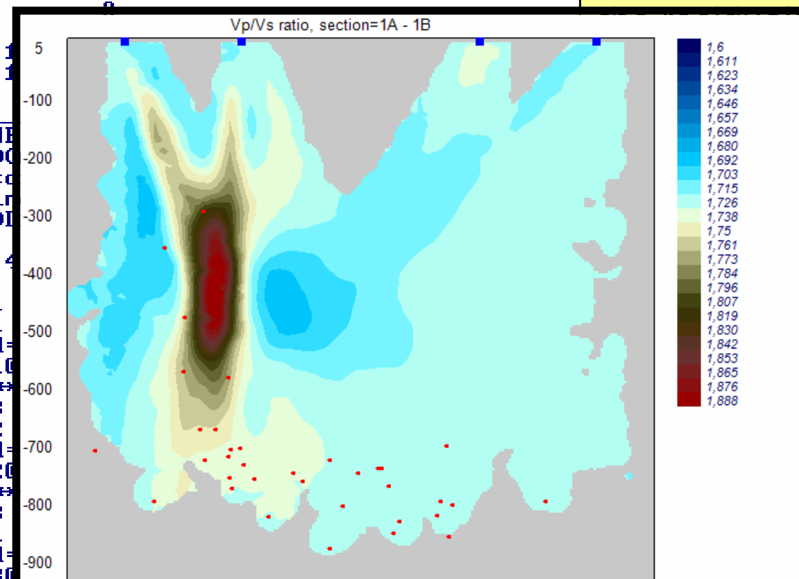
After computing results in four grids, we create one average model

Visualize the result in horizontal and vertical sections



Next ite
locatior
model





After each iteration we can see the inversion results presented in ver and hor sections in folder PICS/MUD_MOD1/MODEL_01/IT1

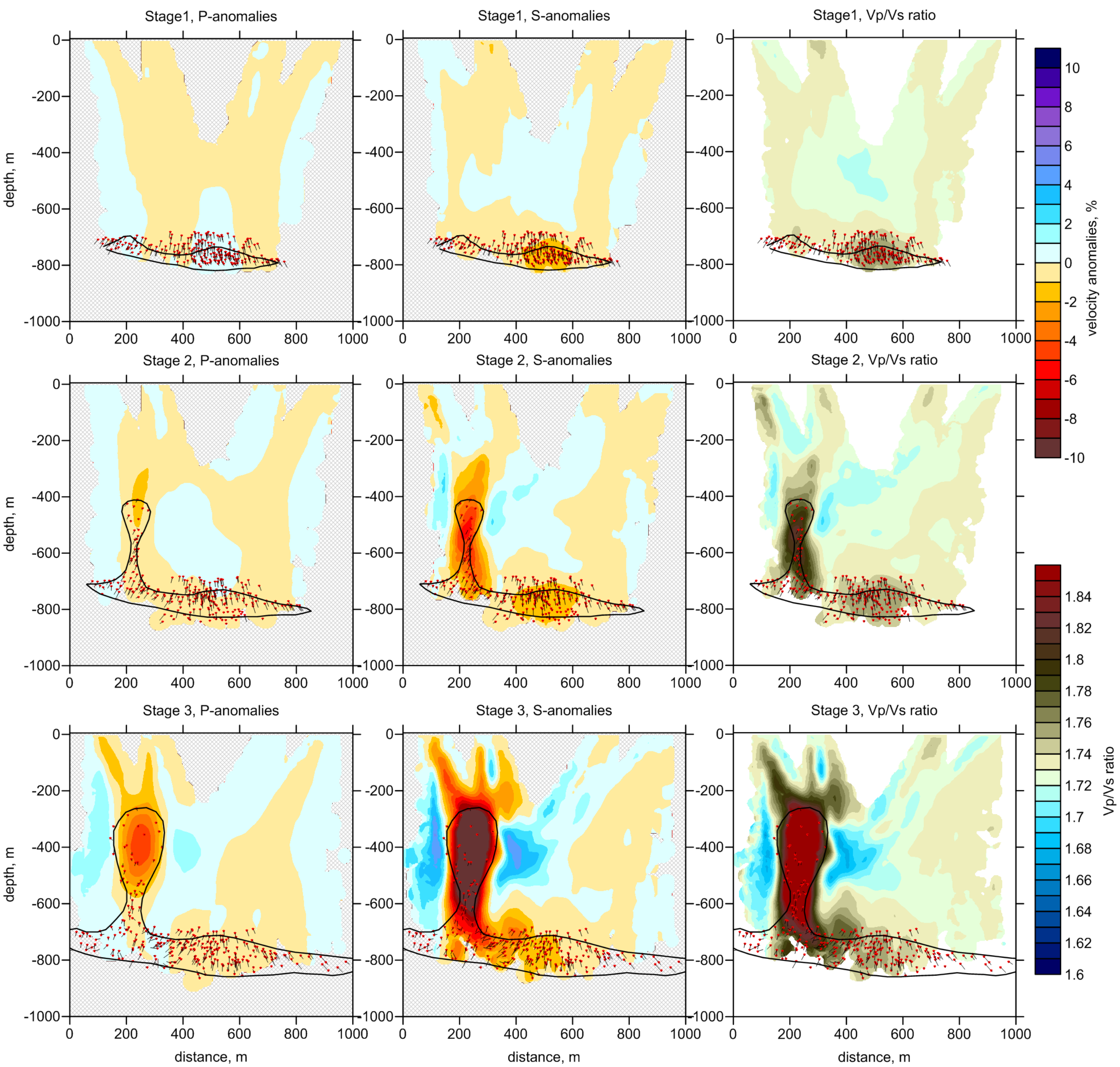
Running the tomographic inversion:

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

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 (VP-VS 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  nzzt=           12
 ilev=           2  nzzt=           20
 ilev=           3  nzzt=          212
 ilev=           1  zzz=   300.0000
 ilev=           2  zzz=   500.0000
 ilev=           3  zzz=   700.0000
 ______________________________________________________________
 VISUALIZE THE RESULT IN VERTICAL SECTIONS (VP-VS 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=  0.0000000E+00
 iter=           1  dtot_s=   2.380682      red=  0.0000000E+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
 ___________________________________________________
 nsrces=         291  nray_p=        5183  nray_s=        3849

D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_MANUAL\PROGRAMS\0_START\START>pause
Press any key to continue . . .
```

Presenting the inversion results in Surfer:



Files for visualization in Surfer (5^{th} iteration, 1^{st} section)

Located events in vertical section:
TMP_files\loc\srces_ver5 1.dat

Event mislocations:
TMP_files\loc\shift_ver5 1.bln

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!