

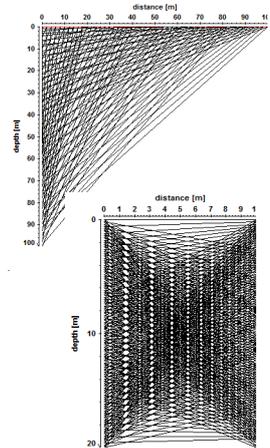
Introduction to the travelttime tomography and prestack migration for borehole-data within REFLEXW

In the following the use of the travelttime tomography and the prestack-migration for different types of borehole data is described. The travelttime tomography allows to build a velocity model from the first arrival traveltimes. The prestack migration allows to trace back the wavefield of single shots or constant offset data to their "source". The migration takes into account arbitrary shot/receiver offsets in contrast to the other migration methods within Reflexw which need zero offset data as input. The following borehole geometries are supported:

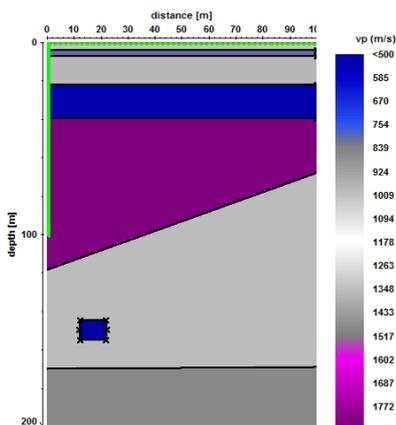
- shots or receivers are located along the x-axis and shots or receivers are located along the y(z)-axis (borehole) - walk away vertical seismic profile (**WVSP**) - see chap. I

- shots and receivers are both located along the y(z) axis within different boreholes which have a distinct x-offset - **crosshole** - see chap. II

The prestack migration tool automatically controls the correct geometry.



I. Walk away VSP data



The used dataset is a synthetic seismic dataset which allows to get informations about the benefits und the critical parameters of the prestack migration.

I.1 Import the data and geometry settings

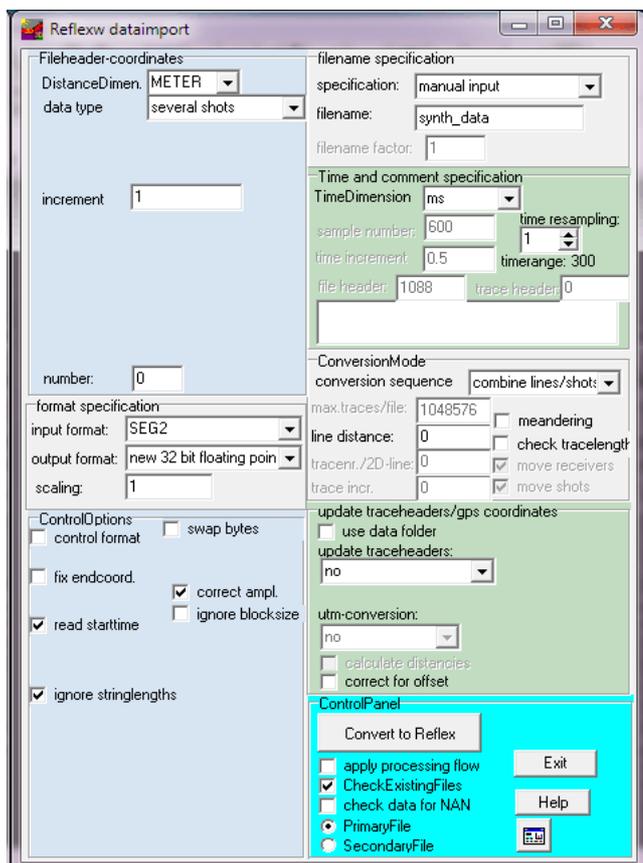
In the following the import and geometry setting of 51 shots (SEG2-format) with different offsets

between 0 and 100 m from the borehole for a receiver line from 100 to 0 m (1 m receiver increment) within the borehole will be described.

1. Import all .SG2 files into a single file

- Data type: several shots
- increment: mean receiver increment within borehole
- input format: SEG2
- output format new 32 bit floating point
- conversion sequence: combine lines/shots

Click on Convert to Reflex and choose all wanted files, in this case 51 files



2) Set the geometry within the CMP-geometry panel

The positions of the shot and the receivers in real z-direction may be stored on the y- or on the z-traceheader coordinates. The x-offsets are stored on the x-traceheader coordinates. In the following the y-traceheader coordinates are used because the CMP-geometry setting only allows to set the x- and y-traceheader coordinates. If wanted it is possible to exchange the y- and z-traceheader coordinates afterwards within the edit/traceheader tabella menu (option y<-> z).

- Click on CMP and then on geometry
- set the standard geometry for a fixed receiver line within the borehole from 100 to 0 m with an increment of 1 m. The shots are located at the surface starting from 0 m to 100 m with an increment of 2 m.
- As standard line direction choose y-direction rec. The receiver increment must be negative because the first receiver has been located at 100 m and the last at 0 m. The nr. of channels is 101 (101 receiver positions).
- click on apply std.geometry and then on save geometry
- use the option edit single traces in order to check the correct geometry.

The screenshot shows the Reflexw - 2D-dataanalysis software interface. The main window displays the CMP-geometry panel with the following settings and data:

Standard Geometry Settings:

- Standard geometry: fixed line
- nr. of channels: 101
- shot start: 0, shot increment: 2, shot offset: 0
- receiver increment: -1, receiver offset: 0
- first receiver: 100, last receiver: 0
- standard line direction: y-direction rec.

Table of Shot and Receiver Coordinates:

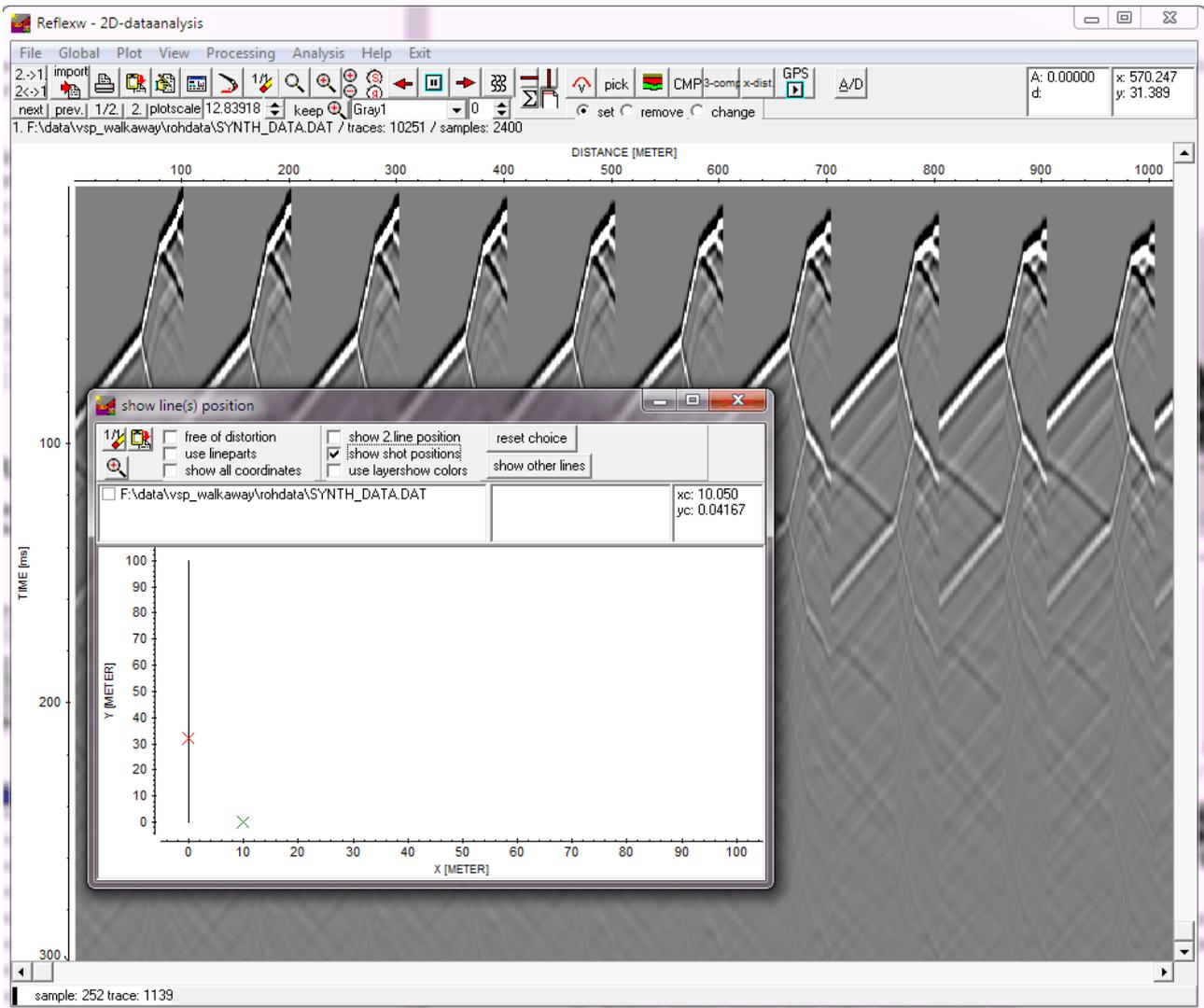
shot no	1.trace	last trace	shot x	shot y	recx start	recx end	recy start	recy end
1	101	1	0	0	0	0	0	100
2	202	102	2	0	0	0	0	100
3	303	203	4	0	0	0	0	100
4	404	304	6	0	0	0	0	100
5	505	405	8	0	0	0	0	100
6	606	506	10	0	0	0	0	100
7	707	607	12	0	0	0	0	100
8	808	708	14	0	0	0	0	100
9	909	809	16	0	0	0	0	100
10	1010	910	18	0	0	0	0	100
11	1111	1011	20	0	0	0	0	100
12	1212	1112	22	0	0	0	0	100
13	1313	1213	24	0	0	0	0	100
14	1414	1314	26	0	0	0	0	100
15	1515	1415	28	0	0	0	0	100
16	1616	1516	30	0	0	0	0	100

Additional Settings:

- show geometry: geometry
- show stand.geometry:
- view geometry:
- load from ASCII-file:
- non equidist.rec:

sample: 0 trace: 653

Another check may be done using the option view/profile line (traceheader coord.) Click show shot position and move mouse over the shot record in the background from left to right to check the geometry.



I.2 Generate a 2D-velocity file for the subsequent migration

The prestack migration needs either a constant velocity or a 2D-velocity distribution. If no other informations are available the 2D-velocity distribution may be generated either from one VSP-data shot using the CMP-vel.analysis module or from a tomographic inversion of the first arrivals of the direct wave.

I.2.1 2D-velocity distribution using the CMP-vel.analysis

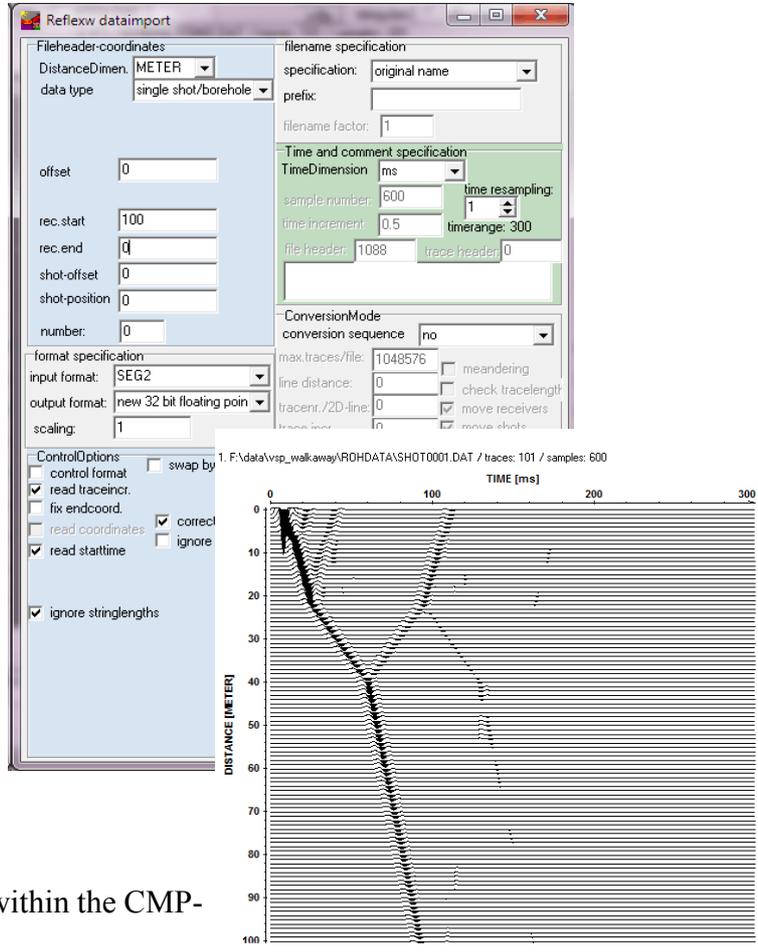
1. Enter the 2D-dataanalysis module:

Import one VSP-data shot:

- data type: single shot/borehole
- set the offset, receiver start and end and shot offset and position.
- conversion sequence set to no

Convert to Reflex this single file. If receiver start is bigger than end coordinate the file will be automatically flipped (first trace at top and last trace at bottom).

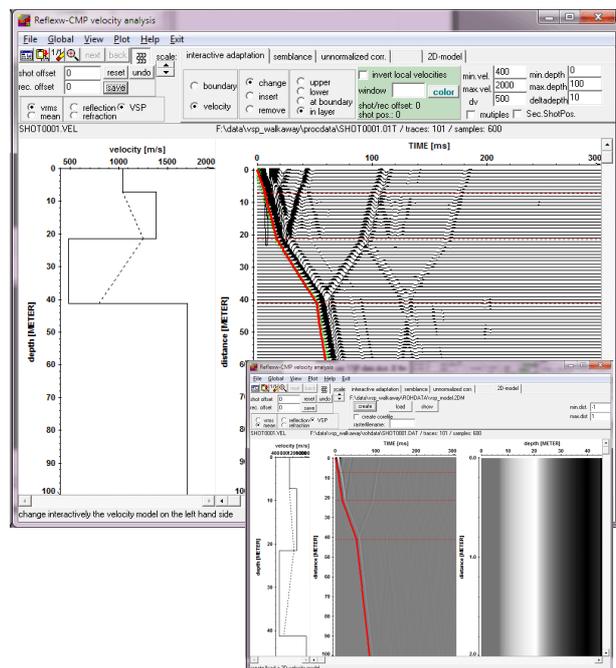
Optionally you may pick the first arrivals.



2. Perform the VSP-velocity inversion within the CMP-vel.analysis module

- load the VSP-data shot.
- If the shot has an offset you must enter the correct shot offset.
- Optionally you also may load the picked first arrivals.
- activate VSP and adapt the first arrivals
- if picked traveltimes have been loaded a direct inversion (option invert local velocities) is possible
- save the final 1D-model
- activate the option 2D-model
- click on create and load the saved 1D-model
- enter the filename for the 2D-velocity distribution

The resulting 2D-velocity distribution is laterally homogeneous.



I.2.2 2D-velocity distribution using a tomographic inversion of the first arrivals

1. Enter the 2D-dataanalysis.

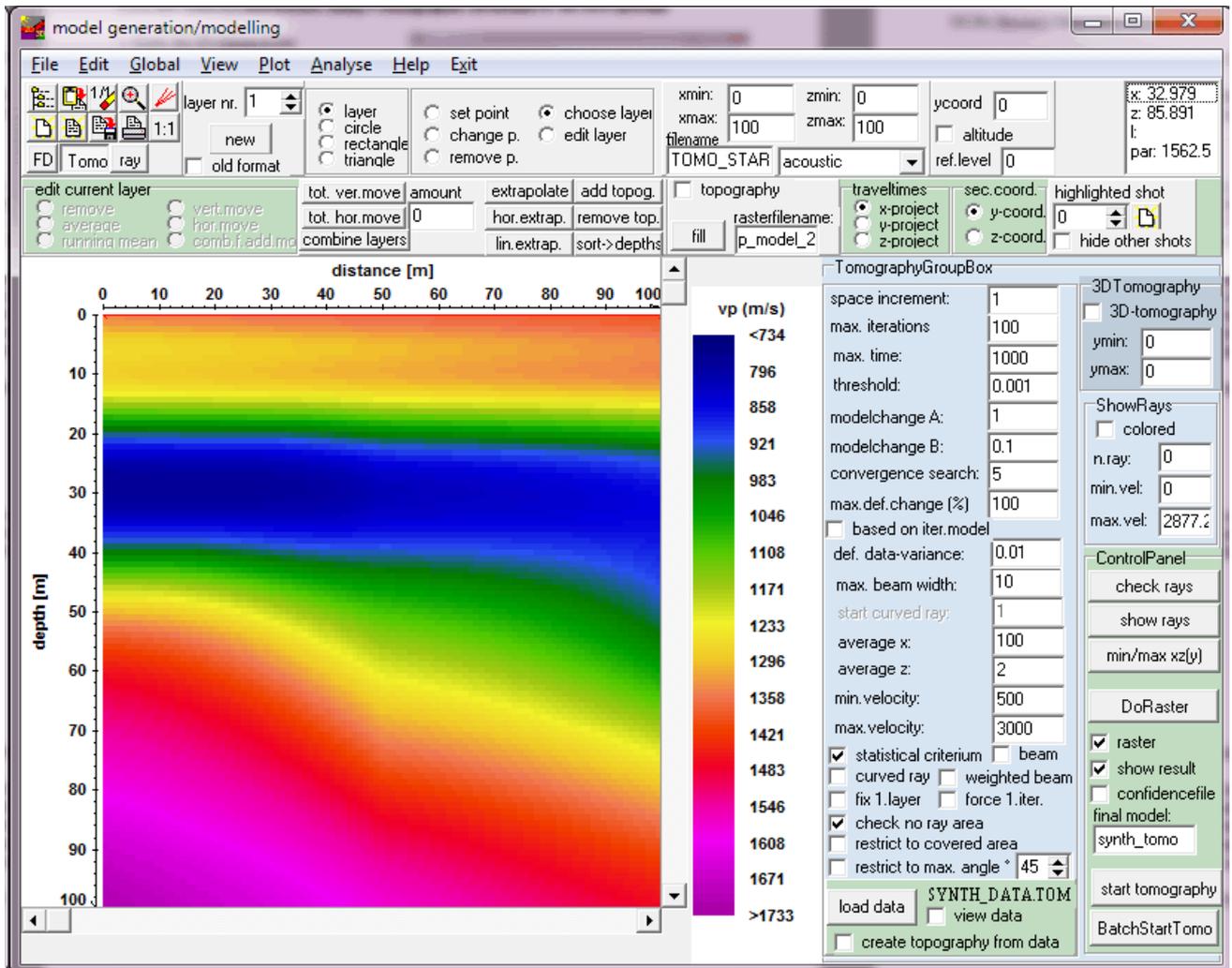
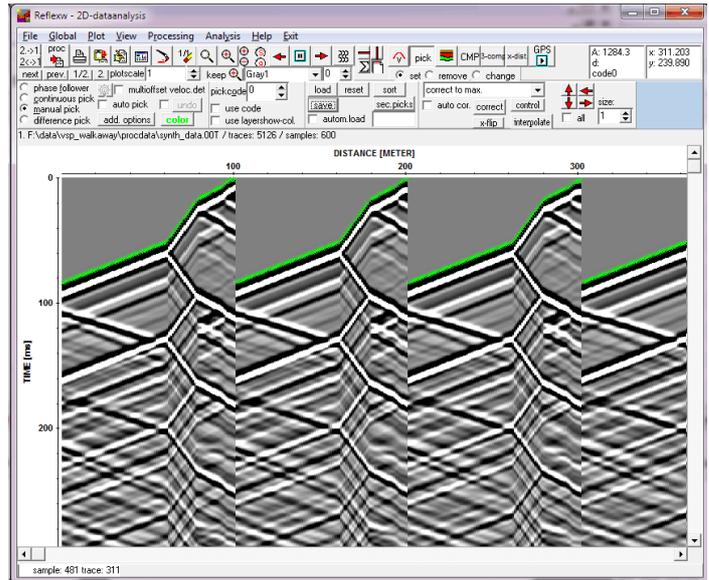
Load the combined data which still include the direct wave (without fk-filtering for example). **Pick** the first arrivals and store them using the ASCII-3D-tomography format.

2. Enter the modelling module.

Create a **start model** with a constant velocity (e.g. 1000 m/s) and the necessary min/max. x- and z-coordinates which cover the whole data range, in this case x from 0 to 100 m and z from 0 to 100.

Load the traveltimes data and set the tomography parameters. The parameters for the tomography may be changed depending on your needs. The space increment should be within the range or smaller than the receiver increment. Max.def. Change should be large enough to ensure strong enough velocity changes. Straight rays are faster and lead to a less smoothed model than curved rays. Averaging should be done in x-direction because the covering is much higher in z-direction than in x-direction. Min. and max.velocity restrict the range of the inverted velocities.

Start the **tomography**.



I.3 processing before applying the prestack migration

The aim of the pre-migration filtering is to prepare the dataset for the subsequent prestack migration. The most important processing steps are:

- energy normalization
- elimination or suppression of the direct waves and other non desired waves

The **energy normalization** should be the first filter step especially if you are using multi-channel filters (e.g. FK-filter) for the suppression of non desired waves. This filter step is applied to correct for the amplitude effects of wavefront divergence and damping. It is also necessary if a subsequent filter shall be applied for eliminating the surface waves.

The easiest way would be a manual gain function, e.g. manual gain (y) or the div. compensation filter. In the case of different coupling conditions this gain recovery function is not very suitable. In this case the filter scaled windowgain(x) may be a good choice.

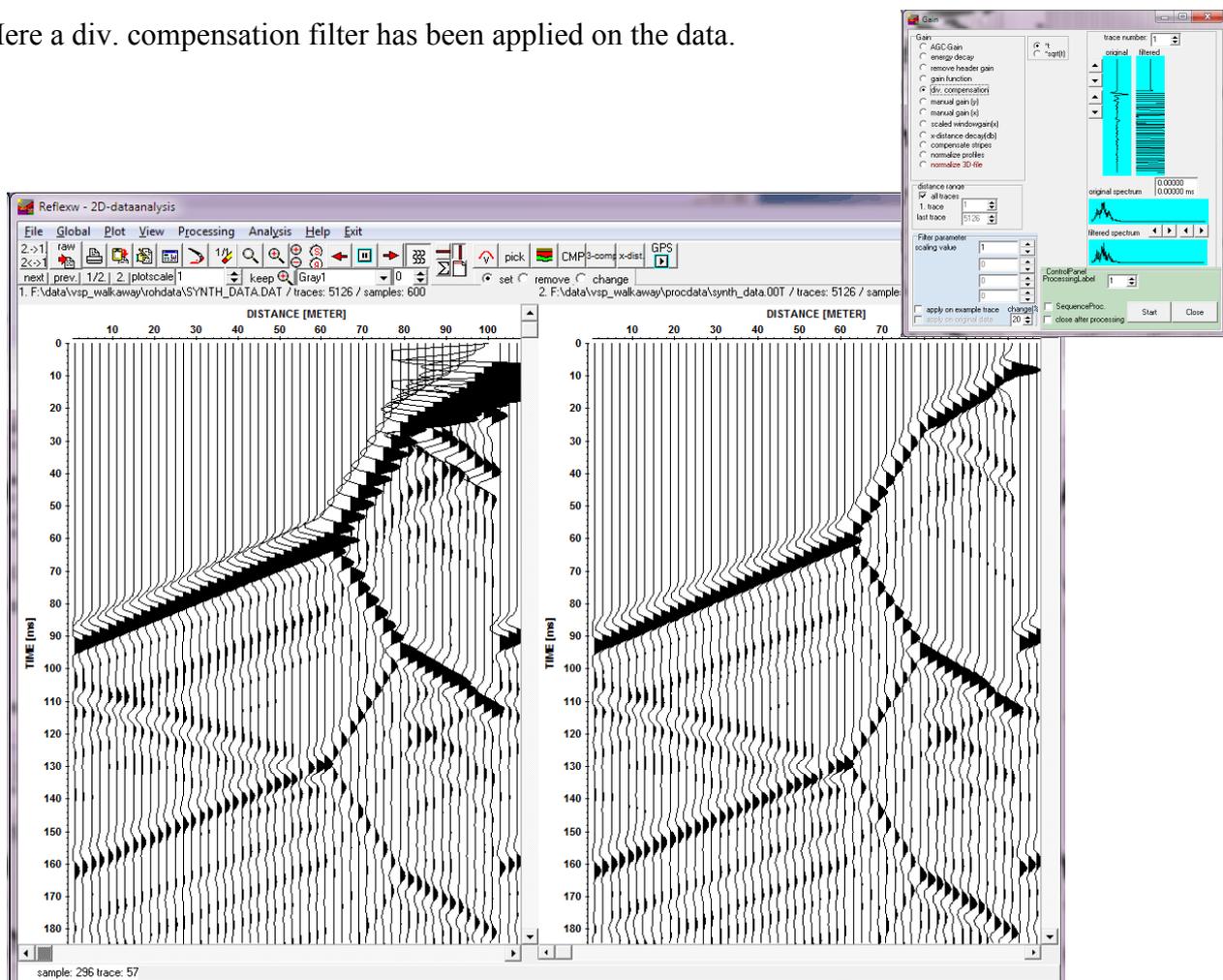
To be considered: Filtering and stacking are always done on the true amplitude data. The option `tracenormalize` within the `plotoptions` is only a `plotoption` and does not effect the filtering/stacking process. Therefore the option `tracenormalize` within the `plotoptions` should be deactivated because otherwise the effect of the energy normalization may not be controlled correctly.

The second filter step consists of the **elimination of the direct waves** and other non desired waves. For that purpose you may distinguish between editing and 2D-filter steps.

Editing may be used for muting (set to zero) special data parts or to delete single traces or trace ranges. 2D-filters may be used to suppress unwanted signals. A FK-filter may be a good choice.

1. Energy normalization

Here a div. compensation filter has been applied on the data.



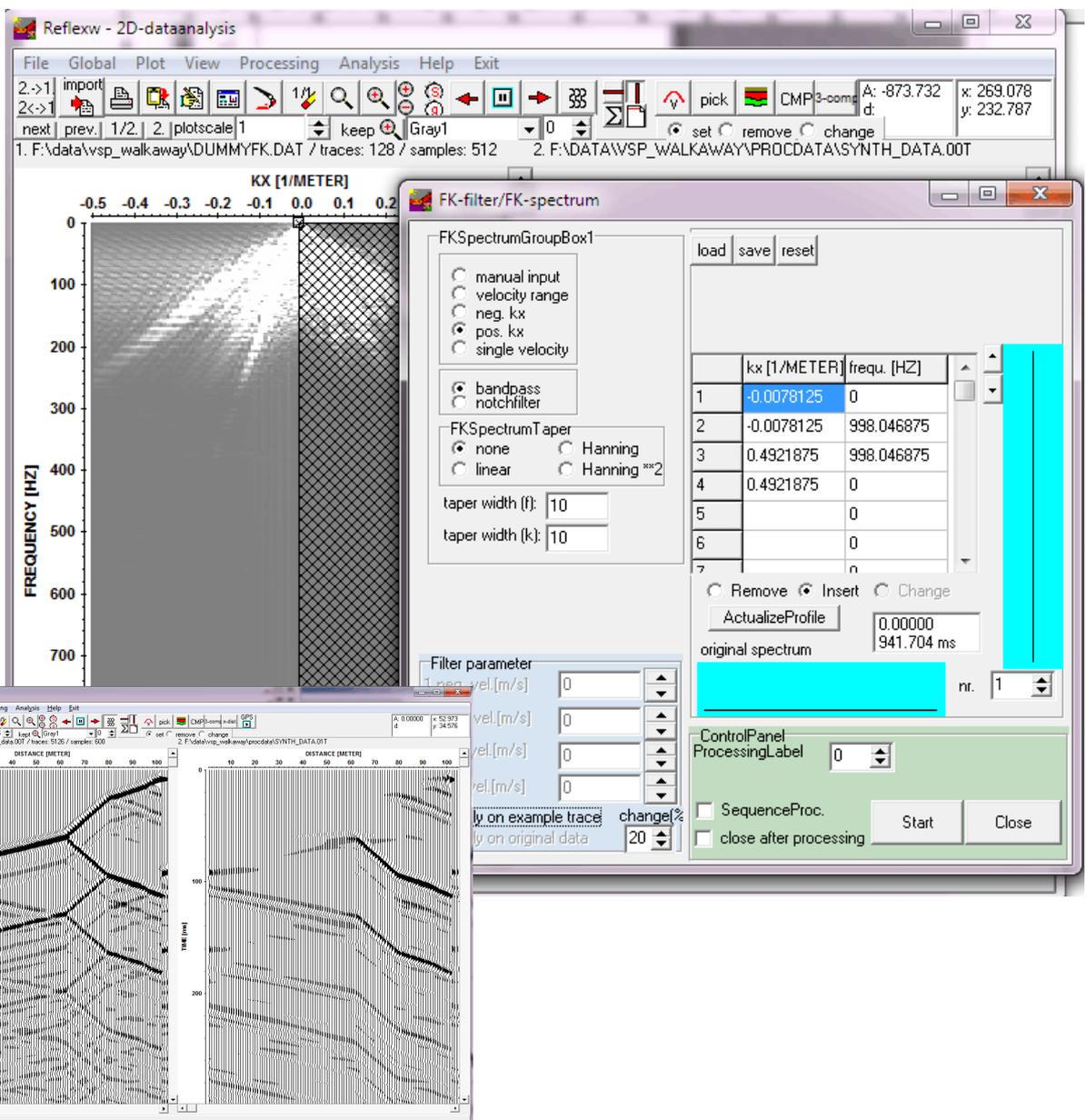
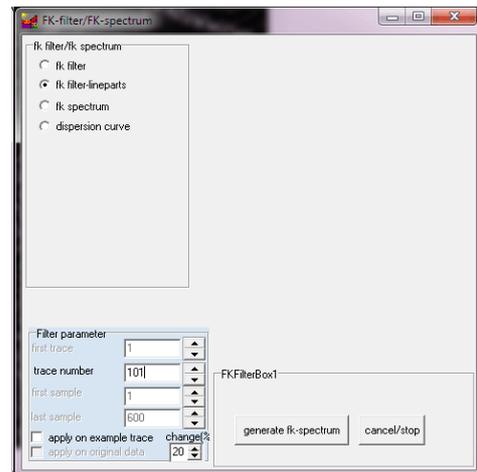
2. Direct wave suppression

For the direct wave suppression here a fk-filtering has been used - option **Processing/FK-filter/FK-spectrum**.

The FK-filter/FK-spectrum window appears. Enter the following parameters or options:

- activate the option **fk filter-lineparts**
- enter the filterparameter **tracenumber** (corresponds to the number of traces per shot) - in this case 101
- activate the option **generate fk-spectrum**

A new FK-filter/FK-spectrum window appears. The direct wave is located within a different kx range than the reflections which shall be included for the prestack migration of VSP data. The direct waves are located within the negative kx-range in this case as the receiver line goes from larger values to smaller ones (100 m to 0 m). Therefore the pos. fk-range has been chosen for filtering the data.



I.4 Perform the prestack migration

The prestack migration needs either a constant velocity or a 2D-velocity distribution. Depending on the choice of the 2D-velocity distribution (see chap. I.3) the velocities may be determined from

- CMP-analysis** (chap. I.3.1)
- rasterfile layer** using the inverted tomogram (chap. I.3.2). Reflections originating from below the defined velocity tomogram are migrated with an extrapolated velocity equal to the velocity at the bottom of the tomogram.

Parameter settings:

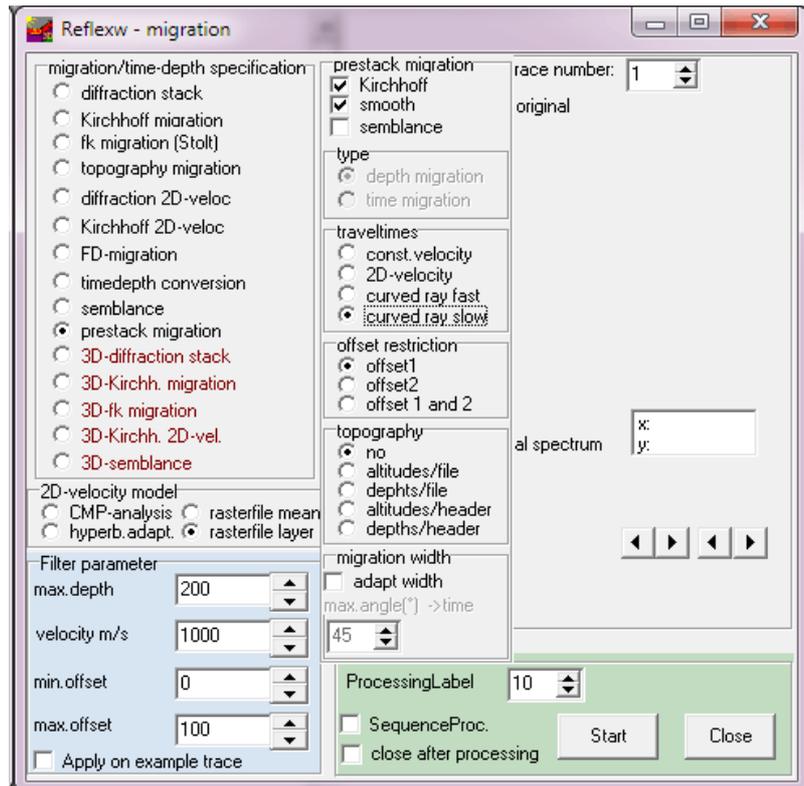
maxdepth: defines the maximum depth range for the depth migration. The value may be set to larger depths than the borehole depth in order to also include deeper reflections. The value should not exceed the maximum reached depth defined by the acquisition time range.

velocity: defines the velocity in case of const.velocity migration and will be used for the smooth option if a depth migration will be performed.

min. and max. offset: restrict the range for the summation

activated option **smooth:** the summation is done over a depth range corresponding to the real wavelength. The parameter velocity is used for the calculation of the wavelength. A very high value will lead to a strong smoothing, a smaller value will decrease the smoothing.

activated option **Kirchhoff:** weighted factors are used for the summation

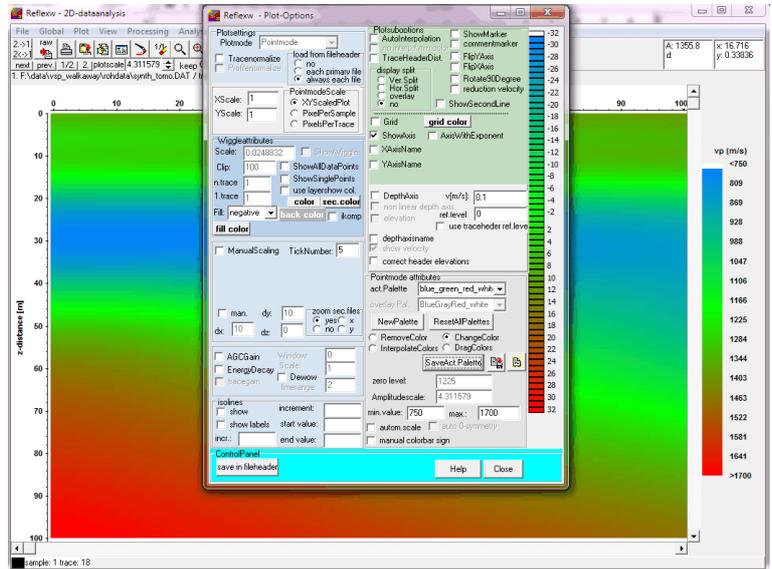


I.5 Overlay tomogram and prestack migration result

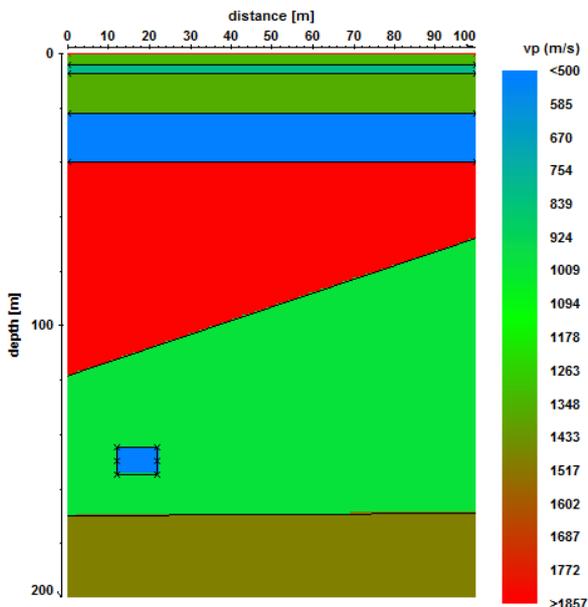
The prestack migration may be **overlayed** with the tomogram. For this purpose you must perform the following steps:

1. Set the correct plot settings both for the migrated section and the tomogram and save them within the fileheader.

- tomogram - load the tomogram, enter the plotoptions menu and set pointmode and the wanted plot interval (in this case min.value to 750 m/s and max.value to 1700 m/s, if the depth of the tomogram is smaller than the max.depth of the migrated section you may set min.value to a smaller value than the min.tomogram velocity in order to use a white color for this value range and below), click on save in fileheader
- migrated section - load the migrated section, enter the plotoptions menu and set wigglemode and the wanted wiggle scale (in this case 0.001) and fill to positive, click on save in fileheader

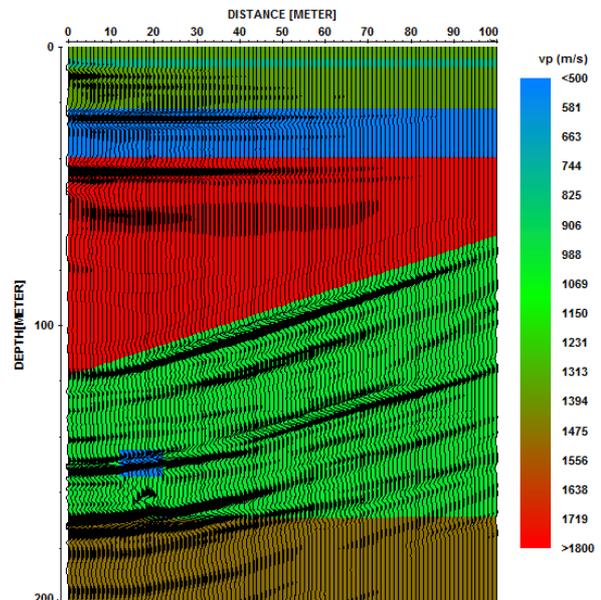


2. Load the migrated section as a primary file and the tomogram as a secondary file
3. Select “always each file” within the plotoption
4. Select the overlay button either within the plotoptions or within the control panel

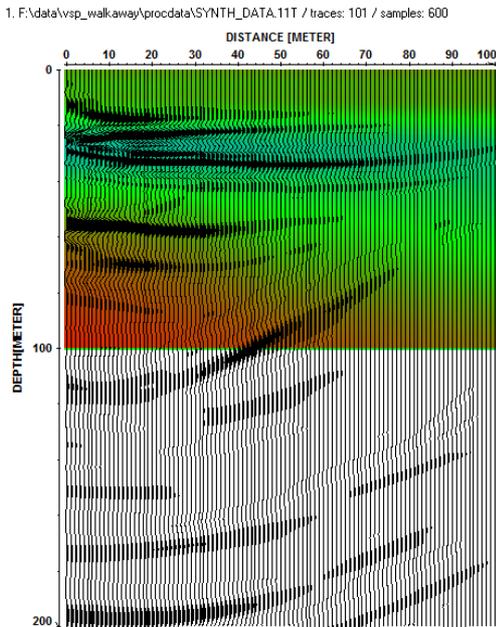


Model used for the generation of the synthetic dataset

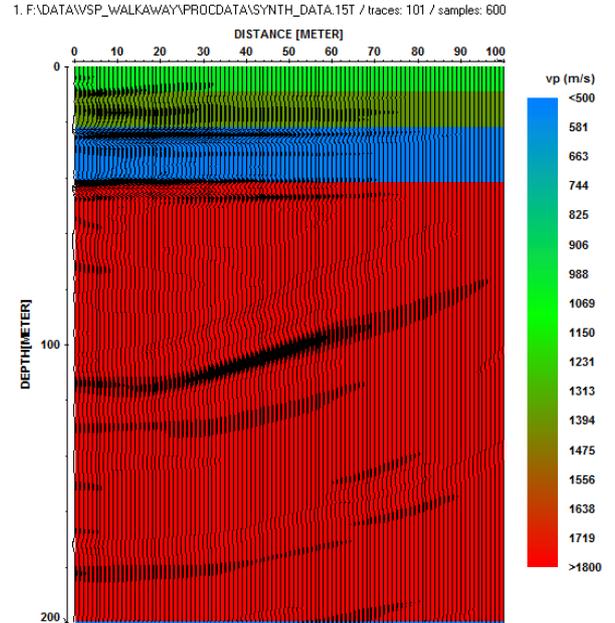
1. F:\data\vsp_walkaway\prodata\SYNTH_DATA.10T / traces: 101 / samples: 600



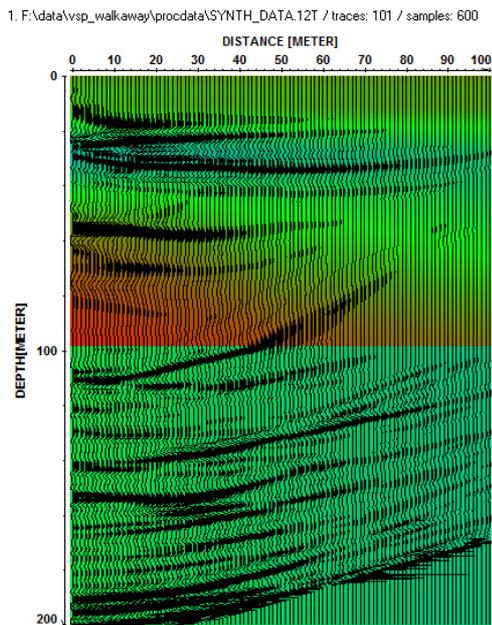
Prestack migration based on the initial model which has been underlaid



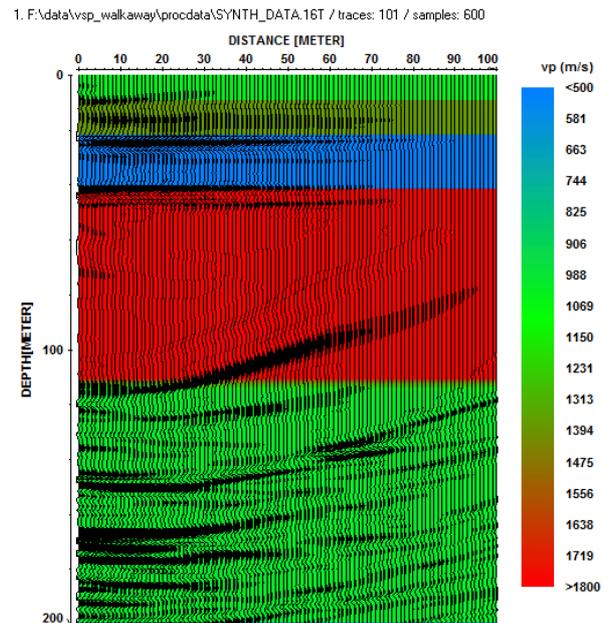
Prestack migration based on the inverted tomogram without adapting the velocities below 100 m (end of borehole and therefore end of tomographic inversion)



Prestack migration based on the VSP-inverted 1D-velocity distribution. Again below 100 m the velocity has been simply extrapolated



Prestack migration based on the inverted tomogram with manual change of the lower velocities (below 100 m,) to 1000 m/s



Prestack migration based on the VSP-inverted 1D-velocity distribution including lower velocities of 1000 m/s below 110 m

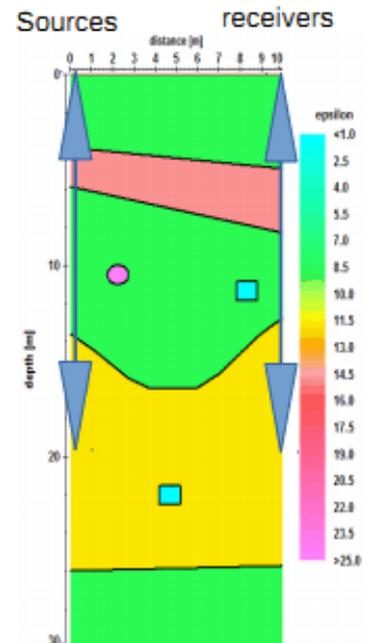
A better result is achieved if the VSP-inverted 1D-velocity distribution is used because of the smoothing of the tomographic inversion. The lower reflections (diffractions) below the borehole are only reconstructed if the correct velocity is used. Therefore additional informations about the velocity there is needed. The migration result based on the VSP-inverted 1D-velocity distribution including the velocity decrease below 100 m shows a very good reconstruction of all elements within the initial model.

II. Crosshole data

The used dataset is a synthetic GPR dataset (model see right picture) which allows to get informations about the benefits und the critical parameters of the prestack migration.

II.1 Import the data and geometry settings

In the following the import and geometry setting of 101 shots (SEG2-format) located within borehole 1 at different depths starting at 0 m until 20 m for a receiver line within borehole 2 (separated by 10 m from borehole 1) from 20 to 0 m (0.2 m receiver increment) will be described.



1. Import all .SG2 files into a single file

Data type: several shots

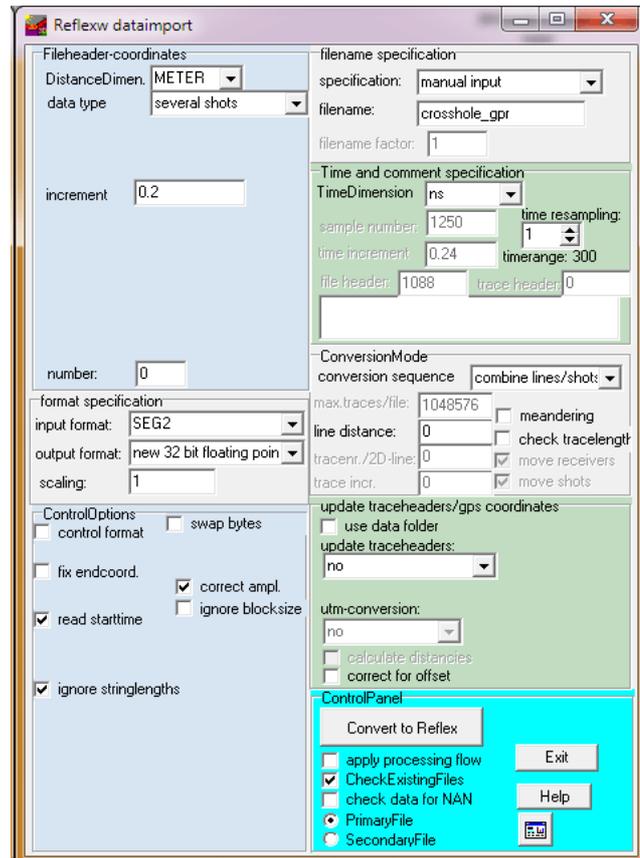
increment: mean receiver increment within borehole

input format: SEG2

output format new 32 bit floating point

conversion sequence: combine lines/shots

Click on Convert to Reflex and choose all wanted files, in this case 101 files



2) Set the geometry within the CMP-geometry panel

The positions of the shot and the receivers in real z-direction may be stored on the y- or on the z-traceheader coordinates. The x-offsets are stored on the x-traceheader coordinates. In the following the y-traceheader coordinates are used because the CMP-geometry setting only allows to set the x- and y-traceheader coordinates. If wanted it is possible to exchange the y- and z-traceheader coordinates afterwards within the edit/traceheader tabella menu (option y<-> z).

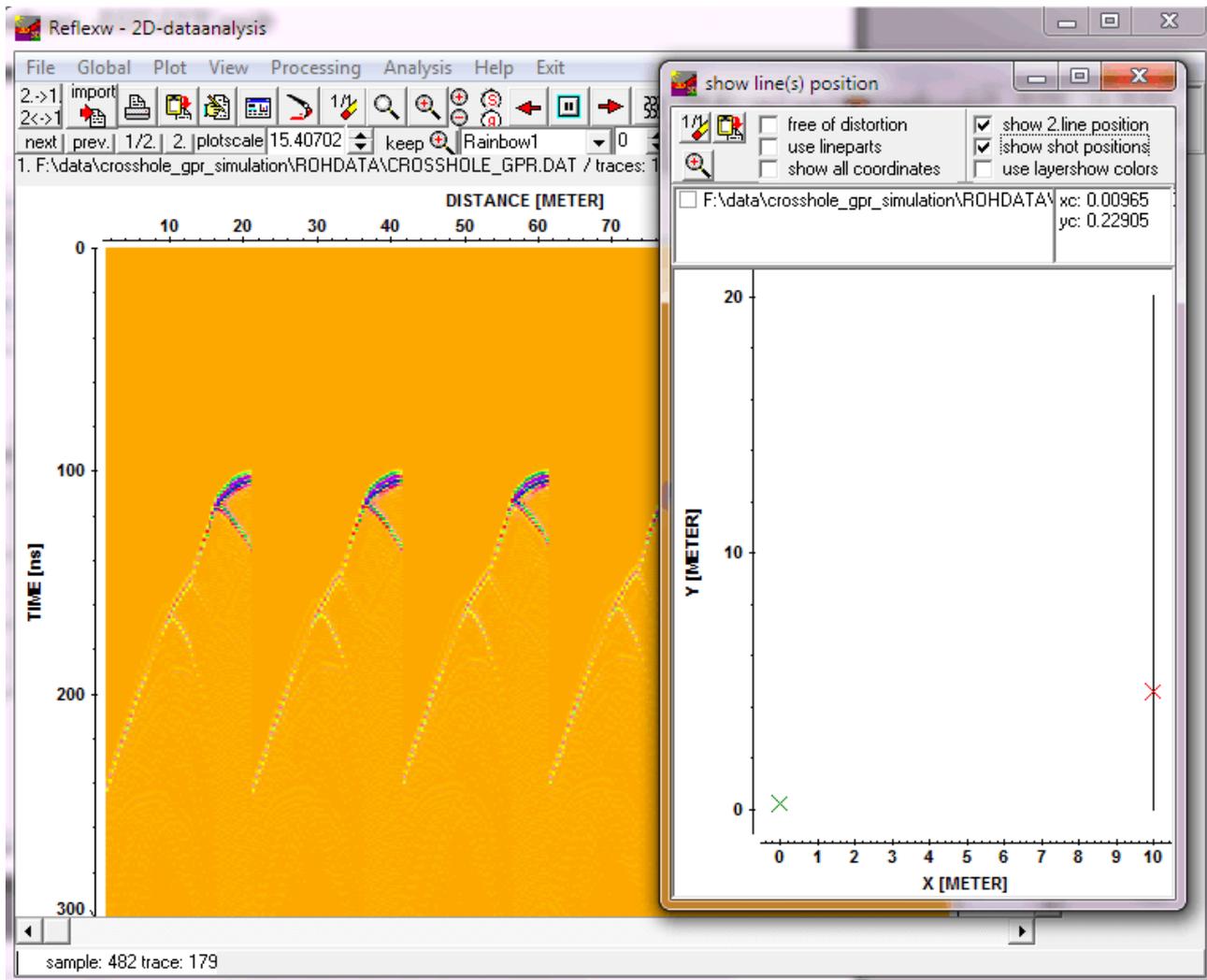
- Click on CMP and then on geometry
 - set the standard geometry for a fixed receiver line within the borehole 2 at an offset of 10 m from 20 to 0 m with an increment of 0.2 m. The shots are located within borehole 1 at an offset of 0 m starting from 0 m to 20 m with an increment of 0.2 m.
- As standard line direction choose y-direction shots/rec. The receiver increment must be negative because the first receiver has been located at 20 m and the last at 0 m. The nr. of channels is 101 (101 receiver positions).
- click on apply std.geometry and then on save geometry
 - use the option edit single traces in order to check the correct geometry.

standard geometry
nr. of channels: 101
first trace: 1
last trace: 10201
shot start: 0
shot increment: 0.2
shot offset: 0
receiver increment: -0.2
receiver offset: 10
first receiver: 20
left shot receiver: 0
right shot receiver: 0
last receiver: 0

shot no	1.trace	last trace	shot x	shot y	recx start	recx end	recy start	recy end
1	101	1	0	0	10	10	-2.980232E-7	20
2	202	102	0	0.2	10	10	-2.980232E-7	20
3	303	203	0	0.4	10	10	-2.980232E-7	20
4	404	304	0	0.6	10	10	-2.980232E-7	20
5	505	405	0	0.8	10	10	-2.980232E-7	20
6	606	506	0	1	10	10	-2.980232E-7	20
7	707	607	0	1.2	10	10	-2.980232E-7	20
8	808	708	0	1.4	10	10	-2.980232E-7	20
9	909	809	0	1.6	10	10	-2.980232E-7	20
10	1010	910	0	1.8	10	10	-2.980232E-7	20
11	1111	1011	0	2	10	10	-2.980232E-7	20
12	1212	1112	0	2.2	10	10	-2.980232E-7	20
13	1313	1213	0	2.4	10	10	-2.980232E-7	20
14	1414	1314	0	2.6	10	10	-2.980232E-7	20
15	1515	1415	0	2.8	10	10	-2.980232E-7	20

sample: 0 trace: 1342

Another check may be done using the option view/profile line (traceheader coord.) Click show shot position and move mouse over the shot record in the background from left to right to check the geometry.



II.2 processing before applying the migration

The aim of the pre-migration filtering is to prepare the dataset for the subsequent prestack migration. The processing is not as critical as for the case of WVSP data. In many cases even no processing is necessary except standard **bandpass filtering** for the suppression of noise. In addition an **energy normalization**, e.g. the filter **scaled windowgain(x)**, in the case of different coupling conditions is often suitable.

To be considered: Filtering and stacking are always done on the true amplitude data. The option `tracenormalize` within the `plotoptions` is only a `plotoption` and does not effect the filtering/stacking process. Therefore the option `tracenormalize` within the `plotoptions` should be deactivated because otherwise the effect of the energy normalization may not be controlled correctly.

The second filter step may consist of the **elimination of the direct waves** and other non desired waves. In contrast to the WVSP data a `fk`-filtering is not suitable because reflections and diffractions may have the same slope as the direct waves. Therefore only editing (**muting**) might be a choice for muting (set to zero) special data parts or to delete single traces or trace ranges.

II.3 Generate a 2D-velocity file for the subsequent migration by a tomographic inversion of the first arrivals

The prestack migration needs either a constant velocity or a 2D-velocity distribution. If no other informations are available the 2D-velocity distribution may be generated from a tomographic inversion of the first arrivals of the direct waves.

1. Enter the 2D-dataanalysis.

Load the combined data which still include the direct wave (without muting for example).
Pick the first arrivals and store them using the ASCII-3D-tomography format.

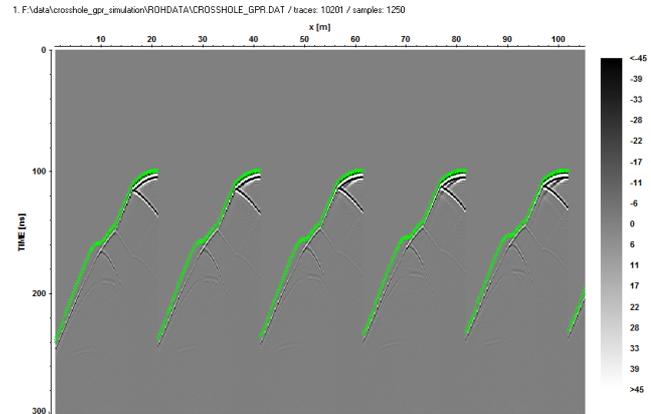
2. Enter the modelling module.

Create a **start model** with a constant velocity (e.g. 2000 m/s) and the necessary min/max. x- and z- coordinates which cover the whole data range, in this case x from 0 to 100 m and z from 0 to 100.

Load the traveltimes data and set the tomography parameters. Use the option check rays in order to check the shot/receiver geometry.

Start the **tomography**.

The parameters for the tomography may be changed depending on your needs (see also chap. I.2.2.2). In this case the max. depth of tomographic inversion has been set to 30 although the boreholes only reach a depth of 20 m in order to extrapolate the inverted velocity at 20 m depth to larger depths for the subsequent prestack migration.



II.4 Perform the prestack migration

The prestack migration needs either a constant velocity or a 2D-velocity distribution. Here we are choosing

rasterfile layer using the inverted tomogram (chap. II.3). Reflections originating from below the defined velocity tomogram are migrated with an extrapolated velocity equal to the velocity at the bottom of the tomogram. This only holds true if the calculation of the tomogram used a smaller depth than the maxdepth used for the prestack migration (see chap. I.4).

Parameter settings:

maxdepth: defines the maximum depth range for the depth migration. The value may be set to larger depths than the borehole depth in order to also include deeper reflections. The value should not exceed the maximum reached depth defined by the acquisition time range.

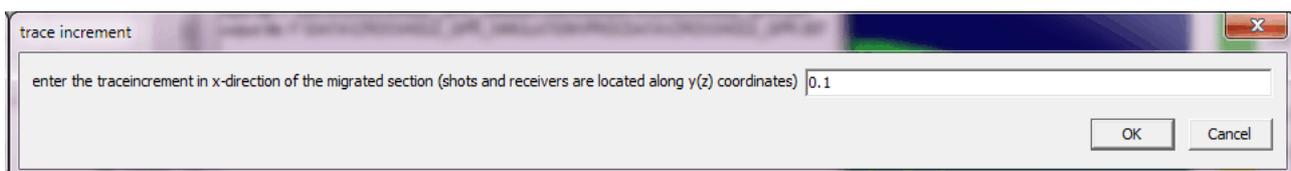
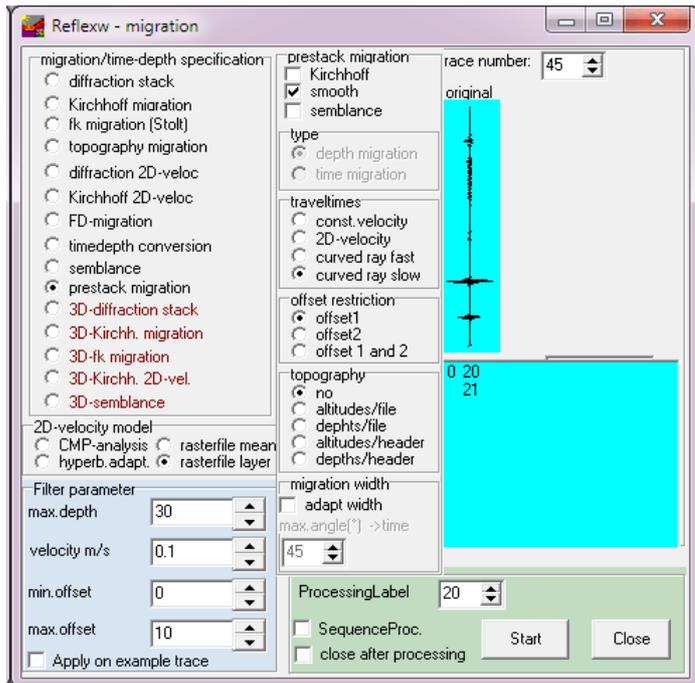
velocity: defines the velocity in case of const. velocity migration and will be used for the smooth option if a depth migration will be performed.

min. and max. offset: restrict the range for the summation

activated option **smooth**: the summation is done over a depth range corresponding to the real wavelength. The parameter velocity is used for the calculation of the wavelength. A very high value will lead to a strong smoothing, a smaller value will decrease the smoothing.

deactivated option **Kirchhoff**: no weighted factors are used for the summation

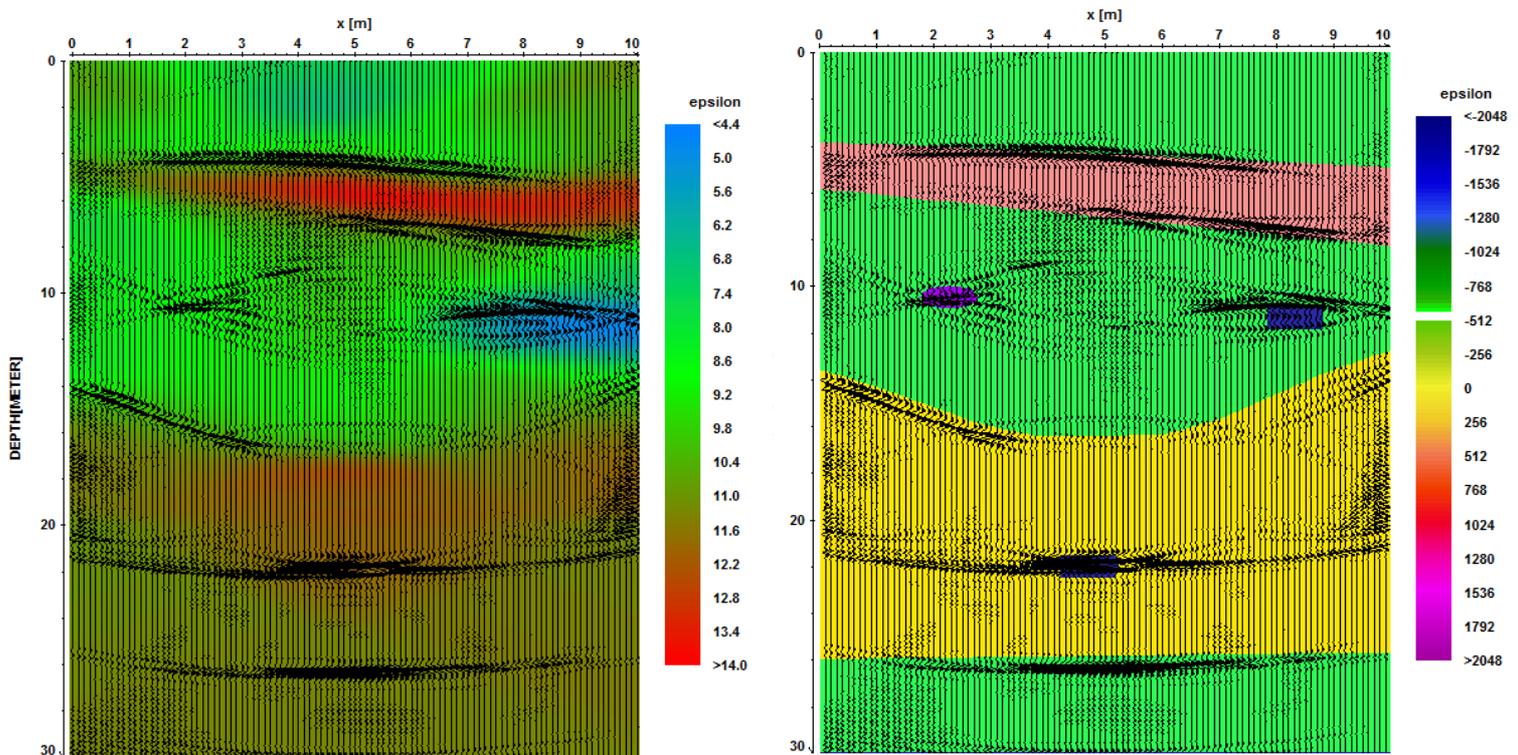
After having started the prestack migration the tomogram is asked for and afterward the trace increment for which the prestack migration shall be performed. It is recommended to use a smaller increment than the default which is taken from the receiver increment within the borehole although a smaller value leads to a greater CPU time.



II.5 Overlay tomogram and prestack migration result

The prestack migration may be **overlaid** with the tomogram. For this purpose you must perform the following steps:

1. Set the correct plot settings both for the migrated section and the tomogram and save them within the fileheader.
 - tomogram - load the tomogram, enter the plotoptions menu and set pointmode and the wanted plot interval (in this case min.value to 4.4 and max.value to 14), click on save in fileheader
 - migrated section - load the migrated section, enter the plotoptions menu and set wigglemode and the wanted wiggle scale (in this case 5) and fill to positive, click on save in fileheader
2. Load the migrated section as a primary file and the tomogram as a secondary file
3. Select “always each file” within the plotoption
4. Select the overlay button either within the plotoptions or within the control panel



It is quite obvious that the prestack migration gives much more information than the pure traveltime inversion (left picture). This is also documented if the initial model used for the creation of the synthetic dataset is overlaid (right picture).