

Import & Smooth invert line P6 3.36 : edit shot pos. in .HDR batch since missing in SEG-2 :

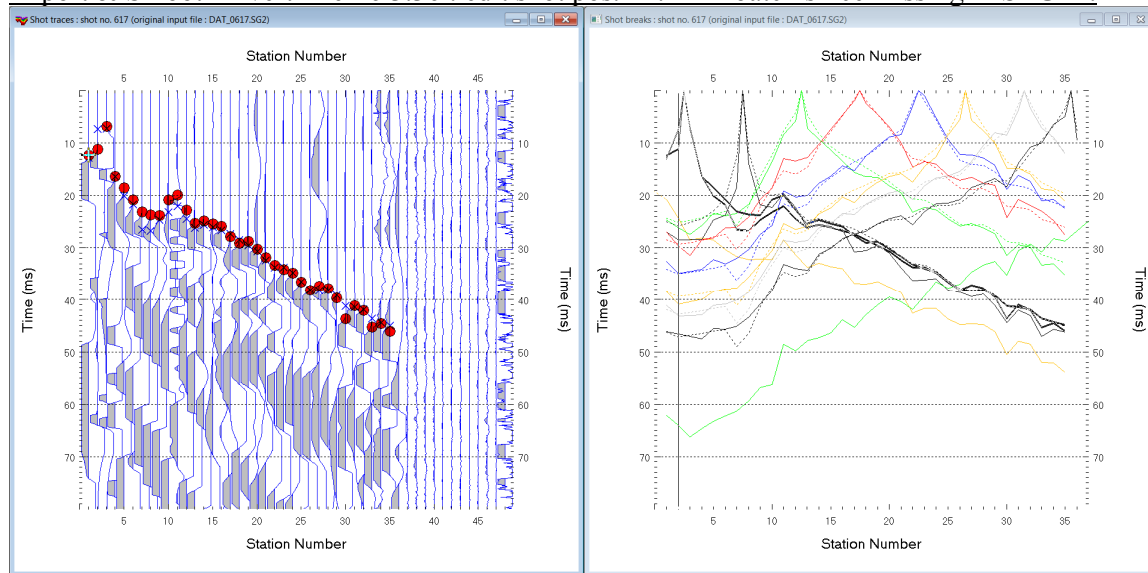


Fig. 1 : left : *Trace|Shot gather*, right : *Refractor|Shot breaks*. Shows fit between picked times (solid colored curves, red circles) and modeled times (dashed colored curves, blue crosses) obtained for Smooth invert output (Fig. 6)

To create the profile database, import the data and browse the imported shots do these steps :

- **File|New Profile...**, set *File name* to **P6** and click *Save button*
- in the prompt (Fig. 20) click *Yes button* to force **Profile start** and first receiver at station no. 1.
- in **Header|Profile...** set *Line type* to **Refraction spread/line**. Set *Station spacing* to 5.0 m.
- check box *Force grid cell size* and set *Cell size[m]* to 0.25m. See Fig. 2.
- unzip archive **P6.zip** with SEG-2 .sg2 shot files & files **BATCH.HDR** & **COORDS.COR** & **SHOTPTS.SHO** & **BREAKS.LST** in directory **c:\RAY32\P6\INPUT**
- select **File|Import Data...** and set *Import data type* to **SEG-2**. See Fig. 3.
- click *Select button* and navigate into **c:\RAY32\P6\INPUT**
- set *Files of type* to **ABEM (*.SG2)** and select any file e.g. **DAT_0616.sg2** & click button *Open*
- click button **.HDR batch** & select file **BATCH.HDR** & click button *Open*
- leave *Default spread type* at 10: **360 channels**
- check box *Batch import* & click **Import shots button**. All shots listed in **BATCH.HDR** are imported.
- select **File|Update header data|Update Station Coordinates** & **COORDS.COR**. Click *Import & Reset*.
- **File|Update header data|Update Shotpoint coordinates** with **SHOTPT.SHO**. Click *Open button*.
- select **File|Update header data|Update First Breaks**. Select file **BREAKS.LST** & click *Open button*
- select **Trace|Shot gather** and select **Window|Tile** to obtain Fig. 1
- click on title bar of **Trace|Shot gather** window and press F1 to zoom time axis (Fig. 1 left)
- click on title bar of **Trace|Shot gather** window and press CTRL+F1 to zoom trace amplitude
- browse shots in **Trace|Shot gather** window with F7/F8 (Fig. 1 left)
- click on title bar of **Refractor|Shot breaks** window (Fig. 1 right) and press ALT+P. Edit *Maximum time* to 80 ms & hit ENTER key to redisplay. Do the same for **Trace|Shot gather** window (Fig. 1 left).

To configure and run *Smooth inversion* :

- select **Grid|Surfer plot Limits**. Edit fields as in Fig. 4. Click *OK button*.
- check **Grid|GS CENTERED font for receivers** to work around Surfer 11 issues with receiver display
- select **Smooth invert|WET with 1D-gradient initial model**
- wait for the 1D-gradient starting model to display as in Fig. 5
- confirm prompt to continue with WET inversion to obtain WET output shown in Fig. 6 & 7

Edit Profile

Line ID:

Line type:

Job ID:

Instrument:

Client:

Company:

Observer:

Note:

Time of Acquisition

Date:

Time:

Time of Processing

Date:

Time:

Units:

Sort:

Const:

Station spacing [m]:

Min. horizontal separation [%]:

Profile start offset [m]:

Cell size [m]:

☐ Left handed coordinates

☒ Force grid cell size

Add borehole lines for WET tomography

Borehole 1 line:

Borehole 2 line:

Borehole 3 line:

Borehole 4 line:

OK Cancel Reset

Fig. 2 : Header|Profile

Import shots

Import data type:

Input directory : select one data file. All data files will be imported

Select:

Take shot record number from:

Optionally select .HDR batch file and check Batch import

.HDR batch:

Write .HDR batch file listing shots in input directory

Output .HDR:

☐ Write .HDR only ☐ Import shots and write .HDR

Overwrite existing shot data

☒ Overwrite all ☐ Prompt overwriting

☐ Batch import ☐ Limit offset

Maximum offset imported [station nos]:

Default shot hole depth [m]:

Default spread type:

Target Sample Format:

☐ Turn around spread by 180 degrees during import

☐ Correct picks for delay time (use e.g. for .PIK files)

Default sample interval [msec]:

Default sample count:

Import shots Cancel import Reset import

Fig. 3 : File|Import Data

Edit Surfer plot limits

Plot Limits

☒ Plot limits active

Min. offset: [m]

Max. offset: [m]

Min. elevation: [m]

Max. elevation: [m]

Min. velocity: [m/sec.]

Max. velocity: [m/sec.]

Plot Scale

☐ Proportional XY Scaling

☐ Page unit centimeter. Uncheck for inch.

X Scale length: [inch]

Y Scale length: [inch]

Color Scale

☒ Adapt color scale

Scale height: [inch]

Velocity interval: [m/sec.]

Coverage interval: [paths/pixel]

OK Cancel Reset Reset to grid Redisplay grid

Fig. 4 : Grid|Surfer plot Limits

Surfer plot limits shown in Fig. 4 are used for WET inversion output (Fig. 6&7) only and not for the 1D-gradient starting model (Fig. 5). To display the starting model using these plot limits :

- select **Grid|Image and contour velocity and coverage grids**
- navigate into directory c:\RAY32\P6\GRADTOMO
- select file **GRADIENT.GRD**

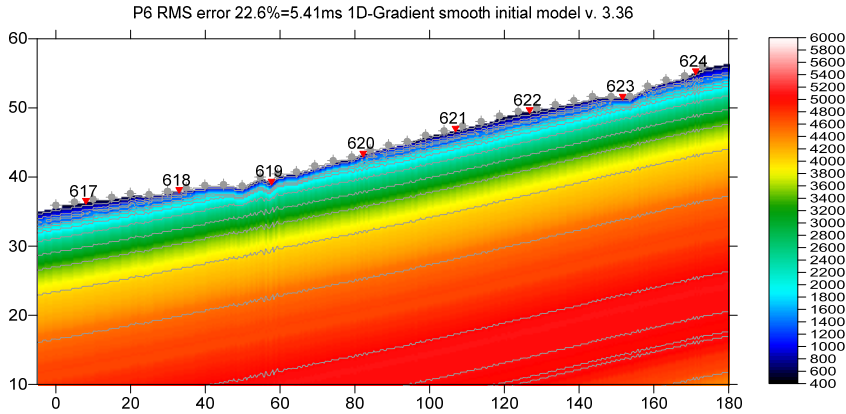


Fig. 5 : 1D-gradient starting model obtained with *Smooth invert|WET with 1D-gradient initial model*

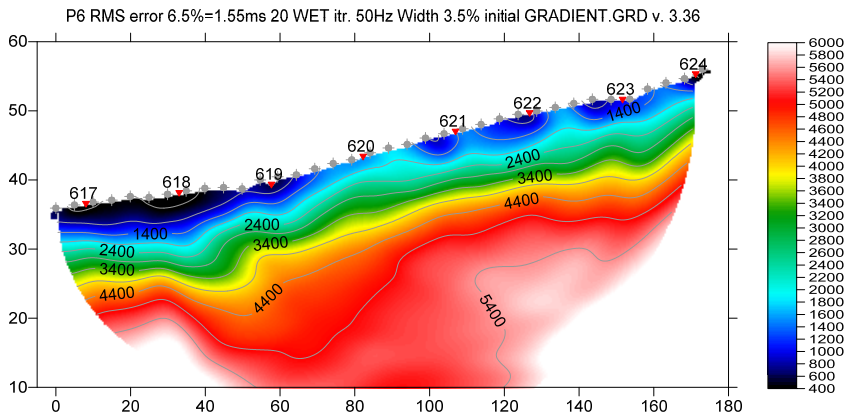


Fig. 6 : 2D WET output obtained with *Smooth invert|WET with 1D-gradient initial model* & starting model shown in Fig. 5. 20 WET iterations using Steepest Descent method & Gaussian update weighting & full WET smoothing.

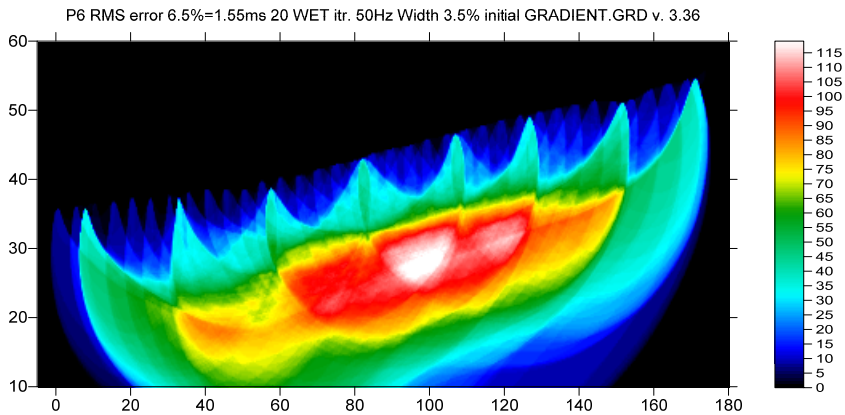


Fig. 7 : WET wavepath coverage plot obtained with Fig. 6. Unit is wavepaths per pixel.

To create your own copy of **BATCH.HDR** file follow these steps :

- select *File|Import Data* & check box *Write .HDR only* & uncheck box *Batch import*
- click button *Output .HDR* & set *File name* to **MYBATCH.HDR** & click *Save button*
- optionally set *Take shot record number from* to **File number** or leave at default **DOS file name**
- click button *Import shots*
- open **MYBATCH.HDR** in Windows Notepad. Columns **Layout start** and **Shot pos.[station no.]** have value 0.0 for all shots since in above **.SG2 SEG-2** files traces header values for **SOURCE_LOCATION** and **RECEIVER_LOCATION** are bad / have value of all 0 for x/y/z coordinates (value string "0 0 0").
- edit column **Layout start.[station no.]** to 1.0 for all shots as in **BATCH.HDR**
- edit column **Shot pos.[station no.]** as in **BATCH.HDR** & save edited file to **MYBATCH.HDR**

Next we try to increase the WET resolution by increasing the WET iteration count :

- select *WET Tomo|Interactive WET tomography*
- set *Number of WET tomography iterations* to 100
- click button *Start tomography processing* to obtain WET output shown in Fig. 8 :

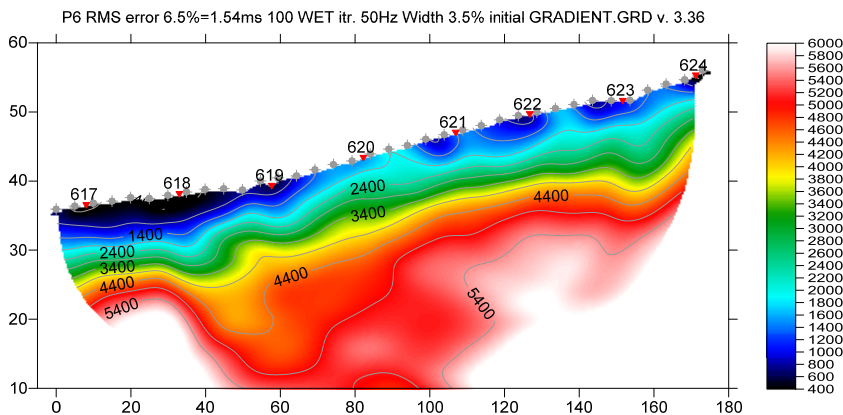


Fig. 8 : 2D WET output obtained with *WET Tomo|Interactive WET tomography* & 100 WET iterations & 1D-gradient starting model shown in Fig. 5

Fig. 8 shows a fault zone dipping at 45 degrees from offset 30m at topography to offset 60m in basement. This dipping fault zone is also visible in *Refractor|Midpoint breaks* and *Refractor|Offset breaks* displays (Fig. 15) after mapping traces to refractors (Fig. 16). These displays show raw traveltimes before doing any inversion. Instead of sorting your picks by common shot (Fig. 1 right) we now sort picks by common midpoint (CMP ; Fig. 15 left) and by common offset (Fig. 15 right) as described by Gebrande and Miller. See our [DeltatV](#) draft paper.

Our modeling in [thrust](#) and [thrust12](#) tutorials shows that Smooth inversion and DeltatV inversion can detect dipping fault zones if these zones are wide enough. For an objective comparison of tomographic refraction analysis methods see [Zelt et al. 2013](#) (JEEG, September 2013, Volume 18, Issue 3, pp. 183–194).

The shot spacing of 6 receiver stations (Fig. 1 right) is too wide for reliable WET inversion. We recommend to **record a shot at every 3rd receiver station** for more meaningful WET inversion.

How we created the **COORDS.COR** file based on known elevations for known inline offsets along slope :

- import SEG-2 shots with **BATCH.HDR** as described above
- *File|Export header data|Export Station Coordinates* to **COORDS.COR**
- open **COORDS.COR** in Windows Notepad. Edit elevation in column no. 4 for all shot & receiver stations.
- *File|Update header data|Update Station Coordinates* with edited & saved **COORDS.COR**
- in *Header|Station* click button **Correct x** to convert inline offset along slope to horizontal offset
- leave Station editor with **ESC** key

➤ *File|Export header data|Export Station Coordinates to COORDS.COR* with corrected x coordinate

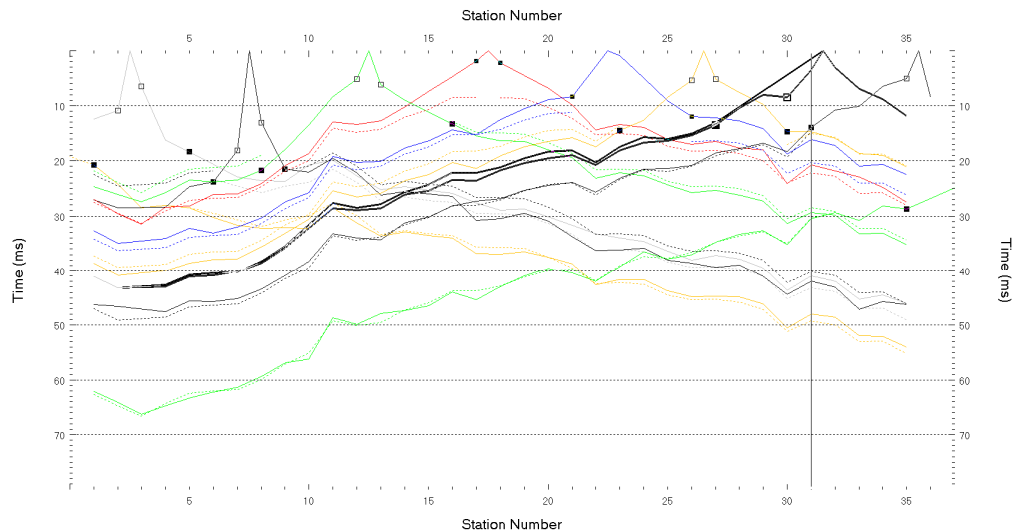


Fig. 9 : *Refractor|Shot breaks*. Shows fit between picked times (solid colored curves) and modeled times (dashed colored curves) for deepest refractor in Plus-Minus starting model (Fig. 12). Hollow squares separate direct wave from overburden refractor. Solid squares separate overburden refractor from basement refractor. Pick both branch points at same station for pinchouts (blue shot curve) or outcrops (red shot curve). Press ALT+L to map traces to refractors.

Now we try Smooth inversion using Plus-Minus layered refraction starting model :

- first we pick branch points in *Refractor|Shot breaks* (Fig. 9)
- press **CTRL+F1** to pick first branch point (hollow squares) separating direct wave from overburden refractor for each shot traveltime curve in forward & reverse direction. Browse shots with F7/F8.
- press **CTRL+F2** to pick 2nd branch point (solid squares) separating overburden refractor from basement refractor.
- map traces to refractors with **ALT+L** in *Refractor|Shot breaks* (Fig. 9)
- select *Depth|Plus-Minus* to display Plus-Minus layered refraction starting model (Fig. 12). When prompted to continue with WET inversion press No button (Fig. 11).
- click on Plus-Minus depth section window & press **ALT+M**. Decrease *Base filter width* from default 10 stations to 4 stations (Fig. 10). Press **ENTER** key to confirm.
- once the Plus-Minus model is recomputed and redisplayed in Surfer confirm prompt to continue with WET inversion (Fig. 11)
- now we obtain Smooth inversion WET output (Fig. 13) using the Plus-Minus starting model (Fig. 12).
- select *WET Tomo|Interactive WET tomography* & set **Number of WET tomography iterations** to 100
- click button **Start tomography processing** to obtain WET output shown in Fig. 14.
- compare Fig. 13 with Fig. 6 and Fig. 14 with Fig. 8. We can see the same dipping fault zone as described for Fig. 8.
- smooth WET inversion is not dependent on the starting model when using full WET smoothing & Steepest Descent search method : Fig. 6 and Fig. 13 (20 WET iterations each) are similar to each other. Fig. 8 and Fig. 14 (100 WET iterations each) match each other even more closely.
- interactive WET inversion with 100 iterations (Fig. 8 and Fig. 14) takes about 2 minutes on a MacBook Air 2017 laptop using Intel Core i5-5350U processor with 2 hyper-threaded CPU cores at 1.8 GHz running Windows 7 64-bit Pro in Parallels desktop. This allows for a fluent workflow when varying WET inversion parameters.

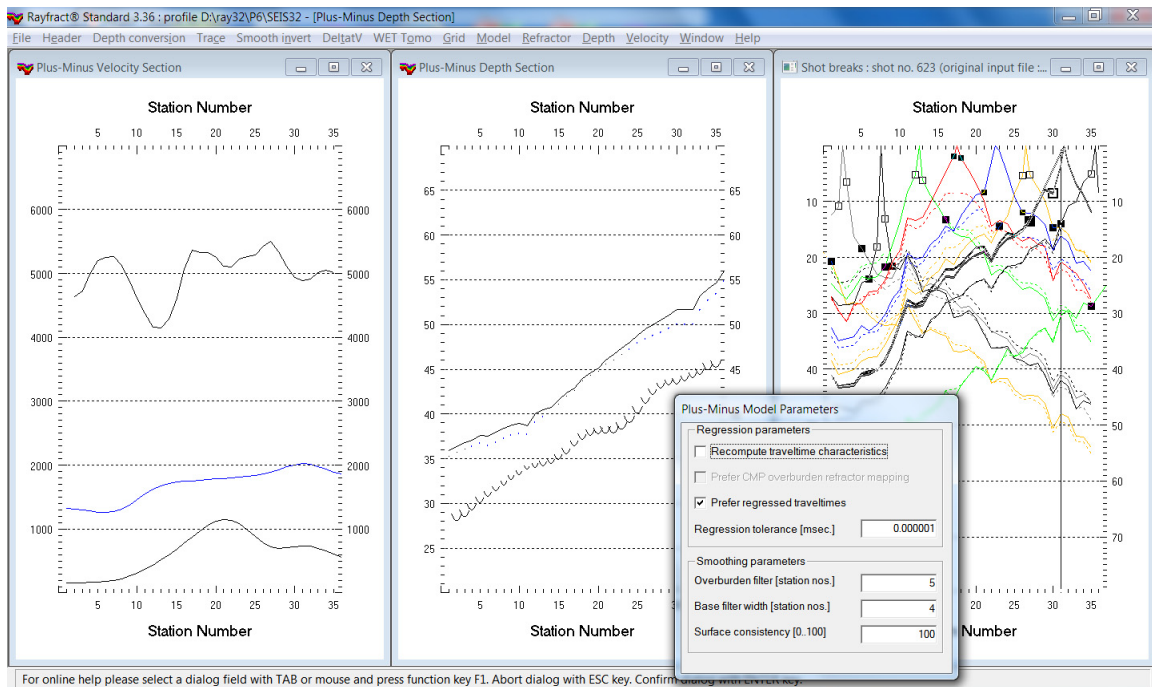


Fig. 10 : Plus-Minus layered refraction method. Press ALT+L in *Refactor*|*Shot breaks* to map traces to refractors. Select *Depth*|*Plus-Minus* to display initial Plus-Minus model. Click No button in WET continuation prompt (Fig. 11). Press ALT+M in *Depth*|*Plus-Minus* window to bring up parameter dialog. Change Base filter width from default 10 to 4 stations. Press ENTER key to confirm parameters and redisplay Plus-Minus model. Now click Yes button in WET continuation prompt (Fig. 11).

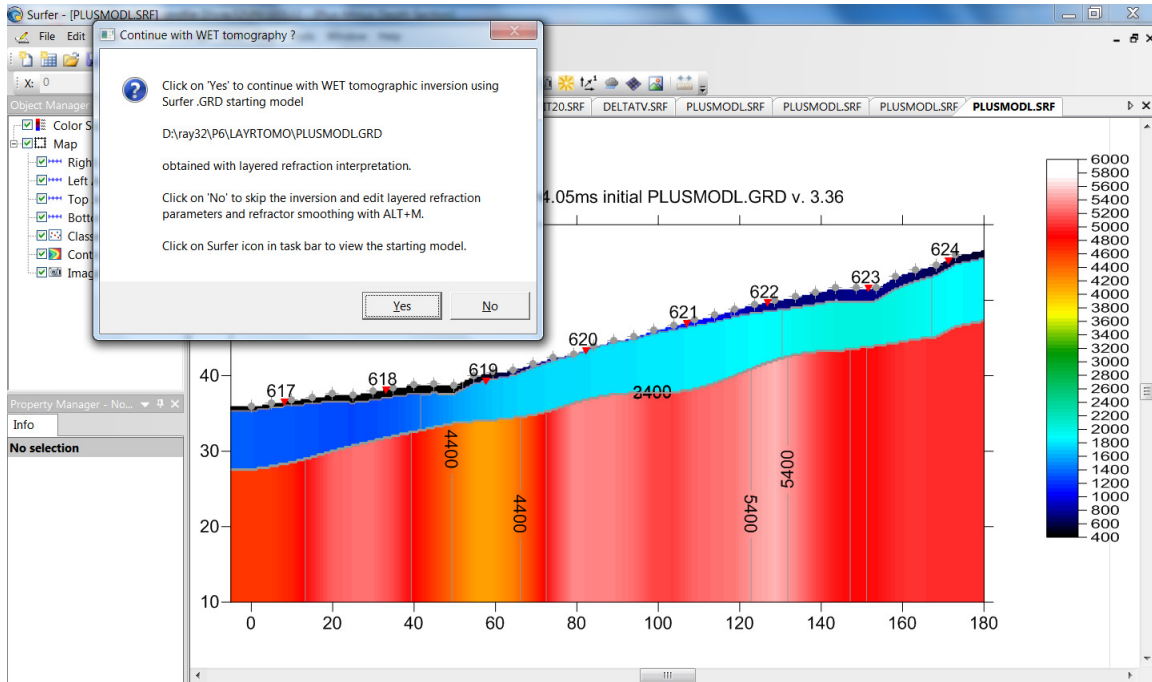


Fig. 11 : Plus-Minus method starting model shown in Surfer. WET continuation prompt is displayed on top of Surfer window.

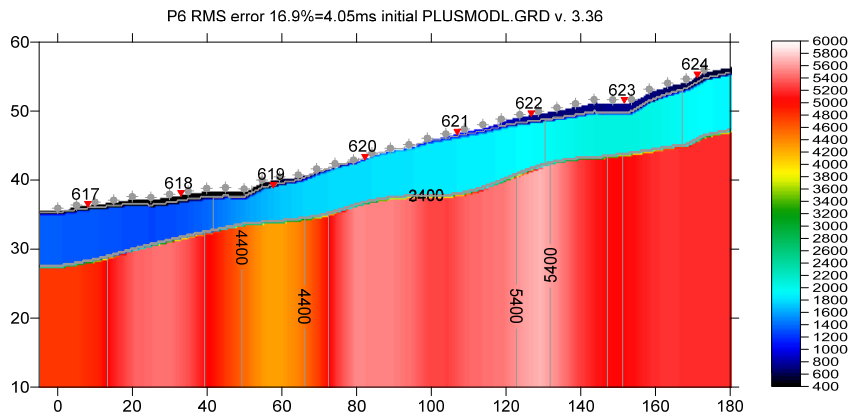


Fig. 12 : Plus-Minus method starting model

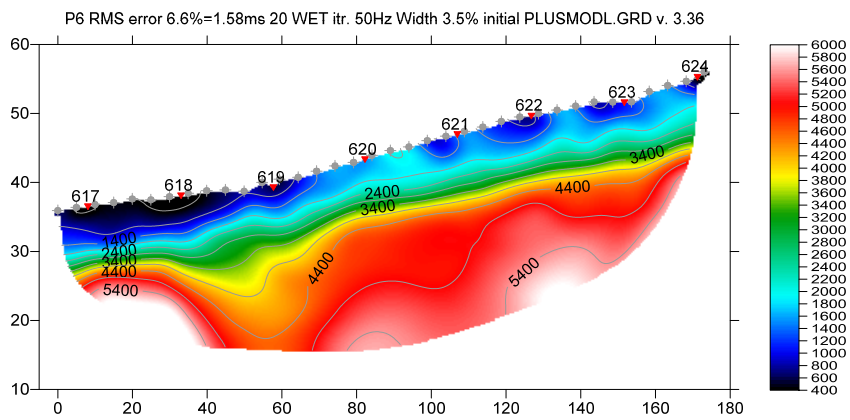


Fig. 13 : Smooth inversion using Plus-Minus method starting model (Fig. 12). 20 WET iterations using Steepest Descent method & Gaussian update weighting & full WET smoothing. Compare with Fig. 6.

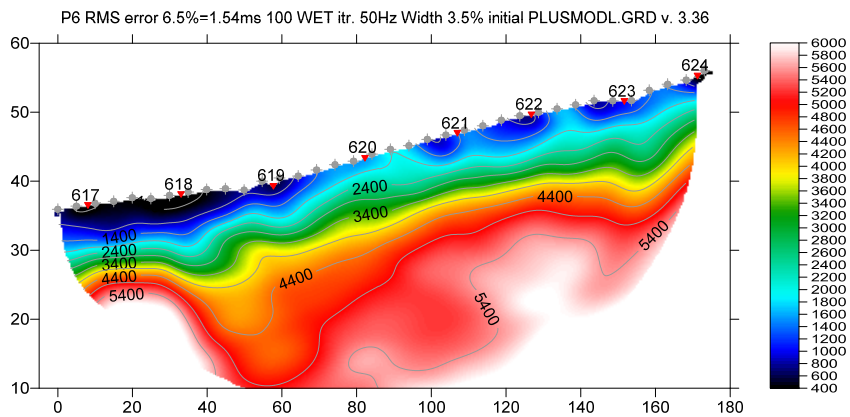


Fig. 14 : 2D WET output obtained with WET Tomo|Interactive WET tomography & 100 WET iterations & Plus-Minus method starting model shown in Fig. 12. Compare with Fig. 8.

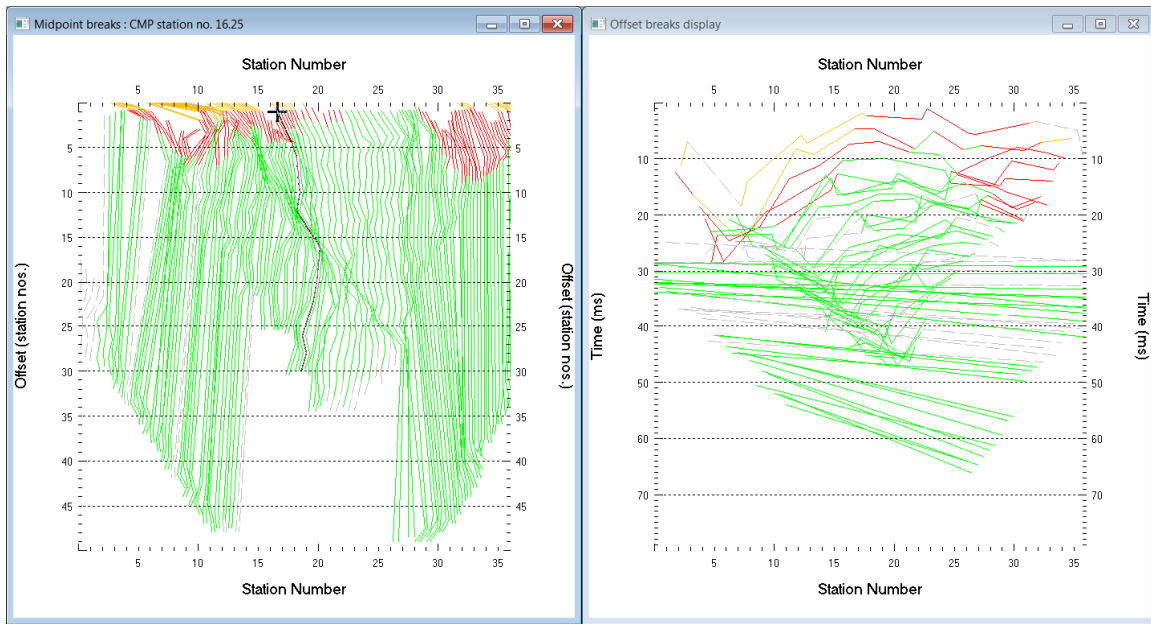


Fig. 15 : *Refractor|Midpoint breaks* (left) : shows raw picks sorted by common midpoint CMP. Map traces to refractors with ALT+M (Fig. 16). *Refractor|Offset breaks* (right) shows raw picks sorted by common offset. Note dipping fault zone visible in both displays.

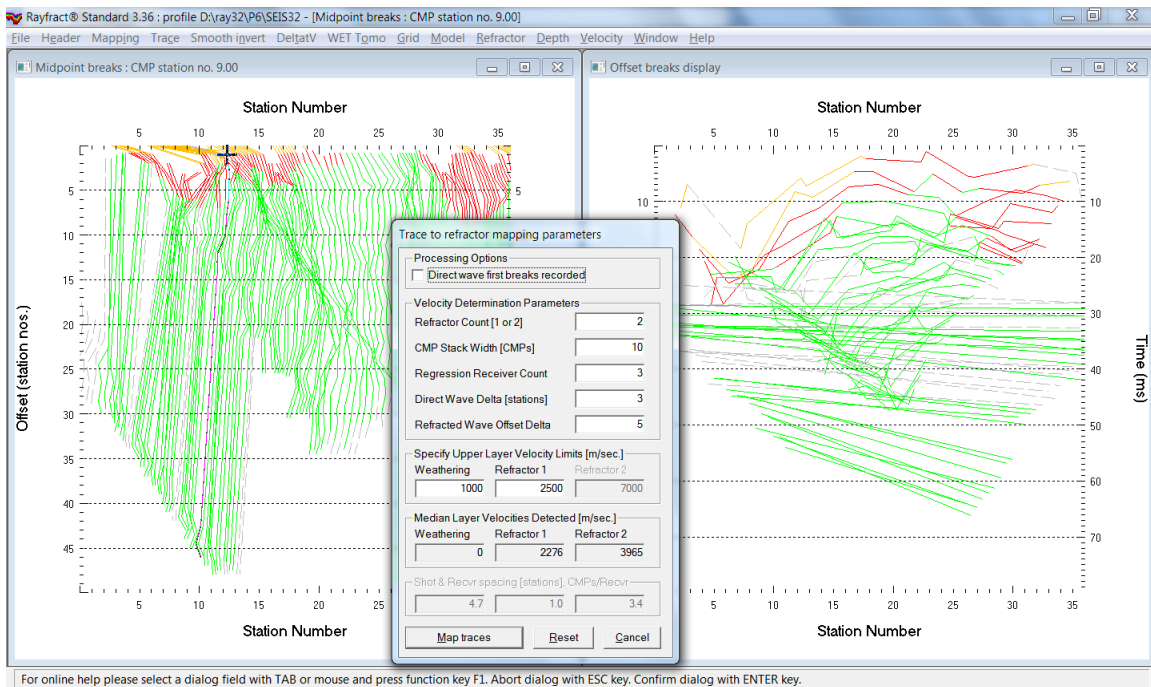


Fig. 16 : Map traces to refractors with ALT+M in *Refractor|Midpoint breaks* (left). Edit *CMP Stack Width* to 10 CMP's, *Weathering velocity limit* to 1,000 m/s and *Refractor 1 velocity limit* to 2,500 m/s. Uncheck box *Direct wave first breaks recorded*. Click *Map traces*. Now smooth crossover distances with ALT+G.

In Fig. 17 we show pseudo-2D DeltatV inversion using *CMP curve stack width 25*, *Regression over offset stations 7*, *CMP gather datum specific static corrections* with *Process every CMP offset* checked.

Fig. 18 shows *WET Tomo|Automatic WET tomography* with Fig. 17 grid selected as starting model and with no WET blanking with all options in *WET Tomo|WET tomography Settings|Blank* unchecked.

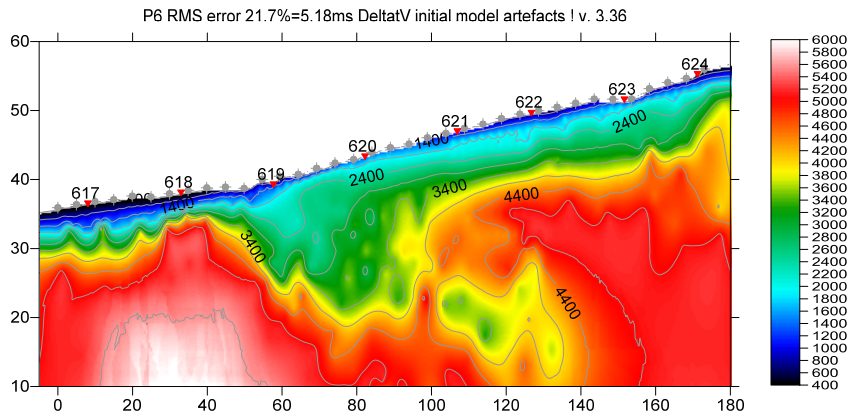


Fig. 17 : interactive DeltatV inversion with CMP stack width 25, regression over 7 offset stations, CMP gather datum static correction, Process every CMP offset

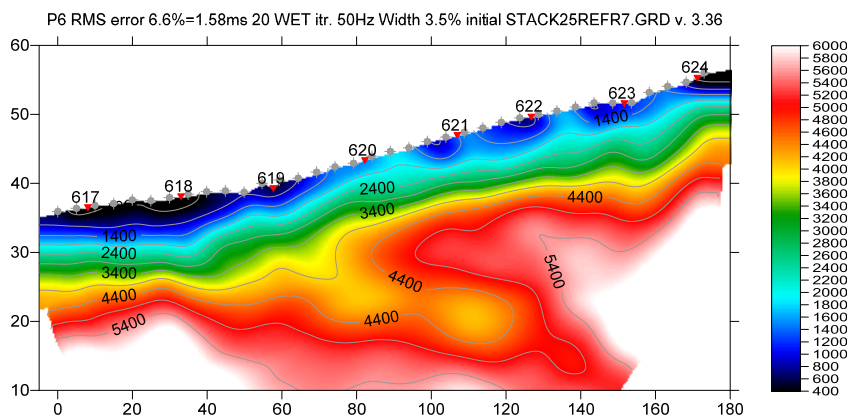


Fig. 18 : Smooth WET inversion with DeltatV starting model shown in Fig. 17. 20 WET iterations, default WET settings and full WET smoothing. No WET blanking.

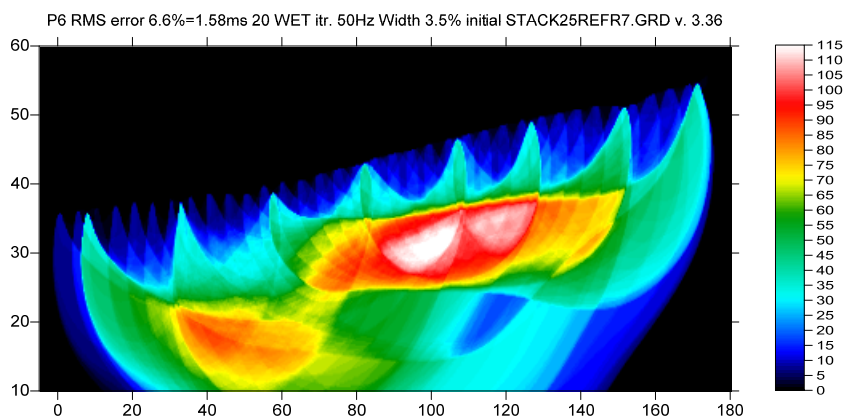


Fig. 19 : WET wavepath coverage plot obtained with Fig. 18. Unit is wavepaths per pixel.

Fig. 17 and Fig. 18 better match the imaged dipping fault zone to raw picked traveltimes plots shown in Fig. 15 than our previous WET interpretations shown in Fig. 6/8/13/14.

Here is the [profile database archive](#) for Fig. 18. Here is the [WET subdirectory archive](#) for Fig. 18.

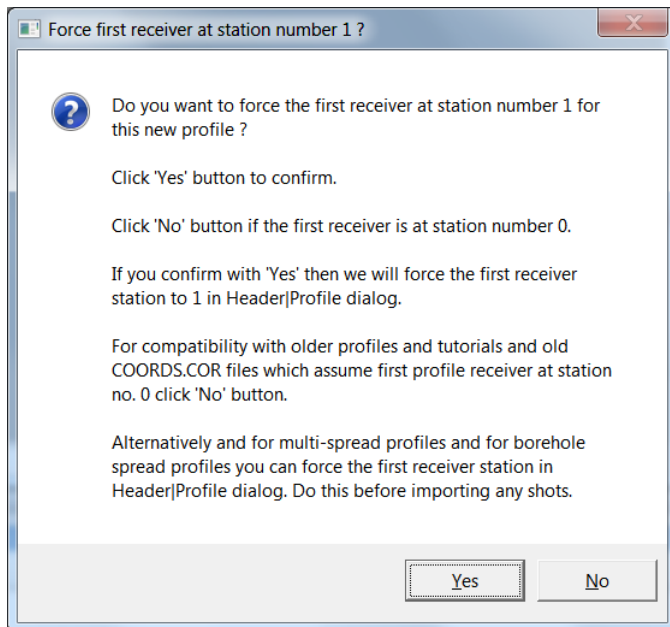


Fig. 20 : click Yes button to force profile start / first receiver station number at station no. 1.

For compatibility with older profiles and tutorials and old COORDS.COR files which assume first profile receiver at station no. 0 click No button.

Alternatively force the first receiver station in Header|Profile dialog. Do this before importing any shots via File|Import Data dialog.

Above tutorial shows imaging of a fault zone in Norway. We show that even in Norway velocity can increase gradually with depth below topography, with deep weathering. These results contrast with the strictly Plus-Minus layered refraction subsurface assumption made by NGU for their [fault zone modeling](#), with abrupt increase of velocity at bottom of thin weathering layer and strictly vertically oriented fault zones. Smooth inversion and DeltatV can detect dipping fault zones in favorable geological settings when modeling a more realistic gradual increase of velocity in overburden, as shown with our own modeling in our [thrust](#) tutorial. We now also show DeltatV detection of dipping fault zone in our updated [SAGEEP11 tutorial](#) and in our updated [Mt. Bulga tutorial](#) (last pages).

However in general and especially in case of strong topography and/or strong lateral velocity variation in overburden, with basement velocities approaching topography we always recommend using our default [Smooth inversion](#) with 1D-gradient starting model instead. See [Palmer syncline](#) model and [Sheehan epikarst](#) model. The question is how realistic is it that basement velocities are present so close to the surface ? For [field surveys deep weathering](#) can often be observed instead, with faulted overburden and faulted basement. For more instructions see our [pdf help](#).

The [Plus-Minus](#) based NGU model used in our [1_1D tutorial](#) may not be realistic and imposes the classical layered refraction assumption, with abrupt increase of velocity to basement velocity of over 4,000 m/s below thin weathering layer or directly below topography without any [velocity increase in basement](#). Synthetic traveltime data generated for such a strongly layered model is best interpreted with the Plus-Minus refraction method. See our earlier [NGUP1_1 tutorial](#).

The [SAGEEP 11 blind refraction model](#) uses more realistic velocity gradients and deep weathering including a dipping fault zone, all of which can be modeled with diving waves and [seismic refraction tomography](#) instead of strictly critically refracted rays used with classical refraction methods. The [1D-gradient starting](#) model works better than DeltatV starting model for SAGEEP 11 synthetic data set.

In <http://rayfract.com/samples/SAGEEP2011shootout.pdf> Prof. Bob Whiteley compares the GRM interpretation (Stoyer, 2012) of above synthetic data with our published blind interpretation and the true model (Zelt et al. 2013). The GRM interpretation is too shallow.

([Hagedoorn 1959](#)) already shows Fresnel volumes (seismic transmission volume) and gradual increase of velocity with depth both in basement and in overburden, resulting in curved rays and diving waves in Fig. 1 of his classical Plus-Minus refraction method paper.