Import SEG-2 .DAT & Update header data & Smooth invert & layered WET Line3 v. 4.05 :

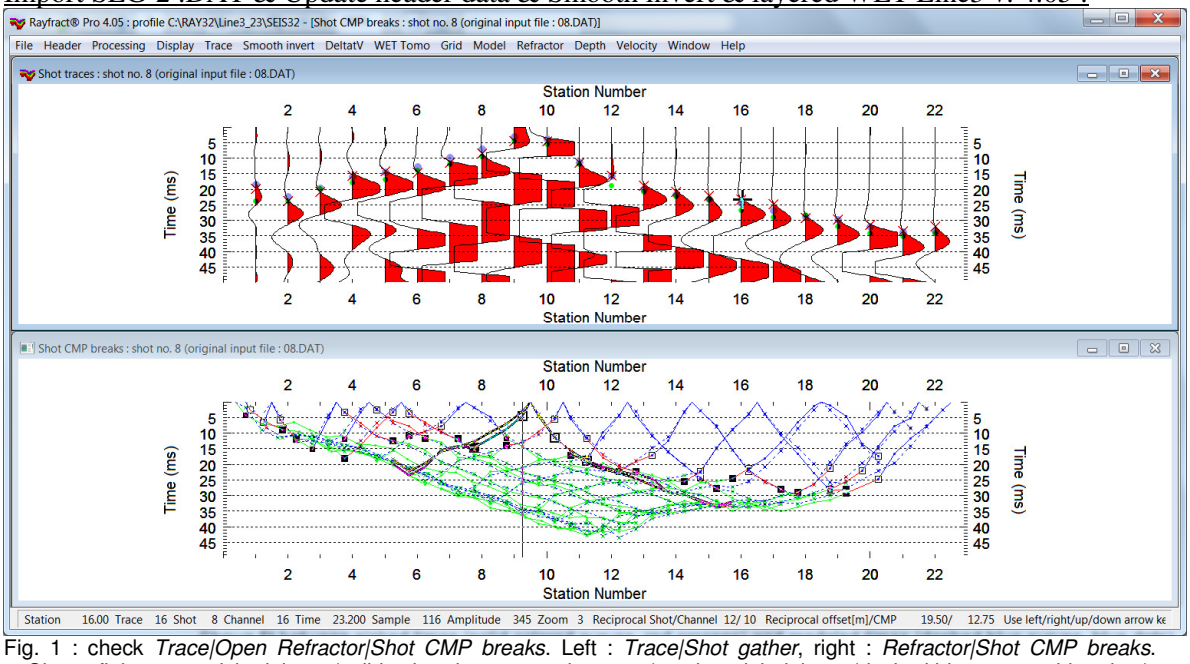


Fig. 1 : check *Trace|Open Refractor|Shot CMP breaks*. Left : *Trace|Shot gather*, right : *Refractor|Shot CMP breaks*. Shows fit between picked times (solid colored curves, red crosses) and modeled times (dashed blue curves, blue dots). Green dots are your reciprocal picks.

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

- ***File|New Profile***…, set *File name* to **`LINE3_23`** and click *Save button*
- in the prompt shown next (Fig. 4) click ***Yes*** button to force ***Profile start*** at station no. 1.
- in ***Header|Profile***… set *Line type* to **`Refraction spread/line`** . Set *Station spacing* to 3.0 m. Set *Profile start offset* to 3.0m. See Fig. 2.
- set *Extrapolate [station spacings]* to 5. Check *Extrapolate tomograms*. Click *OK* button. See Fig. 2.
- check setting *File|SEG-2 import settings|Receiver Coordinates specified*
- unzip archive https://rayfract.com/tutorials/LINE3_INPUT.zip with **`SEG-2 .DAT`** shot files & files **`COORDS.COR & SHOTPTS.SHOT & BREAKS.LST`** & **`BATCH.HDR`** & **`BRANCHES.BRN`** in directory **`C:\RAY32\LINE3_23\INPUT`**
- select ***File|Import Data***… and set *Import data type* to **`SEG-2`**. See Fig. 3.
- click *Select button* and navigate into **`C:\RAY32\LINE3_23\INPUT`**
- set *Files of type* to **`Seismic data files (*.DAT)`** and select a file e.g. **`01.DAT`** & click *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*.
- select *File|Update header data|Update Shotpoint coordinates*. Select **`SHOTPTS.SHO &`** click *Open*.
- select *File|Update header data|Update First Breaks*. Select file **`BREAKS.LST`** & click *Open*.
- select option *Trace|Open Refractor|Shot CMP breaks with Shot gather*
- select *Trace|Shot gather* to obtain Fig. 1
- 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 top)
- click on title bar of *Refractor|Shot CMP breaks* window (Fig. 1 bottom) and press ALT+P. Edit *Maximum time* to 50 ms & press ENTER key to redisplay. Do the same for *Trace|Shot gather* window (Fig. 1 top).
- click on title bar of *Refractor|Shot CMP breaks* window (Fig. 1 bottom). Select *Display|Blue direct wave first breaks*.

To configure and run our default fail-safe *Smooth inversion* :

- check option *Grid|Receiver station ticks on top axis*
- edit *Grid|Surfer plot Limits* as in Fig. 10
- select option *Grid|Plot refractors on tomogram*
- uncheck option *WET Tomo|WET tomography Settings|Blank below envelope after last iteration*
- 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

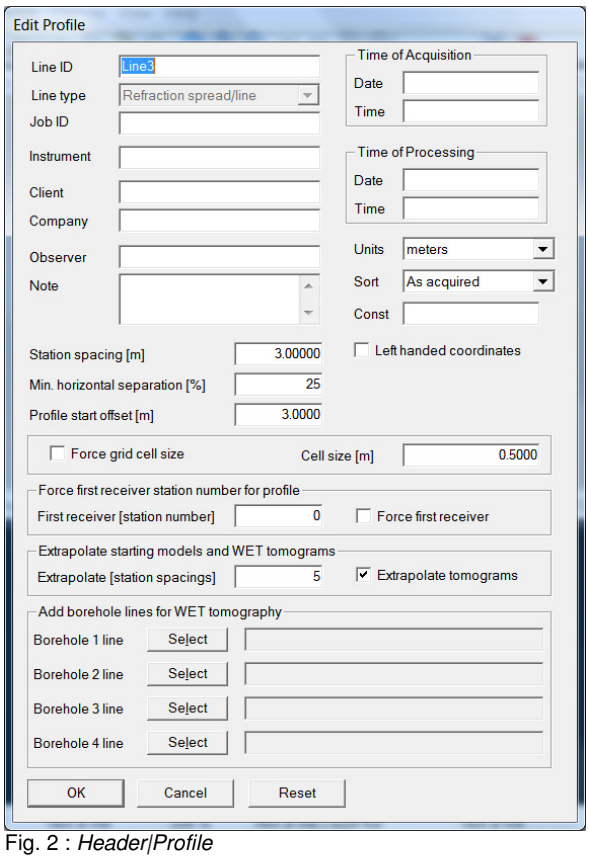


Fig. 2 : *Header|Profile*

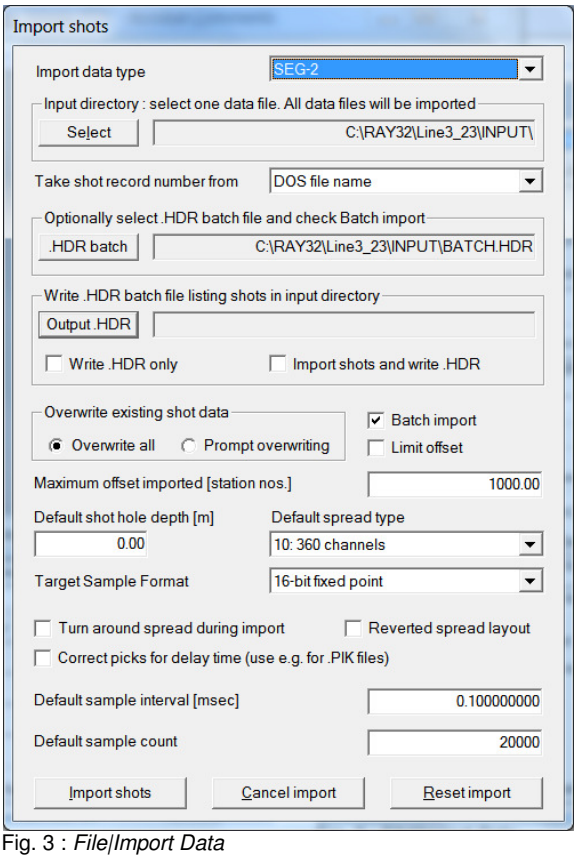


Fig. 3 : *File|Import Data*

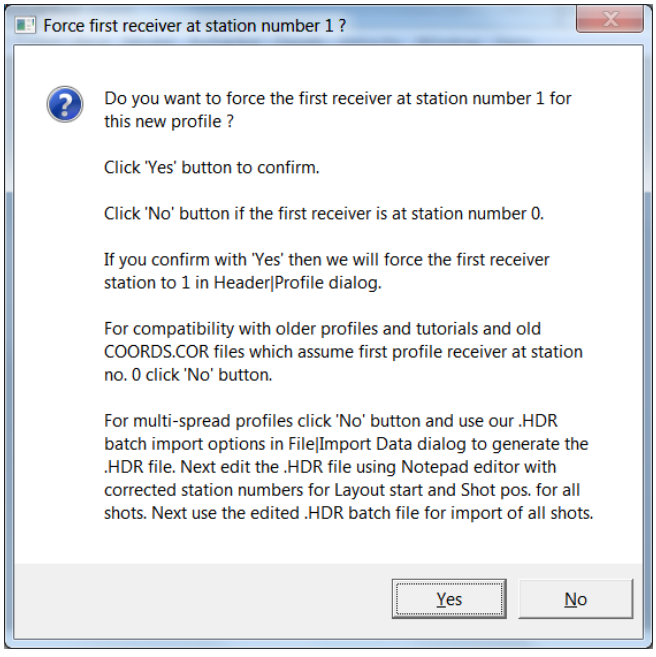


Fig. 4 : click Yes button to force profile start / first receiver station number at station no. 1.

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

For multi-spread profiles click No button and use our .HDR batch import options in *File|Import Data* dialog to generate the .HDR file. Next edit the .HDR file using MS Notepad editor with corrected station numbers for *Layout start* and *Shot pos.* for all shots. Next use the edited .HDR batch file for import of all shots.

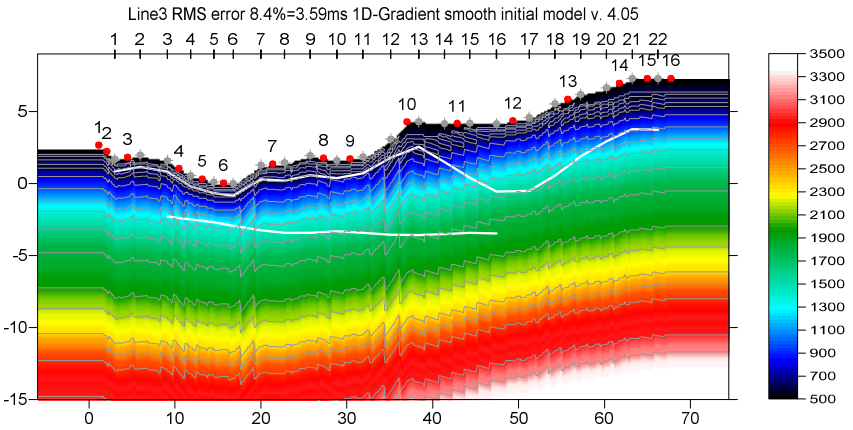


Fig. 5 : 1D-gradient starting model obtained with *Smooth invert|WET with 1D-gradient initial model*. White lines are your Plus-Minus refractors from Fig. 21.

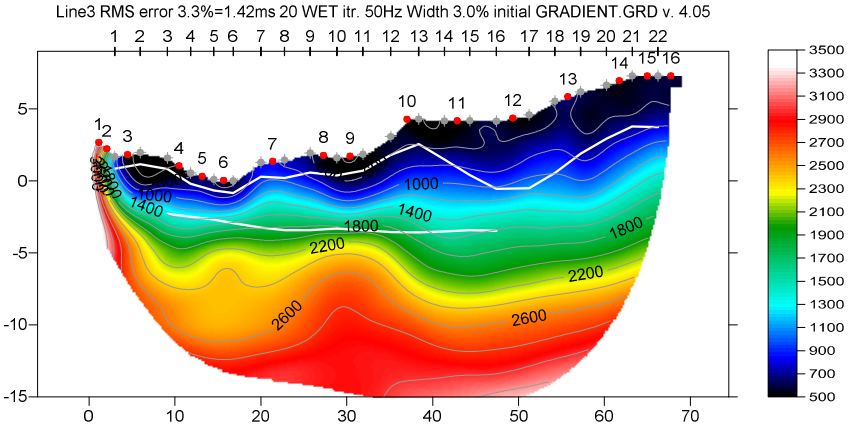


Fig. 6 : 2D WET output obtained with *Smooth invert|WET with 1D-gradient initial model* & starting model shown in Fig. 5. 20 WET iterations using Steepest Descent method & Gaussian update weighting & full WET smoothing.

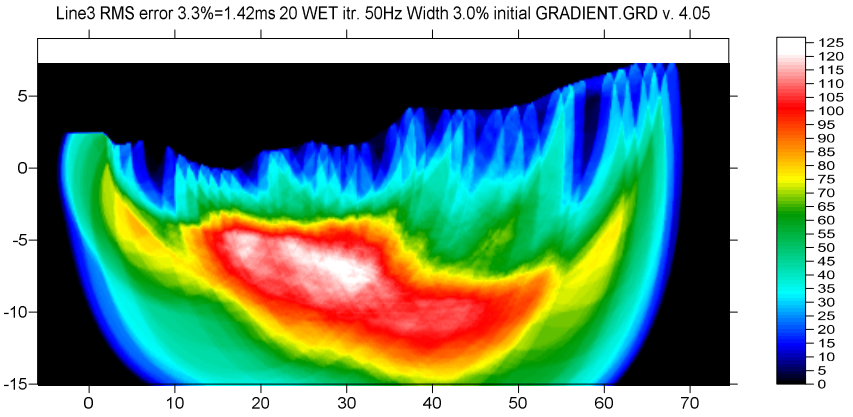
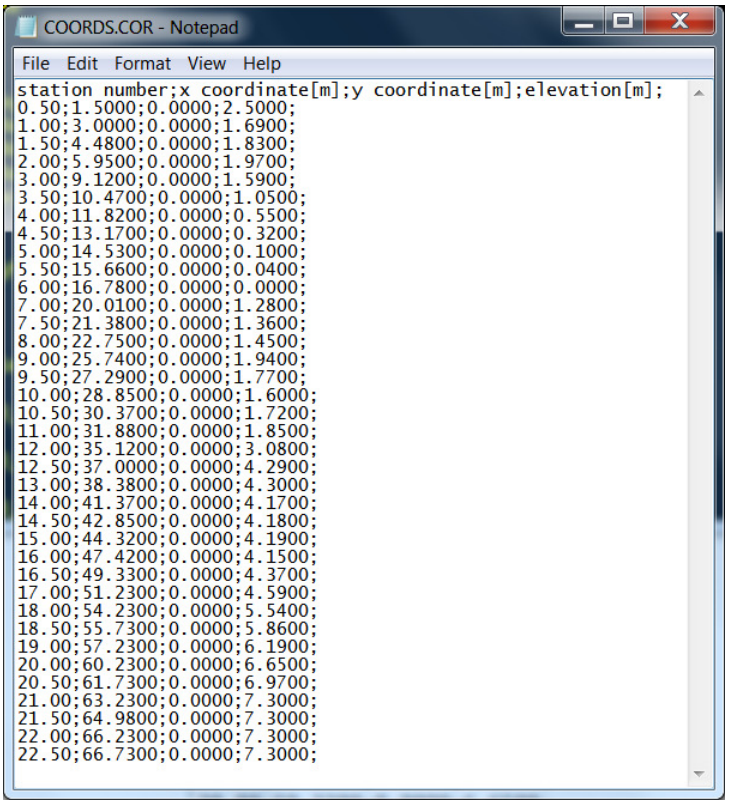


Fig. 7 : WET wavepath coverage plot obtained with Fig. 6. Unit is wavepaths per pixel.

<u>How we created the **COORDS.COR** file based on known elevations for known horizontal inline offsets :</u>

- import SEG-2 .DAT shots as described above
- *File|Export header data|Export Station Coordinates* to **COORDS.COR**
- open **COORDS.COR** in Windows Notepad. Edit ***x coordinate*** in column no. 2 and ***elevation*** in column no. 4 for all shot & receiver stations listed in the **COORDS.COR** (Fig. 8). Save edits back to **COORDS.COR** .
- *File|Update header data|Update Station Coordinates* with edited & saved **COORDS.COR**



Note shot stations ending .5 in column no. 1 in the **COORDS.COR** (Fig. 8). These shot stations were copied from the **BATCH.HDR** (Fig. 9) during above batch import.

Fig. 8 : edit x coordinates and elevations for station numbers listed in the COORDS.COR in Microsoft Notepad editor.

To create your own copy of the **BATCH.HDR** batch 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*
- click button *Import shots*
- open **MYBATCH.HDR** in Windows Notepad
- edit column ***Shot pos.[station no.]*** as in **BATCH.HDR** and save edited file to **MYBATCH.HDR** . We edited all shot stations to end in .5 except for the first two shot files **01.DAT** and **02.DAT** . See Fig. 9. We did this so the shot stations are not rounded to and merged with whole receiver stations in the COORDS.COR file. This lets you specify the shot point coordinates directly in the COORDS.COR without needing to edit the SHOTPTS.SHO.

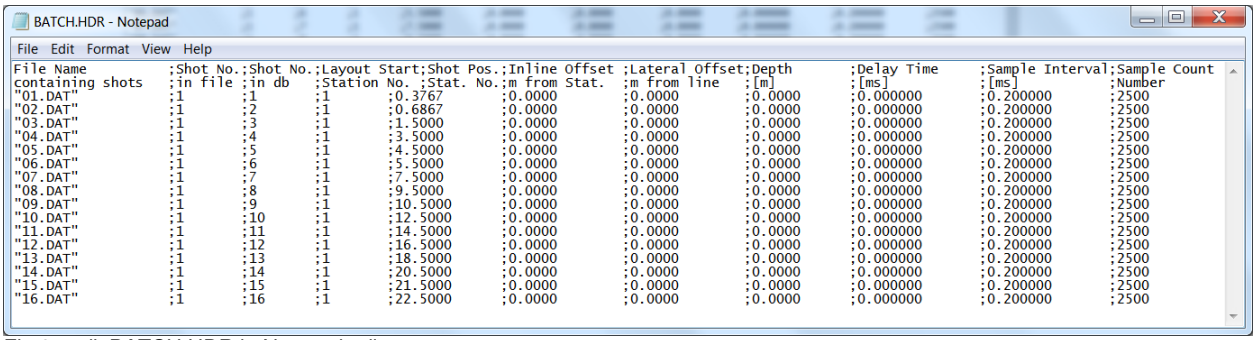


Fig 9 : edit BATCH.HDR in Notepad editor

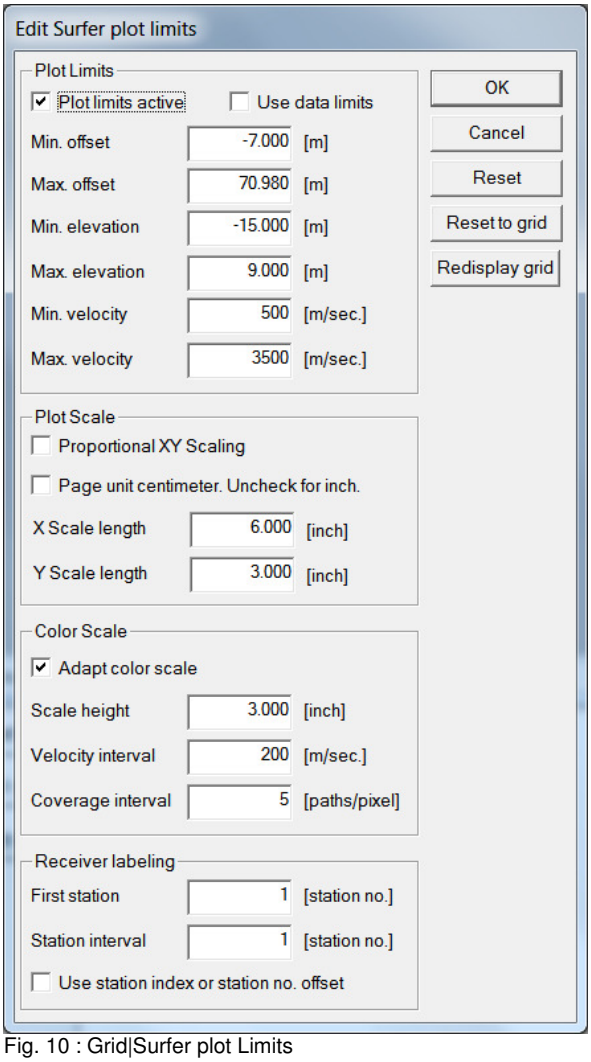


Fig. 10 : Grid|Surfer plot Limits

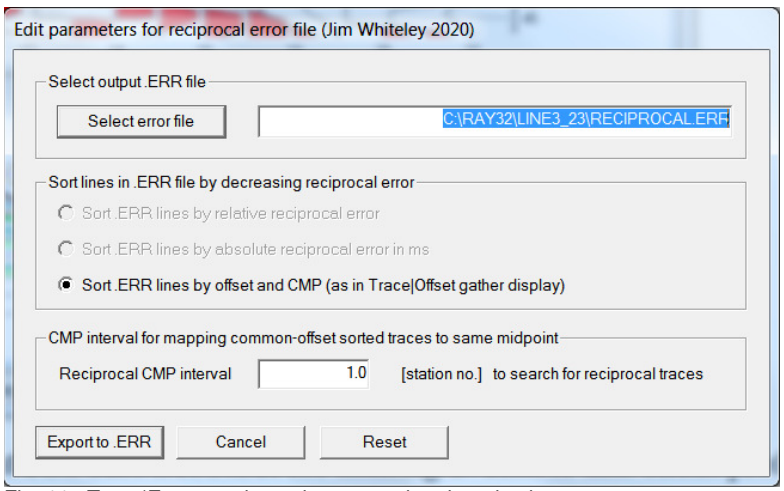


Fig. 11 : Trace|Export reciprocal errors and update database

How to plot your reciprocal traveltime picks on shot-sorted trace gathers

Next we show how to plot your reciprocal traveltime picks on shot-sorted trace gathers. This lets you quality-control your first break picks and check the validity of your recording geometry specification (shot station numbers and receiver station numbers). See Whiteley J. et al. 2020 : Landslide monitoring using seismic refraction tomography – The importance of incorporating topographic variations :

- select ***Trace\Export reciprocal traveltime picks and update database***
- click button *Select error file* and click *Save* button (Fig. 11)
- click button *Export to .ERR*
- optionally check new option ***Trace\Open Refractor\Shot CMP breaks with Shot gather***
- select *Trace\Shot gather* to obtain a window display as in our Fig. 1
- check new version 4.05 option ***Display\Show reciprocal picks on Shot Gather***
- browse and zoom trace gathers with function keys F7/F8, F1/F2 etc. as usual
- navigate traces with arrow-left and arrow-right keys
- if a reciprocal pick was determined/matched to the current trace then this is plotted as a green dot on the trace
- also we show ***Reciprocal Shot/Channel*** and ***Reciprocal offset[m]/CMP*** in status bar at bottom of window (Fig. 1) if a reciprocal pick is available in the .ERR file

How to determine a layered refraction starting model and use this for 2D WET inversion

Next we show how to determine a layered refraction starting model using our Plus-Minus method and using our WET Tomo\Interactive WET dialog to specify 20 WET iterations. Also we enable WDVS (Wavelength-Dependent Velocity Smoothing; Zelt and Chen 2016) to get a more robust interpretation with sharper contrast between overburden and basement :

- check option *Window\Display annotations in Arial*
- check option *Window\Large annotations*
- check option *Trace\Open Refractor\Shot CMP breaks with Shot gather*
- uncheck option *WET Tomo\WET tomography Settings\Blank below envelope after last iteration*
- select option *Grid\Plot refractors on tomogram*
- select ***Refractor\Midpoint breaks***. Press ALT+U to undo current mapping of traces to refractors.
- press ALT+M in *Refractor\Midpoint breaks* and semi-automatically map traces to refractors (Fig. 12). Edit *Weathering limit* to 550m/s. Edit *refractor 1 limit* to 800m/s. Check box ***Update branch points***. Edit other fields as shown in Fig. 12. Set *Regression Receiver Count* to 2. Set *Direct Wave Delta* to 2 stations. Set *Refracted Wave Offset Delta* to 3. Click button *Map traces*.
- press ALT+G and confirm to smooth crossover distances (Fig. 13).
- select ***Depth\Plus-Minus*** to obtain a first version of our Plus-Minus method starting model. When prompted to continue with WET inversion click No button. Click on title bar of *Depth section* window and press ALT+M. Decrease Plus-Minus ***Base filter width*** from default 10 to 8 stations as described in Fig. 20. Click OK button.
- select *Trace\Shot gather* (Fig. 14)
- interactively edit branch points separating refractors in ***Refractor\Shot CMP breaks*** (Fig. 14 bottom)
- map traces to refractors with ALT+L in *Refractor\Shot CMP breaks*
- select *Depth\Plus-Minus* to obtain Plus-Minus layered refraction starting model (Fig. 15)
- select ***Model\WDVS Smoothing***. Edit as in Fig. 19. Check ***use WDVS*** and click OK.
- select ***WET Tomo\Interactive WET***. Edit as in Fig. 18 (left). Edit *Wavepath frequency* to 20Hz.
- edit *Ricker differentiation* to -2 for Cosine-Squared WET update weighting across wavepath
- click Edit velocity smoothing (Fig. 18 right). Check ***Minimal smoothing***. Click Accept parameters.

➢ click *Start tomography processing* to obtain Fig. 16 and Fig. 17

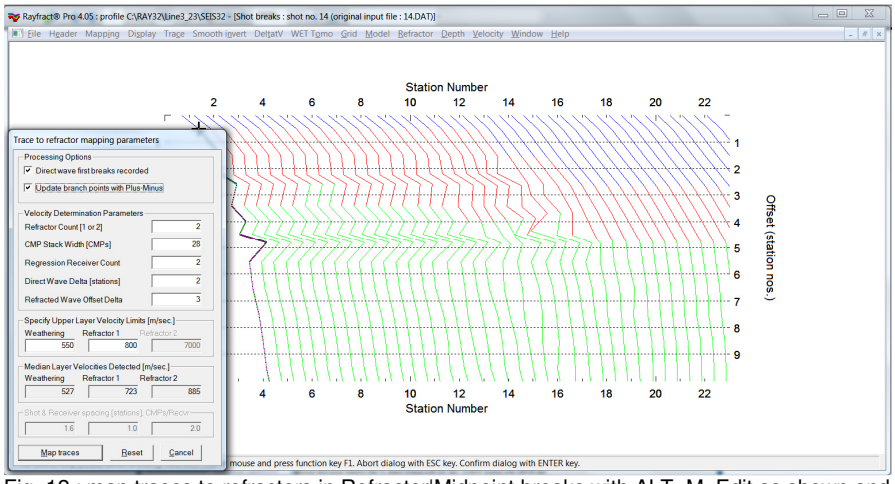


Fig. 12 : map traces to refractors in Refractor|Midpoint breaks with ALT+M. Edit as shown and click Map traces.

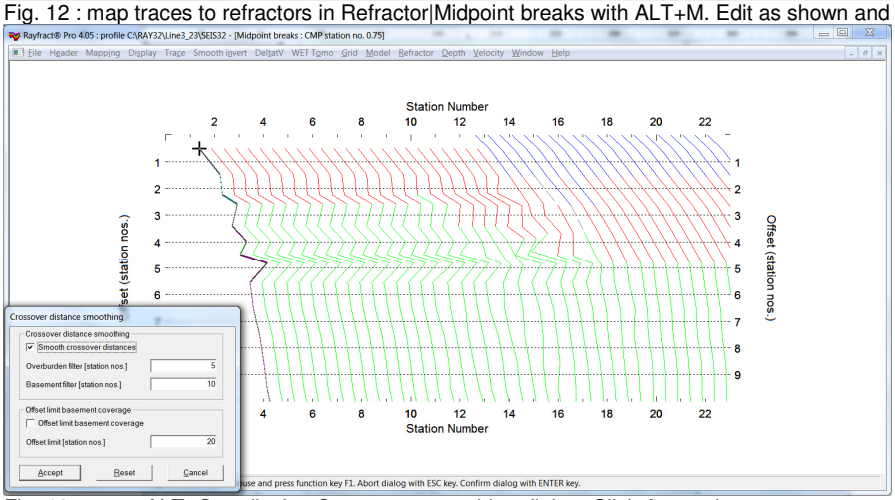


Fig. 13 : press ALT+G to display Crossover smoothing dialog. Click Accept button.

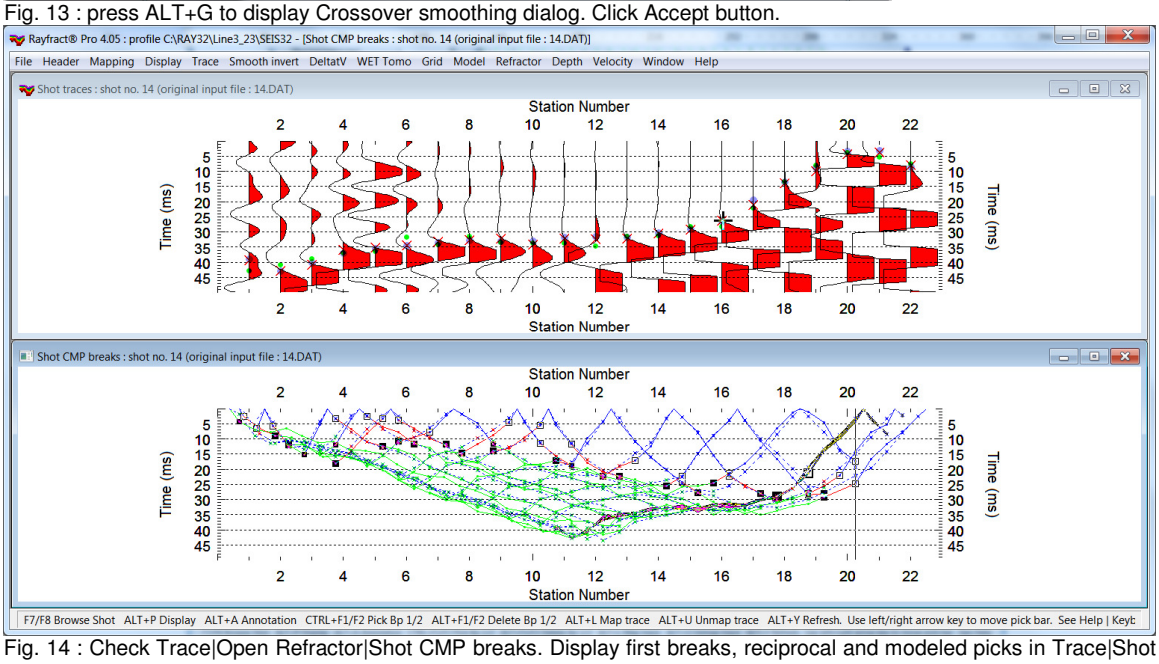


Fig. 14 : Check Trace|Open Refractor|Shot CMP breaks. Display first breaks, reciprocal and modeled picks in Trace|Shot gather (top). Pick branch points in Refractor|Shot CMP breaks (bottom). Map traces to refractors with ALT+L.

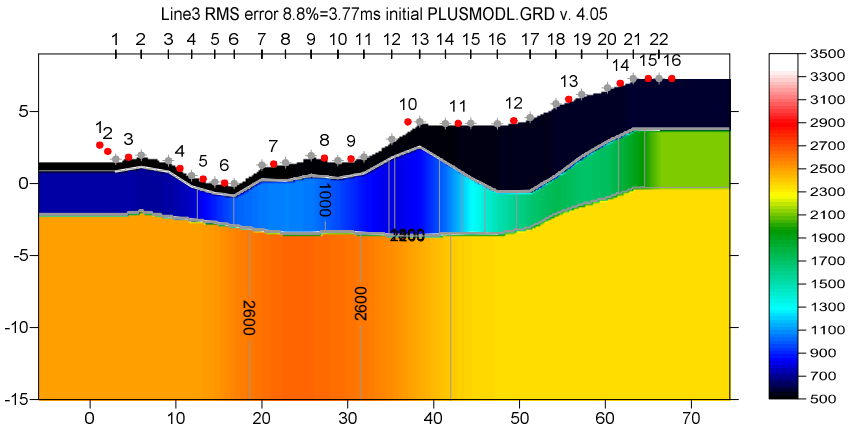


Fig. 15 : Plus-Minus method starting model obtained by mapping traces to refractors in Fig. 14 (bottom) and selecting Depth|Plus-Minus. Basement refractor smoothing over 8 stations instead of default 10 stations (Fig. 20).

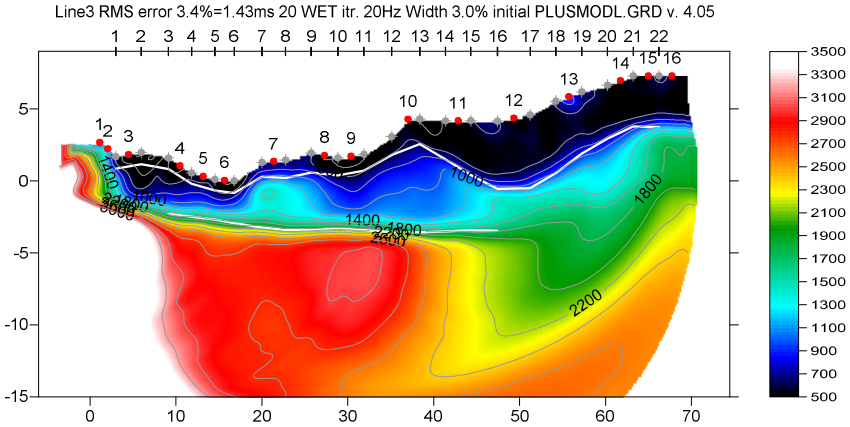


Fig. 16 : 20 Steepest-Descent WET iterations with Plus-Minus starting model (Fig. 15). WET wavepath frequency lowered to 20Hz. Ricker differentiation -2 (Cosine-Squared WET update weighting across wavepath; Fig. 18 left). Minimal WET smoothing (Fig. 18 right). WDVS Smoothing@300Hz (Fig. 19). White lines are Plus-Minus refractors from Fig. 15.

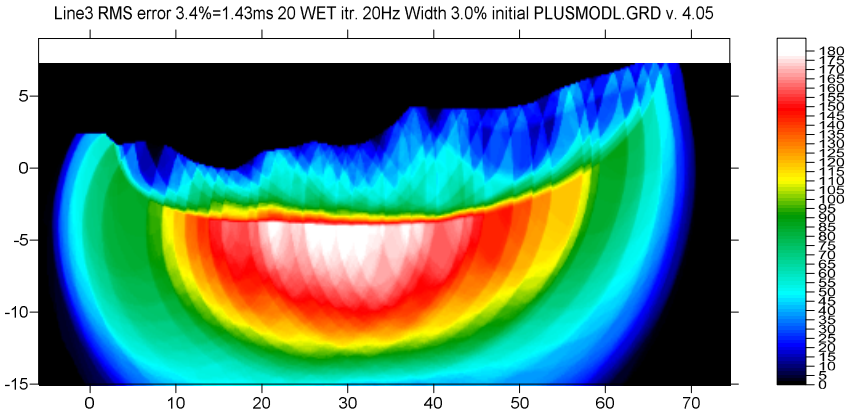


Fig. 17 : WET wavepath coverage plot obtained with Fig. 16. Unit is wavepaths per pixel.

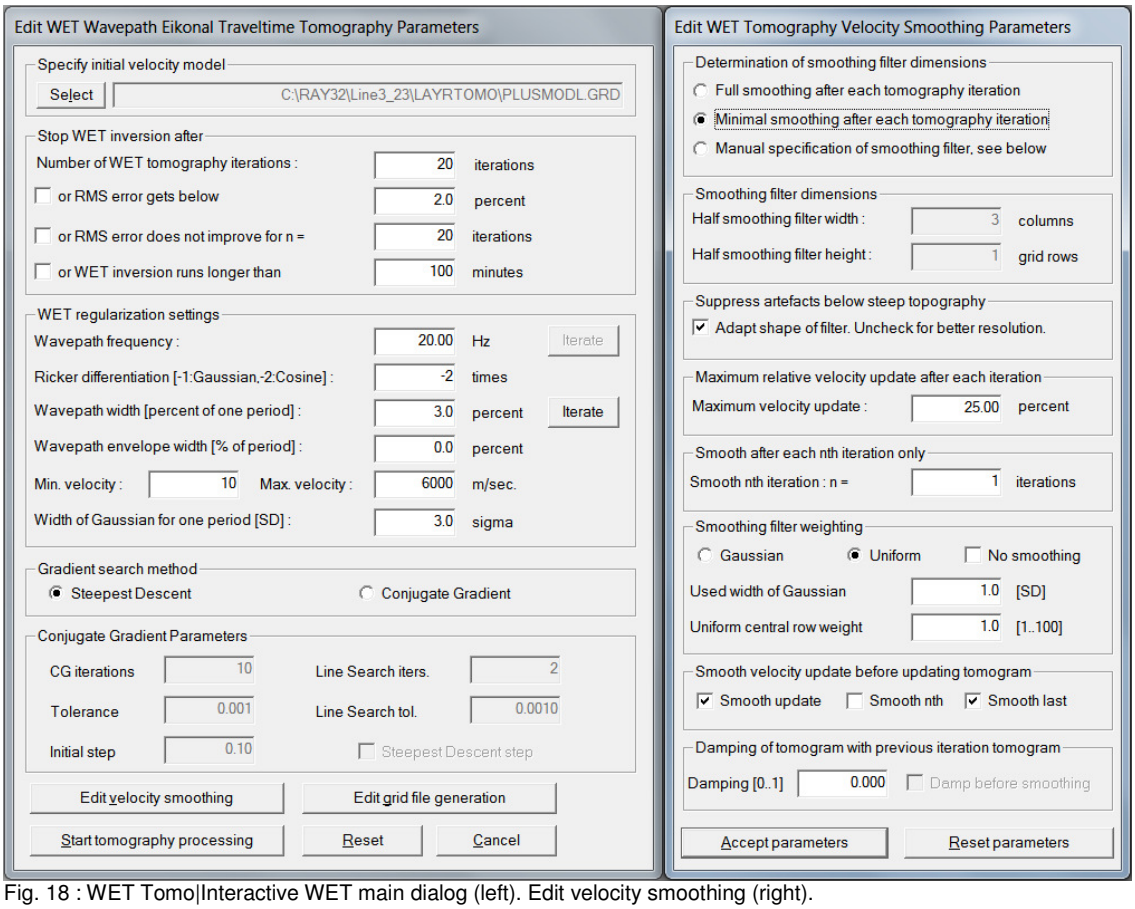


Fig. 18 : WET Tomo|Interactive WET main dialog (left). Edit velocity smoothing (right).

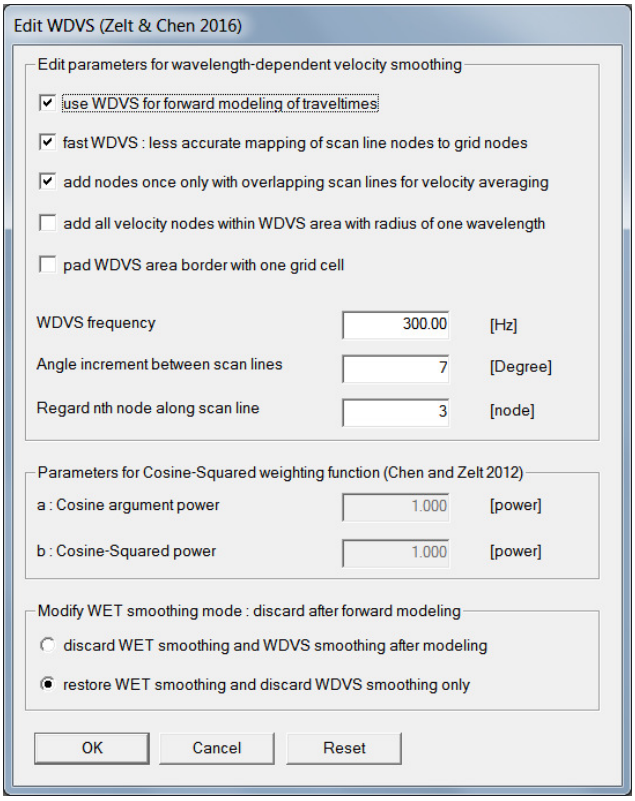


Fig. 19 : enable WDVS (Zelt and Chen 2016) at default frequency of 300Hz. Check box use WDVS for forward modeling of traveltimes. Click OK.

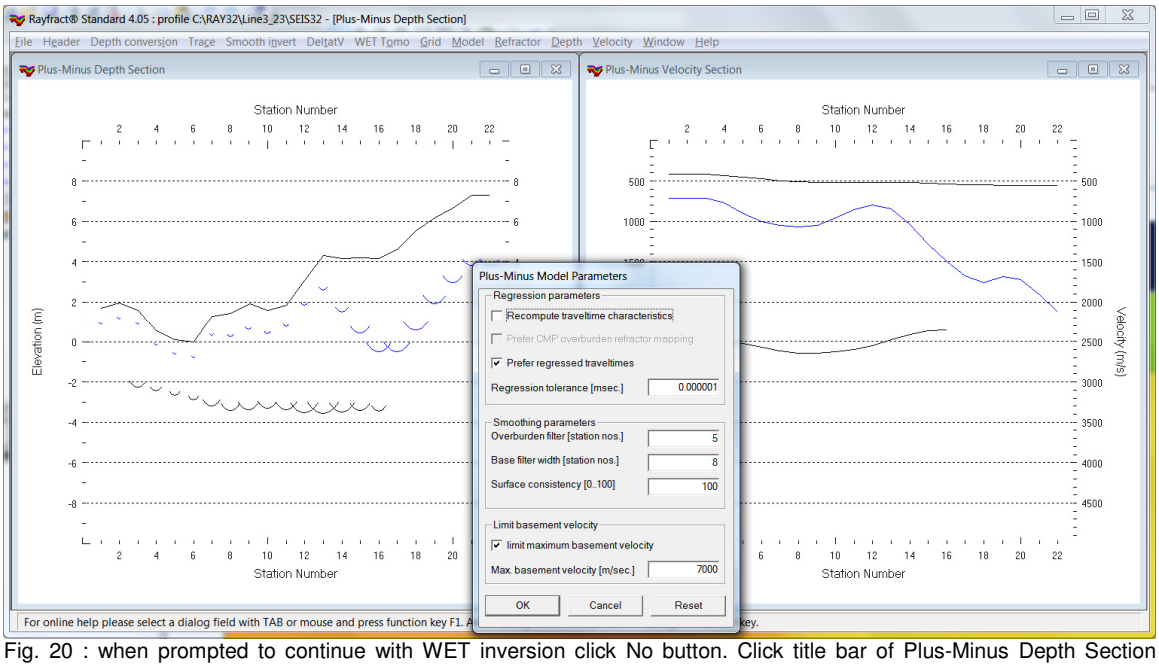


Fig. 20 : when prompted to continue with WET inversion click No button. Click title bar of Plus-Minus Depth Section window. Press ALT+M. Decrease ***Base filter width*** from default 10 to 8 stations. Click OK to obtain Fig. 15 starting model.

To reuse the same trace-to-refractor mapping as we used in Fig. 14 (bottom) for obtaining the Plus-Minus starting model :

- first backup your current mapping to .BRN file with ***File\Export header data\Export refractor branches to .BRN***
- select ***Refractor\Shot CMP breaks\Mapping\Delete branch points for all shots***
- select ***File\Update header data\Update refractor branches from .BRN*** and ASCII file C:\RAY32\LINE3_23\INPUT\BRANCHES.BRN to update the branch points delimiting refractors in *Refractor\Shot CMP breaks* display (Fig. 14 bottom)
- select *Trace\Shot gather* to redisplay Fig. 14
- remap traces to refractors with ALT+L in *Shot CMP breaks* window (Fig. 14 bottom)
- reselect *Depth\Plus-Minus* to obtain our Plus-Minus refraction starting model (Fig. 15)

<u>Next we redo the Plus-Minus starting model with ***Base filter width*** 5 stations instead of 8 stations :</u>

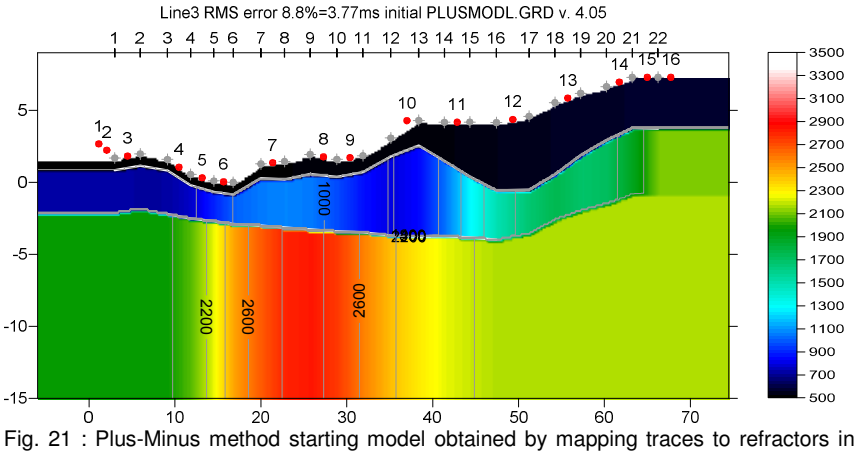


Fig. 21 : Plus-Minus method starting model obtained by mapping traces to refractors in Fig. 14 (bottom) and selecting Depth|Plus-Minus. Basement refractor smoothing over 5 stations instead of default 10 stations (Fig. 20).

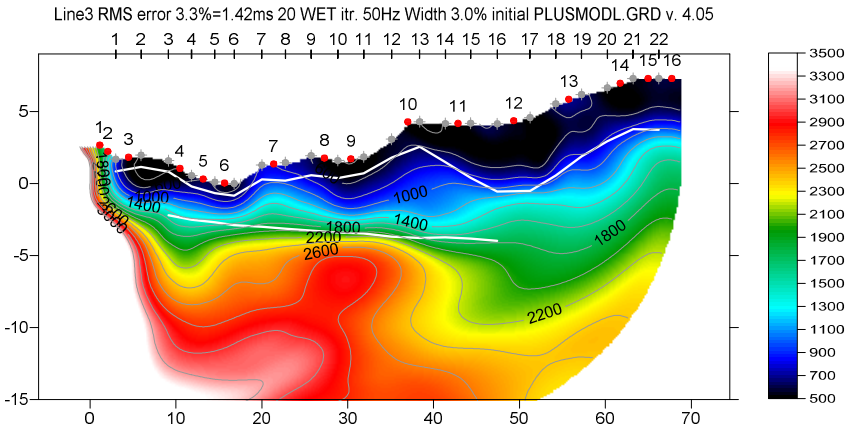


Fig. 22 : 20 Steepest-Descent WET iterations obtained with WET Tomo|Automatic WET and Plus-Minus starting model (Fig. 21). Default WET wavepath frequency 50Hz. Default Ricker differentiation -1 (Gaussian WET update weighting across wavepath). Default Full WET smoothing. WDVS Smoothing@500Hz (Fig. 19). White lines are your Plus-Minus refractors from Fig. 21.

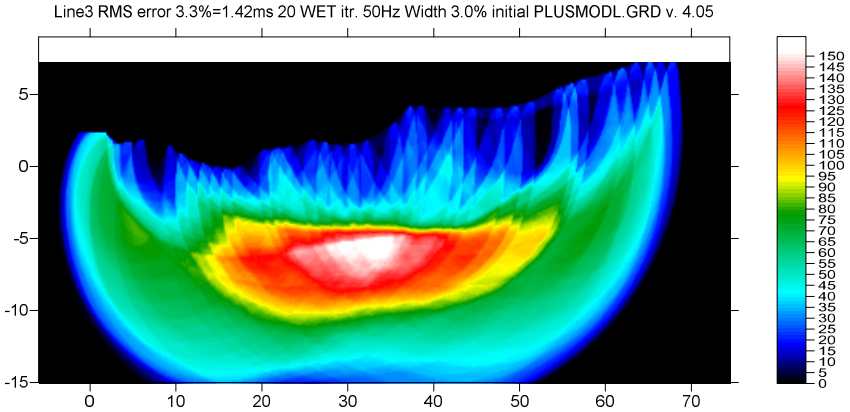


Fig. 23 : WET wavepath coverage plot obtained with Fig. 22. Unit is wavepaths per pixel.

To obtain the revised starting model Fig. 21 and an alternative WET tomogram Fig. 22 :

- select *Model|WDVS Smoothing*. Increase ***WDVS frequency*** to 500Hz from default 300Hz (Fig. 19) and click OK button
- select option *Grid|Plot refractors on tomogram*
- remap traces to refractors in *Refractor|Shot CMP breaks* with ALT+L
- reselect *Depth|Plus-Minus*
- when prompted to continue with WET inversion click No button
- click on title bar of *Plus-Minus Depth section* window and press ALT+M (Fig. 20)
- decrease ***Base filter width*** to 5 stations and click OK button to obtain Fig. 21 starting model
- select *WET Tomo|Automatic WET* and C:\RAY32\LINE3_23\LAYRTOMO\PLUSMODL.GRD to obtain WET tomogram Fig. 22 and WET wavepath coverage plot Fig. 23

Here is the .RAR archive with C:\RAY32\Line3_23 profile folder obtained with WET tomogram shown in Fig. 16 :

https://www.dropbox.com/scl/fi/4qi8io86vkfkyyopoi9b2/Line3_23_Oct20.rar?rlkey=v9v2k1jaz4mjqkm7bl00owgjn&dl=0

Download and unzip in Windows Explorer in your C:\RAY32 folder.

The profile was recorded in a dry river bed in Italy in summer of 2023.

There are two boreholes available for this line, S4 close to Geophone 11 at Station 11 and S1 close to Geophone 14 at Station 14.

Both boreholes show an upper layer of alluvial deposits, made of sand and gravel with boulders and big boulders, on a bed made by fractured metamorphic rock.

The borehole S4 at Geophone 11 shows bedrock at an elevation of -4m. The borehole S1 at Geophone 14 shows bedrock at an elevation of -8m.

These borehole results confirm our WET imaged basement step between G11 and G14 shown in Fig. 6, Fig. 16 and Fig. 22.

We thank our Italian agent Dr. Mario Foresta at IGS IdroGeoStudi.it for making available this interesting client profile data.

For Smooth inversion of synthetic traveltimes forward-modeled for a constructed basement step model using our laterally averaged 1D-gradient starting model see our tutorial

https://rayfract.com/tutorials/step.pdf

To normalize the RMS error with the maximum picked time instead of the average picked time select

- ***Model\Forward modeling Settings\Normalize RMS error with maximum picked time***

before running our WET inversion as described above. This results in RMS errors below 5 percent as shown above. This used to be the default setting for earlier versions of our software.

For an overview of our WDVS (Wavelength-Dependent Velocity Smoothing; Zelt and Chen 2016) see these publications :

Zelt, C. A. and J. Chen 2016. Frequency-dependent traveltime tomography for near-surface seismic refraction data, Geophys. J. Int., 207, 72-88, 2016. See https://dx.doi.org/10.1093/gji/ggw269 and https://www.researchgate.net/publication/305487180_Frequency-dependent_traveltime_tomography_for_near-surface_seismic_refraction_data .

Rohdewald S.R.C. 2021a. Improving the resolution of Fresnel volume tomography with wavelength-dependent velocity smoothing, Symposium on the Application of Geophysics to Engineering and Environmental Problems Proceedings : 305-308. https://doi.org/10.4133/sageep.33-169 . Slides at https://rayfract.com/pub/SAGEEP%202021%20slides.pdf

Rohdewald S.R.C. 2021b. Improved interpretation of SAGEEP 2011 blind refraction data using Frequency-Dependent Traveltime Tomography, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-4214,
https://doi.org/10.5194/egusphere-egu21-4214 . https://rayfract.com/tutorials/sageep11_16.pdf .

For an objective comparison of tomographic refraction analysis methods see these publications :

Zelt, C.A., Haines, S., Powers, M.H. et al. 2013. Blind Test of Methods for Obtaining 2-D Near-Surface Seismic Velocity Models from First-Arrival Traveltimes, JEEG, Volume 18(3), 183-194. https://www.researchgate.net/publication/267026965 .

Hiltunen, D. R., Hudyma, N., Quigley, T. P., & Samakur, C. 2007. Ground Proving Three Seismic Refraction Tomography Programs. Transportation Research Record, 2016(1), 110–120. https://doi.org/10.3141/2016-12 . https://www.researchgate.net/publication/242072938 .

Sheehan J.R., Doll W.E. and Mandell W.A. 2005a. An Evaluation of Methods and Available Software for Seismic Refraction Tomography. Journal of Environmental and Engineering Geophysics, volume 10, pp. 21-34. ISSN 1083-1363, Environmental and Engineering Geophysical Society. JEEG March 2005 issue. https://dx.doi.org/10.2113/JEEG10.1.21 . https://rayfract.com/srt_evaluation.pdf . https://www.researchgate.net/publication/242159023 .

More references :

W. Doll et al. 2010. Short Course Notes : Processing of Seismic Refraction Tomography Data. SAGEEP 2010 meeting in Keystone Colorado. https://rayfract.com/SAGEEP10.pdf .

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