NGU G4 NGU report 2020_044 : import data, update header data, remodel synthetic breaks, run DeltatV & Plus-Minus & Smooth inversion with Rayfract® version 4.03 released in Dec 2022 :

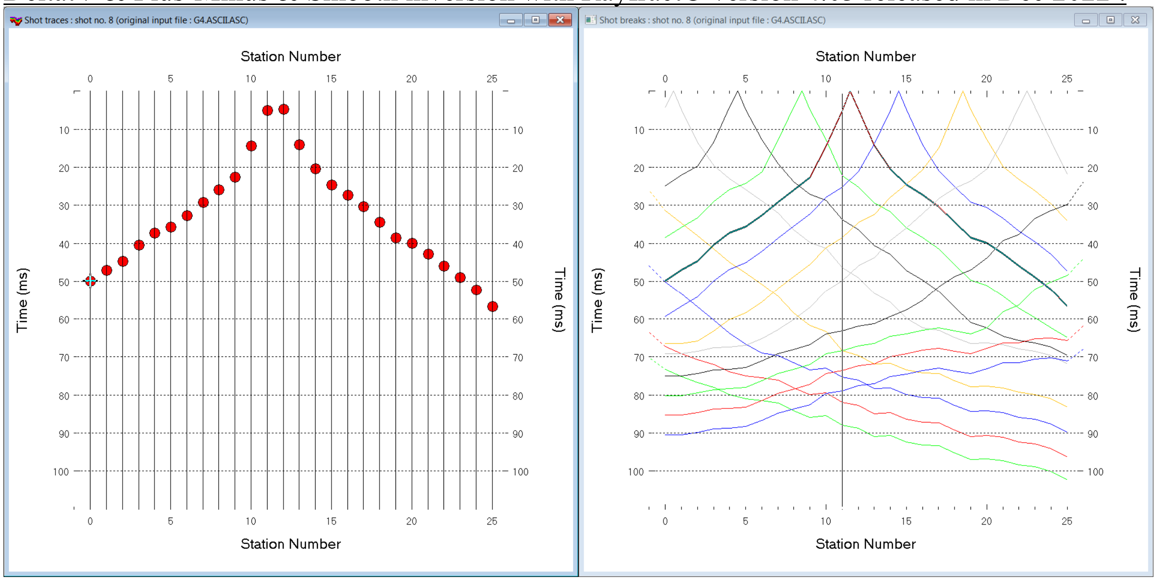



Fig. 1 : left : *Trace|Shot gather*, right : *Refractor|Shot breaks*. Traveltimes shown are synthetic times obtained after redoing synthetic forward modeling over G4_SYNTHETIC.GRD with correct off-end shot point elevations.

To create the profile database and import the data with latest Rayfract® version 4.03 Dec 2022 :

- ***File|New Profile***..., set *File name* to **`NGU_G4`** and click *Save button*
- in the prompt (Fig. 37) click ***No*** button to leave ***Profile start*** and first receiver at station no. 0.
- 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 0.5m. See Fig. 2.
- check box *Extrapolate tomograms* and edit *Extrapolate [station spacings]* to 30. Click button *OK*.
- unzip [input ngu g4.zip] with files **`G4.ASCII.ASC`**, **`G4.COORDS.COR`**, **`G4.SHOTPTS.SHO`**, **`G4.SHOTS.COR`**, **`G4_SYNTHETIC.GRD`** & **`G4.BRANCHES.BRN`** in directory **`C:\RAY32\NGU_G4\INPUT`**
- leave *File|Import Data Settings|Extrapolate receiver line coordinates* unchecked as per default
- select ***File|Import Data***... and set *Import data type* to **`ASCII column format`**. See Fig. 3.
- leave *Default spread type* at **`10: 360 channels`**
- click *Select button*, navigate into **`C:\RAY32\NGU_G4\INPUT`** and select file **`G4.ASCII.ASC`**
- set *Default sample count* to 1100 to setup the y scale for *Trace|Shot gather* & *Refractor|Shot breaks*
- check options *Batch import* and *Overwrite all*
- click ***Import shots button***. All shots in the **`G4.ASCII.ASC`** file are imported automatically.
- select *File|Update header data|**Update Station Coordinates*** with **`G4.SHOTS.COR`** containing shot point elevations at off-end shot stations. Click *Open* button and *Import and Reset*.
- *File|Update header data|**Update Shotpoint coordinates*** with **`G4.SHOTPTS.SHO`**. Click *Open* button.

Next we redo forward modeling of synthetic traveltimes with correct shot point elevation for off-end shots :

- select ***Model|Model synthetic shots*** & **`C:\RAY32\NGU_G4\INPUT\G4_SYNTHETIC.GRD`**. Click *Open*.
- select *Trace|Shot gather* and *Window|Tile* to obtain Fig. 1.
- browse shots in Fig. 1 with F7/F8 function keys
- select *File|Export header data|Export First Breaks as ASCII.ASC*
- navigate into folder **`C:\RAY32\NGU_G4\ExpJan9`**. Click *Save* button.

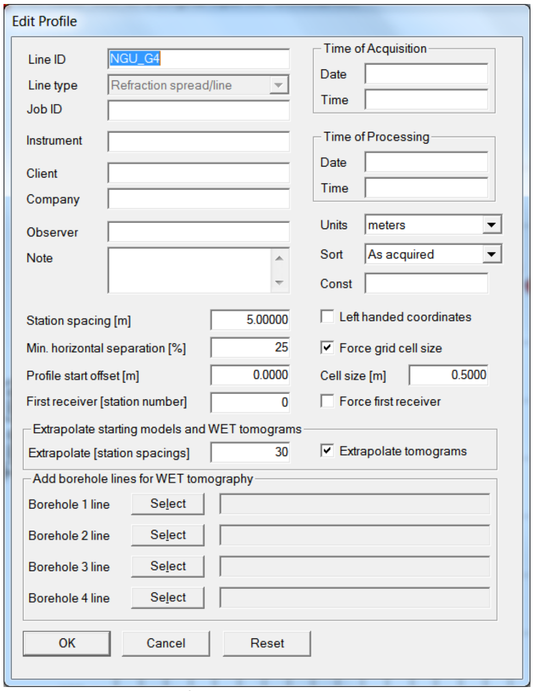



Fig. 2 : *Header|Profile*

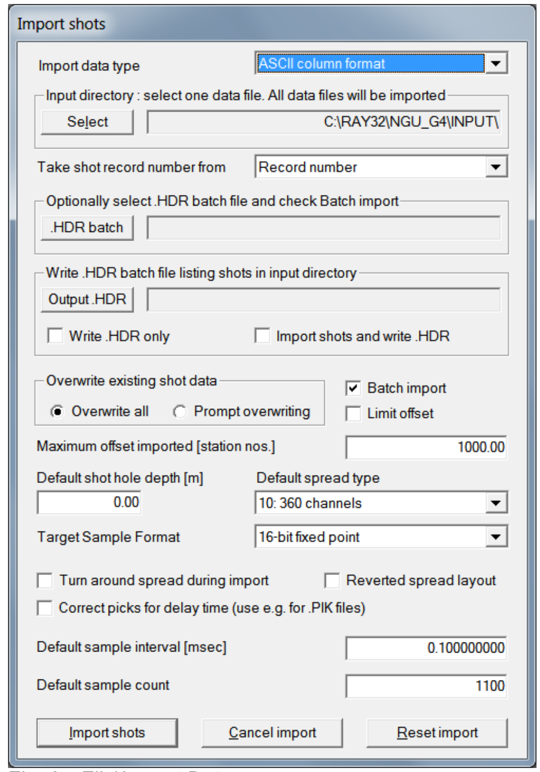



Fig. 3 : *File|Import Data*

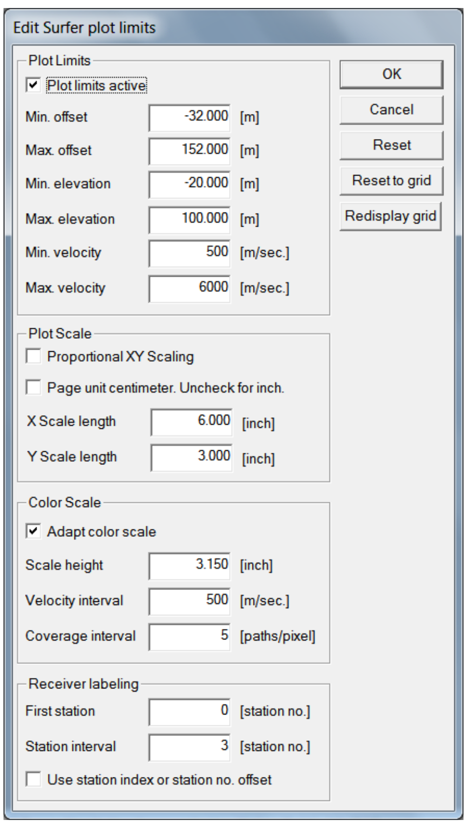



Fig. 4 : *Grid|Surfer plot Limits*

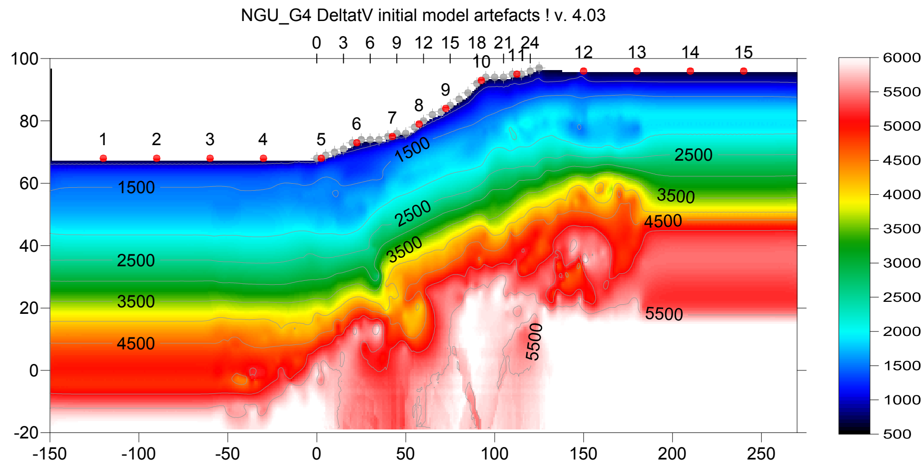



Fig. 5 : *DeltatV|Automatic DeltatV* inversion. Default *DeltatV settings*. Extrapolate tomogram over 30 station spacings. *Max. velocity exported* 5,800m/s (Fig 9). Don't limit DeltatV velocity to max. 1D-gradient velocity.

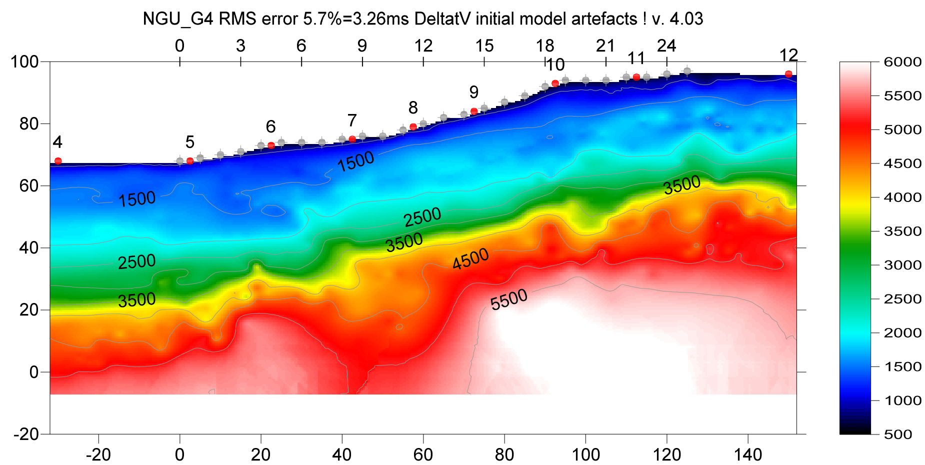



Fig. 6 : DeltatV options *Suppress velocity artefacts* and *Process every CMP offset* (Fig. 8). *Max. velocity exported* 5,800m/s (Fig 9). Don't limit DeltatV velocity to max. 1D-gradient velocity. *Grid|Surfer plot limits* as in Fig. 4.

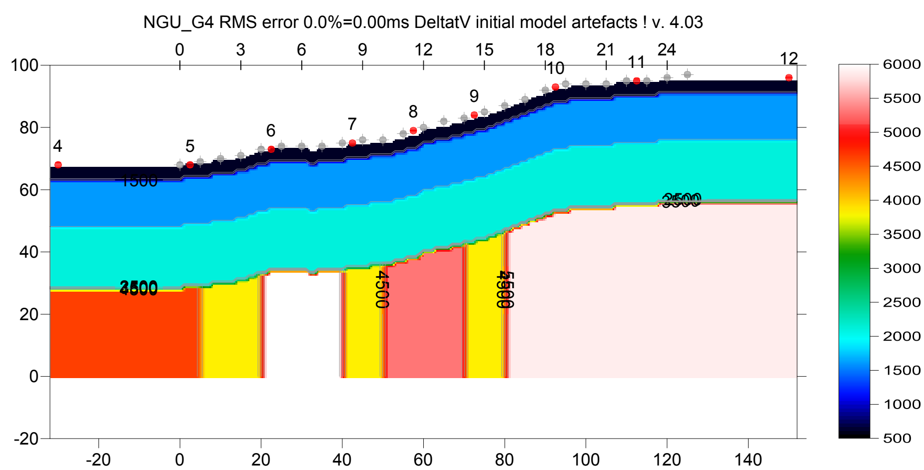
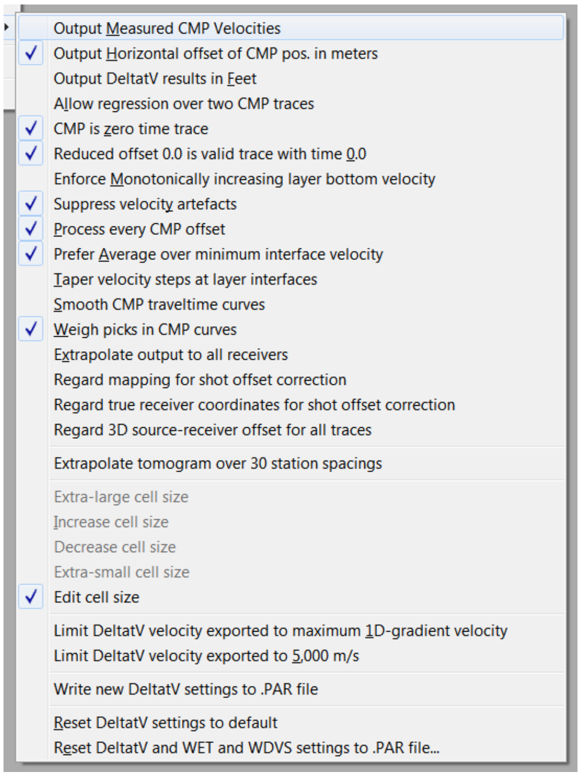



Fig. 7 : select *Grid|Image and contour velocity and coverage grids* & **`C:\RAY32\NGU_G4\INPUT\G4_SYNTHETIC.GRD`**

- select *DeltatV|Automatic DeltatV* and confirm artefacts warning prompt (Fig. 14) to obtain Fig. 5.
- select *Grid|Surfer plot Limits* and edit as in Fig. 4. Click button *OK*.
- uncheck *DeltatV|DeltatV settings|Limit DeltatV velocity exported to maximum 1D-gradient velo.* (Fig. 8)
- check *DeltatV|DeltatV settings|Suppress velocity artefacts* (Fig. 8)
- check *DeltatV|DeltatV settings|Process every CMP offset* (Fig. 8)

- select *DeltatV|DeltatV Export options*. Set *Max. velocity exported* to 5,800m/s (Fig. 9). Click button *Accept*. Select *DeltatV|Automatic DeltatV* and confirm prompts.
- select *Model|Forward model traveltimes* & `C:\RAY32\NGU_G4\TOMO\DELTATV.GRD`
- select *Grid|Image and contour velocity* & `C:\RAY32\NGU_G4\TOMO\DELTATV.GRD` to obtain Fig. 6
- select *Grid|Image and contour velocity* & `C:\RAY32\NGU_G4\INPUT\G4_SYNTHETIC.GRD` to obtain Fig. 7



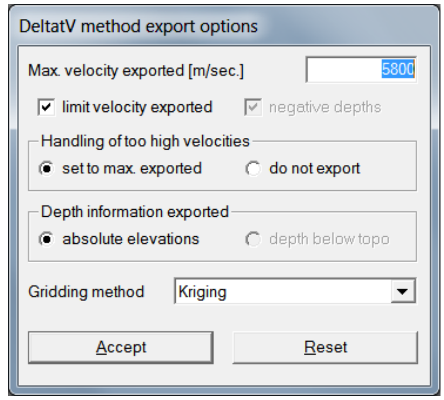




Fig. 9 : *DeltatV|DeltatV Export Options*. Increase *Max. velocity exported* to 5,800m/s. Click button *Accept.*

Fig. 8 (left) : *DeltatV|DeltatV Settings*. Check options *Suppress velocity artefacts* & *Process every CMP offset*. Uncheck the two options *Limit DeltatV velocity exported to…* .

DeltatV ***apparent velocity*** pseudo-sections can be compared to ER ***apparent resistivity*** pseudo-sections. See e.g. https://pages.mtu.edu/~ctyoung/LOKENOTE.PDF chapter 2.3 on page 8. Quote :

"The pseudosection is useful as a means to present the measured apparent resistivity values in a pictorial form, and as an initial guide for further quantitative interpretation. One common mistake made is to try to use the pseudosection as a final picture of the true subsurface resistivity." quoted from page 8 of LOKENOTE.pdf .

For processing of densely recorded lines longer than the recommended minimum of 500m with our *DeltatV* method see OT0608.pdf & GEOXMERC.pdf & 3016.pdf. DeltatV and *Smooth inversion* using ***1D-gradient starting model*** obtained by laterally averaging DeltatV match each other nicely as shown in these .pdf tutorials.

Above receiver spacing of 5m and a shot at every $4^{th}$ receiver only are both too wide for DeltatV.

For detailed description of our *DeltatV* method and other inversion methods see our manual .

On the next page we show layered refraction interpretation of above synthetic picks for NGU_G4 with conventional *Plus-Minus* method (Fig. 10). Note the good fit between synthetic picks and modeled traveltimes (Fig. 12) forward-modeled over the Plus-Minus .GRD file (Fig. 10) with RMS error 2.2%.

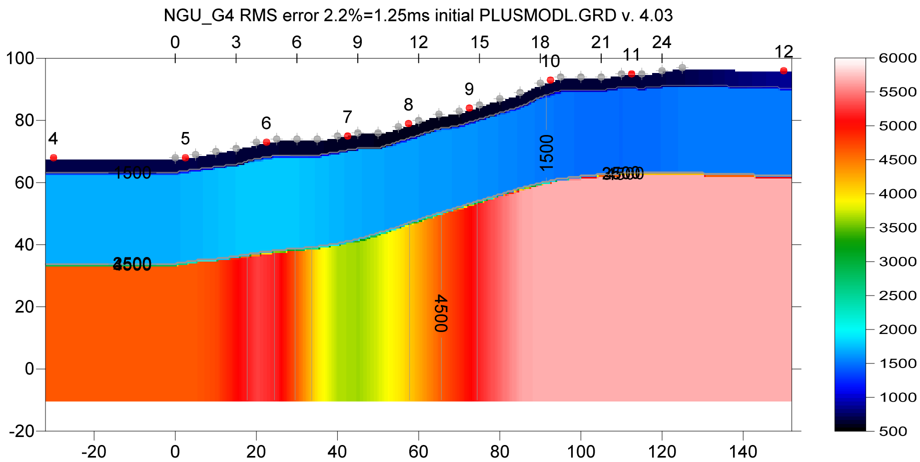



Fig. 10 : Plus-Minus method interpretation as 3-layer case. RMS error is 2.2%/1.25ms. For *Plus-Minus model parameters* see Fig. 13. *Overburden filter* 5. *Base filter width* 3. *Max. basement velocity* 5,500 m/s. For branch points see Fig. 12.

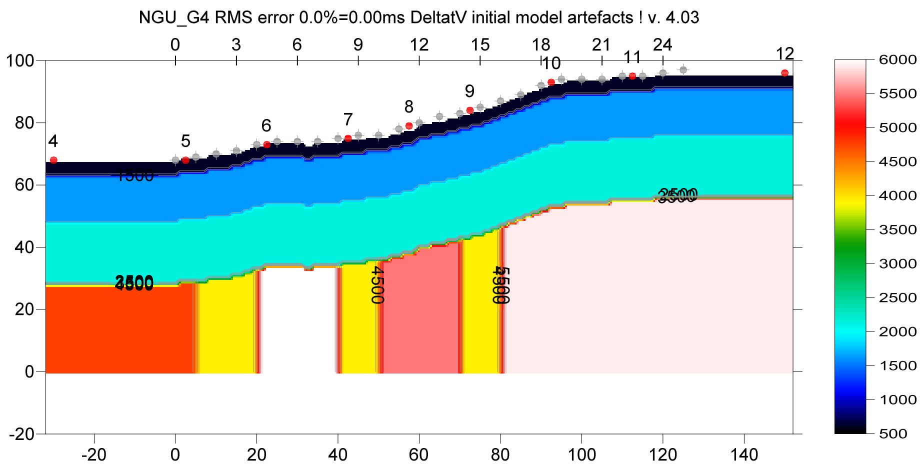



Fig. 11 : **C:\RAY32\NGU_G4\INPUT\G4_SYNTHETIC.GRD** plotted at same scale and color scale as Fig. 10.

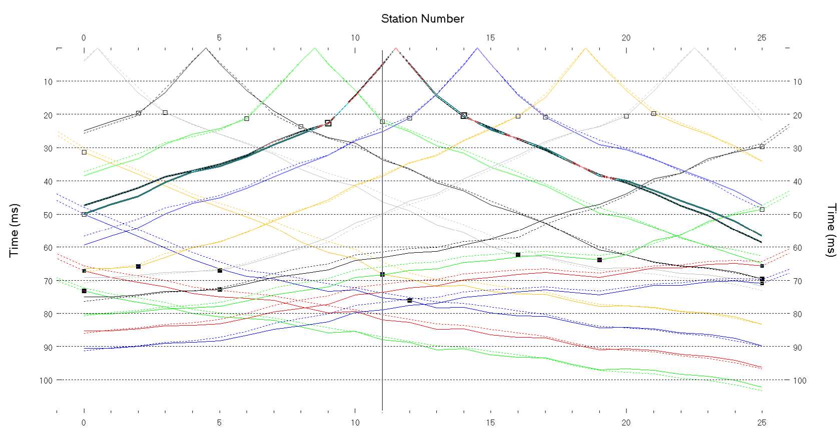



Fig. 12 : *Refractor|Shot* breaks. Solid curves are synthetic traveltime curves. Dashed curves are traveltimes forward modeled over **C:\RAY32\NGU_G4\LAYRTOMO\PLUSMODL.GRD** (Fig. 10). Hollow squares are branch points separating the direct wave from first refractor. Black filled squares are branch points separating first refractor from 2$^{nd}$ refractor. Update with *File|Update header data|Update refractor branches from .BRN...* & **G4.BRANCHES.BRN**. Press **ALT+L** to remap traces to refractors. See .pdf help chapter *Mapping traces to refractors*.

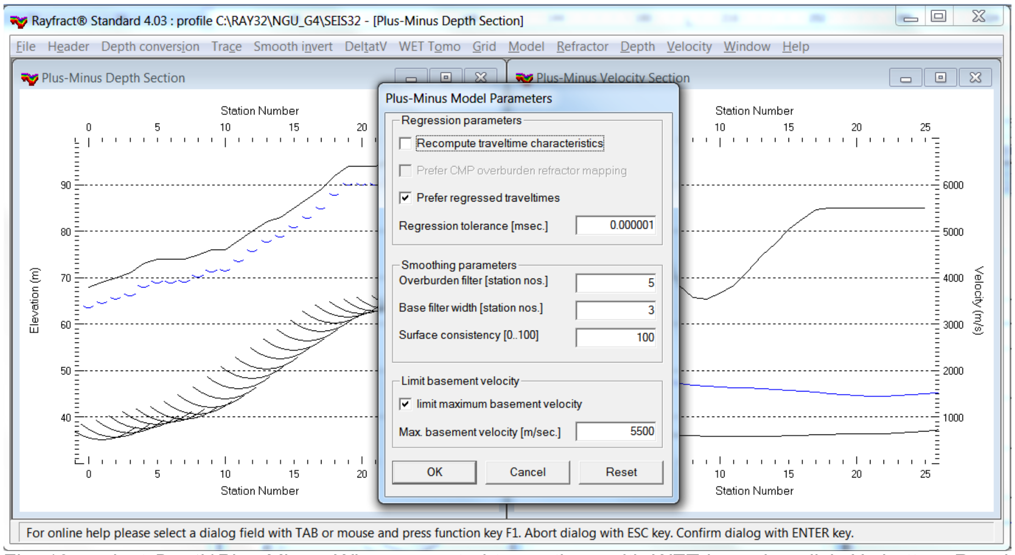



Fig. 13 : select *Depth|Plus-Minus*. When prompted to continue with WET inversion click *No* button. Reselect *Depth|Plus-Minus* and press **ALT+M** to show *Plus-Minus Model Parameters* dialog. Set *Overburden filter* to 5. Set *Base filter width* to 3. Check box *limit maximum basement velocity*. Set *Maximum basement velocity [m/s]* to 5500. Edit as shown and click *OK* button or press **ENTER** key to obtain Fig. 10.

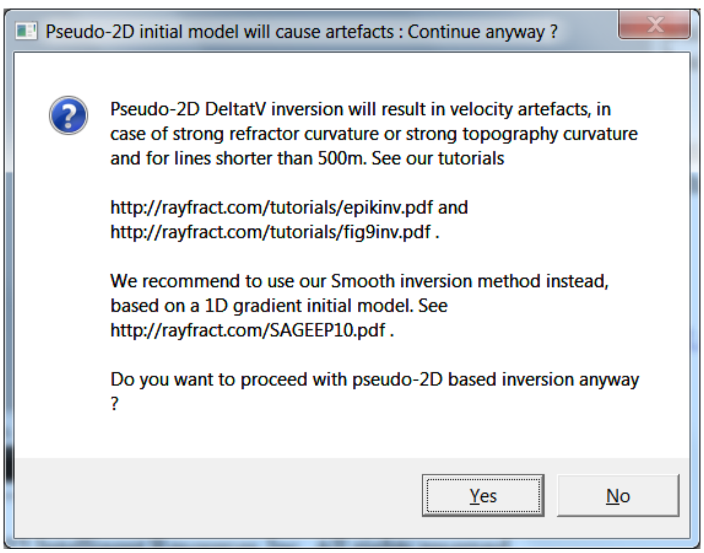



Fig. 14 : artefact warning prompt shown when user selects DeltatV menu items, recommending using Smooth inversion method instead.

As shown above our *pseudo-2D DeltatV* method can give reasonable output even for too short profiles with too wide receiver and shot spacing, as long as there is no strong lateral velocity variation in overburden and with not too strongly undulating topography.

NGU shows their DeltatV interpretation of above synthetic fault zone data in NGU report 2020_044 in their Fig. 11 in the rightmost column.

As shown in our earlier tutorial NGU_G1_remodeled_traveltimes.pdf NGU did not regard the off-end shot point station elevations for their forward modeling of synthetic traveltimes. Also NGU used non-default/bad settings for *DeltatV static corrections*. See our tutorial for NGU_G1 model also shown in their Fig. 11 in the leftmost column.

We ask NGU to stop their misrepresentation of the DeltatV method (Gebrande and Miller 1985; Gebrande 1986; Colombo 2016; Gibson et al. 1979) and to start following instructions in our manual and tutorials, including using default *DeltatV settings* with our *Automatic DeltatV* inversion and also showing our *Smooth inversion* method using our *1D-gradient starting model* (Fig. 15 and Fig. 16). See also our earlier Aaknes-1 tutorial, our 3016 tutorial and Line14 tutorial. This reminds us of earlier publications by Dr. Palmer discrediting our software and also completely ignoring our fail-safe default *Smooth inversion* method available since 2005 in his 2010 EAGE publication https://dx.doi.org/10.1111/j.1365-2478.2009.00818.x .

In general we always recommend preferring our default and fail-safe ***Smooth inversion*** method as shown on next page (Sheehan et al. 2005). See the warning prompt shown with *DeltatV* menu items (Fig. 14).

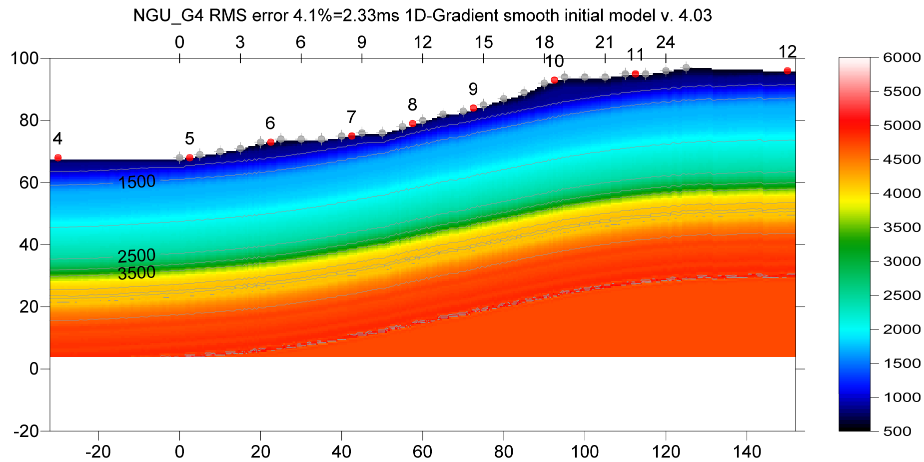



Fig. 15 : *Smooth invert|WET with 1D-gradient initial model* gives 1D-gradient initial model with *Smooth inversion Settings Allow XTV inversion for 1D initial model* & *Optimize XTV for layered starting model* (Fig. 20). RMS error is 2.33ms.

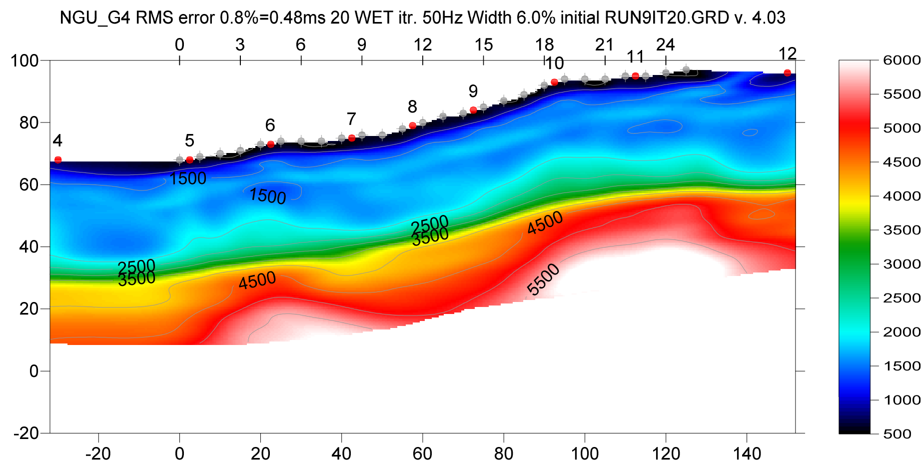



Fig. 16 : Multiscale Steepest-Descent *WET inversion* with *WET Tomo|Interactive WET* (Fig. 21 & 22). 1D-gradient starting model (Fig. 15). *Model|WDVS Smoothing|Discard WET smoothing* checked. WDVS activated at 500Hz (Fig. 19). *Minimal WET smoothing* (Fig. 22).

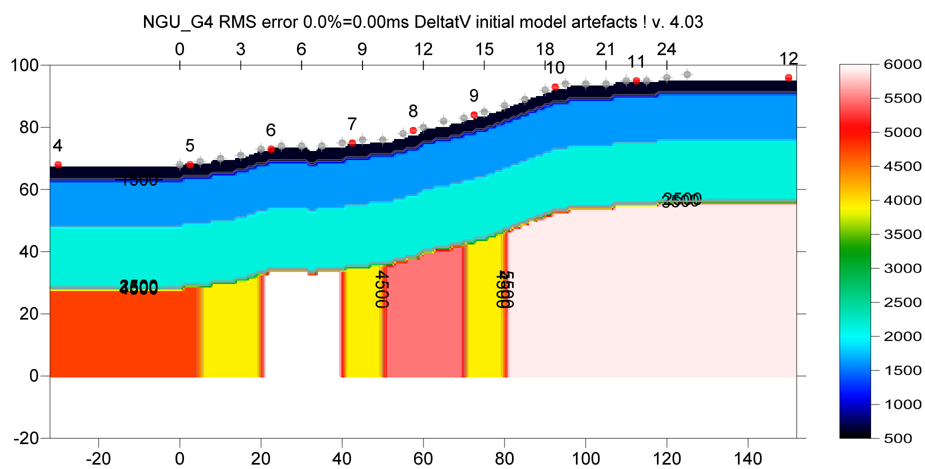



Fig. 17 :*Grid|Image and contour velocity* with `C:\RAY32\NGU_G4\INPUT\G4_SYNTHETIC.GRD` plotted at same scale as Fig. 16 using *Grid|Surfer plot Limits* shown in Fig. 4.

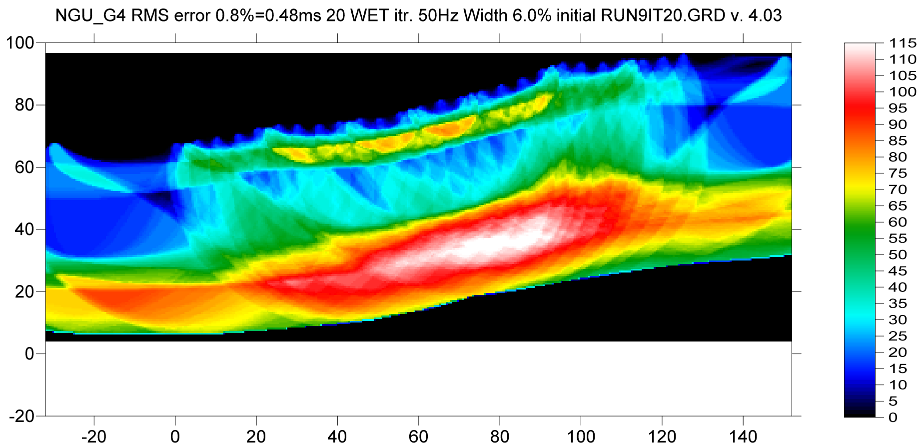



Fig. 18 : WET wavepath coverage plot obtained with Fig. 16. Unit is wavepaths per pixel.

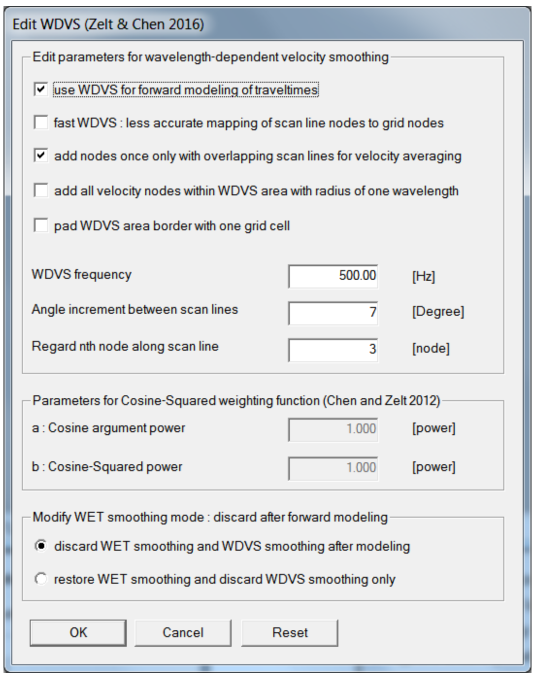



Fig. 19 : *Model|WDVS Smoothing…*

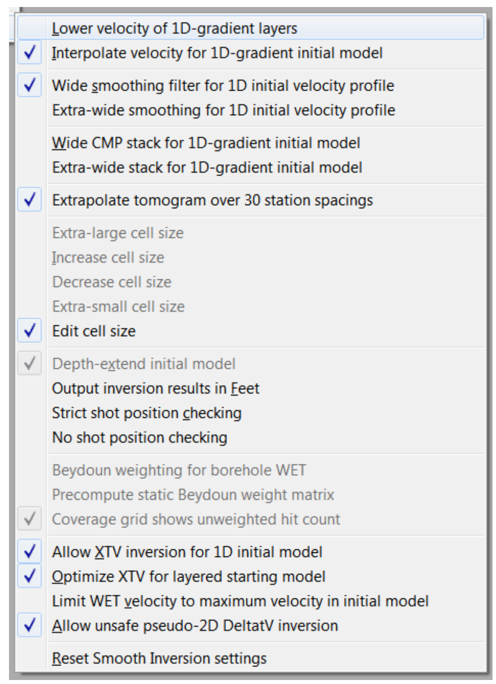



Fig. 20 : *Smooth invert|Smooth inversion Settings*

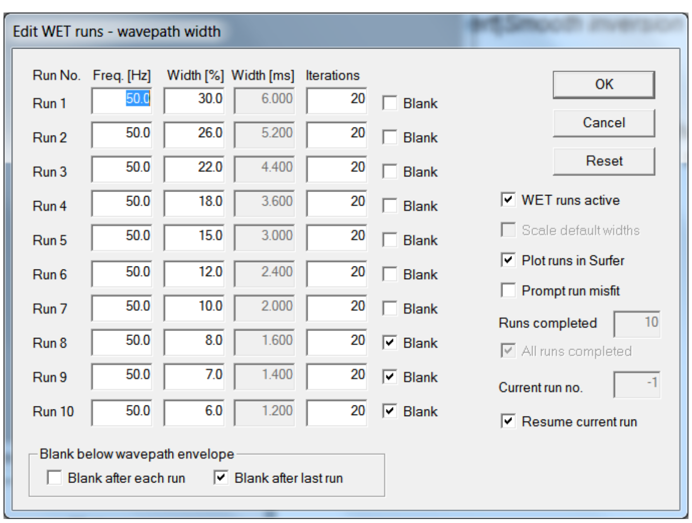



Fig. 21 : *WET Tomo|Interactive WET Tomography|Iterate*. Edit runs for multiscale WET.

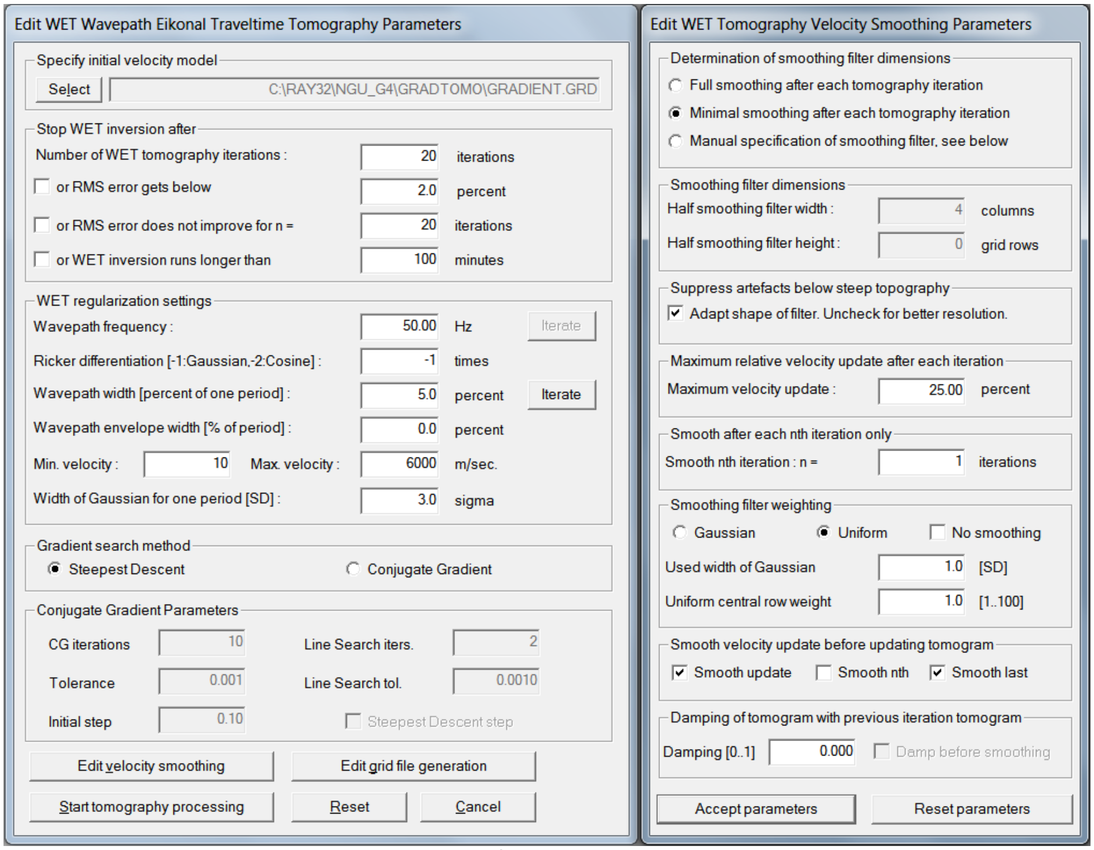



Fig. 22 : *WET Tomo|Interactive WET* main dialog (left). Edit velocity smoothing (right).

Next we show further optimized *interactive DeltatV* inversion with layered XTV settings in version 4.03 of our software :

- check *DeltatV|DeltatV settings|Taper velocity steps at layer interfaces* (Fig. 26)
- check *DeltatV|DeltatV settings|Suppress velocity artefacts* (Fig. 26)
- check *DeltatV|DeltatV settings|Process every CMP offset* (Fig. 26)
- uncheck …|*DeltatV settings|Limit DeltatV velocity exported to maximum 1D-gradient velo.* (Fig. 26)
- select *DeltatV|XTV parameters* and edit as in Fig. 27. Set *Minimum velocity ratio* to 1.10.
- select *DeltatV|Interactive DeltatV*. Leave main dialog settings at defaults (Fig. 28).
- click button *Static Corrections*. Leave at defaults (Fig. 29) and click button *Accept*.
- click button *Export Options*. Increase *Max. velocity exported* to 5,800 m/s (Fig. 9) and click *Accept*.
- click button *DeltatV Inversion* (Fig. 28)
- in *Save DeltatV output* dialog move mouse cursor over yellow *Create New Folder* icon at top right
- left-click this icon. Edit name of new folder to …`\Intercept1.10_Jan9`. Press **ENTER** key.
- double-click this new folder `C:\RAY32\NGU_G4\Intercept1.10_Jan9` & click *Save* button.
- select *Model|Forward model traveltimes* & `C:\RAY32\NGU_G4\Intercept1.10_Jan9\DELTATV.GRD`
- select *Grid|Image and contour velocity* & …`\Intercept1.10_Jan9\DELTATV.GRD` to obtain Fig. 25
- obtain Fig. 23 as Fig. 25 but with *DeltatV|XTV parameters/Minimum velocity ratio* 1.05 (Fig. 27)

At offset range 0m to 80m Fig. 23 and Fig. 25 better match the true model (Fig. 24) than Fig. 6 for which *XTV parameters* (Fig. 27) were implicitly set to option *Gradient model* during *DeltatV|Automatic DeltatV*.

To the right of offset 80m Fig. 23 and Fig. 25 show more artefacts at top-of-basement than Fig. 6 & 10. These artefacts are due to strong refractor curvature and strong topography curvature and missing receivers to the right of station no. 25. See our broadepi tutorial and DeltatV artefact warning prompt (Fig. 14).

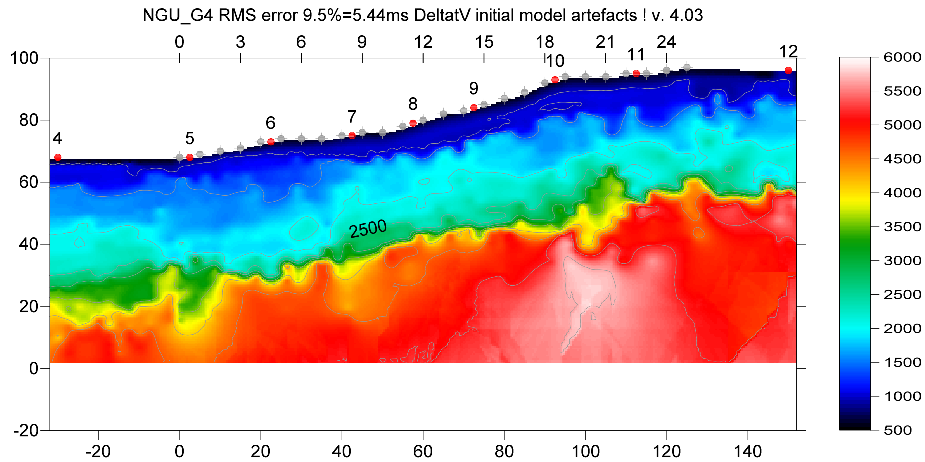



Fig. 23 : check DeltatV options *Suppress velocity artefacts*, *Process every CMP offset, Taper velocity steps at layer interfaces.* Uncheck *Limit DeltatV velocity to maximum 1D-gradient velo*city (Fig. 26). Increase *Max. velocity exported* to 5,800m/s (Fig. 9). Activate *Surfer plot limits* (Fig. 4). Layered XTV with *Minimum velocity ratio* 1.05 (Fig. 27).

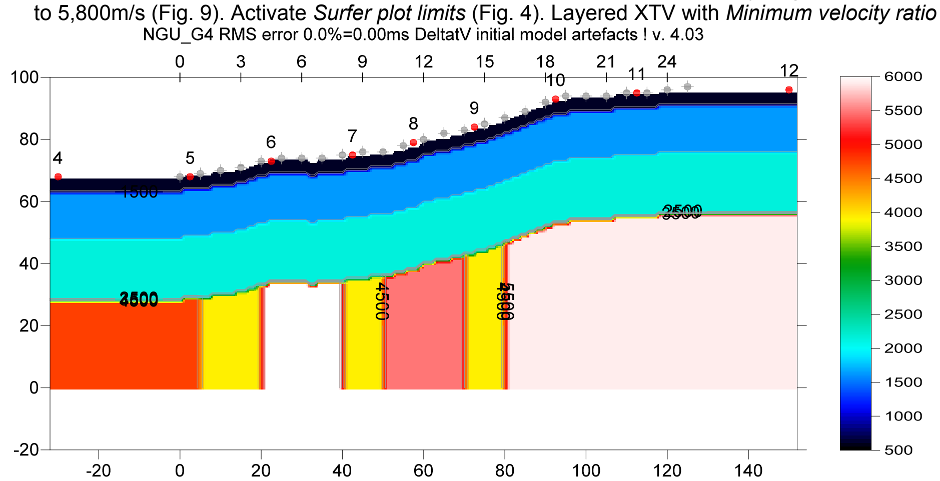



Fig. 24 : True model. *Grid|Image and contour velocity* with **C:\RAY32\NGU_G4\INPUT\G4_SYNTHETIC.GRD** plotted at same scale as Fig. 23 using *Grid|Surfer plot Limits* shown in Fig. 4.

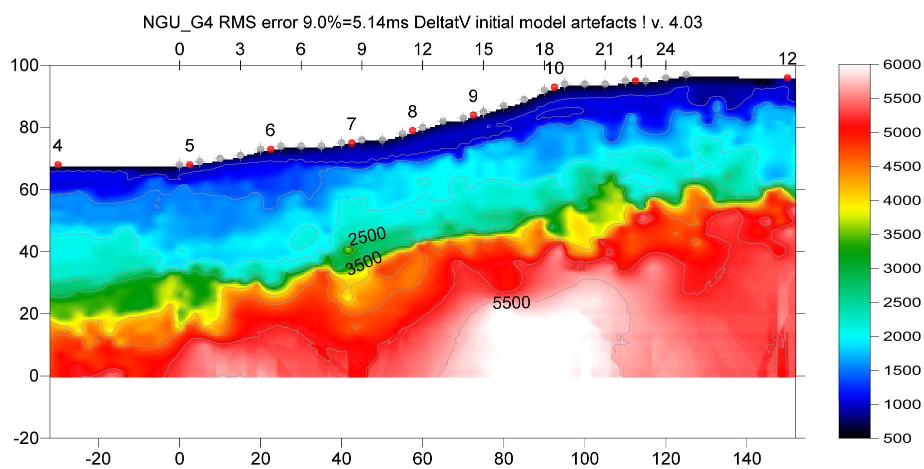



Fig. 25 : Default ***Weathering crossover*** 10 stations (Fig. 29). Default ***Topography filter*** 15 stations (Fig. 29). Check DeltatV options *Suppress velocity artefacts*, *Process every CMP offset, Taper velocity steps at layer interfaces.* Uncheck *Limit DeltatV velocity to maximum 1D-gradient velo*city (Fig. 26). Increase *Max. velocity exported* to 5,800m/s (Fig. 9). Activate *Surfer plot limits* (Fig. 4). Layered XTV with *Minimum velocity ratio* 1.10 (Fig. 27).

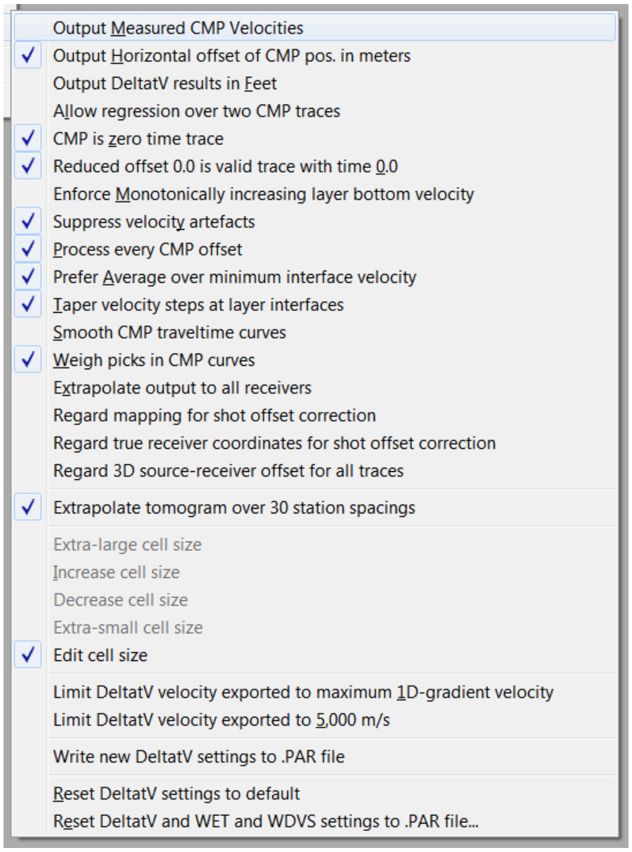



Fig. 26 : *DeltatV|DeltatV Settings* for Fig. 23 & Fig. 25

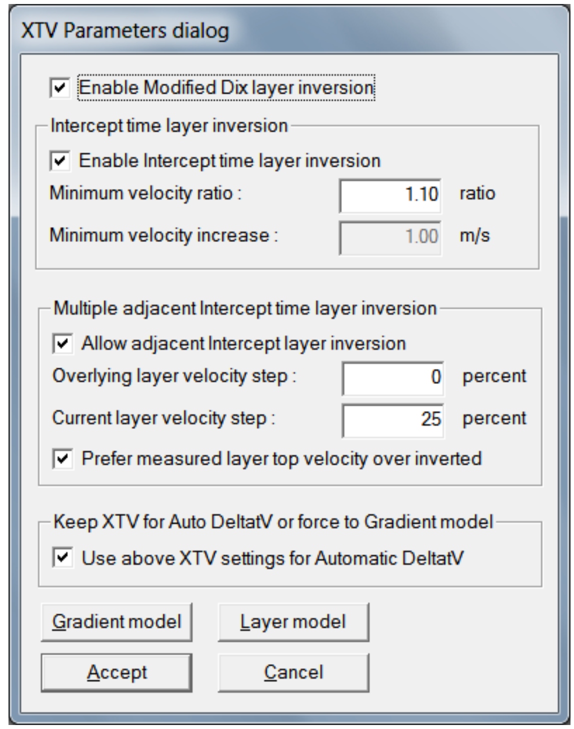



Fig. 27 : *DeltatV|XTV parameters* for Fig. 23 & 25. For Fig. 23 set *Minimum velocity ratio* to 1.05.

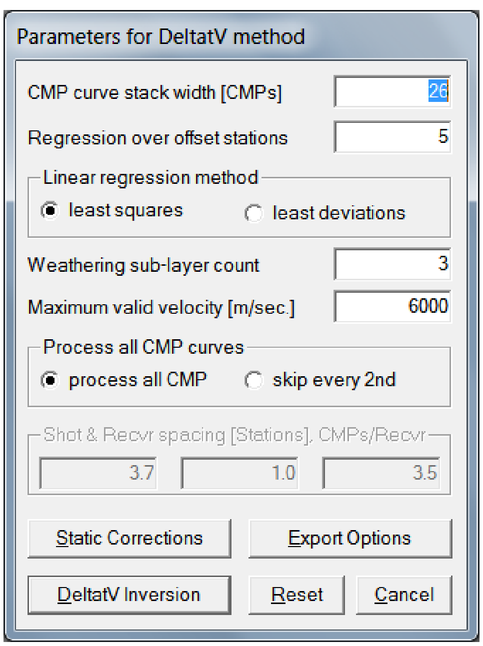



Fig. 28 : *DeltatV|Interactive DeltatV* main dialog. Default settings for Fig. 23 and Fig. 25.

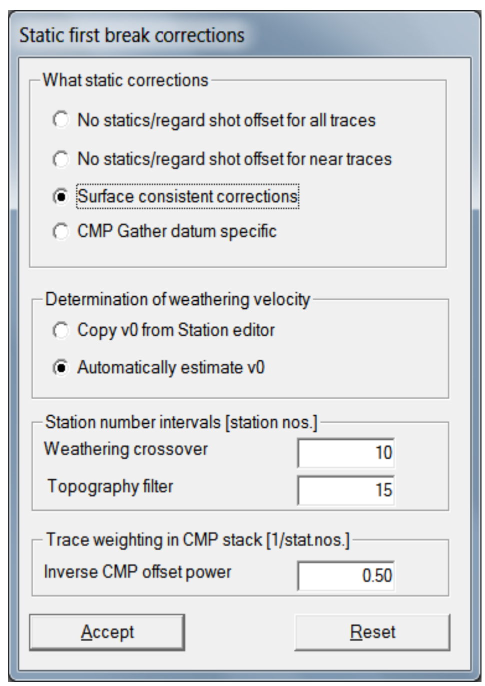



Fig. 29 : *DeltatV|Interactive DeltatV|Static Corrections.* Default settings for Fig. 23 and 25.

For recommended default settings for DeltatV static corrections dialog see our .pdf help https://rayfract.com/help/rayfract.pdf chapter ***DeltatV Static Corrections*** on page 208. For latest description see https://rayfract.com/help/DeltatV_Static_Corrections_July12_2022.jpg .

For recommended default settings in interactive DeltatV main dialog see our .pdf help https://rayfract.com/help/rayfract.pdf chapter ***Interactive DeltatV*** on page 206. For latest description see https://rayfract.com/help/DeltatV_Interactive_Main_Dialog_July12_2022.jpg .

For latest version of our help chapter on pseudo-2D DeltatV inversion see https://rayfract.com/help/DeltatV_Inversion.pdf .
For latest version of our help chapter on XTV inversion see https://rayfract.com/help/XTV_inversion_July_2022.pdf .

DeltatV interpretations shown in Fig. 23 and Fig. 25 display a realistic shape of the top-of-basement in offset range 0m to 80m when compared to the traditional Plus-Minus interpretation (Fig. 10). DeltatV interpretations are a bit too deep compared to the true model (Fig. 24) and include noise and artefacts especially before first/after last profile receiver and at the location of strong refractor curvature.

To the right of offset 80m Fig. 23 and Fig. 25 show more artefacts at top-of-basement than Fig. 6 & 10. These artefacts are due to strong refractor curvature and strong topography curvature and missing receivers to the right of station no. 25. See our broadepi tutorial and DeltatV artefact warning prompt (Fig. 14).

Our latest version 4.03 released in Dec 2022 offers a new option at bottom of *DeltatV|XTV parameters* dialog named *Use above XTV settings for Automatic DeltatV* (Fig. 27). Check this option to obtain Fig. 23 and Fig. 25 with *DeltatV|Automatic DeltatV* instead of *DeltatV|Interactive DeltatV*. You still first need to increase the *Max. velocity exported* in dialog *DeltatV|DeltatV Export Options* or in *DeltatV|Interactive DeltatV|Export Options* (Fig. 9).

Here is the .zip archive with NGU model G4 model files made available by NGU May 23, 2022
Here is the .zip archive with correctly remodeled traveltime files done Jan 9, 2023
Here is the .rar archive with DeltatV files for Fig. 6
Here is the .rar archive with Plus-Minus files for Fig. 10
Here is the .rar archive with multiscale inversion files for Fig. 16
Here is the .rar archive with DeltatV files for Fig. 25

On the next page we show multiscale Steepest-Descent WET inversion using the DeltatV+XTV starting model shown in Fig. 23. We enable WDVS (Wavelength-Dependent Velocity Smoothing; Zelt and Chen 2016) to obtain sharper imaging of fault zones in the basement.

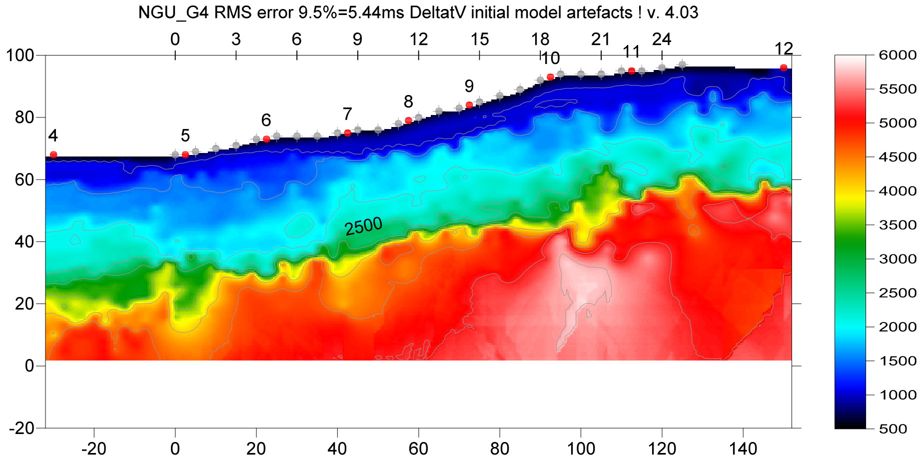



Fig. 30 ( same as Fig. 23) : Layered XTV with *Minimum velocity ratio* 1.05 (Fig. 27). Default ***Weathering crossover*** 10 stations (Fig. 29). Default ***Topography filter*** 15 stations (Fig. 29). Check DeltatV options *Suppress velocity artefacts*, *Process every CMP offset, Taper velocity steps at layer interfaces.* Uncheck *Limit DeltatV velocity to maximum 1D-gradient velo*city (Fig. 26). Increase *Max. velocity exported* to 5,800m/s (Fig. 9). Activate *Surfer plot limits* (Fig. 4).

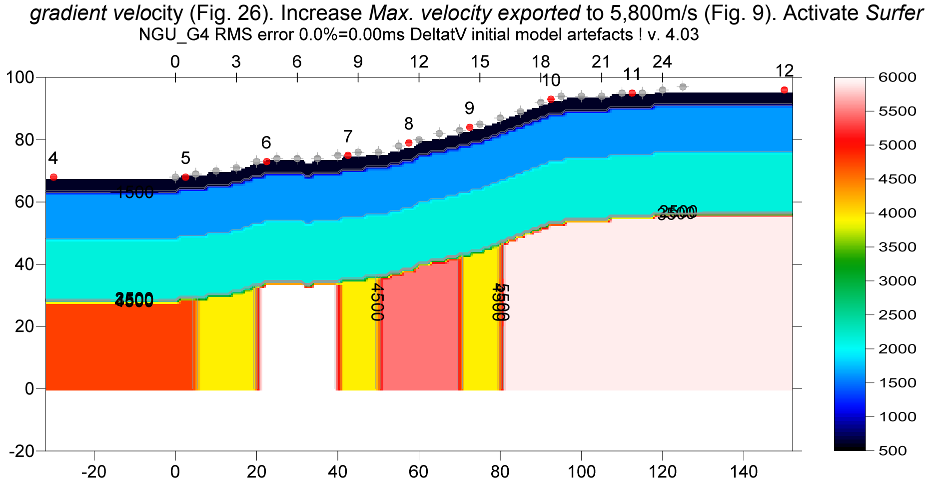



Fig. 31 : True model. *Grid|Image and contour velocity* with **C:\RAY32\NGU_G4\INPUT\G4_SYNTHETIC.GRD** plotted at same scale as Fig. 30 using *Grid|Surfer plot Limits* shown in Fig. 4.

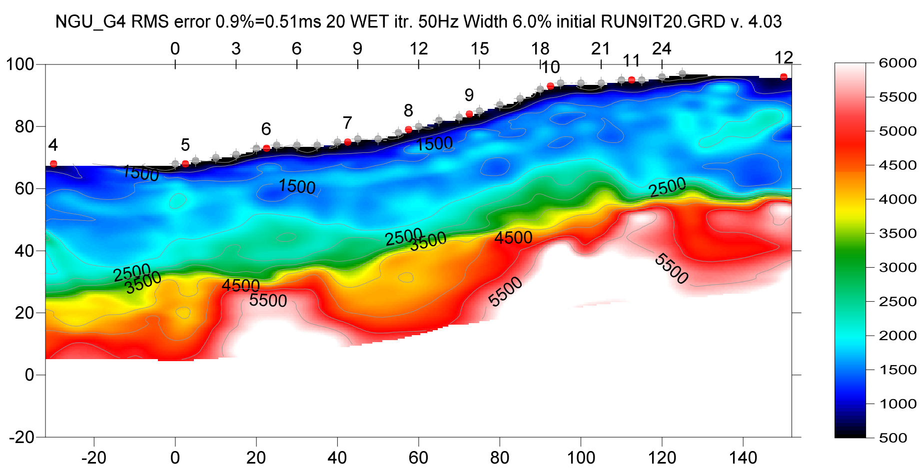



Fig. 32 : Multiscale Steepest-Descent WET. Output of 10th WET run shown. Starting model is Fig. 30. WDVS @500Hz. Discard WET smoothing after WDVS (Fig. 35). Minimal WET smoothing. Gaussian WET smoothing filter weighting. Used width of Gaussian 3.0 sigma (Fig. 34 right). Multirun WET schedule as in Fig. 36. Surfer plot Limits as in Fig. 4.

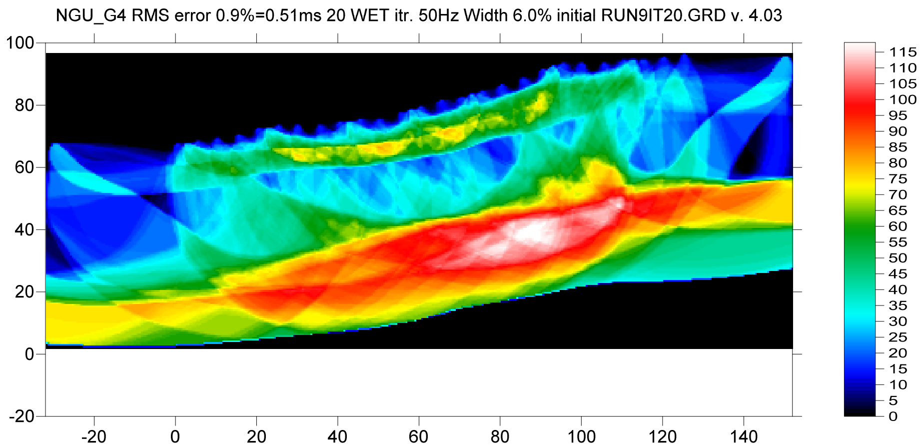


Fig. 33 : WET wavepath coverage for Fig. 32. Unit is wavepaths per pixel.

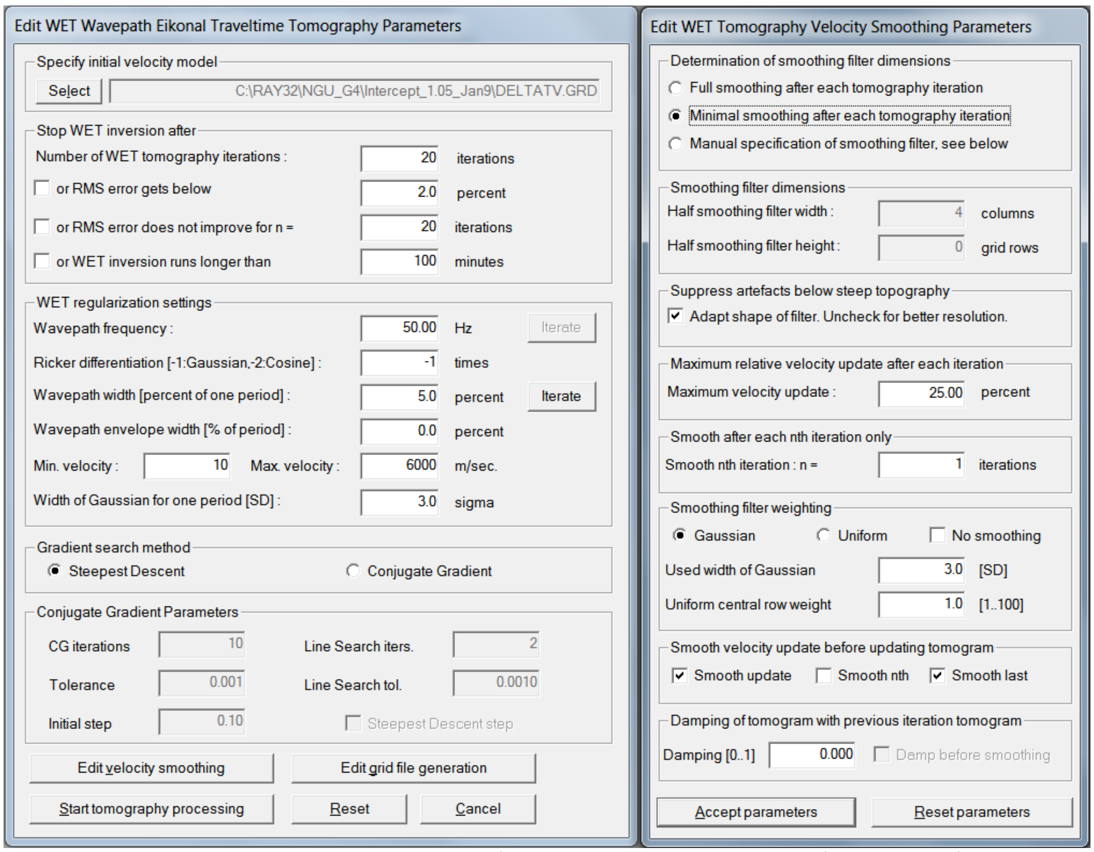


Fig. 34 : *WET Tomo|Interactive WET* main dialog (left). Edit velocity smoothing (right). Settings used for Fig. 32.

Here is the .rar archive with 10 WET runs for Fig. 32

Here is the .rar archive with seis32.* profile database files for Fig. 32

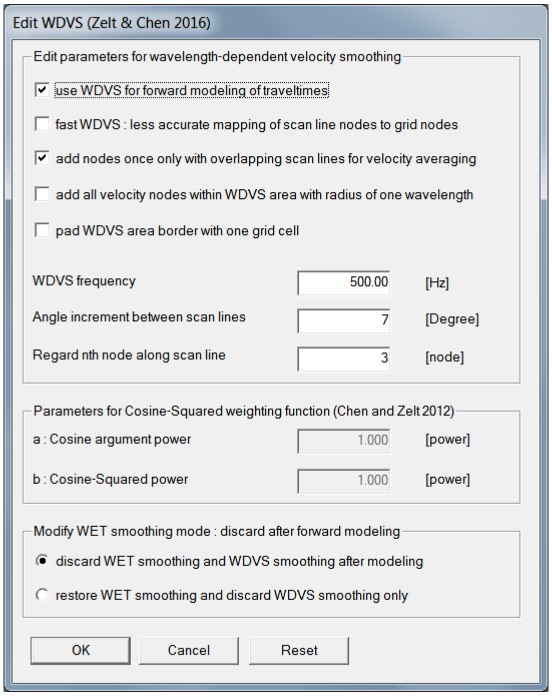



Fig. 35 : *Model|WDVS Smoothing*. Settings used for Fig. 32. Use WDVS for forward modeling of traveltimes. WDVS frequency 500Hz. Discard WET smoothing after forward modeling.

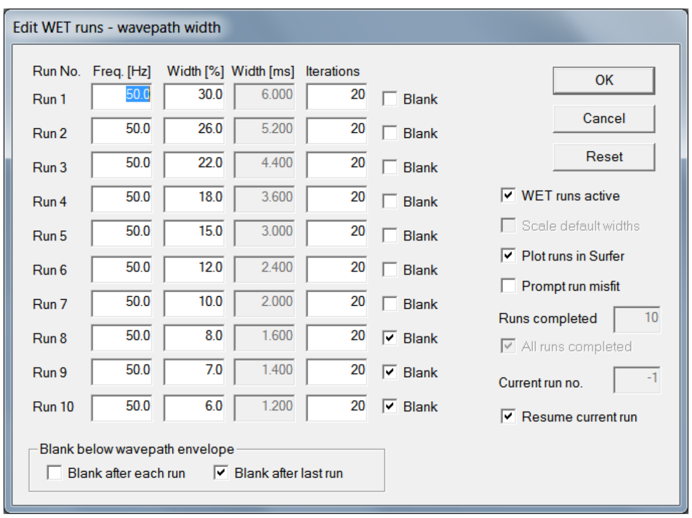



Fig. 36 : *WET Tomo|Interactive WET Tomography|Iterate*. Edit runs for multiscale WET for Fig. 32.

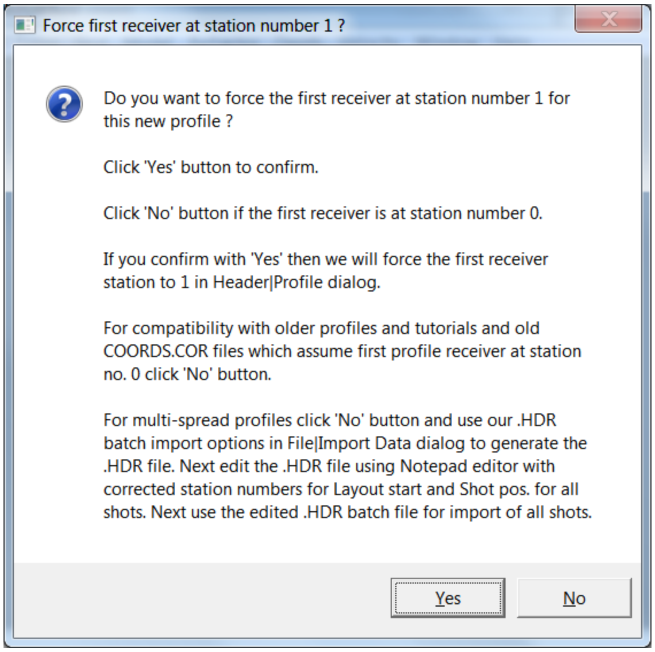



Fig. 37 : click No button to leave profile start / first receiver station number at station no. 0.

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.

.

We thank NGU for making available above synthetic data and model files.

As shown in our companion short tutorial you need to correctly specify off-end shot elevations to obtain correct synthetic first breaks picks with *Model|Model synthetic shots* over NGU G4_SYNTHETIC.GRD model.

See also our updated Aaknes-1 tutorial showing optimized (Fig. 29) and pessimized (Fig. 28) *DeltatV* interpretation of field-recorded data from Norway.

Next we show ***Automatic WET inversion*** using our Plus-Minus layered refraction starting model (Fig. 10). We discard WET smoothing after forward modeling (Fig. 35) for improved resolution but leave WDVS disabled :

- select *Model|WDVS Smoothing*
- uncheck box *use WDVS for forward modeling of traveltimes* (Fig. 35)
- check box *discard WET smoothing and WDVS smoothing after modeling* (Fig. 35). Click *OK*.
- select ***WET Tomo|Automatic WET tomography…***
- navigate into folder **C:\RAY32\NGU_G4\LAYRTOMO**
- select file **PLUSMODL.GRD** and click *Open* button
- confirm prompt showing fit between modeled and picked traveltimes with *OK* button
- confirm completion prompt with *OK* button
- click on Surfer icon in task bar to view the WET tomogram (Fig. 40) obtained with default WET parameters : 20 *Steepest-Descent* WET iterations, *Wavepath frequency* 50Hz, *Ricker differentiation* -1 (Gaussian), *Full WET smoothing.*

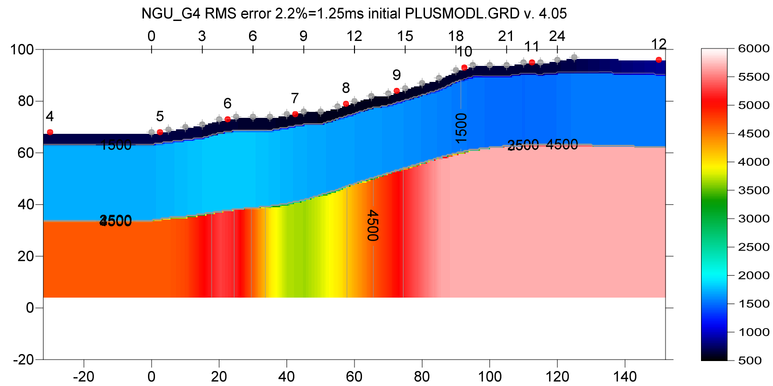



Fig. 39 : Plus-Minus method starting model. Same as Fig. 10.

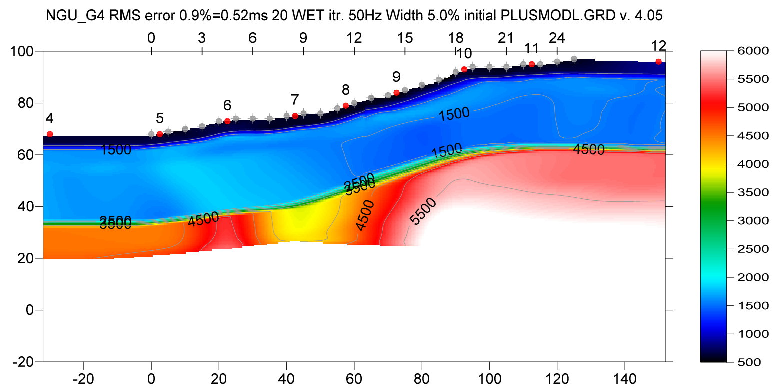



Fig. 40 : WET Tomo|Automatic WET. Starting model Fig. 39. Discard WET smoothing (Fig. 35) but don't enable WDVS.

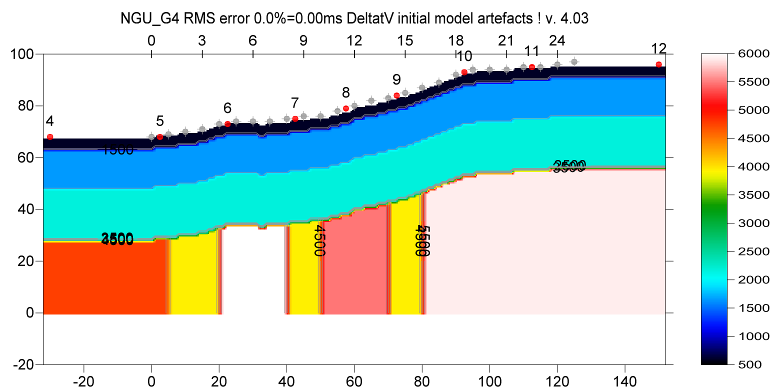



Fig. 41 : synthetic model used for forward modeling of synthetic traveltimes. Made available by NGU.

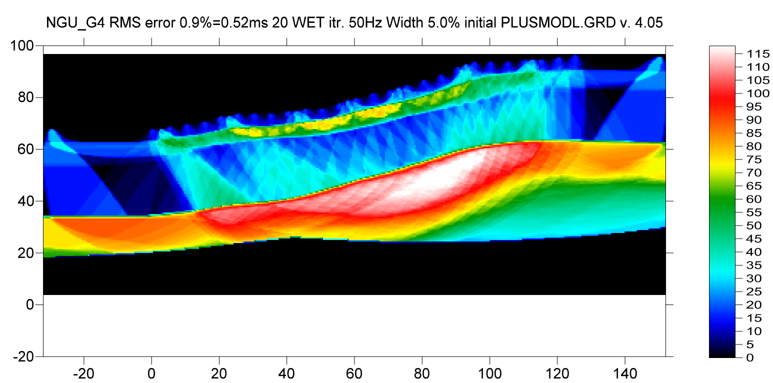



Fig. 42 : WET wavepath coverage plot obtained with Fig. 40. Unit is wavepaths per pixel.

Here is the .rar archive with LAYRTOMO folder for Fig. 40 .
Here is the .rar archive with seis32.* profile database files for Fig. 40 .

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

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 .

We thank NGU for making available above synthetic data and model and parameter files.