Multiscale WET inversion Line14 : Conjugate Gradient & Ricker wavelet weighting ver. 4.02 & 1D-Gradient & Plus-Minus & DeltatV starting model with WDVS@300 Hz :

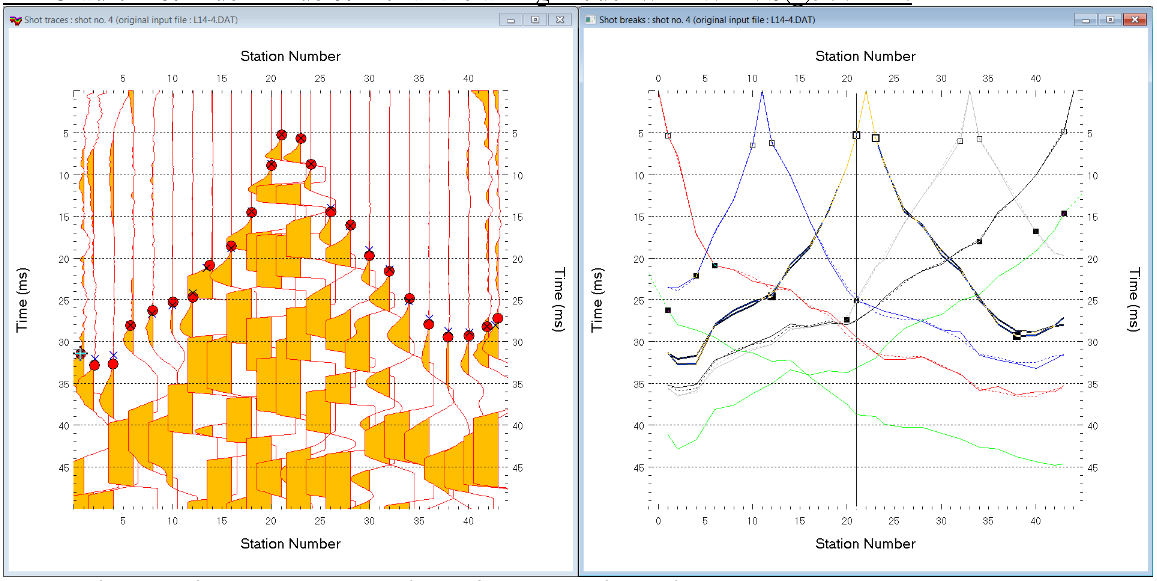

Fig. 1 : left : *Trace|Shot gather*, right : *Refractor|Shot breaks*. Shows fit between picked times (solid colored curves, red circles) and modeled times (dashed colored curves, blue crosses) obtained for multirun WET output (Fig. 10)

We show optimized WET inversion of our Line14 sample profile installed already in your folder **`C:\RAY32\Line14`** . So you don't have to reimport the SEG-2 shots. See our earlier tutorial from 2003 describing SEG-2 import and update with Interpex Gremix .GRM header data.

- select *File|Open Profile* and select **`SEIS32.DBD`** in folder **`C:\RAY32\Line14`**
- select *Trace|Shot gather* and *Window|Tile* to obtain Fig. 1
- configure *Band-Pass* and *High-Pass* frequency filters as in Fig. 26 and Fig. 27
- select *Header|Profile* and check box *Force grid cell size*. Edit *Cell size [m]* to 0.5m (Fig. 2). Click *OK*.

Configure and run DeltatV, display DeltatV starting model and refine with Smooth inversion :

- check *DeltatV|DeltatV Settings|Limit DeltatV velocity exported to maximum 1D-gradient velocity*. See Fig. 12.
- select *DeltatV|XTV parameters*. Click buttons *Gradient model* & *Accept*. See Fig. 14. XTV settings are regarded for *interactive DeltatV* only. For *Automatic DeltatV* we always assume gradient model XTV.
- select *Grid|Surfer plot limits* and edit as in Fig. 3. Click button *OK*.
- select *Grid|Receiver station ticks on top axis*
- select *Grid|GS CENTERED font for shot points and receivers* to work around Surfer display issues
- check *WET Tomo|WET tomography Settings|Blank|Blank no coverage after last iteration* (Fig. 5)
- uncheck *WET Tomo|WET tomography Settings|Blank|Blank below envelope after last iteration* (Fig. 5)
- select *Model|WDVS Smoothing* and edit as in Fig. 4. Click button *OK*.
- select *DeltatV|Automatic DeltatV and WET inversion* and confirm DeltatV artefacts prompt (Fig. 15)
- wait for the *DeltatV+WET inversion* to complete to obtain Fig. 8 & 9

Configure and run multiscale WET inversion and display 2D inversion output :

- select *Grid|Surfer plot Limits.* Click *button Reset to grid*. Navigate into profile subdirectory **`C:\RAY32\LINE14\TOMO`**. Click on **`VELOIT20.GRD`** and click *Open*.
- check *box **Plot limits active***. Set *Min. elevation* to -30m. Set *Max. elevation* to 1m. See Fig. 3.
- set *Min. velocity* to 500 m/s and *Max. velocity* to 6,000 m/s. Edit other fields as in Fig. 3. Click *OK*.
- check *WET Tomo|WET tomography Settings|Edit maximum valid WET velocity* (Fig. 14)

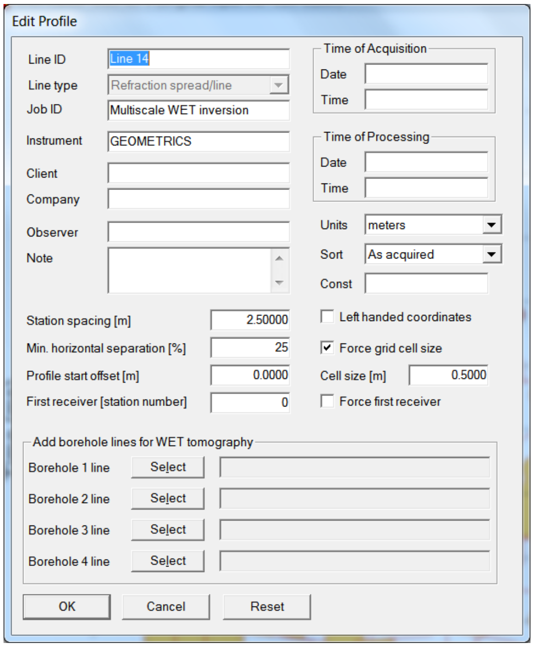

Fig. 2 : *Header|Profile*

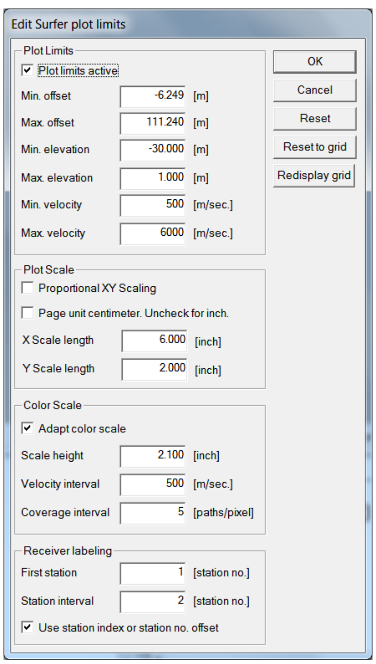

Fig. 3 : *Grid|Surfer plot Limits*

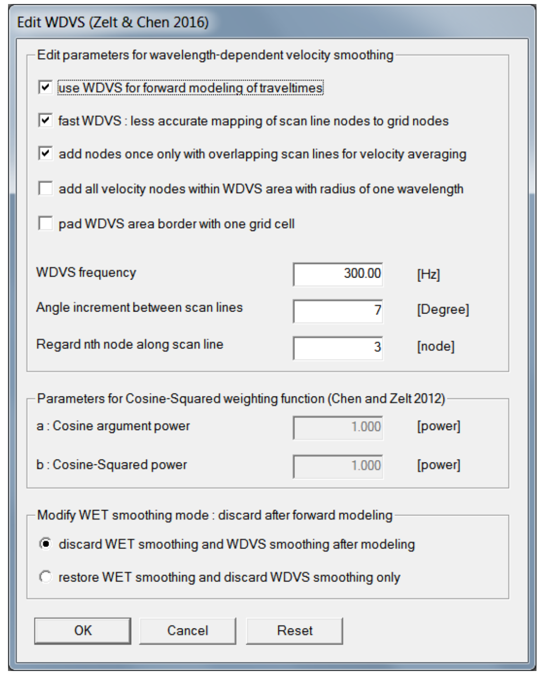

Fig. 4 : edit WDVS parameters and click *OK* button

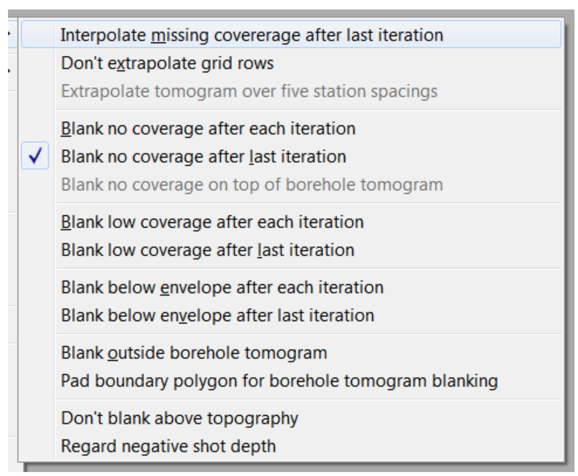

Fig. 5 : *WET Tomo|WET tomography Settings|Blank*

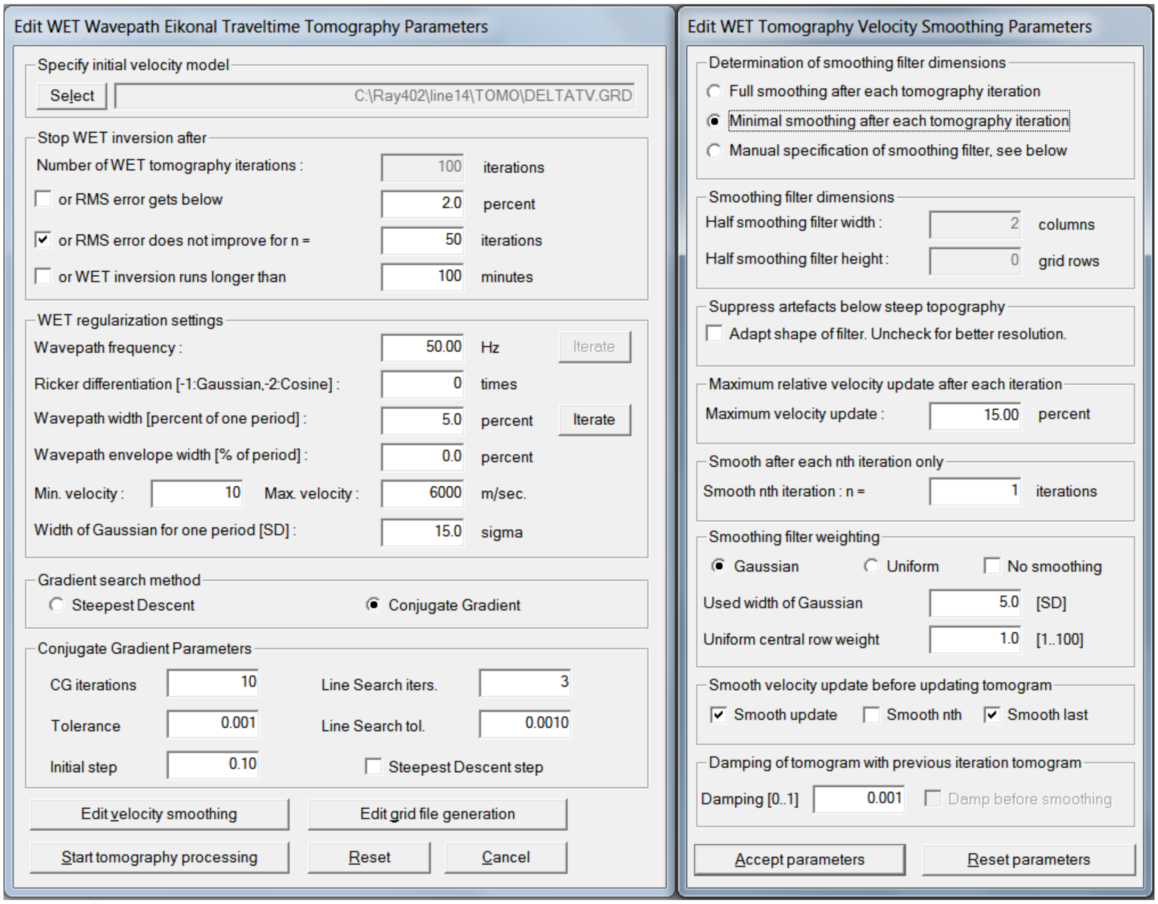

Fig. 6 : left : *WET Tomo|Interactive WET tomography* main dialog   right : *Edit velocity smoothing* . We show settings used to obtain Fig. 10.

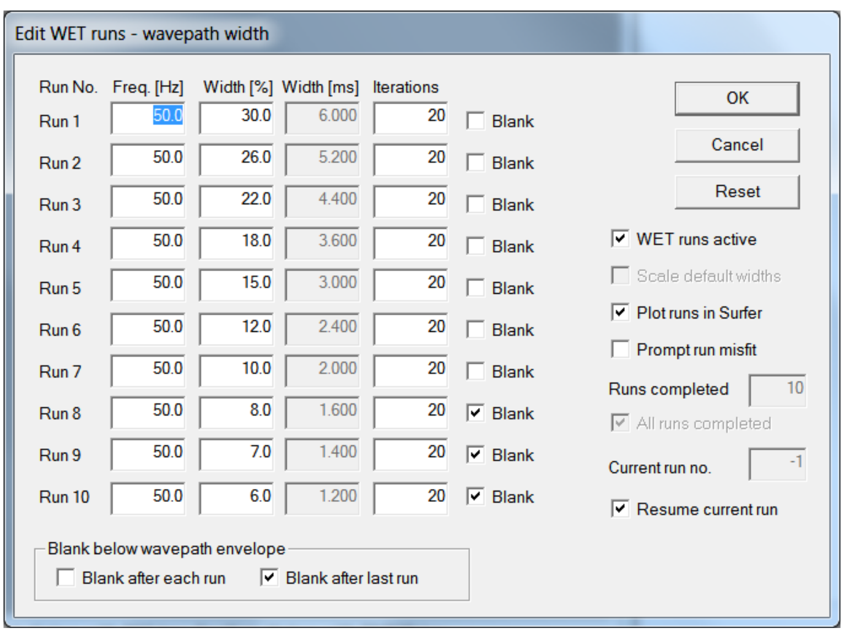

Fig. 7 : *WET Tomo|Interactive WET tomography|Iterate* lets you edit the multirun *WET wavepath width* or *WET frequency* schedule. Also lets you edit the number of *WET iterations* for each run (effective for *Steepest Descent* only) and blanking after each run. For *Conjugate Gradient* the number of WET iterations is determined with WET Tomo main dialog controls *CG iterations* (outer loop) and *Line Search iters.* (inner loop; Shewchuk 1994; Fig. 6 left).

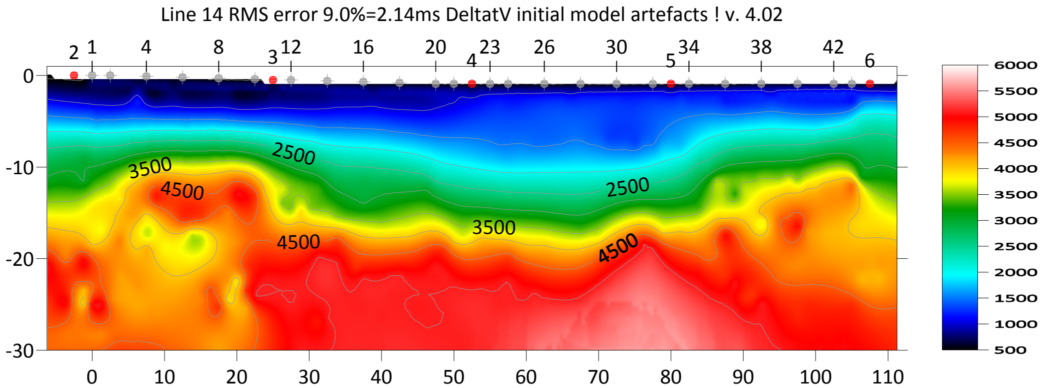

Fig. 8 : *DeltatV|Automatic DeltatV and WET inversion, DeltatV* starting model. See Fig. 12&13 for *DeltatV Settings* and *XTV parameters*. Default DeltatV and default XTV settings used.

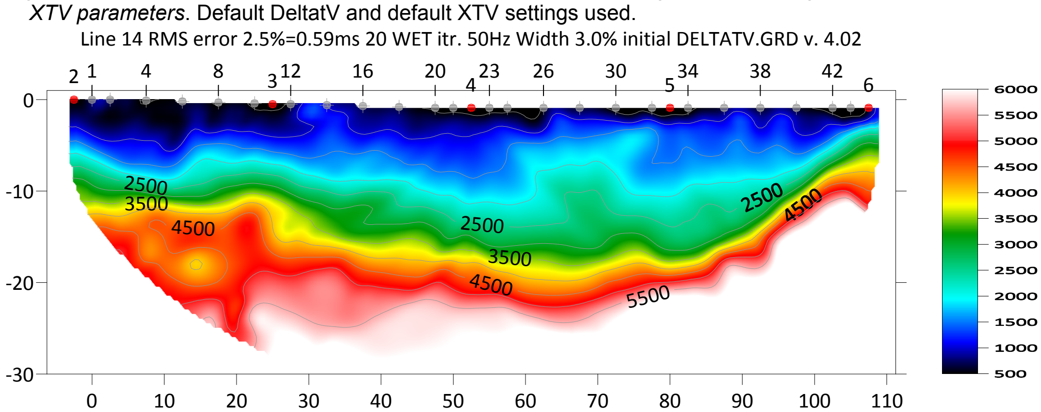

Fig. 9 : *DeltatV|Automatic DeltatV and WET inversion,* 20 WET iterations with full WET smoothing & WDVS @ 300Hz (Fig. 4). See Fig. 5 for WET blanking & Fig. 14 for WET settings.

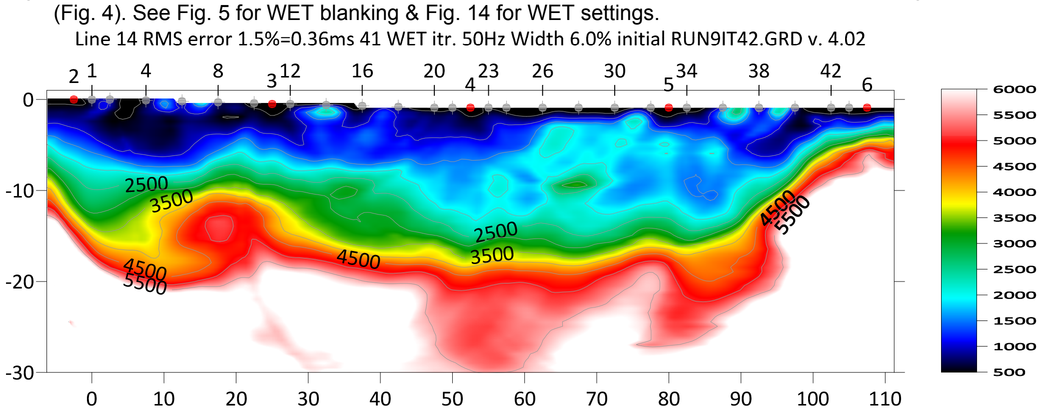

Fig. 10 : Multirun Conjugate-Gradient WET showing output of 10th run. Starting model for 1st run is Fig. 8. See Fig. 1 for misfit between modeled and picked traveltimes. WDVS @300Hz (Fig. 4). For WET settings see Fig. 5/6/7 & Fig. 14.

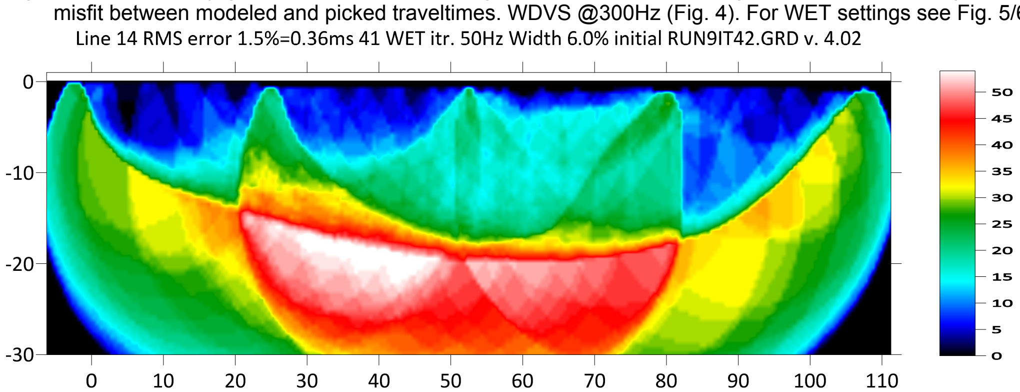

Fig. 11 : WET wavepath coverage plot obtained with Fig. 10. Unit is wavepaths per pixel.

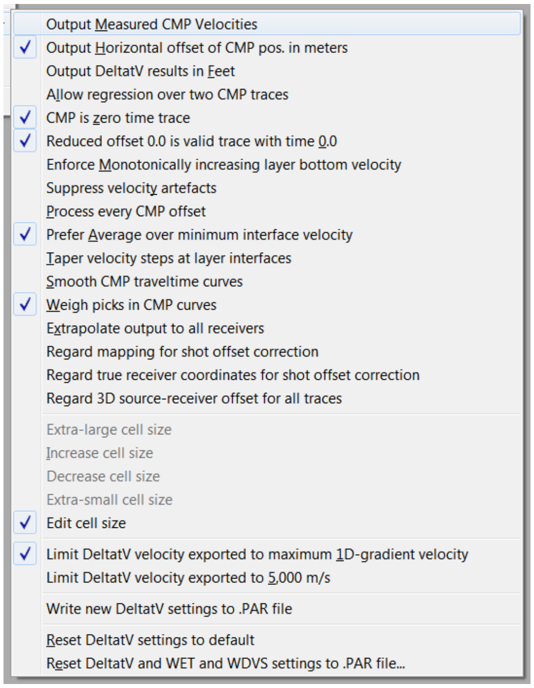

Fig. 12 : *DeltatV|DeltatV Settings*. Check *Limit DeltatV velocity exported to maximum 1D-gradient velocity*.

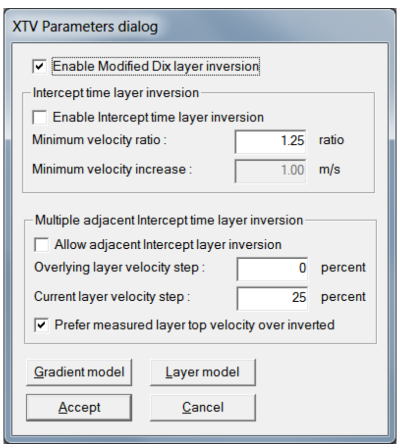

Fig 13 : edit *XTV parameters*. Click button *Gradient model* and button *Accept*.

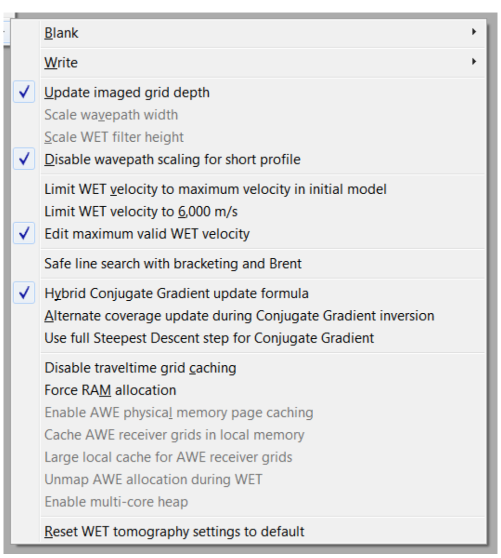

Fig. 14 : edit menu *WET Tomo|WET tomography Settings*

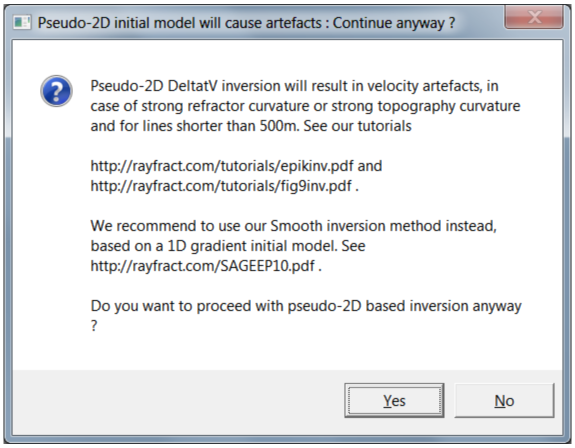

Fig. 15 : DeltatV artefact warning prompt shown when user selects *DeltatV menu* inversion items

- set *WET Tomo|Interactive WET tomography|**Ricker differentiation*** to 0 [Ricker wavelet]. See Schuster 1993 for WET inversion theory. Alternatively set to -1 [Gaussian] or -2 [Cosine-Squared] (Fig. 6 left).
- leave *Min. velocity* at 10 m/s and *Max. velocity* at 6,000 m/s. See Fig. 6 (left).
- click radio button ***Conjugate Gradient***
- leave *CG iterations* (outer loop) at 10 and set *Line Search iters.* (inner loop) to 3. See Shewchuk 1994 .
- click button *Edit grid file generation* & set *Store each nth iteration only : n =* to 20. Click *OK*.
- click ***Edit velocity smoothing***. Check radio button ***Minimal smoothing***. See Fig. 6 (right).
- uncheck ***Adapt shape of filter***. Leave ***Maximum velocity update*** at 15% for Conjugate Gradient
- click ***Gaussian*** *button*. Set *Used width of Gaussian* to 5.0 sigma [Standard Deviations; SD].
- change ***Damping*** from default 0.9 for Conjugate Gradient to 0.001 with WDVS enabled (Fig. 4).
- click ***Accept parameters*** and ***Iterate*** & check ***WET runs active***. Edit as in Fig. 7 and click ***button OK***.
- click *button* ***Start tomography processing*** to obtain Fig. 10 & 11

Here some references to help file chapters and other relevant tutorials and published papers :

- for our ***multiscale WET*** inversion see updated help file chapter ***WET tomography processing***
- ***WDVS velocity smoothing*** is described on page 167 of our updated help file
- see also our 2018 tutorial showing multiscale WET inversion of 1_1D synthetic NGU profile data
- see also our SAGEEP11 tutorial showing ***Conjugate Gradient WET*** inversion using 1D-gradient initial model for SAGEEP11 synthetic data forward-modeled over fault zone model
- see also our 2017 tutorial showing ***Steepest Descent WET inversion*** using Plus-Minus layered refraction starting model for NGU 2017 P1_1 synthetic data
- see our earlier tutorial from 2003 showing single-run WET inversion without WDVS smoothing
- our EGU 2021 abstract describes multiscale WET+WDVS inversion of SAGEEP11 synthetic data
- our SAGEEP 2021 expanded abstract shows WET+WDVS inversion of Broad Epikarst synthetic data
- for Wavelength-Dependent Velocity Smoothing (WDVS) theory see Zelt and Chen 2016

To restore database files and result files :

Subdirectories `C:\RAY32\Line14\Tomo\WETRUN1` to …`\WETRUN10`, …`\INPUT`, …`\seis32_Mar10_2022` are available in this .RAR archive. Open the …`\WETRUN10\VELOIT42.PAR` file e.g. with Windows Notepad editor to review *WET inversion* parameters used.

Use Rayfract® 4.02 command ***Grid|Reset DeltatV and WET settings to .PAR file…*** with file …`\Tomo\WETRUN10\VELOIT42.GRD` to reset your profile's *DeltatV and WET inversion settings* to …`\Tomo\WETRUN10\VELOIT42.PAR` .

Or quit our software via ***File|Exit*** and copy all 33 `seis32.*` database files from directory `C:\RAY32\Line14\seis32_Mar10_2022` into `C:\RAY32\Line14` directory in Windows Explorer. Now reopen your profile with ***File|Open Profile…*** and select `C:\RAY32\Line14\SEIS32.DBD` .

Smooth interpretation using fail-safe 1D-gradient starting model :

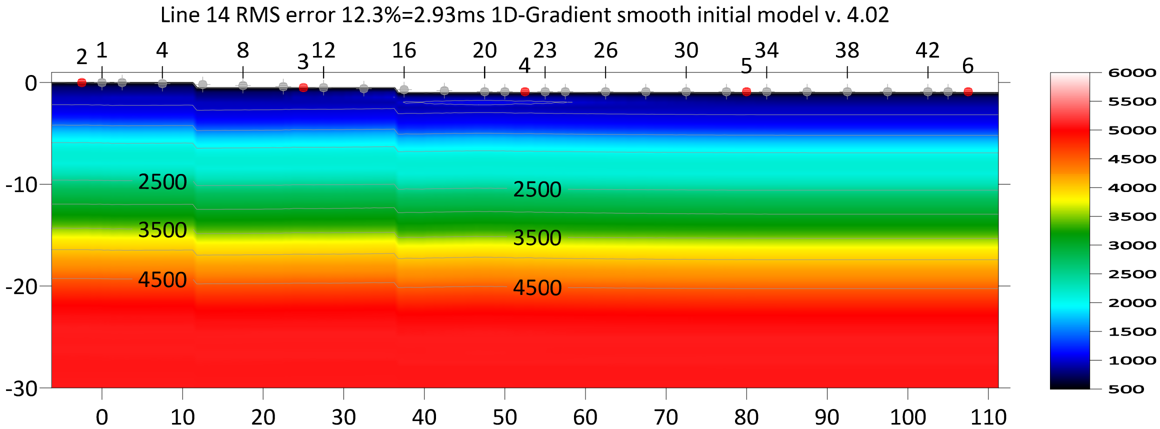

Fig 16 : 1D-gradient starting model obtained with *Smooth invert|WET with 1D-gradient initial model*. Default Smooth inversion settings & default DeltatV settings.

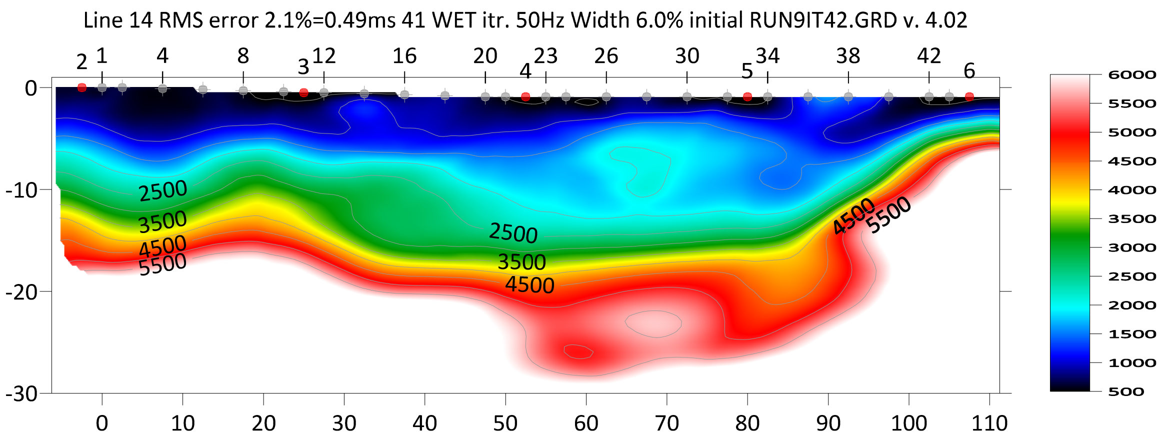

Fig. 17 : Multirun Conjugate-Gradient WET : output of 10th run. Starting model for 1st run is Fig. 16. WDVS @300Hz (Fig. 4). For WET settings see Fig. 5/7/14 & Fig. 19. Compare with Fig. 10 obtained using DeltatV starting model.

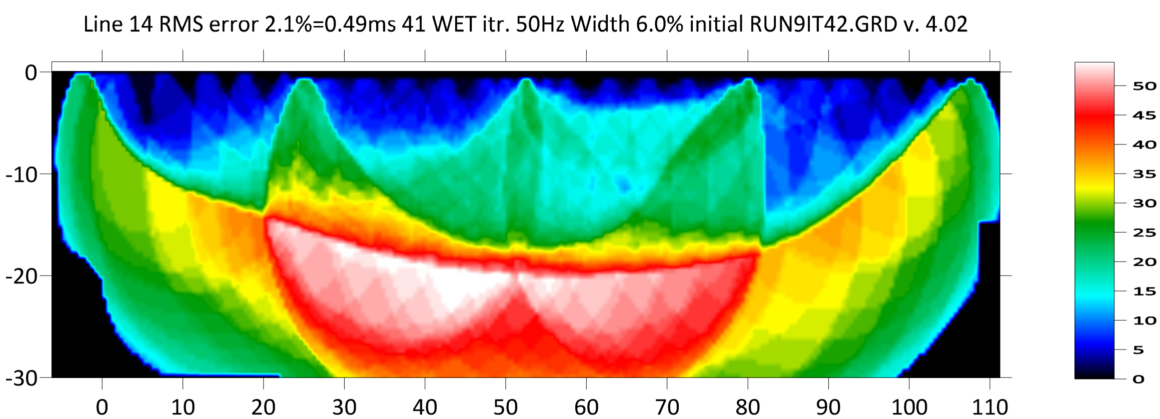

Fig. 18 : WET wavepath coverage plot obtained with Fig. 17. Unit is wavepaths per pixel.

In Fig. 17 we show multirun Conjugate-Gradient WET inversion using 1D-gradient starting model (Fig. 16) and interactive WET parameters (Fig. 19). We use *Full smoothing* mode instead of *Minimal smoothing* mode (Fig. 19 right). Also we decrease *Used width of Gaussian* to 3.0 from 5.0 as used for multirun WET inversion with DeltatV starting model (Fig. 6 and Fig. 10). Fig. 17 is a bit smoother than Fig. 10. But Fig. 17 may show fewer artefacts than Fig. 10. Reliable imaging of basement is more difficult in case of velocity inversions in overburden (offset 60m to 80m in Fig. 10 and in Fig. 17).

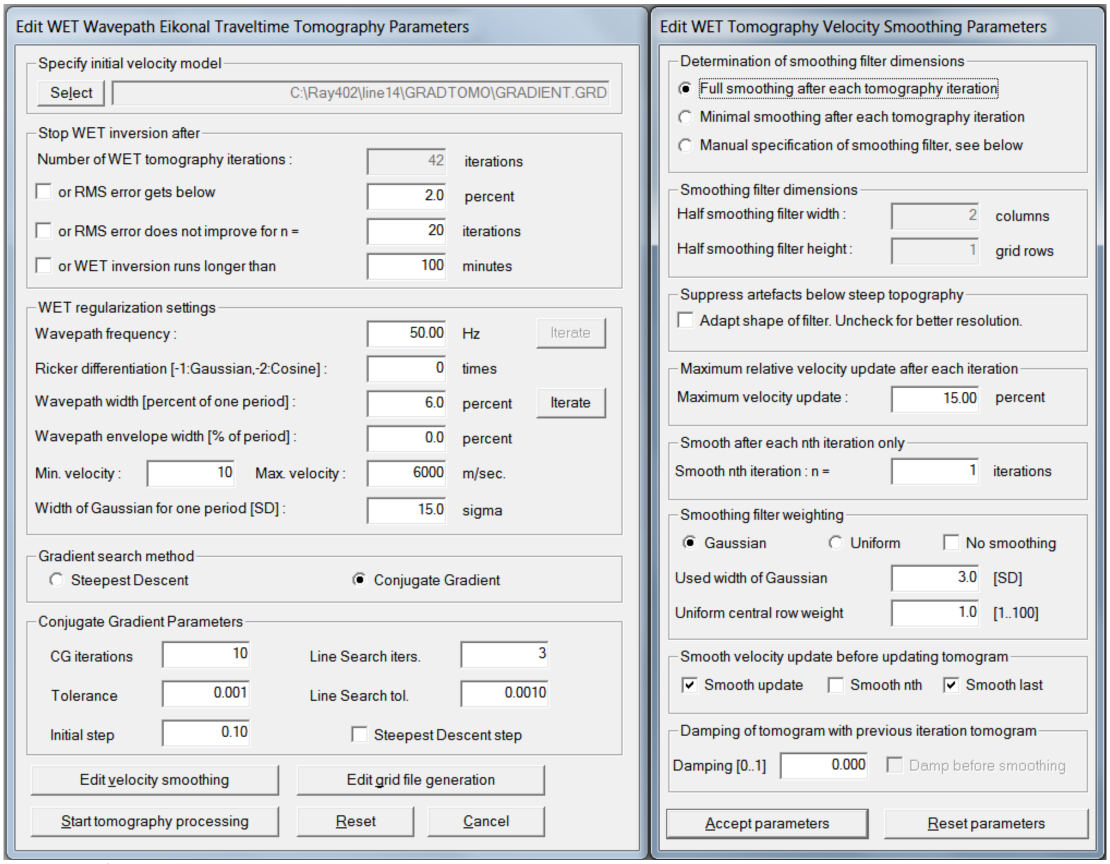

Fig. 19 : left : *WET Tomo|Interactive WET tomography* main dialog. right : *Edit velocity smoothing* . We show settings used for Fig. 17. Compare with Fig. 6 settings used to obtain Fig. 10.

Layered interpretation using Plus-Minus refraction starting model :

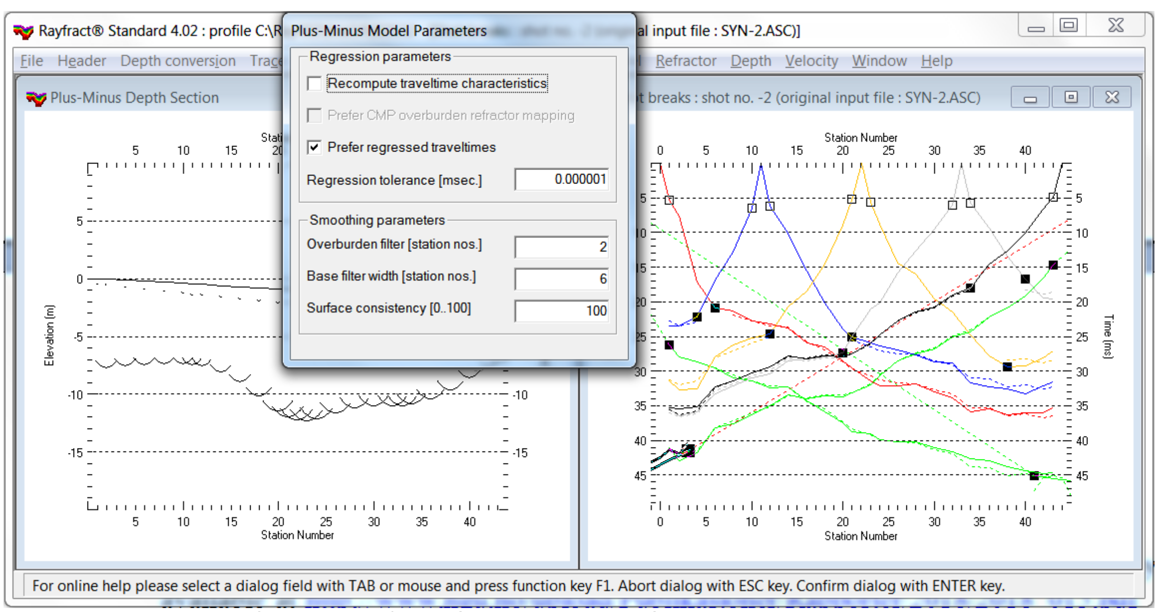

Fig. 20 : Map traces to refractors in *Refractor|Shot breaks* (right). Outlined squares are branch points separating direct wave from first refractor. Black squares are branch points separating first refractor from 2nd refractor. Laterally smooth Plus-Minus refractors with ALT+M in *Depth|Plus-Minus* depth section (left). Click *No button* in *WET continuation prompt* to display depth section. See our .pdf reference chapter ***WET inversion with layered refraction starting model*** on page 145.

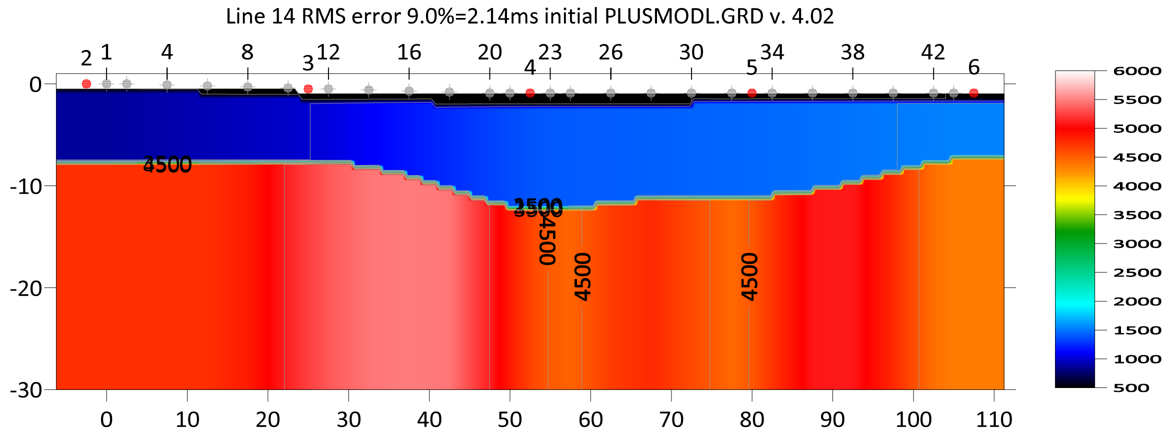

Fig. 21 : Plus-Minus layered refraction starting model obtained with *Depth|Plus-Minus*. ***Overburden filter*** 2. ***Base filter width*** 6 (Fig. 20).

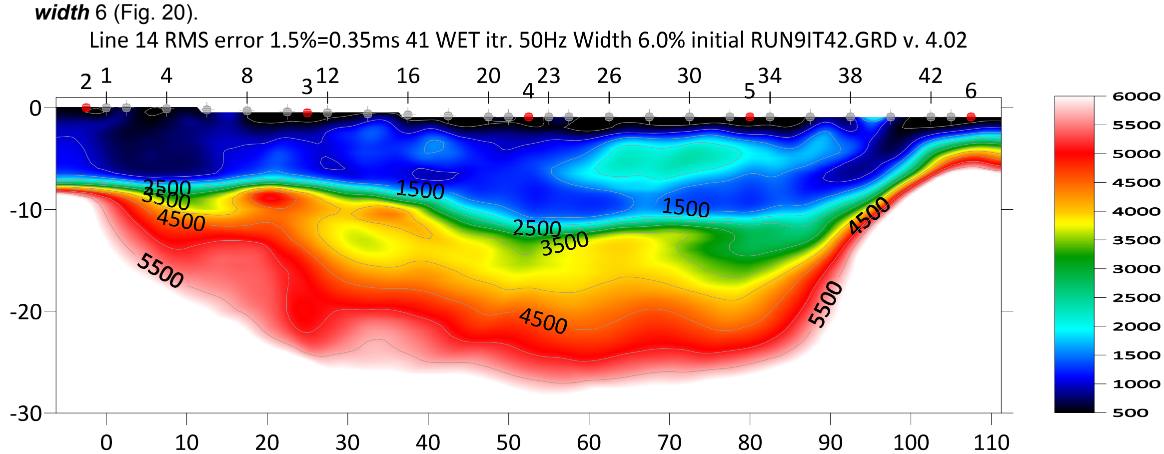

Fig. 22 : Multirun Conjugate-Gradient WET showing output of 10th run. Starting model for 1st run is Fig. 21. WDVS @300Hz (Fig. 4). For WET settings see Fig. 5/7/14 & Fig. 24. Compare with Fig. 17 obtained using 1D-gradient starting model.

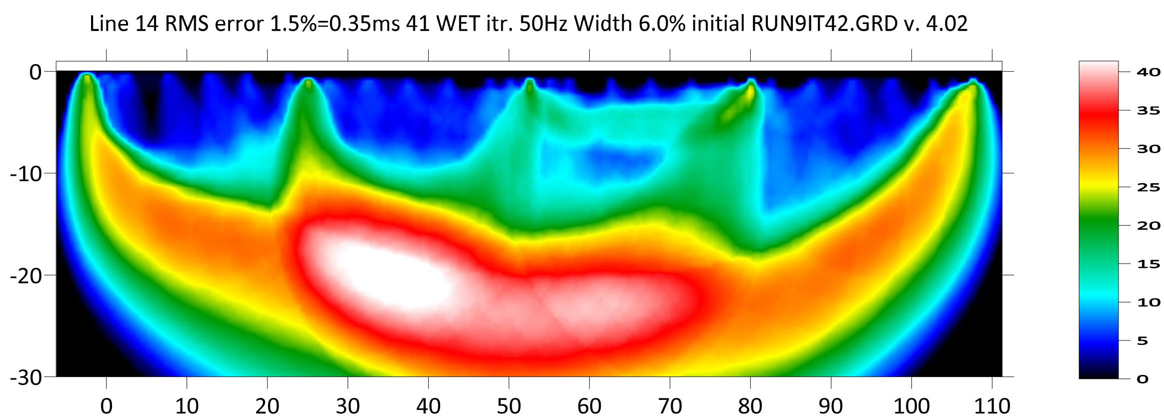

Fig. 23 : WET wavepath coverage plot obtained with Fig. 22. Unit is summed wavepath weight squared. Wavepath coverage plot is sharpened with *WET Tomo|Coverage plot setup|**Raise wavepath weight to power*** = 2.0. See Fig. 25.

In Fig. 22 we show multirun Conjugate-Gradient WET inversion using Plus-Minus layered refraction starting model (Fig. 21) and interactive WET parameters as shown in Fig. 24. We use ***Ricker differentiation of -1 [Gaussian]*** (Fig. 24 left) with ***Width of Gaussian for one period = 20 sigma*** and with *Full smoothing* mode (Fig. 24 right). Also we increase WET smoothing parameter ***Used width of Gaussian*** to 3.5 from 3.0. Also we check smoothing option ***Adapt shape of filter*** (Fig. 24 right). Fig. 22 shows stronger layering than Fig. 17. But Fig. 17 may show fewer layering artefacts than Fig. 22 and shows better lateral resolution in the basement similar to Plus-Minus starting model (Fig. 21).

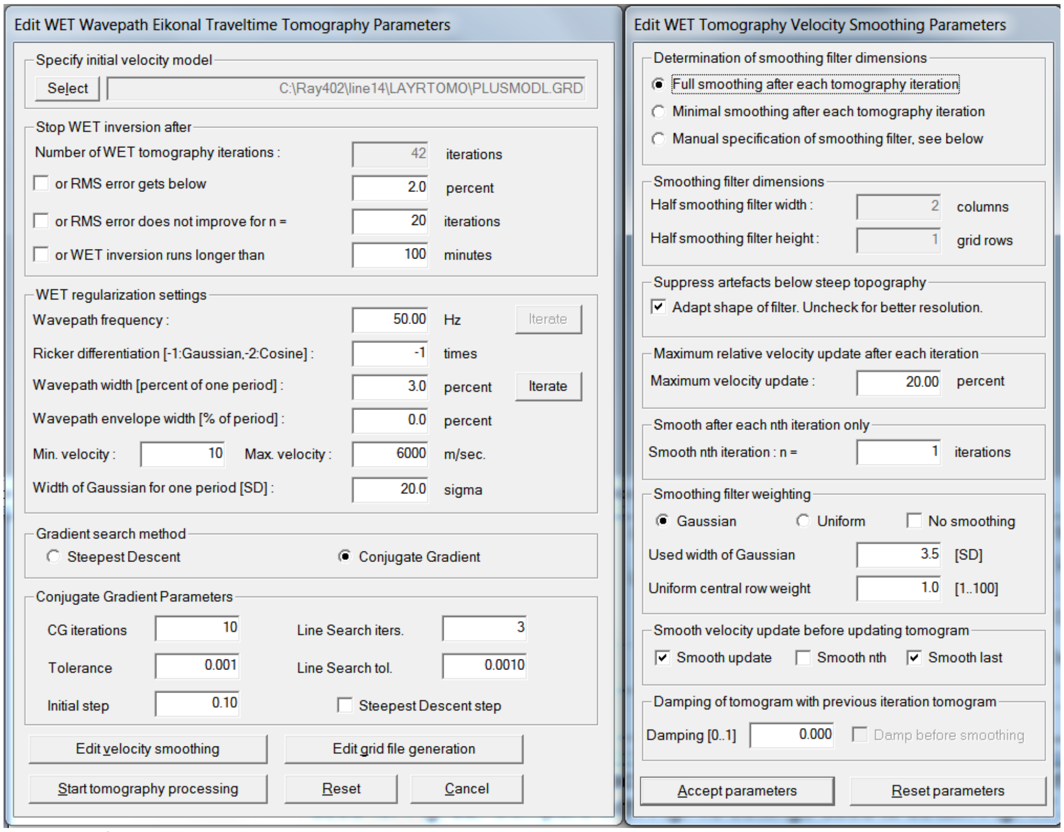

Fig. 24 : left : *WET Tomo|Interactive WET tomography* main dialog. right : *Edit velocity smoothing* . We show settings used for Fig. 22. Compare with Fig. 19 settings used to obtain Fig. 17.

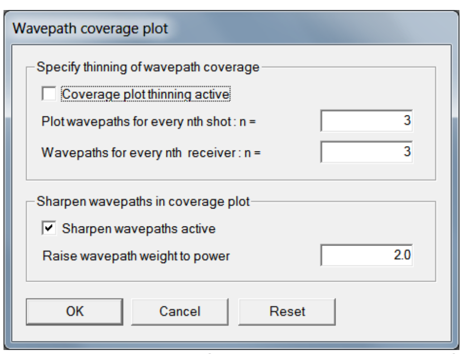

Fig. 25 : *WET Tomo|Coverage plot setup* used for Fig. 23

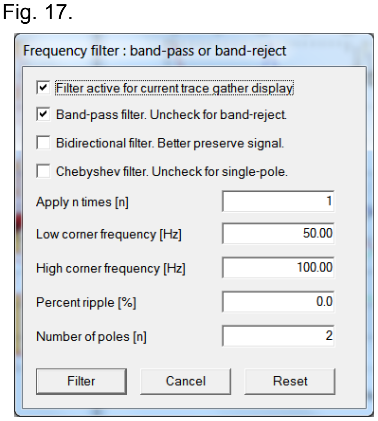

Fig. 26 : Band-pass. SHIFT+Q in *Trace|Shot gather*.

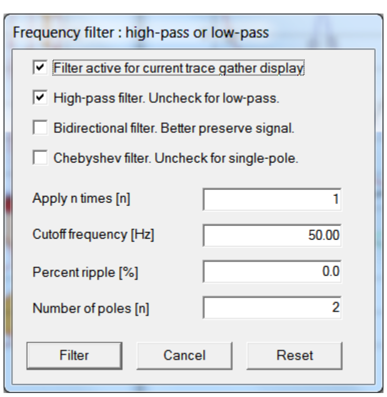

Fig. 27 : High-pass. ALT+Q in *Trace|Shot gather*.

Here are instructions on how to obtain Fig. 22 and Fig. 23 :

- edit ***WET Tomo|Coverage plot setup*** dialog as in Fig. 25
- leave ***WDVS parameters*** as in Fig. 4
- edit ***WET Tomo|Interactive WET Tomography*** as in Fig. 24 left
- edit ***WET velocity smoothing*** shown with button *Edit velocity smoothing* as in Fig. 24 right and click button *Accept parameters*
- leave ***WET run parameters*** shown with *Iterate* button as in Fig. 7
- click button *Start tomography processing* to obtain Fig. 22 and Fig. 23
- here is the matching .RAR archive with folders **`LAYRTOMO`** and **`SEIS32_Mar21_2022`**

Summary, optimization of interpretation parameters :

NGU 2018 report with Fig. 4.5.1 showing *multirun WET inversion* of synthetic model data is available at http://www.ngu.no/upload/Publikasjoner/Rapporter/2018/2018_015.pdf . We show multiscale Conjugate-Gradient WET inversion of this synthetic data in our 2018 tutorial .

WET inversion shown in Fig. 10 using 10 WET runs with 10 Conjugate-Gradient iterations each and parameters shown in Fig. 6 and Fig. 7 took about 3 minutes on 2017 Apple iMac. This iMac comes with 2.3 GHz Intel Core i5 processor running 4 OpenMP threads under Windows 10 Pro 64-bit in Parallels Desktop 17 for Mac.

- try varying WET smoothing parameter ***Used width of Gaussian*** between 4.0 and 5.0 (Fig. 6 right). A lower value results in more smoothing. For layered refraction starting model set this parameter to 3.0 and click radio button *Full smoothing* instead of *Minimal smoothing* (Fig. 6 right).
- with Conjugate-Gradient method we usually recommend setting WET damping to 0.9 (Fig. 6 right) for more robust WET inversion. With WDVS enabled (Fig. 4) try reducing damping to almost 0.0 e.g. 0.001 for more detailed imaging with consistently picked first breaks. See below. Alternatively set damping to 0.25.
- we uncheck *WET smoothing* option ***Adapt shape of filter*** for better resolution. Try enabling this for improved repeatability of multiscale WET inversion and in case of strongly undulating topography.
- we limit ***Maximum velocity update*** to 15%. Limiting the maximum velocity update can help to better focus *WET inversion* especially with strong topography curvature.
- we use 3 *Line Search* iterations per *Conjugate-Gradient* iteration (Fig. 6 left) for better focussing of our multiscale WET inversion. Per default 2 Line Search iterations are done per CG iteration (Shewchuk 1994).
- our latest software version 4.02 allows ***WDVS Wavelength-Dependent Velocity Smoothing*** (Zelt and Chen 2016) for better resolution in WET tomograms. We enable WDVS option *Discard WET smoothing* (Fig. 4) for more detailed imaging. Enable this option with consistently picked first breaks, small reciprocal traveltime errors and correctly specified recording geometry only. Select ***Trace|Export reciprocal errors*** to generate .ERR text file with reciprocal errors.
- with WDVS activated you may want to uncheck WET blanking option *Blank below envelope after last iteration* (Fig. 5) to better model off-end shots at line start/end and minimize the RMS error.
- also when activating WDVS with option *use WDVS for forward modeling* (Fig. 4) and especially when selecting WDVS option *Discard WET smoothing* we recommend selecting *Steepest-Descent* option for *Gradient search method* instead of *Conjugate Gradient* option (Fig. 24) for more repeatable and more robust WET inversion. See e.g. our 3016 tutorial where we use Steepest Descent exclusively.
- as shown in our 3016 tutorial you can leave option *use WDVS for forward modeling* (Fig. 4) unchecked but still check option *Discard WET smoothing* (Fig. 4) for faster WET convergence to small RMS error. With this setting of *Model|WDVS Smoothing* options you can run fewer WET iterations without incurring increased WET runtime with WDVS smoothing.

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 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.

As shown by (Watanabe 1999, Fig. 4) for crosshole surveys, it is not possible to reliably image seismic subsurface velocity at a resolution much smaller than one wavelength of dominant frequency of the first break pulse. E.g. with 100 Hz and basement velocity of 4,000 m/s, one wavelength is 4000/100 = 40m. In case of bad or noisy picks and recording geometry errors, resolution may not be better than two wavelengths. For refraction surveys, resolution at bottom and edges of tomogram is further reduced, because here rays and wavepaths are aligned predominantly parallel to each other (White 1989). In our 2018 tutorial we are imaging fault zones not wider than 10m @ 4,000 m/s. This is far below one wavelength of 40m @ 100 Hz.

Above we show ***improved lateral resolution in basement*** in Fig. 10 obtained using multiscale Conjugate-Gradient WET inversion with minimized WET smoothing vs. Fig. 9 showing default 20 Steepest-Descent WET iterations with full WET smoothing.

The used shot spacing of 11 station intervals (Fig. 1 right) is too wide. We recommend placing a shot at every 3rd receiver station.

Our Rayfract® software offers multiple interpretation methods and parameters to explore the non-uniqueness of the solution space. It is the user's job to sufficiently explore the solution space with our methods and varying parameters, and to find an appropriate combination of methods and parameters for each individual data set. This choice may be guided by a-priori information e.g. from boreholes or other geophysical methods.

We thank again NGU for making available above NGU 2018 report and synthetic data & models. However we still don't understand why NGU keeps completely ignoring our fail-safe *1D-Gradient* starting model (Fig. 16; Sheehan 2005) and insists on always using our pseudo-2D *DeltatV* method with suboptimal parameter settings instead even for such short lines. NGU completely ignores our instructions in our help file and ***warning about DeltatV artefacts*** shown in Fig. 15, recommending using our *Smooth inversion* method with *1D-Gradient* starting model instead. This reminds us of earlier publications by Dr. Derecke Palmer also completely ignoring our *1D-gradient* starting model and *Smooth inversion* e.g. in his 2010 EAGE syncline model paper. We show building this syncline model and forward modeling synthetic traveltimes in our palmfig9.pdf tutorial. Also we show *Smooth inversion* with 100 WET iterations using our fail-safe *1D-Gradient* starting model (Sheehan 2005) obtained by laterally averaging pseudo-2D DeltatV velocity and available in our software since 2005.

Also we don't understand why NGU insists on using unrealistic synthetic models with such abrupt velocity increase between thin weathering layer and basement at over 4,000 m/s and no vertical increase of synthetic velocity inside basement.

For an objective comparison of tomographic refraction analysis methods see Zelt et al. 2013 (JEEG, September 2013, Volume 18, Issue 3, pp. 183–194).

See earlier comments at end of our P6 tutorial and in our Aaknes-1 tutorial.

Also we thank our Spanish reseller IGT/Medios Geofísicos S.L. in Madrid for making available above data (SEG-2 .DAT trace files and Line14.GRM Interpex Gremix file in **INPUT** folder of this .RAR archive).

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