

WET NGU P1-1D : Conjugate Gradient&Cosine-Squared WET update weighting 3.36 & DeltatV+XTV starting model / 1D-gradient starting model with topography smoothing over 2 stations & WDVS@1200Hz & discard WET smoothing & extrapolate tomograms 4.06 :

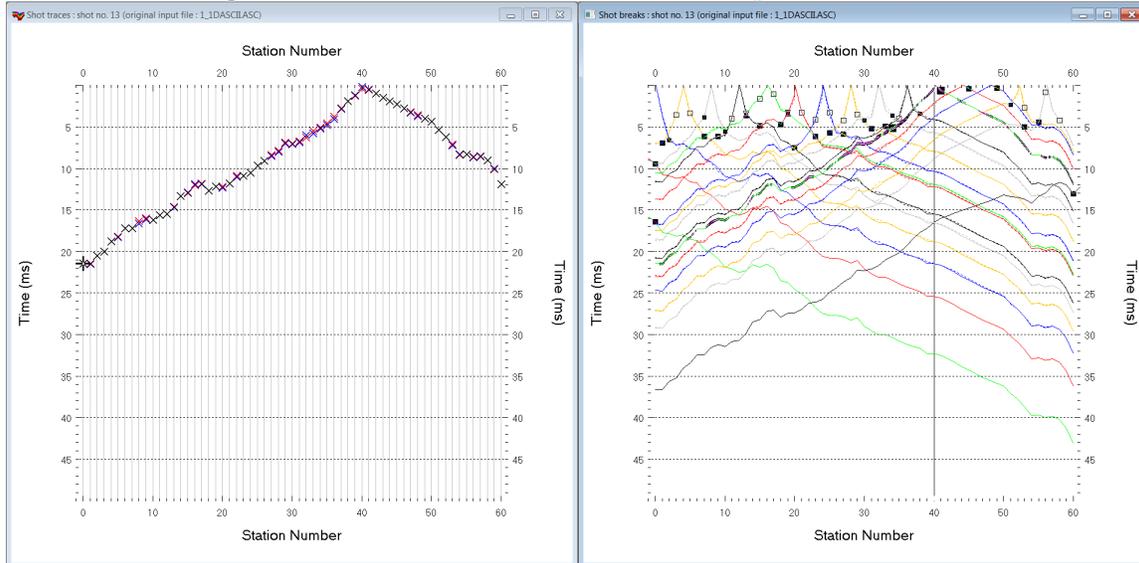


Fig. 1 : left : *Trace|Shot gather*, right : *Refractor|Shot breaks*. Shows fit between picked times (solid colored curves, red crosses) and modeled times (dashed colored curves, blue crosses) obtained for multirun WET output (Fig. 10)

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

- **File|New Profile...**, set *File name* to **1\_1D** and click *Save button*
- in **Header|Profile...** set *Line type* to **Refraction spread/line**. Set *Station spacing* to 2.0 m.
- check box *Force grid cell size* and set *Cell size[m]* to 0.4m. See Fig. 2.
- unzip **1\_1D.zip** with files **1\_1DASCII.ASC**, **1\_1DCOORDS.COR**, **1\_1DSHOTS.SHO** & **1\_1D.CLR** in directory **C:\RAY32\1\_1D\INPUT**
- 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\1\_1D\INPUT** and select file **1\_1DASCII.ASC**
- set *Default sample count* to 500 to setup the y scale for *Trace|Shot gather* & *Refractor|Shot breaks*
- click **Import shots button**. The *Import shot dialog* is shown for each shot in the .ASC file.
- for each shot leave *Layout start* and *Shot pos.* at shown values and click *Read button*
- select **File|Update header data|Update Station Coordinates**
- navigate into directory **C:\RAY32\1\_1D\INPUT**
- select file **1\_1DCOORDS.COR**. Click *Open button*.
- **File|Update header data|Update Shotpoint coordinates** with **1\_1DSHOTS.SHO**
- select **Trace|Shot gather** and **Window|Tile** to obtain Fig. 1

To configure and run DeltatV+XTV inversion and display the pseudo-2D starting model :

- uncheck **DeltatV|DeltatV Settings|Reduced offset 0.0 is valid trace with time 0.0**. See Fig. 12.
- check **DeltatV|DeltatV Settings|Suppress velocity artefacts**
- check **DeltatV|DeltatV Settings|Process every CMP offset**
- check **DeltatV|DeltatV Settings|Smooth CMP traveltimes curves**
- select **DeltatV|XTV parameters**. Click buttons **Layer model & Accept**. See Fig. 14.
- select **DeltatV|Interactive DeltatV**. Confirm prompt and edit parameters as in Fig. 13.
- click button **DeltatV inversion**
- in dialog **Save DeltatV output** click yellow **Create new folder** icon at upper right
- name new folder as **Nov18Regr4**. Double-click this new folder to enter it.
- set *File name* to **Nov18Regr4**. Click *Save button*.
- wait for the **DeltatV+XTV inversion** to complete to obtain Fig. 8

**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:

Left handed coordinates

Force grid cell size

Station spacing [m]:

Min. horizontal separation [%]:

Profile start offset [m]:

Cell size [m]:

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

Fig. 4 : Grid|Surfer plot Limits

**WET update weighting**

Parameters for Cosine-Squared weighting function

a: Cosine argument power:  [power]

b: Cosine-Squared power:  [power]

OK Cancel Reset

Fig. 5 : WET Tomo|WET Update weighting

### Edit WET Wavepath Eikonal Traveltime Tomography Parameters

Specify initial velocity model  
 D:\ray32\1\_1D\Nov18Regr4\NOV18REGR4.GRD

Stop WET inversion after

Number of WET tomography iterations :  iterations

or RMS error gets below  percent

or RMS error does not improve for n =  iterations

or WET inversion runs longer than  minutes

WET regularization settings

Wavepath frequency :  Hz

Ricker differentiation [-1:Gaussian,-2:Cosine] :  times

Wavepath width [percent of one period] :  percent

Wavepath envelope width [% of period] :  percent

Min. velocity :  Max. velocity :  m/sec.

Width of Gaussian for one period [sigma] :  sigma

Gradient search method

Steepest Descent  Conjugate Gradient

Conjugate Gradient Parameters

CG iterations  Line Search iters.

Tolerance  Line Search tol.

Initial step   Steepest Descent step

### Edit WET Tomography Velocity Smoothing Parameters

Determination of smoothing filter dimensions

Full smoothing after each tomography iteration

Minimal smoothing after each tomography iteration

Manual specification of smoothing filter, see below

Smoothing filter dimensions

Half smoothing filter width :  columns

Half smoothing filter height :  grid rows

Suppress artefacts below steep topography

Adapt shape of filter. Uncheck for better resolution.

Maximum relative velocity update after each iteration

Maximum velocity update :  percent

Smooth after each nth iteration only

Smooth nth iteration : n =  iterations

Smoothing filter weighting

Gaussian  Uniform

Used width of Gaussian  sigma

Uniform central row weight  [1..100]

Smooth velocity update before updating tomogram

Smooth velocity update  Smooth last iteration

Damping of tomogram with previous iteration tomogram

Damping [0..1]   Damp before smoothing

Fig. 6 : left : WET Tomo|Interactive WET tomography

right : Edit velocity smoothing . See also Fig. 16 .

### Edit WET runs - wavepath width

Run No.	Freq. [Hz]	Width [%]	Width [ms]	Iterations	
Run 1	<input type="text" value="60.0"/>	<input type="text" value="30.0"/>	<input type="text" value="5.000"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank
Run 2	<input type="text" value="60.0"/>	<input type="text" value="28.0"/>	<input type="text" value="4.667"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank
Run 3	<input type="text" value="60.0"/>	<input type="text" value="26.0"/>	<input type="text" value="4.333"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank
Run 4	<input type="text" value="60.0"/>	<input type="text" value="24.0"/>	<input type="text" value="4.000"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank
Run 5	<input type="text" value="60.0"/>	<input type="text" value="22.0"/>	<input type="text" value="3.667"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank
Run 6	<input type="text" value="60.0"/>	<input type="text" value="20.0"/>	<input type="text" value="3.333"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank
Run 7	<input type="text" value="60.0"/>	<input type="text" value="18.0"/>	<input type="text" value="3.000"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank
Run 8	<input type="text" value="60.0"/>	<input type="text" value="16.0"/>	<input type="text" value="2.667"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank
Run 9	<input type="text" value="60.0"/>	<input type="text" value="14.0"/>	<input type="text" value="2.333"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank
Run 10	<input type="text" value="60.0"/>	<input type="text" value="12.0"/>	<input type="text" value="2.000"/>	<input type="text" value="20"/>	<input checked="" type="checkbox"/> Blank

Blank below wavepath envelope

Blank after each run  Blank after last run

WET runs active

Scale default widths

Plot runs in Surfer

Prompt run misfit

Runs completed

All runs completed

Current run no.

Resume current run

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 controls CG iterations (outer loop) and Line Search iters. (inner loop; [Shewchuk 1994](#)).

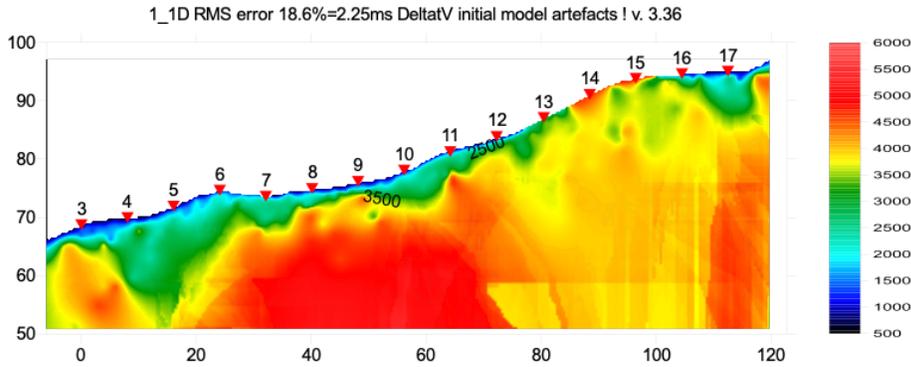


Fig. 8 : *DeltatV*|*Interactive DeltatV* output. See Fig. 12&13&14 for *DeltatV* Settings & parameters and XTV parameters.

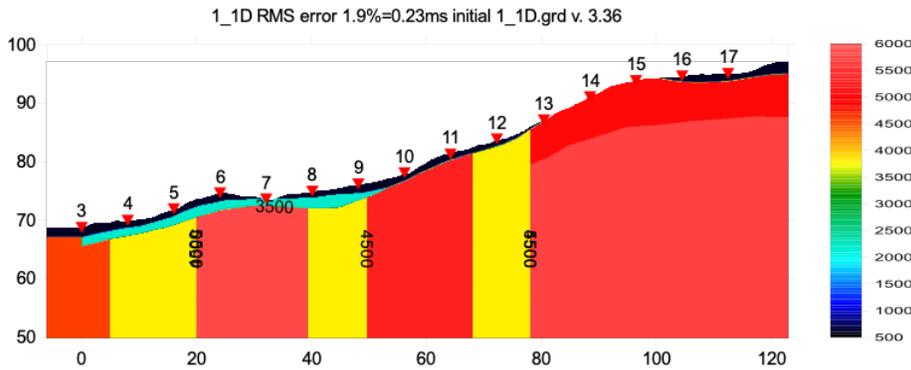


Fig. 9 : true model for line 1\_1D built by NGU and used for synthetic shots (Fig. 1) forward modeled by NGU. See ... \MODEL subdirectory in [RAR archive](#) for Surfer .GRD file.

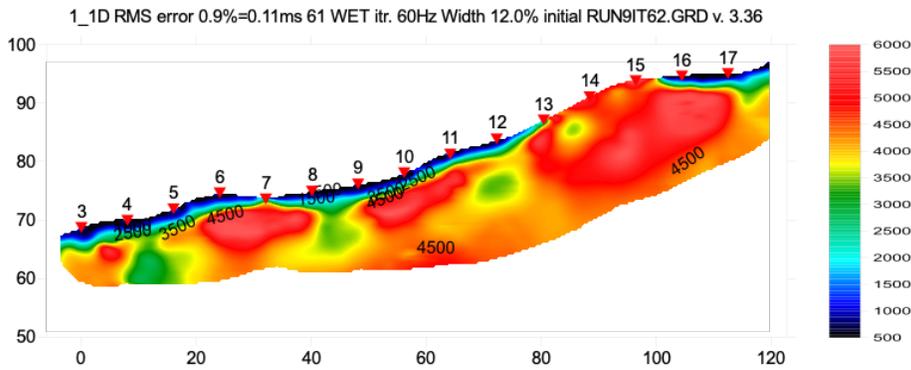


Fig. 10 : Multirun WET showing output of 10<sup>th</sup> run. Starting model for 1<sup>st</sup> run is Fig. 8. See Fig. 1 for misfit between modeled and picked traveltimes.

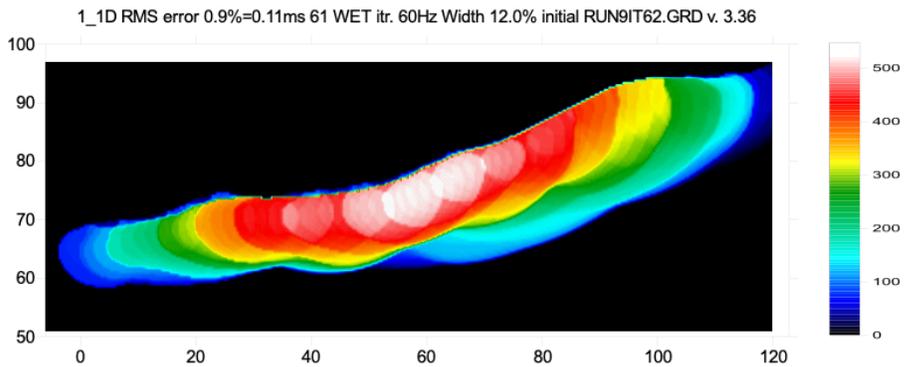


Fig. 11 : WET wavepath coverage plot obtained with Fig. 10. Unit is wavepaths per pixel.

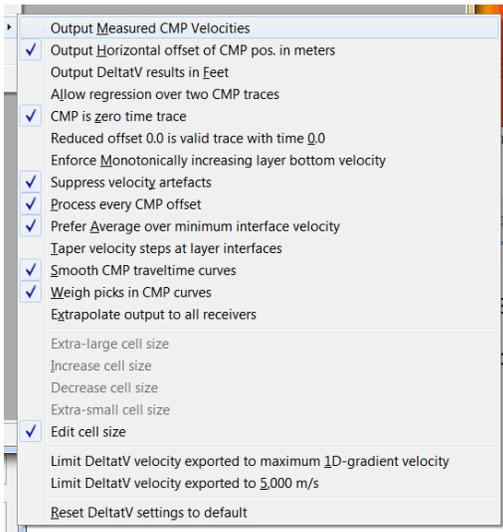


Fig. 12 : *DeltatV|DeltatV Settings*. Check *Suppress velocity artefacts* to enforce continuous CMP sorted traveltimes curves and filter out bad picks from traveltimes curves.

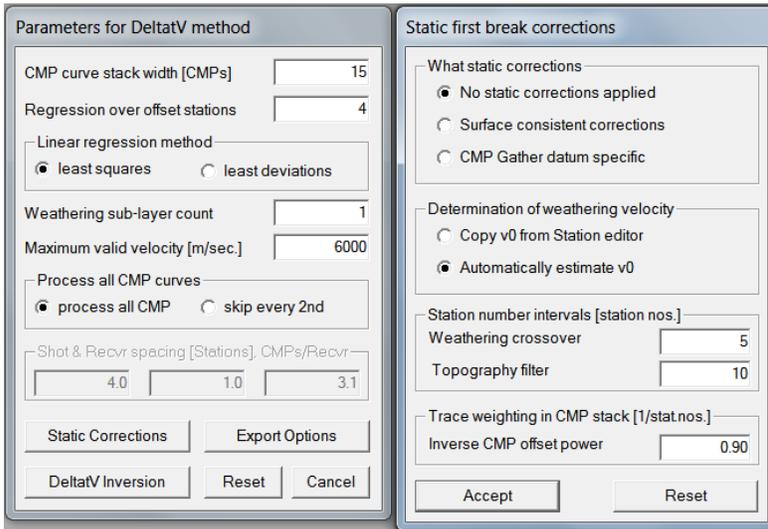


Fig. 13 : edit parameters in dialog *DeltatV|Interactive DeltatV* (left). Click button *Static Corrections* to edit more parameters (right). Check radio button *No static corrections applied* to completely disable static corrections. Increase *Inverse CMP offset power* from default 0.5 to 0.9 to give more weight to central CMP curve when stacking CMP curves. This increases the lateral resolution. Decreasing *Inverse CMP offset power* increases lateral smoothing.

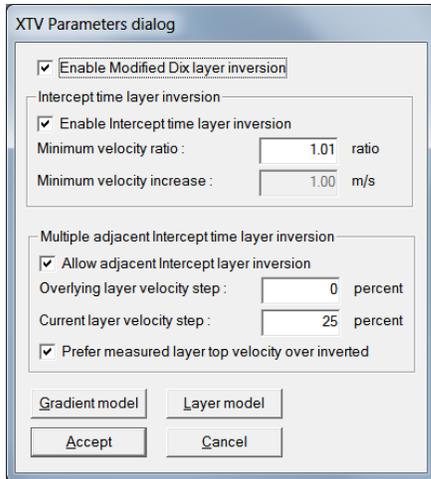


Fig 14 : edit XTV parameters. Click button *Layer model* and button *Accept*.

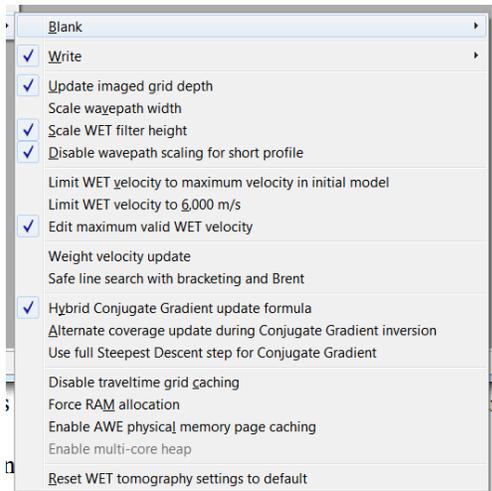


Fig. 15 : edit menu *WET Tomo|WET tomography Settings*

To configure and run WET inversion and display 2D inversion output :

- select *Grid|Surfer plot Limits*. Click *button Reset to grid*. Navigate into profile subdirectory `c:\RAY32\1_1D\Nov18Regr4`. Click on `Nov18Regr4.GRD` and click *Open*.
- check box ***Plot limits active***. Set *Min. elevation* to 50m. Set *Max. elevation* to 100m. See Fig. 4.
- set *Min. velocity* to 500 m/s and *Max. velocity* to 6,000 m/s. Click *OK*.
- *Grid|Image and contour velocity and coverage grids & ...\model\1\_1D.grd* to obtain Fig. 9
- check *WET Tomo|WET tomography Settings|Blank no coverage after last iteration*.
- uncheck *WET Tomo|WET tomography Settings|Blank below envelope after last iteration*
- uncheck *WET Tomo|WET tomography Settings|Scale wavepath width*. See Fig. 15.
- check *WET Tomo|WET tomography Settings|Scale WET filter height*
- check *WET Tomo|WET tomography Settings|Edit maximum valid WET velocity*
- in *WET Tomo|WET Update weighting* set *a* to 0.5 and *b* to 10.0. Click *OK*. See Fig. 5.
- set *WET Tomo|Interactive WET tomography|Ricker differentiation* to -2 [Cosine-Squared]
- set *Min. velocity* to 150 m/s & *Max. velocity* to 6,000 m/s. See Fig. 6 (left).
- click radio button ***Conjugate Gradient***
- set *CG iterations* (outer loop) to 20 and *Line Search iters.* (inner loop) to 2. 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 ***Manual specification of smoothing filter*** . See Fig. 6 (right).
- set ***Half smoothing filter width*** to 3 columns & set ***Half smoothing filter height*** to 1 rows
- uncheck ***Adapt shape of filter***. Set ***Maximum velocity update*** to 5% .

- set **Smooth nth iteration : n** = to 25 .
- click **Gaussian** button. Set *Used width of Gaussian* to 5.5 sigma
- in latest version 3.36 click box **No smoothing** to completely disable WET smoothing. See Fig. 16 .
- leave **Damping** at default 0.9 for Conjugate-Gradient method
- 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
- in Surfer 16 click on **menu View**. Check **Properties check box**.
- in Surfer 16 click on **Custom colormap** button to right of **Colors label**. Click on **Load button**. Navigate into `c:\RAY32\1_1D\INPUT` and select `1_1D.CLR` . Click **Open&Apply&OK buttons**.

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

- for our [multiscale WET](#) inversion see updated [help file](#) chapter **WET tomography processing**
- 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

To restore database files and result files :

Subdirectories `c:\RAY32\1_1D\Nov18Regr4\WETRUN1` to `...\WETRUN10`, `...\INPUT`, `...\MODEL` and `...\seis32_Nov18Regr4` are available in this [RAR archive](#). Open the `...\WETRUN10\VELOIT62.PAR` file e.g. with Windows Notepad editor to review *WET inversion* parameters used.

Use Rayfract® 3.36 command **GridReset DeltatV and WET settings to .PAR file...** with file `...\Nov18Regr4\WETRUN10\VELOIT62.GRD` to reset your profile's *DeltatV* and *WET inversion settings* to `...\Nov18Regr4\WETRUN10\VELOIT62.PAR` .

Or quit our software via **File|Exit** and copy all 33 `seis32.*` database files from directory `c:\RAY32\1_1D\seis32_Nov18Regr4` into `c:\RAY32\1_1D` directory in Windows Explorer. Now reopen your profile with **File|Open Profile...** and `c:\RAY32\1_1D\SEIS32.DBD` .

Summary, optimization of interpretation parameters :

NGU 2018 report with Fig. 4.5.1 showing *multirun WET inversion* of above synthetic model data is available at [http://www.ngu.no/upload/Publikasjoner/Rapporter/2018/2018\\_015.pdf](http://www.ngu.no/upload/Publikasjoner/Rapporter/2018/2018_015.pdf) . In above Fig. 6 & Fig. 7 we further improve our WET inversion settings compared to settings used for Fig. 4.5.1.

WET inversion shown in Fig. 10 using 10 WET runs with 20 Conjugate-Gradient iterations each and parameters shown in Fig. 6 and Fig. 7 took about 4 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 14 for Mac.

- the first interpretation attempt in Fig. 4.2.1 of above report apparently used too much *WET smoothing* e.g. **Used width of Gaussian** 3.0 sigma instead of our 5.5 sigma. This contributes to the horizontal smearing artefacts.
- in Fig. 4.2.1 **WET damping** was reset to 0.0. We use default damping setting for *Conjugate Gradient* of 0.9. The higher the damping the less need to smooth for *Conjugate Gradient* method. *WET smoothing* can destroy the tomogram resolution so WET smoothing needs to be minimized.
- we decrease **WET wavepath width** from 30% to 12% over 10 runs. In Fig. 4.2.1 *WET wavepath width* is decreased from 30% to 21% only. This probably also contributes to horizontal smearing artefacts. Per default wavepath width is decreased from 30% to 6% over 10 WET runs.
- we uncheck *WET smoothing* option **Adapt shape of filter** for better resolution
- we limit **Maximum velocity update** to 5% while in Fig. 4.2.1 *Maximum velocity update* is set to 15%. Limiting the maximum velocity update can help to better focus *WET inversion* especially with strong topography curvature.
- in Fig. 4.2.1 31 *WET iterations* per *WET run* are used. We use 62 WET iterations per WET run by increasing **CG iterations** from default 10 to 20.
- in Fig. 4.2.1 **Smooth nth iteration: n=** is set to 10 while we set this to 25 resulting in less smoothing and less smearing artefacts

- in Fig. 4.2.1 minimum/maximum **WET velocity** is limited to range 500 m/s .. 6,000 m/s. We extend this velocity range to 150 m/s .. 6,000 m/s. This helps WET to more easily find a good solution by allowing WET to explore a larger solution space.
- we uncheck option *WET Tomo|WET tomography Settings|Scale wavepath width* to prevent near-surface velocity artefacts in the tomogram (unrealistic low-velocity anomalies below strong topography curvature) and to obtain more realistic imaging at tomogram bottom i.e. less horizontal smearing
- unchecking *WET smoothing* option **Smooth velocity update** can help to better focus WET inversion
- we have added a new check box **No smoothing** to our *WET Tomo|Interactive WET tomography|Edit WET smoothing* dialog in version 3.36 of our Rayfract® software. See below in Fig. 16. This option makes it easier to completely disable WET smoothing. Enabled *No smoothing* option overrides all other parameters in *Edit velocity smoothing* dialog except *Maximum velocity update* and *Damping*.

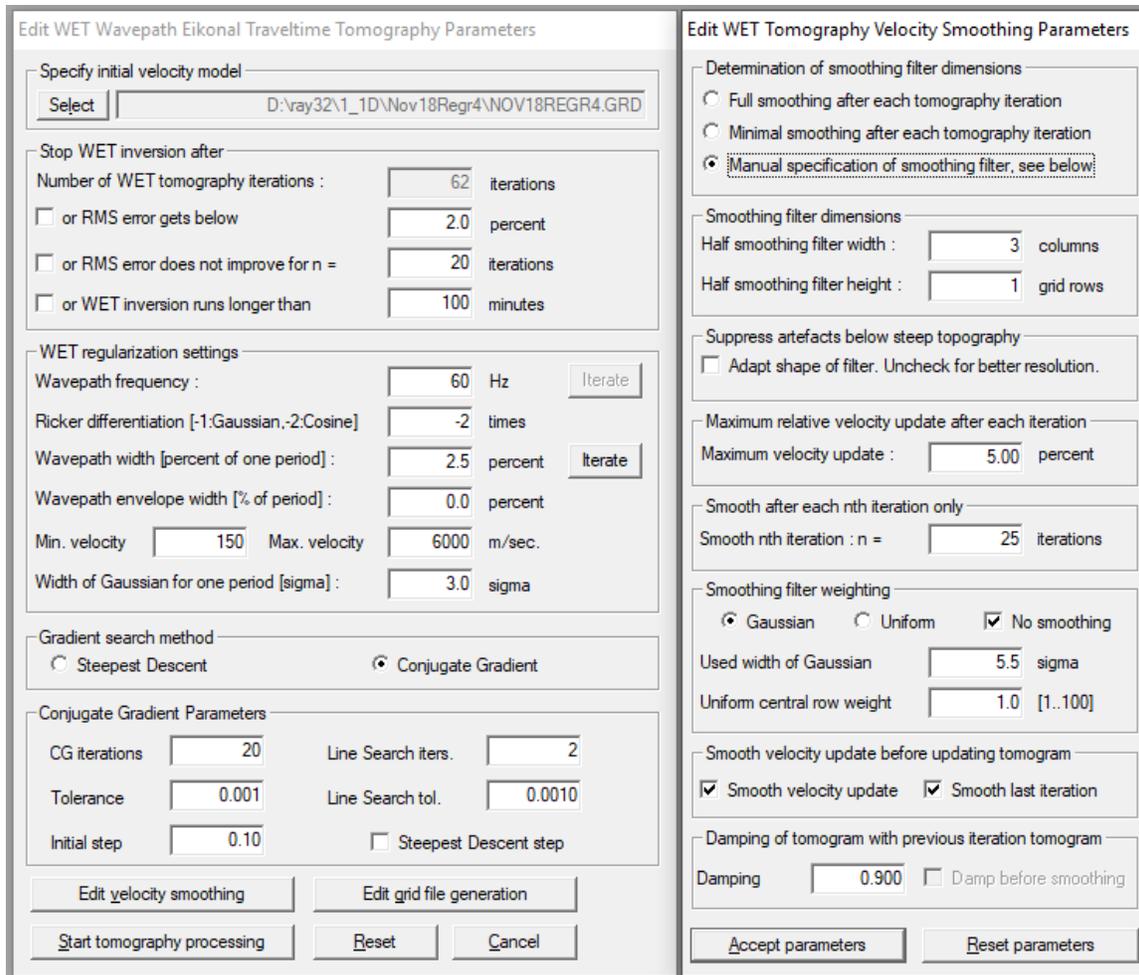


Fig. 16 : *WET Tomo|Interactive WET tomography|Edit velocity smoothing* (right) offers new option **No smoothing**. Check this box to completely disable smoothing during WET inversion. Enabled *No smoothing* option overrides all other parameters in *Edit velocity smoothing* dialog (right) except *Maximum velocity update* and *Damping*.

When forward modeling traveltimes over ...\\MODEL\\1\_1D.GRD with our *Model|Forward model traveltimes...* we obtain an RMS error of 0.23 ms (Fig. 9). Ideally this error should be 0.0 ms when using the same grid cell size and Eikonal solver as NGU used for generating the 1\_1DASCII.ASC synthetic shots. We use the Eikonal solver and “active point process” as described by [Lecomte et al. 2001](#) in Fig. 3.

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](#). DeltatV and *Smooth inversion* using *1D-gradient starting model* obtained by [laterally averaging DeltatV](#) match each other nicely as shown in these .pdf tutorials.

On the following page we show multiscale Conjugate-Gradient WET inversion using our default 1D-gradient starting model obtained with *Smooth invert|WET with 1D-gradient initial model* command.

Obtain the laterally averaged 1D-gradient starting model (Fig. 17; Sheehan 2005a; Rohdewald 2025) :

To configure and obtain an optimized laterally averaged 1D-gradient starting model :

- configure *DeltatV|DeltatV settings* as described on first page (Fig. 12)
- select *Grid|Surfer plot Limits*. Edit as in Fig. 24 and click *OK* button.
- select *Header|Profile* and edit as in Fig. 25
- edit field *Extrapolate [station spacings]* to 32. Check box *Extrapolate tomograms*. Click *OK*.
- select *Smooth invert|Custom 1D-gradient velocity profile* and edit as in Fig. 21.
- check box *Force topography smoothing*. Edit field *Forced filter width [stations]* to 2. Click *OK*.
- select *Smooth invert|WET with 1D-gradient initial model* to obtain Fig. 17
- when prompted to continue with WET inversion click *No* button
- select *Model|WDVS Smoothing*. Edit as in Fig. 22 and click *OK* button.
- select *Model|Forward model traveltimes* . Navigate into folder *c:\RAY32\1\_1D\GRADTOMO* .
- select file *GRADIENT.GRD* and click *Open* button
- select *Grid|Image and contour velocity and coverage grids*
- select *c:\RAY32\1\_1D\GRADTOMO\GRADIENT.GRD* and click *Open* button to obtain Fig. 17

Run multiscale WET via Interactive WET dialog to obtain Fig. 19 :

- check *WET Tomo|WET tomography Settings|Blank no coverage after last iteration*. See Fig. 26.
- uncheck *WET Tomo|WET tomography Settings|Blank below envelope after last iteration*
- uncheck *WET Tomo|WET tomography Settings|Scale wavepath width*. See Fig. 15.
- check *WET Tomo|WET tomography Settings|Scale WET filter height*
- check *WET Tomo|WET tomography Settings|Edit maximum valid WET velocity*
- in *WET Tomo|WET Update weighting* set *a* to 0.5 and *b* to 10.0. Click *OK*. See Fig. 5.
- select *WET Tomo|Interactive WET tomography* and edit as in Fig. 23
- set *WET Tomo|Interactive WET tomography|Ricker differentiation* to -2 [Cosine-Squared] (Fig. 23)
- set *Min. velocity* to 150 m/s & *Max. velocity* to 6,000 m/s. See Fig. 23 (left).
- click radio button **Conjugate Gradient**
- set *CG iterations* (outer loop) to 20 and *Line Search iters.* (inner loop) to 2. 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 **Manual specification of smoothing filter** . See Fig. 23 (right).
- set **Half smoothing filter width** to 1 columns & set **Half smoothing filter height** to 1 rows
- uncheck **Adapt shape of filter**. Set **Maximum velocity update** to 5% .
- set **Smooth nth iteration : n =** to 25 .
- click **Gaussian** button. Set *Used width of Gaussian* to 10.0 sigma.
- uncheck box *Smooth update*. Check box *Smooth nth*. Check box *Smooth last*.
- set **Damping** to 0.2
- 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. 19 & 20
- in Surfer 11 check *View|Managers|Object Manager* and check *View|Managers|Property Manager*
- click on title of *Object Manager* window shown at left-top. Left-click label *Image-VELOIT62.GRD*.
- in Surfer 11 click on label *Property Manager* at left-bottom and click on label *General* tab.
- left-click button ... to the right of *Colors* label. Click on *Load* button. Navigate into *c:\RAY32\1\_1D\INPUT* and select *1\_1D.CLR* . Click *Open&OK* buttons to obtain Fig. 19 with a modified color scale.

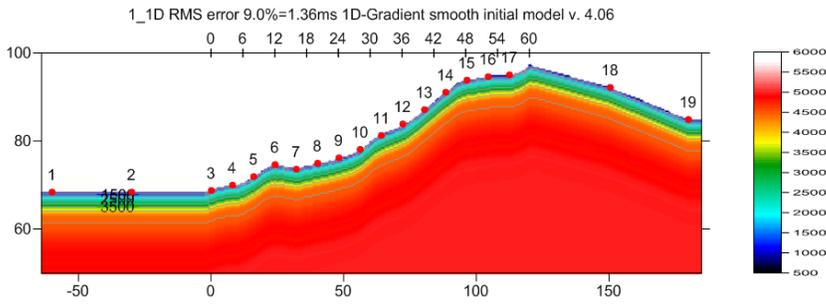


Fig. 17 : fail-safe laterally averaged 1D-gradient starting model obtained with **Smooth invert|WET with 1D-gradient initial model**. The DeltatV 1D velocity profiles are laterally averaged (Sheehan 2005). Force topography smoothing over 2 stations (Fig. 21). Surfer plot limits as in Fig 24. Extrapolate starting models and tomograms over 32 stations in Header|Profile (Fig. 25). Red dots are shot points. Grey dots are receivers.

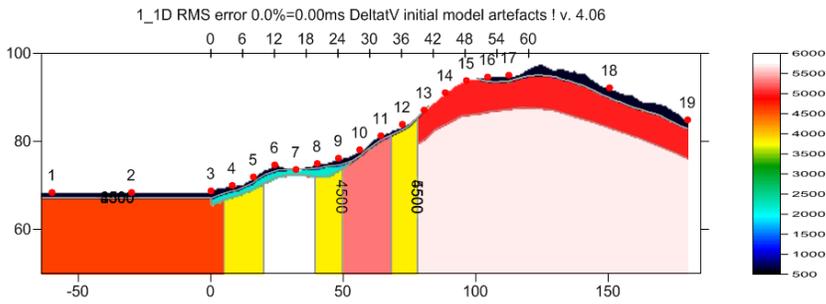


Fig. 18 : True model built and made available by NGU. Surfer plot limits as in Fig 24.

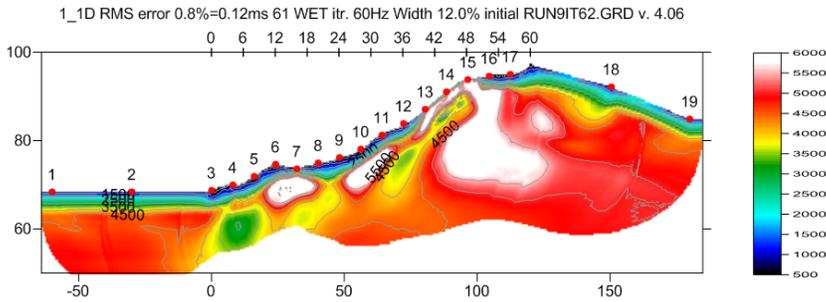


Fig. 19 : multiscale Conjugate-Gradient WET inversion. Output of 10<sup>th</sup> WET run shown. Starting model for first run is 1D-gradient initial model shown in Fig. 17. WDVS enabled at 1200Hz. Discard WET smoothing after forward modeling (Fig. 22). 10 Conjugate-Gradient WET runs (Fig. 7) with 20 Conjugate-Gradient iterations per run (Fig. 23). Ricker differentiation -2 : Cosine-Squared WET update weighting. Minimized WET smoothing (Fig. 23). Surfer plot limits as in Fig 24.

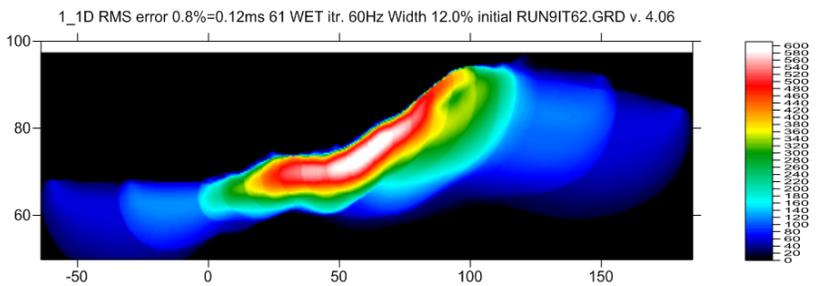


Fig. 20 : WET wavepath coverage plot obtained with Fig. 19. Unit is wavepaths per grid cell.

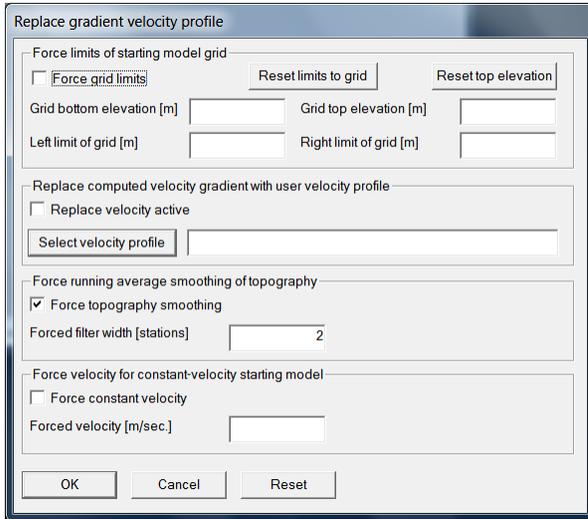


Fig. 21 : **Smooth invert|Custom 1D-gradient velocity profile** . Force topography smoothing over 2 stations.

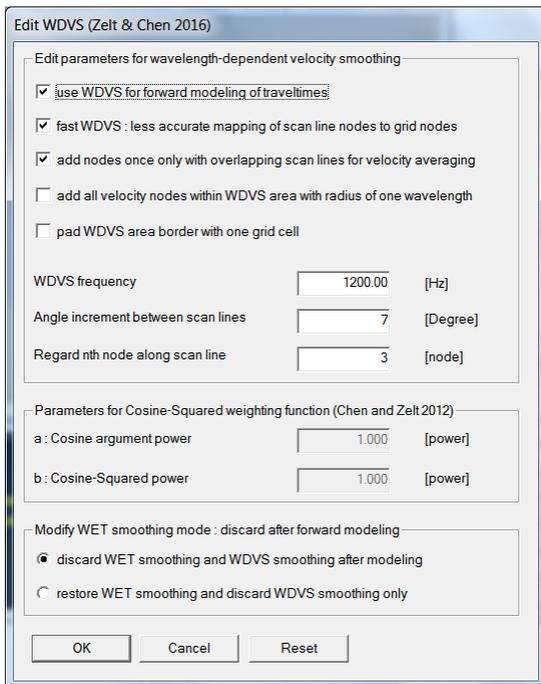


Fig. 22 : **Model|WDVS Smoothing**. Enable WDVS@1200Hz. Discard WET smoothing and WDVS smoothing after forward modeling.

Here is the DropBox link to .RAR archive with profile database files for Fig. 19 :

[https://www.dropbox.com/scl/fi/rcfsexvls2o8s6qa71vov/seis32\\_Feb13\\_2024\\_CGWET.rar?rlkey=tcg0svi4sy7poiqrhymmm&dl=0](https://www.dropbox.com/scl/fi/rcfsexvls2o8s6qa71vov/seis32_Feb13_2024_CGWET.rar?rlkey=tcg0svi4sy7poiqrhymmm&dl=0)

Here is the DropBox link to .RAR archive with GRADTOMO subdirectory obtained with Fig. 19 :

[https://www.dropbox.com/scl/fi/114mcuqm0c1pfq5umhjdrr/1\\_ID\\_GradTomo\\_CGWET\\_WDVS-1200Hz\\_Feb13\\_2024.rar?rlkey=4spmve73unfhyvowachig45f6&dl=0](https://www.dropbox.com/scl/fi/114mcuqm0c1pfq5umhjdrr/1_ID_GradTomo_CGWET_WDVS-1200Hz_Feb13_2024.rar?rlkey=4spmve73unfhyvowachig45f6&dl=0)

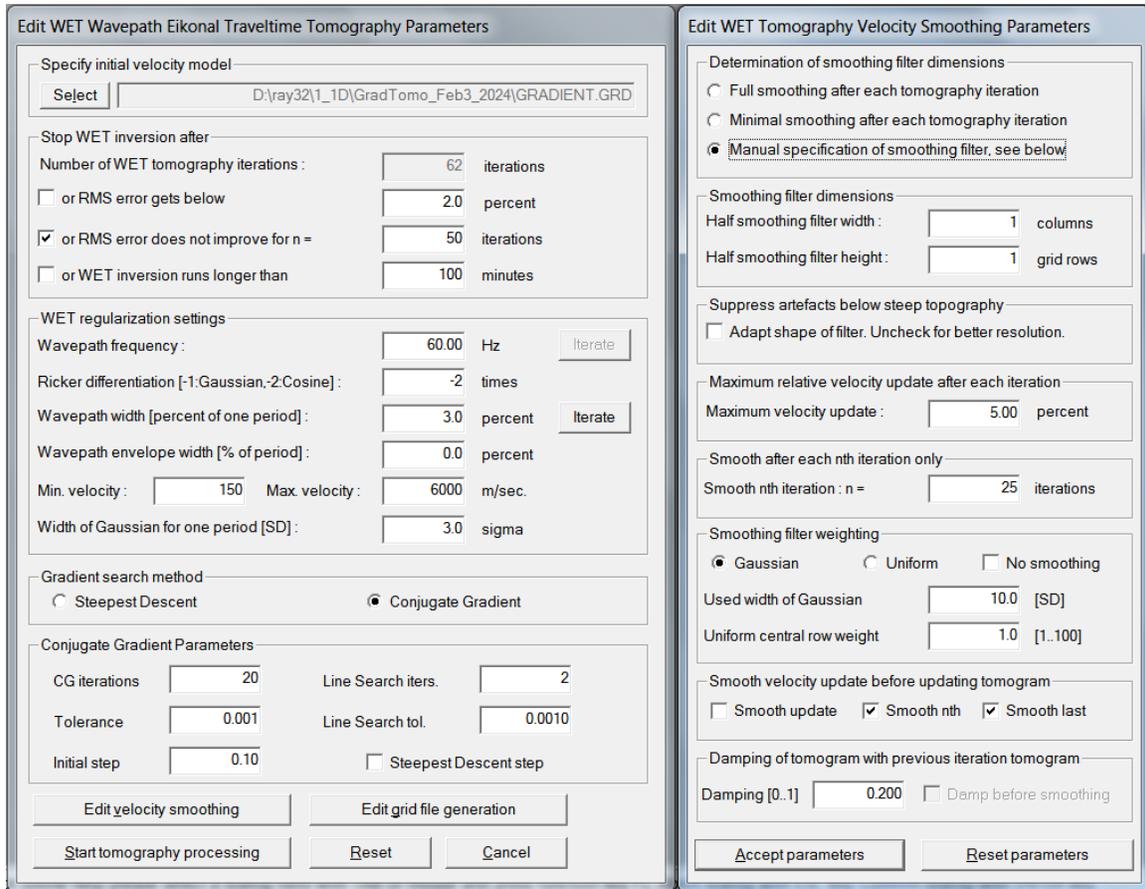


Fig. 23 : **WET Tomo|Interactive WET** main dialog (left). Edit velocity smoothing (right).

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  $4000/100 = 40\text{m}$ . 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 above tutorial we are imaging fault zones not wider than 10m @ 4,000 m/s. This is far below one wavelength of 40m @ 100 Hz.

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.

Fig. 24 : **Grid|Surfer plot Limits**

Fig. 25 : **Header|Profile** : extrapolate starting models and WET tomograms

Fig. 26 : **WET Tomo|WET tomography Settings|Blank** menu.

We thank Dr. Georgios Tassis for making available above NGU 2018 report and synthetic data & models.

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

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](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://scholarship.rice.edu/handle/1911/72113?show=full> . <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://rayfract.com/srt_evaluation.pdf) . <https://www.researchgate.net/publication/242159023> .

More references :

**Canadian Intellectual Property Office - Government of Canada 2025.** Canadian Trademark Details: RAYFRACT — 1176887 <https://ised-isde.canada.ca/cipo/trademark-search/1176887?lang=eng>

**Eidgenössisches Institut für Geistiges Eigentum 2025.** Swiss Trademark Details: Titel RAYFRACT . Markennummer 443830 <https://www.swissreg.ch/database-client/register/detail/trademark/1200041215>

**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> .

**H. Gebrande 1986.** CMP-Refraktionsseismik. Paper presented (in German) at Mintrop Seminar / Uni-Kontakt Ruhr-Universitaet Bochum, Expanded abstract "Seismik auf neuen Wegen", pp. 191-205.

**H. Gebrande and H. Miller 1985.** Refraktionsseismik (in German). In: F. Bender (Editor), *Angewandte Geowissenschaften II*. Ferdinand Enke, Stuttgart; pp. 226-260. ISBN 3-432-91021-5.

**Bruce S. Gibson, Mark E. Odegard and George H. Sutton 1979.** Nonlinear least-squares inversion of traveltimes data for a linear velocity-depth relationship. *Geophysics*, volume 44, pp. 185-194. <https://dx.doi.org/10.1190/1.1440960> .

**I. Lecomte, H. Gjoystdal, A. Dahle and O.C. Pedersen 2000.** Improving modeling and inversion in refraction seismics with a first-order Eikonal solver. *Geophysical Prospecting*, volume 48, pp. 437-454. <https://dx.doi.org/10.1046/j.1365-2478.2000.00201.x> .

**Rohdewald S.R.C. 2025.** Rayfract manual. <https://rayfract.com/help/rayfract.pdf> .

**Rohdewald S.R.C. 2006.** Rayfract short manual. <https://rayfract.com/help/manual.pdf> .

**Gerard T. Schuster and Aksel Quintus-Bosz 1993.** Wavepath eikonal traveltimes inversion : Theory. *Geophysics*, volume 58, pp. 1314-1323. <https://dx.doi.org/10.1190/1.1443514> . <https://csim.kaust.edu.sa/files/short.courses/bp.2011/ppt/wet.pdf>

**Jonathan Richard Shewchuk 1994.** An Introduction to the Conjugate Gradient Method Without the Agonizing Pain. <https://www.cs.cmu.edu/~quake-papers/painless-conjugate-gradient.pdf> .

**Watanabe Toshiki et al. 1999.** Seismic traveltimes tomography using Fresnel volume approach. SEG Houston 1999 Meeting, Expanded Abstracts. <https://www.researchgate.net/publication/240735641> . <https://dx.doi.org/10.1190/1.1820777>

**J. Whiteley et al. 2020.** Landslide monitoring using seismic refraction tomography - The importance of incorporating topographic variations. *Engineering Geology* 2020. <https://www.researchgate.net/publication/339280163>