

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 after 20 WET iterations with 1D-gradient GRADIENT.GRD starting model (Fig. 6)

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

- File New Profile ..., set File name to Aaknes-1 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 1.0m. See Fig. 2.
- unzip archive <u>AAKNES-1.zip</u> with files ASCII.ASC & COORDS.COR & SHOTPTS.SHO in directory C:\RAY32\Aaknes-1\INPUT
- select File Import Data ... and set Import data type to ASCII column format. See Fig. 3.
- click Select button and navigate into C:\RAY32\Aaknes-1\INPUT
- select file ASCII.ASC & click button Open
- leave Default spread type at 10: 360 channels
- check box Batch import & click Import shots button . All shots listed in ASCII.ASC are imported.
- select File|Update header data|Update Station Coordinates & COORDS.COR. Click Import & Reset.
- *File*|*Update header data*|*Update Shotpoint coordinates* with **SHOTPTS**.**SHO**. Click *Open button*.
- select *Trace*|Shot gather and select *Window*|Tile to obtain Fig. 1
- click on title bar of *Trace*|Shot gather window and press F1 to zoom time axis (Fig. 1 left)
- browse shots in *Trace*|Shot gather window with F7/F8 (Fig. 1 left)
- click on title bar of *Refractor*|*Shot breaks* window (Fig. 1 right) and press ALT+P. Edit *Maximum time* to 200 ms & hit ENTER key to redisplay. Do the same for *Trace*|*Shot gather* window (Fig. 1 left).

To configure and run Smooth inversion :

- select *Grid*|*Surfer plot Limits*. Edit fields as in Fig. 4. Click *OK button*.
- check Grid|GS CENTERED font for receivers to work around Surfer 11 issues with receiver display
- select Grid Receiver station ticks on top axis
- uncheck WET Tomo|WET tomography Settings|Blank|Blank below envelope after last iteration
- check WET Tomo|WET tomography Settings|Blank|Blank no coverage 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

- when prompted to continue with WET inversion click No button
- select *WET Tomo*|*Interactive WET tomography*
- click *Select button* and select c:\ray32\aknes-1\gradtomo\gradient.grd
- set *Number of WET tomography iterations* to 20
- increase *Wavepath width [percent of one period]* from default 6.5 percent to 12 percent and set *Max. velocity* to 6,500 m/s (Fig. 15)
- click button *Start tomography processing* to obtain WET output shown in Fig. 6 & 7

E	dit Profile						
		Aaknes-1 Refraction spread	1/line	Ţ	Time of Date	f Acquisi	tion
	Job ID	rtendetion oprede	ų me		Time		
	Instrument					f Proces	sing
	Client				Date	<u> </u>	
	Company				Time		
	Observer			_	Units	meters	•
	Note			*	Sort	As acq	uired 💌
				-	Const		
	Station spacing		2.0	25	,		coordinates
	Min. horizontal s					e grid c	
	Profile start offs	et[m]	0	.0000	Cell size	e (mj	1.0000
	Add borehole	lines for WET tom	ography				
	Borehole 1 line	Select					
	Borehole 2 line	Select					
	Borehole 3 line	Select					
	Borehole 4 line	Select					
	ОК	Cancel	R	eset			

Import shots				
Import data type	ASCII column format			
Input directory : select one data file. All data files will be imported				
Select	D:\ray32\Aaknes-1\INPUT\			
Take shot record number from	Record number			
Optionally select .HDR batch file and check Batch import				
.HDR batch				
Write .HDR batch file listing shots	s in input directory			
Output .HDR				
Write .HDR only	Import shots and write .HDR			
Overwrite existing shot data	Batch import			
Overwrite all Prompt of	- ·			
Maximum offset imported [station i	nos.] 1000.00			
Default shot hole depth [m]	Default spread type			
0.00	10: 360 channels			
Target Sample Format	16-bit fixed point			
Turn around spread by 180 degrees during import				
Correct picks for delay time (use e.g. for .PIK files)				
Default sample interval [msec]	0.10000000			
Default sample count	20000			
Import shots Ca	ncel import <u>R</u> eset import			

Fig. 2 : Header|Profile

Edit Surfer plot limi	ts				
Plot Limits	2		ОК		
Min. offset	0.000	[m]	Cancel		
Max. offset	800.000	[m]	Reset		
Min. elevation	350.000	[m]	Reset to grid		
Max. elevation	580.000	[m]	Redisplay grid		
Min. velocity	500	[m/sec.]			
Max. velocity	7000	[m/sec.]			
Plot Scale Proportional XY Scaling Page unit centimeter. Uncheck for inch.					
X Scale length	6.000	[inch]			
Y Scale length	3.000	[inch]			
Color Scale					
Scale height	3.120	[inch]			
Velocity interval	500	[m/sec.]			
Coverage interval	500	[paths/pixel]			
Receiver labeling					
First station	101	[station no.]			
Station interval	50	[station no.]			
Use station inde	ex or station no	offset			

Fig. 4 : Grid|Surfer plot Limits

Fig. 3 : File|Import Data

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

- select C:\ray32\arknes-1\gradient.grd with Grid|Turn around grid file
- reimage C:\RAY32\Aaknes-1\GRADTOMO\GRADIENT.GRD with Grid|Image and contour velocity and coverage grids

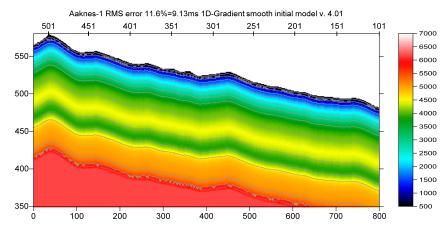
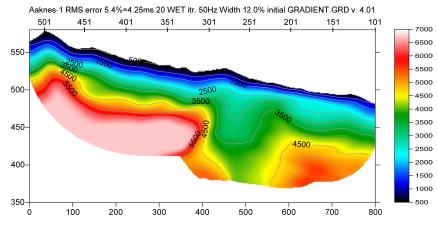
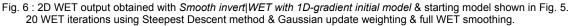
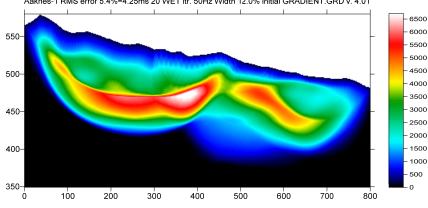


Fig. 5 : 1D-gradient starting model obtained with Smooth invert|WET with 1D-gradient initial model







Aaknes-1 RMS error 5.4%=4.25ms 20 WET itr. 50Hz Width 12.0% initial GRADIENT.GRD v. 4.01

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

Next we try to increase the WET resolution by increasing the WET iteration count but keeping default Full WET smoothing :

- select WET Tomo Interactive WET tomography
- set Number of WET tomography iterations to 50 (Fig. 15)
- click button Start tomography processing to obtain WET output shown in Fig. 8 :

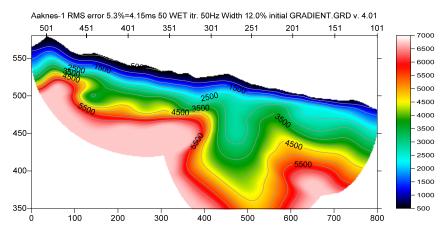


Fig. 8 : 2D WET output obtained with WET Tomo|Interactive WET tomography & 50 WET iterations & 1D-gradient starting model shown in Fig. 5

Fig. 8 shows more detail in relief and lateral variations at top of basement (yellow color) compared to Fig. 6 so increasing the WET iteration count apparently did improve the resolution a bit.

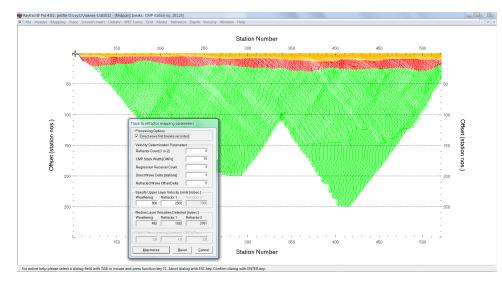
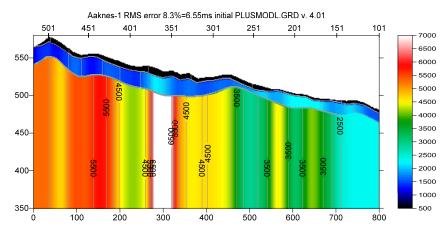


Fig. 9 : map traces to refractors in *Refractor*|*Midpoint breaks*. Press ALT+M to display mapping dialog. Edit as shown and click button *Map traces*.

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

- ▶ map traces to refractors in *Refractor* Midpoint breaks with **ALT+M** (Fig. 9)
- press ALT+G to laterally smooth crossover distance. Set both Overburden filter [station nos.] and Basement filter to 30 and click button Accept.
- ➤ select Depth|Plus-Minus to display Plus-Minus layered refraction starting model (Fig. 10). When prompted to continue with WET inversion click No button.

- click on title bar of *Plus-Minus Depth Section window*. Press ALT+M and set both *Overburden filter* [station nos.] and Base filter width to 20. Press ENTER to redo Plus-Minus method interpretation.
- ▶ when prompted to continue with WET inversion using default WET parameters click *Yes button*.
- ➢ select WET Tomo Interactive WET tomography & set Number of WET tomography iterations to 50
- set Wavepath width [percent of one period] to 12 percent and set Max. velocity to 6,500 m/s
- click button Start tomography processing to obtain WET output shown in Fig. 11.
- Smooth WET inversion is somewhat dependent on the starting model after 50 WET iterations when using default full WET smoothing & Steepest Descent search method : Fig. 8 and Fig. 11 are similar.
- interactive WET inversion with 50 iterations (Fig. 8 and Fig. 11) takes about 16 minutes on 2017 iMac using 2.3 GHz Intel Core i5 processor with 2 hyper-threaded CPU cores running Windows 7 64-bit Pro in Parallels desktop.





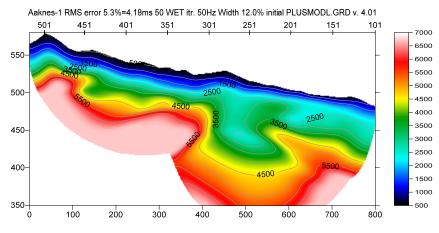


Fig. 11 : Smooth inversion using Plus-Minus method starting model (Fig. 10). 50 WET iterations using default Steepest Descent method & Gaussian update weighting & full WET smoothing. Compare with Fig. 8.

We thank NGU for making available the original input files with inconsistent first break picks and their smoothed and shifted version of the recording geometry.

Also we thank GeoExpert for making available SEGY files with improved first break picks (Fig. 16) and their version of the recording geometry. See Fig. 14 for Smooth inversion using GeoExpert topography and recording geometry. Note the significant differences between Fig. 14 topography and Fig. 8 and Fig. 13 using NGU smoothed and shifted topography. Also note noisy SEGY traces in Fig. 16.

As shown above we always recommend starting with our default <u>Smooth inversion</u> using Steepest Descent search method and full WET smoothing. In case of such uncertain first break picks and such uncertain recording geometry you may want to increase the default WET wavepath width as shown above.

It is not completely clear to us why NGU chose to ignore our default <u>fail-safe Smooth inversion</u> <u>method</u> (Sheehan 2005) and used our pseudo-2D DeltatV method with suboptimal settings instead.

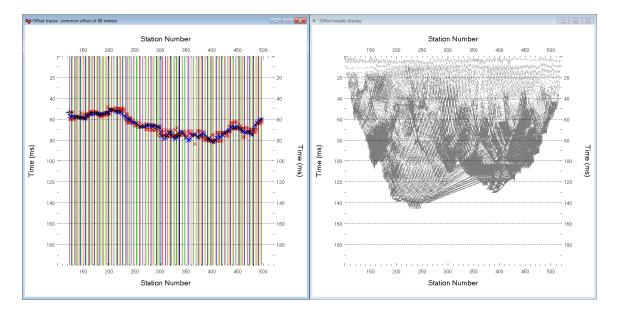
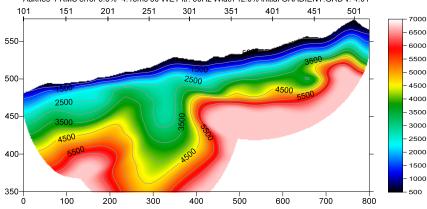
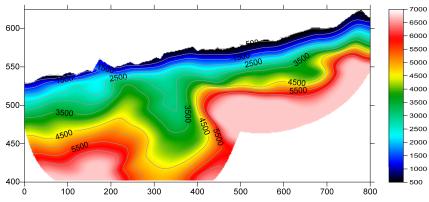


Fig. 12 : *Trace*|*Offset gather* for common offset = 89m (left). Red crosses are picked first breaks. Blue crosses are modeled first break times. Refractor|Offset breaks (right).



Aaknes-1 RMS error 5.3%=4.15ms 50 WET itr. 50Hz Width 12.0% initial GRADIENT.GRD v. 4.01

Fig. 13 : copied from Fig. 8. but un-flipped ...\GRADTOMO\VELOIT50.GRD with Grid|Turn around grid file and reimaged with Grid|Image and contour velocity and coverage grids. Note good correlation with Fig. 12 (right) : Refractor|Offset breaks display.



Aaknes-1 SEGY RMS error 5.6%=4.41ms 50 WET itr. 50Hz Width 12.0% initial GRADIENT.GRD v. 4.01

Fig. 14 : Same WET processing as Fig. 8 & Fig. 13 but with GeoExpert unsmoothed topography

Edit WET Wavepath Eikonal Traveltime Tomography Parameters	Edit WET Tomography Velocity Smoothing Parameters	
Specify initial velocity model Seject D\ray32\Aaknes-1\GRADTOMO_Aug2020\GRADIENT.GRD	Determination of smoothing filter dimensions Full smoothing after each tomography iteration Minimal smoothing after each tomography iteration	
Stop WET inversion after Number of WET tomography iterations : 0 or RMS error gets below 20 percent	C Minimal smoothing after each tomography iteration Manual specification of smoothing filter, see below Smoothing filter dimensions Half smoothing filter width : 10 columns	
or RMS error does not improve for n = 20 iterations or WET inversion runs longer than 100 minutes	Half smoothing filter height: 2 grid rows	
WET regularization settings Wavepath frequency : 50 Hz Iterate	Suppress artefacts below steep topography	
Ricker differentiation [-1:Gaussian,-2:Cosine] : -1 times Wavepath width [percent of one period] : 120 percent Iterate	Maximum relative velocity update after each iteration Maximum velocity update : 25.00 percent	
Wavepath envelope width [% of period] : 0.0 percent Min. velocity : 10 Max. velocity : 6500 m/sec.	Smooth after each nth iteration only Smooth nth iteration : n = 1 iterations	
Width of Gaussian for one period [sigma] : 3.0 sigma	Smoothing filter weighting C Gaussian I Uniform I No smoothing	
Steepest Descent Conjugate Gradient Conjugate Gradient	Used width of Gaussian 1.0 sigma Uniform central row weight 1.0 [1100]	
CG iterations 10 Line Search iters. 2 Tolerance 0.001 Line Search tol. 0.0010	∽Smooth velocity update before updating tomogram √ Smooth update √ Smooth update √ Smooth Iast	
Initial step 0.10 Steepest Descent step Edit velocity smoothing Edit and file generation	Damping of tomogram with previous iteration tomogram Damping [0.1] 0.000 Demp before smoothing	
Start tomography processing Reset Qancel	Accept parameters Reset parameters	

Fig. 15 : WET Tomo|Interactive WET tomography settings to obtain Fig. 8

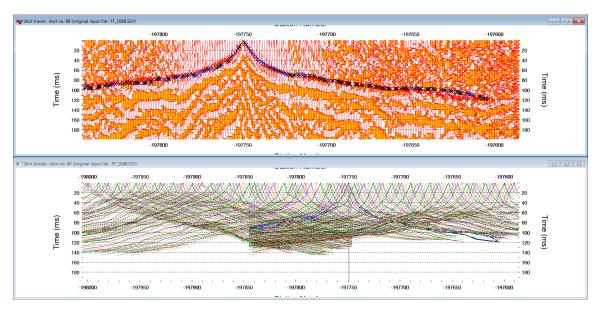


Fig. 16 : sample SEGY shot. Note the low signal-to-noise ratio (top).

Earlier processing of this line shown in 2019 NGU report was done using the original first break picks which are not consistent and show too large reciprocal traveltime errors in *Trace*|*Offset gather*. Even after repicking of the traces the reciprocal traveltime picking errors are still significant at large offsets (Fig. 12, Fig. 27). We recommend stacking shots in the seismograph to improve the signal-to-noise ratio, or using a more powerful seismic source. Also avoid over-interpretation of uncertain field data by decreasing the WET smoothing too much. Don't reuse inversion settings optimized for noise-free synthetic data when processing noisy field data with reciprocal traveltime picking errors and errors in specification of used recording geometry.

Our earlier <u>tutorial Slope1</u> shows how to identify and improve inconsistent traveltime picks in *Trace*|*Offset* gather based on traveltime reciprocity principle.

<u>Sheehan et al. 2005</u> objectively compare our fail-safe default Smooth inversion method using 1D-gradient starting model with other commercially available seismic refraction tomography software.

Here are the <u>profile database files</u> for line Aaknes-1. Here are Surfer .GRD & .PAR & .FIT files for <u>Smooth inversion shown in Fig. 5 to Fig. 8</u> with WET settings as in Fig. 15. Here are Surfer .GRD files for <u>layer-based inversion shown in Fig. 10 and Fig. 11</u>.

As shown in our <u>SAGEEP10 short course tutorials</u>, our <u>short manual</u> and our <u>help file</u> we always recommend running our <u>Smooth inversion</u> as a first step during interpretation. Next you can try to improve the resolution by increasing the number of WET iterations and optionally decreasing WET smoothing for consistent data.

Copying minimized WET smoothing settings optimized for one profile to another profile is not recommended and not supported. Default full WET smoothing filter size and default wavepath width are determined automatically based on grid dimensions (grid cell size, number of columns & rows), velocity distribution in the starting model and maximum picked time. Since these parameters are specific to each profile and starting model you need to always start with our <u>Smooth inversion</u>. Next you can optionally try step-wise decreasing of <u>WET smoothing</u>, for consistently picked traveltimes and correctly specified recording geometry.

If you decrease WET smoothing too much then you effectively prevent WET inversion from improving on the starting model. This is true for any starting model : Plus-Minus, pseudo-2D DeltatV or 1D-gradient obtained with our *Smooth invert WET with 1D-gradient initial model*.

Interactively adapt WET smoothing to your profile data (first breaks and recording geometry) or just use default full WET smoothing. Don't force some arbitrary smoothing copied from a completely different profile and assume that this should just work with your current data. This is not supported by us.

For multi-run WET inversion of synthetic data as shown in <u>SAGEEP11_16</u> tutorial you can decrease *WET smoothing* more than for single-run WET inversion of field surveys as shown e.g. in our new <u>P6 tutorial</u>. For P6 we leave WET smoothing at default *Full smoothing* and increase the *WET iteration count* only, from default 20 to 100. But we keep using default *Ricker differentiation -1 [Gaussian]*, default *Steepest Descent search method* and default *Full smoothing*. Also we use Smooth inversion with default full WET smoothing in our <u>TYLERLN1_2019 tutorial</u>, <u>CLUD1 tutorial</u>, <u>BROADEP1 tutorial</u>, <u>EPIKINV tutorial</u>, <u>FIG9INV tutorial</u>, <u>TRA9002 tutorial</u> and most <u>other tutorials</u>. Use *Conjugate-Gradient* search method for WET inversion instead of default *Steepest Descent* search method for consistently picked travel times and correctly specified source and receiver geometry used to record the data only.

Above NGU line Aaknes-1 and our <u>P6 tutorial</u> show fault zone imaging in Norway. Traveltime curves and results show gradual increase of velocity with depth below topography and deep weathering along fracture zone. This contrasts with the strictly Plus-Minus layered refraction assumption used by <u>NGU</u> for their modeling, with <u>unrealistic abrupt velocity increase to over 4,000 m/s directly below thin weathering layer or topography</u>. We have asked NGU to use more realistic models of weathered subsurface in future, with deep weathering. The modeled velocity should increase gradually with depth both in overburden <u>and in basement</u>. Of course the Plus-Minus method works best to interpret synthetic data obtained by forward modeling over such <u>strongly layered models</u>. We show this in our earlier tutorial <u>NGUP1 1</u>.

The <u>SAGEEP 11 blind refraction model</u> (Zelt et al. 2013) uses more realistic velocity gradients and deep weathering including a dipping fault zone, all of which are better modeled with diving waves and <u>seismic</u> refraction tomography than with strictly critically refracted rays used with classical refraction methods.

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

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

<u>Mattsson et al.</u> compare WET interpretation with conventional refraction processing for imaging of <u>granitic bedrock</u> in Sweden with thin overburden and mapped <u>deformation zones</u>. Mattsson shows deep weathering and diving waves due to gradual increase of velocity with depth in overburden and below topof-basement. These results are contrary to unrealistic <u>NGU synthetic model 1_1D</u> which shows no increase of velocity with depth inside basement and abrupt velocity increase to over 4,000 m/s below thin weathering layer or even directly below topography. These extremely sharp velocity increases at layer boundaries with no layer-internal velocity gradients prevent reliable interpretation with our DeltatV method. <u>DeltatV assumes diving waves</u> due to gradual increase of velocity with depth. This assumption is realistic for most field surveys we have ever seen in recorded traveltime curves. See our tutorials in archives <u>TUTORIAL.ZIP</u> and <u>OLDTUTOR.ZIP</u> for interpretation of client's field survey data. Corner cases for which a starting model method fails can be constructed for every such method : 1D-Gradient, DeltatV, Plus-Minus etc.

DeltatV apparent velocity pseudo-sections can be compared to ER apparent resistivity pseudosections. See e.g. <u>https://pages.mtu.edu/~ctyoung/LOKENOTE.PDF</u> 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."

When you run our DeltatV inversion via *DeltatV menu* items we prompt you about apparent velocity artefacts and recommend using our *Smooth inversion* method instead (Fig. 17).

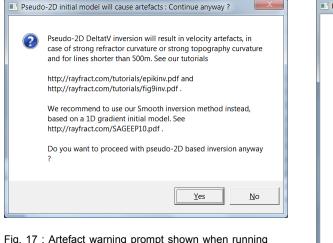


Fig. 17 : Artefact warning prompt shown when running DeltatV method inversion

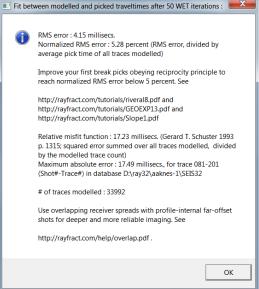


Fig. 18 : Traveltime misfit prompt shown after WET

Also when the normalized RMS error exceeds 5 percent we prompt after WET inversion to improve your traveltime picks regarding the traveltime reciprocity principle (Fig. 18).

Below we show reprocessing of this line with our version 4.01 software with WDVS (Zelt and Chen 2016) enabled, done in Dec 2020. WDVS Wavelength-Dependent Velocity Smoothing is described in

Zelt, C. A. and J. Chen, Frequency-dependent traveltime tomography for near-surface seismic refraction data, Geophys. J. Int., 207, 72-88, 2016

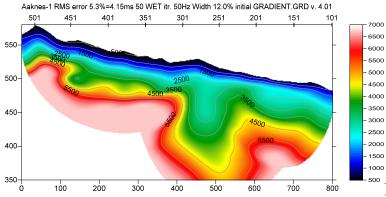
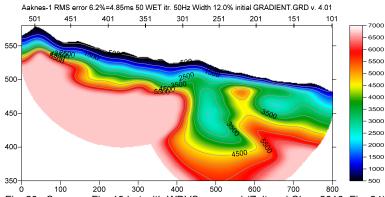
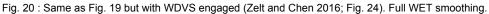
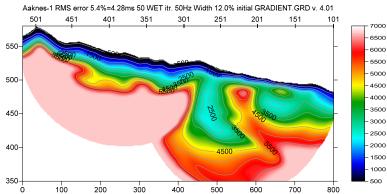
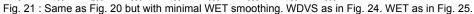


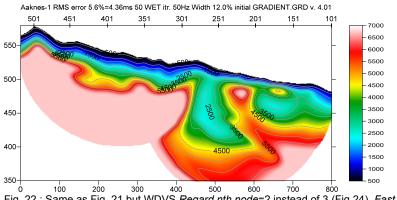
Fig. 19 : 2D WET tomogram obtained with *WET Tomo*|*Interactive WET tomography* & 50 Steepest-Descent WET iterations using 1D-gradient starting model shown in Fig. 5. Same as Fig. 8.



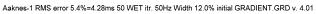


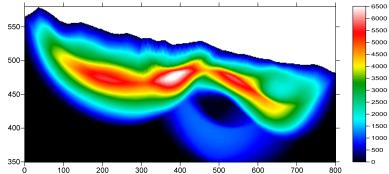


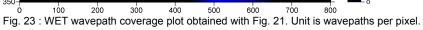












Edit WDVS (Zelt & Chen 2016)				
Edit parameters for wavelength-dependent velocity smoothing				
use WDVS for forward mod	use WDVS for forward modeling of traveltimes			
WDVS frequency	50	[Hz]		
Angle increment	5	[Degree]		
Regard nth node	3	[node]		
Parameters for Cosine-Square	d weighting func	tion		
a : Cosine argument power	1.000	[power]		
b : Cosine-Squared power	1.000	[power]		
OK Cancel	Res	et		



Edit WET Wavepath Eikonal Traveltime Tomography Parameters	Edit WET Tomography Velocity Smoothing Parameters
Specify initial velocity model Seject D:\ray32\aaknes-1\GRAD_WDVS_Dec17\GRADIENT.GRD	Determination of smoothing filter dimensions G Full smoothing after each tomography iteration
Stop WET inversion after Number of WET tomography iterations : 50 iterations	 Minimal smoothing after each tomography iteration Manual specification of smoothing filter, see below
or RMS error gets below 20 or RMS error does not improve for n = 20 iterations	Smoothing filter dimensions Half smoothing filter width : 4 columns Half smoothing filter height : 1 grid rows
WET regularization settings Wavepath frequency : 50 Hz Iterate	Suppress artefacts below steep topography Adapt shape of filter. Uncheck for better resolution.
Ricker differentiation [-1:Gaussian2:Cosine]: -1 times Wavepath width [percent of one period]: 12.0 percent Iterate	Maximum relative velocity update after each iteration Maximum velocity update : 25.00 percent
Wavepath envelope width [% of period] : 0.0 percent Min. velocity : 10 Max. velocity : 6500 m/sec.	Smooth after each nth iteration only Smooth nth iteration : n = 1 iterations
Width of Gaussian for one period [sigma]: 3.0 sigma Gradient search method	Smoothing filter weighting C Gaussian I Uniform No smoothing Used width of Gaussian 1.0 sigma
Conjugate Gradient Parameters	Uniform central row weight 1.0 [1100]
CG iterations 10 Line Search iters. 2 Tolerance 0.001 Line Search tol. 0.0010	Smooth velocity update before updating tomogram
Initial step 0.10 Steepest Descent step Edit velocity smoothing Edit arid file generation	Damping of tomogram with previous iteration tomogram Damping [01] 0.000 Damp before smoothing
Start tomography processing Reset Cancel	Accept parameters Reset parameters

Fig. 25 : WET Tomo|nteractive WET main dialog (left). Edit velocity smoothing (right). Settings used for Fig. 21 & 22 & 23.

Note the apparently improved resolution in the overburden and sharper imaging of top-of-basement when engaging WDVS with minimal WET smoothing (Fig. 21 & Fig. 22). As shown in Fig. 13 & Fig. 14 the recording geometry and topography is highly uncertain and disputed for this line. Fig. 12 (left) shows reciprocal traveltime picking errors in *Trace*|*Offset gather*. These errors are caused by too low signal-to-noise ratio (Fig. 16) and errors in specification of used recording geometry. WET interpretation using WDVS shown in Fig. 20, Fig. 21 and Fig. 22 may *over-fit these noisy first break data* and Fig. 19 (Smooth inversion without WDVS) may be more reliable.

We found the shown and used *WDVS frequency* of 50Hz (Fig. 24) by iteratively decreasing from 400Hz/200Hz/100Hz/75Hz (Zelt and Chen 2016). Decrease WDVS parameters *Regard nth node* and *Angle increment* or *WDVS frequency* to obtain sharper imaging of velocity contrast and more shallow basement top. You need to tune these WDVS parameters for each individual line. If you decrease these WDVS parameters too much then high-velocity anomalies in overburden may show too much contrast (Fig. 22) and top-of-basement may be imaged too shallow and too fast.

Check option WET Tomo|WET tomography Settings|Limit WET velocity to maximum velocity in initial model to counter a bias towards too high velocities in basement when enabling WDVS. This bias gets stronger when you decrease the WDVS frequency or the two other WDVS parameters : Angle increment and Regard nth node. We limited max. WET velocity to 6,500 m/s in Fig. 25 with option WET Tomo|WET tomography Settings|Edit maximum valid WET velocity checked.

WDVS option *Model*|*Fast WDVS Smoothing* maps radial scan line nodes to velocity grid nodes less accurately during WDVS smoothing. See <u>https://rayfract.com/help/release_notes.pdf</u> bullets dated Nov 10 and Nov 12, 2020. See also our 2022 tutorial showing <u>WDVS enabled interpretation of Line14</u> data.

(Zelt and Chen 2016) show the effect of varying the WDVS frequency.

Basically the optimum choice of the *WDVS frequency* is subjective. The lower the WDVS frequency the stronger the contrast of imaged velocity anomalies in overburden and the more shallow the top-of-basement is imaged. Same applies when decreasing WDVS parameters *Regard nth node* and *Angle increment*.

We give you meaningful parameters for <u>WET inversion</u> and *WDVS Smoothing* to explore the non-unique solution space of the misfit function (<u>Schuster, 1993</u>). It is your job to navigate this solution space using these parameters and appropriate heuristics to arrive at a satisfying solution showing small RMS error and good correlation with a priory knowledge from boreholes, outcrops, trenching and other geophysical methods such as resistivity etc.

See our updated <u>help file</u> for description of WDVS parameters in chapter *Forward model traveltimes*. Press F1 function key in *Model*|*WDVS Smoothing dialog* (Fig. 24) to display popup help window for current control. Use TAB key to switch focus between controls. See our updated tutorials showing WDVS :

http://rayfract.com/tutorials/epikinv.pdf http://rayfract.com/tutorials/sageep11_16.pdf http://rayfract.com/tutorials/camp1.pdf http://rayfract.com/tutorials/11REFR.pdf http://rayfract.com/tutorials/jenny13.pdf http://rayfract.com/tutorials/NORCAL14.pdf

Here is the archive with seis32.* profile database files for Fig. 21 and Fig. 23 Here is the archive with Surfer 11 .GRD and .SRF and .PAR files for Fig. 21 and Fig. 23

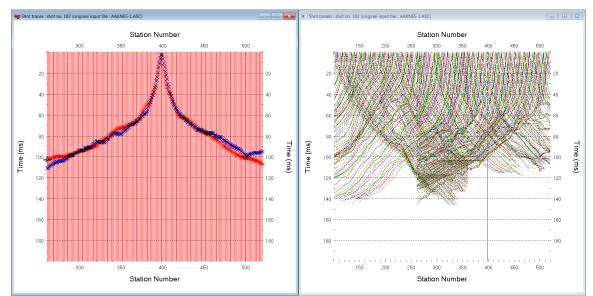


Fig. 26 : Trace|Shot gather (left). Red crosses are picked times. Blue crosses are modeled times. Refractor|Shot breaks (right). Solid curves are picked traveltime curves. Dashed curves are modeled traveltime curves.

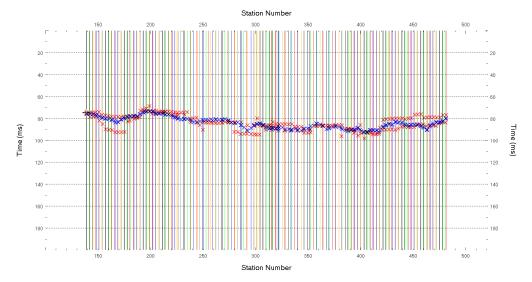
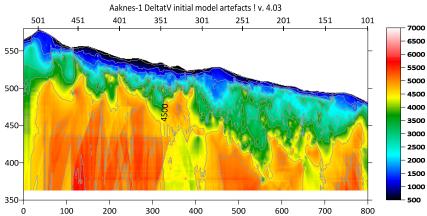


Fig. 27 : Trace|Offset gather. Common offset 149m. Red crosses are picked times. Blue crosses are modeled times.

Note the inconsistent first break picks in Fig. 26 and Fig. 27. Compare these displays with the consistently picked traveltimes in our <u>OT0608 tutorial</u> (Fig. 23 and Fig. 24 on last page).

On the next page we compare *Interactive DeltatV* inversion with suboptimal/pessimized *DeltatV* parameters used by NGU for their Fig. 4.1 in <u>NGU report 2019_004</u> (our Fig. 28) with our *Automatic DeltatV* with max. velocity exported increased to 6,000 m/s (our Fig. 29).

In Fig. 28 we show *DeltatV*[*Interactive DeltatV* inversion with *DeltatV settings* and parameters copied from /reset to DELTATV.PAR made available by NGU for their Fig. 4.1 in <u>NGU report 2019_004</u>. In Fig. 29 we show *DeltatV*[*Automatic DeltatV* with same *DeltatV settings* (Fig. 33) and parameters as for Fig. 28, with *max. velocity exported* increased to 6,000 m/s (Fig. 32). In Fig. 31 we compare NGU DELTATV.PAR used for Fig. 28 with automatic default DELTATV.PAR parameters used for Fig. 29.





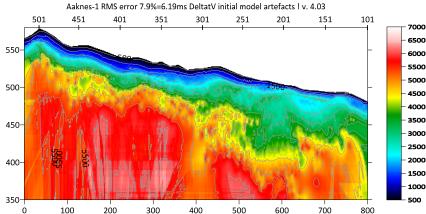
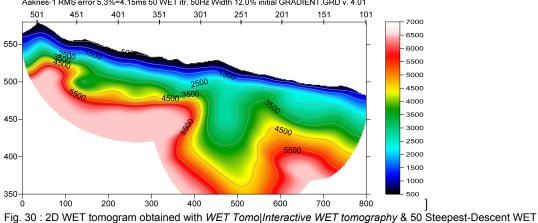


Fig. 29 : Deltat|Automatic DeltatV. DeltatV settings as for Fig. 28 (Fig. 33). Max. velocity exported 6,000m/s (Fig. 32). Default CMP curve stack width 84 CMP's. Default Topography filter 15 stations. See Fig. 31 for differences in DeltatV parameters compared to NGU bad parameters used for Fig. 28.



Aaknes-1 RMS error 5.3%=4.15ms 50 WET itr. 50Hz Width 12.0% initial GRADIENT.GRD v. 4.01

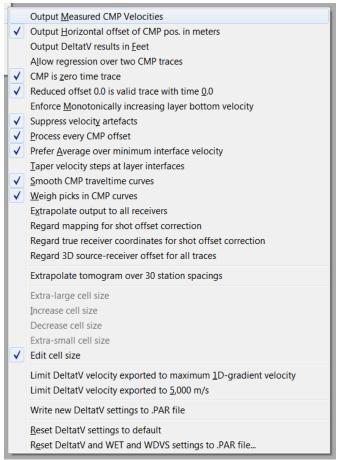
iterations using 1D-gradient starting model shown in Fig. 5. Same as Fig. 8. Note the too wide *Topography smoothing filter* 100 stations (Fig. 31 right) used by NGU & for Fig. 28

compared to default *Topography smoothing filter* 15 stations (Fig. 31 left) used to obtain Fig. 29.

Also note the too narrow **DeltatV CMP curve stack width** 15 CMP's (Fig. 31 right) used by NGU & for Fig. 28 compared to default **DeltatV CMP curve stack width** 84 CMP's (Fig. 31 left) used for Fig. 29. The CMP curve stack width is determined automatically based on your profile's length and station spacing.

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f 1: Change 1 line (2, first file) to 1 line (2, second file)		
ay32\aaknes-1\TOMO_July9_2022\DELTATV.PAR	🕒 🔻 🍓	D:\ray32\aaknes-1\Tomo_July9_Fig4.1Settings\TOMO_JULY9_FIG4.1SETTINGS.PAR
Delta-t-v parameters : Delta-t-v stack width : 84 Regression over offset stations : S Lingar regression : 1 Weathering sub-layer count : 3 Maximum valid velocity : 6000 Output at every 2M f: 1 Delta-t-v static parameters : No statics : Surface consistent corrections : 1 CMP Gather datum plane specific corrections : 0 Take v0 from Station & Shotpoint editor : 0 Estimate v0 automatically, with weathering crossover : 1 Woography smoothing filter width : 15 Inverse CMP offset power : 0.50 Delta-t-v export parameters : Maximum velocity exported : 6000 Flave to export parameters : Maximum velocity exported : 10 Export depth velocities : 0 Gridding method (see 'ray22\reftyridding.txt) : 2 XTV parameters : Modified Dix inversion for constant velocity layers : 1 Intercept time inversion for constant velocity layers : 0 Winimum velocity contrast for intercept time layer : 0 Velocity step for previous intercept time layer : 0 Velocity step for previous intercept time layer : 1 Export dept of previous intercept time layer : 25 Prefer measured layer top velocities : 0 Export CMP results in feet : 0 Wean of unsigned difference between measured and inverted velocs : 1 Export depta dayer top velocities : 0 Export CMP ray offset in meters : 1 Export depta for previous intercept time layer : 0 Velocity step for current intercept time layer : 0 Velocity step for unrent intercept time layer : 25 Prefer measured layer top velocity over inverted : 1 Export Delta-t-V results in feet : 0 Mean of unsigned difference between measured and inverted velos : Standard deviation of unsigned difference between velocities : 7.4 First horizontal offset, at topography : -5.35600 ist borizontal offset, at topography : -5.35600 ist borizontal offset to transmeants : 1 HI	8.10 11	<pre>1 Delta-t-V parameters : 2 Delta-t-V stack width :15 3 Regression over offset stations : 5 4 Median fit regression : 5 Median fit regression : 6 Meathering sub-layer count : 3 5 Meathering sub-layer count : 3 6 Meathering sub-layer count : 3 7 Meathering sub-layer count : 3 9 Output at every CMP : 1 9 Output at every CMP : 1 10 Output at every CMP : 1 10 Delta-t-V static parameters : 11 Most Statics : 0 12 Surface consistent corrections : 1 13 CMP Cather datum plane specific corrections : 0 13 Take V0 from Station & Shotpoint editor : 0 14 Take V0 from Station & Shotpoint editor : 0 15 Stimate V0 automatically, with the 16 Stimate V0 automatically, with the 17 Take V0 from Station & Shotpoint editor : 0 18 Take V0 from Station & Shotpoint editor : 0 19 Delta-t-V export parameters : 20 Delta-t-V export parameters : 21 Delta-t-V export parameters : 22 Delta-t-V export parameters : 22 Delta-t-V export parameters : 23 Delta-t-V export parameters : 24 Delta-t-V export parameters : 25 Delta-t-V export parameters : 26 Delta-t-V export parameters : 27 Delta-t-V export parameters : 28 Delta-t-V export parameters : 29 Delta-t-V export parameters : 20 Delta-t-V export parameters : 20 Delta-t-V export parameters : 20 Delta-t-V export parameters : 21 Delta-t-V export parameters : 22 Modified Dix inversion for constant velocity layers : 1 23 Try parameters : 23 Modified Dix inversion for constant velocity layers : 1 24 Try parameters : 25 Modified Dix inversion for constant velocity layers : 0 26 Minimum velocity contrast for intercept time layer : 25 27 Prefer measured layer top velocity over inverted : 1 28 Modified Dix inversion for constant velocity layers : 0 29 Meanters time tercept time layer : 25 20 Prefer measured layer top velocity over inverted : 1 20 Dout measured layer top velocity over inverted : 1 20 Dout measured layer top velocity over inverted : 1 20 Dout measured layer top velocity over inverted : 1 20 Dout measured layer top velocity over inverted velos : 11.27 20 Standard deviation of unsigned diffe</pre>
Col 1 97 lines INS Read-only Edit Plug-in Newer 3.6 KB	ANSI	Ln 2, Col 1 97 lines INS Read-only Edit Plug-in Older 3.6 KB ANSI

Fig. 31 : compare NGU DELTATV.PAR (right, used for Fig. 28) with automatic default DELTATV.PAR for Fig. 29 (left).



DeltatV method export options				
Max. velocity exported [m/sec.]				
✓ limit velocity exported	🔽 negative depths			
Handling of too high velocities				
Depth information exported absolute elevations C depth below topo				
Gridding method Kriging	•			
Accept	Reset			

Fig. 32 (above) : DeltatV|Interactive DeltatV|Export Options. Increase Max. velocity exported to 6,000 m/s. Click Accept and Cancel buttons.

Fig. 33 (left) : *DeltatV*|*DeltatV* Settings used for Fig. 28 and Fig. 29.

To obtain Fig. 28 do these steps :

- create the profile database and import the .ASC and update header data with .COR and .SHO as on first page of this tutorial if not yet done so
- open Windows Explorer window
- create directory C:\NGU_Fig4.1 in Windows Explorer
- b download archive Fig 4.1.zip and copy into C: \NGU_Fig4.1 folder in Windows Explorer and unzip
- ➢ select DeltatV |DeltatV Settings | Reset DeltatV and WET and WDVS settings to .PAR file
- select C: \NGU_Fig4.1\DELTATV.GRD and confirm prompt with Yes button
- ▶ select *DeltatV Interactive DeltatV*. Confirm artefact prompt and click button *DeltatV Inversion*.
- click Save button to save file DELTAT. TXT into folder C:\RAY32\AAKNES-1
- ▶ wait for Surfer to complete the gridding and imaging of C:\RAY32\AAKNES-1\DELTATV.GRD
- select Model Forward model traveltimes and C:\RAY32\AAKNES-1\DELTATV.GRD
- select Grid|Turn around grid file by 180 degrees and C:\RAY32\AAKNES-1\DELTATV.GRD
- select Grid Image and contour velocity and C:\RAY32\AAKNES-1\DELTATV.GRD

Next obtain Fig. 29 with these additional steps :

- ➢ select DeltatV |DeltatV Export options or DeltatV |Interactive DeltatV |Export options
- ▶ increase Max. velocity exported to 6,000 m/s (Fig. 32). Click buttons Accept and Cancel.
- ➢ select DeltatV Automatic DeltatV and confirm artefact warning prompt with Yes button
- ➢ select Model | Forward model traveltimes and C:\RAY32\AAKNES-1\TOMO\DELTATV.GRD
- ➢ select Grid|Turn around grid file by 180 degrees and C:\RAY32\AAKNES-1\TOMO\DELTATV.GRD
- select Grid Image and contour velocity and C:\RAY32\AAKNES-1\TOMO\DELTATV.GRD

The too wide *Topography smoothing filter* 100 stations used by NGU (Fig. 31 right) causes overcorrection of basement-refracted first breaks with too large static time corrections to too smooth floating datum obtained with this too wide *Topography smoothing filter* 100 stations (Fig. 28). Also due to the too narrow *CMP curve stack width* of 15 CMP's (Fig. 31 right) used by NGU the pseudo-2D DeltatV plot (Fig. 28) is not smoothed enough laterally/in horizontal direction with such strong topography. This constitutes not an optimization but rather a pessimization of default DeltatV parameter settings by NGU. Compare Fig. 28 with Fig. 4.1 (top right) in <u>NGU report 2019_004</u> to see similar artefacts caused by the same pessimized DeltatV settings.

The *CMP curve stack width* in *DeltatV*[*Interactive DeltatV* main dialog is automatically determined based on your profile's length and *Station spacing*. We strongly recommend leaving the *CMP curve stack width* at this already optimized default setting. Also we strongly recommend using *DeltatV*[*Automatic DeltatV* instead of *DeltatV*[*Interactive DeltatV* for more reliable DeltatV interpretation. DeltatV main dialog and DeltatV static corrections dialog are reset to safe default values with *Automatic DeltatV* inversion.

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

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

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

For latest version of our help chapter on XTV inversion see <u>https://rayfract.com/help/XTV_inversion_July_2022.pdf</u>.

Here is the <u>archive with Surfer 23 .GRD and .SRF and .PAR files for Fig. 28</u> Here is the <u>archive with Surfer 23 .GRD and .SRF and .PAR files for Fig. 29</u> Here is the <u>archive with seis32.* profile database files for Fig. 29</u> Here is the <u>archive with NGU DELTATV.PAR for Fig. 28</u>, made available by NGU on July 4, 2022

See also our <u>NGU_G1 tutorial</u> comparing pessimized DeltatV static correction settings used by NGU (Fig. 30) with our optimized DeltatV+XTV settings and default static correction settings (Fig. 25 and Fig. 32).

Conclusions

With significant errors in reciprocal traveltime picks (Fig. 27) of up to 15ms and strong and uncertain topography (Fig. 13 and 14) we strongly recommend using our default fail-safe *Smooth inversion* method (*Smooth invert*|*WET with 1D-gradient initial model*) which eliminates DeltatV artefacts by laterally averaging DeltatV velocities over the whole profile (<u>Sheehan, 2005</u>). Over-fitting such noisy data with our multirun WET inversion and too much minimized WET smoothing does not make sense. Low-resolution input gives low-resolution output. However WDVS (<u>Zelt and Chen 2016</u>) can help even with noisy picks (Fig. 21, Fig. 22).

Also we strongly recommend using *DeltatV*[*Automatic DeltatV* instead of *DeltatV*]*Interactive DeltatV* for more reliable DeltatV interpretation. DeltatV main dialog and DeltatV static corrections dialog are reset to safe default values with *Automatic DeltatV* inversion. Edit export options (Fig. 32) with new *DeltatV menu* item *DeltatV Export options* available in latest 4.03 build dated July 14, 2022. Edit XTV parameters with *DeltatV menu*|*XTV parameters* & check version 4.03 box *Use above XTV settings for Automatic DeltatV*.

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