SRT imaging of buried stream channel in estuary setting with 21 shots into 67 receivers :

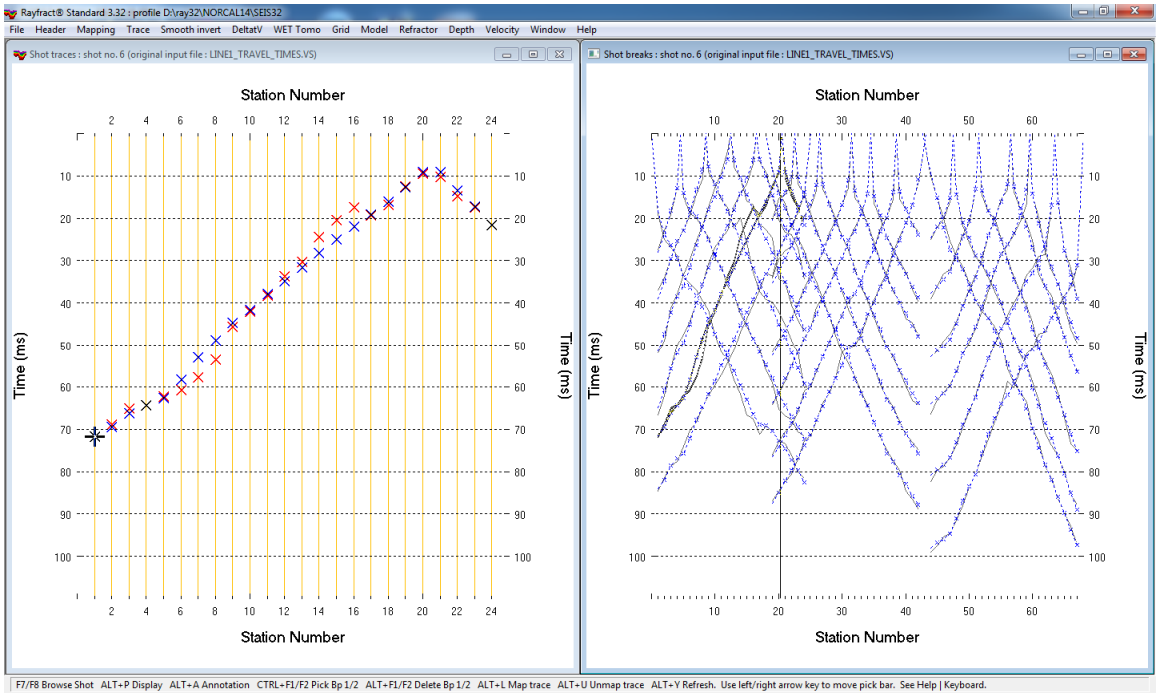

Fig. 1 : left : *Trace|Shot gather*, right : *Refractor|Shot breaks*. Shows fit between picked times (solid grey curves, red crosses) and modeled times (dashed blue curves, blue crosses) obtained by forward modeling over Fig. 2b. Compare with Fig. 15 showing fit for Fig. 12.

- *File|New Profile…*, set *File name* to NORCAL14 and click *Save button*
- set *Station spacing* to 6.096m in *Header|Profile…*
- unzip NORCAL14.ZIP with `Line1_travel_times.VS` and `Line1.COR` in `C:\RAY32\NORCAL14\INPUT`
- uncheck *File|Import Data Settings|Default distance unit is meter* to specify unit feet
- uncheck *File|Import Data Settings|Default time unit is seconds* to specify unit ms
- select *File|Import Data…* and set *Import data type* to `Geometrics PlotRefa .VS`
- leave *Default spread type* at *10: 360 channels*
- click upper *Select button*, navigate into `C:\RAY32\NORCAL14\INPUT` and select the .VS file
- click *Open button*, *Import shots button.* The *Import shot dialog* is shown for each shot in the .VS file.
- for each shot leave *Layout start* and *Shot pos.* at shown values and click *Read button*
- *File|Update header data|Update Station Coordinates* with `C:\RAY32\NORCAL14\INPUT\Line1.COR`
- select *Trace|Shot gather* and *Window|Tile* to obtain Fig. 1 .
- for both windows click title bar, press ALT+P, set *Maximum time* to 110 ms and hit ENTER key.
- uncheck *Smooth invert|Smooth inversion Settings|Interpolate velocity for 1D-gradient initial model*
- uncheck *Smooth inversion Settings|Wide smoothing filter for 1D initial velocity profile*
- check *Smooth inversion Settings|Limit WET velocity to maximum velocity in initial model*
- select *Smooth invert|WET with 1D-gradient initial model* and confirm for default interpretation
- select *WET Tomo|Interactive WET tomography…*
- set *Number of WET tomography iterations* to 100 and click *Start tomography processing* for Fig. 2 & 3
- for *WET parameters* used see archive NORCAL14_332GRADTOMO.RAR with starting model files GRADIENT.GRD & GRADIENT.PAR, VELOIT100.GRD & .PAR and .SRF Surfer 11 plots
- see Fig. 4 and Fig. 5 for *WET parameters* and *WET settings* used
- for help on our new *WET smoothing* and *Conjugate Gradient* parameters see updated .pdf reference chapter ***WET Wavepath Eikonal Traveltime tomography***

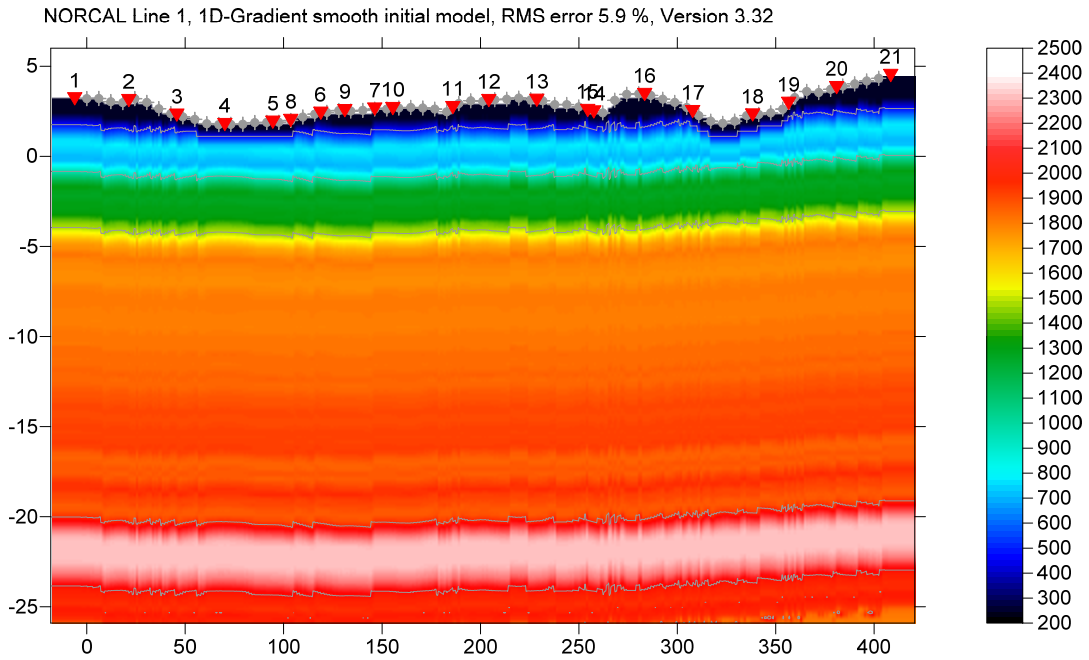

Fig. 2a : 1D-gradient starting model, obtained by horizontally averaging DeltatV inversion output. Smooth inversion settings as in Fig. 5. Default DeltatV settings.

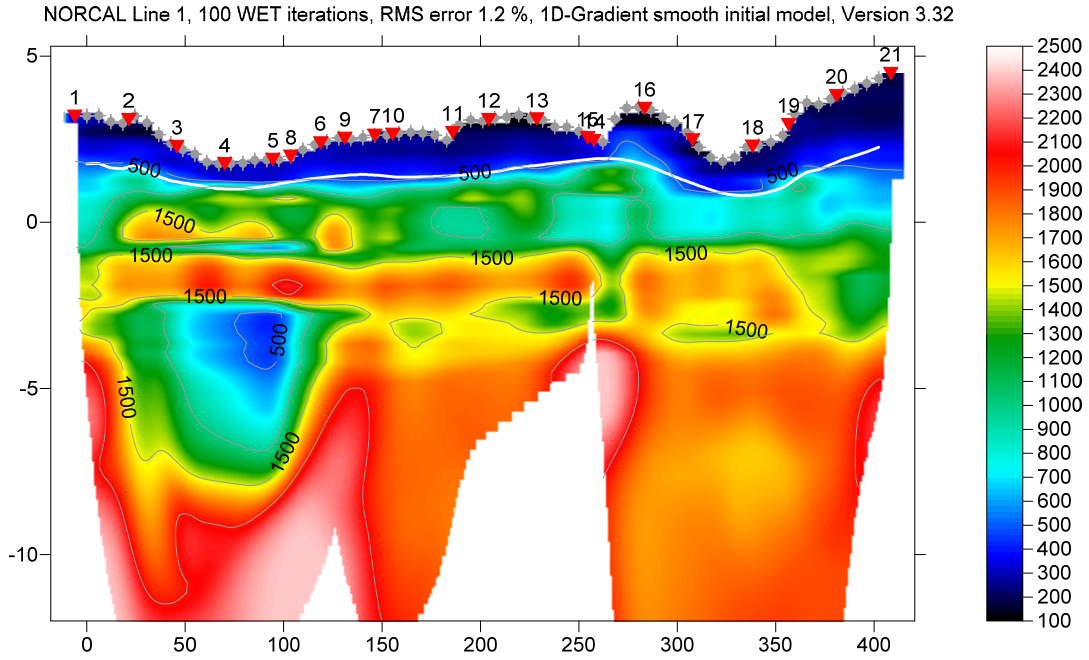

Fig. 2b : Tomogram with 1D-gradient starting model Fig. 2a, 100 Steepest Descent WET iterations, default settings. Wavepath width 5%, Gaussian smoothing. Smooth after every 2nd WET iteration. Smooth velocity update, smooth after last iteration. Smoothing sigma 1.0. Full smoothing filter : half filter width 18, half filter height 1. Maximum velocity update 25%. Don't adapt shape of rectangular filter. WET settings and blanking as in Fig. 5. Note the good correlation between CMP refractor from Fig. 10 (plotted as thick white line) and tomogram velocities.

The geology for this line consists of dry sand over saturated sand over terrace deposits in an estuary setting. The apparent cavity shown in Fig. 2b at horizontal offset 50m to 100m and elevation of -5m is probably a buried stream channel. According to Bachrach and Nur 1998 Fig. 1 the P-wave velocity of dry sand is about 200 m/s. See our Fig. 10 for CMP refraction model obtained assuming an overburden velocity of 200 m/s. We use this as a starting model for WET inversion. See Fig. 11 and following Figs. and instructions on page 3 and 5 of this tutorial.

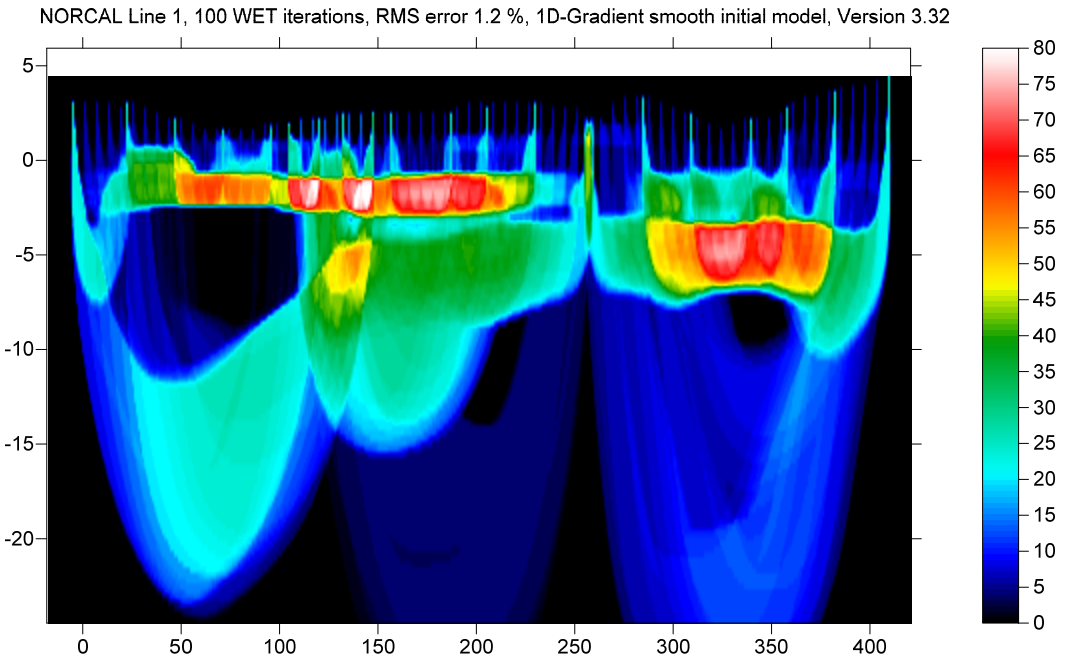

Fig. 3 : WET wavepath coverage plot obtained with Fig. 2b. Shows number of wavepaths per pixel.

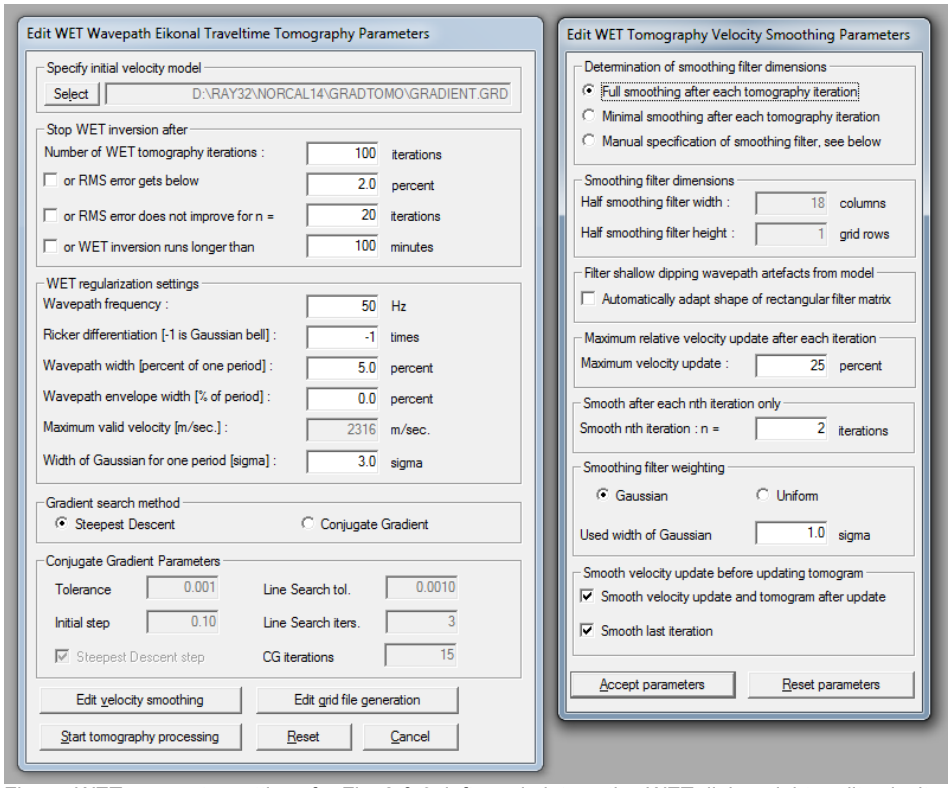

Fig. 4 : WET parameter settings for Fig. 2 & 3. left : main interactive WET dialog. right : edit velocity smoothing

- select *Header|Station* and click *button Reset v0*. Confirm prompt. Edit *v0* to 200 m/s and hit ENTER key
- select *Refractor|Midpoint breaks* and press ALT+M. Uncheck ***Direct wave first breaks recorded***.
- set *Refractor Count* to 1, *Weathering* limit to 1000 m/s, *CMP Stack Width* to 50. See Fig. 6.
- click *button Map Traces*. Press ALT+G & click *Accept button* to laterally smooth crossover distances.
- check *Grid|Plot refractors on tomogram.* Select *Depth|CMP Intercept-Time Refraction* and confirm to obtain Fig. 10. Continue as described on page 5 with *WET inversion* using Fig. 10 as starting model.

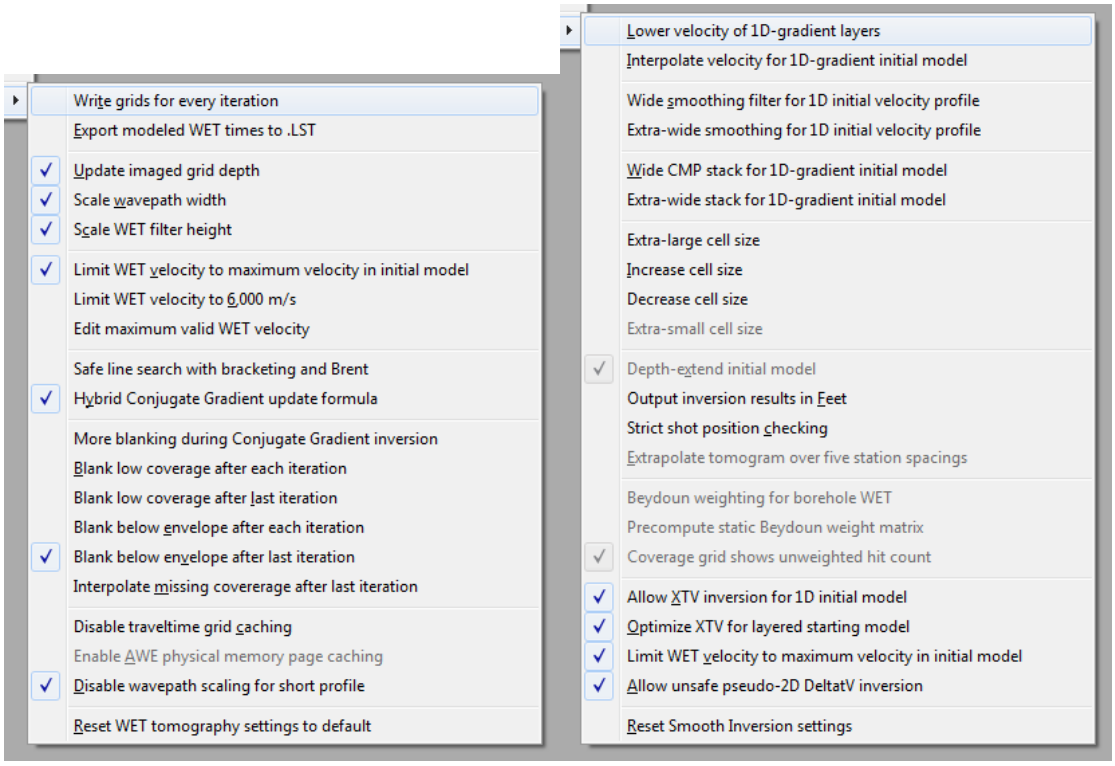

Fig. 5 : left : WET Tomo|WET tomography Settings . right : Smooth invert|Smooth inversion Settings for Fig. 2 & 3.

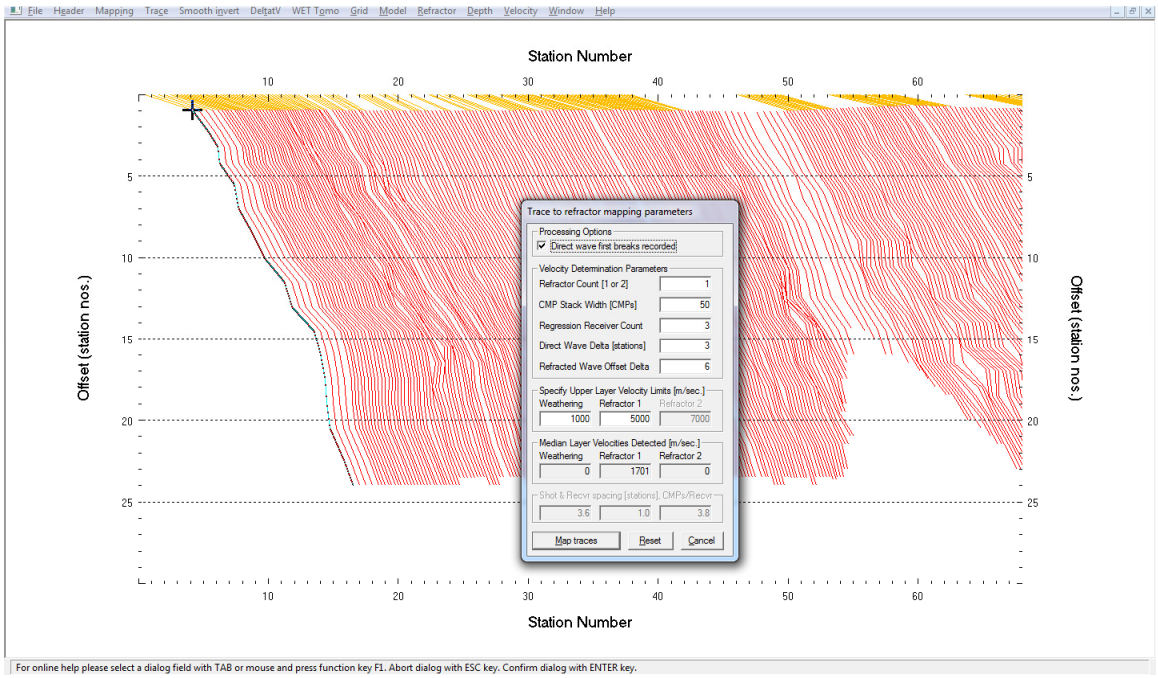

Fig. 6 : map traces to refractors in Refractor|Midpoint breaks with ALT+M

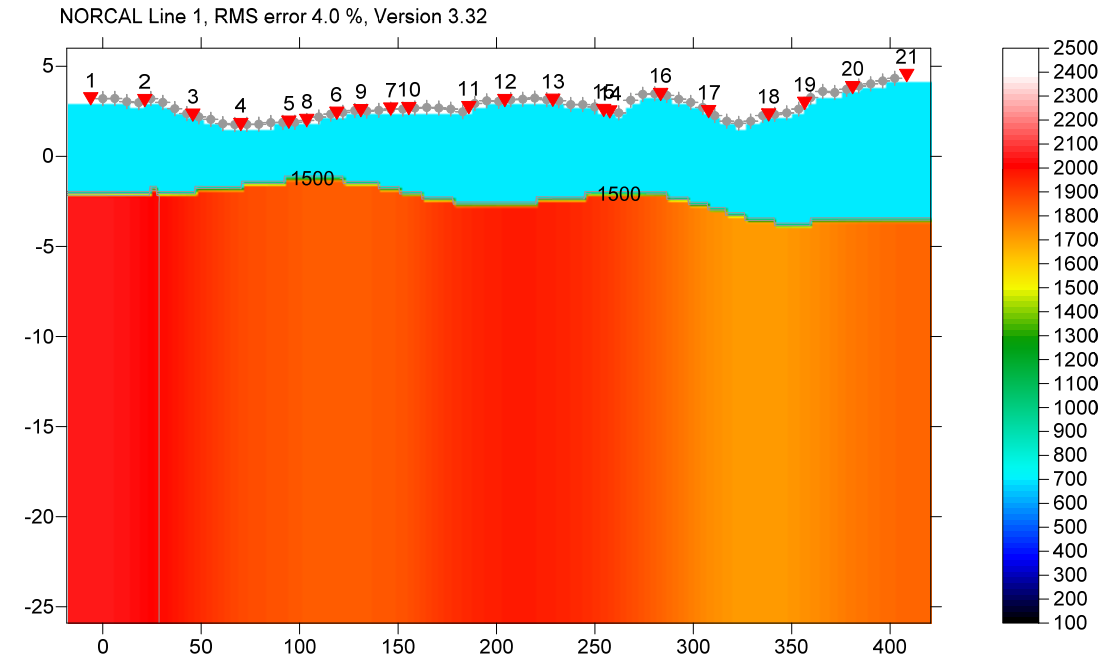

Fig. 7 : CMP intercept-time refraction starting model, obtained with Depth menu and mapping as in Fig. 6, weathering velocity edited to 700 m/s in Header|Station

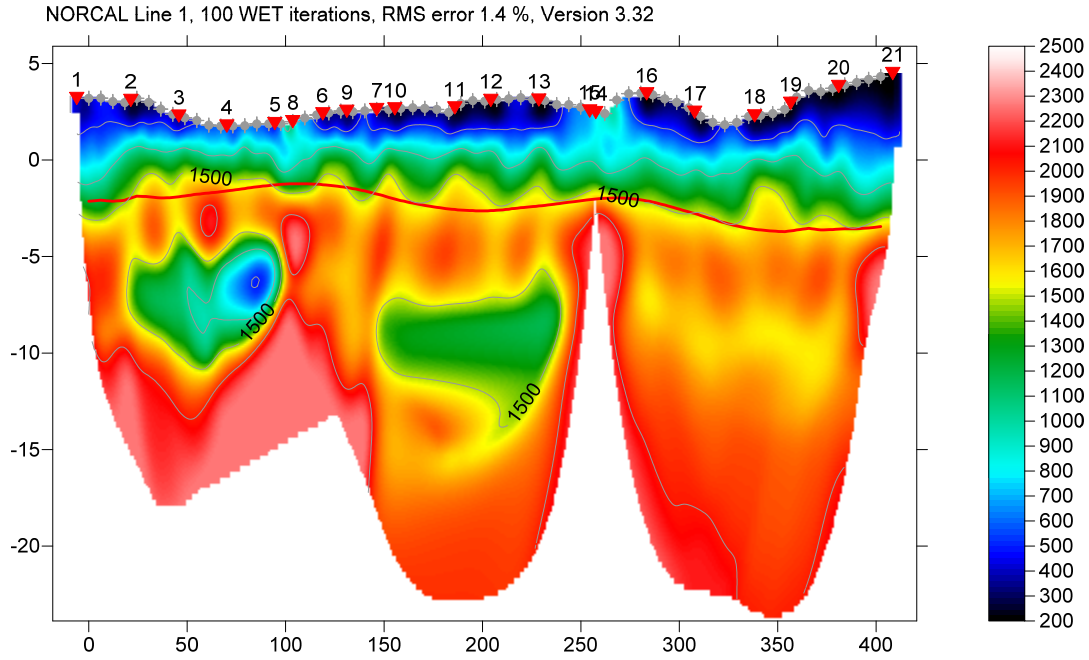

Fig. 8a : WET inversion 100 iterations, wavepath width 10%, Steepest Descent, minimal smoothing, adapt rectangular filter shape, uniform smoothing, starting model Fig. 7. Smooth after each 2nd WET iteration. Smooth velocity update, smooth after last iteration. See Fig. 9 for WET parameters used. WET settings and blanking as in Fig. 5. CMP refractor from Fig. 7 is plotted in red color. For .GRD & .PAR files and Surfer 11 plots see this archive.

- ***uncheck*** all ***WET blanking flags*** shown as checked Fig. 5 in *WET Tomo|WET tomography Settings*
- check *WET Tomo|WET tomography Settings|Limit WET velocity to maximum velocity in initial model*
- *WET Tomo|Automatic WET tomography* with `\RAY32\NORCAL14\LAYRTOMO\CMPMODL.GRD` to obtain Fig. 11
- select *WET Tomo|Interactive WET tomography…* and set *Number of WET tomography iterations* to 50
- set other *WET parameters* in main dialog and smoothing dialog as shown in Fig. 14
- click *button Start tomography processing* to obtain Fig. 12 and Fig. 13
- select *Refractor|Shot breaks* to display Fig. 15 showing fit between picked and modeled times

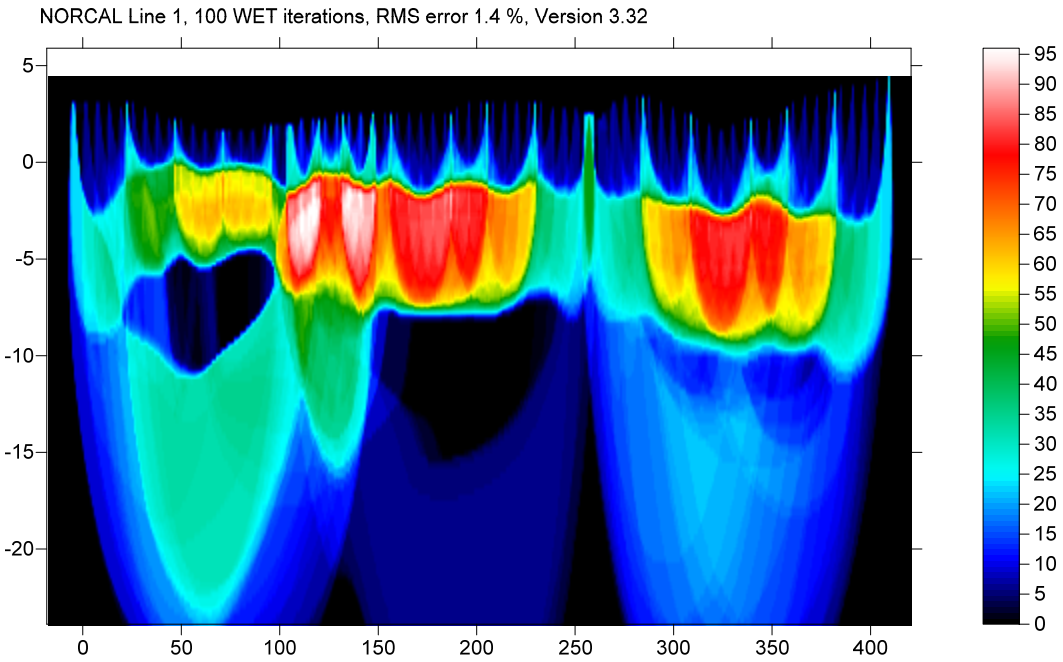

Fig. 8b : WET wavepath coverage plot obtained with Fig. 8a. Shows number of wavepaths per pixel. Note low coverage below elevation -7m at horizontal offset 150m to 250m. This means corresponding low-velocity anomaly in Fig. 8a is not certain.

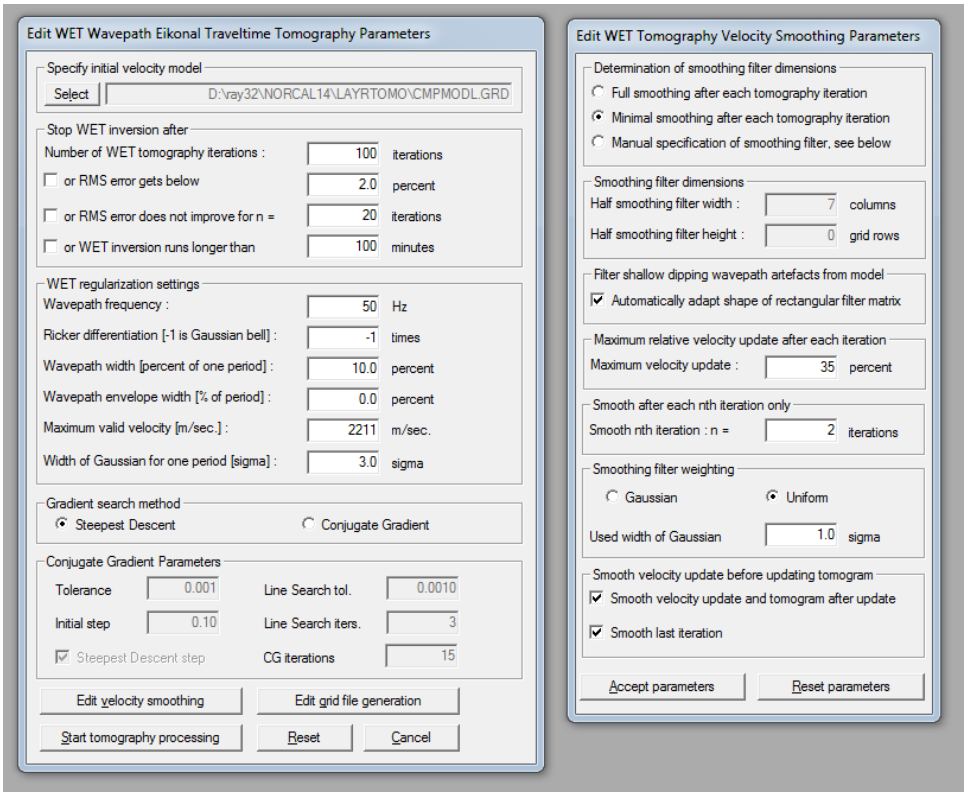

Fig. 9 : WET parameters to obtain Fig. 8 tomogram, with Fig. 7 as starting model. WET settings and blanking as in Fig. 5. To reset WET parameters for Fig. 8 unzip this archive in directory C:\RAY32\NORCAL14\LAYRTOMO and select *Grid|Reset DeltatV and WET settings to .PAR file...* & C:\RAY32\NORCAL14\LAYRTOMO\VELOIT100.GRD .

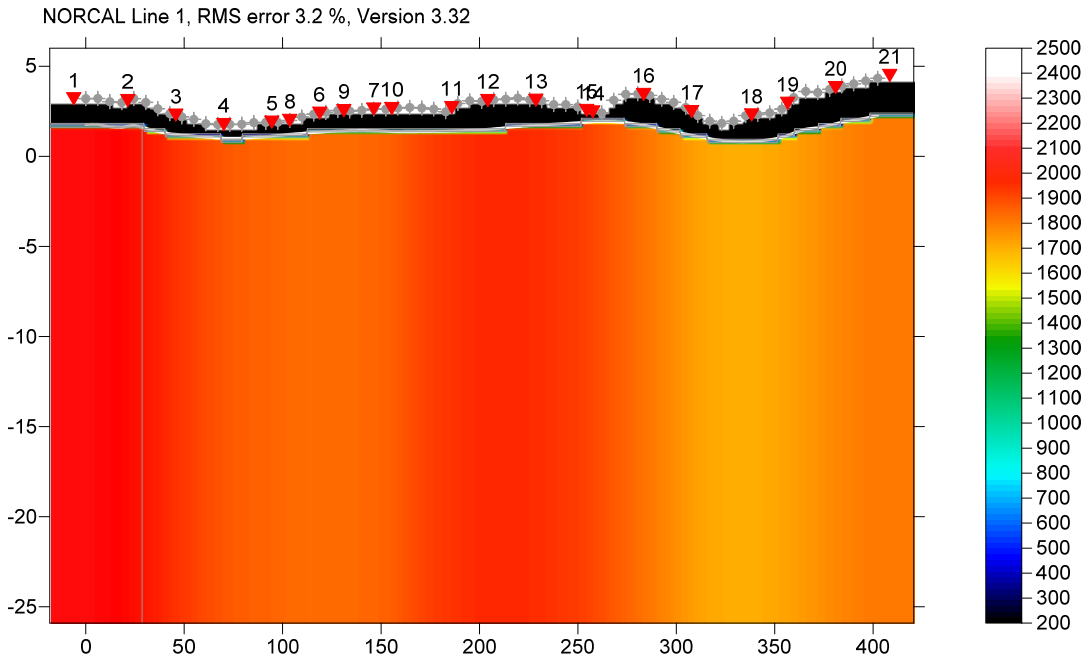

Fig. 10 : CMP intercept-time refraction starting model, obtained with Depth menu and mapping as in Fig. 6, weathering velocity edited to 200 m/s in Header|Station. Compare with Fig. 7 : weathering velocity fixed at 700 m/s.

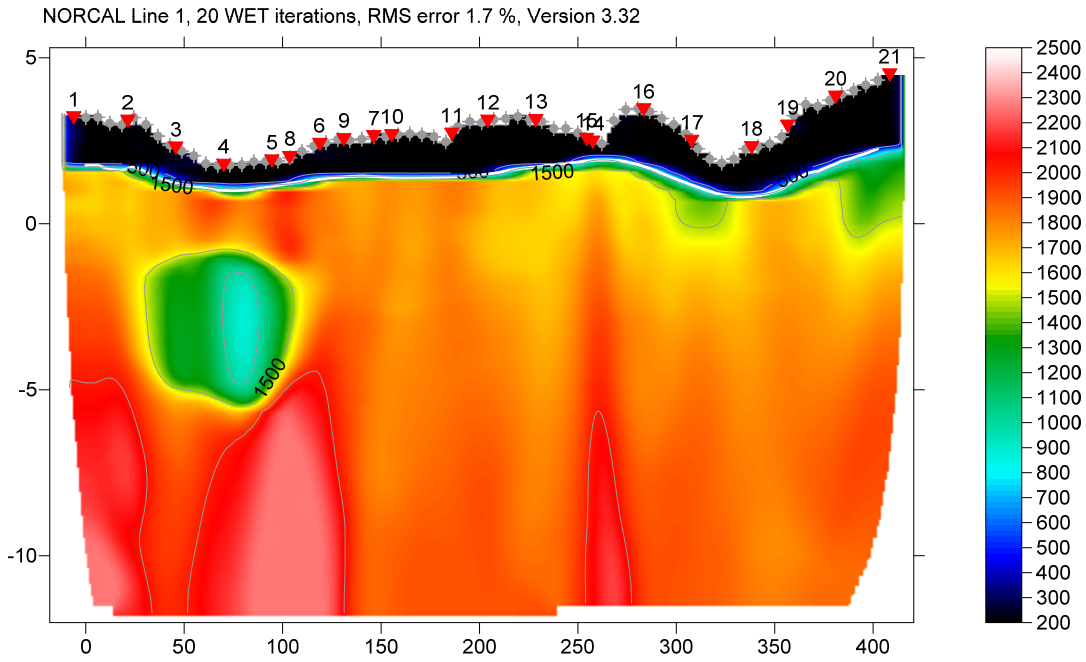

Fig. 11 : WET inversion 20 iterations, wavepath width 5%, Steepest Descent, full smoothing, don't adapt rectangular filter shape, Gaussian smoothing, starting model Fig. 10. Smooth after each 2nd WET iteration. Smooth velocity update, smooth after last iteration. Don't blank at tomogram bottom. See Fig. 14 for WET parameters used. WET settings as in Fig. 5 but no blanking below envelope. CMP refractor from Fig. 10 is plotted in white color.

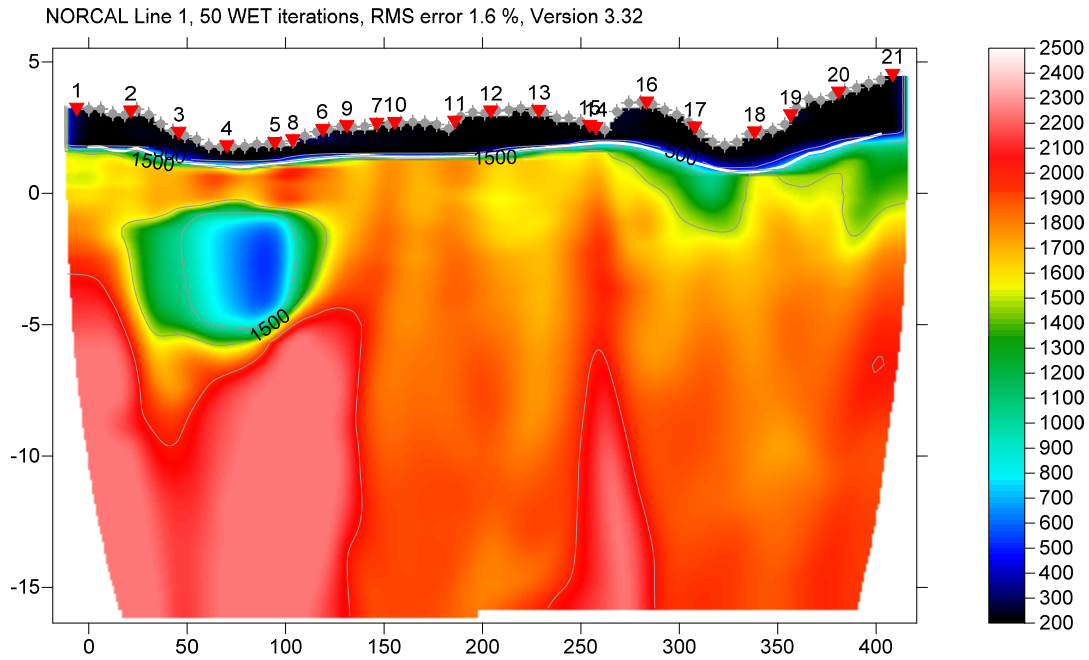

Fig. 12 : WET inversion 50 iterations, wavepath width 5%, Steepest Descent, full smoothing, don't adapt rectangular filter shape, Gaussian smoothing, starting model Fig. 10. Smooth after each 2nd WET iteration. Smooth velocity update, smooth after last iteration. Don't blank at tomogram bottom. See Fig. 14 for WET parameters used. CMP refractor from Fig. 10 is plotted in white color.

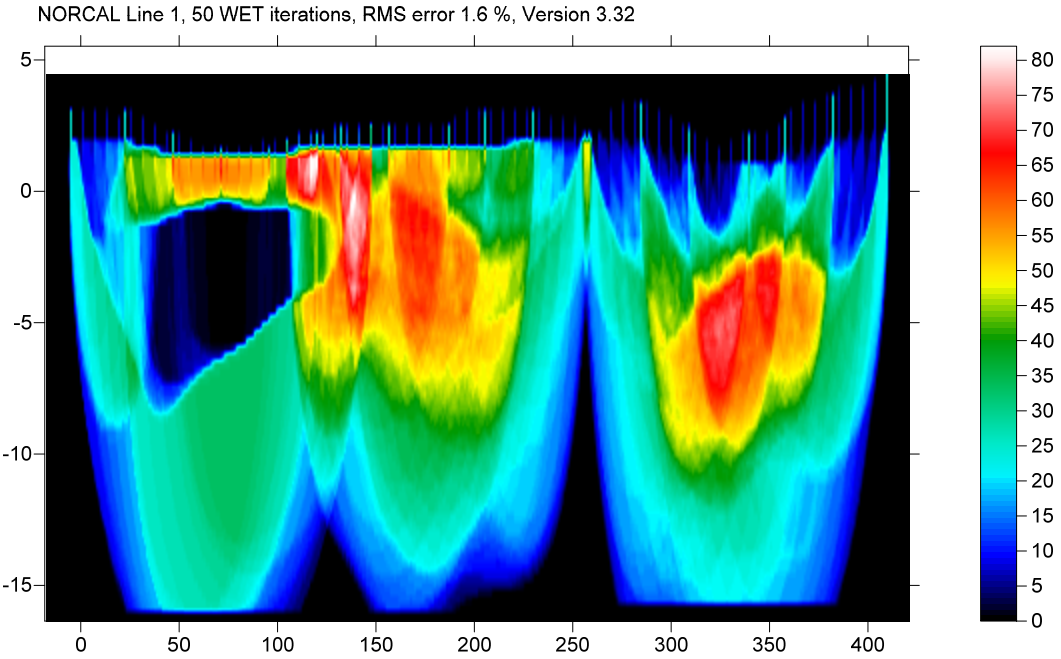

Fig. 13 : wavepath coverage plot obtained with Fig. 12. Shows number of wavepaths covering each pixel.

The low velocity in the cavity at offset 50m to 100m can be explained by high water content and possibly organic rich sediments. This would result in gas in the pores which reduces the P-wave velocity. The shape and elevation of this low-velocity anomaly is not well constrained by the data and varies between Fig. 2b, 8, 11 and 12. For .GRD files and VELOIT50.PAR file and starting model CMPMODL.GRD & .PAR for Fig. 10 to 13 see this archive.

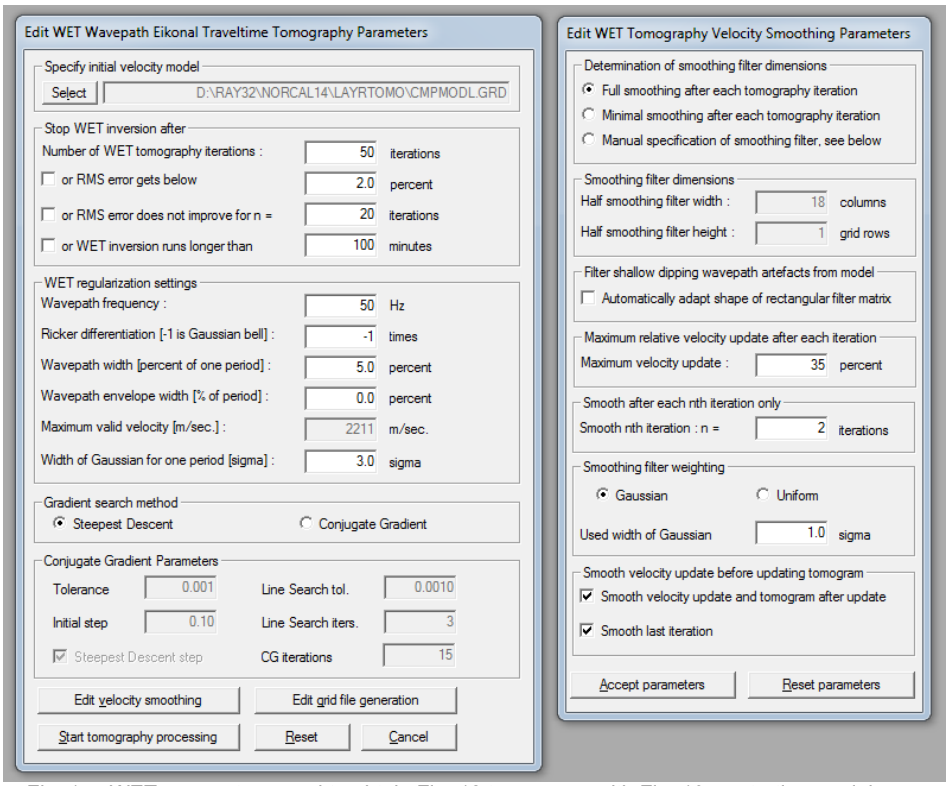

Fig. 14 : WET parameters used to obtain Fig. 12 tomogram, with Fig. 10 as starting model.

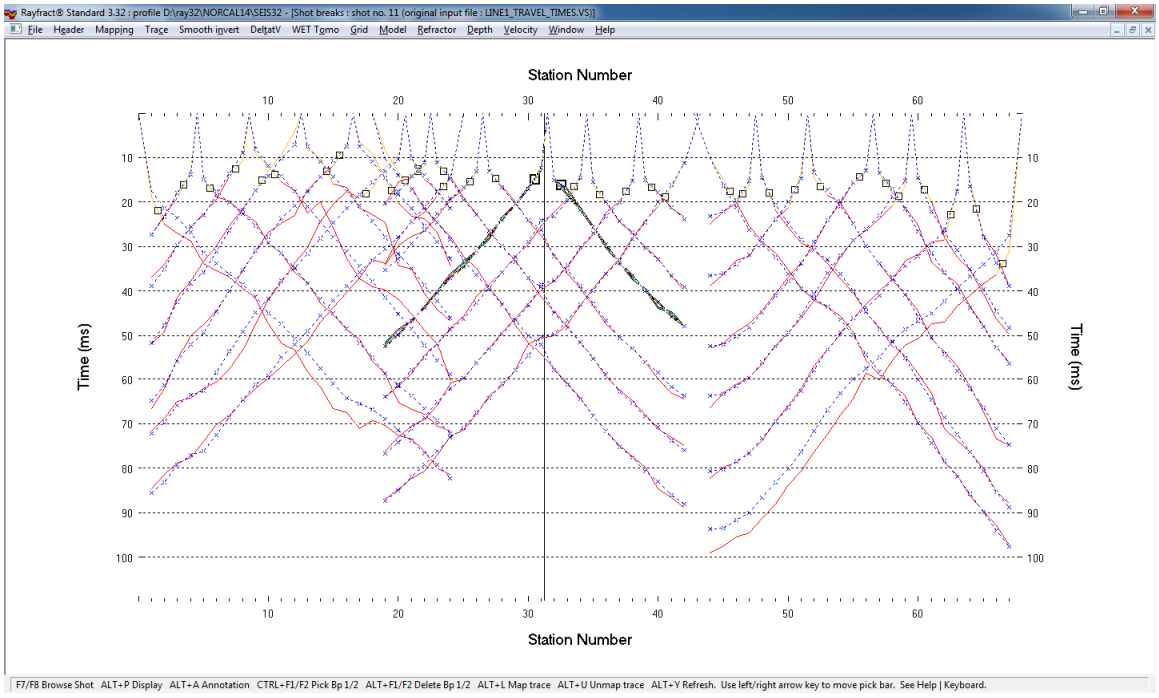

Fig. 15 : fit between picked traveltimes (yellow : weathering layer, red : basement refractor) and modeled times (dashed blue curves with blue crosses), after 50 WET iterations and forward modeling over Fig. 12. Leftmost and rightmost shots have shifted fit because of high elevation at line start & end. When disregarding these two shots the RMS error shown as 1.6% in Fig. 12 should decrease. Compare with Fig. 1 showing fit for Fig. 2b.

The low-velocity layers (velocity < 1,500 m/s) at elevation -1m and -3m in Fig. 2b could be layers of organic rich sediments with gas. These thin low-velocity anomalies are not visible in Fig. 8 due to more vertical smoothing (***Automatically adapt shape of rectangular filter matrix*** enabled) and the layered starting model (Fig. 7). Fig. 11 and Fig. 12 are also based on a layered starting model (Fig. 10) while Fig. 2b is based on a 1D-gradient starting model (Fig. 2a).

For intermediate vertical smoothing change WET parameters shown in Fig. 4 :

- select ***WET Tomo|Interactive WET tomography…*** and click button ***Edit velocity smoothing*** (Fig. 4)
- check ***Manual specification of smoothing filter*** (Fig. 4)
- increase ***Half smoothing filter height*** from 1 to 2 grid rows (Fig. 4)
- leave ***Automatically adapt shape of rectangular filter matrix*** unchecked as per default since 3.31
- click buttons ***Accept parameters*** and ***Start tomography processing*** (Fig. 4) to redo WET inversion

Alternatively redo WET inversion after unchecking ***WET Tomo|WET tomography Settings|Scale WET filter height*** (Fig. 5).

For more reliable data interpretation use overlapping receiver spreads and a shorter receiver separation to better constrain the overburden velocity. Check first breaks for reciprocity errors in *Trace|Offset gather*.

Below we show reprocessing of this data with our version 4.01 software with WDVS enabled, done in Dec 2020. We forced the *grid cell size* to 0.25m in *Header|Profile*. We use default WDVS settings : 200Hz, *Angle increment* 7 degrees, *Regard nth node* = 3.

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

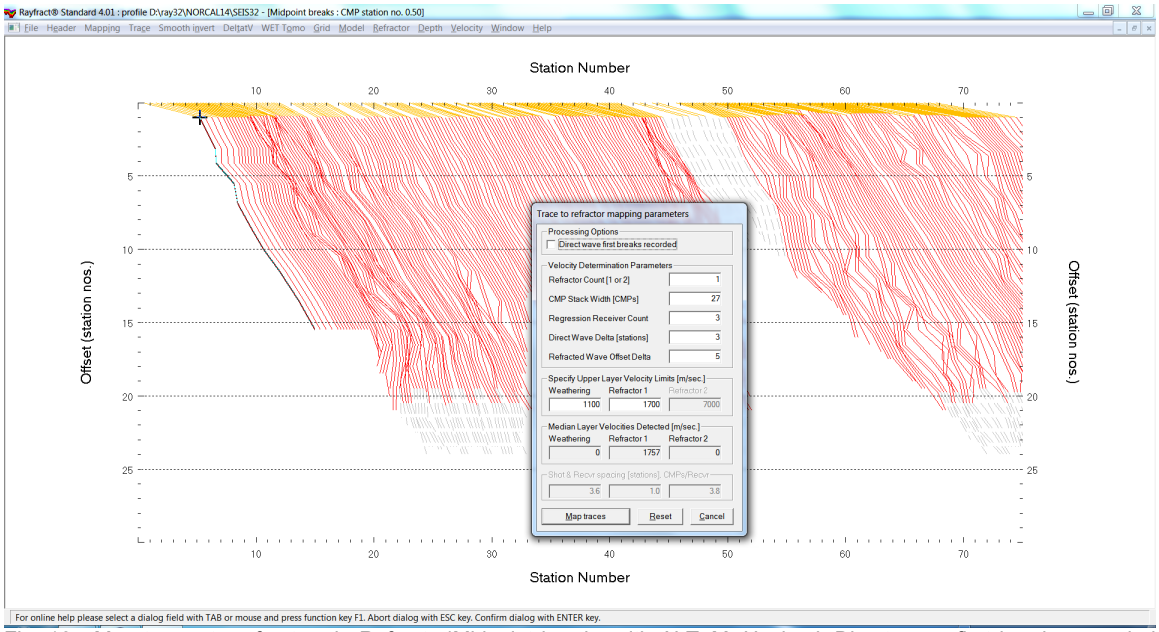

Fig. 16 : Map traces to refractors in Refractor|Midpoint breaks with ALT+M. Uncheck Direct wave first breaks recorded and specify 1D velocity model. Click Map traces. Press ALT+G, set Basement filter to 50 and click Accept to smooth crossover distance. Weathering velocity was determined previously by manual branch point picking (Fig. 15) and copied to Header|Station with ALT+L.

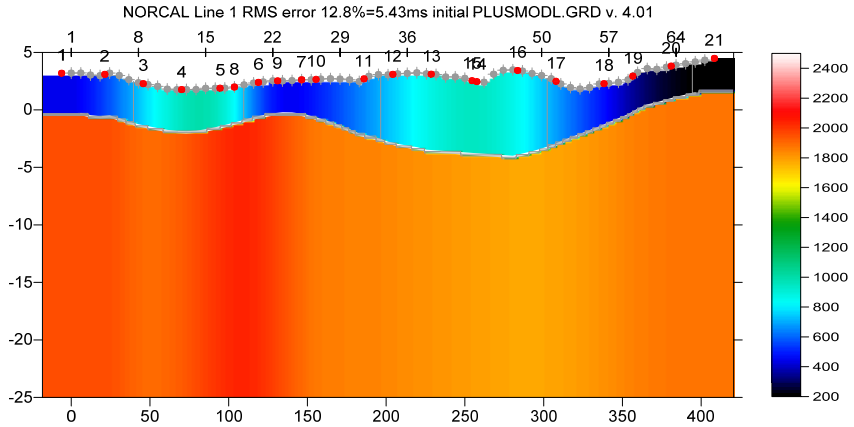

Fig. 17 : Plus-Minus method starting model. Map traces to refractors as in Fig. 16. Select Depth|Plus-Minus and proceed as in Fig. 20.

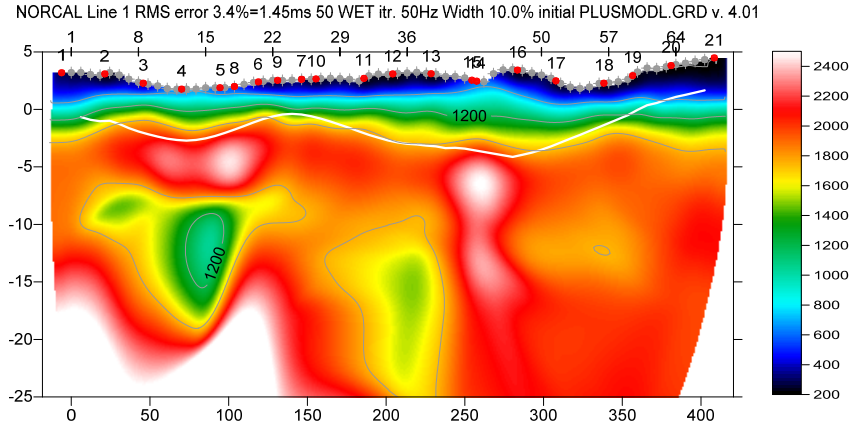

Fig. 18 : Smooth inversion with starting model Fig. 17 and WDVS enabled (Fig. 21). 50 Steepest-Descent WET iterations with full WET smoothing. Wavepath width set to 10 percent in WET Tomo|Interactive WET. All blanking flags unchecked in WET Tomo|WET tomography Settings|Blank submenu. See Fig. 20 for instructions.

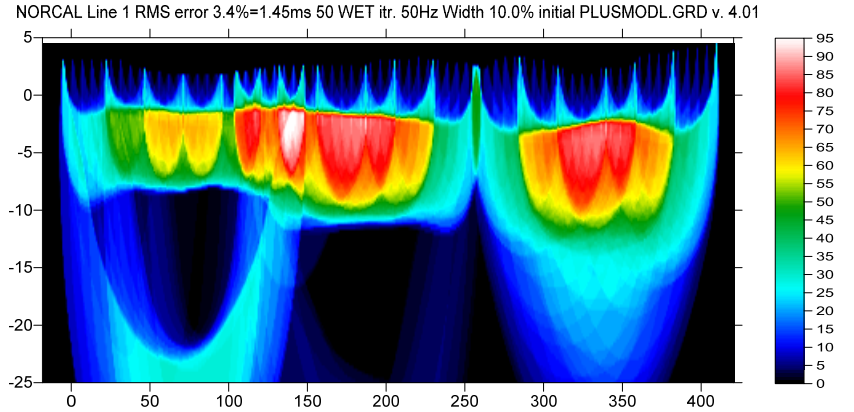

Fig. 19 : WET wavepath coverage plot obtained with Fig. 18. Unit is wavepaths per pixel.

As shown above enabling WDVS for Smooth inversion can help to better image low-velocity regions below higher-velocity lenses.

Here is the .RAR archive with profile database files for Fig. 17 to 19.
Here is the .RAR archive with Surfer 11 .GRD & .PAR & .SRF files for Fig. 17 to 19.

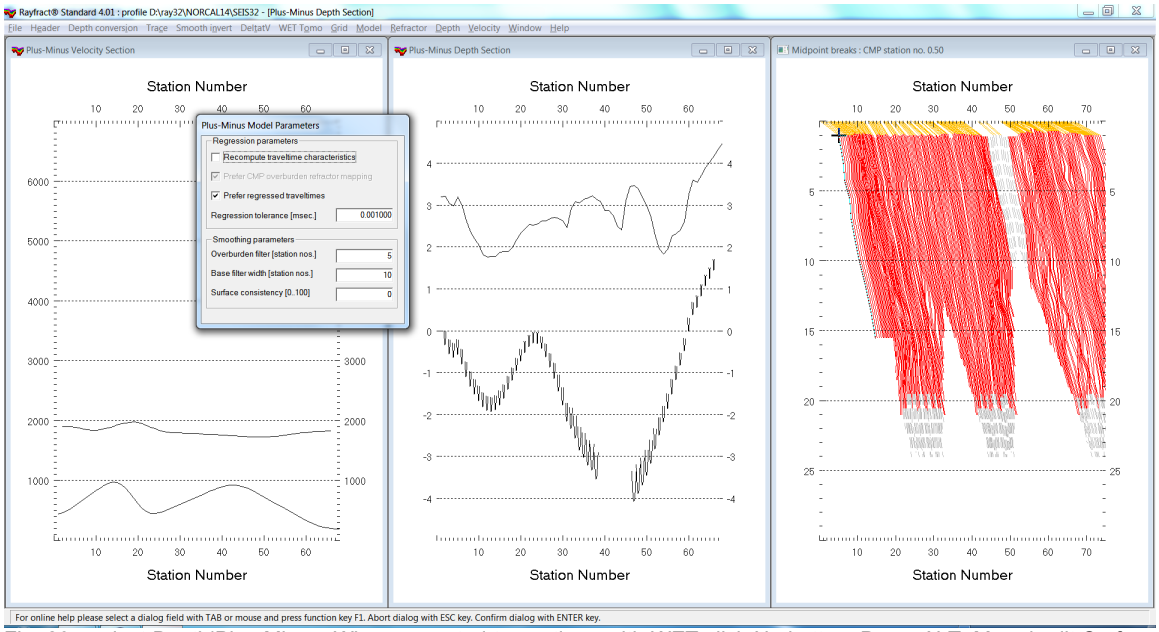

Fig. 20 : select Depth|Plus-Minus. When prompted to continue with WET click No button. Press ALT+M and edit Surface consistency from default 100 percent to 0. Press ENTER key to redo Plus-Minus and obtain Fig. 17 starting model. When prompted to continue with WET click Yes button. Increase WET wavepath width to 10% in WET Tomo|Interactive WET. Increase number of WET iterations to 50. Click button Start tomography processing to obtain Smooth inversion in Fig. 18 and 19.

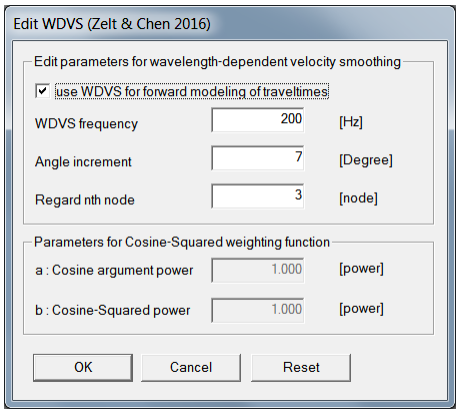

Fig. 21 : Model|WDVS Smoothing. Uncheck Model|Fast WDVS Smoothing.

The anomalous velocity profile at station no. 43 in Fig. 18 is due to the receiver spreads not overlapping at that station. See Fig. 15 and Fig. 19. Use overlapping receiver spreads when recording your shots in the field.

Below we show interactive WET inversion (Fig. 26) with WDVS (Fig. 27) and with starting model Fig. 23. We forced the weathering velocity to 200 m/s in Header|Station and mapped traces in Refractor|Midpoint breaks (Fig. 22).

Note the impression of wavepaths (Fig. 25) onto the WET tomogram (Fig. 24). This is related to the too wide shot spacing and the too much minimized WET smoothing in combination with enabling WDVS. See Fig. 28 for a smoother interpretation : same WET inversion as Fig. 2b but with WDVS enabled (Fig. 27).

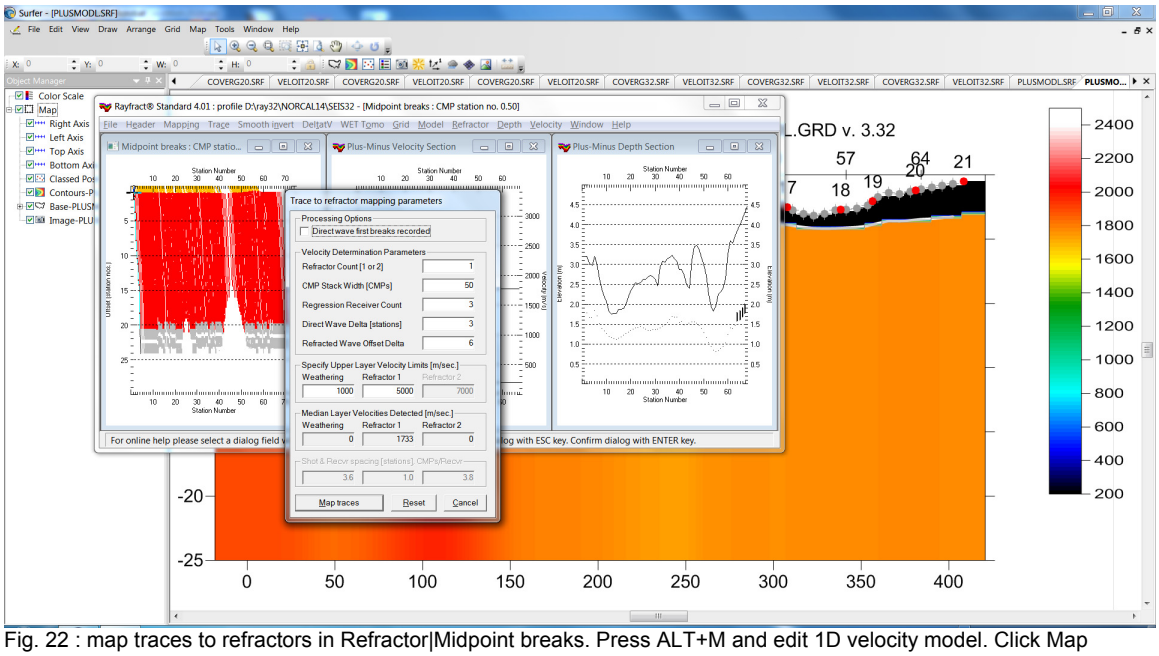

Fig. 22 : map traces to refractors in Refractor|Midpoint breaks. Press ALT+M and edit 1D velocity model. Click Map traces. Press ALT+G to smooth crossover distance. Set Basement filter to 50 stations and click Accept. Weathering velocity was forced to 200 m/s in Header|Station before opening Refractor|Midpoint breaks.

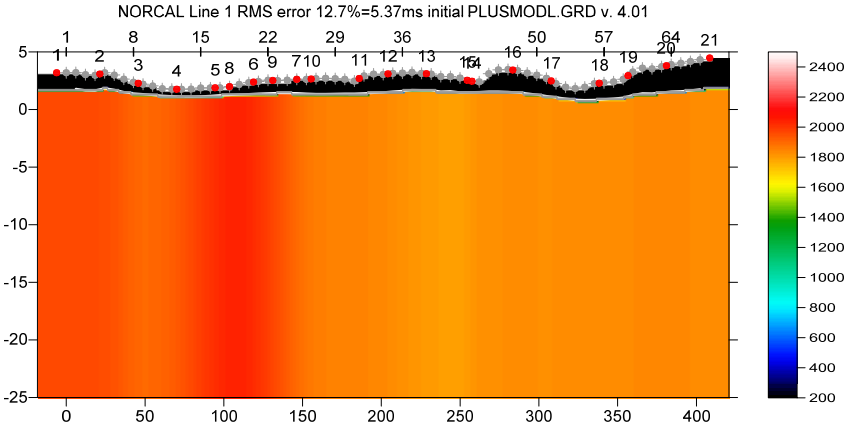

Fig. 23 : select Depth|Plus-Minus and confirm prompts to obtain Plus-Minus method starting model.

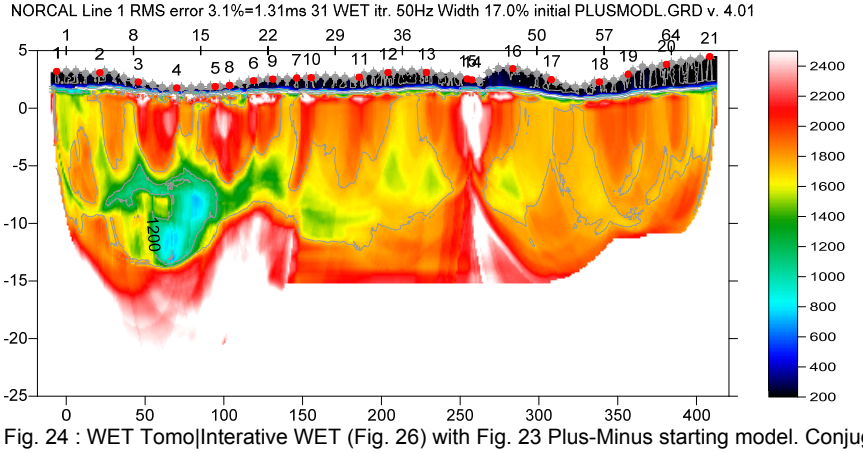

Fig. 24 : WET Tomo|Interative WET (Fig. 26) with Fig. 23 Plus-Minus starting model. Conjugate-Gradient WET inversion with minimized WET smoothing (Fig. 26). WDVS enabled (Fig. 27). Compare with Fig. 18 using full WET smoothing. Also compare with our earlier Fig. 2b obtained without WDVS.

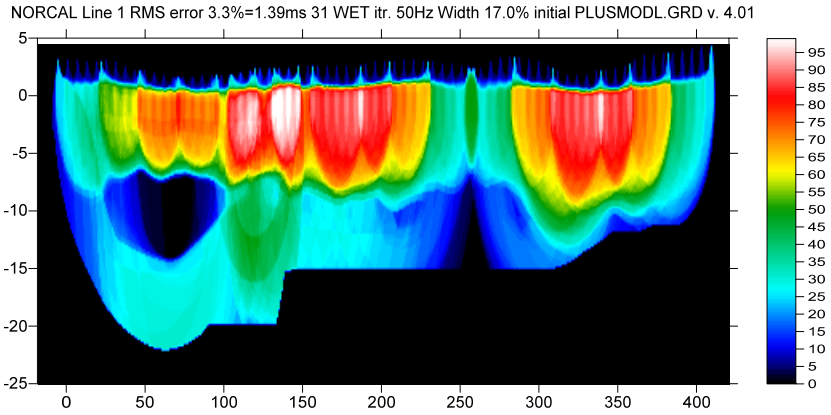

Fig. 25 : WET wavepath coverage plot obtained with Fig. 24. Unit is wavepaths per pixel.

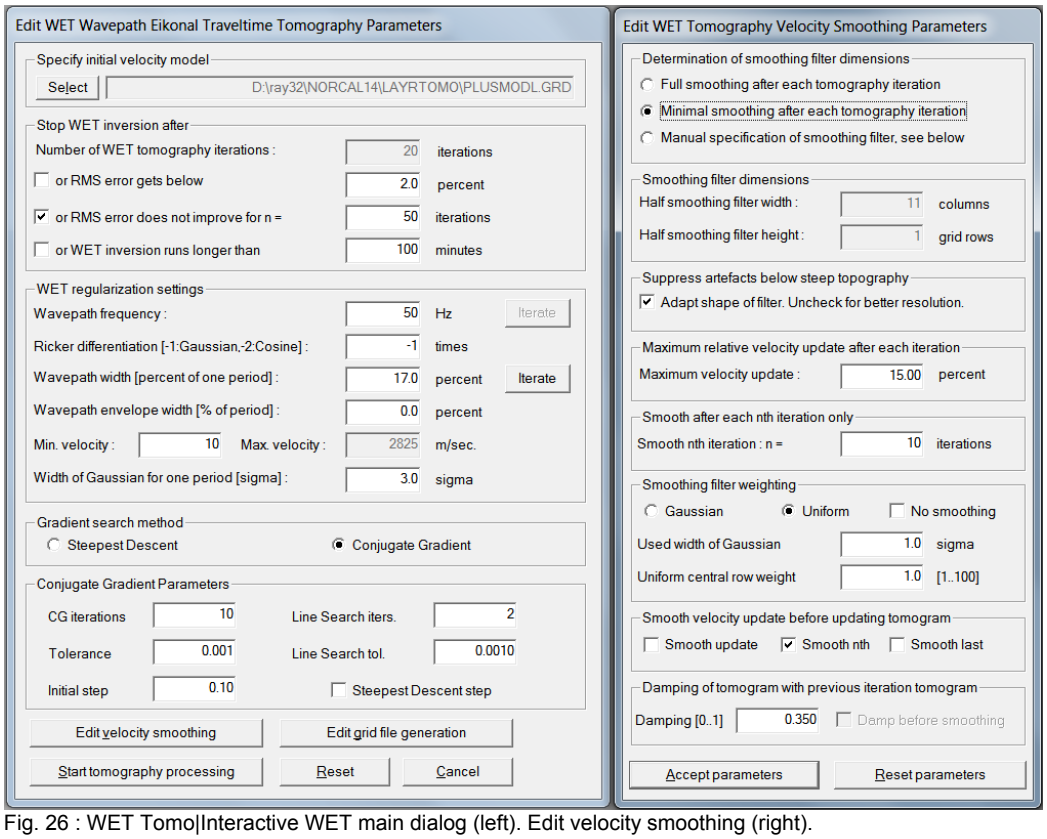

Fig. 26 : WET Tomo|Interactive WET main dialog (left). Edit velocity smoothing (right).

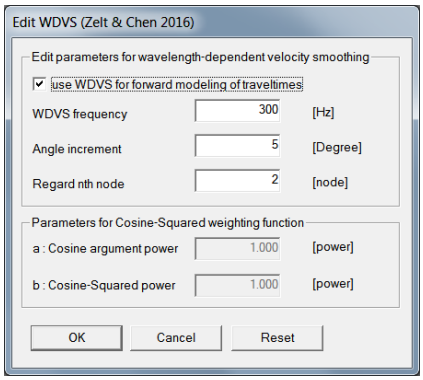

Fig. 27 : Model|WDVS Smoothing. Uncheck Model|Fast WDVS Smoothing

Here is the .RAR archive with profile database files for Fig. 23 to 25.
Here is the .RAR archive with Surfer 11 .GRD & .PAR & .SRF files for Fig. 23 to 25.

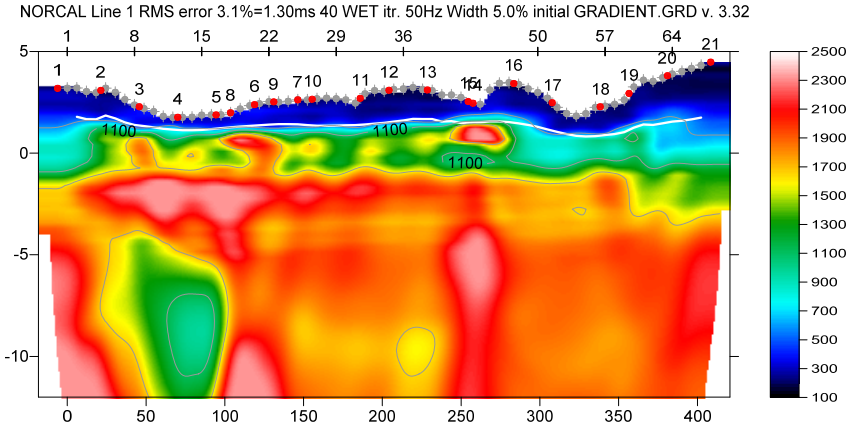

Fig. 28 : Same WET inversion as Fig. 2b but with WDVS enabled (Fig. 27). Using 1D-Gradient Starting model Fig. 2a. 40 Steepest-Descent WET iterations with WET smoothing as in Fig. 4.

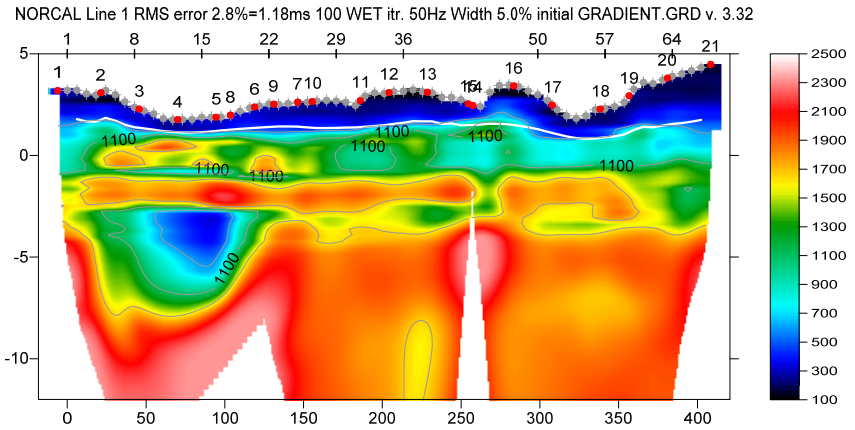

Fig. 29 : Same WET inversion as Fig. 28 but without WDVS. Same as Fig. 2b obtained with version 3.32 in 2014. Starting model Fig. 2a. 100 Steepest-Descent WET iterations with WET smoothing as in Fig. 4.

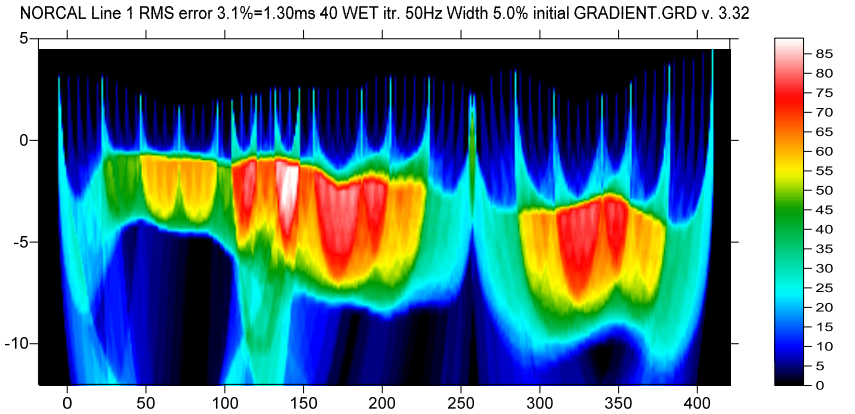

Fig. 30 : WET wavepath coverage plot obtained with Fig. 28. Unit is wavepaths per pixel.

Here is the .RAR archive with profile database files for Fig. 28 and 30.
Here is the .RAR archive with Surfer 11 .GRD & .PAR & .SRF files for Fig. 28 and 30.

Below we show Smooth inversion with Plus-Minus starting model using manual picking of branch points.

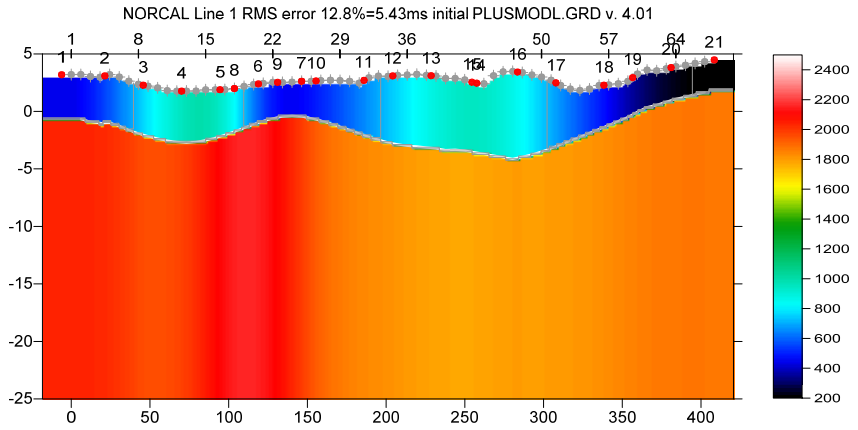

Fig. 31 : Map traces to refractors in Refractor|Shot breaks with ALT+L (Fig. 15). Select Depth|Plus-Minus and confirm prompts to obtain this starting model and Smooth inversion tomogram (Fig. 32).

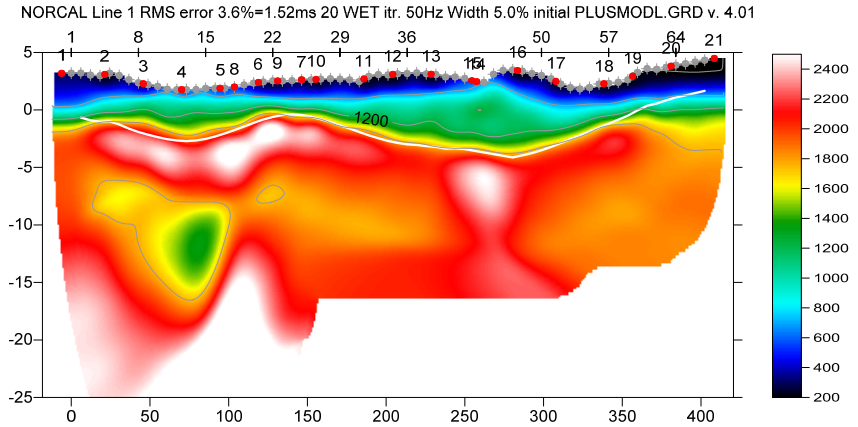

Fig. 32 : Smooth inversion with starting model Fig. 31. 20 Steepest-Descent WET iterations. WDVS as in Fig. 21.

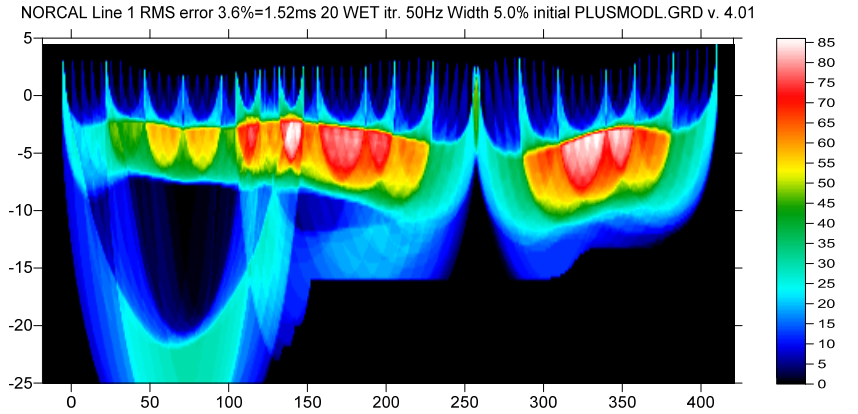

Fig. 33 : WET wavepath coverage plot obtained with Fig. 32. Unit is wavepaths per pixel.

Here is the .RAR archive with profile database files for Fig. 31 to 33.
Here is the .RAR archive with Surfer 11 .GRD & .PAR & .SRF files for Fig. 31 to 33.

We repicked the branch points separating the direct wave from the refracted wave in Fig. 15 and rerun our Smooth inversion with Plus-Minus starting model with 20 and 50 Steepest-Descent WET iterations with WDVS enabled. We forced the *grid cell size* to 0.25m in *Header|Profile*. See below.

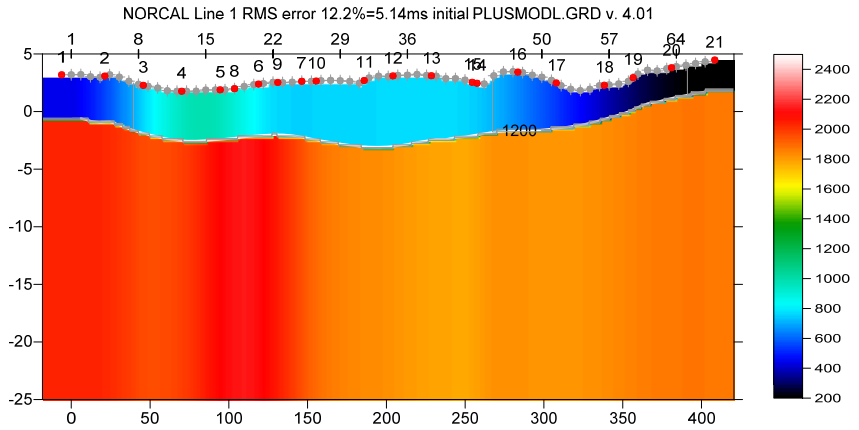

Fig. 34 : Map traces to refractors in Refractor|Shot breaks with ALT+L (Fig. 15). Select Depth|Plus-Minus and confirm prompts to obtain this starting model and Smooth inversion tomogram in Fig. 35.

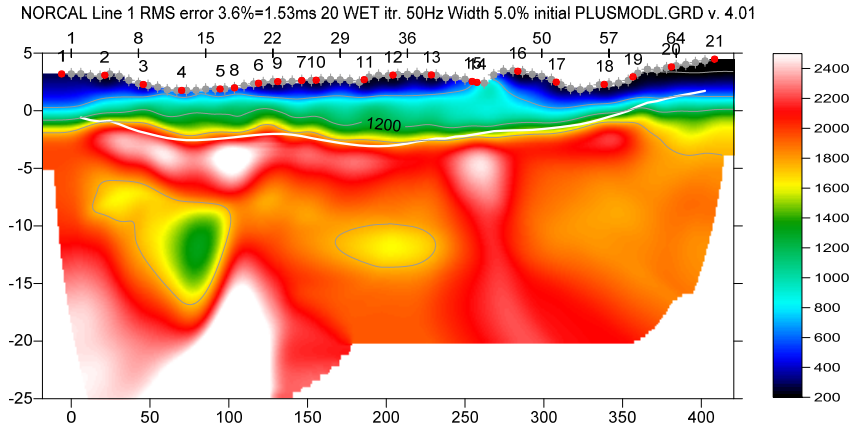

Fig. 35 : Smooth inversion with default 20 Steepest-Descent WET iterations and full WET smoothing. WDVS enabled (Fig. 21). Starting model is Fig. 34.

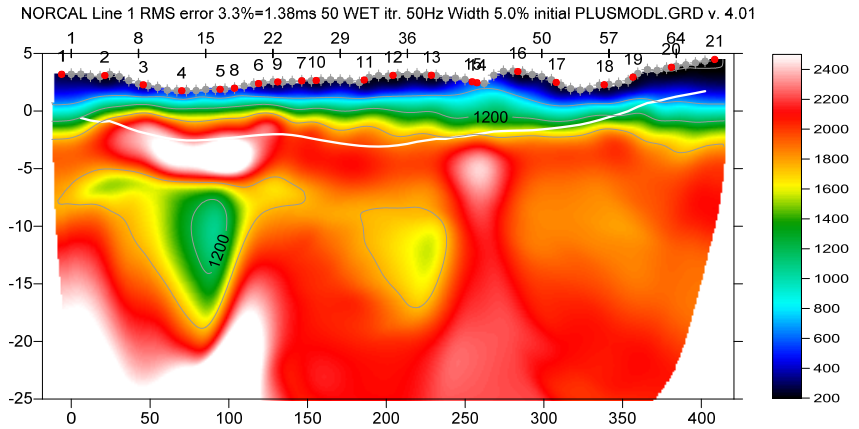

Fig. 36 : Smooth inversion with 50 Steepest-Descent WET iterations and full WET smoothing. WDVS enabled (Fig. 21). Starting model is Fig. 34. Select WET Tomo|Interactive WET and increase Number of WET iterations from default 20 to 50. Click button Start tomography processing to obtain this figure and Fig. 37.

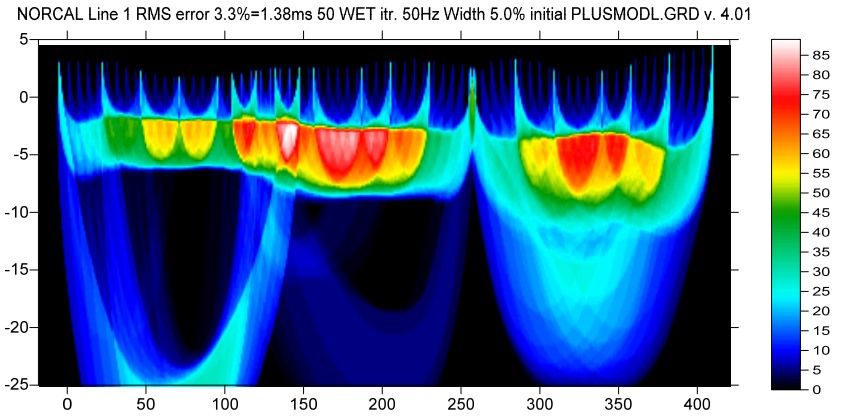

Fig. 37 : WET wavepath coverage plot obtained with Fig. 36. Unit is wavepaths per pixel.

Here is the .RAR archive with profile database files for Fig. 34 to 36.
Here is the .RAR archive with Surfer 11 .GRD & .PAR & .SRF files for Fig. 34 to 36.

Fig. 36 shows a better match with Fig. 28 and a smaller RMS error than Fig. 35. This shows that enabling WDVS can improve the vertical resolution when increasing the WET iteration count even with our Smooth inversion using full WET smoothing.

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 thank our client William Black at NORCAL Geophysical Consultants Inc. for making available this data set and for his background information on the geological setting of this line.

Edited in Vancouver, Canada on Dec 10, 2020 by Siegfried Rohdewald, Dipl. Informatik-Ing. ETH.