VSP constrained refraction tomography with Rayfract® version 3.35 & 4.01 Oct 2020 :

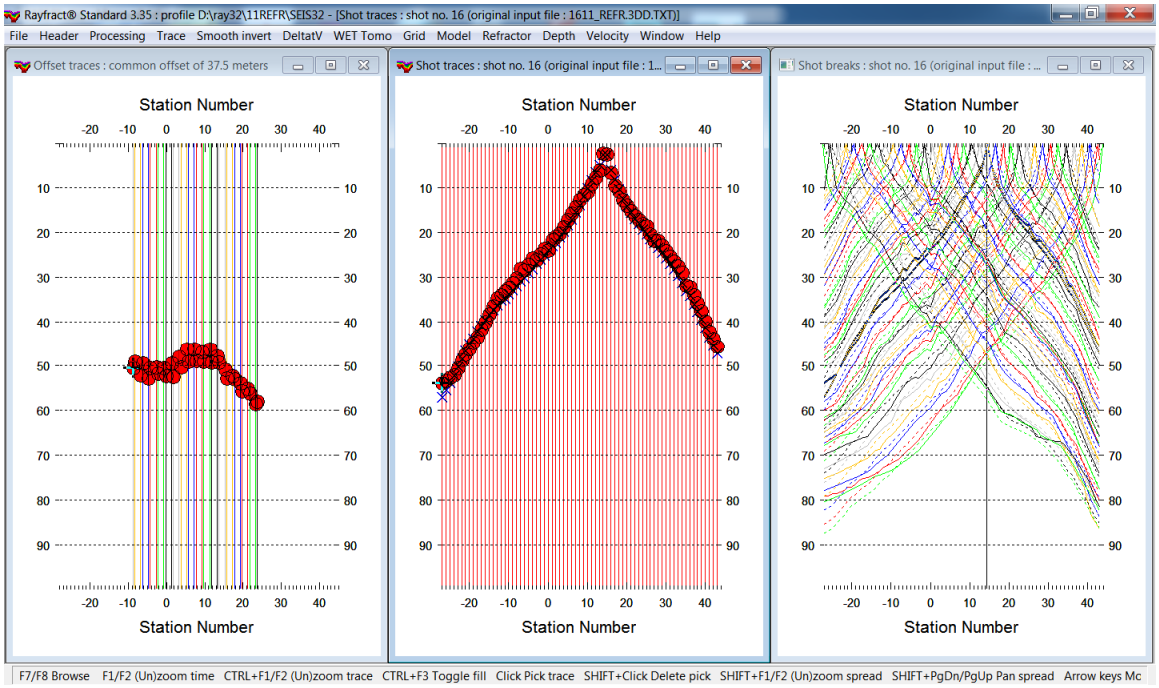

Fig. 1 : left : *Trace|Offset gather*, center : *Tace|Shot gather*, right : *Refractor|Shot breaks*. Shows fit between picked times (solid colored curves) and modeled times (dashed colored curves) obtained by forward modeling over Fig. 2.

- *File|New Profile…*, set *File name* to `11REFR` and click *Save button*
- set *Station spacing* to 1.0m in *Header|Profile…* . Set *Profile start offset[m]* to -28.0 .
- set *Cell size [m] to* 0.5 . Check box *Force grid cell size.*
- unzip `1611_refr.3dd.rar` with `1611_refr.3dd.txt` in `C:\RAY32\11REFR\INPUT`
- check *File|Import Data|Settings|Import horizontal borehole survey or .3DD refraction survey* if this option is enabled. Since 2020 version 3.36 you can skip this step.
- check *File|Import Data Settings|X coordinate is corrected for topography already*
- select *File|Import Data…* and set *Import data type* to `Tweeton GeoTomCG .3DD`
- leave *Default spread type* at *10: 360 channels.* Set *Default sample count* to 2000 .
- click upper *Select button*, navigate into `C:\RAY32\11REFR\INPUT` and select file `1611_refr.3dd.txt`
- click *Open button*, *Import shots button.* The *Import shot dialog* is shown for each shot in the `.3DD` file.
- for each shot leave *Layout start* and *Shot pos.* at shown values and click *Read button*
- select *Trace|Shot gather*, *Trace|Offset gather* and *Window|Tile* to obtain Fig. 1
- for each window click title bar, press ALT+P, set *Maximum time* to 100 ms and hit ENTER key
- for *Trace|Shot gather* & *Trace|Offset gather* click title bar. Uncheck *Display|Use red cross for picked first breaks*. Check *Display|Solid color pick display* & *Picks always cover traces*.
- click title bar of *Refractor|Shot breaks* window. Uncheck *Mapping|Display raytraced traveltimes*.
- check *Mapping|Color picked traveltime curves*
- uncheck all blanking options in *WET Tomo|WET tomography Settings|Blank* submenu
- check *WET Tomo|WET tomography Settings|Edit maximum valid WET velocity*
- create borehole profile 1611HOLE and import VSP shots as described in tutorial `1611HOLE.pdf`
- in *Header|Profile* click topmost *Select button* and select `C:\RAY32\1611HOLE\SEIS32.DBD` . See Fig. 5 .
- select *Smooth invert|WET with 1D-gradient initial model* and confirm for default interpretation
- select *Grid|Surfer plot Limits*. Set *X Scale* to 4.5 inch. Click *button Reset to grid* and select `C:\RAY32\11REFR\GRADTOMO\VELOIT20.GRD` . Check box *Plot limits active*.
- set *Min. velocity* to 200m/s and *Max. velocity* to 5000m/s. Click *OK button*.

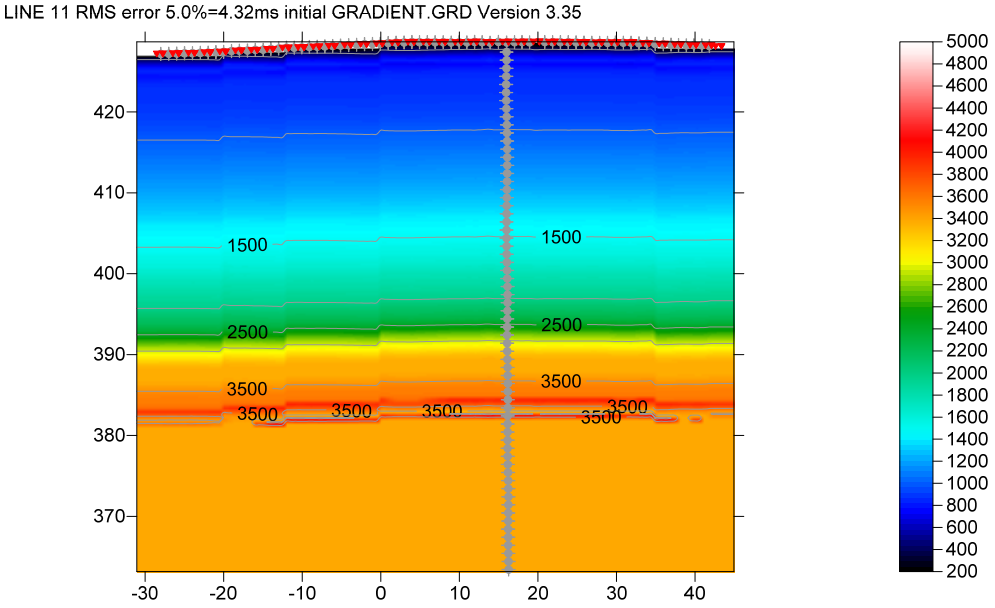

Fig. 2a : 1D-gradient starting model, obtained by horizontally averaging DeltatV inversion output. Default Smooth inversion settings, default DeltatV settings.

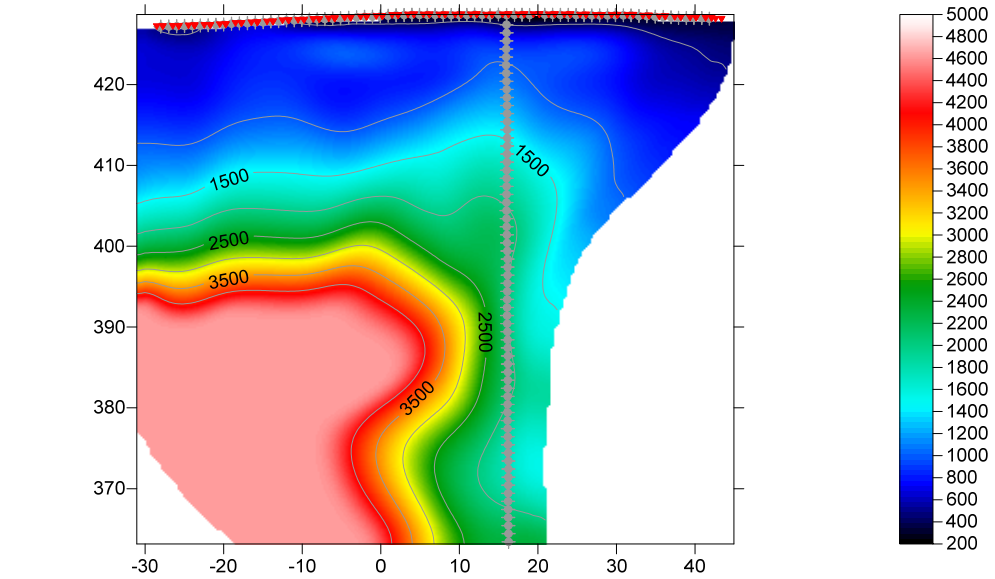

Fig. 2b : Tomogram with 1D-gradient starting model Fig. 2a, 100 Steepest Descent WET iterations, default WET settings. Wavepath width 19%, Max. velocity 4,500 m/s. WET settings as in Fig. 4.

- set *WET Tomo|Interactive WET tomography|Number of iterations* to 100. Set *Wavepath width* to 19% and *Max. velocity* to 4500m/s. See Fig. 4. Click *Start tomography processing* to obtain Fig. 2 & 3.
- for *WET parameters* used see archive `GRAD335 Width19% 100Iters.rar` with starting model files `GRADIENT.GRD` & `GRADIENT.PAR`, `VELOIT100.GRD` & `.PAR` and `.SRF` Surfer 11 plots
- click *WET Tomo|Interactive WET tomography|Iterate* and specify multiscale tomography parameters as shown in Fig. 6
- check *box WET runs active*, click *OK button* and *Start tomography processing button* for Fig. 7 & 8

For help on *WET inversion* parameters see .pdf reference chapter ***WET Wavepath Eikonal Traveltime tomography***.

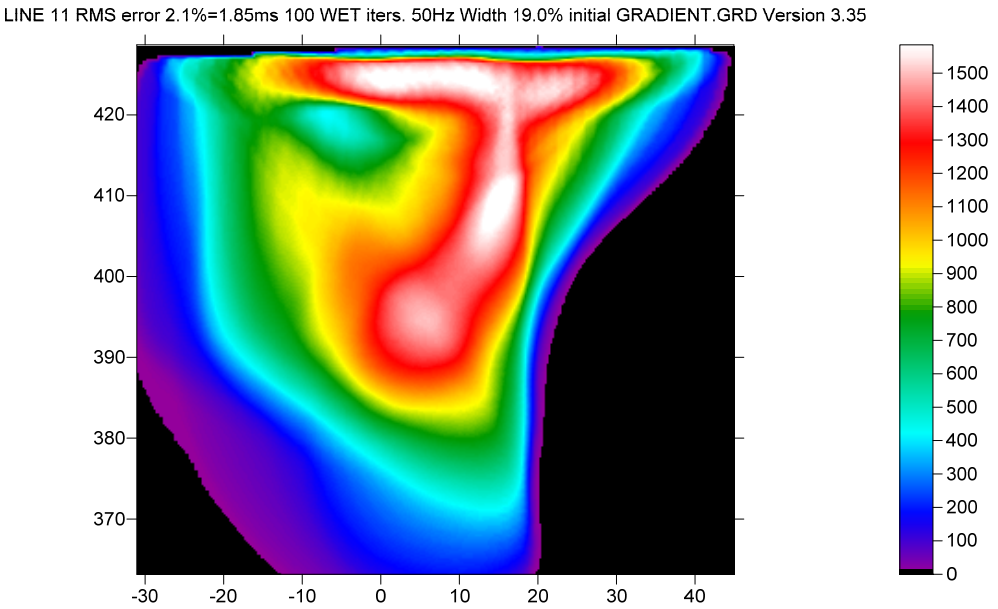

Fig. 3 : WET wavepath coverage plot obtained with Fig. 2b. Shows number of wavepaths per pixel.

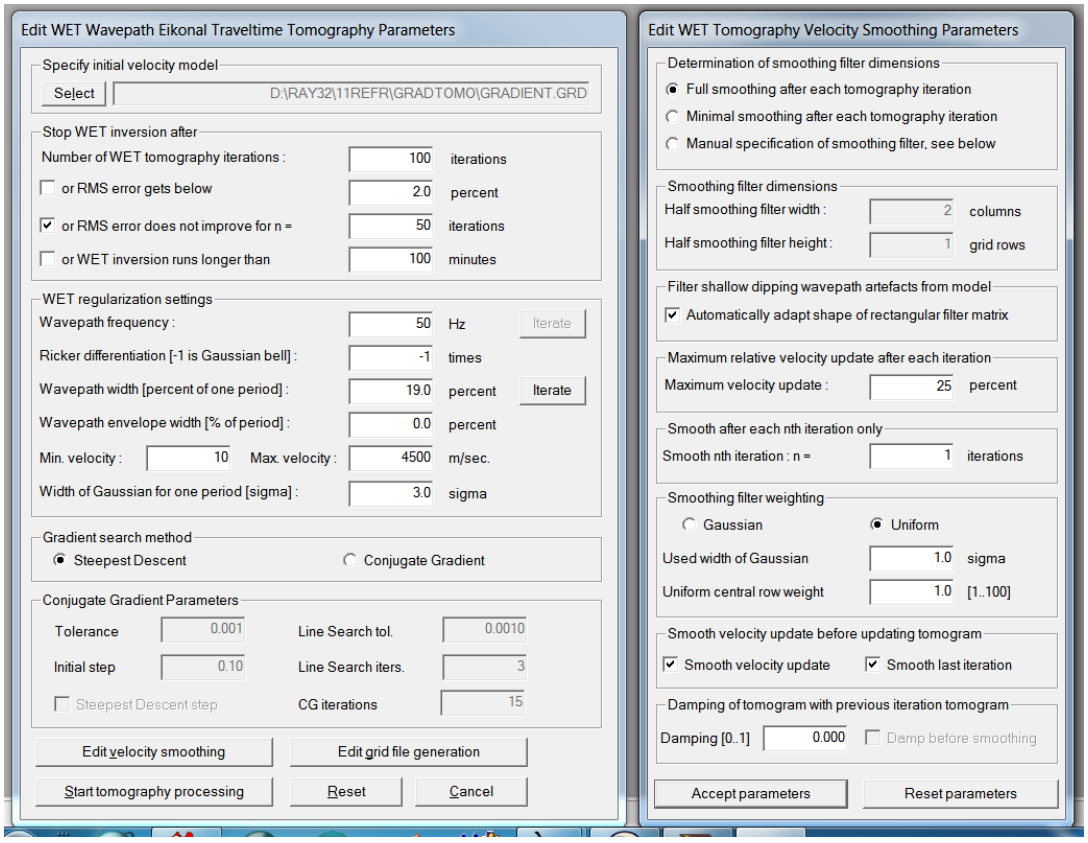

Fig. 4 : WET parameter settings for Fig. 2 & 3. left : main interactive WET dialog. right : edit velocity smoothing

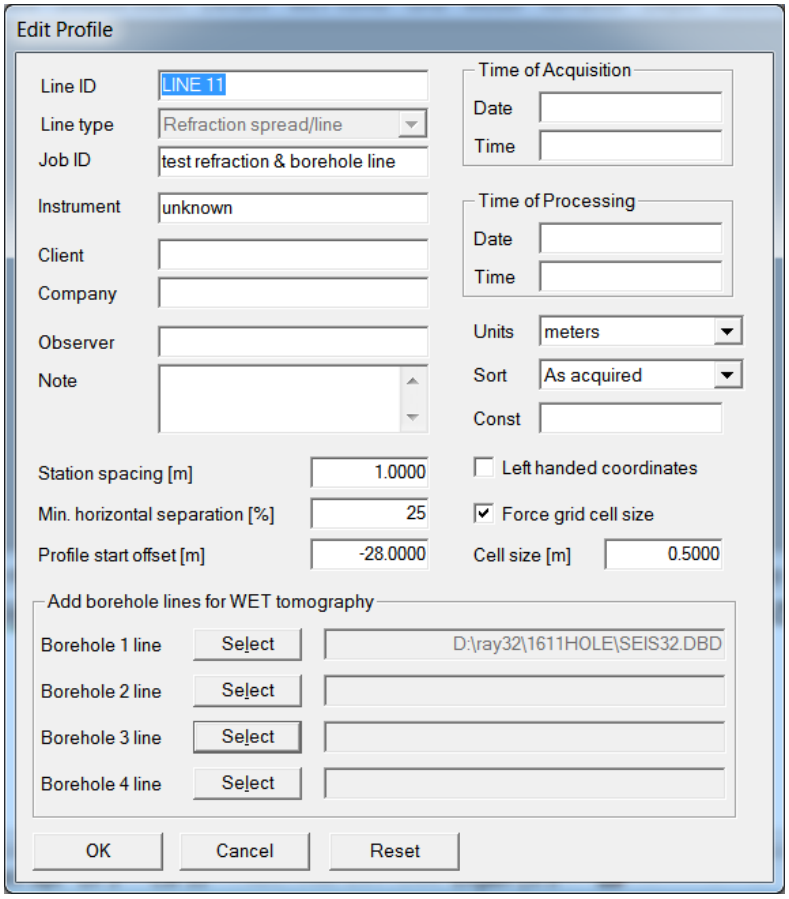

Fig. 5 : *Header|Profile* dialog. Easily add borehole line(s) with *Select button(s)*.

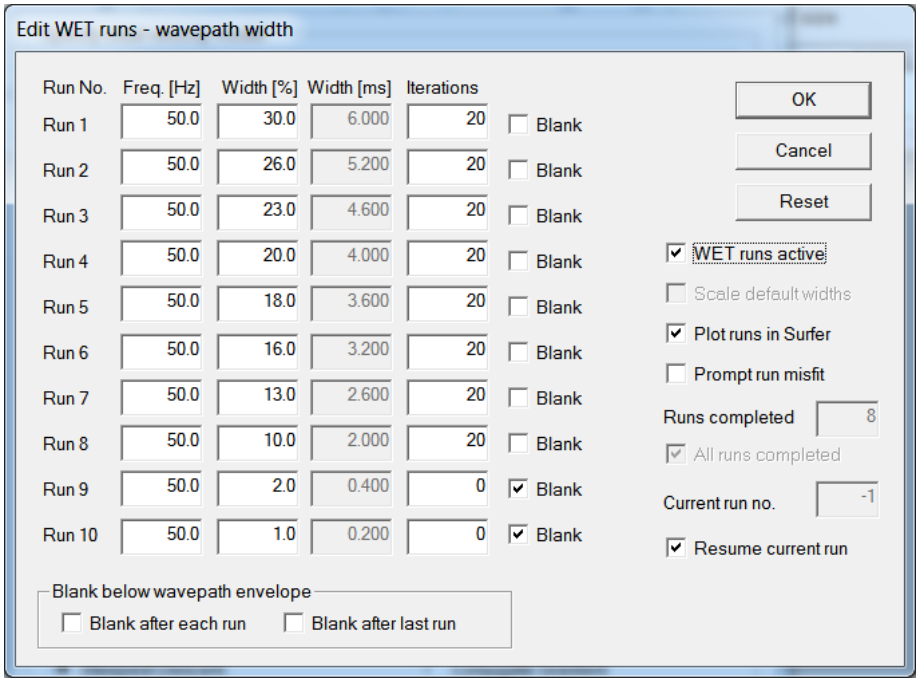

Fig. 6 : *WET Tomo|Interactive WET tomography|Iterate* . Specify parameters for multiscale tomography.

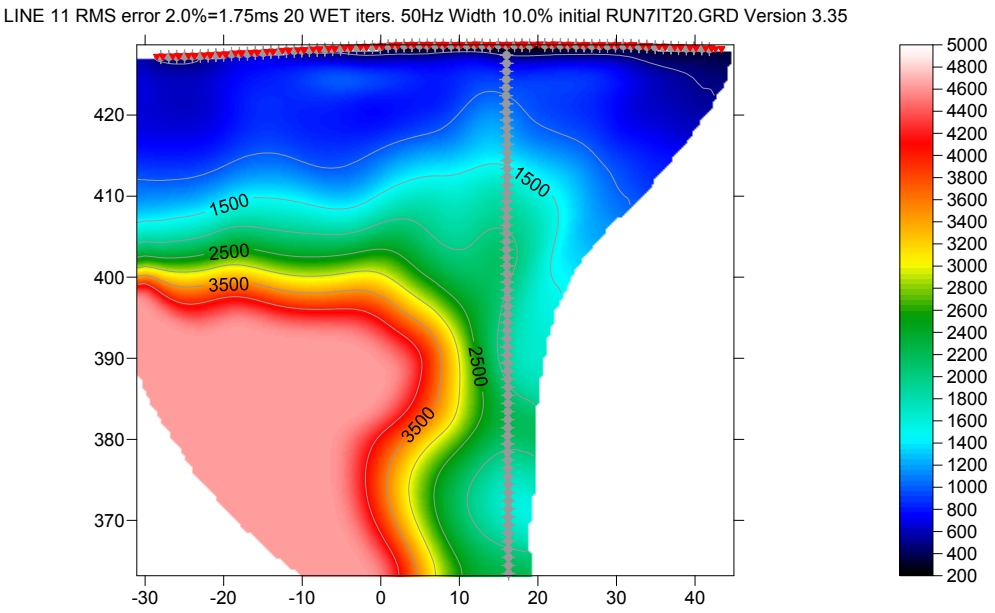

Fig. 7 : multiscale tomography obtained with multirun WET parameters shown in Fig. 6

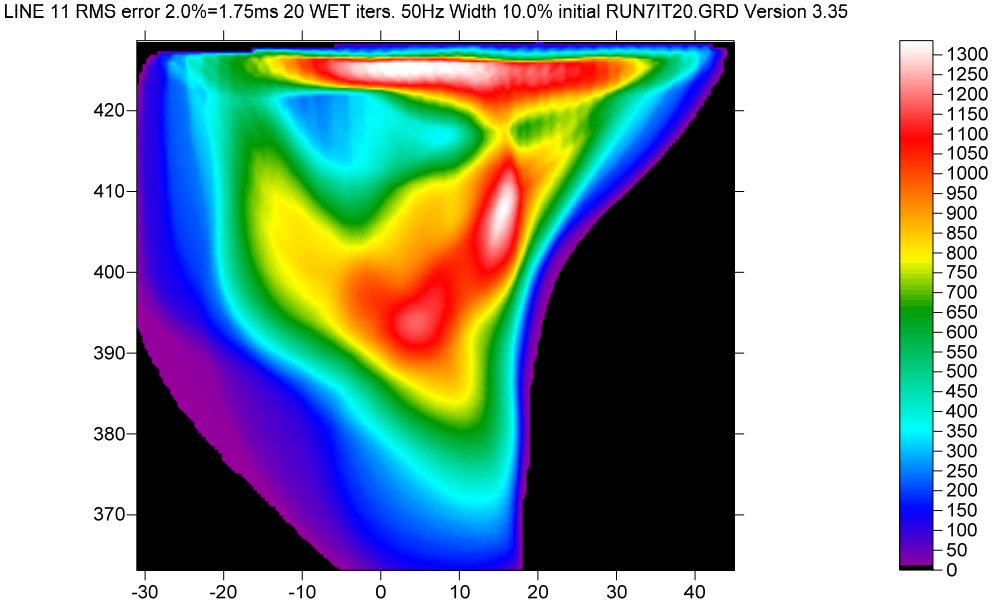

Fig. 8 : WET wavepath coverage plot obtained with Fig. 7. Unit is wavepaths per pixel.

Note the improved vertical resolution at top of basement in Fig. 7 showing multiscale tomography when compared to Fig. 2b showing single-run WET inversion.

`WETRUN8 Gradient Start.rar` contains files for Fig. 7. `WETRUN8 ConstVelo Start.rar` contains the same files obtained with ***constant-velocity starting model***. See `WETRUN1 Gradient Start.rar` and `WETRUN1 ConstVelo Start.rar` for starting models and tomograms obtained with first WET run.

Since Oct 2020 our latest software version 4.01 allows WDVS Wavelength-Dependent Velocity Smoothing (Zelt and Chen 2016). In Fig. 9&10 we show 200 Steepest-Descent WET iterations (Fig. 12) with Plus-Minus method starting model (Fig. 11) and WDVS enabled with ***WDVS frequency*** 200Hz, ***Angle increment*** 7 degrees and ***Regard nth node*** = 3 (Fig. 13). Note the ***minimized WET smoothing*** settings in Fig. 12. We can reduce WET smoothing this much since we enabled *WDVS smoothing* see Fig. 13.

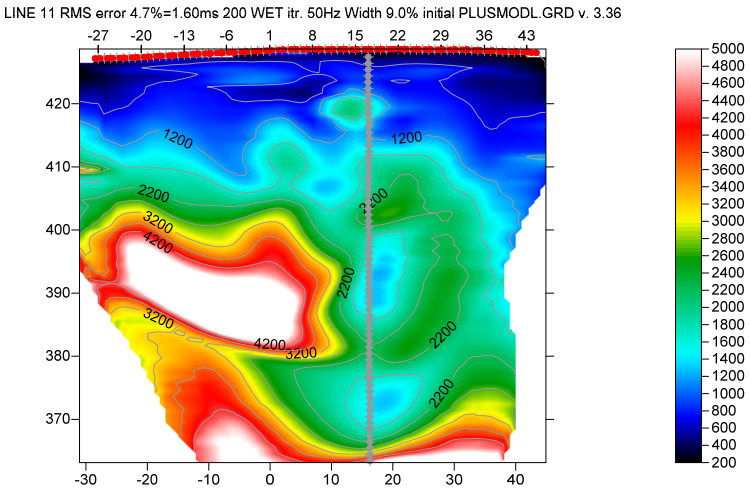

Fig. 9 : Single-run Steepest Descent WET inversion. 200 WET iterations, wavepath width 9% (Fig. 12). Plus-Minus starting model (Fig. 11). WDVS frequency 200Hz, Angle increment 7 degrees, Regard nth node = 3 (Fig. 13).

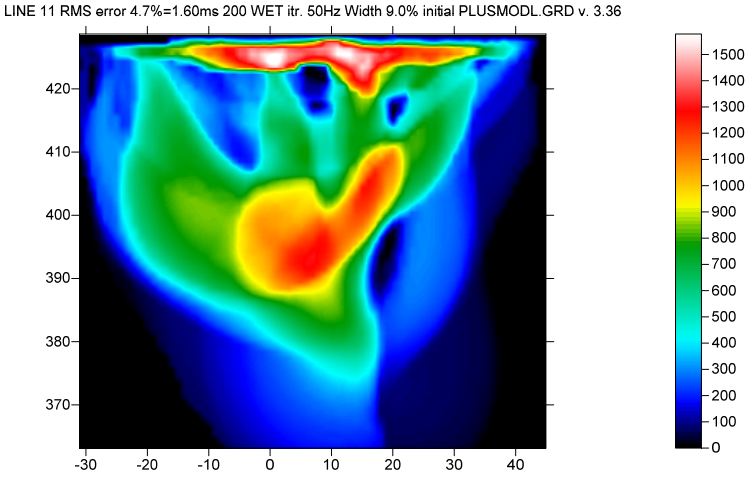

Fig. 10 : WET wavepath coverage obtained with Fig. 9

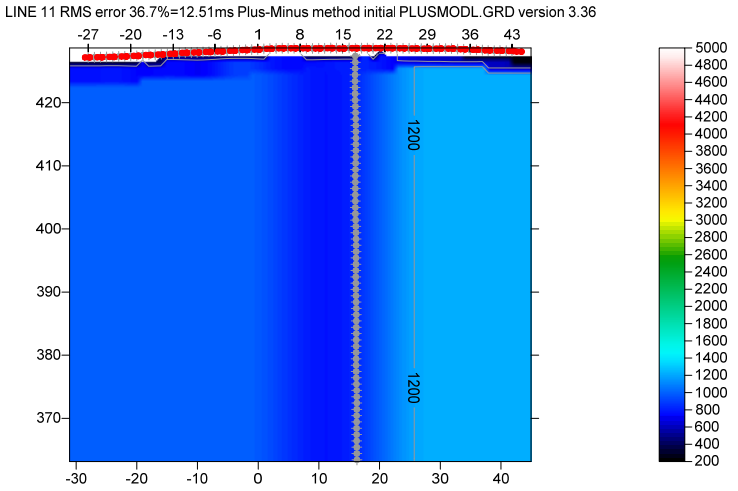

Fig. 11 : Plus-Minus method starting model used for Fig. 9 and Fig. 10

In Fig. 11 we show the Plus-Minus method starting model used to obtain Fig. 9 & 10. We forced the ***grid cell size*** to 1.0m in *Header|Profile* to speed up WDVS velocity smoothing. In Fig. 12 we show interactive WET settings used for Fig. 9. In Fig. 13 we show WDVS settings for Fig. 9.

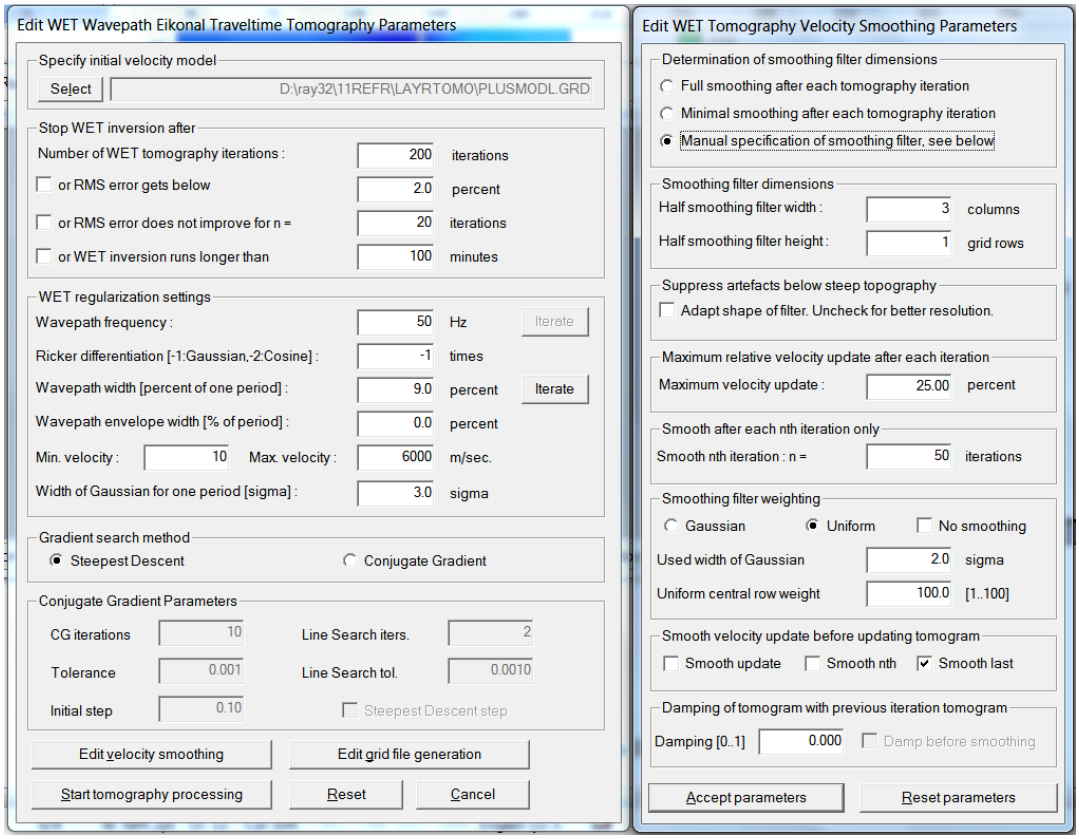

Fig. 12 : WET Tomo|Interactive WET settings used for Fig. 9. Note the minimized WET smoothing settings. We can reduce WET smoothing this much since we enabled WDVS smoothing see Fig. 13.

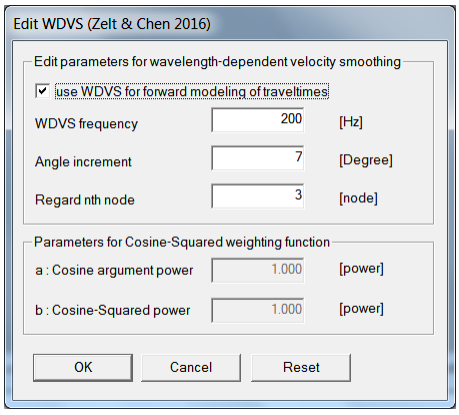

Fig. 13 : WDVS settings used for Fig. 9. WDVS frequency 200Hz. Angle increment 7 degrees. Regard nth node = 3.

With WDVS enabled (Fig. 13) we can ***minimize WET smoothing*** (Fig. 12) and still get robust WET inversion output (Fig. 9 & 10). WDVS 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.

11REFR LAYRTOMO Oct24 2020.rar contains Surfer 11 files for Fig. 9.
11REFR seis32 LayrTomo Oct24 2020.rar contains profile database files for Fig. 9.

Next we disregard VSP shots and invert first break picks for refraction shots only :

- select *Header|Profile* (Fig. 5). Click *Reset* to delete all borehole line selections. Click *button OK*.
- select *Smooth invert|Custom 1D-gradient velocity profile*
- click *button Reset limits to grid* and select `C:\RAY32\11REFR\GRADTOMO\VELOIT100.GRD`
- check *box Force grid limits* and click *button OK*

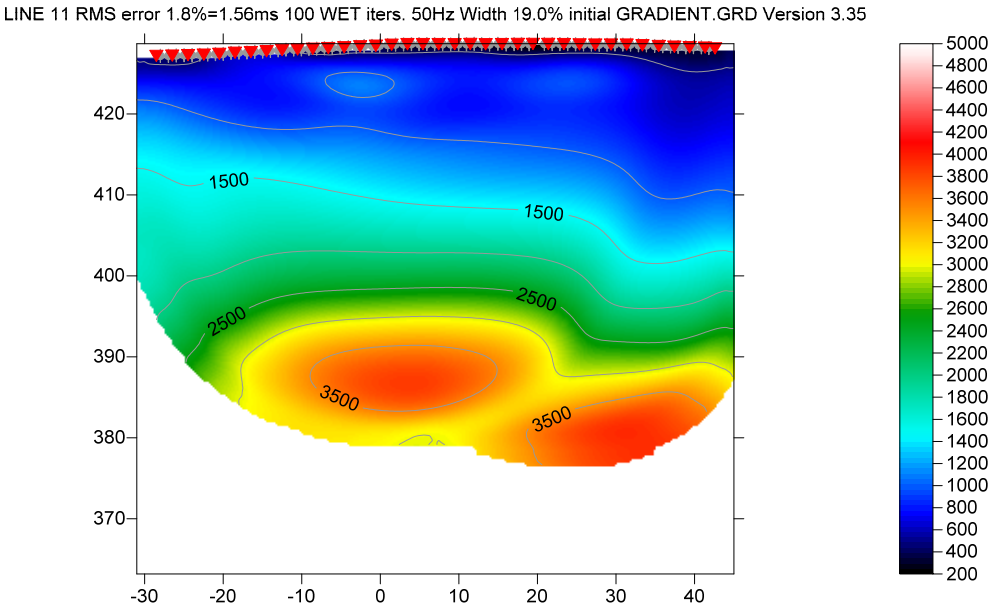

Fig. 14 : WET inversion of refraction shots only, disregard VSP shots

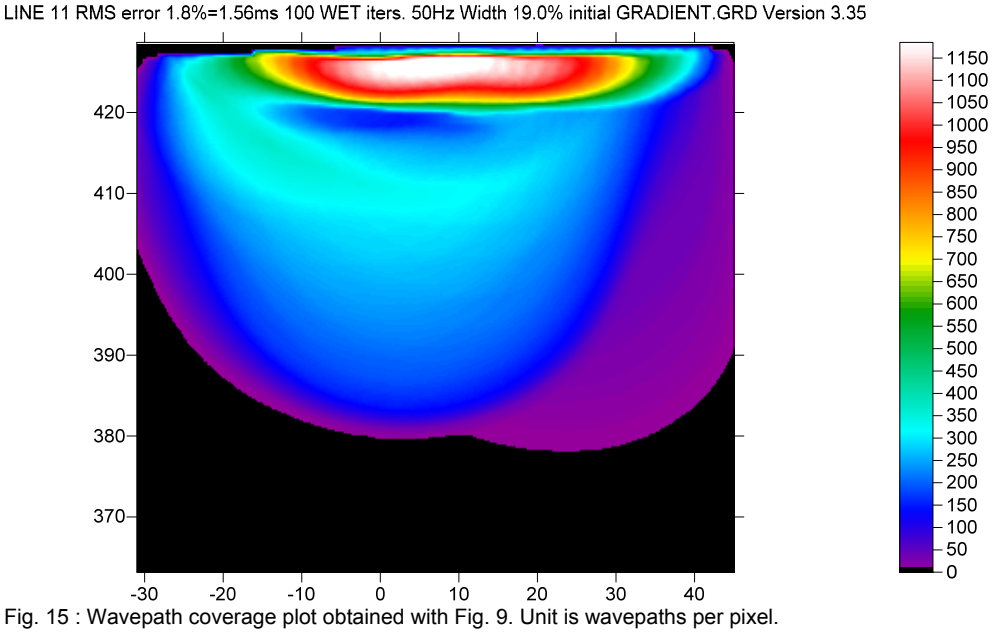

Fig. 15 : Wavepath coverage plot obtained with Fig. 9. Unit is wavepaths per pixel.

- select *Smooth invert|WET with 1D-gradient initial model* and confirm for default interpretation
- set *WET Tomo|Interactive WET tomography|Number of iterations* to 100. See Fig. 4.
- set *Wavepath width* to 19% and *Max. velocity* to 4500m/s. See Fig. 4.
- click *Iterate* and uncheck *WET runs active*. Click *OK* and *Start tomography processing* for Fig. 9&10.

Note the limited depth penetration in Fig. 14&15 due to the shallow high-velocity layer at elevation 425m and lower-velocity region below this layer. Classic refraction theory states that you cannot image below a velocity inversion. As shown we still get a meaningful estimate of top of bedrock with *WET inversion*.