XTV inversion of synthetic data for layered model sent by Jacques Jenny in 2010, with Rayfract® version 3.22 :

Start up Rayfract® via desktop icon. Select *File|New Profile…* . Set *File name* to `JENNY10` and click *Save button*. Specify *Station spacing* of 5 m in *Header|Profile* (Fig. 1).

Unzip archive jenny10.zip in directory \RAY32\JENNY10\INPUT . Select *File|ASCII column format…* . Set *Column 5* to *Receiver elevation*, *Column 6* to *Shot elevation* (Fig. 2).

Uncheck *File|Import data Settings|Round shot station to nearest whole station number*.

Select *File|Import Data…* and specify *Import data type* `ASCII column format`. Click *button Select* and select file THEORIC2.ASC in \RAY32\JENNY10\INPUT (Fig. 3).

Click *button Import shots*. Click *button Read* to import each of 11 shots into the profile database, without editing any field.

Select *Refractor|Shot breaks*. Press ALT+P. Set *Maximum time* to 110 msecs. (Fig. 4). Hit ENTER key to redisplay traveltime curves. Select *Mapping|Color picked traveltime curves*. Browse curves with F7/F8 (Fig. 5).

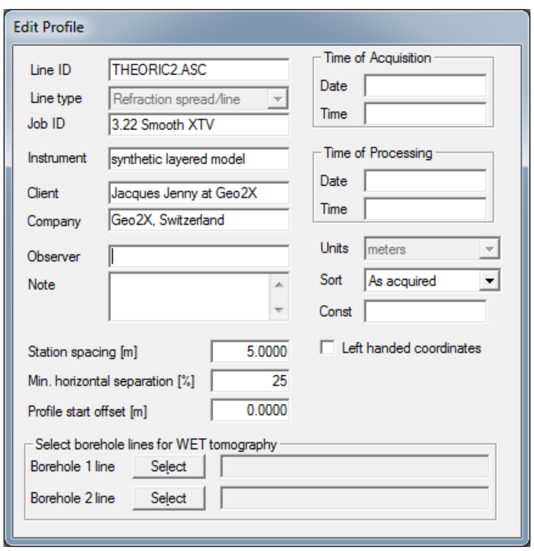

Fig. 1 : *Header|Profile*, edit profile header data

- check *Smooth invert|Smooth inversion Settings|Allow XTV inversion for 1D initial model*
- uncheck *Smooth invert|Smooth inversion Settings|Interpolate velocity for 1D-gradient initial model*
- uncheck *DeltatV|DeltatV Settings|Reduced offset 0.0 is valid trace with time 0.0*
- select *DeltatV|XTV parameters for constant-velocity layers*… to display XTV parameters dialog (Fig. 7)
- check box *Enable Modified Dix layer inversion*
- check box *Enable Intercept time layer inversion*
- check box *Allow adjacent Intercept time layer inversion*
- set *Minimum velocity ratio* to 1.01
- click *Accept button*
- run *Smooth invert|WET with 1D-gradient initial model* to obtain Fig. 6, 8 and 9.

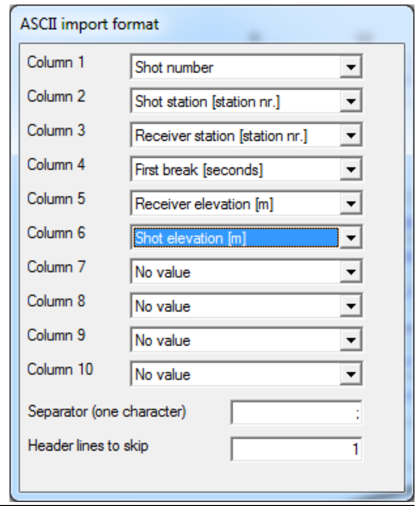

Fig. 2 : *File|ASCII column format…* dialog

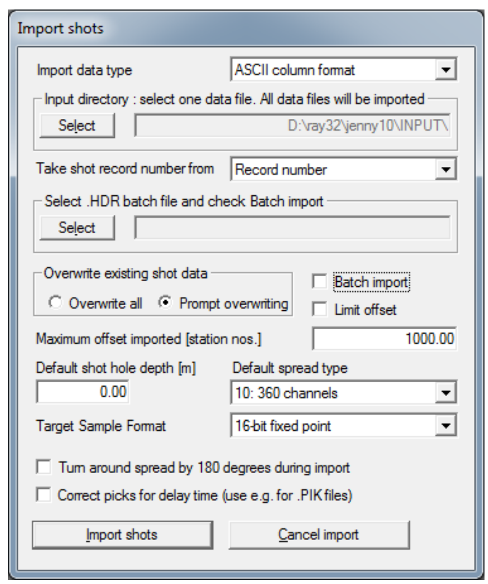

Fig. 3 : *File|Import Data…* dialog

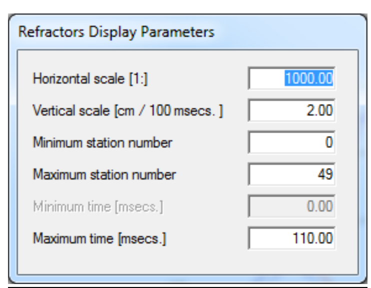

Fig. 4 : ALT+P in *Refractor|Shot breaks*, edit *Refractor Display Parameters* dialog.

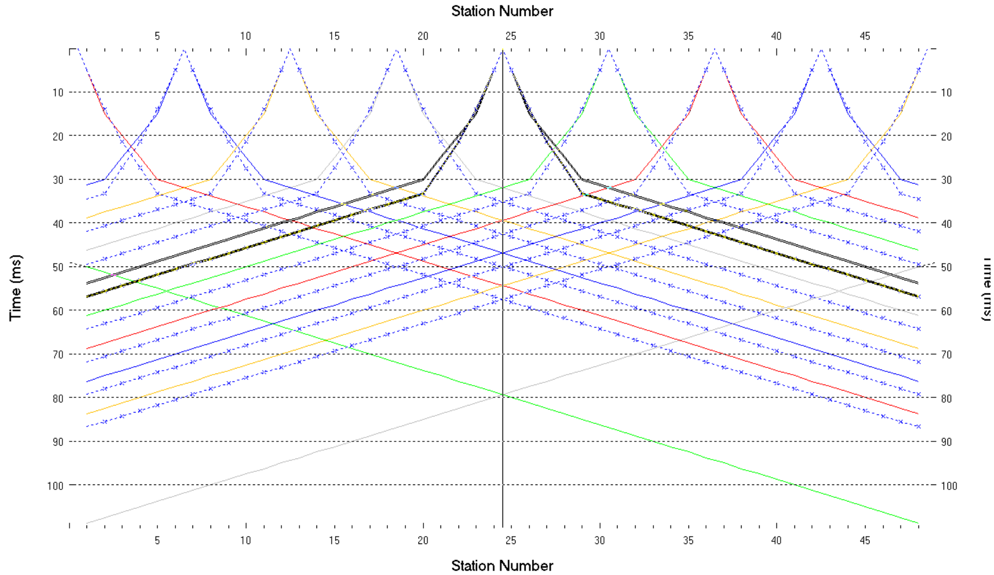

Fig. 5 : *Refractor|Shot breaks* display. Browse traveltime curves with F7/F8. Solid colored curves are picked times, dashed blue curves are modeled times, for 1D initial model shown in Fig. 6 .

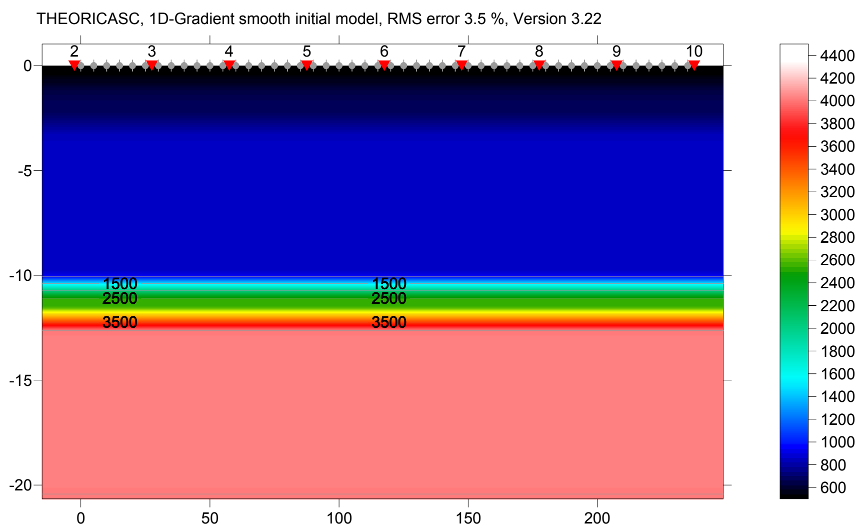

Fig. 6 : 1D initial model obtained with Smooth inversion, with XTV inversion enabled . RMS error is 3.5%. Horizontal/vertical axis in meters, color coding shows velocity in m/s.

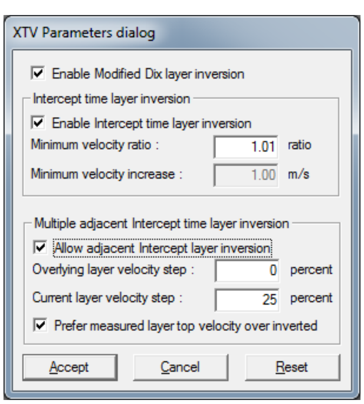

Fig. 7 : *DeltatV|XTV parameters for constant-velocity layers…*

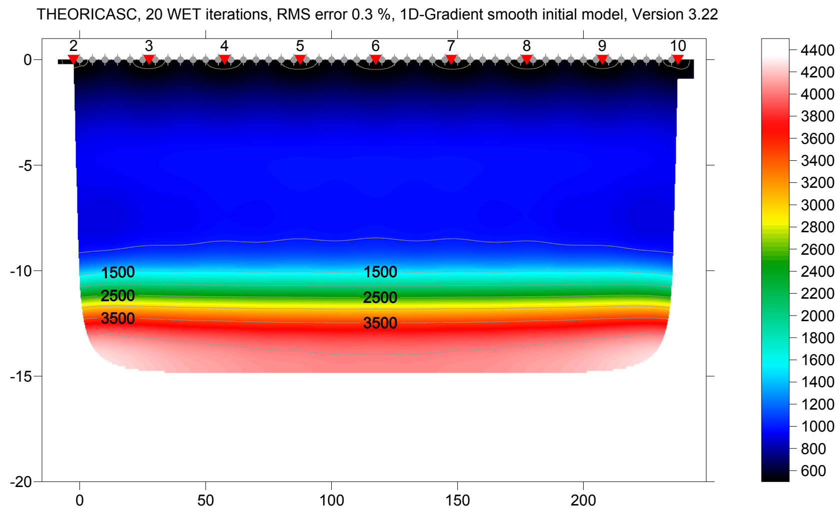

Fig. 8 : Smooth XTV inversion, velocity tomogram obtained with 20 WET iterations. RMS error is 0.3%. Compare with initial model (Fig. 6). Horizontal/vertical axis in meters, color coding shows velocity in m/s.

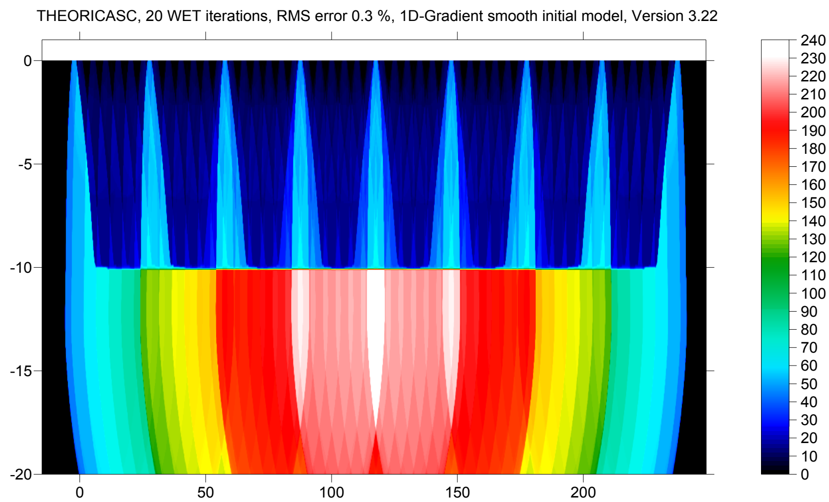

Fig. 9 : WET wavepath coverage plot obtained with Fig. 8. Color coding shows number of wavepaths per pixel.

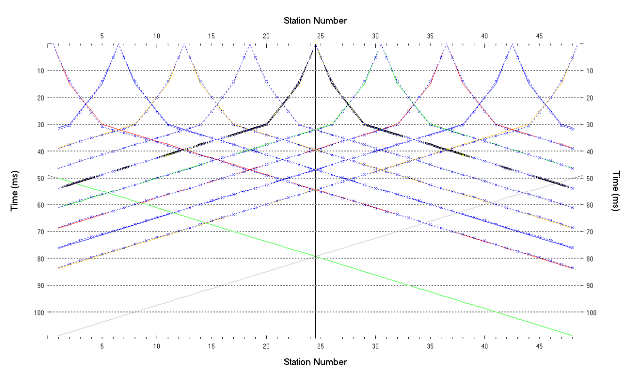

Fig. 10 : *Refractor|Shot breaks*, fit between picked times (solid colored curves) and forward-modeled times (dashed blue curves) obtained with last WET iteration (Fig. 8).

Compare with Fig. 5, showing traveltime fit for 1D initial model (Fig. 6).

Below we show pseudo-2D XTV inversion (Fig. 14), which is the basis for the 1D initial model (Fig. 6), without the horizontal averaging step. Also, we show how gridding the depth vs. velocity data points with Golden Software Surfer® version 8 can generate artefacts, caused solely by the gridding algorithm and not the data (Fig. 16).

- check *Smooth invert|Smooth inversion Settings|Allow unsafe pseudo-2D DeltatV inversion*
- select *DeltatV|Interactive DeltatV…*
- click on *Reset button* to reset settings (Fig. 11)

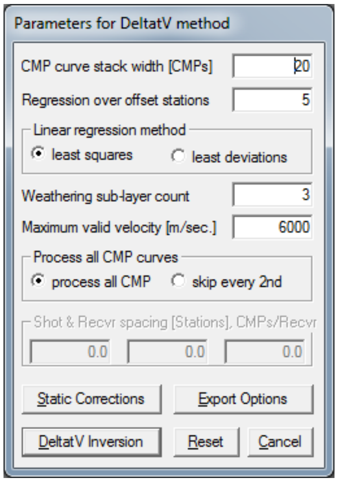

Fig. 11 : *DeltatV|Interactive DeltatV…*

- click on *Export Options button* (Fig. 12)
- set *Gridding method* to `Natural Neighbor`
- click *Accept button*
- click *DeltatV Inversion button*
- in *Save DeltatV dialog* (Fig. 13) , set *File name* to `XTVNaturalNeighbor` and click *Save button*

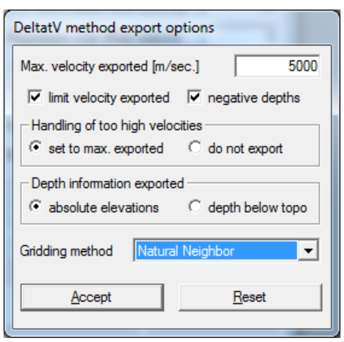

Fig. 12 : DeltatV export options

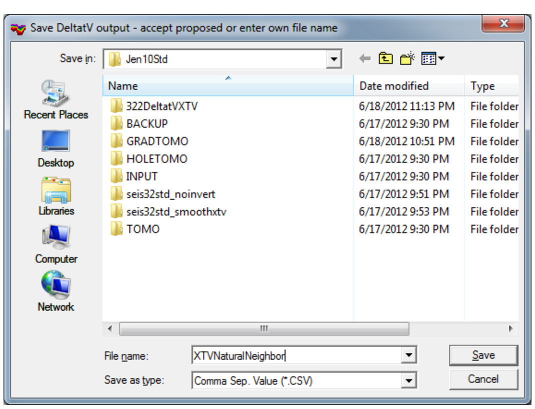

Fig. 13 : Save DeltatV dialog

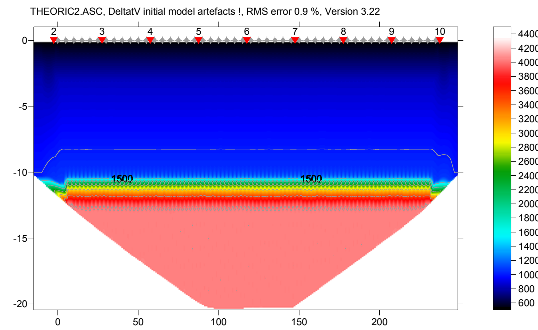

Fig. 14 : pseudo-2D XTV inversion, imaged with Natural Neighbor gridding method. RMS error is 0.9%

- select *Model|Forward model traveltimes..*
- select file XTVNaturalNeighbor.GRD
- click *Open button*
- select *Grid|Image and contour velocity and coverage grids…*
- select again file XTVNaturalNeighbor.GRD and click *Open button* to obtain Fig. 14
- select *Refractor|Shot breaks* to obtain Fig. 15

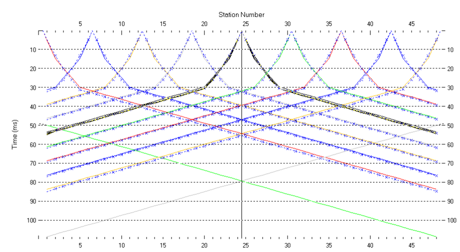

Fig. 15 : traveltime fit for Fig. 14

- go back to Fig. 12 and set *Gridding method* to `Kriging`
- click *buttons Accept & DeltatV inversion*
- save DeltatV output as file `XTVKriging.CSV`
- obtain Fig. 16. Note strong artefacts, caused by Surfer kriging algorithm.

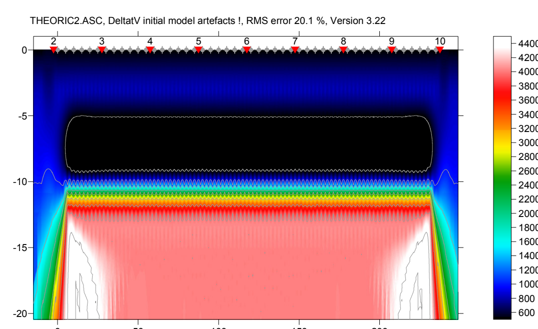

Fig. 16 : pseudo-2D XTV inversion, imaged with Kriging gridding method. RMS error 20.1% ! Note strong artefacts, when comparing to Fig. 14.

Compare data files XTVNaturalNeighbor.CSV and XTVKriging.CSV in jenny10.zip with fc command in a command prompt. These files are identical.

The black-colored low-velocity layer in Fig. 16 at elevation -10m to -5m is solely an artefact of the Surfer Kriging algorithm, and not contained in the data points generated by our DeltatV + XTV inversion. There are no data points between elevation of -3.07m and -10.63m, in file XTVNaturalNeighbor.CSV. Velocity at -3.07m is 840 m/s. Velocity at -10.63m is 1065 m/s. Surfer Natural Neighbor method (Fig. 14) correctly interpolates these velocities. But Kriging method (Fig. 16) overshoots and extrapolates the grid Z data beyond the limits of the original data file, thus causing this low-velocity layer artefact.

For real data sets, vary Surfer gridding method as shown above. Choose the gridding method which shows least amount of apparent artefacts, and smallest RMS error. Then use this initial model for WET inversion, with *WET Tomo|Interactive WET tomography…* .

The slightly too late synthetic traveltimes in Fig. 5 (dashed blue curves) when compared to Fig. 15 can be partly explained by the vertical smoothing step performed by our Smooth XTV inversion algorithm, after horizontally averaging DeltatV velocities (Fig. 14). This vertical smoothing is necessary to filter out horizontal layering artefacts in the 1D initial model. See SAGEEP11.pdf Fig. 4, showing removal of layering artefacts in the basement with a low-pass initial velocity filter.

XTV inversion can work well in case of homogeneous overburden with little lateral velocity variation, e.g. in marine settings. See above. Also, XTV works best for long lines, e.g. longer than 1km. See tutorials ot0608.pdf and GEOXMERC.pdf . In case of strong lateral velocity variation in overburden, we recommend using our Smooth inversion instead. See tutorials epikinv.pdf, fig9inv.pdf, thrust12.pdf.

Also, pseudo-2D DeltatV and XTV inversion is more sensitive to bad picks than Smooth inversion. Identify bad picks in *Trace|Offset gather* according to reciprocity principle. See tutorials riveral8.pdf and GEOXMERC.pdf . Then correct single trace picks in *Trace|Shot gather* and *Trace|Offset gather*, or correct *Trigger delay* in *Header|Shot*, for all traces.

As shown by (Watanabe 1999, Fig. 4) it is not possible to reliably image seismic subsurface velocity at a resolution smaller than one wavelength of dominant frequency of the first break pulse. E.g. with 100 Hz and basement velocity of 4,000 m/s, one wavelength is 4000/100 = 40m. 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).

As shown in tutorials thrust12.pdf , epikinv.pdf, SAGEEP11.pdf and fig9inv.pdf, our Smooth inversion method is capable of imaging strong lateral velocity variation, if shots are spaced closely enough. If first break picks don't obey the laws of physics (reciprocity principle) or shots are spaced too wide apart then inversion becomes highly non-unique, as shown by Dr. Palmer in his SAGEEP 2012 presentation and in our bulgatrl.pdf. To reduce this non-uniqueness and uncertainty, space shot points closely enough and pick first breaks accurately. Position a shot point at every 3rd receiver, and use at least 24 channels per receiver spread.

Wavepath Eikonal Traveltime inversion (WET, Schuster 1993) aka Fresnel Volume Tomography (FVT) uses "fat rays" or Fresnel volumes for modeling of first break energy propagation, instead of conventional "thin rays". Thin rays assume infinite frequency of first break signal. FVT/WET assume finite frequency and correctly model loss of resolution with increasing distance from source/receiver, due to widening of wavepath/Fresnel volume (Hagedoorn 1959, Fig. 1) . The wavepath/Fresnel volume is the 2D subsurface volume involved in propagation of the first break pulse (Watanabe 1999, Fig. 1). For forward modeling we use the Eikonal solver described by Lecomte et al. 2000.

Thus FVT/WET in a physically meaningful way smoothes the velocity tomogram, based on distance of the imaged pixel from source and receiver. The larger this distance, the wider the wavepath is at this pixel, and the more this tomogram region is naturally smoothed, when back-projecting traveltime residuals along wavepaths during SIRT. Tutorial bulgatrl.pdf shows how to explore and control non-uniqueness by varying the WET wavepath width.

Below we include file rayfract,plotrefra,winsism1.pdf sent by Jacques Jenny in March 2010. Note our improved interpretation in Fig. 8, compared to Rayfract® 3.16 output shown below. Also note distorted/biased color coding used for Rayfract® velocity tomograms shown below. Compare color scales used for Rayfract® vs. SeisOpt® output. We append our own output obtained with Rayfract® 3.14, scaled to same size and color encoding of SeisOpt® output sent by Jacques Jenny in 2009, for the same synthetic traveltime data THEORIC2.ASC .

We thank Jacques Jenny for making available these synthetic data and his comparison of interpretations. Use our updated free trial to work through pages 1 to 3 of this tutorial.