

Smooth inversion of synthetic data for thrust fault model, with Rayfract® free trial version 3.22 :

Download our [free trial](#) and install it under Windows XP/Windows 2000/Windows Vista or Windows 7.

Start up Rayfract® trial 3.22 via desktop icon. Select *File|New Profile...* . Set *File name* to THRUST12 and click *Save button*. Specify *Station spacing* of 2 m in *Header|Profile* (Fig. 1).

Unzip archive [thrust.zip](#) in directory \RAY32\THRUST12\INPUT.

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

Select *File|Import Data...* (Fig. 2) and specify *Import data type* ASCII column format. Click *button Select* and select file THRUST.ASC in \RAY32\THRUST12\INPUT. Check *box Batch import*. For ASCII.ASC import no .HDR batch file is required.

Click *button Import shots*, to import all 25 shots specified in THRUST.ASC.

Select *Refractor|Shot breaks*. Press ALT+P. Set *Maximum time* to 40 msec. (Fig. 3). Hit ENTER key to redisplay traveltimes curves. Select *Mapping|Color picked traveltimes curves*. Browse curves with F7/F8 (Fig. 4).

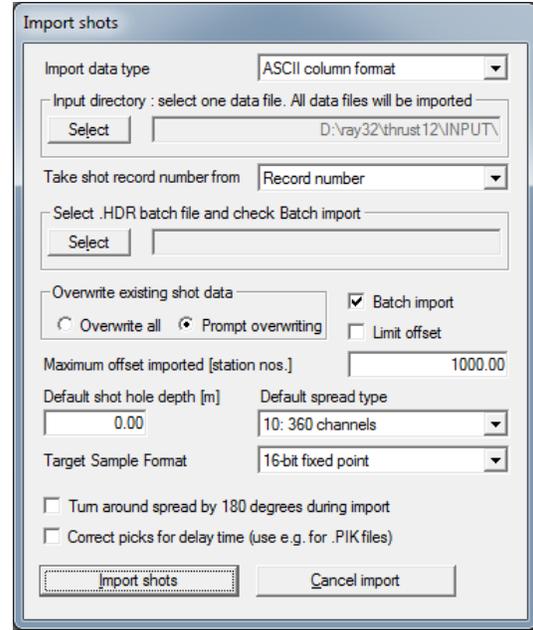


Fig. 2 : *File|Import Data...* dialog

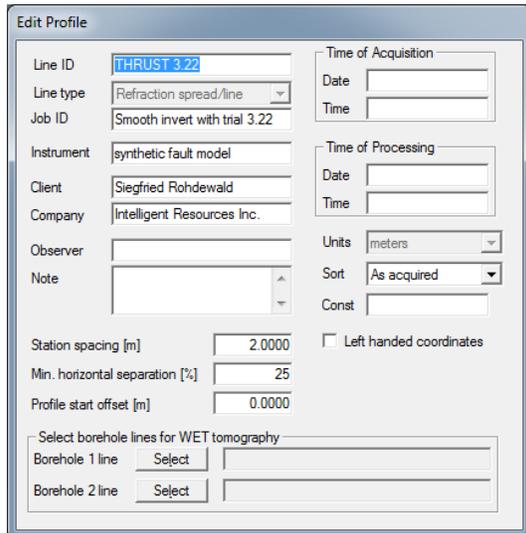


Fig. 1 : *Header|Profile*, edit profile header data

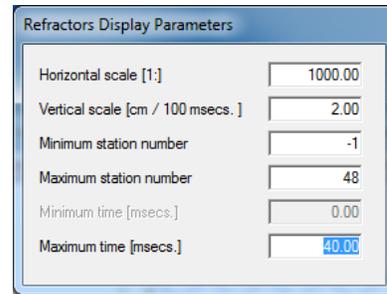


Fig. 3 : ALT+P in *Refractor|Shot breaks*, edit *Refractor Display Parameters* dialog.

To invert the synthetic traveltimes data with our [Smooth inversion](#) method :

- run *Smooth invert|WET with 1D-gradient initial model*
- confirm prompts to obtain Fig. 5, 6 and 7.

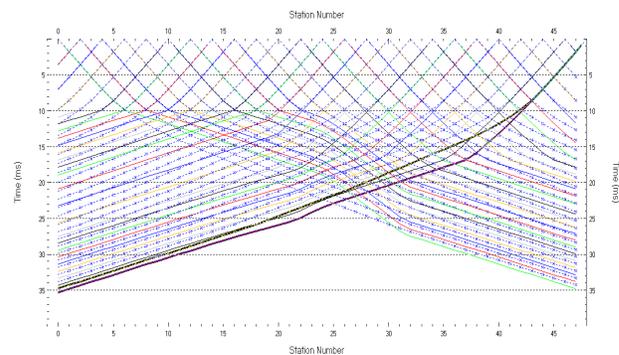


Fig. 4 : *Refractor|Shot breaks* display. Browse traveltimes curves with F7/F8. Solid colored curves are picked times, dashed blue curves are modeled times, for initial model shown in Fig. 5 . RMS error is 4.1%.

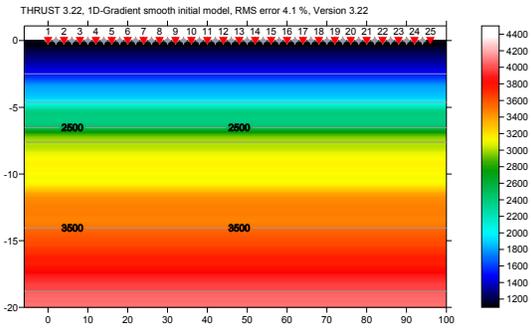


Fig. 5 : 1D initial model obtained with Smooth inversion, with default settings. RMS error is 4.1%. Horizontal/vertical axis in meters, color coding shows velocity in m/s.

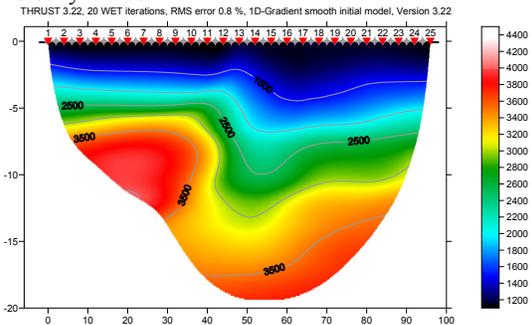


Fig. 6 : Velocity tomogram with Smooth inversion, 20 WET iterations, default settings, wavepath width 3%. RMS error is 0.8%. Initial model is Fig. 5.

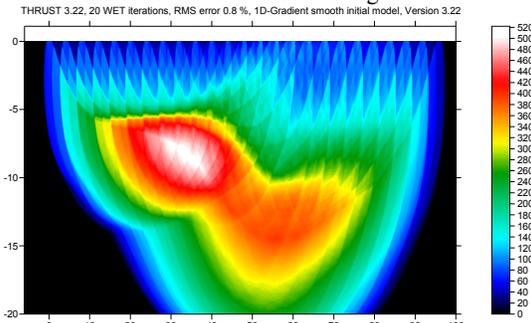


Fig. 7 : WET wavepath coverage plot obtained with Fig. 6. Color coding shows number of wavepaths per pixel / coverage of subsurface with first break energy.

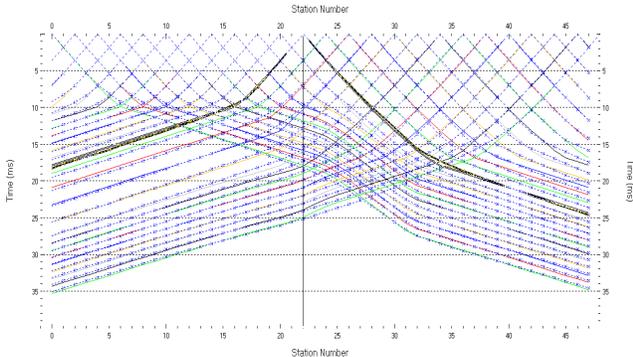


Fig. 8 : Refractor|Shot breaks, fit between picked (colored solid curves) and modeled (dashed blue curves) after 20 WET iterations.

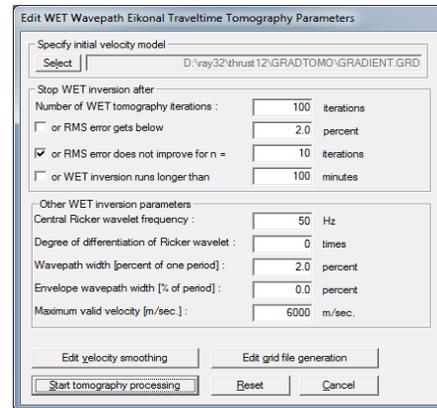


Fig. 9 : WET Tomo|Interactive WET tomography...

The following steps are not possible with the trial :

- uncheck *WET Tomo|WET tomography Settings|Disable wavepath scaling for short profile*, to enable scaling.
- select *WET Tomo|Interactive WET tomography*
- make sure *initial velocity model* is set to `\RAY32\THRUST12\GRADTOMO\GRADIENT.GRD`
- change *Wavepath width* from default value of 3% to 2%. See Fig. 9.
- change *Number of WET tomography iterations* from default 20 to new 100
- edit other settings in *Stop WET inversion after frame* as shown in Fig. 9
- click *Edit grid file generation button*, and change *Store each nth iteration only* to 20
- click buttons *Accept parameters* and *Start tomography processing*. Obtain Fig. 10.

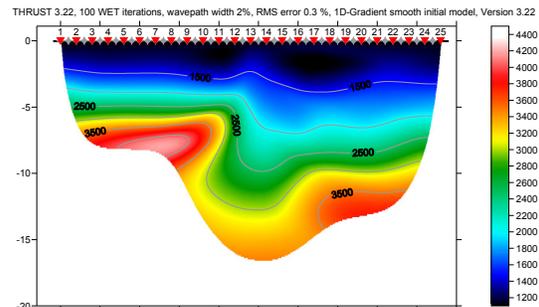


Fig. 10 : 100 WET iterations, wavepath width 2%. RMS error is 0.3%, initial model Fig. 5.

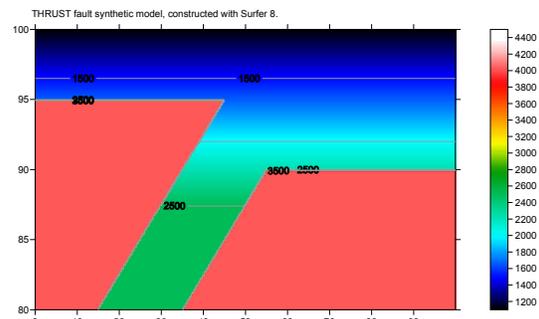


Fig. 11 : synthetic model, built in [Thrust tutorial](#).

Compare agreement between WET inversion output and original model (Fig. 11), for Fig. 6 and Fig. 10. WET after 100 iterations (Fig. 10) more closely images the original model (Fig. 11) than after 20 iterations (Fig. 6). The traveltimes misfit decreased continuously; otherwise the WET inversion would have stopped after fewer than 100 iterations. See (Fig. 9) for WET stop criteria.

Wavepath Eikonal Traveltime inversion (WET, [Schuster 1999](#)) aka Fresnel Volume Tomography (FVT) uses “fat rays” or Fresnel volumes for modeling of first break energy transport, 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](#).

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 traveltimes residuals along wavepaths with SIRT algorithm.

Decreasing the WET wavepath width from 3% (Fig. 6) to 2% (Fig. 9 and 10) helps to more clearly image the fault zone. Decreasing the wavepath width sometimes can improve the resolution, but only if shots are spaced closely enough (at every 3rd receiver) and if first break picks are picked accurately. Otherwise decreasing the wavepath width can instead increase the amount of artefacts, and render WET inversion less stable, see [bulgatr1](#). **Increasing the WET wavepath width is a physically meaningful way to control the non-uniqueness of the solution space.** Increasing the wavepath width will render WET output more smoothly, and diminishes the risk of imaging artefacts. Resolution will typically decrease with increased wavepath width, but maximum imaged depth can increase. See tutorial [ot0608.pdf](#).

For wide shot spacing and inconsistent first break picks, do not decrease the wavepath width from its default setting. An optimal wavepath width suppresses WET inversion artefacts and starting model artefacts, and avoids over-fitting to noisy traveltimes data including bad picks, see [bulgatr1](#). Increasing the wavepath width helps to manage uncertainty : a smoother tomogram contains less artefacts. This can be regarded as a probabilistic imaging approach ([Grandjean 2004](#)). Don't increase wavepath width too much, otherwise targets are imaged too smoothly or blurred, and resolution is lost. Adjusting the WET wavepath width lets you trade off resolution vs. uncertainty. Decreasing the wavepath width can result in higher resolution for consistent and redundant data, or can increase uncertainty if the inversion becomes unstable, due to too wide shot spacing, inconsistent picks or with too strong velocity variation causing diffraction at transition between weathering overburden and basement ([SAGEEP11.pdf](#), 90 degree corner in basement surface).

Enabling WET wavepath scaling can help to improve the resolution directly below topography. But again, if shots are spaced too widely and/or first break picks are inaccurate, this may instead cause artefacts in the WET output. [XTV inversion](#) can work well in case of homogeneous overburden with little lateral velocity variation, e.g. in marine settings. See tutorial [jenny10.pdf](#).

Pseudo-2D DeltatV and XTV inversion are 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 of one shot.

As shown by ([Watanabe 1999](#), Fig. 4) for crosshole surveys, 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 $4000/100 = 40\text{m}$. In case of bad or noisy picks, resolution will not be better than two wavelengths. For refraction surveys, resolution at bottom and edges of tomogram is further reduced, because here rays and wavepaths are aligned predominantly parallel to each other ([White 1989](#)).

As shown above and in tutorials [thrust.pdf](#), [broadepi.pdf](#), [epikinv.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 [bulgatr1.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. The 1D smooth starting model (Fig. 5) used by our Smooth inversion is mandatory for robust WET inversion, to prevent artefacts caused by the starting model ([Sheehan et al. 2005](#), Fig. 1).

Process synthetic data BROADEPI.ASC contained in archive [broadepi.zip](#) and described in [broadepi.pdf](#) and [epikinv.pdf](#) just as above THRUST.ASC, in a separate profile database named e.g. EPIK12.