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

Start up Rayfract<sup>®</sup> 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).

Edit Profile	_	
Line ID Line type Job ID	THEORIC2.ASC Refraction spread/line 3.22 Smooth XTV	Time of Acquisition Date Time
Instrument Client Company Observer Note	synthetic layered model Jacques Jenny at Geo2X Geo2X, Switzerland	Time of Processing Date Time Units Meters Sort As acquired  Const
Station spacing [m]     5.0000     Image: Left handed coordinates       Min. horizontal separation [%]     25       Profile start offset [m]     0.0000       Select borehole lines for WET tomography       Borehole 1 line     Select       Borehole 2 line     Select		

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 constantvelocity 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.

ASCII import format		
Column 1	Shot number	
Column 2	Shot station [station nr.]	
Column 3	Receiver station [station nr.]	
Column 4	First break [seconds]	
Column 5	Receiver elevation [m]	
Column 6	Shot elevation [m]	
Column 7	No value 💌	
Column 8	No value 💌	
Column 9	No value 💌	
Column 10	No value 💌	
Separator (one character)		
Header lines to skip 1		
	,	

Fig. 2 : File ASCII column format... dialog

Import shots		
Import data type ASCII column format Input directory : select one data file. All data files will be imported Select D:\ray32\yenny10\\INPUT\		
Take shot record number from     Record number       Select .HDR batch file and check Batch import       Select       Overwrite existing shot data		
Overwrite all     ** Prompt overwriting     Limit offset       Maximum offset imported [station nos.]     1000.00       Default shot hole depth [m]     Default spread type       0.00     10: 360 channels		
Target Sample Format     16-bit fixed point       Tum around spread by 180 degrees during import       Correct picks for delay time (use e.g. for .PIK files)       Import shots     Cancel import		

Fig. 3 : File Import Data ... dialog

Refractors Display Parameters		
Horizontal scale [1:]	1000.00	
Vertical scale [cm / 100 msecs.]	2.00	
Minimum station number	0	
Maximum station number	49	
Minimum time [msecs.]	0.00	
Maximum time [msecs.]	110.00	

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 <u>XTV inversion</u> enabled . RMS error is 3.5%. Horizontal/vertical axis in meters, color coding shows velocity in m/s.

XTV Parameters dialog		
Enable Modified Dix layer inversion		
Intercept time layer inversion		
Enable Intercept time layer inversion		
Minimum velocity ratio :	1.01	ratio
Minimum velocity increase :	1.00	m/s
Multiple adjacent Intercept time layer inversion		
Overlying layer velocity step :	0	percent
Current layer velocity step :	25	percent
Prefer measured layer top velocity over inverted		
Accept Cancel	E	leset

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













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).

190

120

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)

Parameters for DeltatV method		
CMP curve stack width [CMPs] 20		
Regression over offset stations 5		
Linear regression method		
least squares     C least deviations		
Weathering sub-layer count 3		
Maximum valid velocity [m/sec.] 6000		
Process all CMP curves		
Shot & Recvr spacing [Stations], CMPs/Recvr		
0.0 0.0 0.0		
Static Corrections Export Options		
DeltatV Inversion Reset Cancel		

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

DeltatV method export options			
Max. velocity exported [m/sec.] 5000			
☑ limit velocity exported ☑ negative depths			
Handling of too high velocities			
Depth information exported absolute elevations C depth below topo			
Gridding method Natura	Neighbor		
Accept	Reset		

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 <u>SAGEEP11.pdf</u> Fig. 4, showing removal of layering artefacts in the basement with a low-pass initial velocity filter.

<u>XTV inversion</u> 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 <u>ot0608.pdf</u> and <u>GEOXMERC.pdf</u>. In case of strong lateral velocity variation in overburden, we recommend using our <u>Smooth</u> inversion instead. See tutorials <u>epikinv.pdf</u>, 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 <u>riveral8.pdf</u> and <u>GEOXMERC.pdf</u>. 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 (<u>Watanabe 1999</u>, 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 (<u>White 1989</u>).

As shown in tutorials <u>thrust12.pdf</u>, <u>epikinv.pdf</u>, <u>SAGEEP11.pdf</u> and <u>fig9inv.pdf</u>, our <u>Smooth inversion</u> 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 nonunique, as shown by <u>Dr. Palmer</u> in his <u>SAGEEP 2012</u> presentation and in our <u>bulgatrl.pdf</u>. To reduce this nonuniqueness and uncertainty, space shot points closely enough and <u>pick first breaks accurately</u>. Position a shot point at every 3<sup>rd</sup> receiver, and use at least 24 channels per receiver spread.

Wavepath Eikonal Traveltime inversion (WET, <u>Schuster 1993</u>) 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 (<u>Hagedoorn 1959</u>, 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 <u>bulgatrl.pdf</u> 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 <u>free trial</u> to work through pages 1 to 3 of this tutorial.

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