Thrust Fault Modeling and Imaging with Surfer® 8 and Rayfract® 3.19

We show how to define the recording geometry by importing dummy shots into a Rayfract® profile database, without first break picks. Next we create a thrust fault model grid with Surfer. Then we generate synthetic shots with our Eikonal Solver, by forward modeling wave propagation through this model grid. Finally these synthetic shots are interpreted with default method *Smooth inversion* , and pseudo-2D DeltatV inversion.

Create a new Rayfract profile database, import dummy shots

Extract file ONESHOT.ASC from archive http://rayfract.com/tutorials/thrust.zip . Now create a new Rayfract® profile database named THRUST, as described in our manual as available at http://rayfract.com/help/manual.pdf . Specify a *station spacing* of 2 meters, in *Header|Profile*. Then copy above file ONESHOT.ASC into directory \RAY32\THRUST\INPUT. ONESHOT.ASC specifies 48 channels, with first breaks set to -1. You may edit such a dummy .ASC shot with any text editor e.g. Windows WordPad.

Now import file ONESHOT.ASC repeatedly, once for each shot position which we want to model, as in above manual.pdf . Set *Import data type* to *ASCII column format*. Leave *Default spread type* at default setting *10: 360 channels* or set to or *02:48 channels*. Specify *Shot pos. [station no.]* 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48. Specify *Shot Number* 1 to 25 for these shots, during import. Leave *Layout start* at 0.0 . Once done with import, set topography elevation "z" to 100.0 in *Header|Station* for one station. Hit ENTER and confirm prompt, to extrapolate elevation 100.0 to all stations.

Model grid file generation with Surfer 8

Create a new profile subdirectory \RAY32\THRUST\MODEl, in Windows Explorer. Next start up Surfer 8. Select *Grid|Function...* and set the "function" text field to "z = 2500 - max(y - 87.5, 0) * (1500 / 13.5)". Specify the other grid generation parameters as follows :
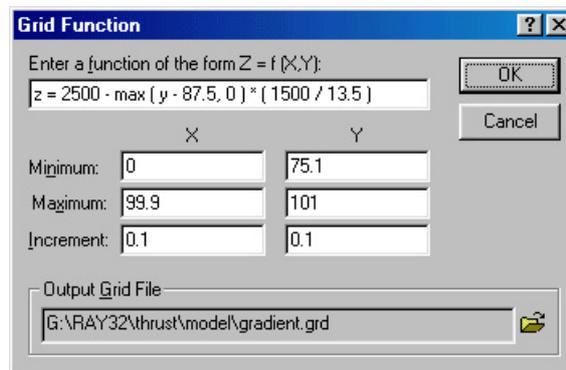

Click on *OK* to generate our 1D overburden velocity-gradient grid file. Select *Grid|Function...* again and set the "function" text field to "z = 4000". Specify \RAY32\THRUST\MODEL\BASEMENT.GRD as output file. Click on *OK* to generate the constant-velocity basement grid file. Now select *Start|Run...*, enter the program name NOTEPAD.EXE and hit RETURN. Then enter the following content :
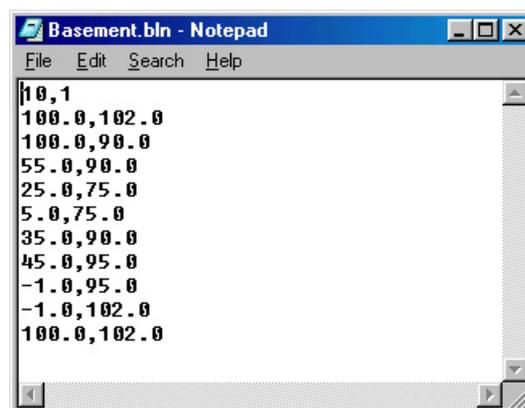
Be sure to hit ENTER at end of last line 100.0, 102.0, to force an end-of-line character in the disk file. Select *File|Save As...* . Set *Save as type* to *All Files*. Set *File name* to \RAY32\THRUST\MODEL\BASEMENT.BLN. Click on *Save button*. This file is a *Golden Software Blanking File*; see your Surfer 8 manual Appendix C. Our blanking file describes the "overburden + fault plane low velocity zone" polygon which we want to cut out of above basement grid file. The lower side of the polygon is the "top of basement" topography i.e. relief. Basically we model the thrust fault as a "Basement step" plus low velocity fault plane dipping to the left with a gradient of 0.5 i.e. angle of 26.5 degrees.

Go back into Surfer, select *Grid|Blank...* and then the BASEMENT.GRD file as generated above. Then select our BASEMENT.BLN file. Specify \RAY32\THRUST\MODEL\FAULT.GRD as output file name and click on *Save* to generate our "faulted basement without overburden" grid file.

Now generate our thrust fault model grid file. Select *Grid|Mosaic...* and then above GRADIENT.GRD file. Click on *Add...* and select above FAULT.GRD file. Set *Overlap method* to *Maximum*. Click on the folder icon to the right of field *Output Grid File* and enter file name THRUST.GRD. Our *Grid Mosaic dialog* should now look as follows :
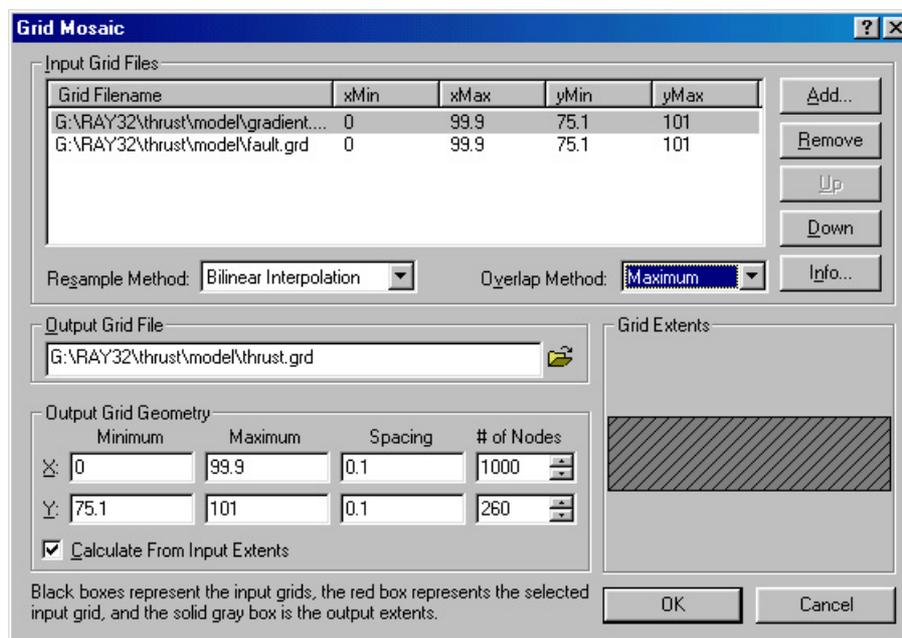
Click on *OK* to generate the thrust fault model grid file. Select *Map|Image Map...* and our THRUST.GRD file. Double-click the resulting plot with left mouse key. Adapt *General, Limits and Scale tabs* to obtain the following output :
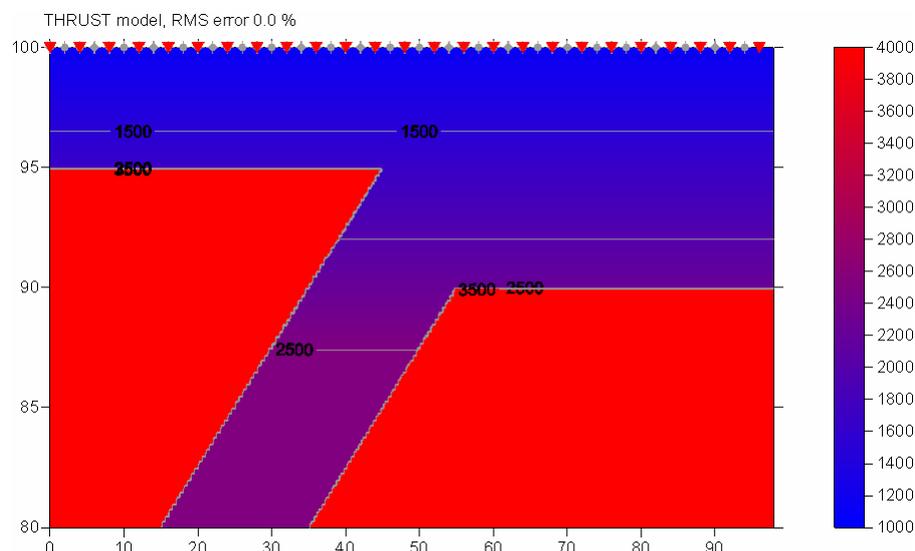
Forward modeling of seismic wave propagation and subsequent inversion with Rayfract

Open profile database \RAY32\THRUST as created above, with Rayfract® *File|Open Profile…* Select *Model|Model synthetic shots…* and \RAY32\THRUST\MODEL\THRUST.GRD . Select *File|Export header data|Export First Breaks as ASCII…* . Save to file THRUST.ASC. Select *Refractor|Shot breaks*. Now press ALT+P, set *Maximum time [msecs.]* to 40 and hit ENTER. Browse through synthetic shots with F7/F8 :
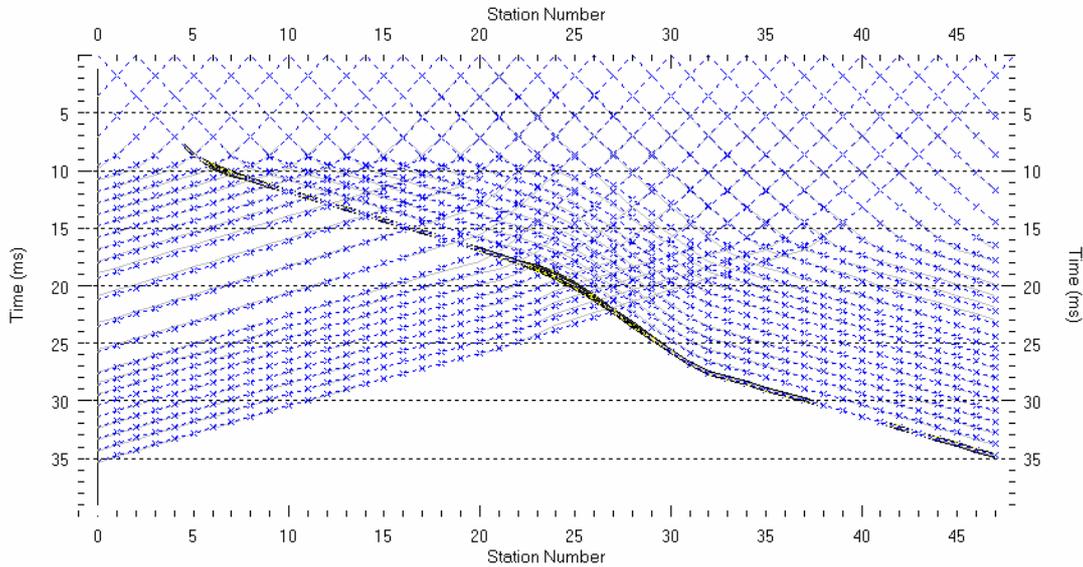

Fig. 1 : shot-sorted traveltime curves. Grey curves are picked times, blue are modeled times.

Next we will invert our synthetic shots and show the resulting thrust fault data set interpretation. Please compare this with the original model as constructed and imaged above :

- select *Smooth inversion|WET with 1D-gradient initial model* and confirm prompts. Obtain Fig. 2.
- select *WET Tomo|Interactive WET tomography*
- make sure the *initial velocity model* is set to \RAY32\THRUST\GRADTOMO\GRADIENT.GRD
- change *Wavepath width* from default value of 3% to 2%
- change *Number of WET tomography iterations* from default 20 to new 100
- click *Edit grid file generation button*, and change *Store each nth iteration only* to 20
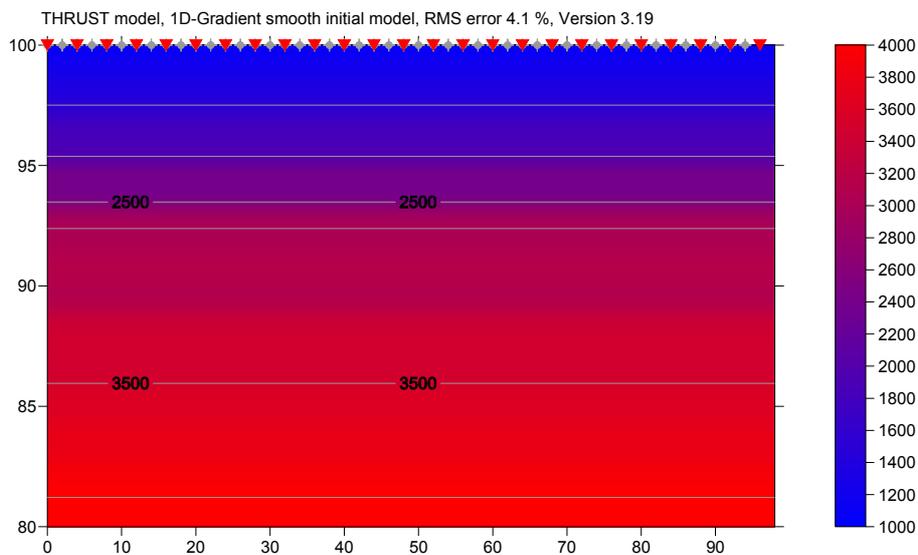- click buttons *Accept parameters* and *Start tomography processing*. Obtain Fig. 3.

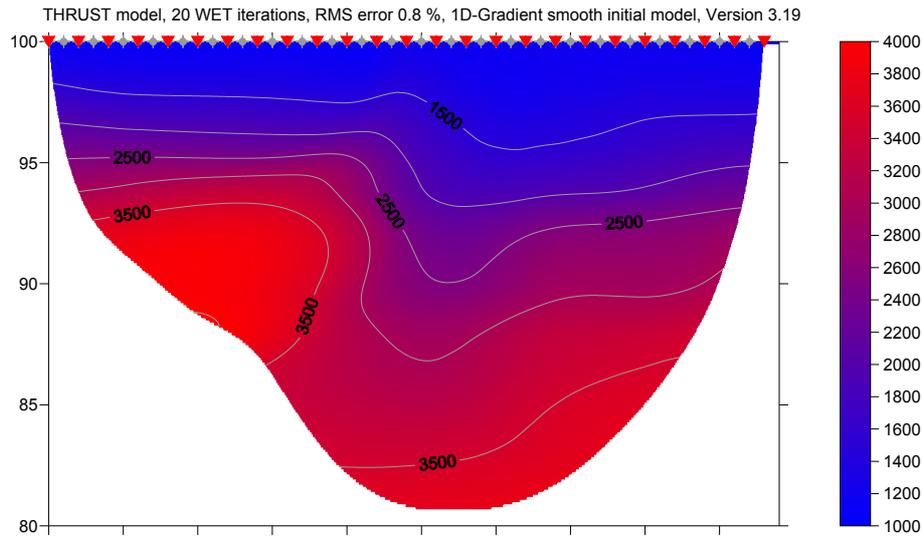Fig. 2 a) : Smooth 1D-gradient initial model, default parameters

Fig. 2 b) : 20 WET iterations, 1D initial model (Fig. 2 a)), WET wavepath width 2%
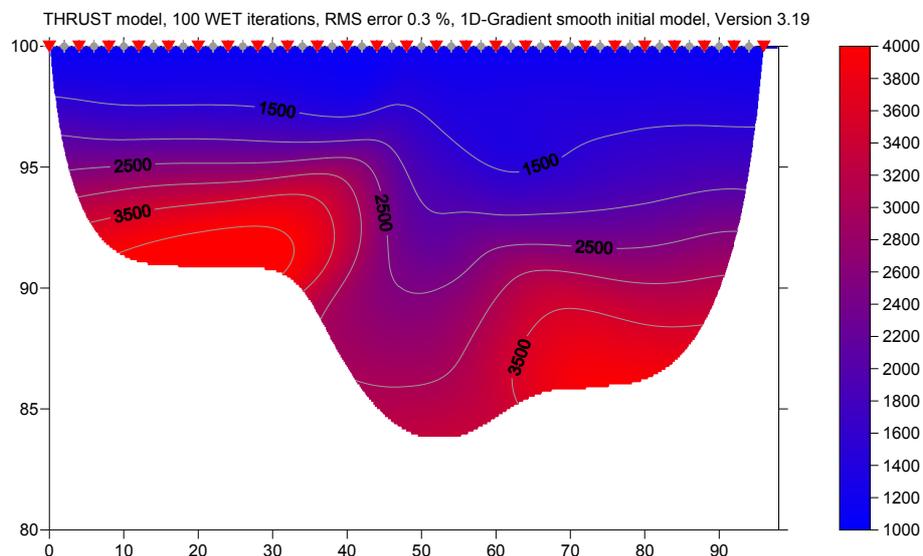

Fig. 3 : 100 WET iterations, 1D initial model (Fig. 2 a)), WET wavepath width 2%

For Smooth inversion of a data set with a shot spacing closer than 3 receivers, you can optionally decrease the WET *wavepath width* by 33%, e.g. from default value of 3% to 2%, to increase resolution. Do this only with consistent first break picks, i.e. if the RMS error of the default Smooth inversion is smaller than 2%, after 20 WET iterations.

Next we show pseudo-2D DeltatV inversion :

- *check Smooth invert|Smooth inversion Settings|Allow unsafe pseudo-2D Delta-t-V inversion*
- *select DeltatV|Automatic Delta-t-V and WET inversion, confirm prompts*. Obtain Fig. 4.
- select *WET Tomo|Interactive WET tomography*
- make sure the *initial velocity model* is set to \RAY32\THRUST\TOMO\DELTATV.GRD
- click *Reset button*, and change *Wavepath width* from default value of 3% to 2%
- click buttons *Accept parameters* and *Start tomography processing*. Obtain Fig. 5.
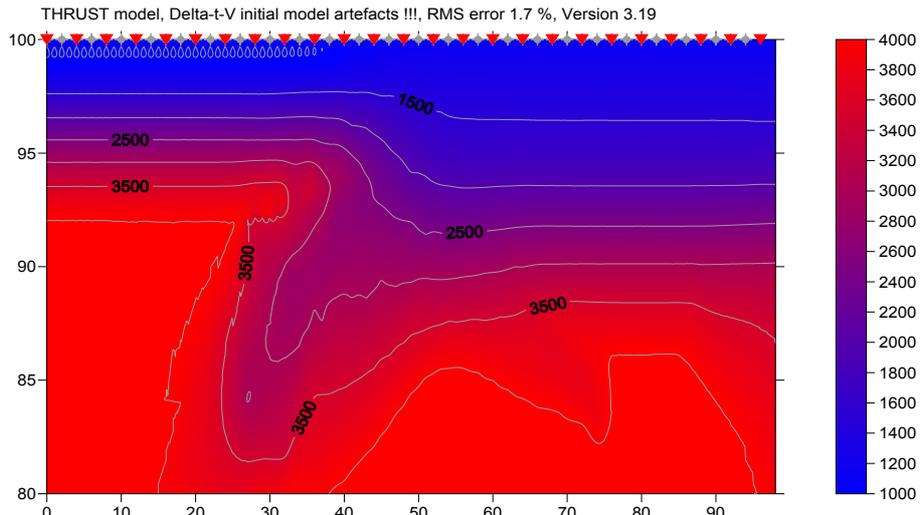
THRUST model, Delta-t-V initial model artefacts !!!, RMS error 1.7 %, Version 3.19

Fig.4 : pseudo-2D DeltatV initial model, default parameters

THRUST model, 20 WET iterations, RMS error 0.5 %, Delta-t-V initial model artefacts !!!, Version 3.19
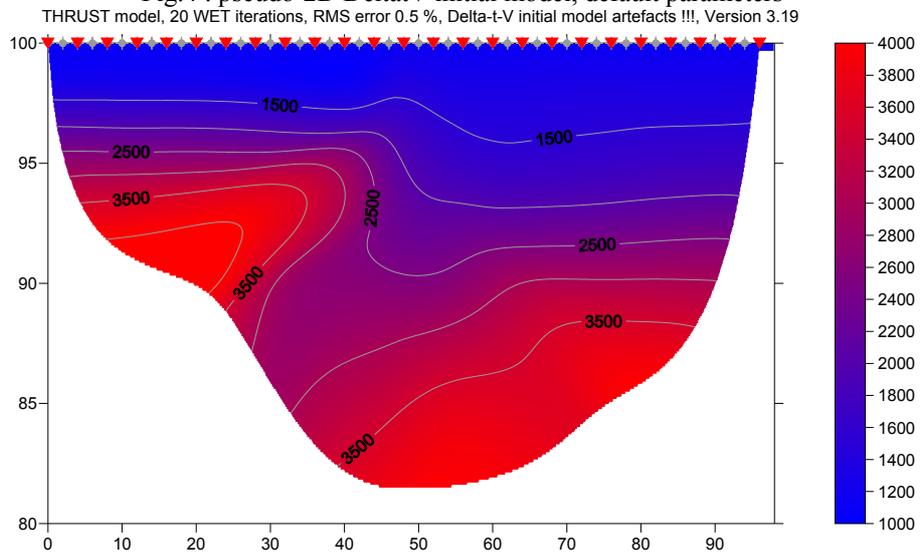
Fig. 5 : 20 WET iterations with pseudo-2D DeltatV initial model (Fig. 4). WET Wavepath width 2%.

As shown in Fig. 4, our pseudo-2D DeltatV inversion can image velocity inversions, with close enough shot and receiver spacing and favorable subsurface geology.

However, in most situations, such as with strong lateral velocity variation, our 1D-gradient initial model based Smooth inversion method works best. DeltatV initial model based inversion typically shows artefacts. See

http://rayfract.com/tutorials/broadepi.pdf
http://rayfract.com/tutorials/epikinv.pdf
http://rayfract.com/tutorials/fig9inv.pdf

We recommend to always invert data with our Smooth inversion with a 1D initial model, as shown above in Fig. 2 and 3. Also, increasing parameter *WET iteration count* from its default value of 20 iterations to 100 iterations lets WET inversion **remove horizontal layering artefacts of the 1D initial model**. Again see Fig. 2 and 3 shown above.