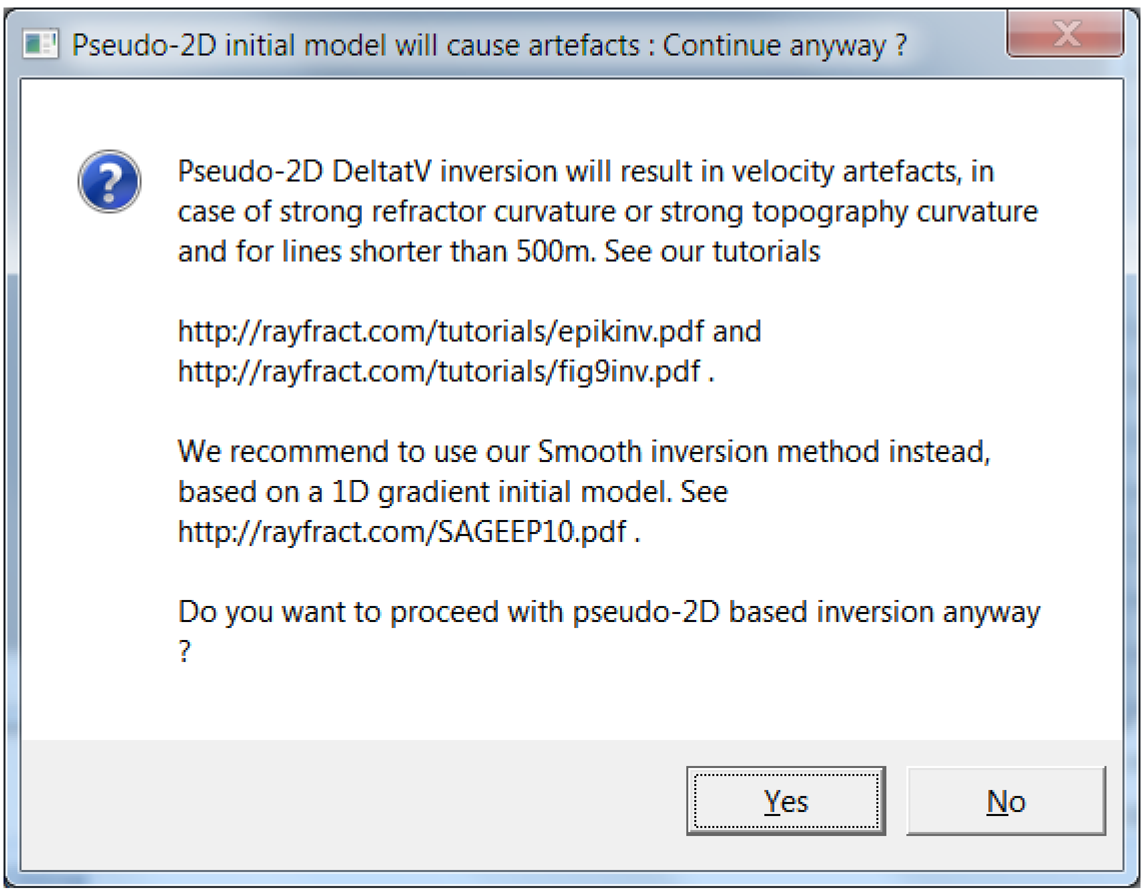
Pseudo-2D DeltatV inversion

Always first invert your refraction data with our fail-safe Smooth inversion method. Smooth inversion gives a more reliable interpretation especially in case of **strong lateral velocity variation in the overburden (Sheehan 2005; https://rayfract.com/srt_evaluation.pdf) and in case of strong topography or with too wide receiver and shot spacing or for too short profiles/profiles shorter than 500m**. The 1D-gradient initial model computed by our Smooth inversion method guarantees that DeltatV artefacts occurring in situations of strong refractor curvature / strong lateral velocity variation / strong topography are eliminated from the interpretation at an early stage by laterally averaging DeltatV velocity (Sheehan 2005) . The pseudo-2D DeltatV initial model will show systematic velocity artefacts in such situations : too low velocity below anticlines and too high velocity below synclines.

DeltatV ***apparent velocity*** pseudo-sections can be compared to ER ***apparent resistivity*** pseudo-sections. See e.g. https://pages.mtu.edu/~ctyoung/LOKENOTE.PDF chapter 2.3 on page 8. Quote :

"The pseudosection is useful as a means to present the measured apparent resistivity values in a pictorial form, and as an initial guide for further quantitative interpretation. One common mistake made is to try to use the pseudosection as a final picture of the true subsurface resistivity." quoted from page 8 of above LOKENOTE.pdf .

When you start DeltatV inversion with DeltatV menu commands *Automatic DeltatV and WET inversion* or *Interactive DeltatV* we show the following artefact warning prompt :



You need to acknowledge above artefact warning prompt by clicking Yes button to continue with unsafe

DeltatV inversion of your first breaks.

DeltatV can work well for long profiles (longer than 500m) with homogeneous overburden and recorded with dense shot and receiver spacing. This includes marine surveys. See tutorials

https://rayfract.com/tutorials/ot0608.pdf and https://rayfract.com/samples/GEOXMERC.pdf and https://rayfract.com/tutorials/3016.pdf .

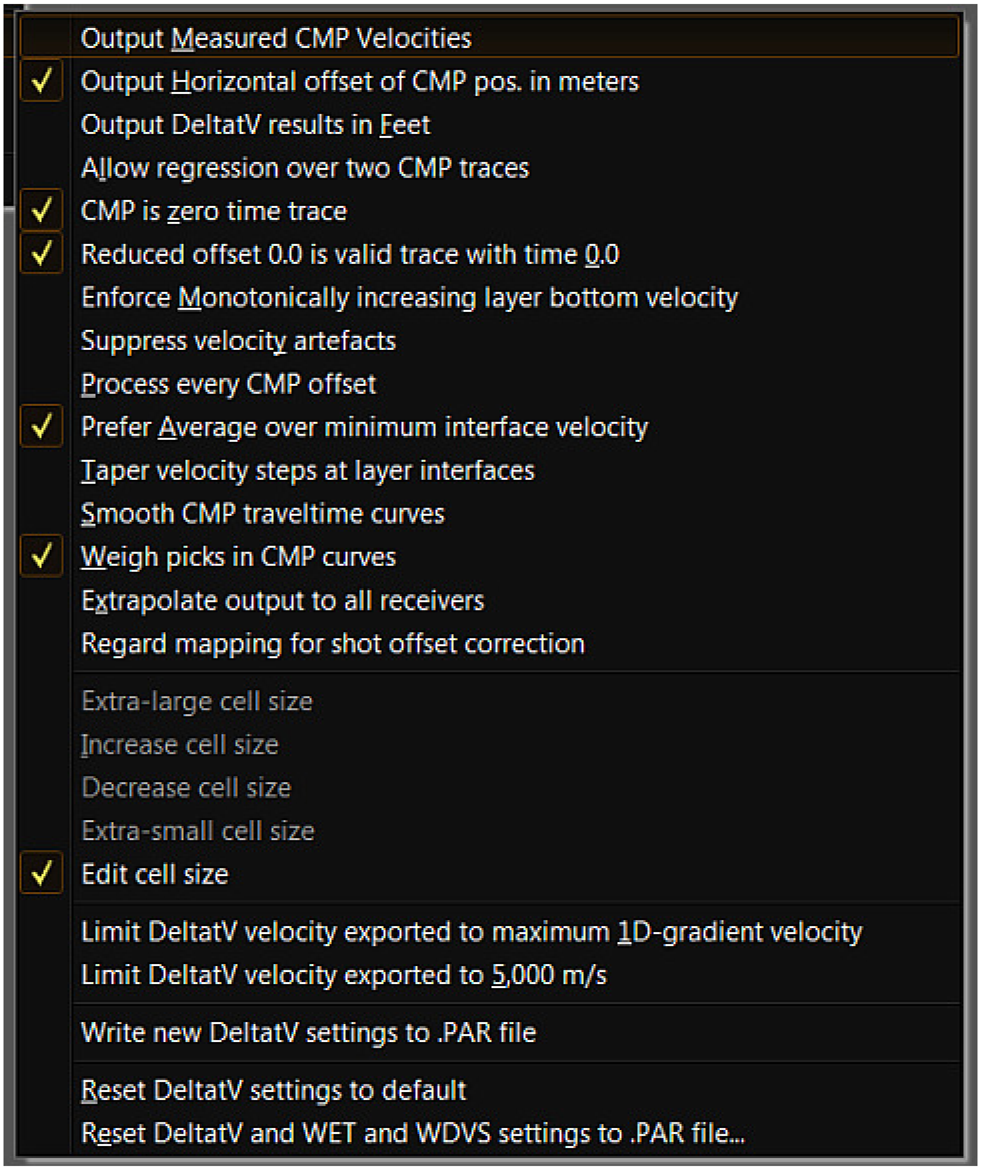
Enable options *Suppress velocity artefacts* and *Smooth CMP traveltime curves* in DeltatV|DeltatV Settings submenu (see below) for long and dense lines, for **more regulare DeltatV output with less artefacts and less noise**. See also above tutorials ot0608 on page 3 and GEOXMERC on page 1. For shorter and lower-coverage lines leave these two options disabled for better resolution.

See our tutorial https://rayfract.com/tutorials/jenny10.pdf for instructions on using our XTV inversion method allowing imaging of constant-velocity weathering overburden. This tutorial also shows **imaging artefacts caused solely by Golden Software Surfer version 8 Kriging gridding method**. Natural Neighbor gridding method works much better at least in this case, for imaging of pseudo-2D XTV inversion output. This may help for DeltatV output as well.

Our tutorial https://rayfract.com/tutorials/thrust.pdf shows construction of a synthetic fault zone model using Surfer and forward modeling of synthetic traveltimes. DeltatV inversion shown in this thrust.pdf tutorial shows quite a realistic image of the fault zone. So pseudo-2D DeltatV can sometimes image fault zones given a favorable geological setting with homogeneous overburden beneath flat topography and close enough spacing of receivers and shots . E.g. use *receiver station spacing* of 2m with 48 or more channels and a shot at every 2nd receiver as shown in thrust.pdf
tutorial. Always also run our Smooth inversion and compare with DeltatV-based WET inversion to identify areas where the two inversions differ. Prefer the *Smooth inversion* output for such areas especially for too short profiles/profiles shorter than the recommended 500m or for profiles with strong topography or with strong refractor curvature or for profiles with too wide receiver and shot spacing.

Review our https://rayfract.com/tutorials/sageep11_16.pdf tutorial where DeltatV inversion fails in Fig. 16. due to too strong refractor curvature in the original synthetic "basement step with fault zone" model shown in Fig. 17 (Zelt et al. 2013).

If the Smooth inversion interpretation shows at least some degree of quasi-horizontal subsurface layering and not too strong lateral velocity variation in the overburden then you may optionally run our pseudo-2D DeltatV based WET inversion . **To start the automated pseudo-2D DeltatV and WET inversion select** *Automatic DeltatV and WET inversion* in our DeltatV menu *.*



To use pseudo-2D DeltatV output as a starting model for WET inversion configure DeltatV in DeltatV|DeltatV Settings menu (shown above) as follows (as per default) :

- select *DeltatV|DeltatV Settings|Output Horizontal offset of CMP pos. in meters*
- optionally select *DeltatV|DeltatV Settings|Output DeltatV results in Feet*
- *DeltatV|Interactive DeltatV|Export options* : if you select option *depth below topo* or do not specify any topography i.e. set the topography to 0.0, you need to select *negative depths* in the same dialog.

Introduction to DeltatV inversion

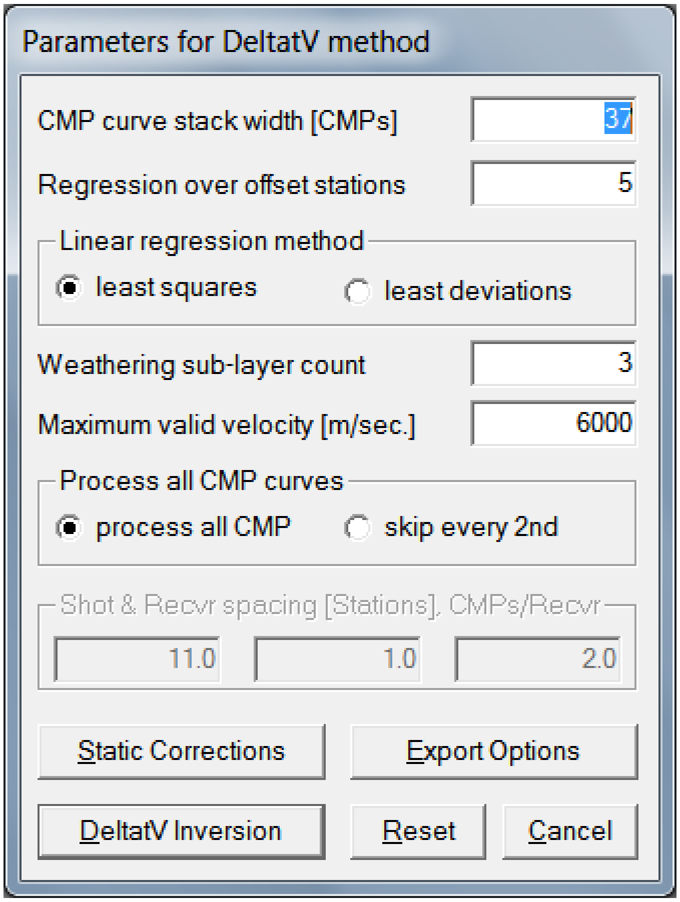
Since version 1.30, released in December 1998, our Rayfract® software implements the **DeltatV method** as described by (Gebrande and Miller 1985). This turning-ray inversion method delivers continuous depth vs. velocity profiles for all profile stations. These profiles consist of (horizontal inline offset, depth, velocity) triples. The profiles are written to an ASCII file which may be processed conveniently with Golden Software's Surfer® etc., to produce **color-coded inline offset vs. depth velocity-contour maps** / **velocity isolines**. The method **handles real-life geological situations such as velocity gradients** / linear increasing of velocity with depth / velocity inversions / pinching out layers and outcrops / faults and local velocity anomalies gracefully. Furthermore, it **does not require the user to map traveltimes to refractors at all**. Importing seismic data and complementing it with geometry information / traveltime picks is all that is needed. Be sure to do **quality control of models obtained by comparing synthetic traveltimes as obtained with our integrated raytracing algorithm against times as measured and picked** (as shown in the *Shot breaks display*). Default values for the DeltatV parameters as proposed by the software automatically will work in most cases and no tuning of the parameter values is necessary (but is possible; see below for a description of all parameters).

Alternatively you may want to have **one core drilling site along the profile** to check depths delivered by the DeltatV method with velocity-depths as reconstructed from the core. Our **DeltatV method requires 10 or more shots per profile for reliable inversion results**. The more shots the better, as long as first breaks are picked carefully. You may want to record uphole picks from such a deep hole bottom, e.g. with the same receiver spread(s) used to record surface shot picks. These uphole picks can then be integrated with surface picks during the **WET tomography inversion**. Typically, **shot point distances** should not exceed 6 times the receiver distance. A ratio of 1:3 would be ideal. You may want to employ an accelerated weight drop of high mobility to reach a high enough number of shots recorded per hour. Be sure to record enough far **offset shots** (inline offset from the receiver spread by one half to one spread length) to reach your targeted depth / increase the maximum depth imaged. **Receiver spreads should overlap** by a few positions ideally by up to one half spread length.

For each CMP station nr. a smoothed *CMP traveltime curve* is computed and automatically partitioned into short segments. Each such segment contains first breaks critically refracted (i.e. with the corresponding rays turning back to the surface) inside one hypothetical layer. An individual velocity gradient function is determined for each such layer, based on first breaks measured. The ASCII (inline offset, depth, velocity) triples will be written to a file named DELTATV.TXT in the current profile database subdirectory e.g. \RAY32\LINE14 when processing the sample profile. One triple will be written for each hypothetical layer interface. The velocity value of that triple is the minimum or average of the bottom velocity of the upper layer and the top velocity of the lower layer. Another file named SEIS32.BLN will be generated in the profile directory e.g C:\RAY32\LINE14 (not for free trial). It contains a Surfer® boundary format definition of the topography which may be used to blank out gridded values situated above the topography with *Surfer® menu item Grid|Blank*.

The DeltatV method may deliver **too deep or too shallow interpretations if the receiver or source spacing is too wide to enable proper identification and imaging of the topmost weathering layers**. These depth errors will be revealed when carrying out quality control of these interpretations with our integrated forward modeling algorithm. Just run the Eikonal solver over the depth-velocity model obtained to get a set of synthetic traveltimes for all profile shots. Then compare the modeled times with times as measured and picked, in the *Shot breaks display*. The closer the agreement, the better the model.

To adjust the subsurface velocity model until the synthetic times optimally match the first break times as measured and picked use **WET Wavepath Eikonal Traveltime tomography processing**.**Subsequent WET tomography processing makes it less important to tune the DeltatV parameters**. Default values for DeltatV parameters should give acceptable initial subsurface velocity models for WET processing in most geological settings.



When looking at DeltatV output, please be aware that you should give most weight to near-surface imaging. **The deeper the structure imaged, the more uncertainty is involved in determining depth and velocity**. This is caused by **accumulation of modeling errors in the overburden, during reduction of deeper traveltimes to the next lower level** ("overburden layer stripping"). These modeling errors may occur if you specify uncalibrated values for parameter *Regression over offset stations* and other DeltatV parameters. As a consequence of these modeling errors in the overburden, deeper traveltimes will be reduced with unrealistic delay times and may be under- /over corrected. This error accumulation may result in unrealistically high/low velocities as imaged beyond a certain depth (e.g. below the bottom of the overburden) or too shallow/deep interpretations. You may want to adjust (increase from default value of 5) the value for parameter *Regression over offset stations*. and vary parameter *CMP curves stack width*. Alternatively, make use as appropriate, of parameters *Maximum valid velocity* and *Maximum velocity exported* (see below) to suppress the consideration during processing and the later output of unrealistically high velocities. The value specified for the former parameter should exceed the value for the latter by e.g. about 500 to 1000 meters per second.

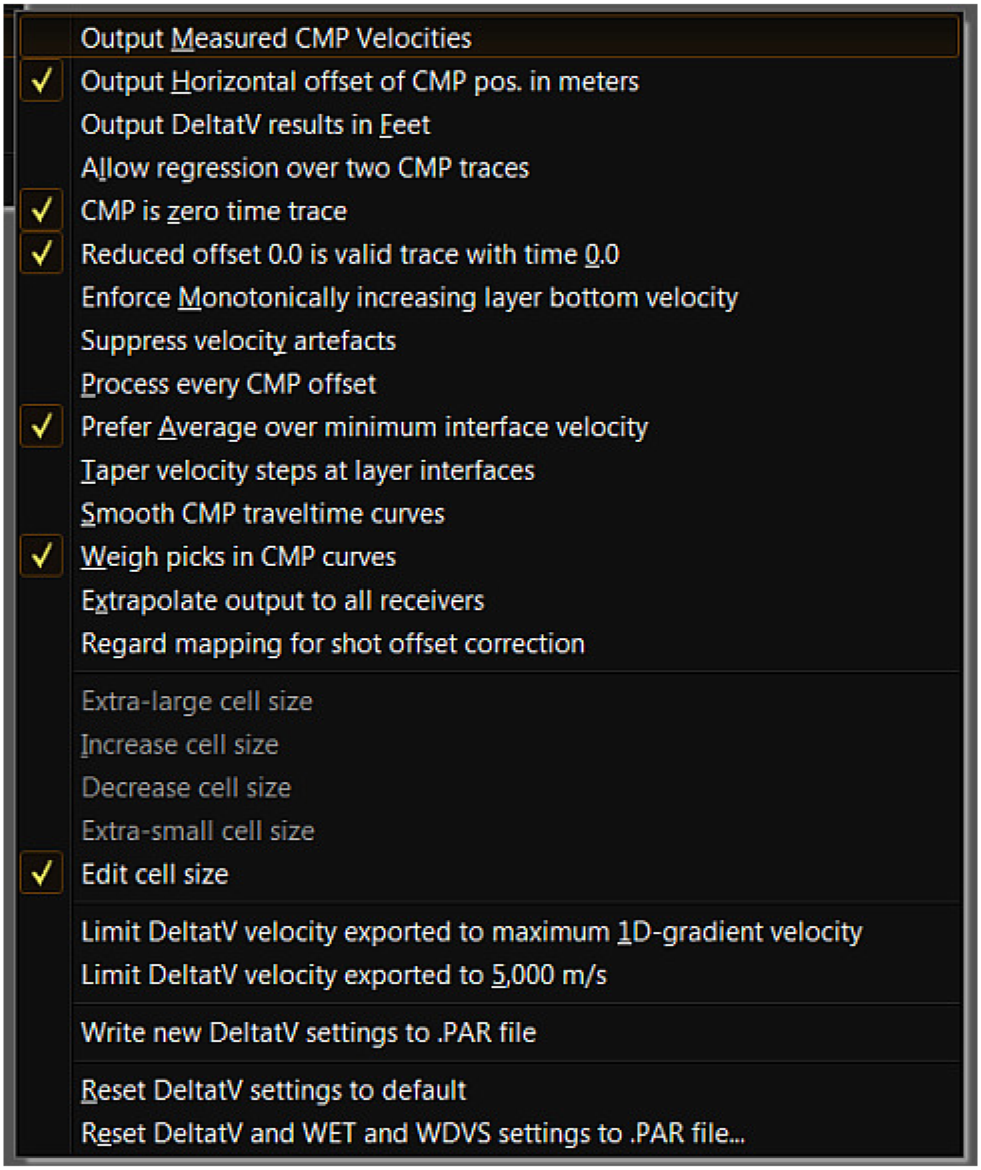
You may obtain a first guess at maximum real velocities present in the subsurface by measuring traveltime curve dips as displayed in your *Shot breaks display*, using a ruler. Alternatively, you may numerically display these velocities at the bottom of your screen during the *semi-automatic picking of first breaks* in your *Shot gather display.* Also, you may carry out a conventional traveltime curve processing as described in topics Mapping traces to refractors and Time-to-Depth Conversion, to obtain basement velocity estimates. But note that these velocity estimates will be too low in most cases, since there almost always exists a positive vertical velocity gradient inside the basement itself as well. I.e. seismic velocity increases with depth of penetration into the basement, at the turning points of the seismic rays sampling the subsurface.

With option *Output Measured CMP Velocities*. activated, our DeltatV method will combine inverted velocities and depths as obtained during inversion of the CMP sorted and stacked traveltime curves with instantaneous velocities as measured directly on the CMP sorted curves as input to the inversion, at corresponding source-receiver offsets. While disabling this option should deliver more realistic results from a strictly wave propagation physics point of view (as verifiable with raytracing), enabling it may help to enhance the imaging of near surface velocity anomalies. Please be aware that enabling this option means that basement velocities are not corrected for anomalies in the overburden. So if your primary objective is to image anomalies in the near surface / overburden, you may want to enable this option. If your main goal is to make an educated guess at the basement structure and depth, we recommend to disable this option. Note that unchecking this option may deliver better results in case of undulating topography along the line (with static corrections applied, as per default). Also, unchecking may help with inaccurately picked first breaks (i.e. in low signal-to-noise ratio situations), with low velocity contrasts between overburden and basement geological units and if shot positions are not specified exactly. For the sample profile TRA9002 (tra9002.pdf tutorial on our web site), we recommend to disable this option because of the deep valley the profile crosses. **This option will be unchecked by default when you create a new profile**.

There will always be a significant mismatch between synthetic and picked traveltimes for some traces when checking DeltatV output with subsequent forward modeling i.e. ray tracing though the model obtained, regardless of DeltatV parameters chosen. So you may just as well generate pseudo-2D DeltatV output with default parameters and then carry out subsequent WET tomography processing to automatically adjust the subsurface velocity model. Even better, use our Smooth inversion method, which builds a 1D initial model virtually free of artefacts. With such a 1D gradient initial model, true 2D WET tomography runs a much lower risk to get stuck in a local minimum of the traveltime misfit function (Schuster 1993, equation 1).

DeltatV Settings

Before inverting the traveltime data with DeltatV method toggle options in menu *DeltatV|DeltatV Settings :*



- *Output Measured CMP Velocities* (see above) Combine inverted velocities and depths with instantaneous velocities as measured directly on the CMP sorted curves.
- *Output Horizontal offset of CMP pos. in meters* CMP positions in DELTATV.TXT files are in meters. Uncheck to list CMP positions in station numbers.
- *Output DeltatV Results in feet* CMP positions in DELTATV.TXT files are in feet.
- *Allow regression over two CMP traces* Allow linear regression over just two CMP-stacked first breaks for velocity determination. Uncheck for regression over at least 3 CMP traces giving less detailed overburden imaging and less artefacts.
- *CMP is zero time trace* First break time of 0.0 is assumed for offset 0.0, at each Common MidPoint (CMP) during DeltatV inversion.
- *Reduced offset 0.0 is valid trace with time 0.0* Near-offset part of CMP sorted and stacked traveltime curves is inverted with more details. Disable if the output obtained (as gridded and contoured with Surfer®) is too noisy.
- *Enforce Monotonically increasing layer bottom velocity* Enforce a strictly physical

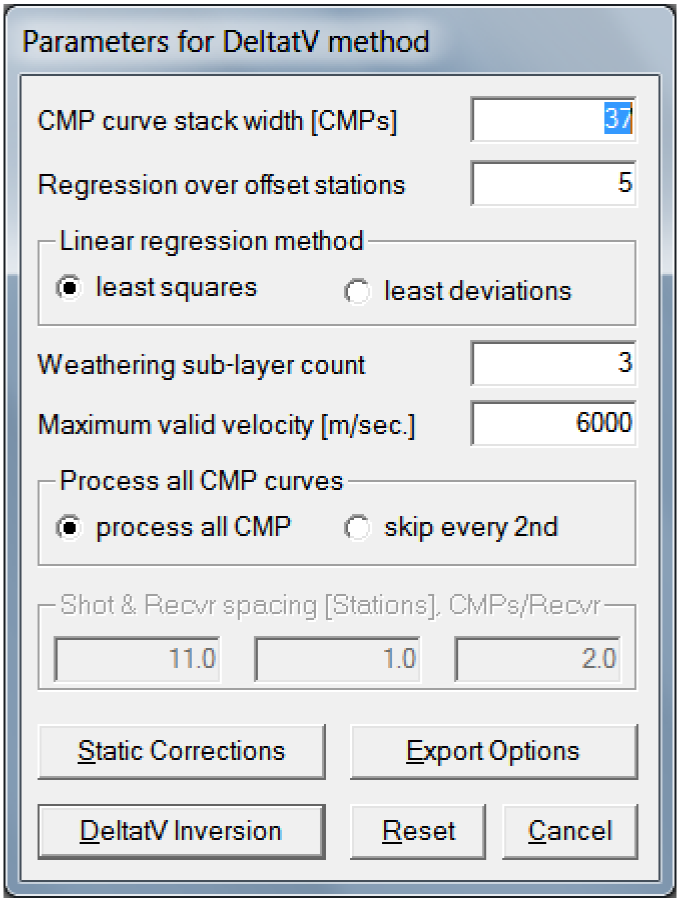
modeling of 1D seismic refraction per CMP. Disable this option to prevent giving too much weight to apparent high velocity anomalies in the shallow i.e. overburden subsurface region.

- *Suppress velocity artefacts* Suppress the generation of processing artefacts, i.e. unrealistic velocity variations. Use best for medium and high coverage profiles. See (Winkelmann 1998), top of page 36.
- *Process every CMP offset* Obtain better vertical velocity resolution, by inverting for an incremental gradient layer at every CMP offset . This option may increase the amount of artefacts in the output, especially for low coverage data sets and noisy first break picks.
- *Prefer Average over minimum interface velocity* Disable this setting to enhance the low-velocity imaging capability of the DeltatV inversion. Enable to enhance the high-velocity anomaly imaging capability in the near-surface region.
- *Taper velocity steps at layer interfaces* This option may result in an enhanced vertical resolution of subsurface layer interfaces, in case of subhorizontal layering and for high coverage surveys (e.g. 15 or more shots per profile). Leave disabled in case of strong lateral velocity variation.
- *Smooth CMP traveltime curves* For high-coverage profiles this option may help to filter out bad picks from CMP sorted and stacked traveltime curves.
- *Weigh picks in CMP curves* Check to weigh traveltime picks with the reciprocal of the square root of the distance (in station nrs.) between the trace CMP and the central stack CMP, when constructing CMP stacked traveltime curves.
- *Extrapolate output to all receivers* Horizontally extrapolate DeltatV inversion output to all receivers, beyond first/last CMP stations. Disabled per default.
- *Regard mapping for shot offset correction* Regard trace-to-refractor mapping and refractor velocities, for correction of first breaks for shot point offset from inline shot station.
- *Extra-large cell size*
- *Increase cell size* Increase the *grid cell size* used for generating Surfer .GRD files. Increasing the cell size will speed up the WET inversion, but may render the inversion less robust, especially in case of velocity inversions.
- *Decrease cell size*
- *Extra-small cell size*
- *Edit cell size* Regard the user-specified *Cell size* in *Header|Profile* when determining the 1D-gradient starting model. Alternatively check *Header|Profile|Force grid cell size*.
- *Limit DeltatV velocity exported to maximum 1D-gradient velocity* Determine the 1D-gradient starting model in a separate DeltatV run, before doing the 1.5D DeltatV inversion. This 1D-gradient starting model is saved to disk as files ..\GRADTOMO\DLTAGRAD.GRD & .PAR .
- *Limit DeltatV velocity exported to 5,000 m/s*
- *Write new DeltatV settings to .PAR file* Write new setting *Regard mapping for shot offset correction* to .PAR file. Uncheck so older version 3.36 or lower builds of our software can still read .PAR files written with 3.36 build May 2020 and higher versions. .PAR files are generated during DeltatV inversion & Smooth inversion and are updated with WET settings during following WET inversion.

Options *Output DeltatV Results in feet* and *Output Horizontal offset of CMP pos. in meters* may not be activated both at the same time.

Interactive DeltatV

To interactively **invert your traveltime data with the DeltatV method**, select *DeltatV|Interactive DeltatV*. Read and confirm the warning prompt(s). Review this *Parameters for DeltatV method dialog* :



Adjust these parameters :

- *CMP curve stack width [CMPs]* : lateral/horizontal smoothing in velocity plot. Specify how many adjacent CMP positions, in a CMP station number interval centered at the current CMP position, are considered when constructing the averaged CMP traveltime curve for the current CMP position. **Leave at automatically determined default value determined** based on your profile's length and *Station spacing*.
- *Regression over offset stations* : vertical smoothing in velocity plot. Specify the length of the offset station interval used to carry out local piecewise linearization of CMP traveltime curves.
- *Least squares regression method* : default regression method. Local apparent velocities on CMP traveltime curves are determined by a least squares linear regression over traveltimes inside an offset interval with width *Regression over offset stations* and centered at the offset currently being evaluated.
- *Least deviations regression method* : alternative regression method for estimating apparent velocity along segments of CMP sorted and stacked traveltime curve.
- *Weathering sub-layer count* : increase this parameter to obtain more detailed velocity imaging in weathering layer
- *Maximum valid velocity [m/s]* : specify the maximum velocity accepted as valid when processing CMP curves. Apparent CMP velocities higher than this value will be skipped.
- *Process all CMPs* : process CMP sorted traveltime curves at every CMP location

- *Skip every 2nd CMP* : process every second CMP only. Use this option to reduce computation time for DeltatV/XTV inversion and for faster gridding with Surfer®.

If you invert the traveltime data for the first time, just accept the default parameter values with button *DeltatV Inversion*. If you are not happy with the output or raytracing shows a significant mismatch between picked and synthesized first breaks, change DeltatV options (see above) or default parameter values as following :

Parameters *CMP curve stack width* and *Regression over offset stations* let you specify to what degree the traveltime data should be smoothed horizontally and vertically. We advise you to **vary parameter *Regression over offset stations* between values of 5 to 20 offset stations**. Generally, smaller values for this parameter will deliver more shallow velocity-depths. For **low coverage surveys** or situations of high velocity contrasts between clearly recognizable layers, we recommend to set this parameter to a value near the minimum value of 5. Also, **vary parameter *CMP curve stack width* between values of 20 to 50** (neighboring Common MidPoints) for lines up to 500m long. For lines exceeding 1 or 2 km in length increase stack width to 100 or 200. One station number interval corresponds to two CMP positions (at station positions .25 and at .75, with all shot stations at .5). As a rule of thumb set this stack width to (line length in station numbers)/5. E.g. with line length of 500m assuming a *Station spacing* of 2m set *CMP curve stack width* to 50. For line length of 2km set to 200. Set to at least 20, especially for short receiver spreads.

Group box *Linear regression method* lets you select between the two methods *least squares* and *least deviations*. The method specified will be used to carry out a piecewise linearization of *CMP traveltime curves*, to determine smoothed local apparent CMP velocities. With option *least deviations*, the inversion will take about ten times as long as with option *least squares*. See (Press et al. 1986) chapter 14 for details. *Least deviations* will recognize outliers / less relevant data points and give them less weight when modeling / linearizing the trend inherent in the data. *Least squares* treats all data points with the same priority. **Compare *least squares* output with *least deviations* output, in situations of high coverage and noisy picks/automatic picking**. Save the resulting DELTATV.TXT files to differently named files and then image both with Golden Software Surfer®, see below. Set limits and scale of both resulting contour plots to the same values, optimally fit the contour plots to the screen size and page through the plots with CTRL-TAB in Surfer, to compare them visually.

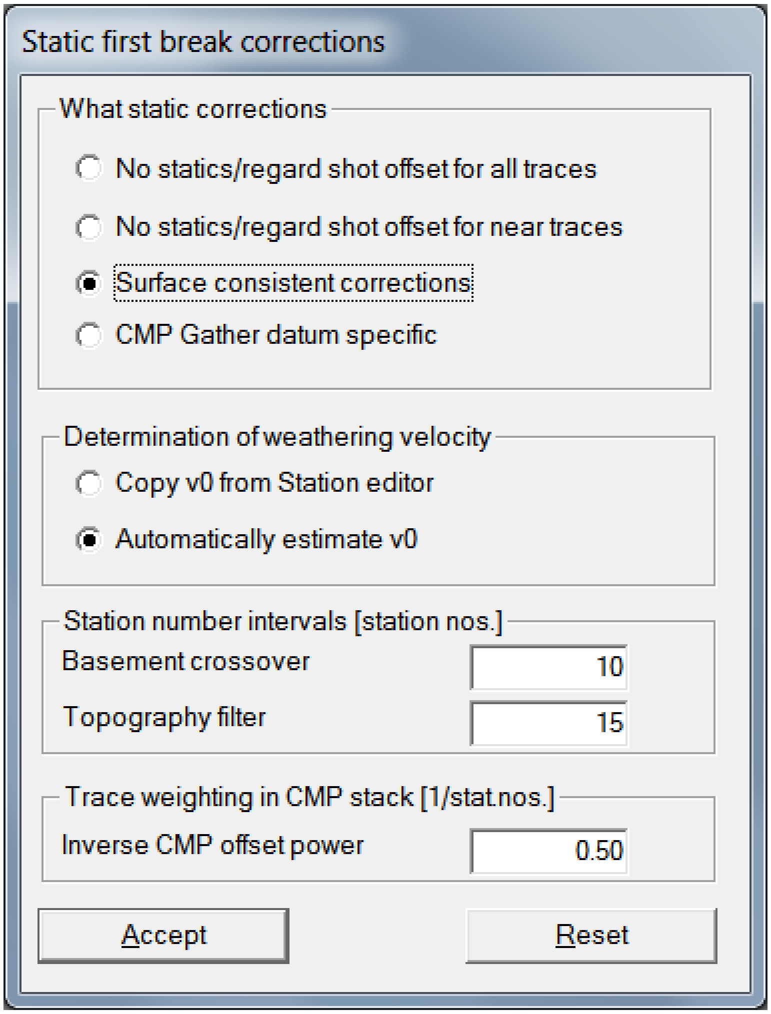
Increase the value of *Weathering sub-layer count* to **obtain slightly slower and more detailed topmost / weathering velocity imaging**. As a consequence, synthetic traveltimes obtained by raytracing through the resulting DeltatV model will be slightly slower.

Parameter *Maximum valid velocity* lets you specify the maximum velocity value accepted as valid when processing CMP curves. Apparent CMP velocities higher than this value will be skipped. See above.

Group box *Process all CMP curves* lets you specify the lateral data density of the ASCII file generated. Option *process all CMP* will process CMP sorted traveltime curves at every CMP location. Option *skip every 2nd* will process every second CMP only. Use this option to reduce computation time for the inversion and the following gridding with Surfer®. This may help to **achieve a fast turnaround time while iteratively calibrating DeltatV parameters against raytracing results or a-priori information** such as core drilling data, data from nearby construction sites such as tunnels or data from geological maps.

DeltatV Static Corrections

In *DeltatV|Interactive DeltatV* main dialog click *button* ***Static Corrections*** to display this dialog :



Edit these parameters, for correction of first breaks for undulating topography :

- *No statics/regard shot offset for all traces* Disable the computation and application to first breaks, of static corrections. This option makes sense in situations of flat topography or topography approximating a dipping plane.
- *No statics/regard shot offset for near traces* Disable the computation and application to first breaks, of static corrections. This option makes sense in situations of flat topography or topography approximating a dipping plane.
- *Surface-consistent static corrections* Compute first break static corrections relative to a floating datum obtained by applying a running-average smoothing filter to the topography. Specify the filter width with ***Topography filter***. **This is the default static correction method**. Works for both undulating topography and flat/constantly dipping topography. Basement-refracted first breaks are corrected for vertical offset of source and receiver from datum plane or floating datum. For this correction we use the laterally varying weathering velocity determined using ***Basement crossover*** *(formerly Weathering crossover).*
- *CMP Gather datum-specific* Compute first break static corrections relative to a dipping datum plane specific to the CMP gather currently being processed. This datum plane is obtained by linear regression through elevations of all sources and receivers employed for recording

traces mapped to that Common Mid-Point. Works well for constant slope of topography.

- *Copy v0 from Station editor* Reuse weathering velocities as specified in the Station editor (Header|Station) for the computation of static corrections. This option will preserve existing mappings of first breaks to refractors and resulting weathering velocities and corrections of first breaks for shot position offsets. Please note that **DeltatV weathering velocity needs to represent the whole overburden and not just the topmost "weathering layer" used in layered refraction interpretation with Plus-Minus method**.
- *Automatically estimate v0* Estimate laterally varying near-surface velocity based on the laterally constant crossover distance ***Basement crossover*** *(formerly Weathering crossover).* Use this option e.g. in situations of locally outcropping bedrock. **This is the default setting for Group box *Determination of weathering velocity***.
- *Basement crossover* Specify the laterally constant estimated average crossover distance (in station numbers) separating direct wave arrivals and overburden-refracted arrivals from basement-refracted arrivals. Formerly named *Weathering crossover*. **Leave at default 10 station numbers**.
- *Topography filter* Specify the filter width (in station numbers) for the running-average filter applied to the line topography to obtain a smoothed floating datum with option *Surface-consistent corrections* selected. **Leave at default 15 station numbers**.
- *Inverse CMP offset power* Weight first break picks when stacking *CMP curves*. Allowed values are in range 0 to 1. Default value is 0.5. Decreasing this parameter to 0.1 or 0.2 means increasing the lateral smoothing in the DeltatV velocity plot. Increasing to 0.9 means decreasing the lateral smoothing in DeltatV plot.

The DeltatV method works best if all sources and receivers are located on a flat or dipping plane. So in case of rough topography you want to compute and apply basement-refracted first break corrections for each source and receiver, hypothetically moving sources and receivers vertically up or down until they are located on a dipping datum plane or floating datum. Basement-refracted wave first breaks will be corrected for shot hole depth and topography, while direct wave refracted first breaks and overburden-refracted first breaks will be corrected for shot position offsets from shot station including shot hole depth (assuming a straight ray path between source and receiver). The algorithm makes the simplifying assumption that the turning rays as corresponding to basement-refracted wave first breaks reach the receiver vertically from below / dip down vertically from the source. For source and receiver elevations above the datum elevation, a negative first break correction is computed and applied, hypothetically moving the source/receiver vertically down to the datum plane. For source and receiver elevations below the datum elevation, a positive first break correction is computed and applied, hypothetically moving the source/receiver vertically up to the datum plane.

Group box *Static first break corrections* lets you select between option *No statics/regard shot offset for near traces* and the two computation methods *Surface consistent* and *CMP gather datum specific*. *Surface-consistent* is the default static correction method and works okay with any kind of topography including undulating topography. *CMP gather datum specific* works well for constant slope of topography. Our CMP gather datum plane is not constricted to a horizontal plane, but will have a constant dip fitting the CMP gather specific source and receiver elevations. This is based on the assumption that subsurface geology roughly follows the topography. Also, first break corrections will be as small in value as possible as a consequence. This reduces the danger of over-correcting first breaks for topography features, e.g. if employing a too low weathering velocity for the computation of the datum corrections as described above. We recommend to process each Rayfract® profile with two DeltatV parameter sets : first with the default values as displayed in above dialogs when processing that profile the first time, with *Surface consistent* static correction. Next reuse the same default values, but use *Static first break corrections* method *No statics/regard shot offset for near traces*.

Group box *Determination of weathering velocity* lets you choose between the two options *Copy v0 from Station editor* and *Automatically estimate v0*.

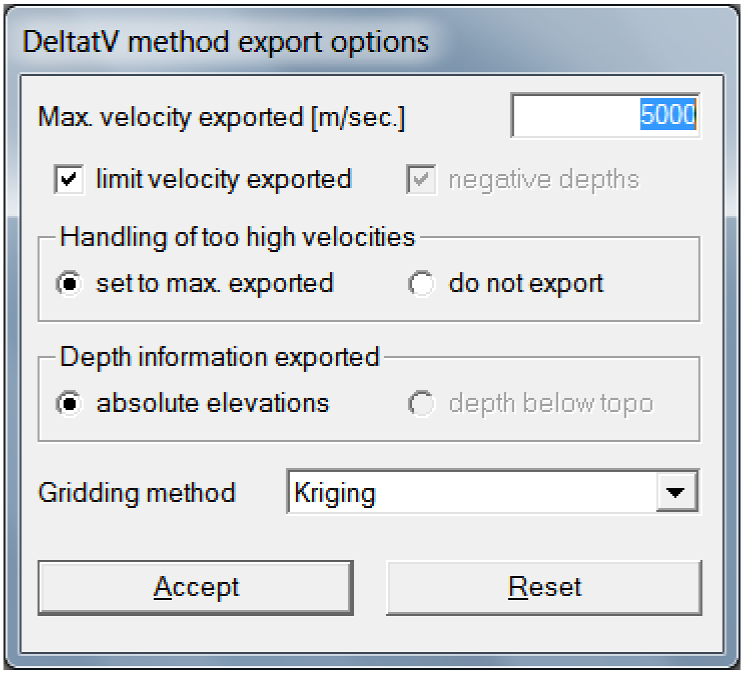
Please note that the **DeltatV weathering velocity needs to represent the whole weathered overburden and not just the topmost "weathering layer" used in layered refraction interpretation with Plus-Minus method**. So the DeltatV weathering velocity typically needs to be much higher than the layered refraction "weathering velocity". Otherwise DeltatV static correction will over-correct first breaks to floating datum especially with strongly undulating topography and strong topography curvature and with too wide *Topography filter* used for *Surface consistent* static corrections or with too low weathering velocity obtained with too low *Basement crossover*.

Parameter *Basement crossover* specifies the estimated average crossover distance (in station numbers) separating direct wave arrivals and overburden-refracted arrivals from basement-refracted arrivals. Guess at this mean crossover distance by looking at the *Midpoint breaks display* or the *Shot breaks display*. Decrease by a few station numbers from average basement crossover so first breaks refracted at weathered basement top are also corrected to datum plane. This parameter is used to estimate the near-surface weathering/overburden velocity needed for static correction of first breaks. This laterally varying velocity estimate is required for the computation of corrections for shot position offset from shot station for direct wave and overburden-refracted arrivals and for static corrections for basement-refracted first breaks. **Leave at default setting of 10 station number**s. If you decrease this too much to e.g. 3 or 4 stations then the estimated overburden velocity obtained with this parameter will be too low and basement-refracted first breaks will be over-corrected for vertical offset of source and receiver from datum plane or floating datum especially in case of strong topography curvature.

Parameter *Topography filter* specifies the running average filter width in station numbers, used to obtain a smoothed topography and floating datum for first break correction method *Surface consistent*. **Leave at default of 15 station numbers**. Do NOT increase for strongly undulating topography with strong curvature. If you increase this filter width too much with strong topography then first breaks will be over-corrected since the smoothed floating datum will cut into the subsurface and even into top-of-basement too much at anticlines. Or the smoothed floating datum will be positioned above topography too much at synclines. See tutorial https://rayfract.com/tutorials/NGU_G1.pdf for default static correction settings (Fig. 25) and for pessimized settings (Fig. 30). Also see tutorial https://rayfract.com/tutorials/Aaknes-1.pdf for default static correction settings (Fig. 29) and for pessimized settings (Fig. 28).

DeltatV Export Options

In *DeltatV|Interactive DeltatV* main dialog click button ***Export Options*** to show the *DeltatV method export options dialog* :



Edit parameters determining the format of the ASCII output file DELTATV.TXT, generated at the end of the DeltatV inversion :

- *Maximum velocity exported* lets you specify the maximum value of velocities written to the DELTATV.TXT. See above.

- Check box *limit velocity exported* to apply a low-pass filter to velocities written to DELTATV.TXT. This helps to prevent horizontal layering artefacts in the 1D initial model, see https://rayfract.com/tutorials/palmfig3.pdf .

- Check box *negative depths* to write depth with a leading minus "-" sign to DELTATV.TXT, in connection with *radio button depth below topography*.

- Group box ***Handling of too high velocities*** lets you specify what should be done with velocities exceeding *Maximum velocity exported* if check box *limit velocity exported* is checked. Select *radio button set to max. exported* to replace the velocity with *Maximum velocity exported*. Select *radio button do not export* if velocities exceeding *Maximum velocity exported* should be skipped during creation of DELTATV.TXT.

- Group box ***Depth information exported*** lets you define if either *absolute elevations* or *depth below topography* should be exported. Select the appropriate radio button.

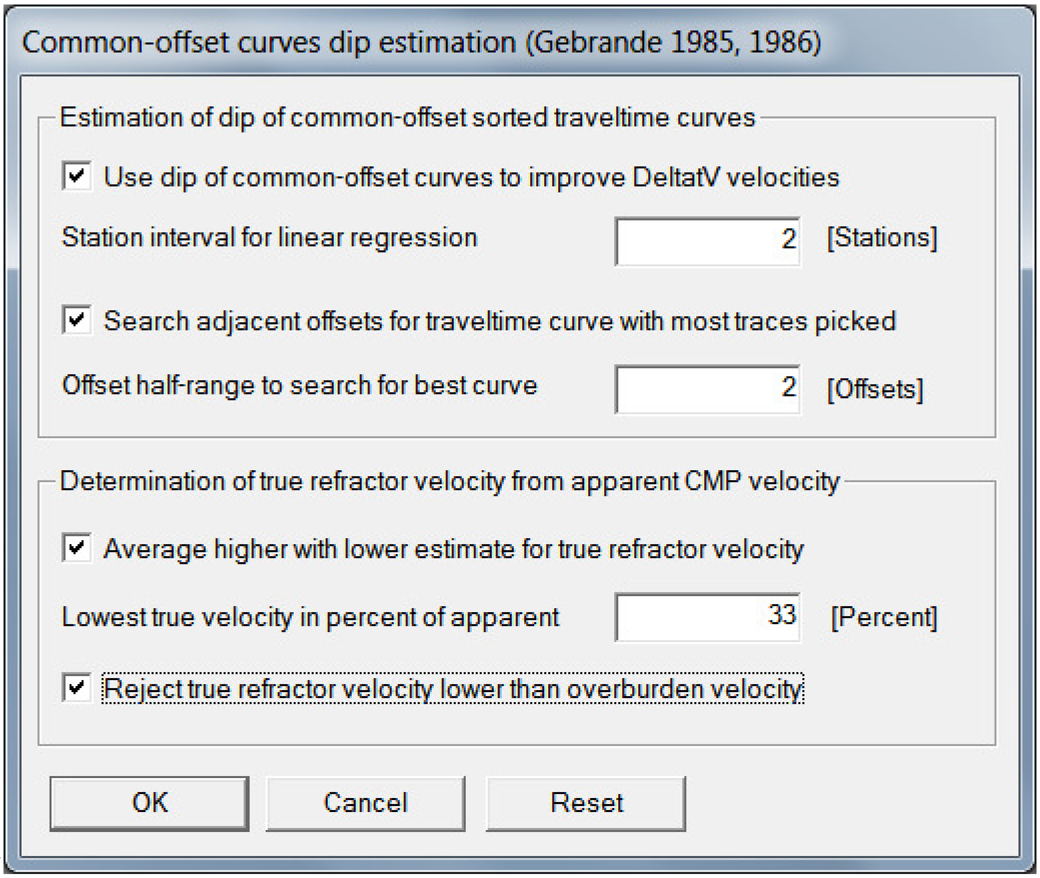
- *Gridding method* let you specify the Surfer® gridding method used for gridding of pseudo-2D DeltatV inversion results. Select methods *Delauney Triangulation*, *Kriging*, *Minimum Curvature*, *Natural Neighbor* and *Nearest Neighbor*. Per default this option is set to method *Kriging*.

Once you have edited all parameter values you want to change or to accept the default parameter values, click button *DeltatV Inversion* to start the inversion or abort the inversion with the ESC key.

Observe messages displayed in the status bar at the bottom of your Rayfract® main window. You may switch to other Windows applications while the inversion proceeds. The size of the resulting DELTATV.TXT ASCII file will give you a hint at how many velocity-depth points have been obtained. Inspect the file with a plain ASCII text editor to check if results have been obtained for most CMP stations.

Common-Offset Dip estimation

In DeltatV menu *select command Common-offset dip estimation...* available with our Pro license and Pro software version to show the *Common-offset curves dip estimation dialog* :



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Edit these parameters for estimation of dip of common-offset sorted traveltime curves and for improved DeltatV velocity estimation :

- *Use dip of common-offset curves to improve DeltatV velocities* Check to to improve DeltatV velocity estimation using common-offset dip (Gebrande and Miller, 1985; Gebrande 1986).
- *Station interval for linear regression* Specify the CMP station interval used for linear regression over common-offset sorted picked traces to determine the dip of common-offset sorted traveltime curves
- *Search adjacent offsets for traveltime curve with most traces picked* Check to activate search of common-offset curve with most traces picked, over offset interval specified with *Offset half-range to search for best curve*
- *Offset half-range to search for best curve* Specify the number of

adjacent offset gathers to search in both directions, for given offset and CMP station during pseudo-2D DeltatV inversion

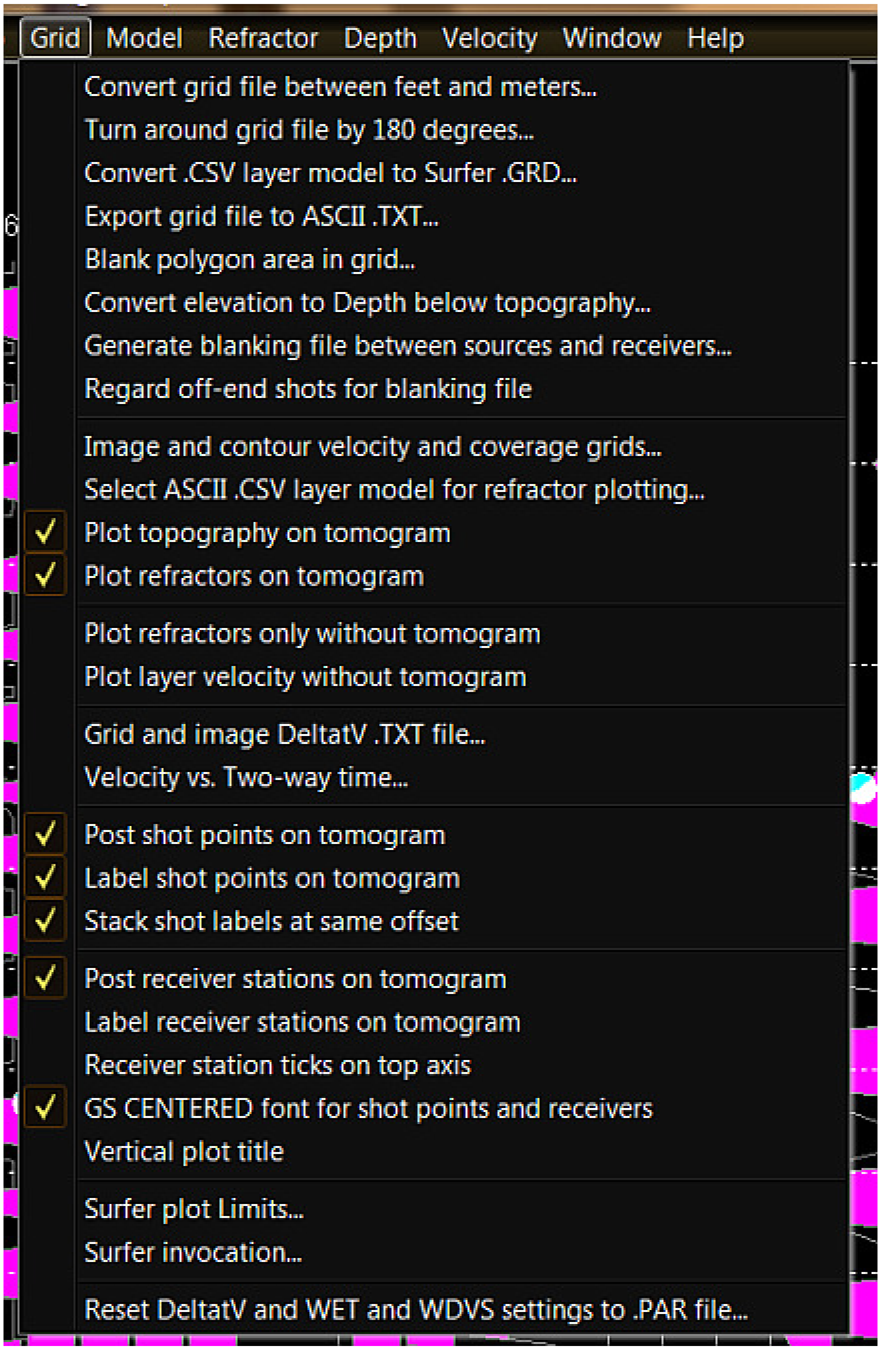
- *Average higher with lower estimate for true refractor velocity* Check to average higher with lower estimate for true refractor velocity based on apparent CMP velocity and offset dip during pseudo-2D DeltatV inversion (Gebrande and Miller 1985; Gebrande 1986).
- *Lowest true velocity in percent of apparent* Specify the smallest accepted estimate for true refractor velocity, in percent of apparent CMP velocity during pseudo-2D DeltatV inversion
- *Reject true refractor velocity lower than overburden velocity* Reject estimated true refractor velocity if lower than overburden velocity during pseudo-2D DeltatV inversion. Regard apparent refractor velocity as true velocity instead.

With steeply dipping refractors the true refractor velocity deviates significantly from the apparent CMP velocity measured on CMP sorted traveltime curves (Gebrande and Miller 1985; Gebrande 1986). Above dialog lets you estimate the true refractor velocity based on local dip of common-offset sorted traveltime curves, apparent CMP velocity and overburden velocity as described by (Gebrande 1986) in equations (13) and (14).

Imaging of DeltatV output

The inversion routine generates files **DELTATV.TXT, MINVELO.TXT** etc. You may want to grid both of these, as described below. The DELTATV.TXT file contains *average interface velocities*, for all CMP's and infinitesimal layers. The MINVELO.TXT contains *minimum interface velocities*. See entry *Z data unit description* of the corresponding .PAR file. Both of these .TXT files normally represent good solutions; the DELTATV.TXT velocities are just a bit faster than the MINVELO.TXT velocities

For gridding and plotting with Golden Software Surfer® select *Grid|Grid and image DeltatV .TXT file...* in our Grid menu :



Then select the DELTATV.TXT or MINVELO.TXT as generated by our software. These .TXT files are located in your \RAY32\ profile subdirectory. Configure display and labeling of shot points and receivers on Surfer® tomogram plots with above *Grid menu* options.

For interactive gridding and plotting with Golden Software Surfer® see our tutorial LINE14.PDF at https://rayfract.com/tutorials/line14.pdf .

Use our **Smooth inversion** to obtain a laterally smoothed 1D-gradient starting model devoid of velocity artefacts. For our pseudo-2D DeltatV inversion you may want to use a different Surfer® gridding method than the default kriging method. Specify your preferred gridding method via *DeltatV|Interactive*

DeltatV|Export Options|Gridding method. Confirm with *Accept button*. You can then abort the interactive DeltatV inversion with *Cancel button*. Now regrid the DELTATV.TXT in subdirectory C:\RAY32\<your profile name> generated during an earlier inversion with *Grid|Grid and image DeltatV .TXT file...* . See our tutorial https://rayfract.com/tutorials/jenny10.pdf for an extreme case of data extrapolation by Surfer kriging method generating a strong artefact / low-velocity layer in y region -5m to -10m. Natural Neighbor gridding method works much better in this case.

Processing of DeltatV output

When specifying Surfer® section limits in Surfer® menu Map (*Map|Limits*) suppress the display of the first five and last five or so CMP stations of the profile, if these are positioned outside the first/last receiver station. Blanking out these margins at the profile start and end will guarantee that the depth-velocity information displayed in the Surfer® section is based on sufficient coverage of CMP's with first breaks (especially direct wave arrivals). Also, be sure to limit the vertical elevation range / maximum depth shown on the section. The bottom part of the section as displayed with Surfer® default section limits will not convey much useful information, and gridding/contouring of the scarce data with Surfer® becomes instable. This is because ray density in that area is very low in most cases. First breaks recorded for the largest source-receiver offsets will penetrate the subsurface to that depth only.

We recommend using the **Surfer® Matrix Smoothing** or **Grid filtering** function to obtain a more regular subsurface image. This will help especially in case of irregular topography and noisy DeltatV output (with static corrections applied). E.g. enter values 1 and 15 for edit fields "Rows on Either Side of Center" and "Columns on Either Side of Center". Our Rayfract® DeltatV method (with default parameter values) implicitly applies a higher degree of vertical smoothing than horizontal (lateral) smoothing, to CMP-binned and stacked traveltime curves. If using Surfer® 11 when you smooth over too many rows (e.g. more than 3), low weathering velocities at the topmost grid pixels will be lost and are not recovered during raytracing by extrapolating velocities from lower rows. As a consequence raytracing will give back too fast synthetic traveltimes. We **recommend using Surfer® 8 or higher Matrix Smoothing** or **Grid filtering** instead. It preserves data at the topography and at the edges of the grid region covered with velocity data.

Use horizontal smoothing aggressively. For a grid of e.g. 800 horizontal by 200 vertical pixels use a user-defined running average filter of 3 rows vs. 41 columns. This ensures that local DeltatV artifacts are filtered out while the general velocity trend with depth is preserved. Keeping the original velocity is important directly below the topography. The weathering velocity typically increases quite suddenly with depth over just a few rows. So we recommend to smooth just over 3 rows.

For reflection seismic processing, you may obtain a rough estimate of zero offset near-surface vertical velocity vs. two-way time with *Grid|Velocity vs. Two-way time...* .

To refine the pseudo-2D DeltatV output with true 2D WET inversion see topic **WET tomography processing**.

Our latest version 4.02 released in May 2022 allows Wavelength-Dependent Velocity Smoothing (WDVS; Zelt and Chen 2016) during WET inversion. **WDVS helps to suppress DeltatV noise and artefacts**.