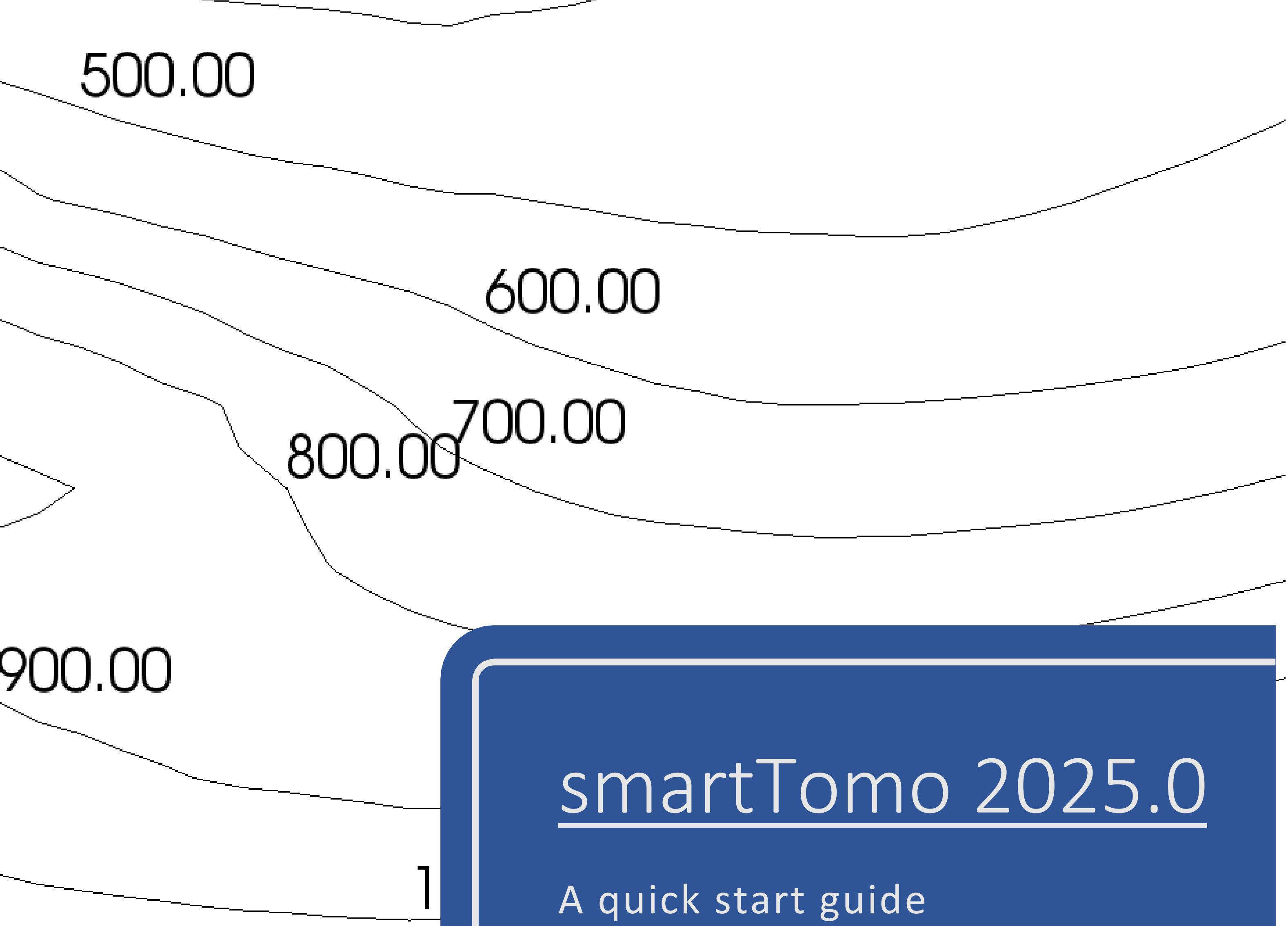

smartTomo 2025.0

A quick start guide

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An introduction to seismic refraction tomography (SRT)

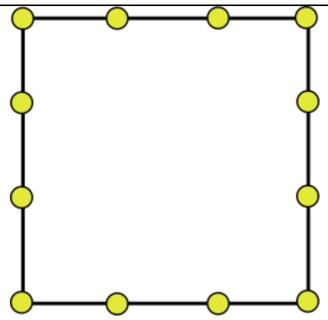
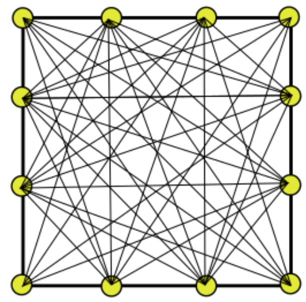
Seismic tomography allows the reconstruction of an image of the subsoil distribution of seismic wave velocity and its anomalies with high resolving power. In detail, refraction seismic survey is an indirect, active seismic survey that uses refracted waves generated by contrasts of waves velocity to reconstruct subsurface characteristics. The velocity of seismic waves depends on the density and elastic properties of the material crossed, i.e., properties attributable to the lithological characteristics of the substrate investigated. The direction of propagation of the waves in depth follows Snell's law and at each interface there are phenomena of refraction, reflection, and diffraction. In refraction surveys, as the name implies, only refracted waves will be considered. Refraction seismic tomography allows to obtain a picture of the velocity distribution in the subsurface highlighting the continuous changes in velocity rather than a layered model typical of refraction surveys (Intercept, delay time, plus minus, GRM).

The refraction seismic survey consists of generating a seismic wave of compression or shear (energization) and recording its arrival at the geophones arranged in a line at known intervals. The interpretation of the recorded measures is based on the analysis of the time taken by the wave generated with the energizations to reach each geophone. In order to reconstruct the speed variation of compression waves in the subsurface, it is necessary to perform several energizations in different positions along the line.

The measurements made using the refraction method can be processed using the tomographic procedure to highlight the local velocity variations in detail.

The tomographic technique involves the creation of an initial synthetic model of the subsurface and its perturbation in search of the minimum deviation between the measurements made on the ground and the "virtual" measurements recorded on the synthetic model through an iterative procedure that cycles between the following two phases:

- In the "forward" phase, the arrival times of the seismic pulse are calculated on the synthetic model (smartTomo is based on the work of Moser, T. J. "Shortest path calculation of seismic rays." Geophysics 56.1 (1991): 59-67). The initial velocity model is divided into a grid whose cells have assigned initial velocity values. On the sides of the cell are multiple nodes (the number of which is chosen by the user) that constitute the nodes of the network of hypothetical seismic rays that connect all sources and all receivers that are also themselves nodes. Each node is connected with nodes in neighboring cells. Increasing the number of nodes increases the detail and accuracy in the seismic ray path but also increases the memory usage. The path of the refracted wave corresponds to the path that takes the shortest time to travel between the source and the receiver.

 Nodes on the sides of the cell	 Nodes linked by seismic rays

- In the "inverse" phase, the synthetic times calculated in the "forward" step are compared with the times measured on the seismograms; the differences between the times are used to update the synthetic model (smartTomo employs an algorithm that can be traced back to the "Simultaneous Iterative Reconstruction Technique" family). In the implementation of this method the speed is replaced by its inverse, the slowness. For example, considering a generic seismic radius j between the source and the receiver the average slowness can be expressed as:

$$S_j = \frac{t_{0j}}{l_j}$$

where t_{oj} is the measured time between the source and the receiver and l_j is the length of the j-th sisimic ray. Therefore, knowing the measured path times t_m and the calculated path time t_c for the j-th ray, the residual path time can be calculated:

$$\Delta t_j = t_{mj} - t_{cj}$$

The residual of the path times is projected onto each cell k on which the slowness correction factor is also calculated as:

$$\Delta S_k = \frac{\sum \Delta t_{ik}}{\sum \Delta l_{ik}}$$

The index i represents each seismic ray incident on the k-th cell. The slowness correction factor will be used to update the velocity model at the end of each iteration of the resolution cycle. This procedure yields a model, with continuous velocity variations and not necessarily constrained by the presence of strong refractors like the bedrock.
Each update cycle is followed by a smoothing phase of the result to make the model more homogeneous by averaging the velocity to the cells adjacent to those crossed by the seismic rays that would not be updated, in this way ensuring greater stability to the calculation procedures and a result more easily interpretable.
Reference: Reinhard Kirsch, "Groundwater Geophysics – A Tool for Hydrogeology" Springer 2006.

Seismic Attenuation Tomography and the Q Factor

The propagation of seismic signals through the subsurface involves various forms of energy dissipation, including geometric spreading and absorption. Geometric spreading results from the spatial dispersion of the seismic impulse, which expands along a spherical wavefront in the case of body waves generated by a point source. Consequently, the energy decreases proportionally to the distance from the source (or the reference station).
Absorption loss, on the other hand, depends on the materials traversed and is directly related to the medium's ability to transmit elastic waves. This component of attenuation is the most significant, as it is intrinsically linked to the properties of the material under investigation.
The decay of the signal amplitude has been observed to follow an exponential trend, and we can therefore express it as follows:

$$A = A_0 e^{-\eta x}$$

Here:
A is the amplitude of the signal measured at a distance x from the reference station,
A_0 is the amplitude measured at the reference station, and
η is the absorption coefficient.
Signal attenuation can also be described as a function of time using the following equation:

$$A = A_0 e^{-ht} cos(2\pi v t)$$

Where:

- h is the damping factor,
- v is the frequency of the wave, and
- t is the time.

The attenuation factor δ can be expressed in terms of amplitude:

$$\delta = log\left(\frac{A}{Aoneciclelater}\right)$$

Alternatively, δ can be expressed in terms of the damping factor h:

$$\delta = hT = 2\pi\, h/\omega$$

Where:

- T is the wave period,
- ω is the angular frequency, defined as ω=2πv.

Quality Factor Q

The Quality Factor Q is defined as:

$$Q = 2\pi \frac{E}{\Delta E} = 2\pi \frac{E}{energy\ lost\ per\ cycle}$$

Given that wave energy (E) is proportional to the square of the amplitude, we can write:

$$E = E_0 e^{-2ht}$$

The energy loss ratio can then be expressed as:

$$\frac{\Delta E}{E} = 2h\Delta t$$

If we set Δt=T (one period), this simplifies to:

$$\frac{\Delta E}{E} = 2hT = 2\delta$$

Thus, the Quality Factor Q can be rewritten as:

$$Q = 2\pi \frac{E}{\Delta E} = \frac{\pi}{\delta}$$

This relationship connects the Quality Factor Q to the signal amplitude, providing a critical link for evaluating material properties in seismic attenuation studies.

In SmartTomo, the amplitude of the refracted signal is calculated by sampling a segment of the signal around the first arrival and measuring the maximum amplitude in the frequency-amplitude domain. The logarithmic attenuation factor δ\deltaδ becomes the target value when constructing the tomographic attenuation profile.

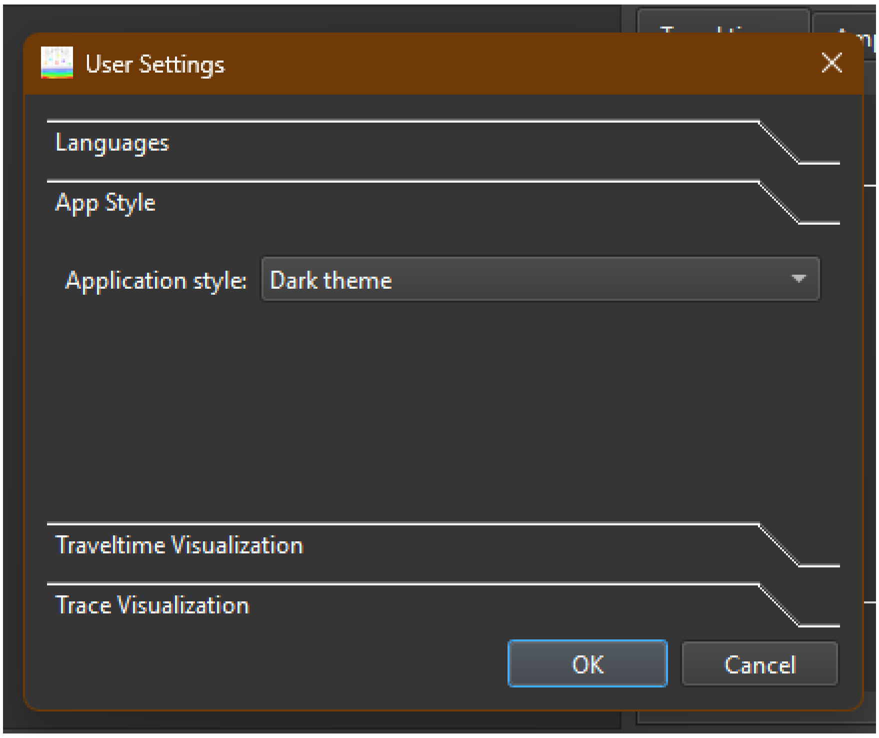
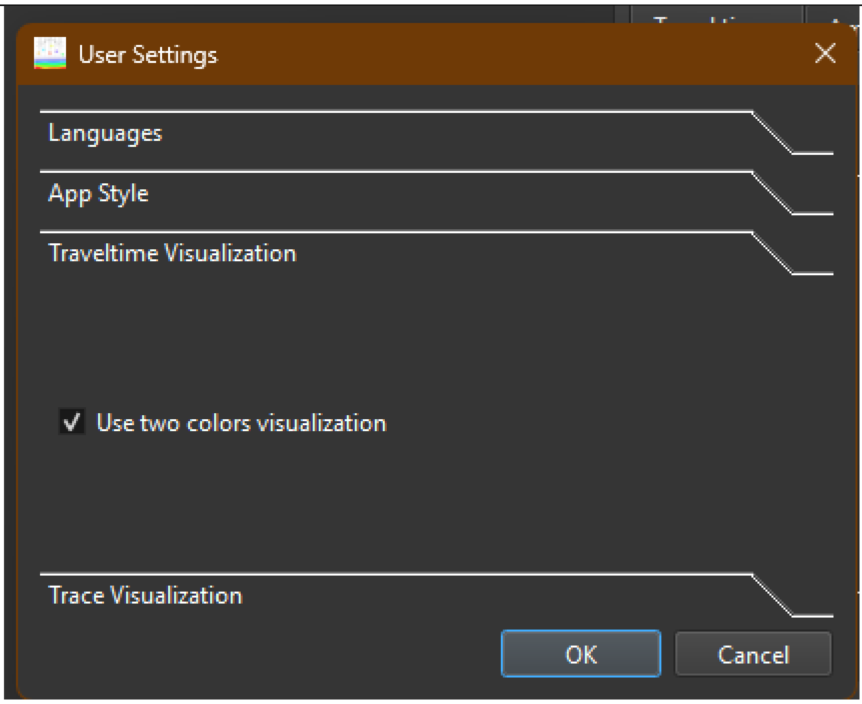
During this process, the seismic ray paths calculated in the velocity tomography analysis are retained, while attenuation values are updated to achieve a fit with the δ\deltaδ values measured on the seismograms. This is achieved by applying a SIRT (Simultaneous Iterative Reconstruction Technique) algorithm.

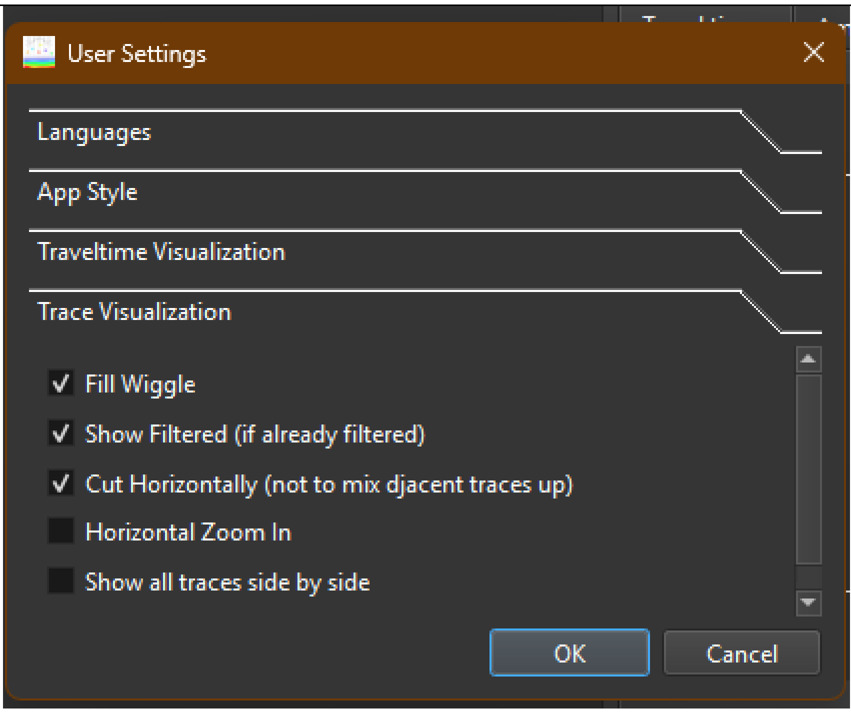
Attenuation tomography and Q-factor tomography are reciprocal to each other, differing only by the constant π\piπ. Lower Q-factor values correspond to higher attenuation.

The following table provides indicative values of attenuation parameters and Q-Factors for various lithologies:

Rock Type	Q-Factor	**δ = η * ƛ (dB)**
Sedimentary rocks	20-200	0,16 – 0,02
Sandstone	70-130	0,04 – 0,02
Shale	20-70	0,16 – 0,05
Limestone	50-200	0,06 – 0,02
Gypsum	135	0,02
Dolomite	190	0,02
Gas-saturated sedimentary rocks	5-50	0,63 – 0,06
Metamorphic rocks	200-400	0,02-0,01
Igneous rocks	75-300	0,04-0,01
Top 3 meters of coastal sediments in the Persian Gulf (Tullos and Reid, 1969)	0,24	13

Software settings



1 The dialog used to set the user preferences in smartTomo

From the File > Settings menu, users can configure the software language or adjust various trace display parameters. The following options are available:

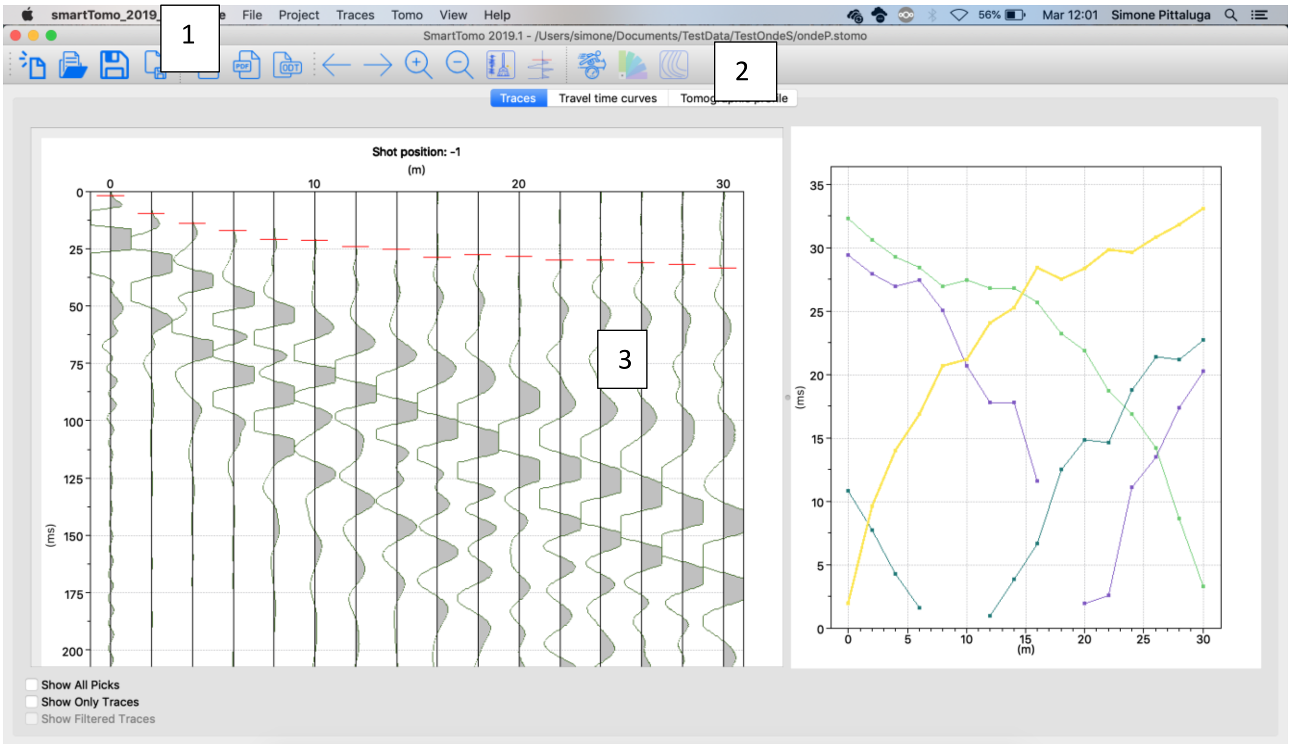
- Enable/disable half-wave filling.
- Enable/disable the automatic display of filtered traces when available.
- Enable/disable overlapping of adjacent traces at high zoom levels.
- Enable/disable horizontal zooming in the trace display window.
- Enable/disable the side-by-side display of all traces.

Additionally, the software's theme can be set to light or dark mode, either manually or automatically, to match the operating system's style

User interface

smartTomo main window is structured in three main components:

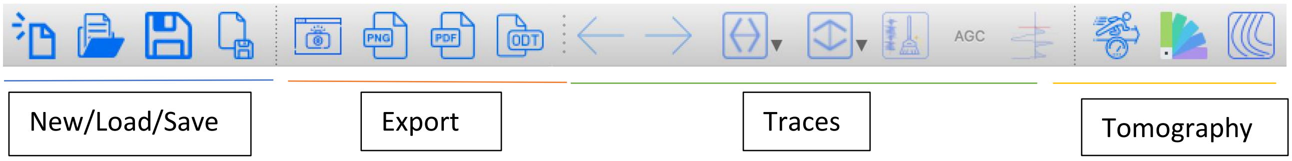
- Menu bar (1);
- Toolbar (2);
- Project area (3);

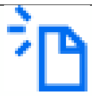
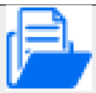
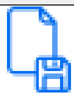
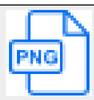


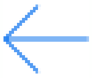
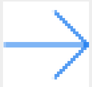
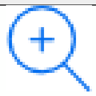
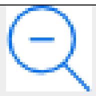
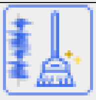
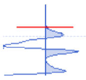
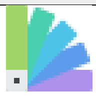
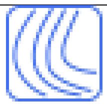
2 SmartTomo main window

The menu options and the tool bar allow selecting the functionalities of the software, while the project area is composed by three tabs showing the seismic traces, the travel time curves and the tomographic profile respectively.

The toolbar



	Create a new project. If a project is already open, the user is asked to save or discard possible applied changes before going on with the creation of the new project.
	Open a previously saved project. If a project is already open, the user is asked to save or discard possible applied changes before opening a new one.
	Save the current project.
	Save screenshot (PNG) of the seismic profile or of the travel times curves.
	Export plots as PNG (image). The user is allowed selecting the list of plots to be saved.

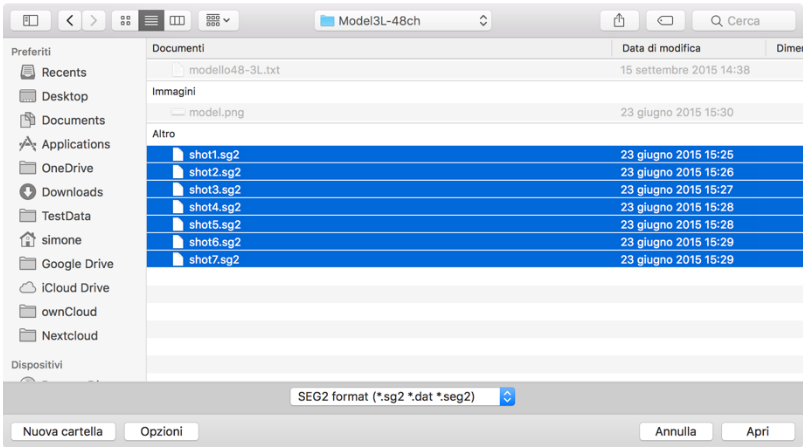
	Export both plots and data tables as PDF (document). The user is allowed selecting the list of plots and tables to be saved.
	Export as ODT (document) the plots and data table. The user is allowed selecting the list of plots and tables to be saved.
	Show the previous traces set.
	Show the next traces set.
	Zoom in on traces. (Check the settings dialog to select the zoom modality)
	Zoom out on traces.
	NoRe – Apply the adaptive Noise Reduction for seismic refraction.
	Apply automatic picking of firsts breaks.
	Set tomography parameters and start the inversion.
	Modify the current color palette or create a new one to visualize the tomographic profile.
	Set parameters to visualize isocontours.

Create new project

To start a new project from scratch, click the menu item File/New or the toolbar button  .

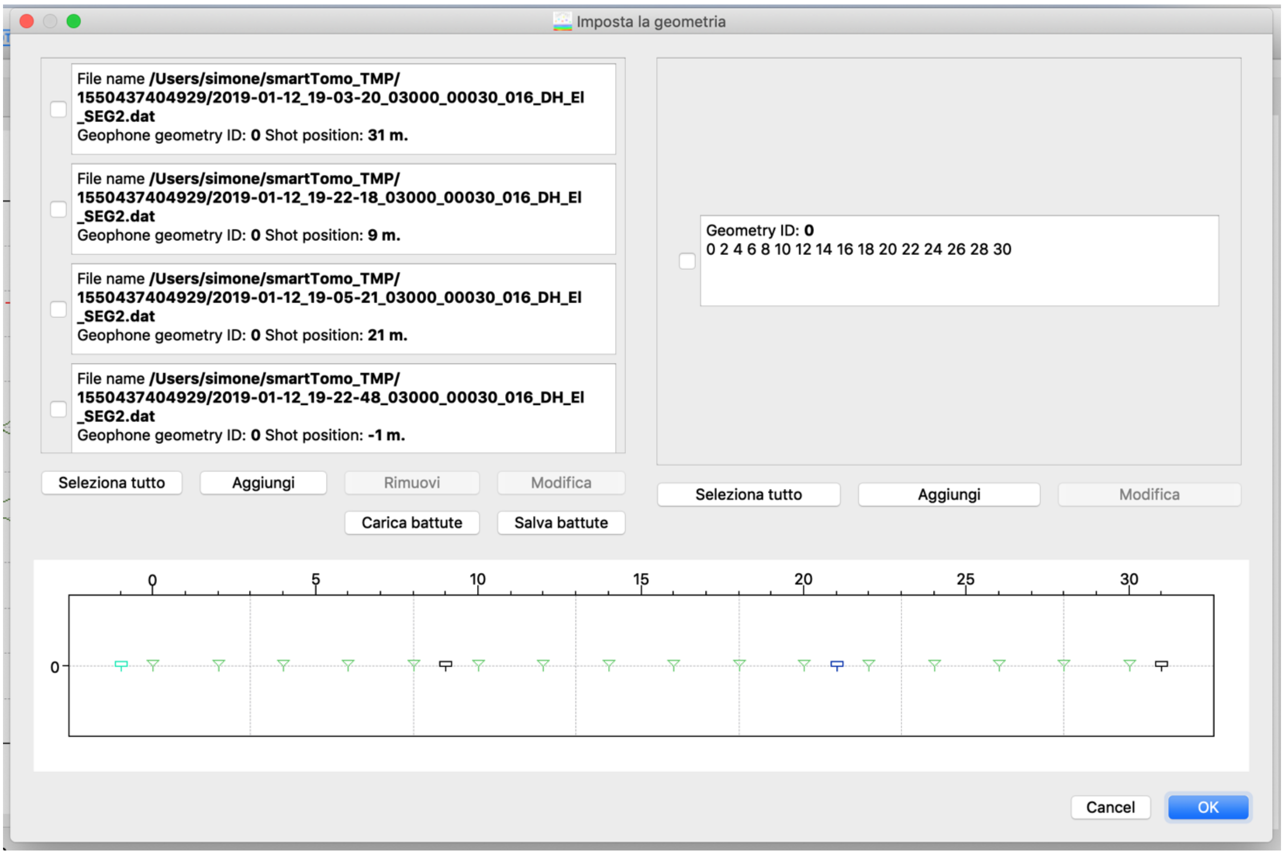
> The demo version has the new project item disabled. To start a new project using the demo dataset, simply restart SmartTomo.

The dialog for select seismic files will be shown.



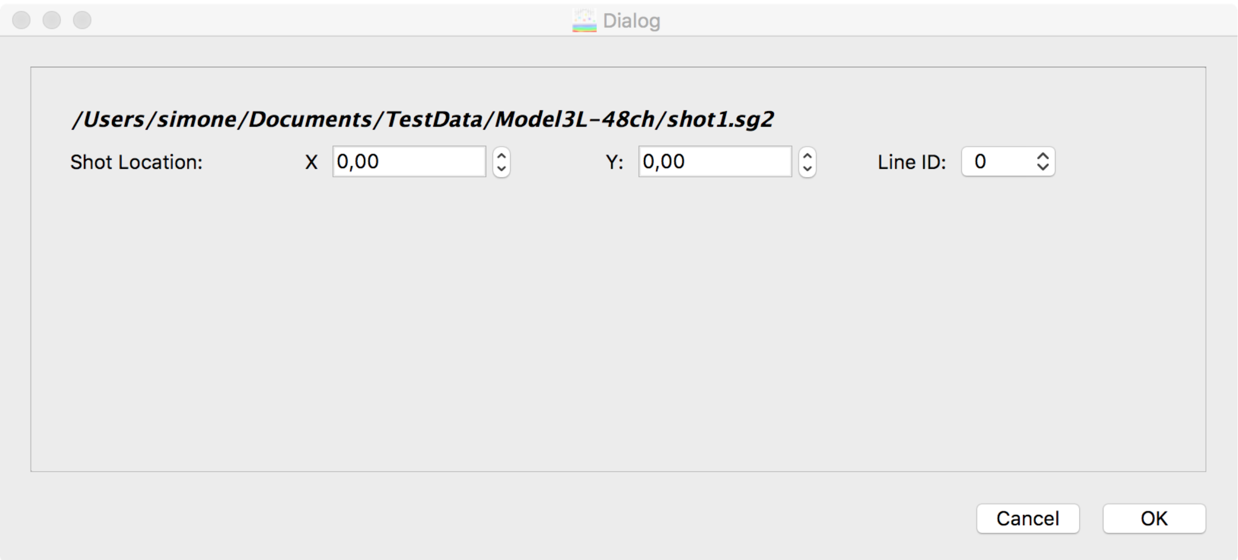
3 Select seismic file dialog

After the input file(s) has/have been selected, the geometry of the seismic line is read from file. If needed, the user can modify it by simply open the specific dialog which appears just after the input file selection.

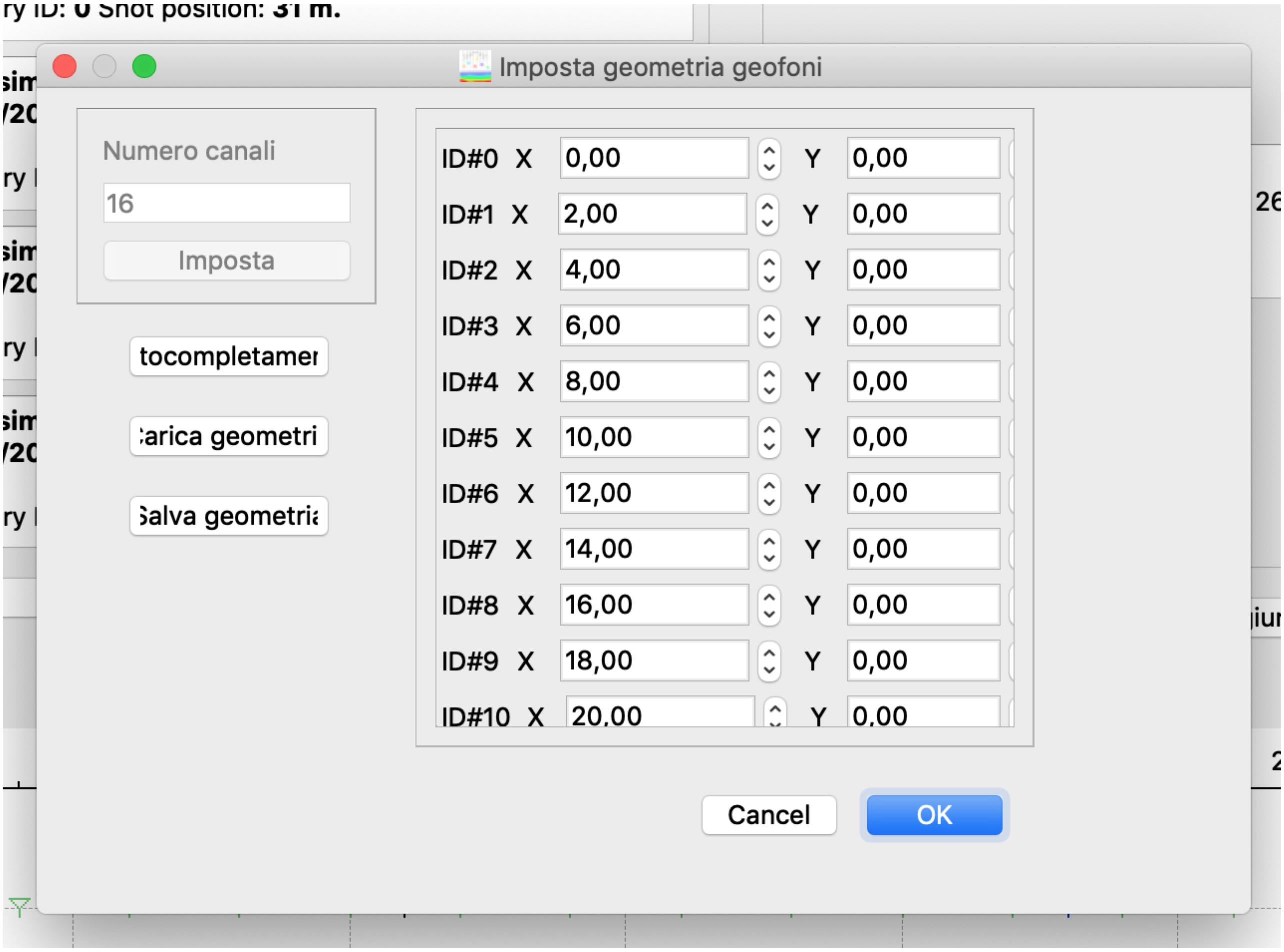


4 Geometry settings; geometry of the shots is on the left, while the geometry of the geophonic line is on the right.

This dialog lists the shots positions on the left and the geophones geometry on the right. The project may have one or more geophones lines as needed in a roll along survey.
Both shots and geophones geometry can be loaded from a CSV file.

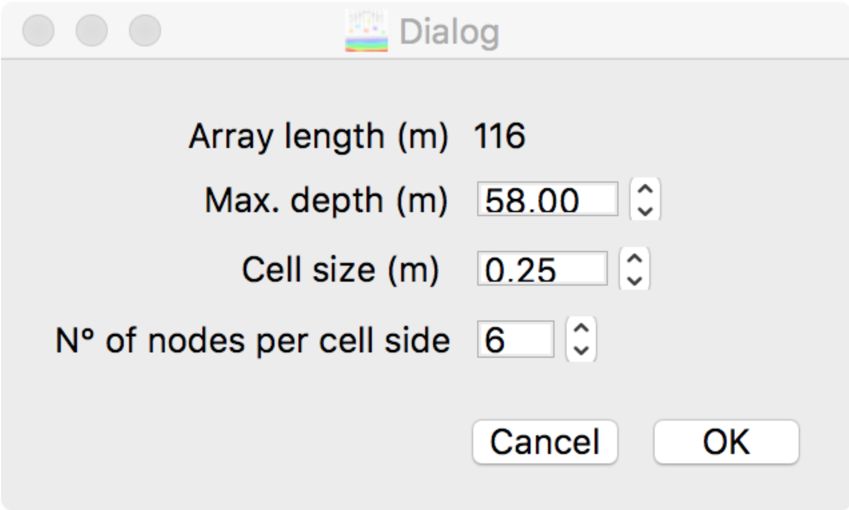


5 Dialog for setting the location of shots points

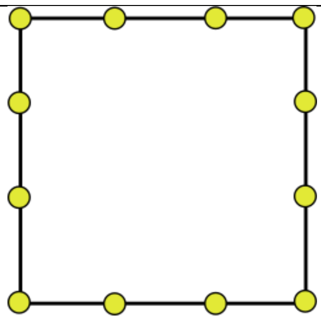
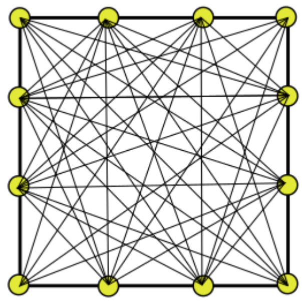


6 Dialog for setting the geometry of geophones line. Y values are the elevations of the geophones.

After the geometry has been defined, the user is asked to set the size of the tomographic grid. The grid is the computational space where the tomographic problem is solved. It is made up of almost square cells with a number of nodes on every side. Each node is connected with its neighbors with a straight line that discretize seismic rays. The user is allowed setting the maximum depth of the tomogram, the length of the cell side and the number of nodes on each cell side.



7 Grid parameter

	
Example of a grid cell with four nodes for side.	Example of lines discretizing seismic rays in a four nodes cell

The optimal cell size is ¼ of the geophonic spacing and the number of nodes between 6 and 11. Larger numbers of nodes do not result in a major improvement of output but in an increase of memory usage.

TOMOGRAPHIC PROCESSING OF CONCATENATED LINES

SmartTomo allows for the tomographic processing of multiple acquisition lines concatenated and aligned along the same profile (not in 3D). For successful connection of lines, it is essential that energy shots are recorded at the same positions across all lines to be processed. If common energy shots are absent, the lines can still be processed within a single project but will be handled independently.

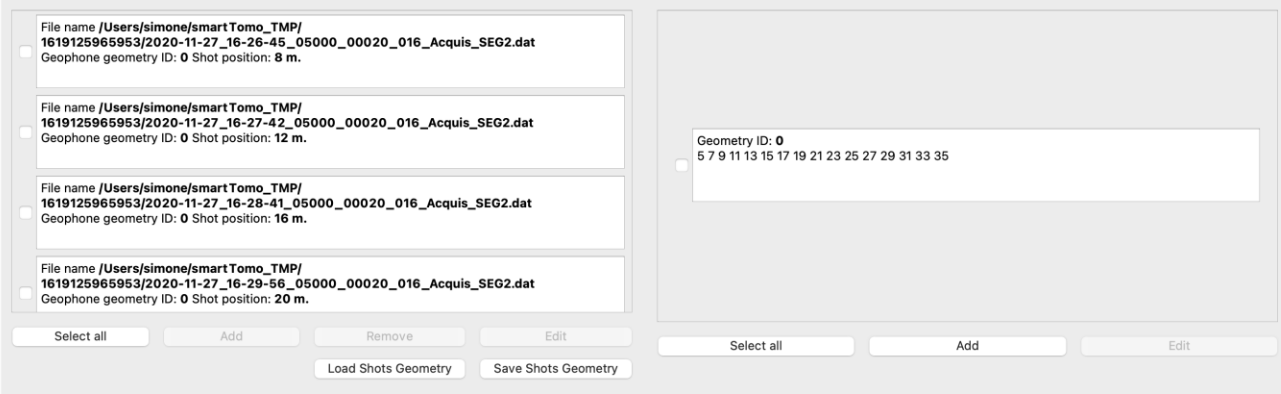
SmartTomo automatically reads the geometry from seismic files (e.g., SEG-2, SGY, SU) and prepares the project for concatenated line processing without user intervention. For this reason, it is important to prepare seismic files in the field with all necessary information to streamline processing.

If it is not possible to include geometry information in the seismic files beforehand, SmartTomo provides the option to edit geometry during project creation.

Steps for Preparing Concatenated Lines

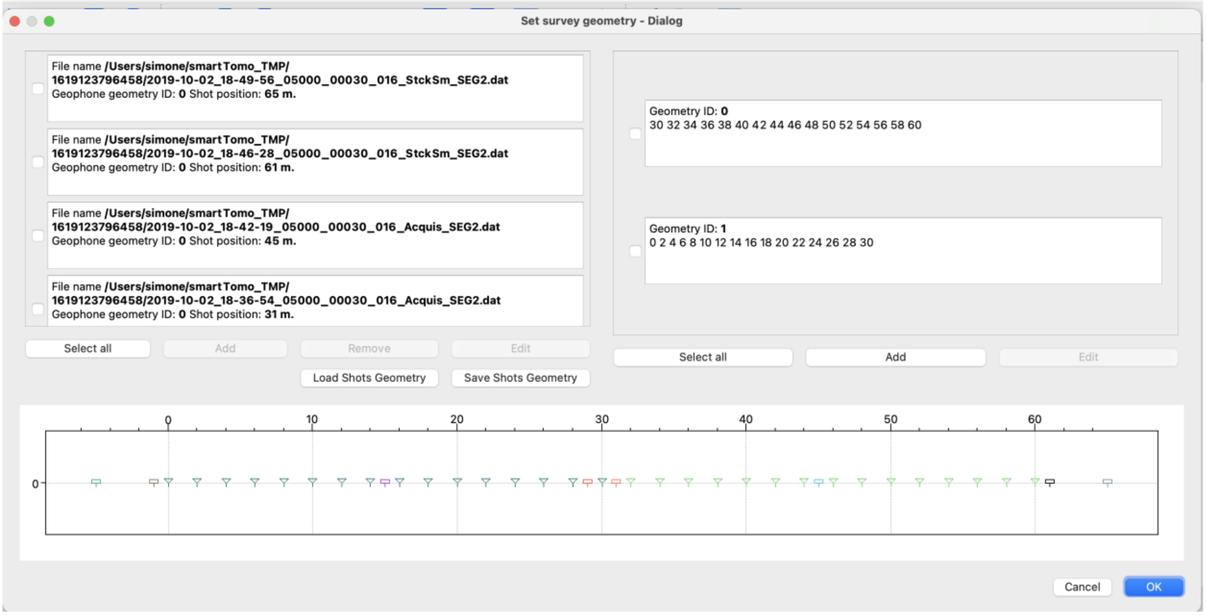
TOMOGRAPHIC PROCESSING OF CONCATENATED LINES

1. Load Seismic Files. In the new project, load all the seismic files for the concatenated acquisition lines. In the geometry setup window, all files will appear in the left column, while the right column will display a single group of geophones (see Figure 8).



8 Geometry Setup. The right column lists a single group of geophones.

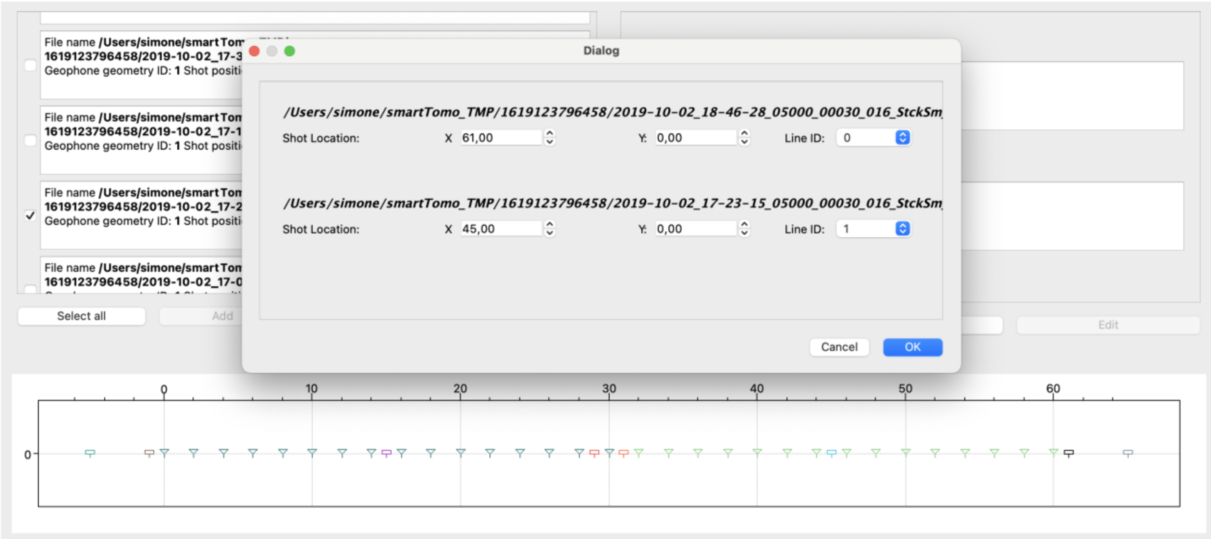
2. Add Geophone Groups. By clicking Add, you can add additional geophone lines, specifying the correct number and geometry. Once this is done, the system will display two geophone groups, as shown in the following image (see Figure 9).



9 : Two geophone groups are shown in the geophone panel. The first (ID 0) ranges from coordinates 30 to 60, and the second (ID 1) from 0 to 30.

3. Associate Energy Shots to Geophone Groups. The final step involves associating each energy shot with the correct geophone group. This operation links the geophone geometry with the traces and the shot positions.
    - To associate the recordings with the geophones, select the relevant files from the left column using the checkbox and press Edit at the bottom.
    - This opens the dialog window shown in Figure 10, where you can use a dropdown menu to assign each recording to the corresponding geophone group.

TOMOGRAPHIC PROCESSING OF CONCATENATED LINES



10 Dialog window for setting shot geometry and the geophone line associated with the acquisition.

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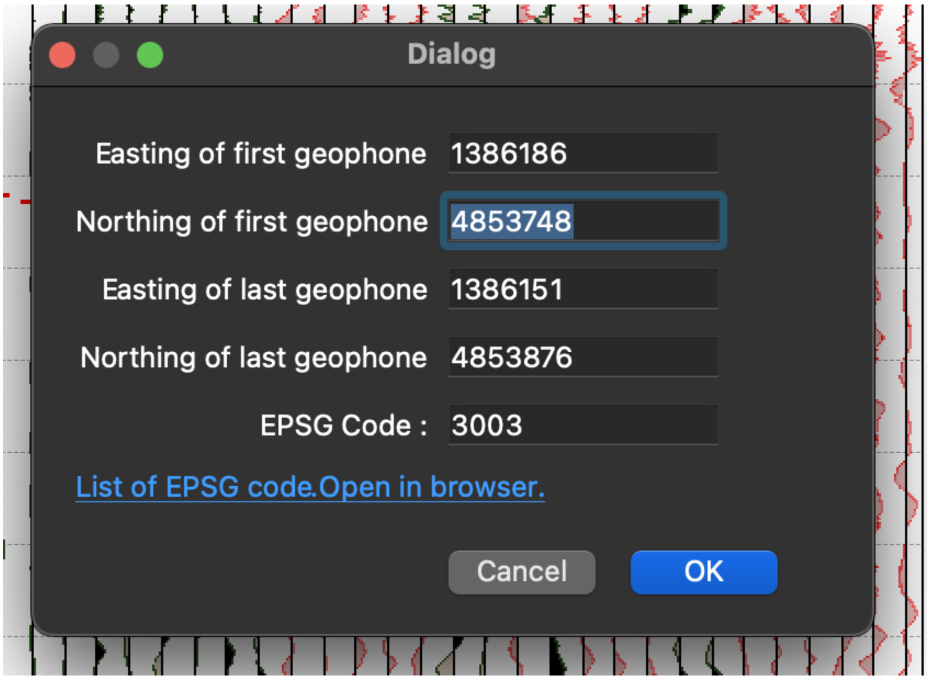
Once this step is completed, you can proceed as usual to configure the grid parameters and process the survey.

Set the geographic coordinates (optional).

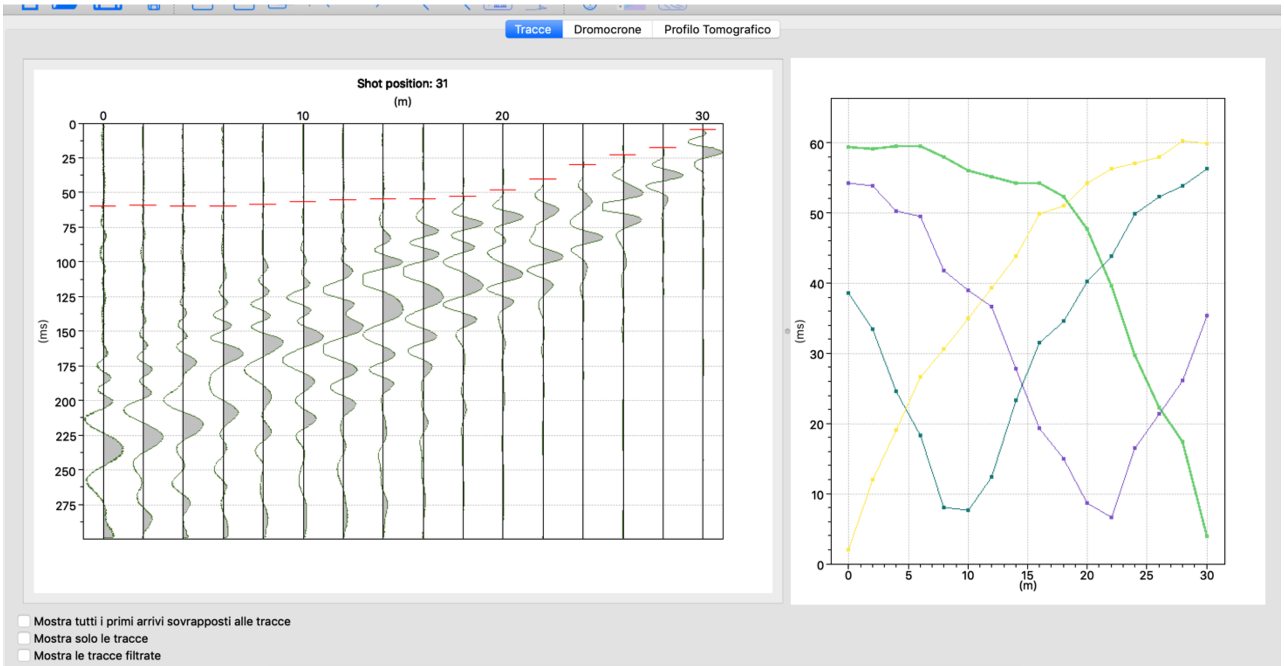


11 Dialog to set geographical coordinates.

The seismic line can be georeferenced. Accessing the Project/Set Geographic Coordinates menu opens the appropriate dialog box (Figure 7). It is possible to enter the coordinates of the first and last geophone of the line in a metric projected coordinate system (e.g. UTM zone 12N has EPSG:32612). The position of the geophones, beyond the first, is determined by calculating the position using the geophone geometry set previously, thus ensuring that the distance between the geophones is as defined. The EPSG code identifies the reference system used. The EPSG parameter is important to export the profile to the KML file for visualization, for example in Google Earth.
A list of EPSG codes can be found at this link https://spatialreference.org/.

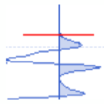
Picking first breaks

The first tab of the main table shows the seismic records and a preview of travel times. From the toolbar, the user can zoom in, zoom out and move back and forth through the recorded files.

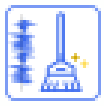


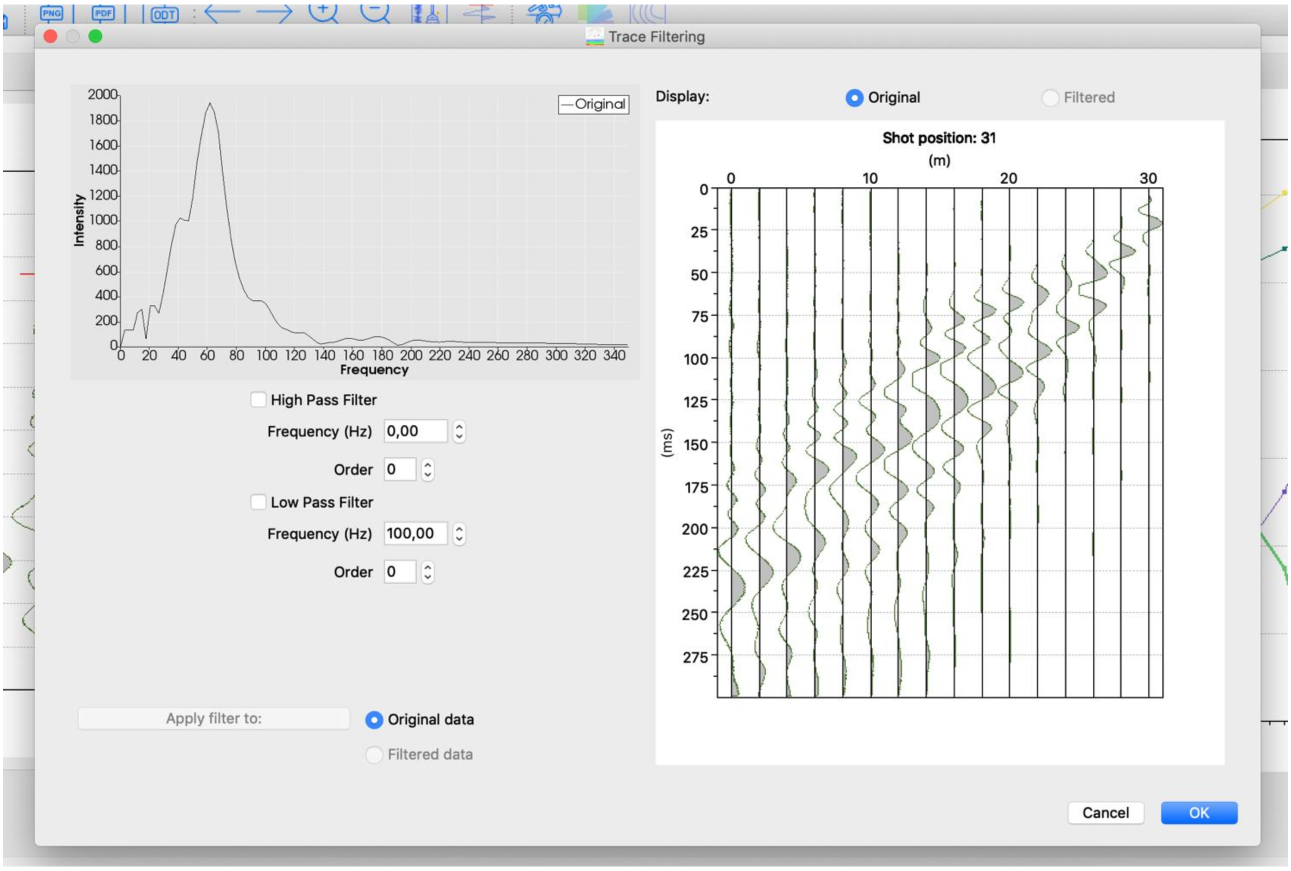
12 Trace tab. Visualization of a selected trace together with a summary of travel time curves.

To set first breaks the user can left click on the trace or run the automatic picking. Conversely, to disable a channel or remove a previously set first break simply press shift+left click on the pick to be deleted. By dragging the mouse, you can set or unset (with shift pressed) the first breaks in a continuous way.
The automatic picking now implements a method to reject inaccurate picks. The traces without an automatic pick will be plotted in red as a disabled channel.

Autopicking of first braek		
From menu: **Tracce/Autopick**	Keyboard shortcut: **-**	Toolbar: 

Recorded signals can be cleaned using two different approaches. An automatic Noise Reduction, called NoRe, can be used to apply an adaptive band pass filter. Alternatively, the user can manually apply different and multiple filters by selecting the menu item Trace/Filter...

Automatic noise reduction (NoRe – The Noise Reduction tool for seismic refraction)		
From menu: **Tracce/Applica NoRe**	Keyboard shortcut: **-**	Toolbar: 



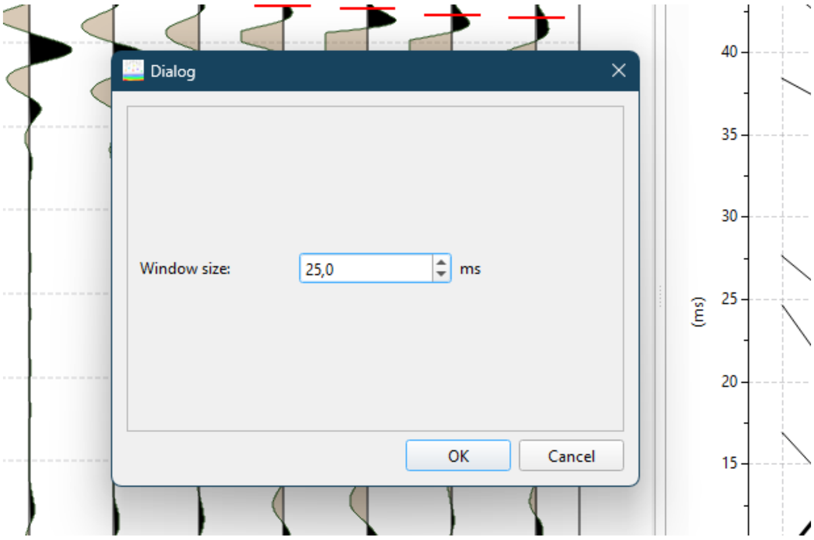
13 Trace filtering dialog

Enabling Seismic Attenuation Tomography and Sampling Attenuation Data

WARNING - GARBAGE IN, GARBAGE OUT
Seismic attenuation tomography uses the amplitude of the refracted seismic wave in the frequency/intensity domain as observed data. Evaluating the quality of acquired data during the analysis phase is challenging, making it essential to conduct field operations carefully to avoid distorting the intensity of the recorded signal. It is recommended to ensure the following: • Geophones are positioned according to the manufacturer's specifications, such as ensuring they are placed vertically. • Avoid placing geophones differently, such as some on base plates and others directly embedded in the ground; the signal may be filtered differently depending on the presence or absence of a base plate. • Geophone-to-cable connectors should all be in the same condition, free of moisture or other issues. • All geophones should be of the same type, ensuring consistent response to external stimuli. • Avoid any local or surface conditions that could alter the intensity of the recorded signal.

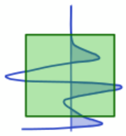
Enabling attenuation tomography		
From menu: **Project/Enable attenuation tomography**	Keyboard shortcut: **-**	Toolbar icon:
Attenuation sampling window		
Da menu: **Traces/Attenaution sampling …**	Keyboard shortcut: **-**	Toolbar icon:

When creating a new project, attenuation tomography is disabled by default.
When the function is enabled, the user is prompted (see Figure 14) to specify the size of the signal window, in milliseconds, to be sampled for calculating signal intensity. The window size is defined starting from the first arrival.



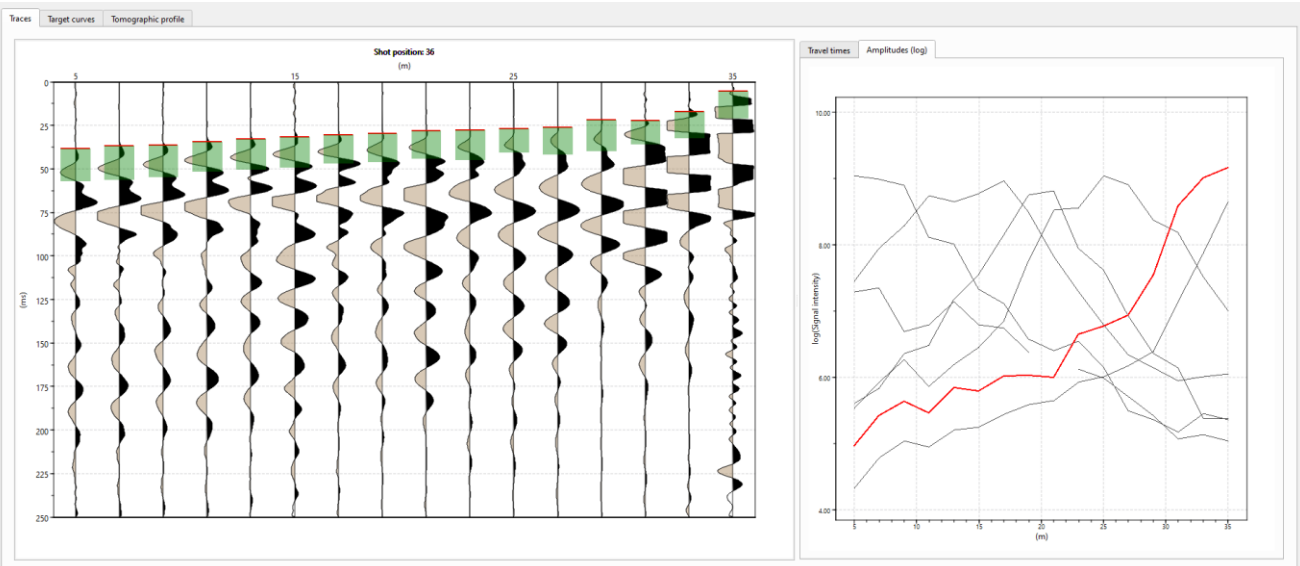
14 Dialog Window for Setting the Sampling Window Size for Signal Intensity

The signal within the defined window (see Figure 14) is analyzed in the frequency/intensity domain, trace by trace. An attenuation graph is generated and can be displayed in the side view, replacing the travel time curves.
It is possible to define the sampling window size manually, trace by trace, by enabling the function from the menu or toolbar. While this function is active, the first arrival cannot be modified. However, the lower boundary of the sampling window (highlighted in green) can be adjusted by clicking with the left mouse button.
Similarly to first-arrival picking, it is possible to disable the sampling for a specific trace by clicking Shift + left mouse button. Disabled traces will no longer display the green window, indicating that the signal portion for that trace is not being sampled.

Manual Selection of the Sampling Window for Attenuation Values		
From menu: **Traces > Attenuation Sampling**	Keyboard shortcut: **-**	Toolbar icon: 

General Recommendations for Setting the Sampling Window

The sampling window can generally be widened as the distance from the source increases. A practical approach for setting the window is to use a recognizable feature in the signal, such as a peak or trough, and align it with its equivalent in neighboring traces to ensure the same portion of the signal is sampled consistently across all traces.

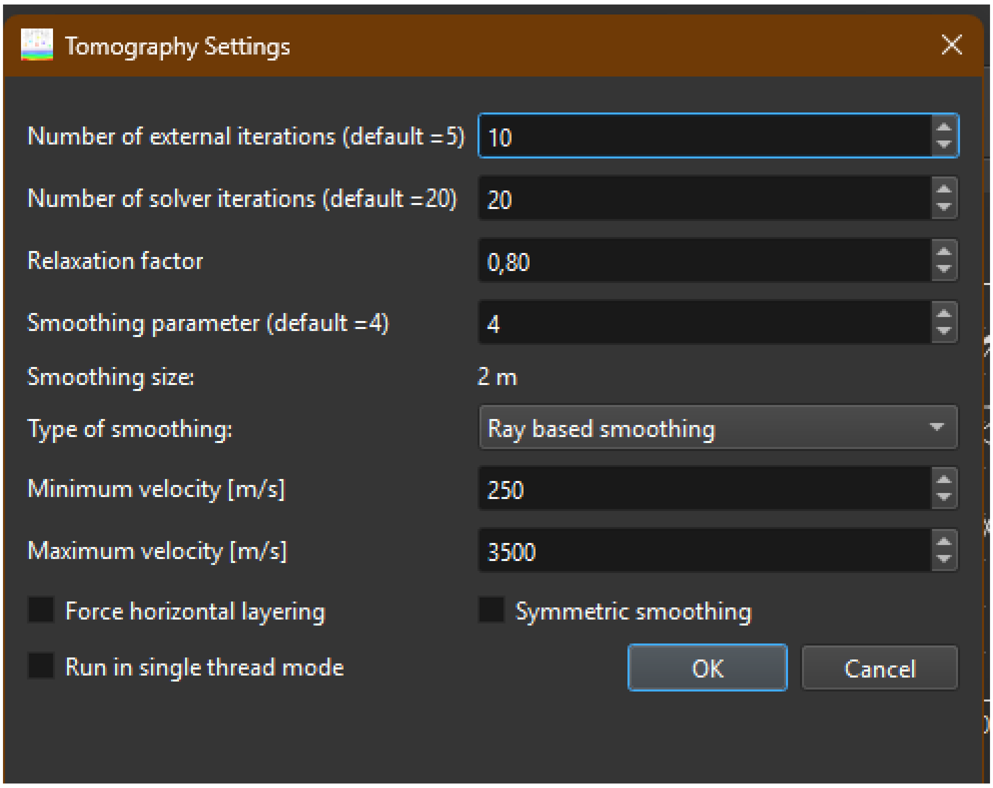


15 On the left side of the window, the sampling windows (highlighted in green) for signal intensity calculation are displayed above traces. On the right panel, the intensity graph is shown as a function of the geophone positions.

Run tomography

Run tomography inversion		
Menu option: **Tomo/Run tomography**	Keyboard shortcut: **-**	Toolbar button: 

To start the tomographic inversion, click the menu item Tomo/run tomography. A specific dialog will allow setting the inversion parameters.



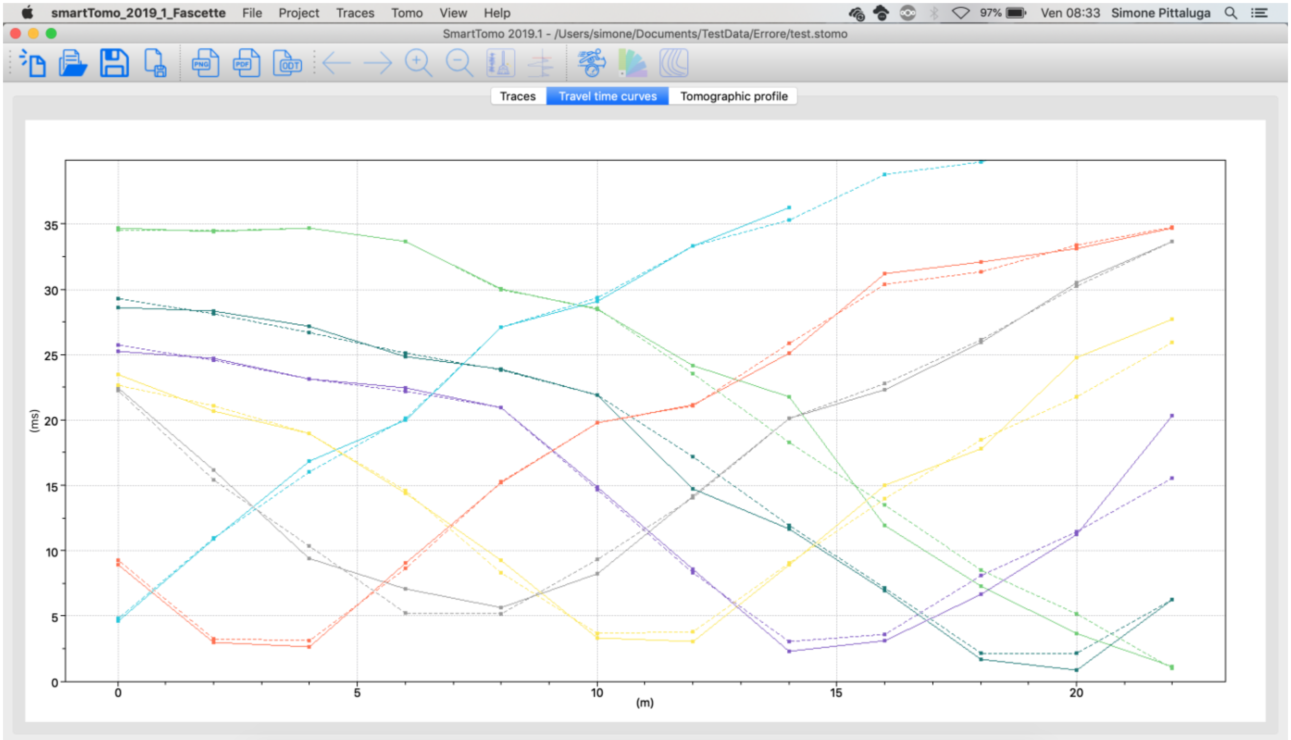
16 Run tomography parameters dialog.

Parameters	Meaning
Number of external iterations	It is the number of times that the solver will be run. Every external iteration updates the model velocity and based on this, it computes the updated ray paths.
Number of solver iterations	It is the number of times that the model velocity will be updated to fit experimental travel times. If the model needs to be strongly updated, this value should be set to value between 25 and 50.
Relaxation factor	A relaxation factor is a parameter that controls the convergence rate of an iterative method for solving a differential equation. It

	is usually denoted by the symbol omega and takes values between zero and one. A relaxation factor close to one means that the method converges faster, but it may also become unstable and diverge. A relaxation factor close to zero means that the method converges slower, but it is more stable and less likely to diverge.
Smoothing parameter	This parameter can be imagined as a moving average that distributes the results over all cells. The value corresponds to the size of the window considered. At every external iteration the model velocity will be smoothed using a moving window. If set to a value lower than 4, a coarse profile is generated. Conversely, if set to a value around 8-10, a smoothed profile is produced. Starting from the 2024 version, the smoothing parameter is also displayed in meters to provide a reference that is easily relatable to the survey scale.
Type of smoothing	This parameter defines the type of moving windows will be applied during the smoothing step. The uniformly weighted smoothing applies the same weight to all the elements moving windows. The linearly weighted smoothing applies more weight to cells close to the center of the moving windows following a linear law. The gaussian weighted smoothing applies more weight to cells close to the center of the moving windows following a gaussian law. The ray based smoothing applies a function to weight taking in account only the cells crossed by seismic rays. Largest velocity values get more smoothing following a logarithmic law. --- *Linear smoothing produces more coarse profile then gaussian.*

Minimum – maximum velocity	The minimum and maximum threshold velocity. If the tomography fails to converge to an acceptable solution, try to set a larger interval of allowed velocity.

The fitting of experimental travel times can be checked in the travel time curves tab. Experimental travel times are drawn with continuous line while dotted lines are used to show computed travel times.



17 Travel time curves tab selected. Visualization of estimated and computed travel time curves (dotted lines). From the preferences the travel times plot can be switched to a 2 colors view (black and red).

The tomographic profile is shown in the tab called Tomographic profile.

Weight distribution														
1	1	1	1	1	0,35	0,45	0,5	0,45	0,35	0,73	0,82	0,85	0,82	0,73
1	1	1	1	1	0,45	0,71	1	0,71	0,45	0,82	0,92	0,96	0,92	0,82
1	1	1	1	1	0,5	1	1	1	0,5	0,85	0,96	1	0,96	0,85
1	1	1	1	1	0,45	0,71	1	0,71	0,45	0,82	0,92	0,96	0,92	0,82
1	1	1	1	1	0,35	0,45	0,5	0,45	0,35	0,73	0,82	0,85	0,82	0,73
Uniform smoothing					Linear smoothing					Gaussian smoothing				

Distribution of the weight applied during the smoothing process. The ray based smoothing does not apply a constant matrix of weight.

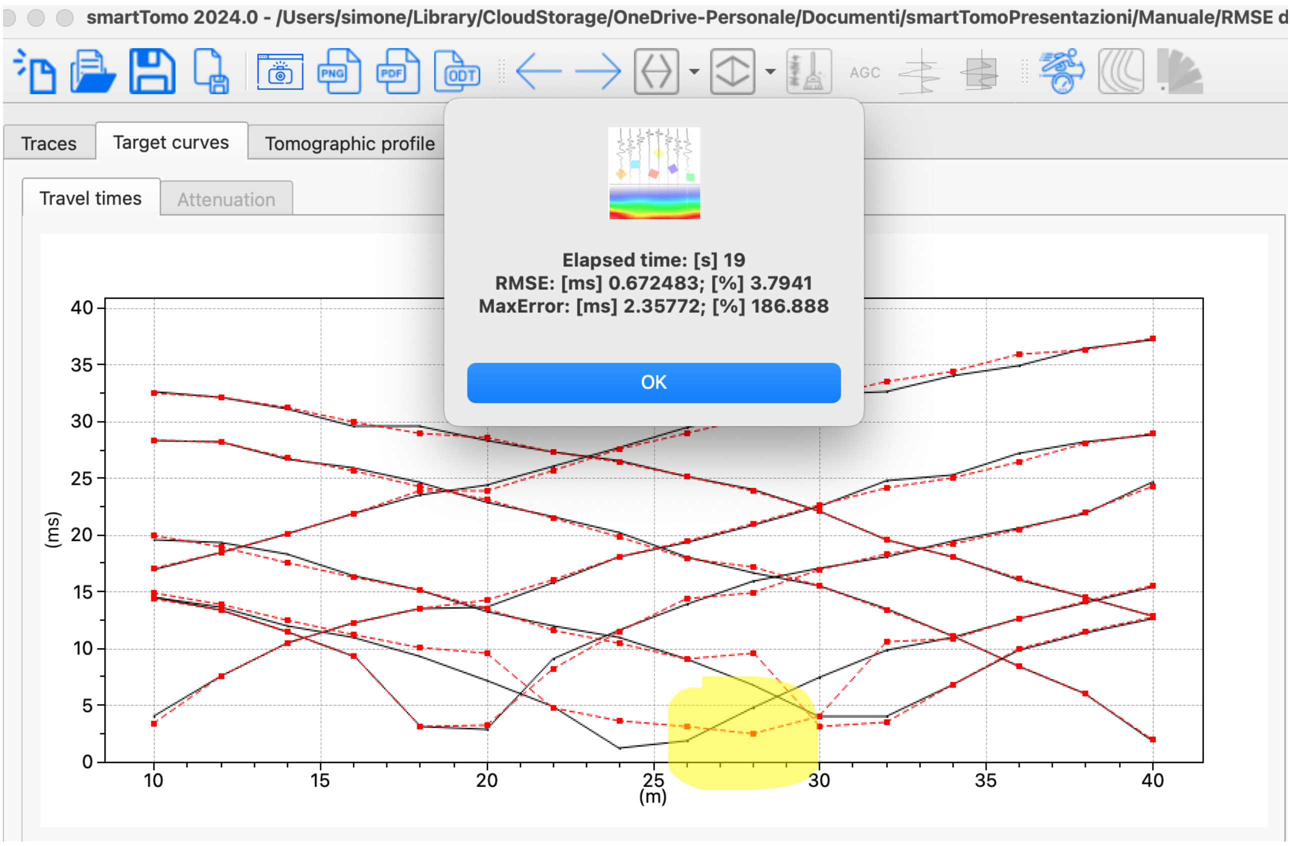
(RMSE) Root mean squared error and maximum error of tomography processing.

One of the ways to measure the quality of seismic tomography inversion results is to evaluate the maximum error and the root mean squared error (RMSE) computed by comparing the fitted travel times with the observed ones. However, there is no definitive criterion to determine whether these errors are small enough to ensure a reliable reconstruction of the subsurface structure.

The suggested workflow is to check the travel times by eye after the tomography inversion is finished to find where the largest difference between computed and measured travel times are.

A large maximum error may indicate a problem with the geometry of the experiment, such as an incorrect location of shots or receivers. Looking at the travel times, an error in the shot geometry can be detected if the computed travel times tend to zero at a location without an effective shot.

Therefore, it is important to check the quality of the data acquisition and processing before performing the inversion.



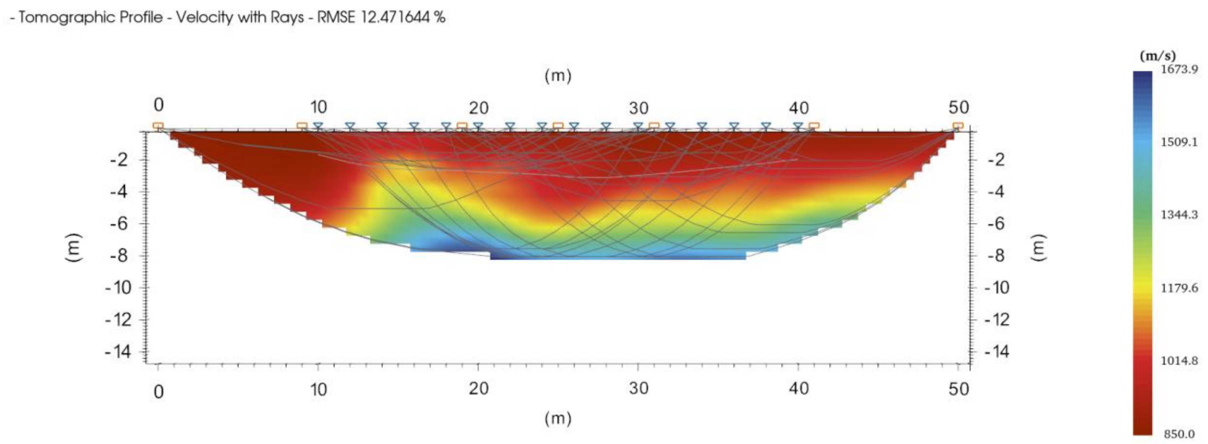
The yellow spot highlights where wrong shot position is; the computed travel times (red dotted line) has a flat low value zone that does not match measured one.

By reviewing both the tomography profile and the travel time plot, the user can detect problems with the minimum and maximum tomography velocity settings.

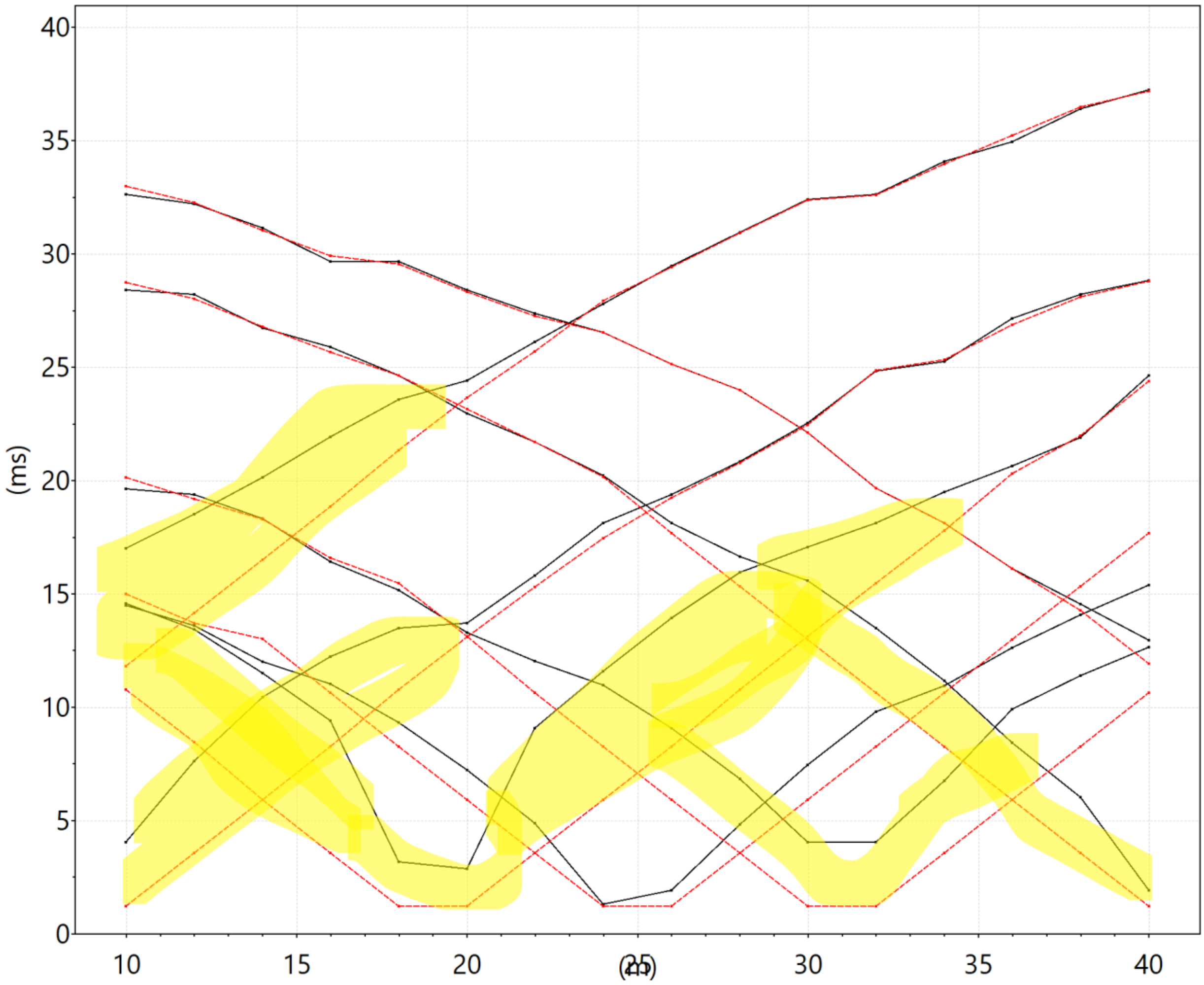
Setting the velocity parameters in the Run Tomography dialog to a range that is not appropriate for the geological context will increase the RMSE and maximum error.

If the minimum velocity is set too high, users may observe the following:

- The profile minimum velocity is close to the minimum velocity set in the dialog.
- The travel times diverge near the shot points and the computed first brakes arrive too early.



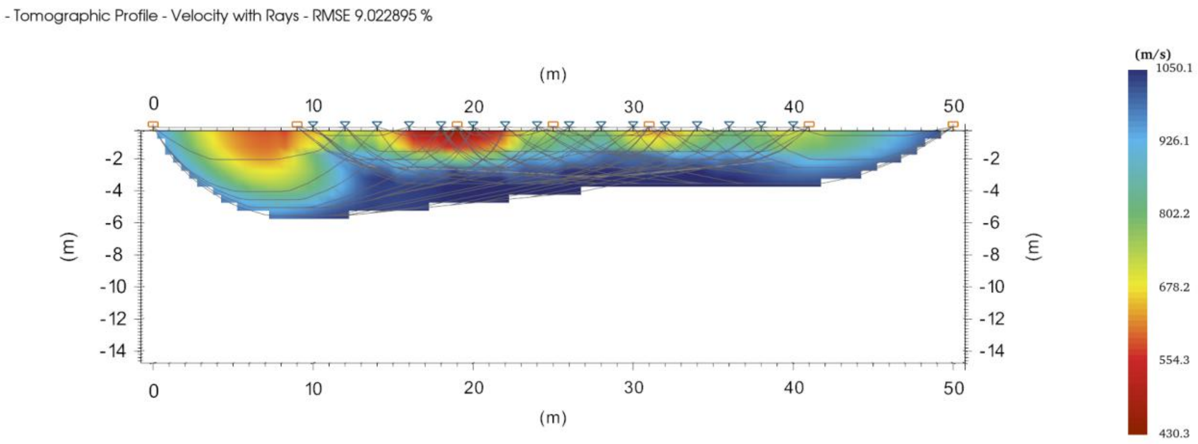
The minimum speed in the seismic profile is nearly the same (850m/s) of the one set in the run tomographic processing dialog to show the artifact due to a wrong speed range.



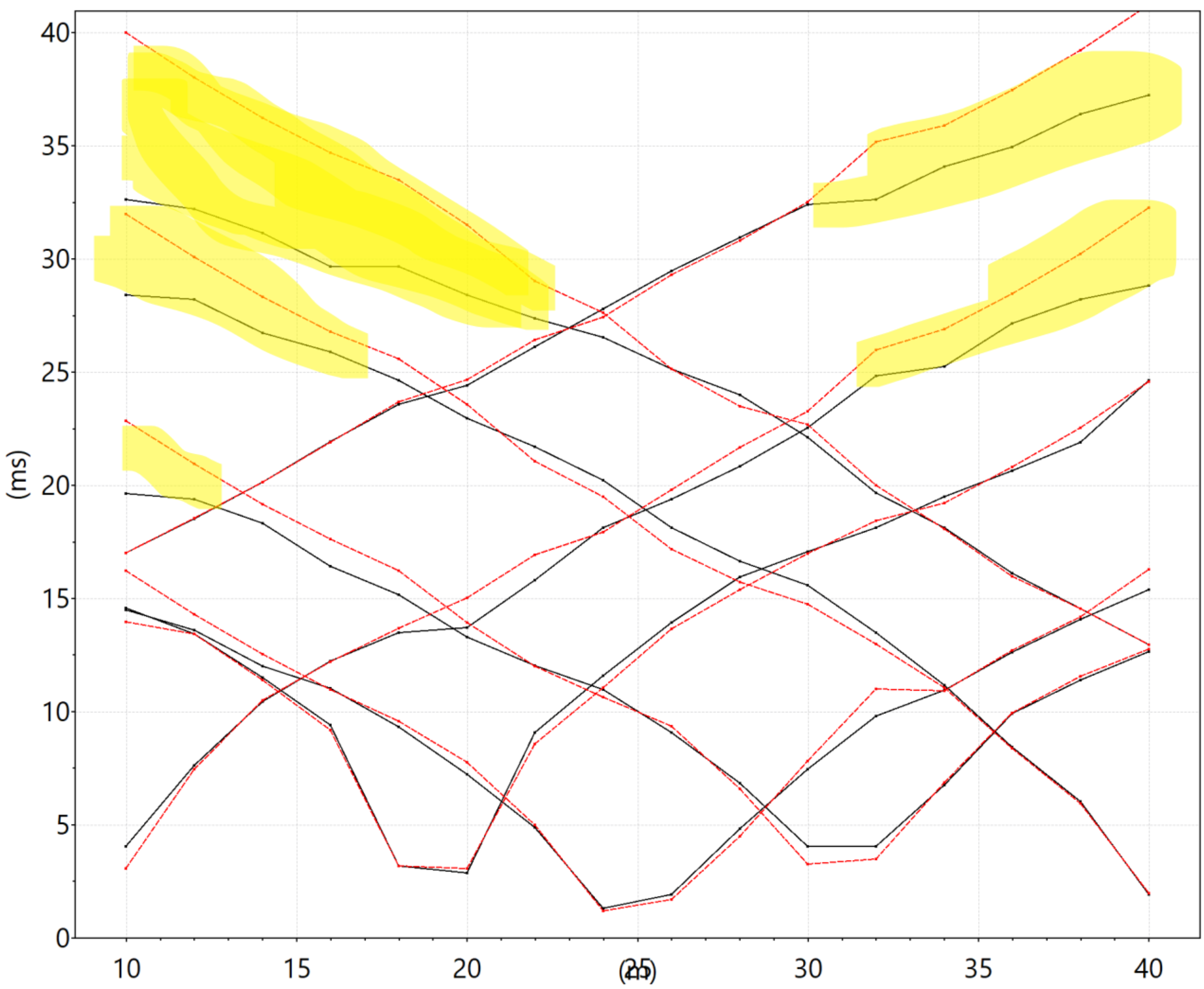
The highlighted area shows where the computed travel times (red) arrive too early.

If maximum velocity is too low, the users can observe:

- Tomographic profile clipped at speed near to the maximum velocity.
- The computed travel times deviate from observed ones and arrive too late at receivers located far away from the shot points.



Tomographic profile clipped at 1050 m/s, the maximum velocity set in the tomography dialog



Computed travel times (red) arrive later then observed (black) at receivers far away from the shot points. The differences are highlighted in yellow.

Finally, the degree of smoothing applied to the inversion process has can affect the fit between the observed and computed travel times. A high smoothing parameter may result in an overly smooth solution that does not capture the details of the heterogeneities, while a low smoothing parameter may result in a noisy solution that does not reflect the true variations in the velocity field. To evaluate the optimal level of smoothing, users must examine the trade-off between the data misfit and the model complexity and choose a value that minimizes both. By doing so, they can obtain a more accurate and robust tomographic image of the subsurface.

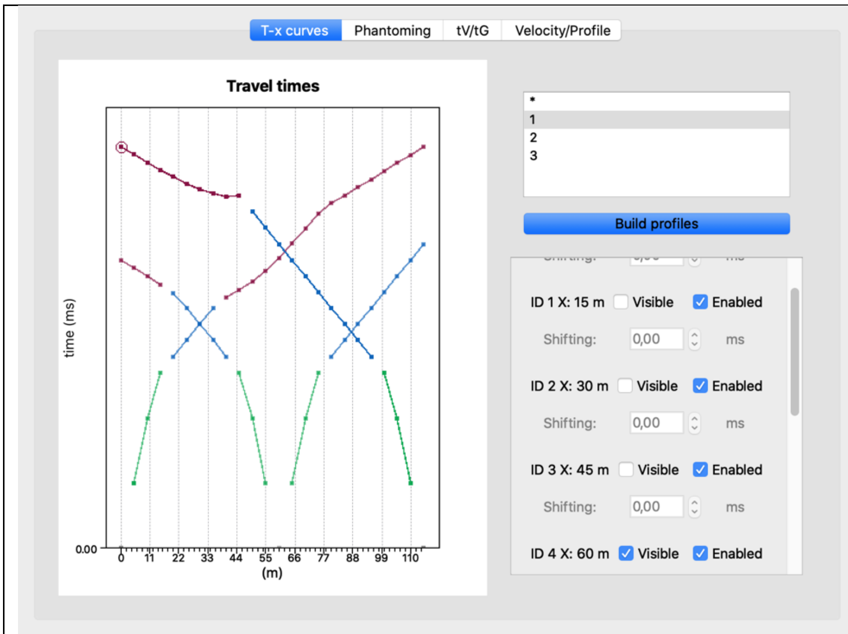
Refraction seismic processing using the reciprocal method (GRM)

SmartTomo since version 2020.0 includes a procedure for processing data with a layered model implementing the Generalized Reciprocal Method, GRM. (Palmer 1980). (https://library.seg.org/doi/book/10.1190/1.9781560802426).

Processing of seismic refraction applying GRM		
Da menu: **Processing/Refraction**	Da tastiera: **-**	Da toolbar: -

The processing and visualization of the results is designed primarily for visualization superimposed on tomography. However, you can export the refraction processing separately as an image.

The seismic processing window contains four tabs.

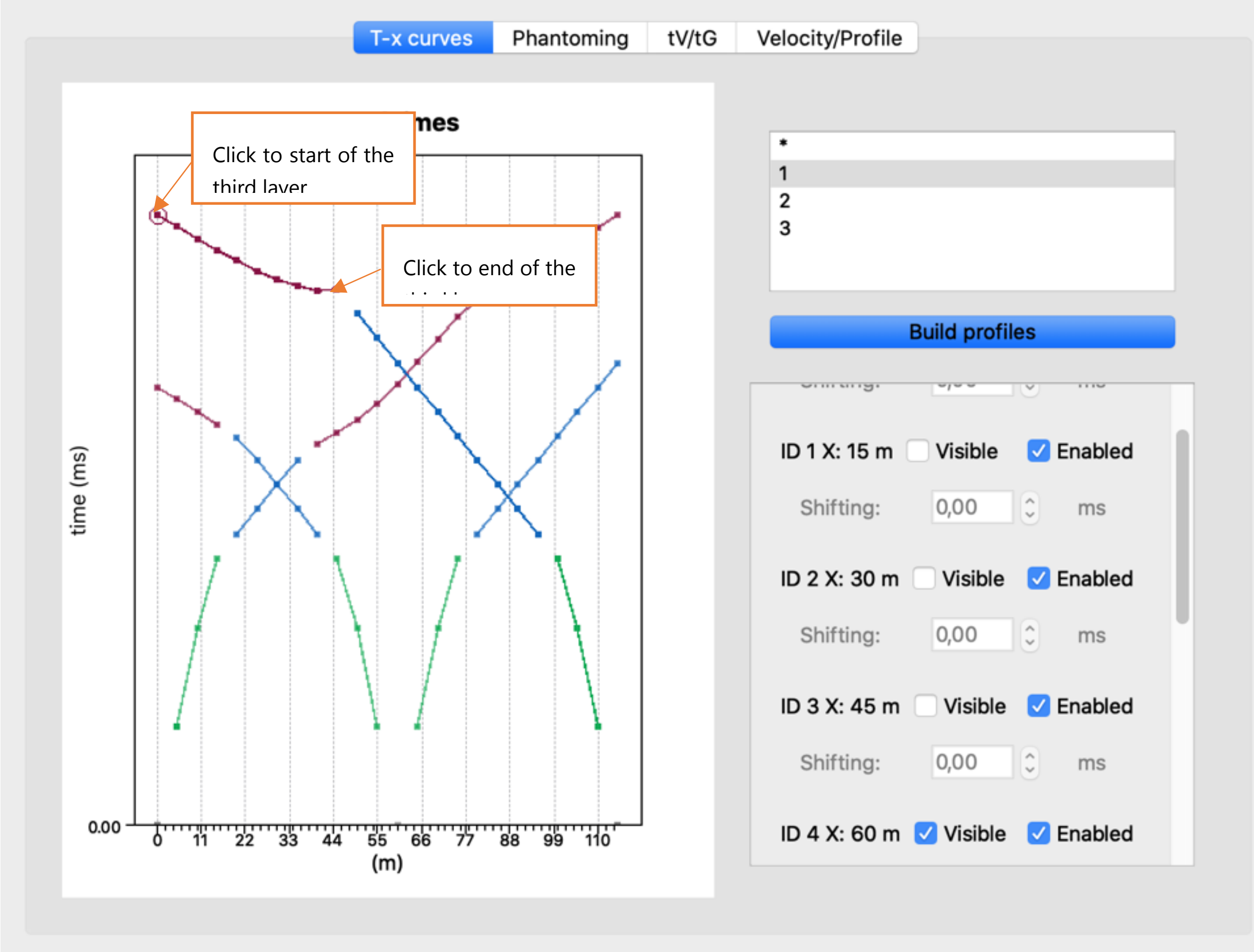


In this tab the user must assign dromochrones to seismic layers.

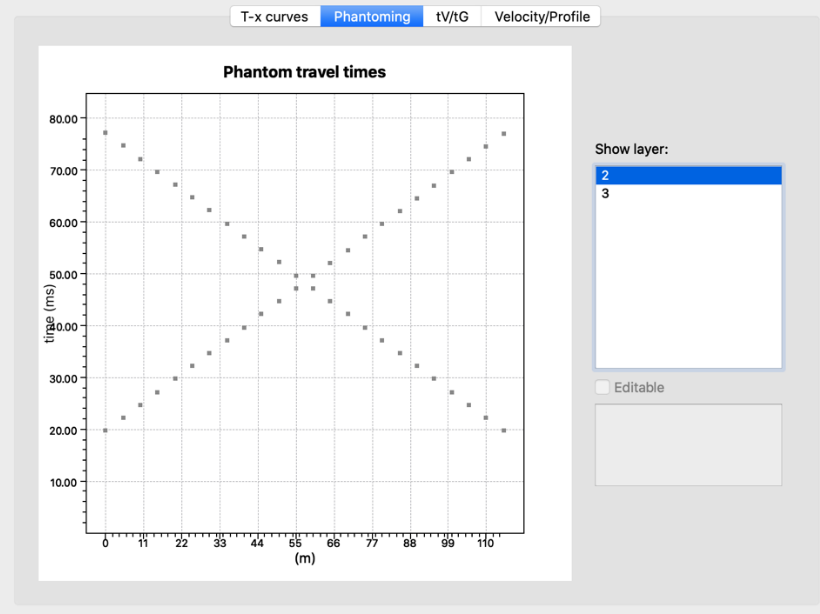
From the list on the top right, the strata to which the arrival is to be associated is chosen. To associate the arrival time to the layer the user has to click on the first point and move to the last point for that layer and click again.

The list on the bottom right shows the sequence of shots and the possibility of displaying and disabling them.

The Build profiles button automatically calculates the refraction section.

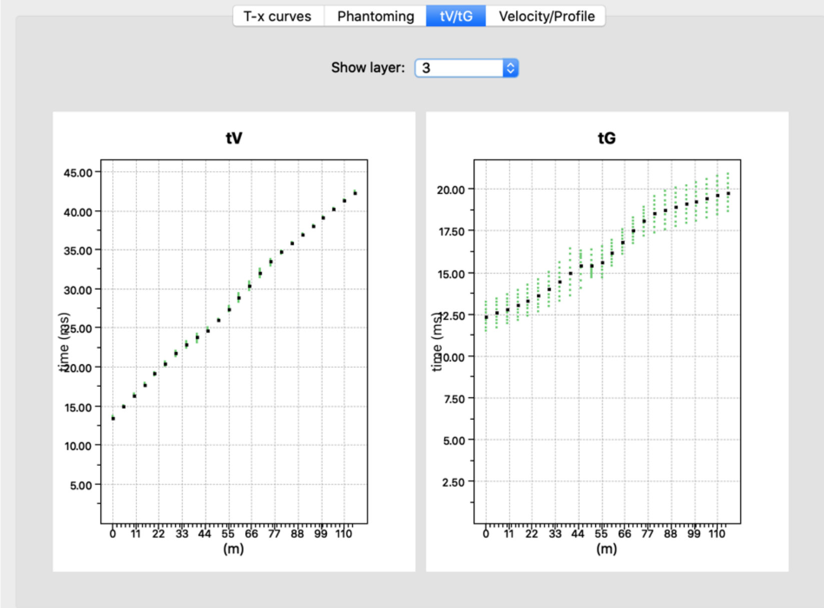


18 Example of assignment of layers to first arrivals in a refraction processing

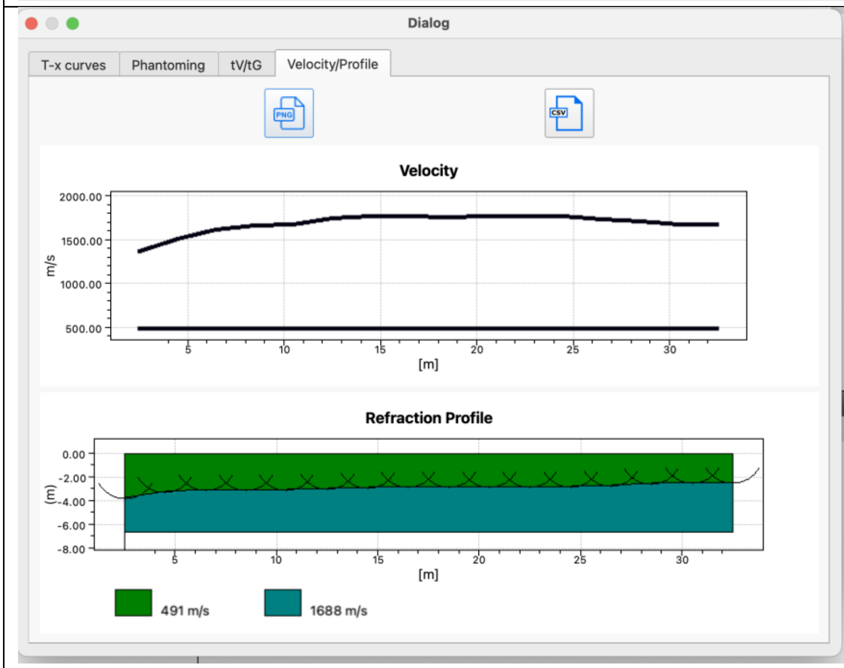


The second tab shows the reconstructed dromochrone. This is an (automatic) process required to combine all arrival times for a layer, sampled over multiple shots in order to generate a continuous dromochrone.

It is important to verify that the out and back path times (reciprocal time) are approximately equal. If not, it is likely that there are problems in the picking. In the image the reciprocal time is about 78 ms.



This tab shows the plot of the Tv and Tg functions.
The black graphs correspond to the function used for the section. The green graphs represent the variability space of the function values as the distance XY varies.



The last tab shows the refraction profile (below) and the velocity of the layers (above).
The button allows the velocity and depth sections to be exported as PNGs.

Tomographic Inversion Outputs

SmartTomo provides several visualization modes for analyzing the results of the tomographic inversion:

Tomographic Section: Displays the velocity distribution in the subsurface.

Vertical Gradient: Represents the vertical variation of velocity, useful for identifying discontinuities.

Weighted Vertical Gradient (*new in version 2022.1*): Shows the vertical variation of velocity weighted by depth.

Laplacian: Highlights omnidirectional velocity variations.

Information Density: Indicates the reliability of the velocity inversion based on the density of seismic rays.

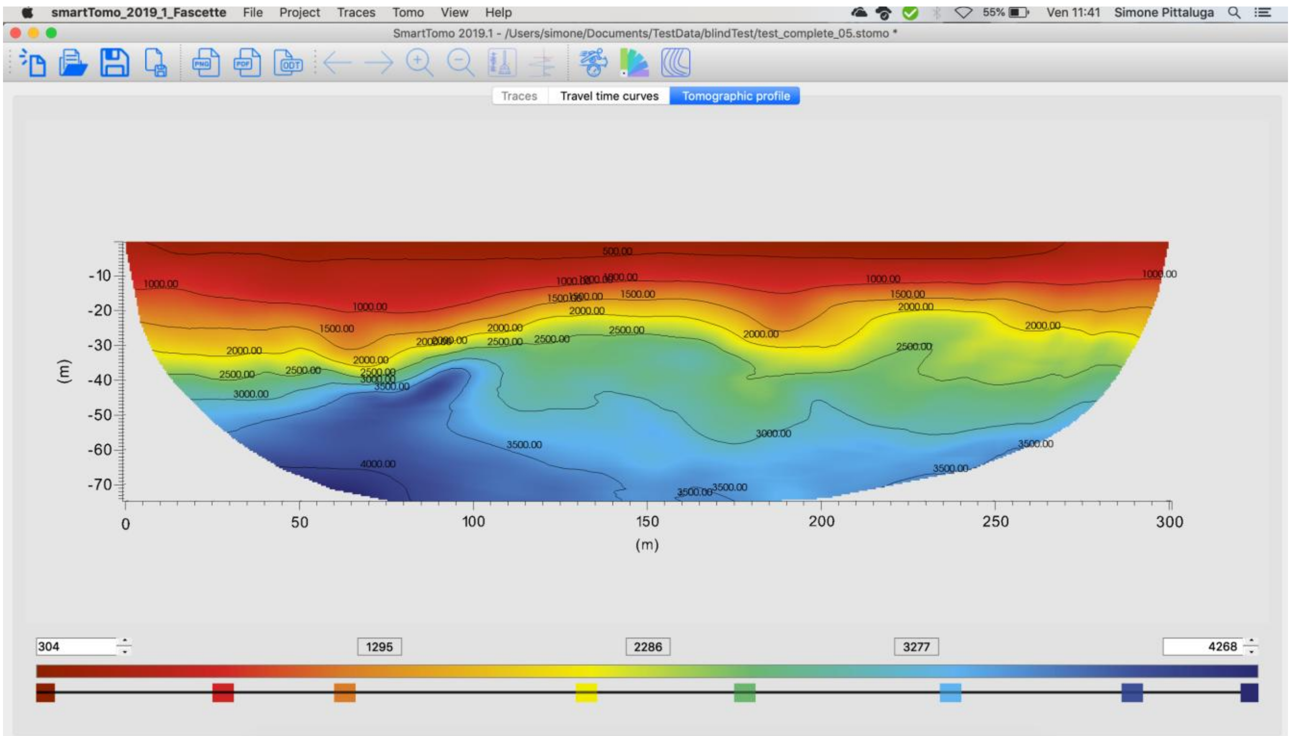
Attenuation (starting from 2024): Represents the ability of materials to attenuate seismic signals. Loose soils and highly altered rocks exhibit higher values.

Q-Factor (starting from 2024): Roughly indicates the quality of the materials. It is inversely proportional to attenuation and directly proportional to velocity. Higher values suggest better material quality.

All visualizations can be displayed using different styles. The table below outlines the modes specific to the velocity profile and vertical velocity gradient.

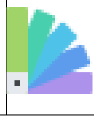
The various visualization modes and options can be accessed via the View menu.

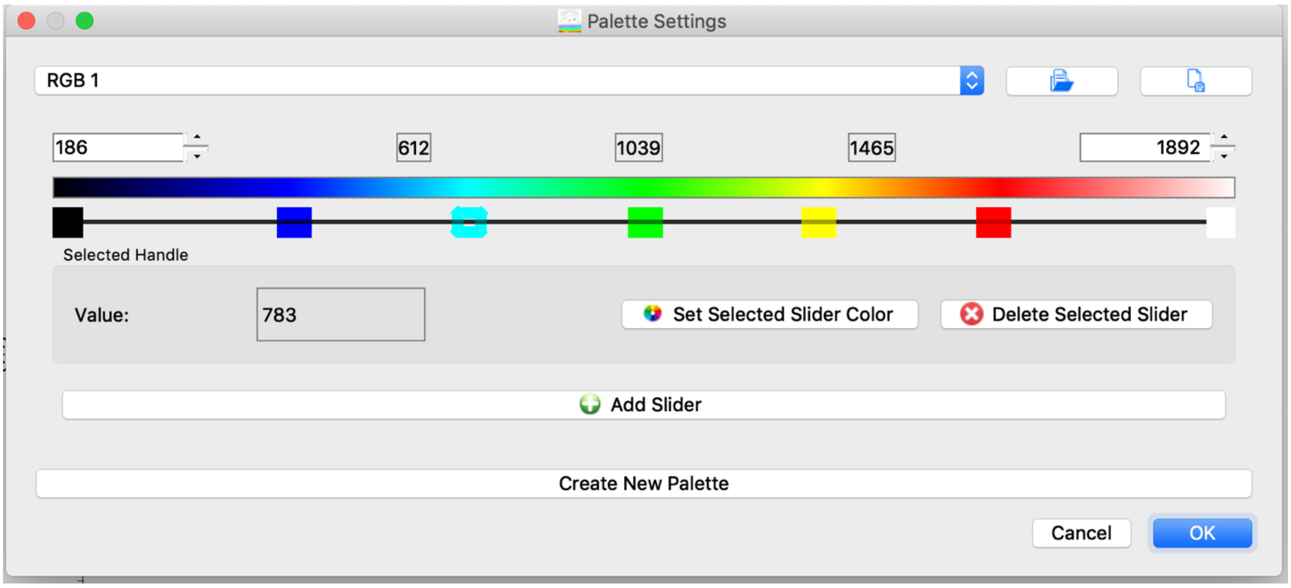
The visualization of the tomographic profile is highly customizable. The user can zoom in and out and pan the plot just using the mouse.



19 Tomographic profile tab. The result of the tomography inversion is visualized, and specific settings (e.g. color palette, contour lines) is enabled.

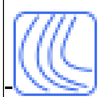
The color palette and the contour lines settings can be easily set both from menu and toolbar.

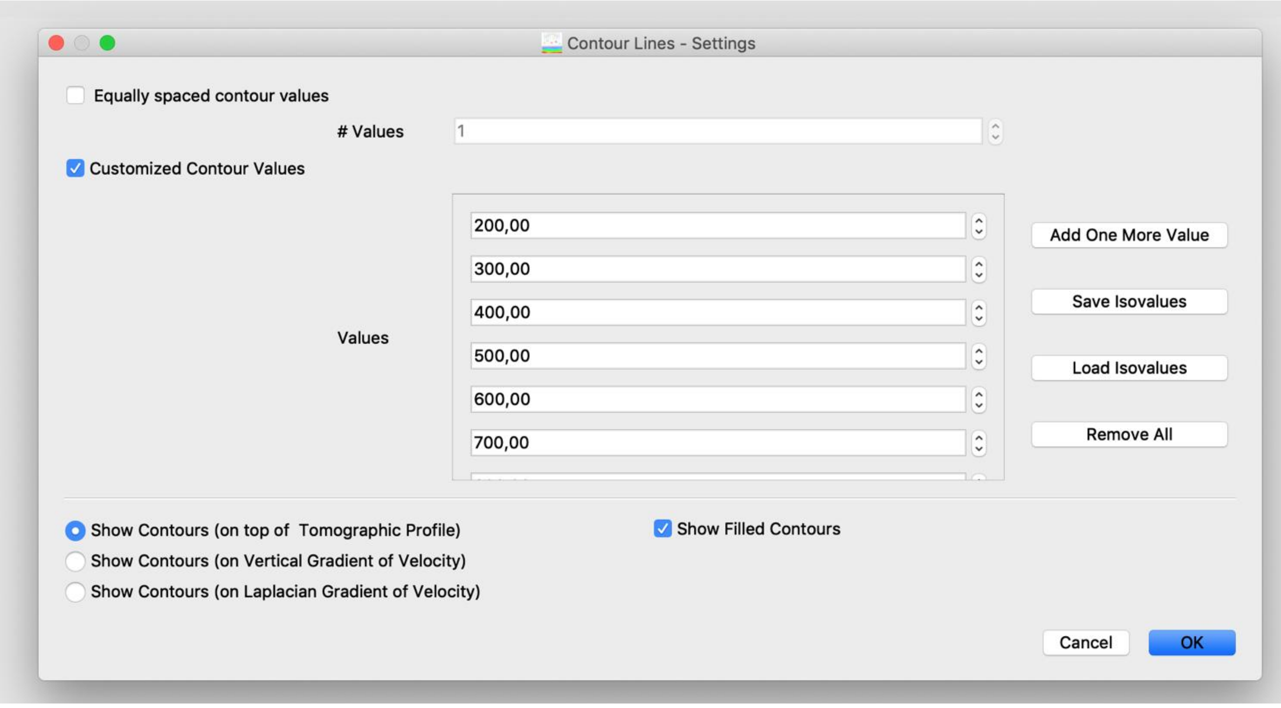
Set color palette		
Menu option: **View/Palette**	Keyboard shortcut: **-**	Toolbar: 



20 Setup of color palette dialog

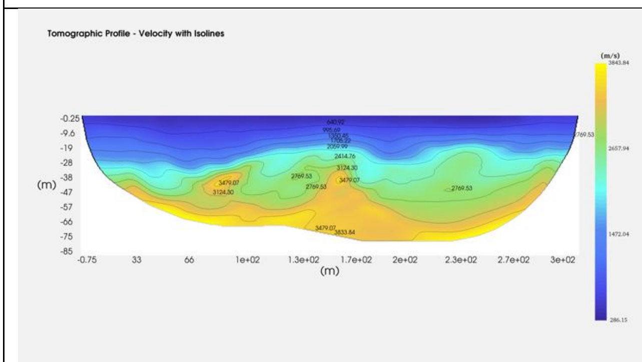
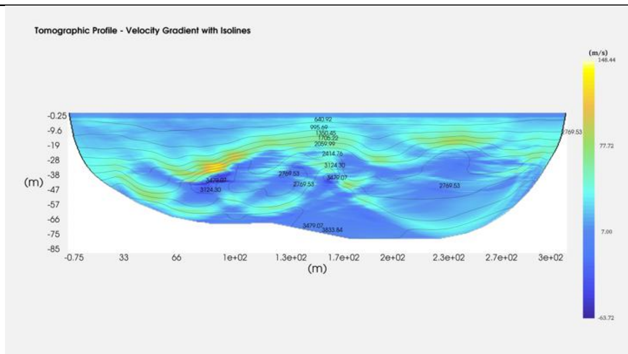
SmartTomo has a set of color palettes that can be used as they are or modified by the user. Any new created color palette can be saved and reloaded in other projects so that the color scaling can be kept coherent among different surveys.

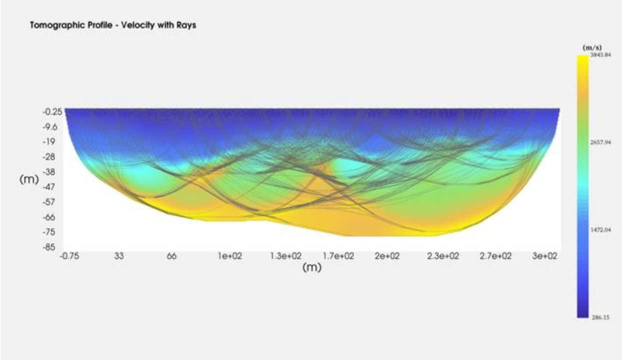
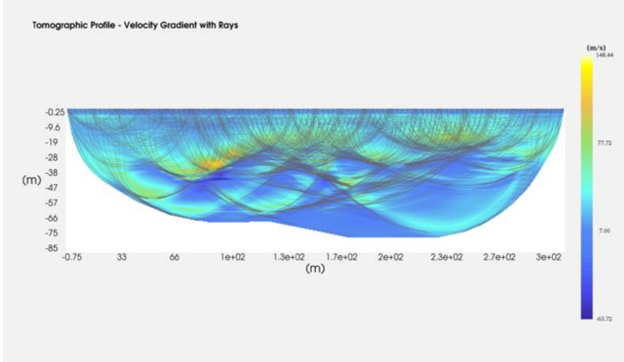
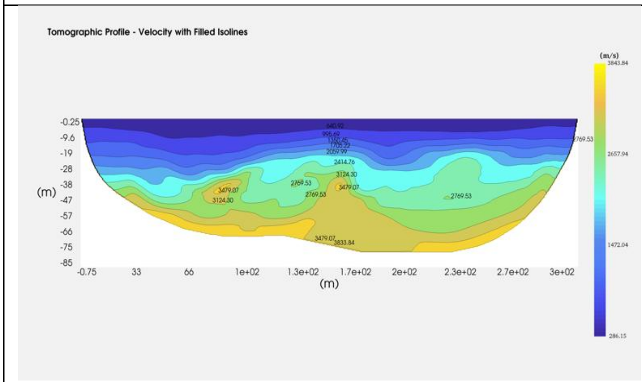
Set contour line		
Menu: **View/contour line**	Keyboard shortcut: **-**	Toolbar: 



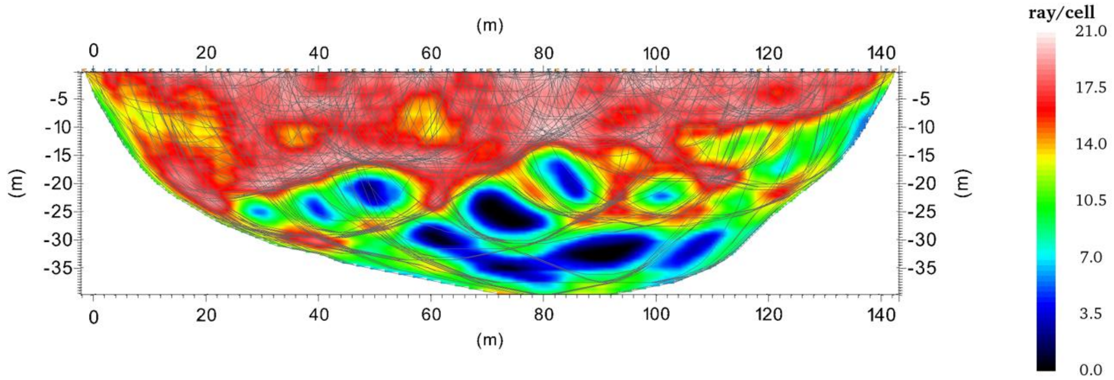
21 Contour lines settings dialog.

The contour line can be displayed either at equal spacing values or at customized values. Customized values of contour lines can be saved in a CSV file to be further reloaded in different projects (I.e. to set the same isovalues).
The contour lines are always referred to seismic velocity, but they can be visualized on different plots, such as the vertical gradient of velocity and the Laplacian gradient of velocity. The user can select different views of the tomogram. Available options are: 1) velocity gradient; 2) Laplacian gradient; 3) the classic velocity profile.

Velocity profile	**Vertical or laplacian Gradient of velocity**
	
Velocity profile with isolines	Gradient with isolines

	
Profile with seismic rays	Gradient with seismic rays
	NA
Profile with filled contour	

Information density layer



22 Example of profile representing information density layer.

The information density profile is a representation of how many seismic rays pass through each cell. This information allows you to assess how much the tomographic profile has been influenced by the measured data. The portions characterized by a higher density of seismic rays are the areas where the solution was calculated using more constraints. In contrast where it is low or equal to zero it means that the resulting profile was determined using a low number of conditions or, at least, matches initial model without having received updates.

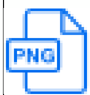
It can be displayed with rays in overlays, or with velocity isolines if already displayed on a previous view.

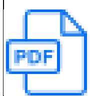
Exporting results.

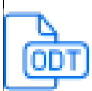
All plot views can be exported in different formats from the “Export” sub menu or from specialized toolbar buttons.

Export the grid of velocity (i.e. to Surfer or Voxler)		
Menu: **File/Export/Gridded data**	Keyboard shortcut: **-**	Toolbar: -

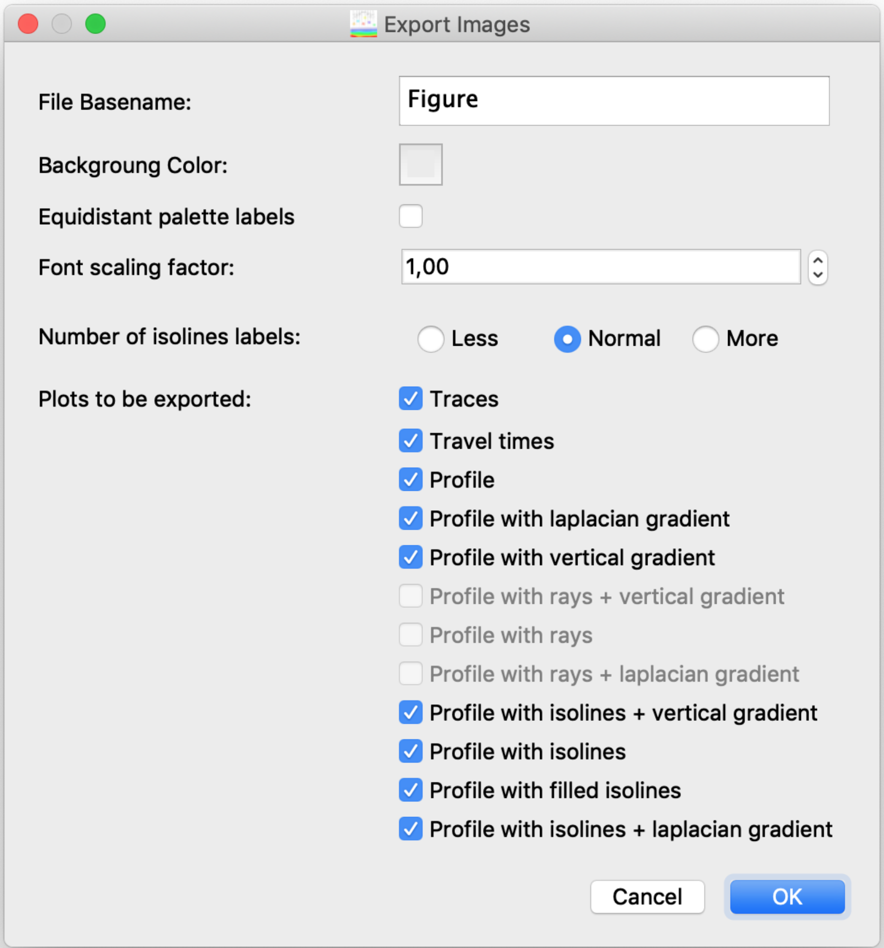
Export KML (Tomography profile or seismic line to be open with Google Earth)		
Menu: **File/Export/KML**	Keyboard shortcut: **-**	Toolbar: -

Export PNG (Images)		
Menu: **File/Export/Images**	Keyboard shortcut: **-**	Toolbar: 

Export PDF (Document)		
Menu: **File/Export/PDF**	Keyboard shortcut: **-**	Toolbar: 

Export ODT (Libre office/Open Office Document)		
Menu: **File/Export/ODT**	Keyboard shortcut: **-**	Toolbar: 

Profile Screenshot PNG (Document)		
Menu: **File/Screenshot**	Keyboard shortcut: **-**	Toolbar: 



23 The export dialog. From this window the user can select which plots to export