Introduction to OpendTect

dGB Earth Sciences - OpendTect version 4.6

Prepared for:

Training Manual
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1 About OpendTect

OpendTect is a complete seismic interpretation software package in an open source environment. It enables the user to process, visualize and interpret multi-volume seismic data using attributes and modern visualization techniques such as RGB-Blending and Volume Rendering.

OpendTect is released under a triple licensing strategy:

- GNU / GPL license
- Commercial license
- Academic license.

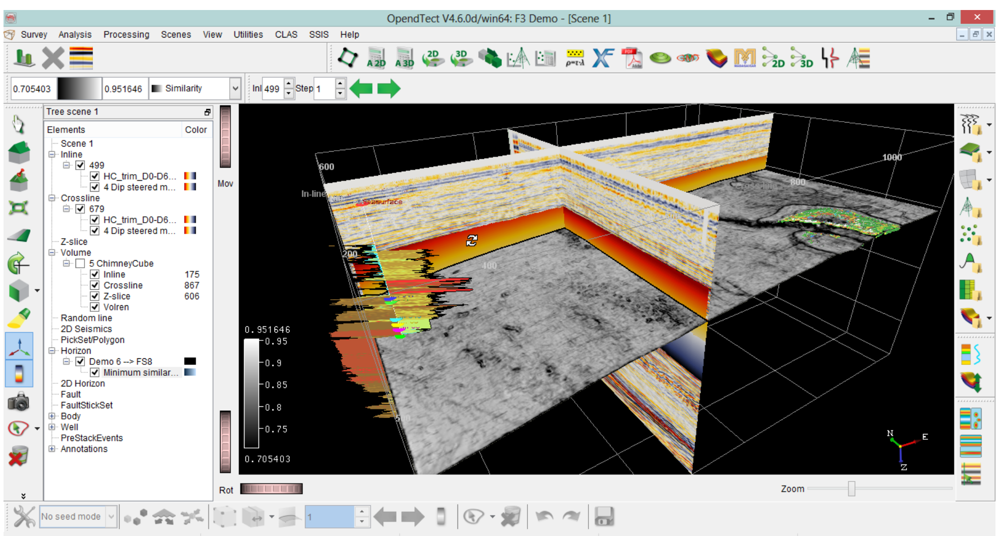
Under the GNU / GPL license, *OpendTect* is completely free-of-charge, including for commercial use. The commercial license enables the user to extend the software with (closed source) commercial plugins that can either be purchased or leased. Under the academic license agreement universities can get free licenses for *OpendTect* and commercial plugins for R&D and educational purposes.

1.1 OpendTect

As stated in the previous section, OpendTect itself is the open-source base software, into which the closed-source plugins attach.

1.1.1 Visualization

Seismic interpreters must be able to quickly scan through multiple volumes of data and combine information to get the optimal view of any geological feature of interest. Therefore, data processing and visualization are rigorously integrated in *OpendTect*. In visualization, elements can be moved freely through data space to interactively analyze data from stored volumes, or data calculated on-the-fly. Volume Rendering and RGB Blending are supported for visualization and better understanding of the data and better interpretation of the results.



1.1.2 Seismic Attributes

OpendTect has a broad attribute engine, with a large variety of purposes. Attributes are used for filtering of the seismic data, for object detection and visualization. *OpendTect* is designed to provide the utmost transparency for the interpreter and attribute-results can easily be optimized using interactive workflows.

1.1.3 Horizon & Fault Interpretation

OpendTect supports various horizon-tracking algorithms, standard amplitude & similarity horizon tracking, step-wise tracking which first tracks the areas that have a minimal amplitude difference with the picked seeds and allows for a greater difference in subsequent steps. This results in a better horizon that requires less editing. *OpendTect* 4.6 comes with HorizonCube (Commercial plugin), which uses a dip-steering multi-horizon auto-tracker that can also be used to track single horizons from user picked seeds.

1.1.4 Well Tie

The *synthetic to seismic well-tie* module enables the interpreter to correlate well information (logs) to the seismic. This allows the comparison of well-based with volume-based data. Deterministic wavelet extraction is supported in this module.

1.1.5 Time to Depth Conversion

OpendTect supports on-the-fly *TD (or DT) conversion* and batch processing of volumes and horizons. An existing velocity model can be used, or created with the volume builder.

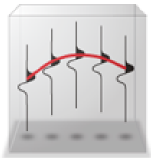
1.2 OpendTect Plugins

OpendTect uses commercial and non-commercial plug-ins. Commercial plug-ins are available for more specialized and advanced tasks. dGB and 3rd party vendors ARKCLS, Earthworks, Sitfal and ArkEX provide commercial plug-ins for OpendTect. See the '*All Plugins*' tab on our website products page: http://www.dgbes.com/index.php/products.html

1.2.1 dGB Plugins

As well as creating the open-source OpendTect software itself, dGB Earth Sciences also develops closed-source plugins for the OpendTect base. See:http://www.dgbes.com/

1.2.1.1 Dip-Steering



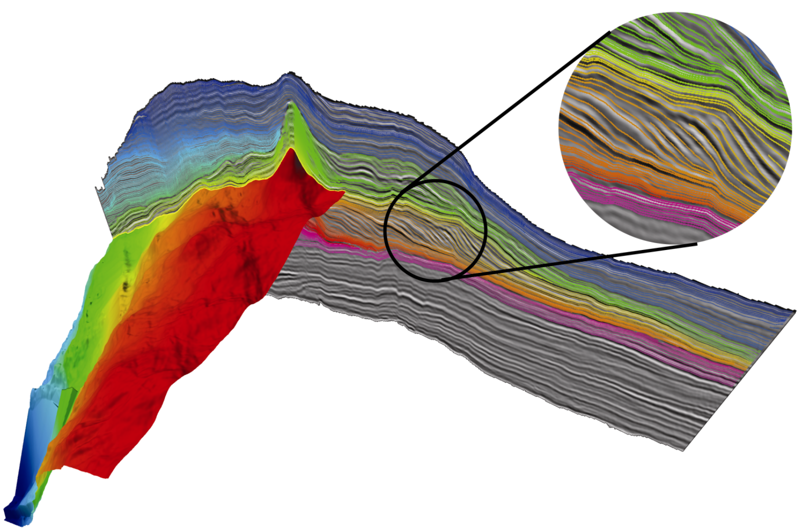
The *dip-steering* plug-in (by dGB) allows the user to create a (dip-) SteeringCube which contains local dip and azimuth information of seismic events at every sample location. The cube is essential for *structure-oriented filtering (aka dip-steered filtering)*, and improves resolution of numerous multi-trace attributes (e.g. *Similarity*) by honoring and following dipping reflectors. It also features unique attributes like *Curvature* and *Dip*. Finally, a SteeringCube is an essential input to the *HorizonCube*

1.2.1.2 HorizonCube

The *HorizonCube* plug-in is developed by dGB. A HorizonCube consists of a dense set of correlated 3D stratigraphic surfaces. Each horizon represents a (relative) geologic time line. Horizons are created either in a model-driven way (stratal / proportional slicing, parallel to upper / lower), or in a data-driven way via a unique dip-steered multi-horizon auto-tracker.

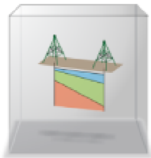
HorizonCubes impact all levels of seismic interpretation. They are used for:

- Detailed geologic model building,
- Low frequency model building for seismic inversions
- Well correlation
- Sequence stratigraphic interpretation system (SSIS).



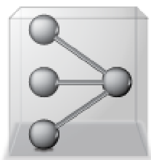
HorizonCube displays a dense set of auto-tracked horizons.

1.2.1.3 Well Correlation Panel (WCP)



The *Well Correlation Panel* plugin (by dGB) is used for picking well markers and correlating markers guided by seismic evidence. In combination with the *HorizonCube*, the interpreter can use the slider for detailed seismic-steered correlations.

1.2.1.4 Neural Networks



The *Neural Network* plug-in (by dGB) supports *Supervised* and *Unsupervised Neural Networks*. The main application of Unsupervised NN is clustering of attributes and/or waveforms for seismic facies analysis. The Supervised approach is used for more advanced seismic facies analysis, to create object "probability" cubes such as TheChimneyCube® and TheFaultCube® and is used for inversion to rock properties (e.g.: porosity, Vshale, Sw etc.).

1.2.1.5 Sequence Stratigraphic Interpretation System (SSIS)

The *SSIS* plugin (*Sequence Stratigraphic Interpretation System*) (by dGB) is an add-on to the *HorizonCube*. *SSIS* supports full sequence stratigraphic analysis, including automated wheeler transforms, systems tracts interpretation and annotations.

1.2.1.6 Common Contour Binning (CCB)

CCB (by dGB) is a seismic hydrocarbon detection technique where the seismic traces are stacked with respect to the depth of a mapped surface. The objective is to detect subtle hydrocarbon related seismic anomalies and to pin-point gas-water, gas-oil, oil-water contacts.

1.2.1.7 Velocity Model Building

The *VMB* plug-in (by dGB) is used to pick up RMO velocities from pre-stack Common Image Gathers. RMO velocities are used to update the 3D velocity model in PSDM workflows. VMB supports picking on semblance gathers and picking of pre-stack events for input to the PSDM- Tomography plug-in. Two VMB modules are supported: Vertical update and Horizon update. Models are constructed from combinations of gridded/smoothed RMO velocities, interval velocities and 3D body velocities (e.g.

Salt body velocity).

1.2.1.8 SynthRock

The *SynthRock* plug-in (by dGB) is a forward pseudo-well modeling and probabilistic inversion package supporting wedge models, stochastic models, pre- and post-stack synthetic seismograms and cross-matching (HitCube) inversion.

1.2.2 ARK CLS Plugins

ARK CLS make the following commercial plugins for OpendTect. See: http://ark-cls.com/

1.2.2.1 Workstation Access

The *Workstation Access* plug-in (by ARK CLS) is used for direct data access to and from SeisWorks and GeoFrame-IESX.

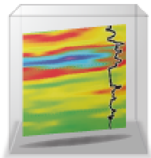
1.2.2.2 Seismic Spectral Blueing

The *Seismic Spectral Blueing* plug-in (by ARK CLS) is a technique that uses well log data (sonic and density) to shape the seismic spectrum in order to optimize the resolution without boosting noise to an unacceptable level.

1.2.2.3 Seismic Colored Inversion

Seismic Colored Inversion (by ARK CLS) enables rapid band-limited inversion of seismic data. SCI is rapid, easy to use, inexpensive, robust and does not require expert users.

1.2.2.4 MPSI - Deterministic and Stochastic Inversion



Deterministic inversion (by Earthworks and ARK CLS) includes a 3D model builder for constructing a priory impedance models using well log and seismic horizon data; a 2D error grid generation module for providing spatial inversion constraints and a model-based deterministic inversion module. Even better deterministic inversion results can be obtained if the low frequency model is built in OpendTect's volume builder using HorizonCube input.

Stochastic inversion includes the MPSI (Multi-Point Stochastic Inversion) ultra-fast stochastic inversion module for generating multiple geo-statistical realizations and the utilities for processing the multiple realizations to represent the inversion uncertainty for lithology, porosity, saturation or other attributes as probability cubes. This plug-in group also requires the purchase of the deterministic inversion plug-in group.

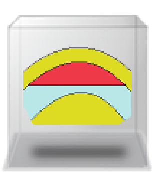
1.2.2.5 PDF 3D

The *PDF3D* plug-in (by ARK CLS) gives the users the capability to produce 3D PDF documents greatly improving communication of complex seismic interpretations. The PDF3D plug-in to *OpendTect* allows volume sections, horizons, and interpretation features to be embedded within a secure technical report.

1.2.2.6 Net Pay

The *Net Pay* plug-in (by ARK CLS) is an add-on to Seismic Coloured Inversion to compute net pay and net-to-gross from thin and not so thin reservoirs. Net Pay is based on BP technology.

1.2.2.7 Seismic Feature Enhancement



The *Seismic Feature Enhancement* plug-in (by ARK CLS) is a flat-spot utility that enhances the signal of consistent flat events and reduces the "noise" of the channel reflections.

1.2.3 Geokinetics Plugins

Geokinetics make the following two commercial plugins. See: http://www.geokin-etics.com/

1.2.3.1 PSDM - Kirchoff

PSDM - Kirchhoff (by Geokinetcs) migrates pre-stack Common Image Gathers in depth with a Kirchhoff migration algorithm. Outputs are PSDM migrated gathers and/or stacked volumes. Travel time tables are computed by 3D ray-tracing through the *OpendTect* supplied velocity model. Kirchhoff migration plug-in is controlled by a job deck builder for Ethos seismic processing jobs. Ethos is the seismic processing package of Geokinetics.

1.2.3.2 PSDM - Tomography

PSDM -Tomography plug-in (by Geokinteics) is like PSDM- Kirchhoff plug-in controlled by Ethos, a seismic processing package of Geokin-etics.
PSDM-Tomography is a grid-based tomographic velocity update module. Inputs are a velocity model and picked pre-stack events and/or RMO picks from *OpendTect-VMB*. Output is the updated velocity model. The distribution of the update is controlled by the user, through a control volume, which specifies areas in which the velocity is allowed to change.

1.2.4 Sitfal Plugins

Sitfal provide the following plugin. See: http://sitfal.com/

1.2.4.1 CLAS Lite

The *CLAS Lite* plug-in (by Sitfal) is a petro-physics package that supports log editing and calculation of derived logs such as porosity, saturation, volume of clay and temperature.

1.2.5 ARKeX Plugins

ARKeX license the following plugin for OpendTect. See: http://www.arkex.com/

1.2.5.1 XField 2D

Create 2D/2.5D geological models by integrating potential field data with seismics and other geophysical datasets in a 3D workspace.

1.3 Links to other Open Source Packages

There are two other open source packages that can be plugged into OpendTect. See the following sections for details.

1.3.1 Madagascar

The *Madagascar* link integrates *OpendTect* with *Madagascar*, an open source seismic processing package that is widely used in R&D circles.

1.3.2 Generic Mapping Tool (GMT)

GMT is an open source collection of tools for manipulating Geographic and Cartesian data sets and producing encapsulated postscript (eps.) file illustrations ranging from simple x-y plots via contour maps to artificially illuminated surfaces and 3-D perspectives views.

OpendTect supports a plug-in (Open Source) that uses GMT tools to create scaled maps.

1.4 Installation

OpendTect is supported on PC-Linux 32 and 64 bits, Mac-OS/X and PC-Windows (XP, Vista, 7, 8 32/64 bits). The latest version of *OpendTect* + *plug-ins* can be downloaded from http://opendtect.org/index.php/download.html

The full instructions for installation can be found via this link: http://opendtect.org/rel/doc/User/base/chapter10.4_installation.htm

1.5 Licenses

OpendTect 4.6 is released under a triple licensing strategy:

- under the GNU / GPL license.
- under a Commercial license.
- under an Academic license.

Under the GNU / GPL license *OpendTect* is completely free-of-charge, including for commercial use. The user can select stable or development version of the open source package of *OpendTect* only.

The commercial license enables the user to extend the system with (closed source) commercial plugins that can either be purchased or leased. If you are interested in evaluating the plugins (commercial - closed source), please send an email to info@opendtect.org, so that we can send you a free demo-license key.

Under the academic license agreement, Universities can get free licenses for OpendTect and commercial plugins for R&D and educational purposes. For more information go to dGB's website: http://www.opendtect.org/index.php/download.html

On the page accessed via the above link, you will also find information on how to install the various license types.

2 Documentation, Tutorials, Users Community & Support

There are many options and ways of getting help with *OpendTect's* interactions and workflows. All available options are listed online at http://www.dgbes.com/index.php/support.html .

2.1 User Documentation & Tutorials

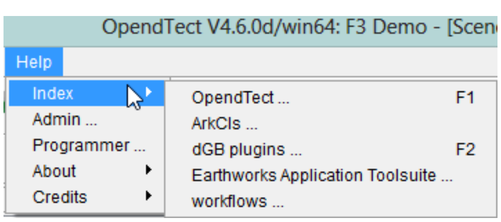
User documentation

The user documentation is structured in the same way as *OpendTect* itself. There are separate documents for *OpendTect* and the plug-ins.

All user-documentations can be accessed in multiple ways:

Online as either HTML or PDF, via http://www.dgbes.com/index.php/support.html

Via the software
The help menu

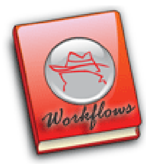


The **Help Icon** in each window will automatically pop-up the most appropriate (sub-)chapter of the user manual.

Tutorials

Via the 'Tutorials' tab on the Support page of the website (http://www.dgbes.com/index.php/support.html), you can find four types of self-study assistance:

Self-study OpendTect Course: This manual is an introduction to all aspects of the software including all plugins (except PSDM and Tomography). The course includes this free training manual, and the F3 Demo dataset that allows free access to the commercial plugins.

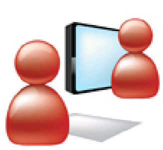


Workflow documentation: This document describes various workflows in OpendTect + plug-ins. We describe the purpose, what software is needed (*OpendTect* only, or *OpendTect* + one or more plug-ins), and how to do it.

Tutorial videos: Here the user can find different tutorial and webinar videos like: Start new project, Horizon tracking, HorizonCube webinar, SSIS interpretation, Dip steered median filter, Chimney Cube etc…

How-to-Manuals: OpendTect workflows are explained here, the pdf version can be downloaded (see link below). Different topics are explained: How to visualize objects in *OpendTect*, Creating a good SteeringCube, Stratal Slicing, Fault Enhancement Filtering, How- To RGB blending etc

2.2 User Mailing List



There is an active User Community. The mailing list *users@opendtect.org* is for sharing information relevant to *OpendTect* users. Anyone on this list can send e-mails to all OpendTect users e.g. to pose or answer questions, suggest workflows, announce innovations etc. Please do not use this mailing list for support questions.

2.3 Support

For support questions please contact OpendTect's support team at:
support@opendtect.org

2.4 Social Media

There are *OpendTect* user groups on Facebook and LinkedIn.

3 About the F3 Demo Dataset

F3 is a block in the Dutch sector of the North Sea. The block is covered by 3D seismic that was acquired to explore for oil and gas in the Upper-Jurassic – Lower Cretaceous strata, which are found below the interval selected for this demo set. The upper 1200ms of the demo set consists of reflectors belonging to the Miocene, Pliocene, and Pleistocene. The large-scale sigmoidal bedding is readily apparent, and consists of the deposits of a large fluviodeltaic system that drained large parts of the Baltic sea region (Sørensen et al, 1997; Overeem et al, 2001).

The deltaic package consists of sand and shale, with an overall high porosity (20-33%). Some carbonate-cemented streaks are present. A number of interesting features can be observed in this package. The most striking feature is the large-scale sigmoidal bedding, with text-book quality downlap, toplap, onlap, and truncation structures. Bright spots are also clearly visible, and are caused by biogenic gas pockets. They are not uncommon in this part of the North Sea. Several seismic facies can be distinguished: transparent, chaotic, linear, shingles. Well logs show the transparent facies to consist of a rather uniform lithology, which can be either sand or shale. The chaotic facies likely represents slumped deposits. The shingles at the base of the clinoforms have been shown to consist of sandy turbidites.

The original F3 dataset is rather noisy, to remove the noise, a *dip-steered median filter* with a radius of two traces was applied to the data. The median filtered data (see chapter 4.6 on filters) was subsequently inverted to acoustic impedance using the industry standard Strata software. A number of horizons were mapped on a loose grid to study the sigmoidal shaped structures. Continuous horizons were created from these coarse grid interpretations by interpolation with an inverse distance interpolation algorithm. Within the survey, four vertical wells are present. All wells had sonic and gamma ray logs. Only two wells (F2-1 and F3-2) had density logs. These logs were used to train a neural network that was then applied to the other two wells (F3-4 and F6-1) to predict density from sonic and gamma-ray logs. Porosity in all cases was calculated from density using the formula: Porosity = (2.65 – Density) / (2.65 – 1.05).

References:

Overeem, I, G. J. Weltje, C. Bishop-Kay, and S. B. Kroonenberg (2001) The Late Cenozoic Eridanos delta system in the Southern North Sea basin: a climate signal in sediment supply? Basin Research, 13, 293-312.

Sørensen, J.C., Gregersen, U, Breiner, M and Michelsen, O. (1997) High frequency sequence stratigraphy of upper Cenozoic deposits. Mar. Petrol. Geol., 14, 99-123.

3.1 Fundamentals

The following chapter describes some of the basic manipulations that you will need to know in order to successfully operate OpendTect. Please see the individual sections below for details.

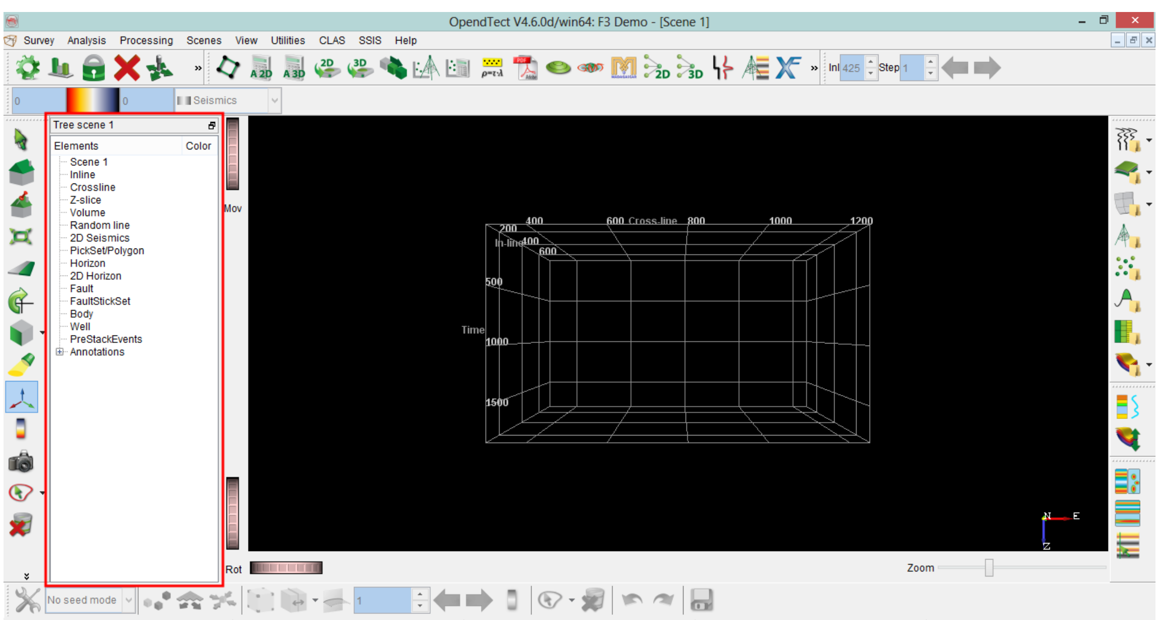
3.1.1 Tree, Scene & Elements

The basic principle of *OpendTect* is that the user only loads or calculates what is needed. Only elements that appear in the tree are currently loaded in memory. This has several advantages over having a tree that is showing elements that are stored on disk:

On one single element, multiple stored volumes can be displayed (up to eight). On-the-fly calculated data (available in memory only) can also be displayed. This enables the interpreter to test attributes and evaluate their parameters before computing the entire volume. This improves results and saves time.

The tree controls what is displayed in the scene. The user can:

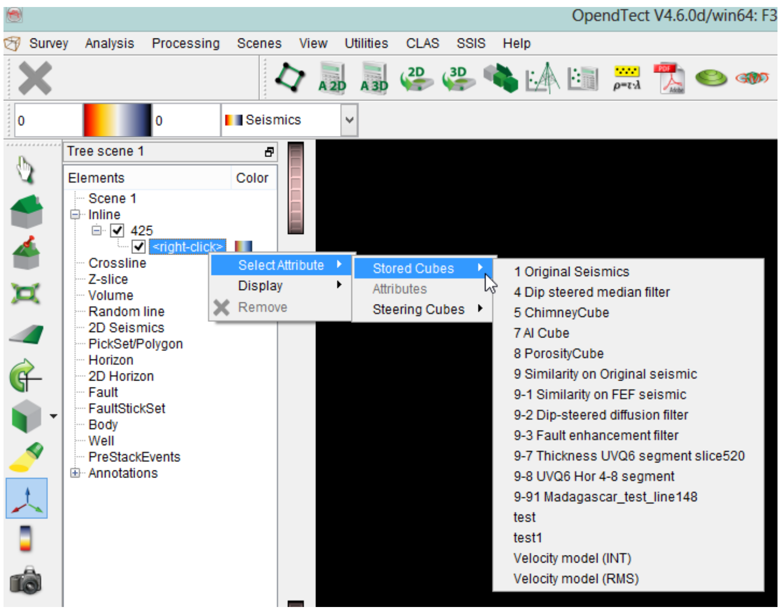
- Display stored data (e.g. seismic, horizons, wells, picksets etc…).
- Calculate attributes on the fly (and display them).
- Create & edit elements (example: create or edit a horizon).

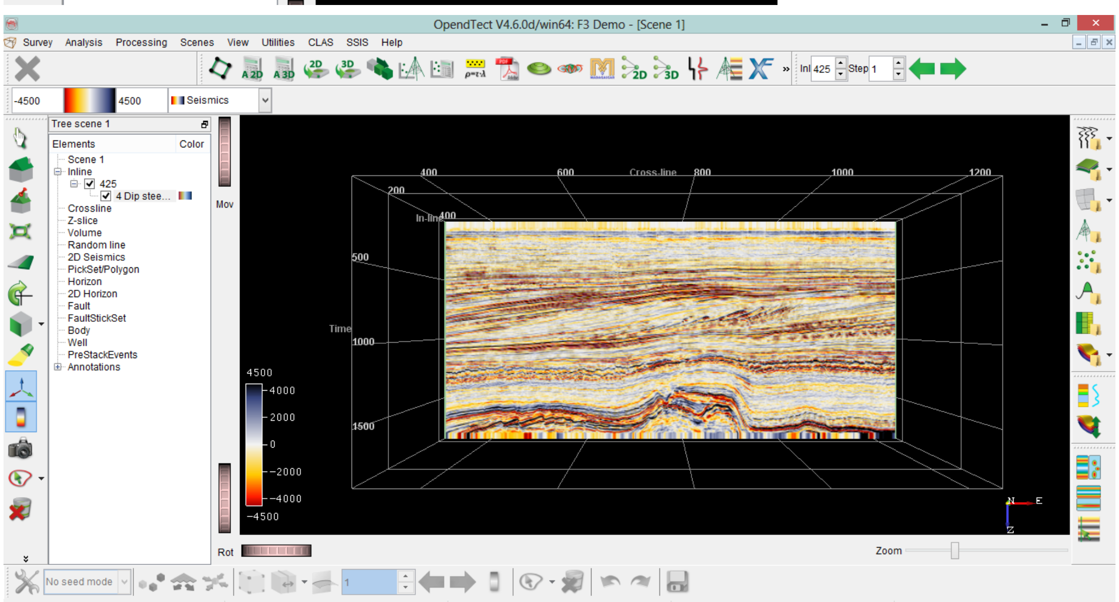


Exercise

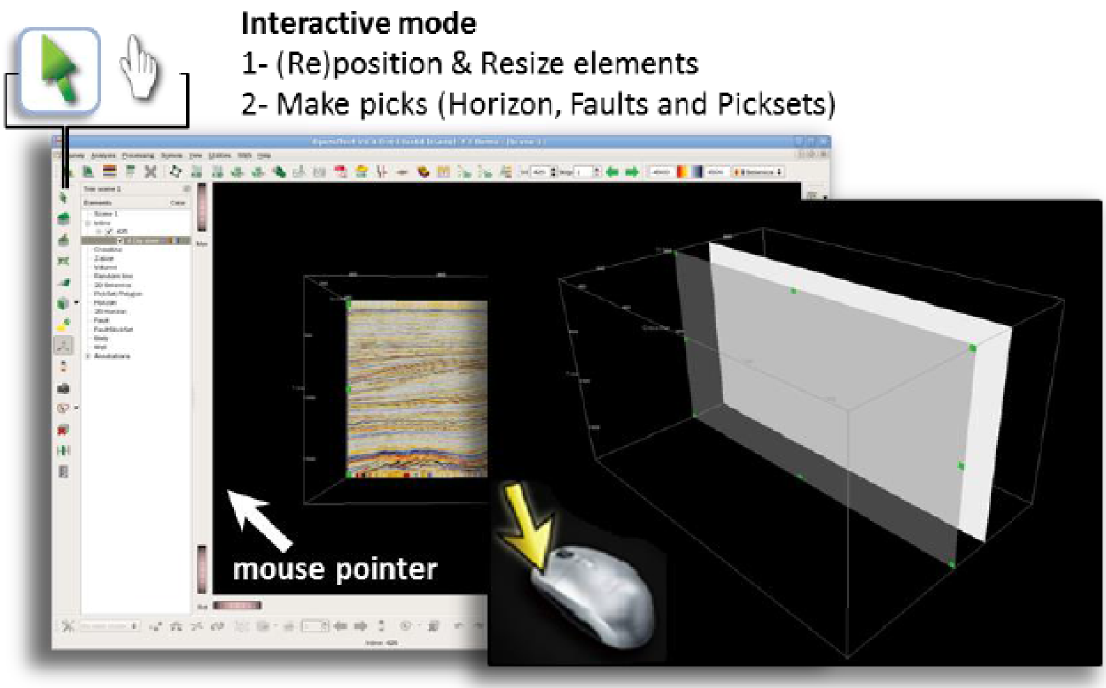
Show the seismic data at an *inline* by doing the following:

1. Click on *Inline* in the tree and select *Add*.
2. Right click on the element *<right-click>*
3. Select *Attribute* > *Stored Cubes*> *"4 Dip steered median filter"*.

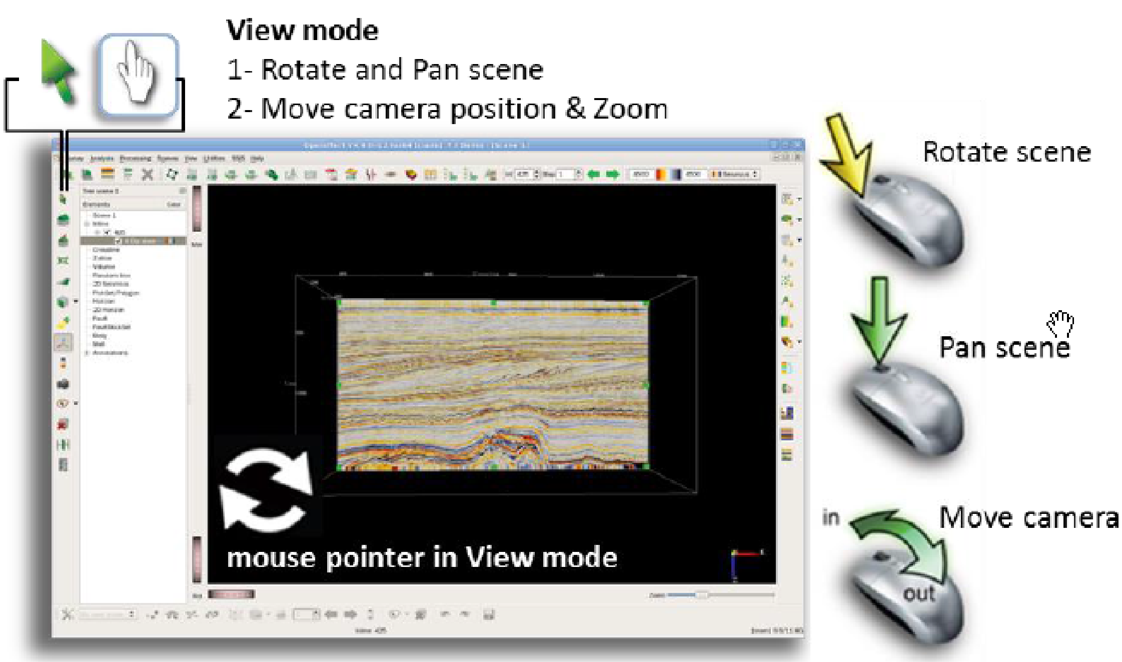




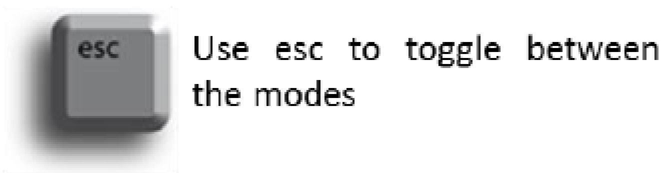
3.1.2 View & Interactive Mode



In *interact mode* elements can be (re)positioned or resized, picks for horizons and picksets can be created.



In *view mode* you can rotate and pan the view. You can also move the camera position and zoom in and out : "*Mov*" moves the camera position back and forth and “*Zoom*” zooms in and out from a fixed camera position. “*Mov*” affects the geometry and angles of the survey box, *Zoom* does not.



Use ‘**Esc**’ to toggle between interact and view modes. The manual has a table describing the different actions in different modes.

Exercise

1. To rotate your display, first select the *View* mode, then left-click and drag the scene. To pan the scene (move the scene horizontally & vertically) press the scroll wheel and drag.
2. Move the camera in and out using the scroll wheel, or fly to an area by using the *Seek*  icon: activate this feature by clicking on it (the cursor becomes a cross) and click in the scene on the point that you wish to become centered in the scene. (Alternatively, do this by typing S and clicking where you want to go). Also try the *Zoom* and *Move* scroll wheel at the side of the display.

3.1.3 Positioning Elements

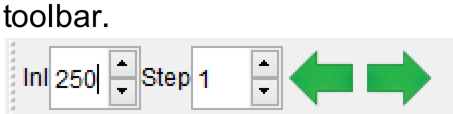
An element can be repositioned in several ways.

Exercise

Option1:

1. Select the Inline in the tree by clicking on the *line-number* (195)

2. Fill in *250* (the new inline position) line number in the *Slice Position* toolbar.



Option 2:

1. Go into *View* mode, rotate the view so you see the inline such that it is displayed 'from its side' or 'end on' as much as possible in the scene.

2. Go into *Interact* mode .

3. Left-click and drag the inline to a new location... release the left mouse button when you have reached the desired new location. The new inline number is displayed in the status bar at the base of the OpendTect window.

4. Now you can either:
- Click in the empty black space to confirm the new data area, the data will then be (re-) loaded automatically.
- Right-click on the slice and select '*Reset Manipulation*' to undo the dragging of the slice.

Option 3:

1. From the tree, right click on the updated *inline-number* and select *Display* > *Position* option in the pop-up menu list.

2. *Position* the Inline at *195*.

Option 4:

1. Scrolling: Right-click on an inline and select *Display* > *Position*, by pressing the *Scroll* button, elements are moved either manually (select Control *Manual*) or automatically (select Control *Auto*)

2. Keyboard shortcuts exist to move slice forward/backward with the step defined in the box above the tree. To know what are these short-cuts and optionally change then, follow *Utilities* > *Settings* > *Keyboard shortcuts*. The default shortcuts are the keys *X* and *Y* to move forward and backward respectively (the inline number must be highlighted for these keys to have effect).

3. For fast scrolling use the volume viewer by doing the following:

a. In the element tree right-click on **Volume** and select *Add*. This will insert an empty element in the tree.
b. Select a stored volume: right-click on *<right-click>* and choose *Select Attribute > Stored Cubes > 4 Dip steered median filter*.
c. In *interact* mode, click and drag an inline/crossline/z-slice, you can then go quickly through the all volume.

Look at what you have from all sides. Note the different actions when you are in *View* mode or in *Interact* mode. Also note that the data values are read out and displayed in both methods, these values are displayed at the bottom of the screen.

Show **crossline 1000** in a similar manner.

Exercise

Show a part of a **Z-slice at 700 ms** TWT by doing the following:

1. Right-click on *Z-slice* and select *Add*.

2. Go to *View*  mode, rotate the view so you see the Z slice from above.

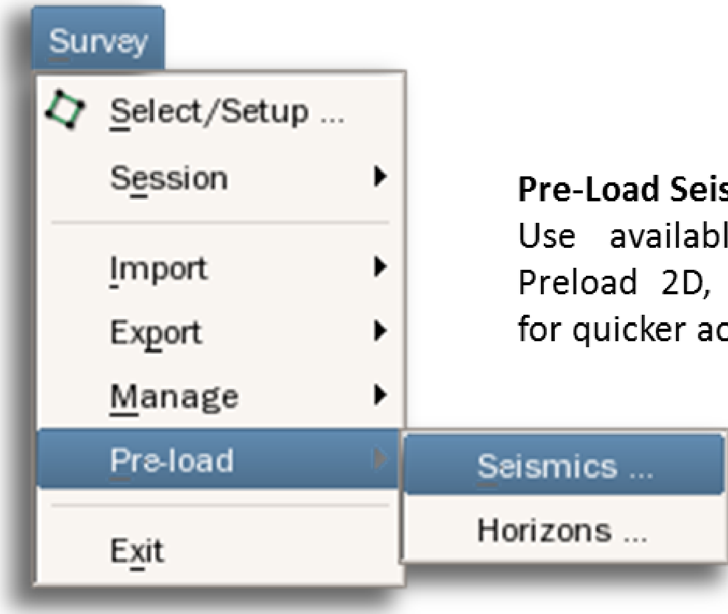
3. Go to *Interact*  mode

4. Make the frame smaller by dragging the green handle points of the frame. (If the handles are not apparent when you are in Interact mode, click on the relevant slice to 'activate' them.)

5. Click in the empty black space to confirm the new data area, the data will then be (re-) loaded automatically. (Or '*Reset Manipulation*')

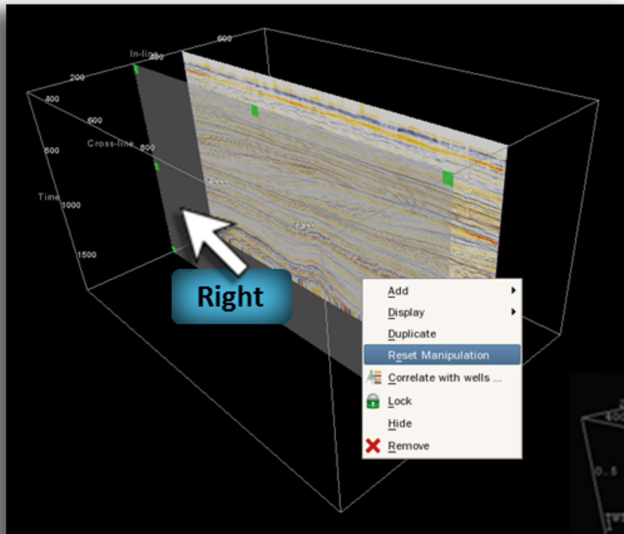
6. Position the frame at 700 ms and select the *“4 Dip steered median filter”* data volume.

Tips & Tricks

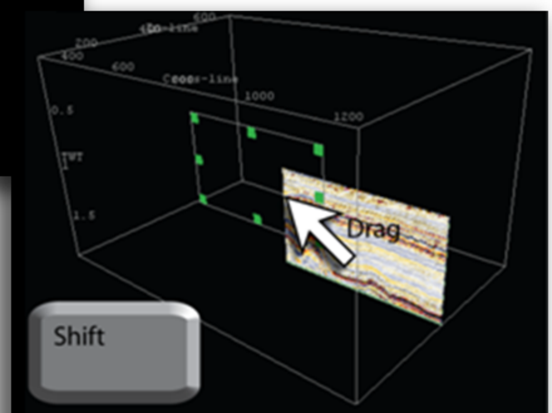


Pre-Load Seismic
Use available memory installed: Preload 2D, 3D, pre-stack seismic for quicker access

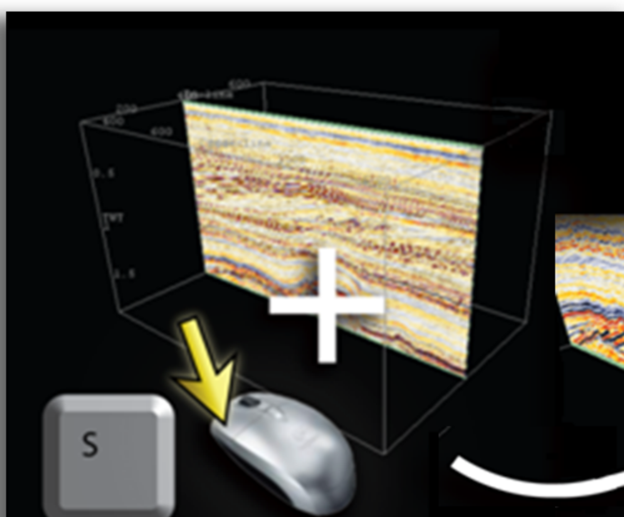
Tips & Tricks

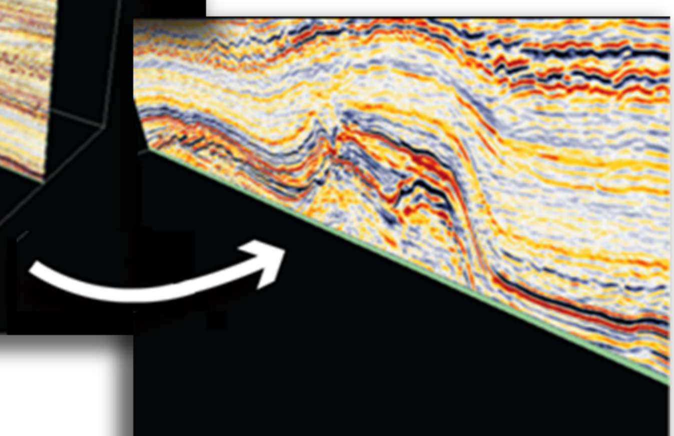


Undo positioning of an element
Right click on the element > Reset Manipulation



Lateral positioning of an element
Type Shift + click & drag the element





Fly-in
Type S then click where to fly

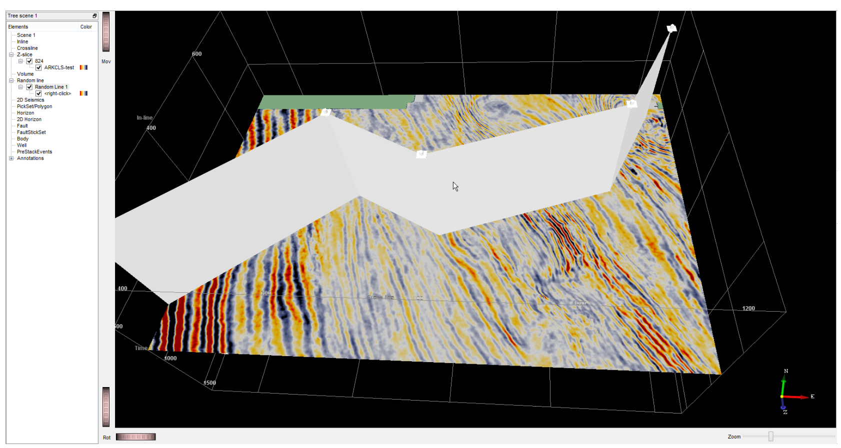
Show a **random line**:

1. Add an empty time-slice in the scene:

    a. Right-click on **Random line** element from the tree and select *New > Interactive*.

    b. Use the left mouse button to draw on the time-slice nodes of random line. You may use a freehand line or by clicking on the time-slice to insert nodes. When this is finished, click outside the survey area and the software will prompt you for the data.

2. You can interactively move the nodes as follows: Select *Interact* mode, you will see the end nodes at all corners of the random line element. A node consists of a little vertical cylinder and a horizontal plane:

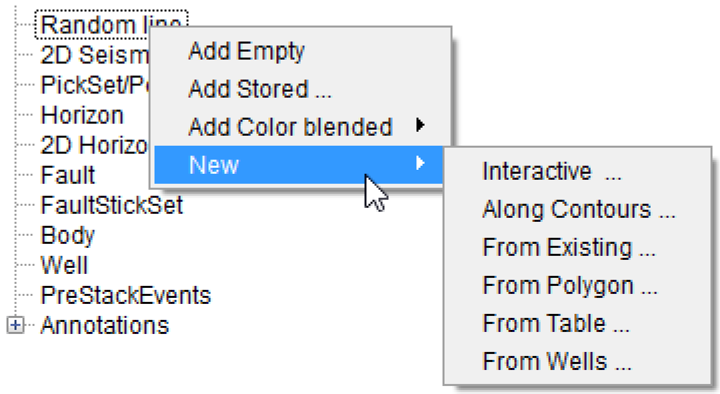


3. Right-click anywhere on the random line, select *Display > Insert node* – before node 1 to create a new node at that position.

4. The time range can be edited by dragging the cylinder of the nodes up and down, the lateral position can be edited by dragging the little plane of each node.

5. Click somewhere in the black area to confirm the position, and select the data to be loaded on this random line. Loading may be slow due to the random data access that is needed to retrieve all necessary data.

Other ways to create random lines are:



Create From Wells: A random line can be created in such a way that it follows well paths. By right clicking on the random line in the tree, and selecting *Create from wells*, a dialog box appears with a list of wells that can be selected in order to set up the random line path. This option is useful for the Well Correlation Panel.

Exercise

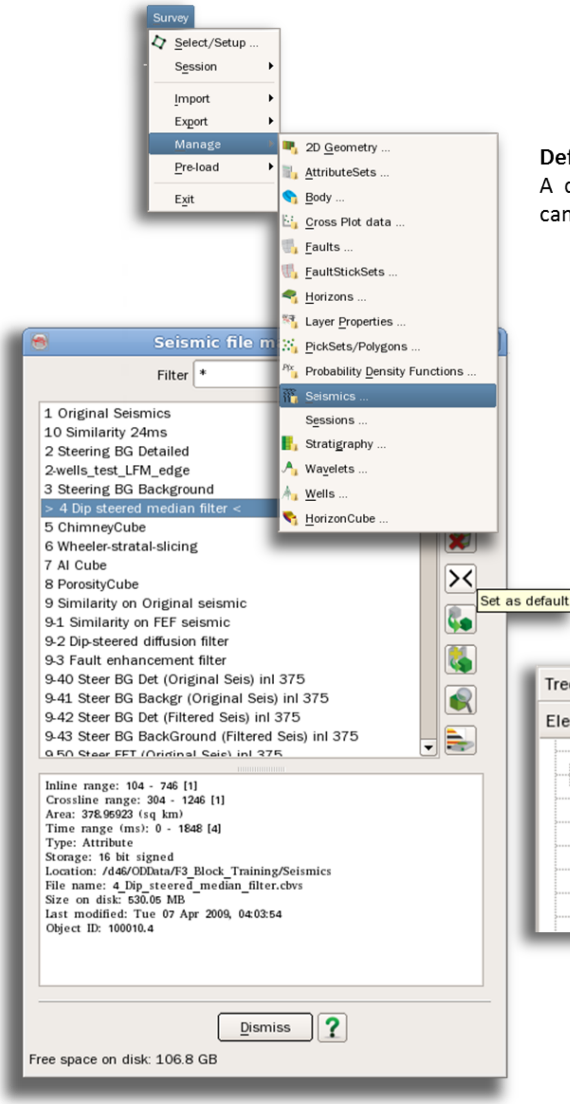
Right-click on Random line (*Random line > New > From Wells...*). Select all four available wells, change the well's order accordingly, (e.g. F03-4, F03-2, F02-1, F06-1) and give a name to your newly created Random line then save it.

Along Contours: allows the generation of random lines between specified contour range. For this, an interpreted horizon grid will be required as contours.

From Existing: This option allows the generation of a random line from an existing random line. There is an option available to generate a random line at some distance away from an existing random geometry and store it in a new random line geometry.

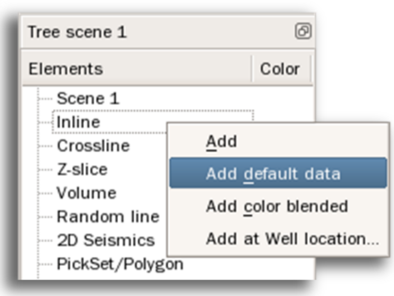
From Polygons: allows creating a random line definition from previously created polygons.

From Table: allows creating a randomline in defining its nodes in a table. Each node is defined by its x/y coordinates and Inline/Crossline information.



Default data

A default seismic volume, horizon, etc… can be set for quick display purposes.



3.2 Attribute Analysis

Seismic attributes are all the measured, computed or implied quantities obtained from the seismic data. Seismic attributes can be used for several purposes:

- To quantify a specific property (example: Porosity prediction)
- For object detection: isolate and visualize a seismic feature (example: Faults)
- To filter data (example: Low pass filter)

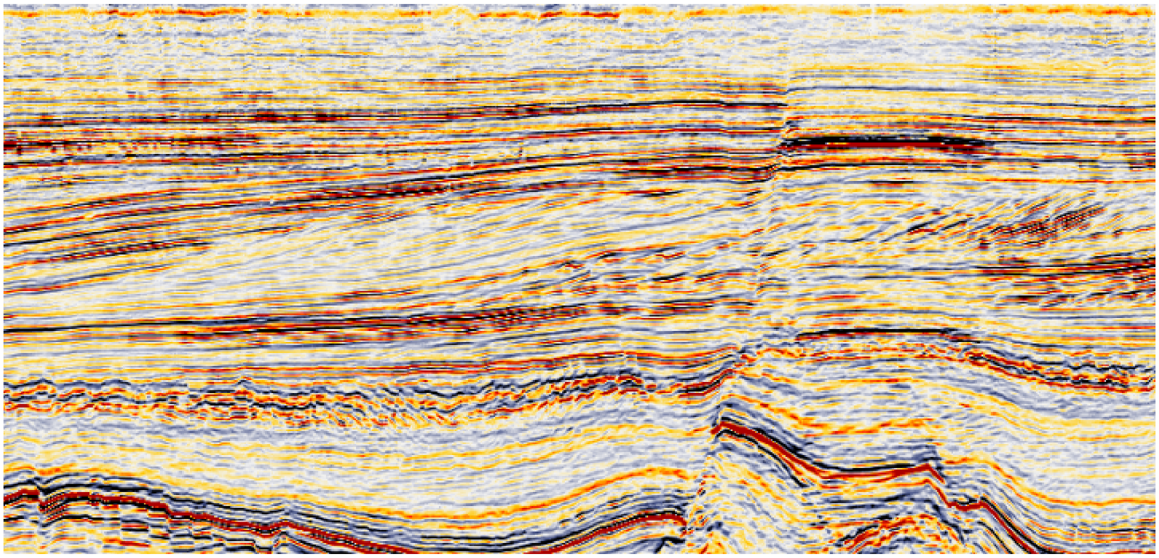
The Attribute engine is very elaborate and contains many standard and unique attributes. It has been designed for both 2D and 3D types of surveys. The transparent and interactive way in which attributes are used, sets *OpendTect* apart from other packages.

The standard workflow for attribute analysis comprises 4 basic steps:

- Display a representative seismic line that contains the object of interest (e.g. Faults).
- Define attribute definition or use one of the default attribute sets.
- Test the attribute parameters on the fly (in memory) in a movie-style way.
- Apply the attribute on-the fly to specific elements in the tree. After you are satisfied with the result, compute a new attribute volume in batch mode.

3.2.1 Bright Spot Detection and Visualizaton

On inline 250, you can see an amplitude anomaly (bright-spot) close to the fault plane. In order to study this feature we will isolate and visualize it using seismic attributes in 3D.



Bright-spot visualized at inline 250

Exercise

1) Define Attribute
In order to define an attribute, launch the attribute set window by clicking on the Attribute 3D  icon.
For example, create an *Energy* attribute as follows:

1. Select attribute type *Energy*.

2. Set input data to be the seismic volume "*4 Dip steered median filter*".

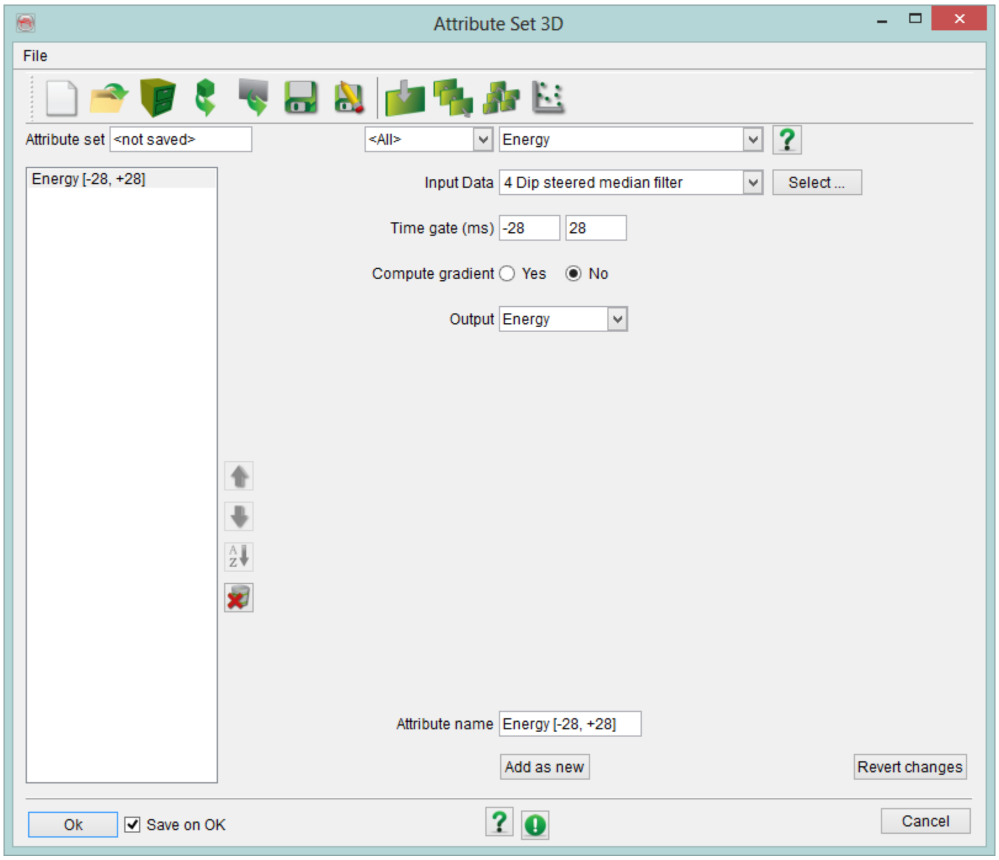
3. Use the default time gate from [–28, +28] ms.

4. Provide a name. There is no restriction on the length of the name: it may contain spaces. It is recommended to use a name that contains all essential information of the attribute. It helps you remember what this attribute does, and prevents having to go back to this attribute window to see the exact definition of the attribute.

5. Press *Add* as new. Not pressing *Add* as new does not add the attribute, but updates the current attribute to this new definition. This would result in an attribute that does not correspond to its name. Therefore, always remember to press *Add* as new when you have created a new attribute.

6. Press *OK* on the bottom left, then *Save* the attribute set.

7. Provide a (new) name for the attribute set. Type a *new name* like '*My first attributes*' press Select. This saves the current attribute set and takes you back to the main window.



Attribute Energy

Your defined attributes are now available. As an exercise, try to describe or sketch in a conceptual sense what the attribute you just created actually calculates. Click directly on help button on the attribute engine or consult the *OpendTect Help* function to see if you got it right.

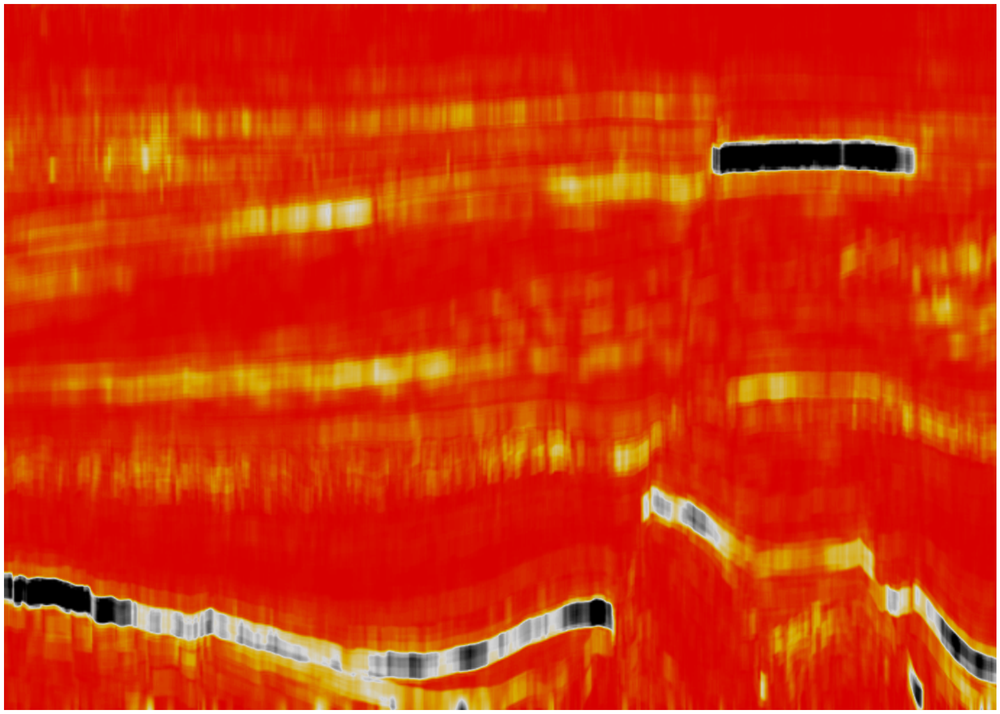
Exercise

2) Display attribute

Try the following:

1. Add an extra layer to inline 250 by right-clicking on the inline number in the tree > *Add* > *Attribute*

2. The attributes available are organized in three categories: Stored, Steering and Attributes (from the active attribute set and calculated on-the-fly). In the Attributes section, select your attribute *Energy[-28,+28] ms*. To change the selected attribute, right-click on the listed attribute > *Select attribute* > *Attributes*, and select your attribute

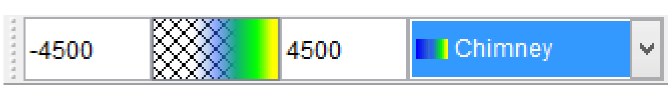


Attribute 'Energy' clearly discriminates the bright-spot (inline 250, at 530ms)

Exercise

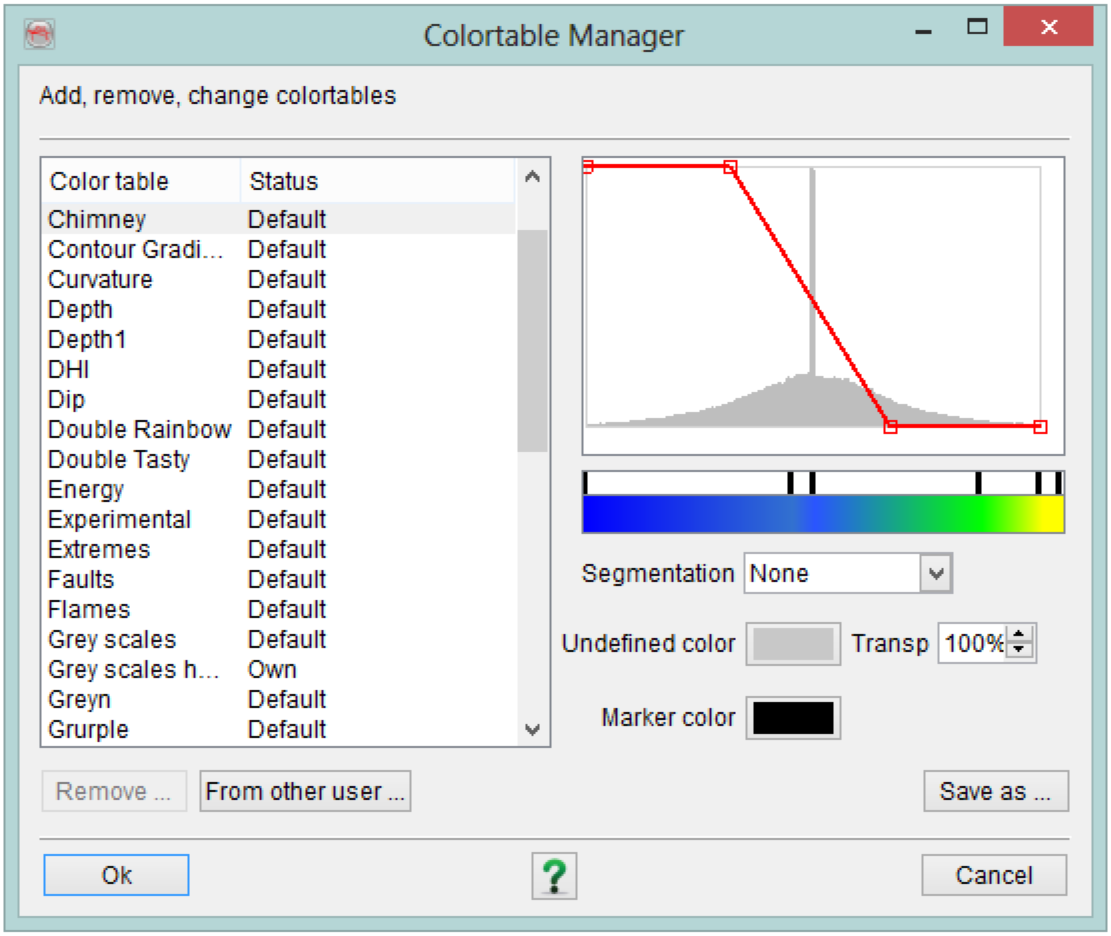
3) Color-bar

Visualizing the results is almost as important as the results themselves. Therefore, try different color-bars for your attribute. Each attribute layer has its own color bar.



1. First select the attribute from the tree, then change the color-bar (try: chimney, faults & grey scales).

2. Right-clicking on the color bar, a menu pops up which allows you to flip the color bar, change the *Ranges/Clipping* (to set the scaling values symmetrical around zero as shown above), *Manage* the color bar, etc.



Color-bar Manager

In the color-bar manager, you can edit the colors in double-clicking or right clicking on the black markers below the histogram. The right-click menu allows to change but also remove the colors but also to edit the position and the colors of the markers. The color-bar can be continuous or segmented. When changing *Segmentation* from None to fixed, you define the number of segment. Segmented color-bar are useful when displaying discrete attribute like Neural network result (one color corresponding to one class). Also the transparency can be modified in moving the red line on the histogram. The changes you are making are applied in the same time in your scene so you can actually QC the color-bar edition. Another possible manipulation is, using the 'red line' in the colortable manager window, to alter the parts of the spectrum that are displayed. Double-clicking on the line inserts another moveable node. The color-bar can be saved with another name.

Exercise

4) Evaluate attribute parameters

Now we are going to optimize the energy attribute by interactively (movie-style) evaluation of its parameter settings:

1. First, select an attribute in the tree.

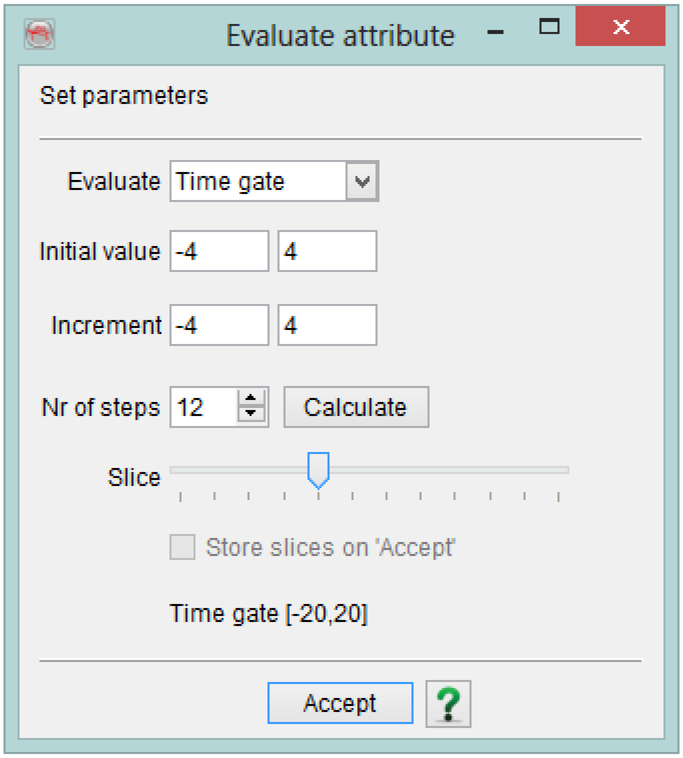
2. In the Attribute Set window, select the Energy attribute and press the 'Evaluate attribute' icon.

3. Provide the parameter variations as depicted below and on pressing Calculate all intermediate parameter settings are evaluated.

4. When the calculation is completed, use the slider in this window to switch quickly from one display to the next. In this way you can movie-style inspect the impact of a parameter change on the attribute.

5. When a small time gate is chosen, the attribute response is scattered, while a large time gate gives a smeared attribute response. Choose the time gate such that is an optimal balance between the two.

6. On pressing Accept the current parameter setting is accepted and the attribute definition in the attribute set window is updated accordingly.



Evaluate 'time gate' window

5) Create a seismic output

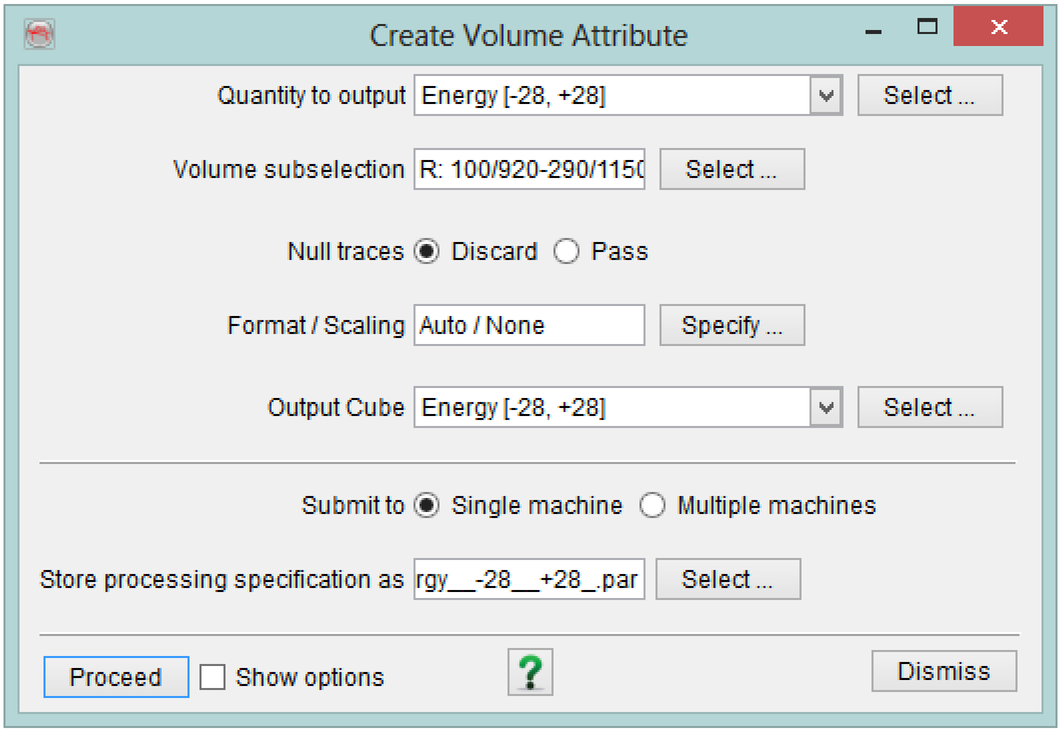
So far, everything was done in memory. It means that each time you are displaying the attribute on a different element OpendTect has to first calculate it on-the-fly. Calculating the attribute every time is much slower than calculating it once for the complete volume (or sub-volume) and then retrieving the stored attribute. Therefore we are now going to calculate and store the Energy attribute on disk.

Exercise

1. Click the Create Seismic Output button or go to *Processing* > *Create Seismic Output* > *Attribute* > *3D…*

2. Select *Energy* as the *Quantity to output*.

3. Select a sub-volume: Inline range (100 – 290), Crossline range (920 – 1150), Time range (448 – 600)ms.



Volume output window

6) Volume Rendering

The last step of this exercise is to fully visualize the bright-spot in 3D:

1. Right-click on *Volume* and select *Add*. It will insert an empty volume in the tree and scene.

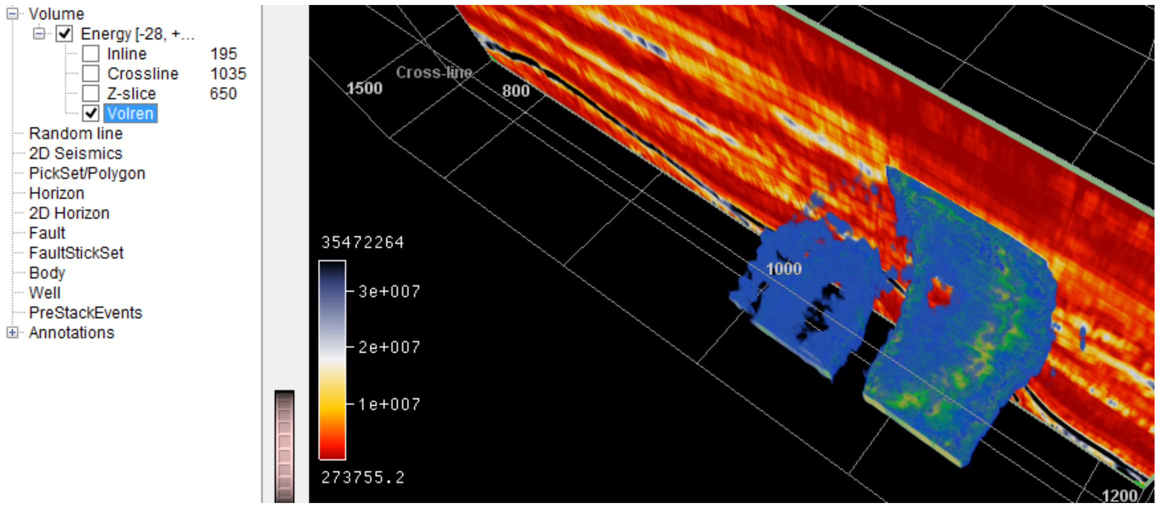
2. Position the volume: Right-click on *<right-click > >Display > Pos-ition*. It will launch a position dialog. Fill in the ranges:

   a. Inline range: 100 – 290
   b. Crossline range 920 – 1150
   c. Time range: 448 – 600

3. Select '*Energy*' from the '*Select view data*' window.

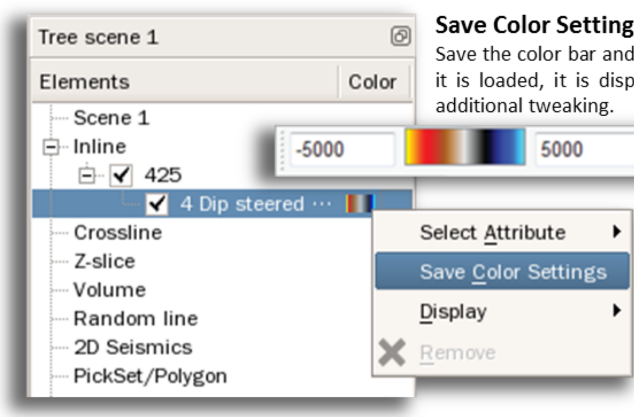
4. Change the color-bar to '*Chimney*'.

5. Deselect *Inline*, *Crossline*, *Z-slice* of the Volume in the tree, and select *Volren**.

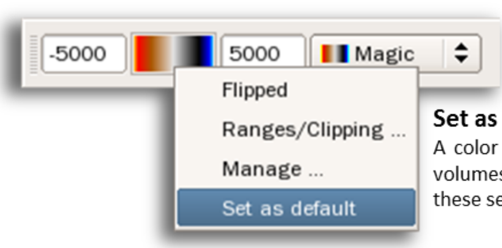


Visualization of the bright-spot using the volume rendering
(* Volume Rendering)

Tips & Tricks



Save Color Settings
Save the color bar and clipping for a given stored seismic volume. Each time it is loaded, it is displayed with the preferred settings without need for additional tweaking.



Set as default
A color bar can also be defined as default for all stored and not stored volumes. Each time an attribute is loaded in the scene, it is displayed using these settings if no display settings have been previously assigned to it.

3.2.2 Spectral Decomposition

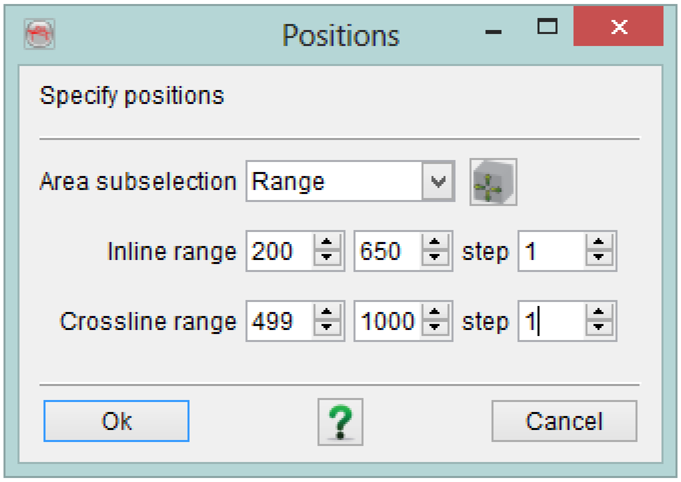
Spectral decomposition is used to study seismic data at a sub-seismic resolution or to study attenuation effects caused by hydrocarbons. The method produces a continuous time-frequency spectra of a seismic trace. It can be done either by using Fourier Transformation (e.g. FFT) or by using Continuous Wavelet Transformation (CWT). The details on both methods have been extensively described in literature. In general, the technique separates the time series into its amplitude and frequency components. The FFT involves explicit use of windows, which can be a disadvantage in some cases. The CWT uses the mother wavelet, and it is equivalent to temporal narrow band filtering. Depending upon the purpose, one of the algorithms can be selected.

- FFT is used to delineate the stratigraphic/structural information along an interpreted horizon.
- CWT is preferably used to delineate hydrocarbon attenuations and thickness changes along an interpreted horizon.

Exercise

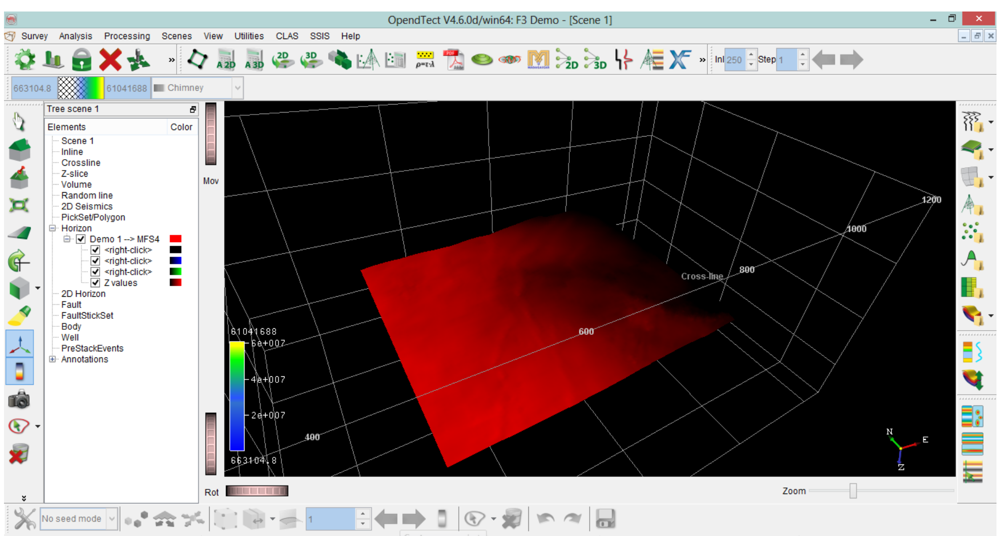
In this exercise, paleo-geomorphological features will be studied by displaying 3 iso-frequencies simultaneous with color stacking. Color stacking, also called RGB blending, allows multiple attributes to be combined into one display for simultaneous analysis. The combined data can be assessed through brightness and color balance. In many cases RGB displays show features with greater clarity and increased detail compared to standard displays.

1. Right click on *Horizon* on the tree, click on *Add color blended…* Choose horizon *Demo 1->MFS4*. (To speed up the exercise, load a sub selection of the horizon: inline 200-650; crossline 500-1000).



In the tree, the horizon appears with 4 separate attribute layers. The three lowest attribute layers represent the RGB channels (see color flags next to each layer). Three attributes can thus be blended into a single display.

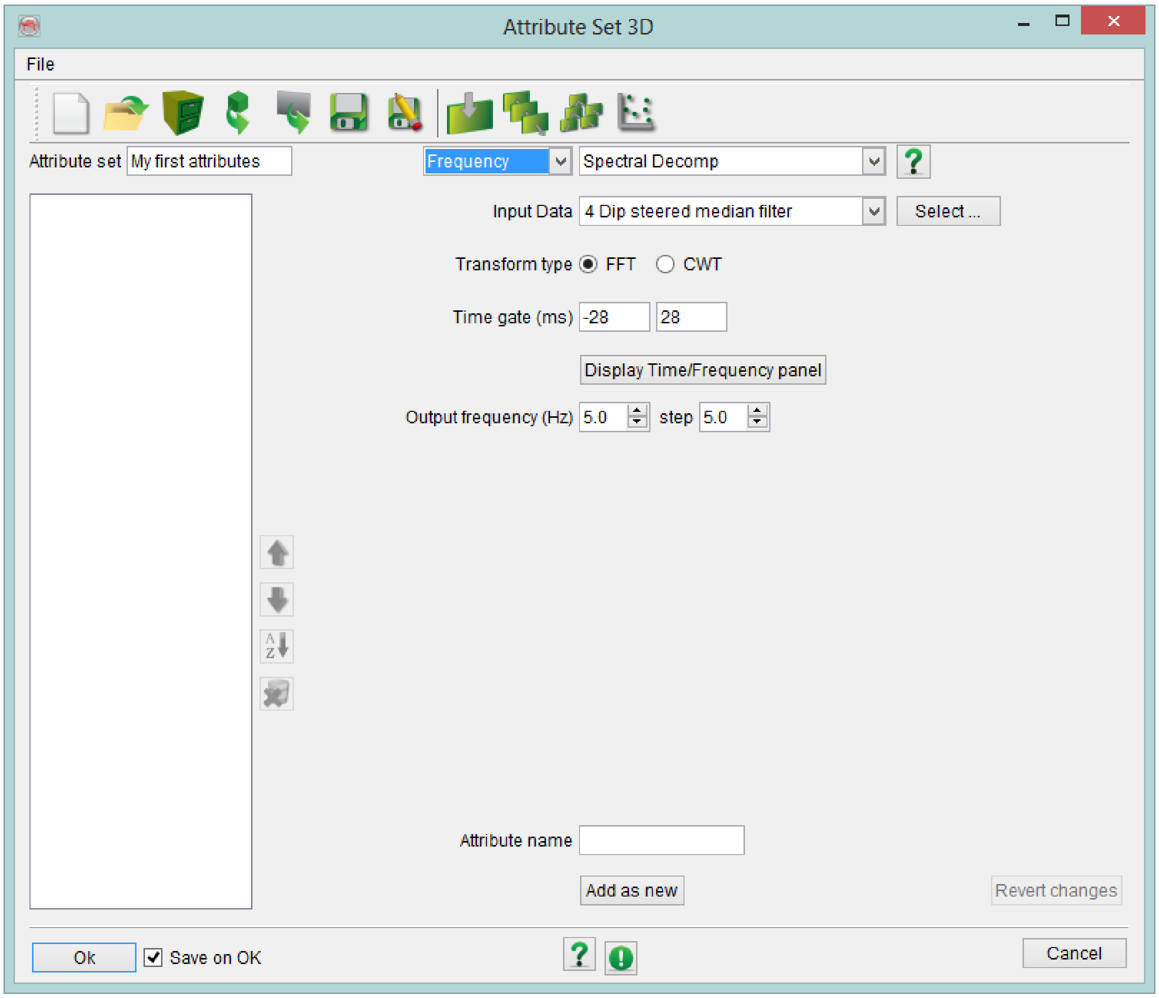
The fourth attribute is the alpha channel, which can be optionally added. The alpha channel will make the horizon transparent where the loaded attribute has a high value. When using attributes like similarity, this will thus display low value areas, i.e. faults/fractures.



2. We need to define 3 different attributes that will be loaded to the RGB channels of the horizon. Open an attribute set  , select *Frequency* then *Spectral Decomposition* as attribute.

It shows us the different parameters, which will be used to calculate the Spectral decomposition attribute:

- The *Input data*
- The *Transform type* (algorithm to use, FFT or CWT)
- The *Time gate*.
- The *Output frequency*.

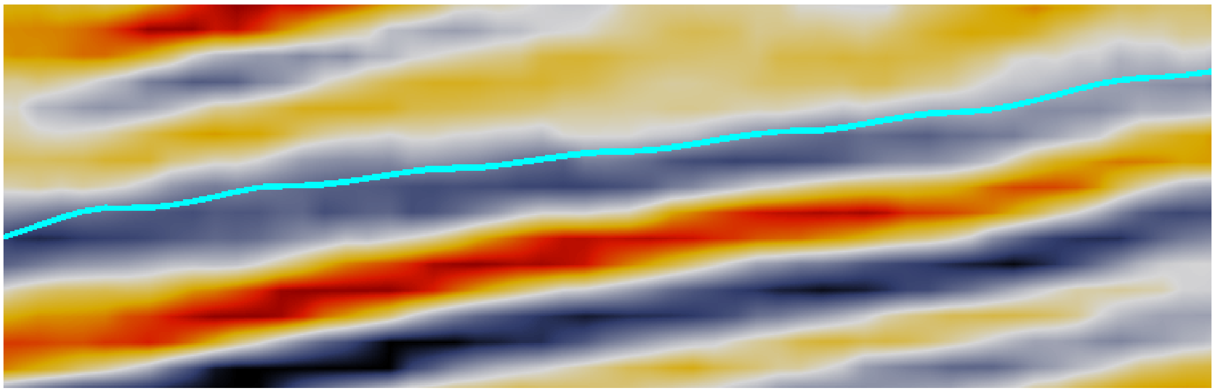


Exercise

1) Defining the time gate:

Since the extraction of spectral decomposition is done on a horizon, choosing the right time gate is critical. The time gate represents the interval of investigation. If a symmetrical time gate is chosen (e.g. [-28, +28ms]) the attribute will highlight geo-logical features above <u>and</u> below the horizon. When an asymmetrical time gate is chosen (e.g. [-8, 24ms] or [-24, 8ms]) the attribute response will highlight geological features below or above the horizon.

1. We are interested in the paleo-geomorphological features below the horizon. Choose your time gate such that it covers these features.



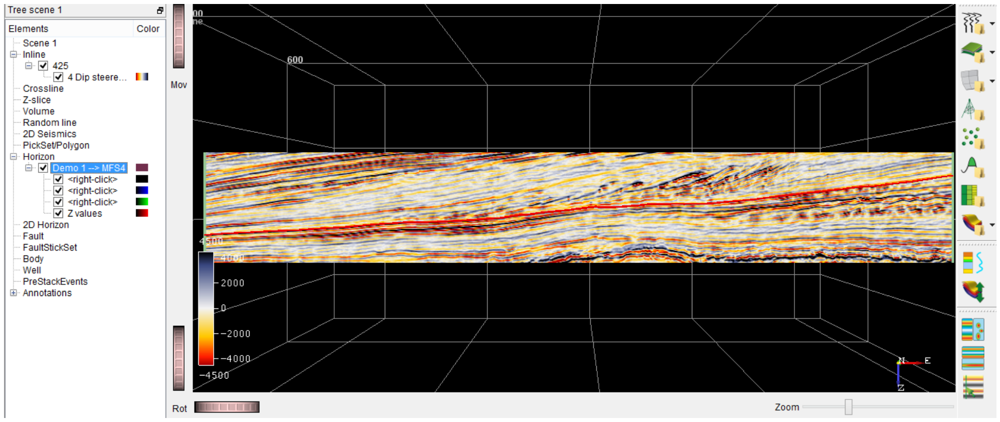
Note: when you display the Horizon *MFS-4* at section only, it becomes clear that the horizon is not picked exactly on the maximum. Compensate for this fact when defining your time gate.

2) Defining three frequencies

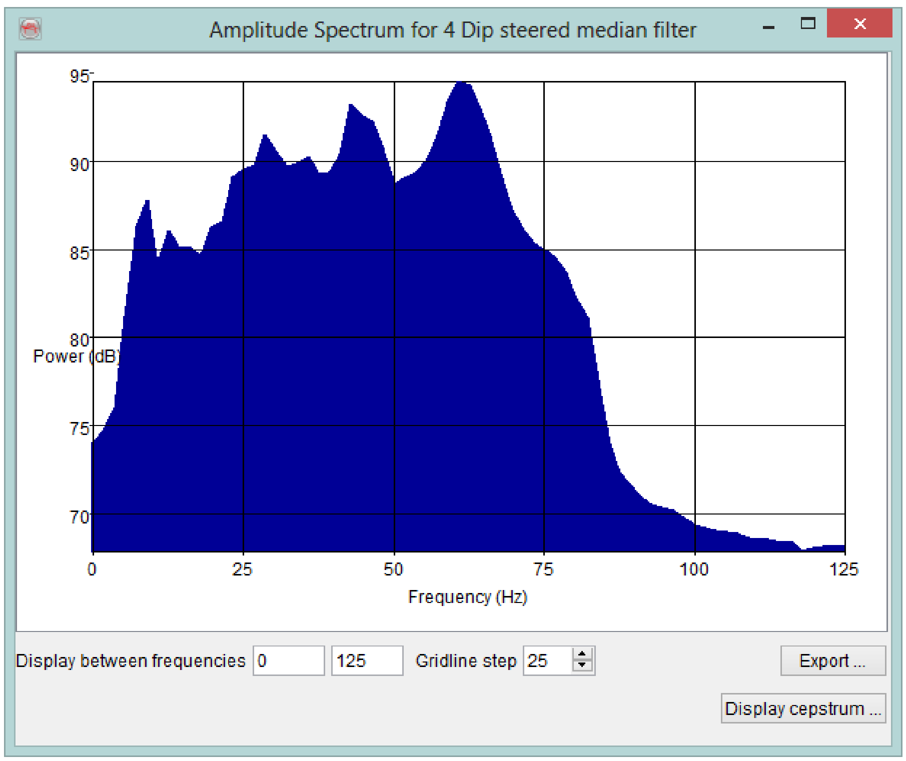
Three different iso-frequencies will be blended in the RGB display. We will choose these frequencies such that they represent the low, middle, and high frequencies of the seismic bandwidth around the horizon.

Exercise

1. Load an inline and reduce the Z range such that it just covers the horizon interval. (as shown below)



2. Right-click on the seismic attribute displayed in the tree and display the seismic bandwidth at target level by selecting *Display > Show Amplitude Spectrum...*



3. Now you can choose your low, middle and high frequencies within the amplitude spectrum. The low frequency can be selected as being the first peak, while the high frequency as the last peak.

3) Defining the three attributes

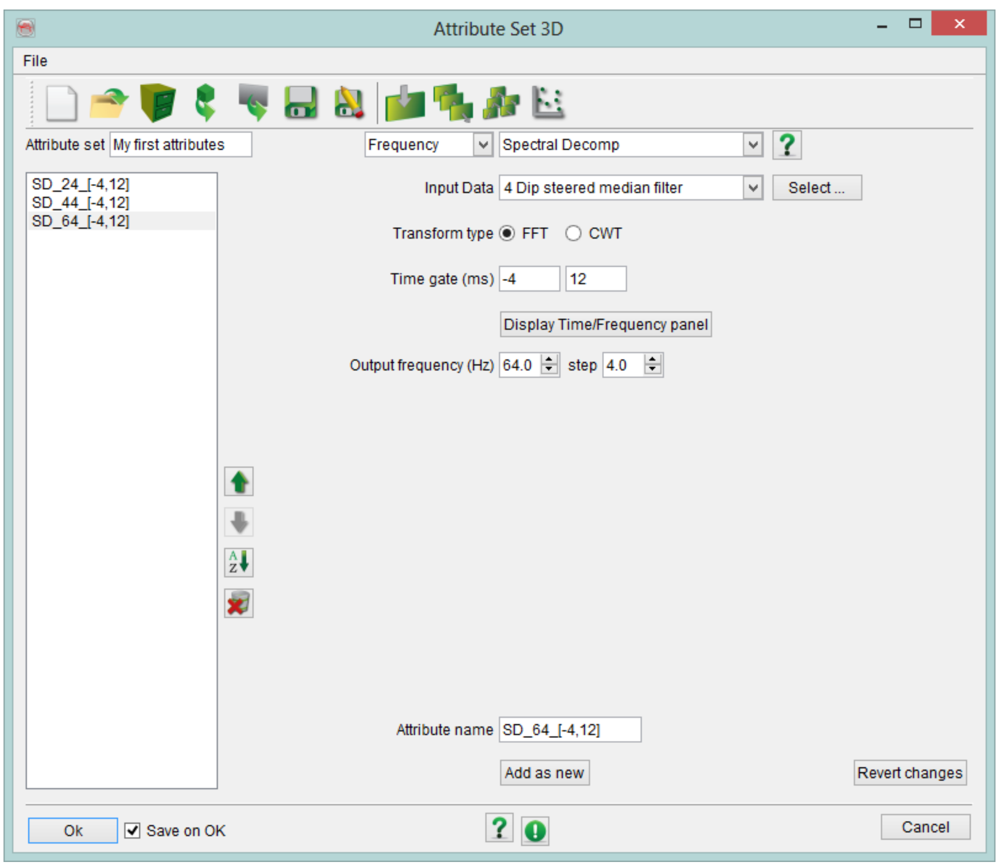
All the parameters have been tailored and the spectral decomposition attributes can be defined:

Exercise

1. Open the attribute set  engine to create the first attribute:

   a. Select '*Spectral Decomposition*' as the attribute to use.
   b. Input data: *4-Dip steered median filter*
   c. Use the FFT in '*Transform type*'.
   d. Define your *Time gate*
   e. *Output frequency*: Low Frequency. (keep the default *step*) Give a name to the new attribute, and press *Add as new*.

2. In the same manner, create the other two attributes, i.e. for middle and high frequencies.

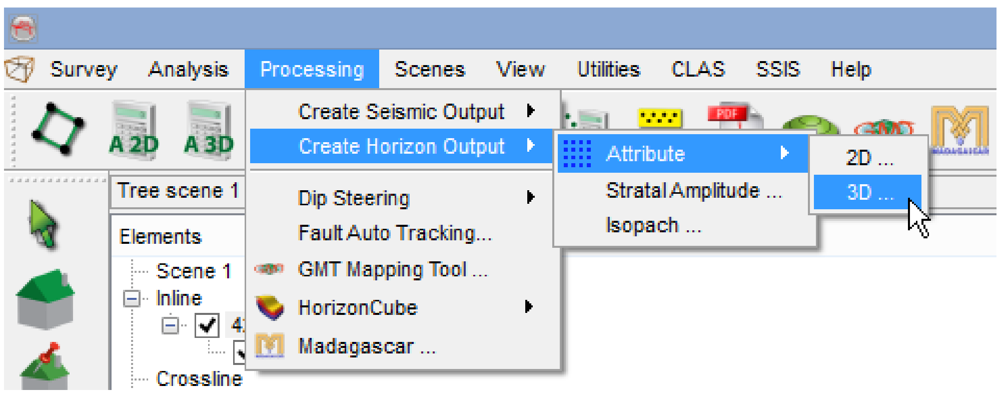


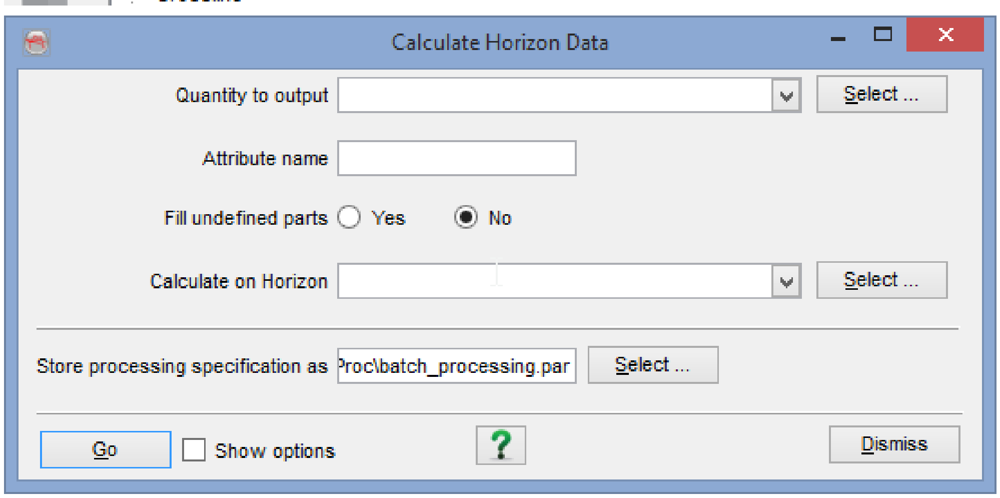
3. Click on *Ok*, optionally give a name to the new attribute set, e.g.: *Spectral Decomposition* (if *Save on OK* is selected)

4) Processing & displaying the results using RGB color blending technique

Exercise

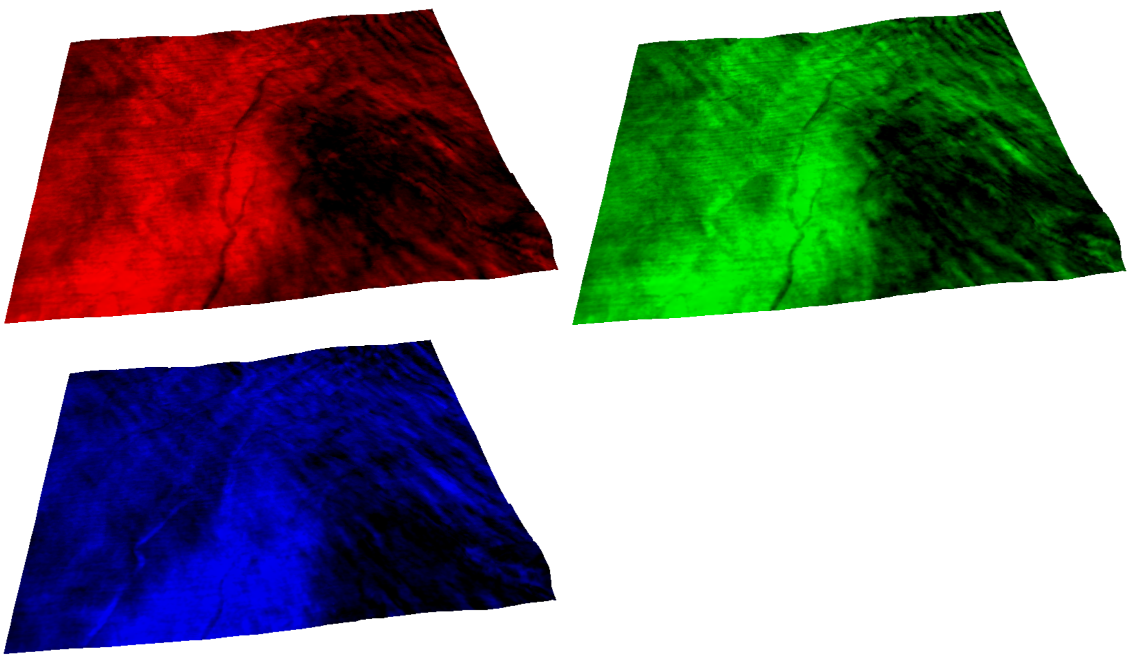
1. Convert your attributes into Horizon Data. Go to *Processing--> Create Horizon Output...*and select both the attribute you wish to output and the horizon on which you wish to output it. (For example, output SD_24_[-4,12] on Demo1->MSF4.)





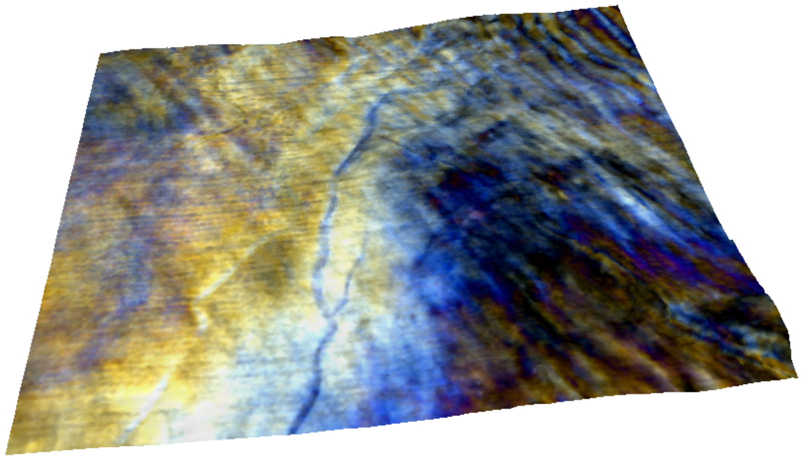
2. Display the three new Horizon Data on *Demo1-> MFS4* as follows:

- Spectral Decomposition 1 (Low frequency) is displayed as red the channel (*right-click on the text adjacent to the red channel--> Select attribute-->Horizon Data...*)
- Spectral Decomposition 2 (Middle frequency) is displayed as the green channel (right-click on the text adjacent to the green channel...)
- Spectral Decomposition 3 (High frequency) represents the blue channel. (right-click blue channel...)



*Time-Gate [-8,24] for **Red:** Low Frequency, 24Hz **Green:** Middle Frequency, 44Hz **Blue:** High frequency, 64Hz*

3. When blending the three inputs, the results should be similar to the one shown below.



4. Try to flip the green channel (Right-clicking on the *color bar*, a menu pops up which allows you to *flip* the color bar), what do you notice? Do you see one feature better than the other ones?

5. Which paleo-geomorphological features can you interpret? What can you conclude in terms of depositional environments, water depth, litho-facies, and direction of currents?

5) RGB and RGBA

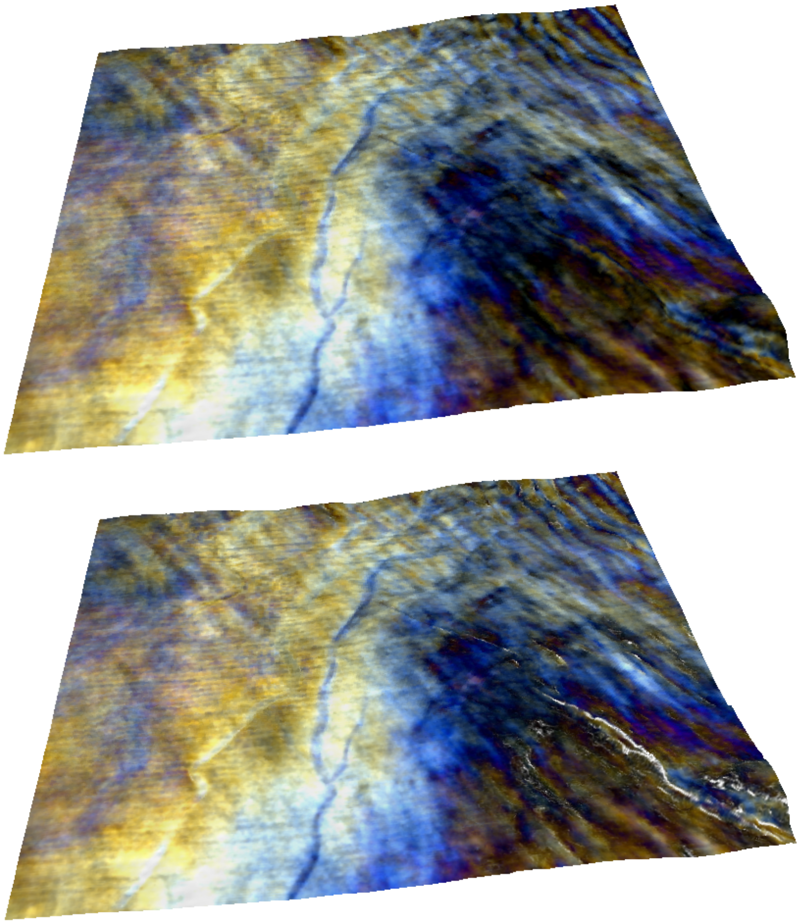
We normally create RGB with three channels representing Red, Green and Blue. The fourth attribute (called Alpha channel) can be optionally added to highlight structural features like faults/fractures.

Exercise

12. Add '*Similarity*' to the fourth layer,

    a. Define '*Similarity*' as a new attribute (See Similarity definition in the exercise of the section 4.4)
    b. right click on the fourth element in *Demo1 > select attribute > Attributes 3D > Similarity*.

What do you notice? Do you see any structural features (faults, fractures)?



RGB (above) and RGBA (below) displays

3.3 Crossplots

The crossplot tool is available to extract and compare data (well/seismic). The data points are extracted in a given volume or in a region of interest e.g. by drawing a polygon. The extracted data is displayed in a spreadsheet. The spreadsheet is then used to manipulate and plot the data.

The cross-plotting tool has several functionalities. These include the following:

- Scattered plots
- Density plots (useful when larger number of data points are selected)
- Regression fit
- Multi-data selection
- Interactive on-the-fly *Geo-body* extraction
- Creating *Probability Density Functions* for rock property predictions
- Vertical variograms analysis
- Extracting *Picksets* extraction for NN-prediction
- ASCII file output
- Quick cross-plot snapshots

The exercises will cover the following:

- *Attribute Vs Attribute* cross-plots
- *Attribute Vs Log* cross-plot

3.3.1 Attribute vs. Attribute Crossplot

Exercise

Attribute vs. Attribute cross-plots are mostly used for identifying a relationship between the attributes, supervised prediction, creating bodies etc.

In this exercise, we will create a spectral cross-plot i.e. a cross-plot between three iso-frequency responses. The exercise will cover two aspects: first, how to create attributes cross-plots and secondly, how to take benefit from such plots.

1. Load a color blended Demo-6 -> FS8 horizon

2. Launch Attribute Set window and create three attributes

a. Spectral Decomposition [FFT] – time gate: [-12,12]ms (24Hz, 44hz, 64Hz)
Names: *FFT [-12, 12]ms 24Hz*, *FFT[-12,12]ms 44Hz*, *FFT[-12,12]ms 64Hz*.

b. *Save* the attribute set (optional)

c. Apply these three attributes on the horizon (red-24Hz, green-44Hz, and blue-64Hz) (*right-click on the text adjacent to the red channel--> Select attribute--> Attributes 3D...*, repeat for both green and blue)

3. Observe that there is one prominent bright spot, which is a shallow gas pocket. Two more bright spots stand out along this horizon. However, we will restrict our cross-plot along the larger one. So, draw a *polygon* along the larger bright amplitude and save it (see the following image).

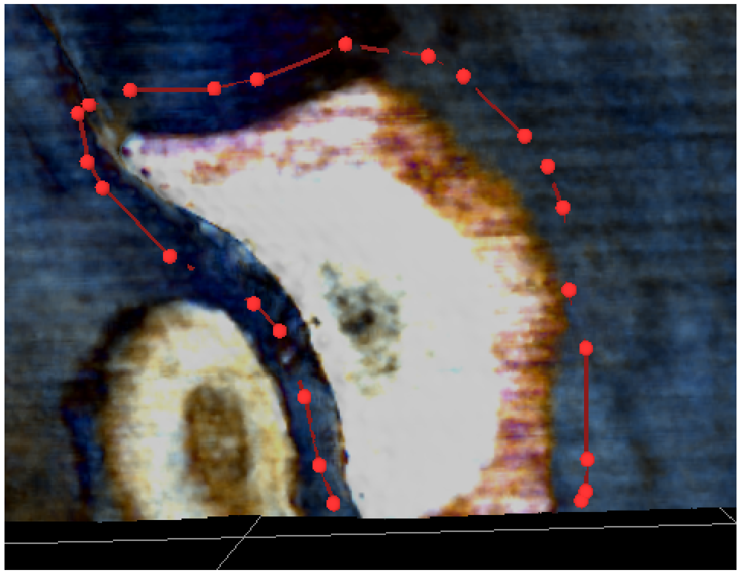
a. From the Tree Scene list, right click on the element “PickSet”.

b. In the pop-up menu, select *New > Polygon …* sub menu.

c. It will ask you to provide the name for this newly added polygon. Call it as ‘**Shallow Bright Spot**’.

d. It will add the polygon sub-item in the PickSet element. Make sure that this is selected (clicked). Now use left mouse button to click on the horizon to outline a polygon. When you are done, right click on this newly added polygon (in the Tree) to *Close Polygon*. Finally right click again on the polygon name and click on *Save*.

A color blended Demo-6 -> FS8 horizon (spectral decomposition) map. The green colored polygon outlines the area of cross-plot data extraction.



4. Go to the menu *Analysis > Cross-plot > Attribute Vs Attribute Cross-plot* or click on the  icon in the toolbar to launch the attribute cross-plot window. (Or launch Attribute Set window again and press the cross-plot button )

5. In the pop-up window, specify the followings

    a. *Input Attributes* – Select the attributes that were created in step-2a

    b. *Select location* by – Polygon (select *Shallow Bright Spot* polygon that you created in the Step # 3)

    c. Further, change the settings of Inline step to 1, Cross line step to 1, Time step to 4ms

    d. *Location filter* by *Horizon* (check it)

    e. Select the horizon i.e. *Demo 6 -> FS8*.

    f. Proceed by pressing *Ok* button (twice)

6. This will extract scattered data (attributes) along the surface. The pop-up window works similar to anExcel sheet. Select the following

axis to be cross-plotted.

a. X-axis – *FFT [-12,12]ms 24Hz* (select/highlight the column and press button)

b. Y1-axis – *FFT[-12,12]ms 44Hz* (select/highlight the column and press button)

7. Press Cross-plot button.

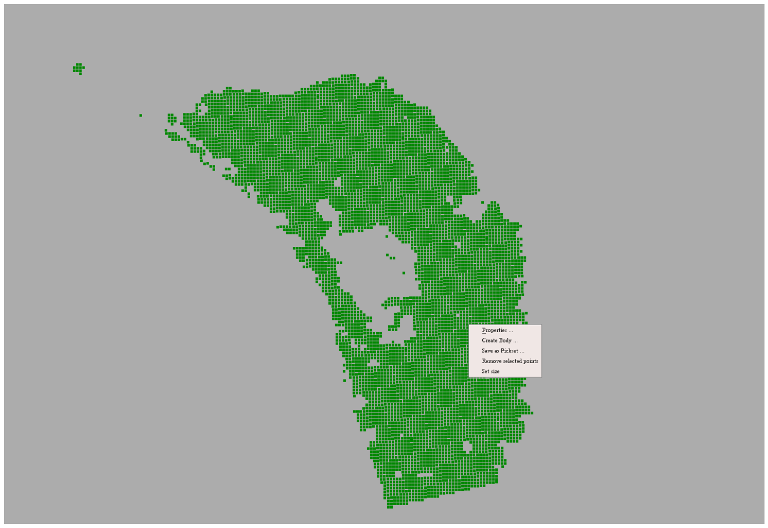
8. This will display a scattered cross-plot between the selected attributes (figure below). Toggle the density plot on by pressing button in the cross-plot and set the color table as Rainbow.

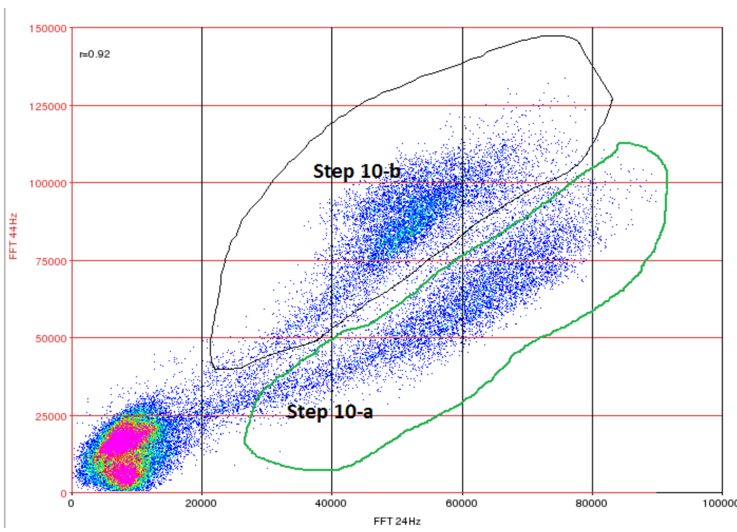
9. Now in this cross-plot, you see various responses i.e. high frequency and high amplitude, low frequency and low amplitude, low frequency and high amplitudes etc (with different slopes).

10. Use polygon tool to select scattered points. (change selection mode from to and reverse in clicking on the icon).

a. Toggle interact mode on and select the separation as shown in the*green polygon* of the cross-plot figure below.

Press (chose option *selected picks*) to display the selected scattered data in the scene. In the scene, save the green colored displayed picks (as Picksets/Body) by right clicking over them.



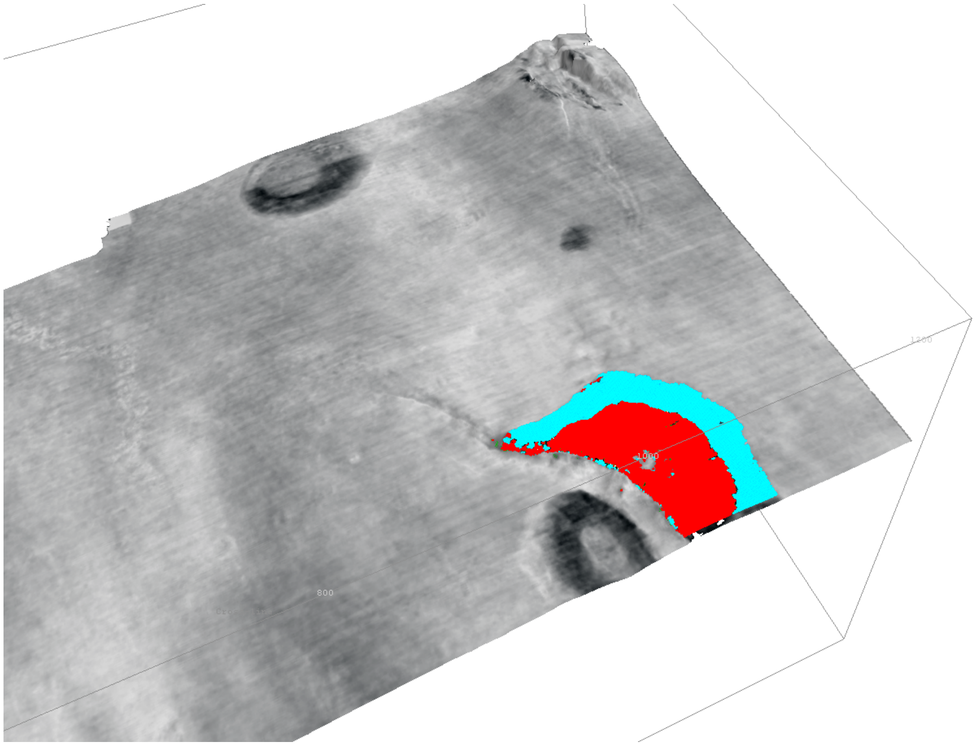


A density cross-plot of spectral cross-plot along a horizon, which is plotted between two iso-frequency responses (24Hz and 44Hz) within a selected polygon. Note that there is a clear vertical separation of bright amplitudes at higher frequencies. The selected data within the polygons (black/white) can be displayed in the scene that later on can be stored as Pickset/Body.

b. Repeat the same exercise for other response (**black polygon**)

11. Note that (figure below) the cross-plot has helped to identify the changes in the gas pocket that are possibly due to differences in saturation/thicknesses. Optionally, you can repeat the exercise from step-

6 to cross-plot FFT 24Hz, 44Hz and 64Hz attributes.



The scattered data selected in the previous figure are displayed as picksets. Note that the separation of frequency highlights two different regions of the bright spot.

3.3.2 Attribute vs. Log Crossplot

Seismic attributes and well logs can also be cross-plotted using the same tool.

Exercise

1. Define some seismic attributes in the attribute set window e.g. instantaneous amplitude, dominant frequency, energy etc. Save the attribute definition and close the window.

2. Go to the menu *Analysis* > *Cross-plots* > *well logs↔Attributes* or click on the cross-plot icon in the *OpendTect* toolbar. It will launch the attribute/well cross plotting window. In the upper section, select the desired attributes. In the middle section, select all available wells and

logs. The remaining options are the filters to extract scattered data (vertically/laterally) relative to the well position.

a. Extract between *Truncation* and *FS4* markers. Optionally you can extract within a Time range or Depth range (TVDSS). By default the extraction is done in depth but can also be done in time by selecting the option. The extraction step (m or ms) can be also modified.

b. Distance above/below: *Default (0,0)*

c. Log re-sampling method: *Nearest sample*. If there is no sample at the extraction position, all the available methods will look at the different samples with a time/depth gate centered on the extraction position and of the size of the defined extraction step. The nearest sample method will take the value of the sample the closest to the extraction position.

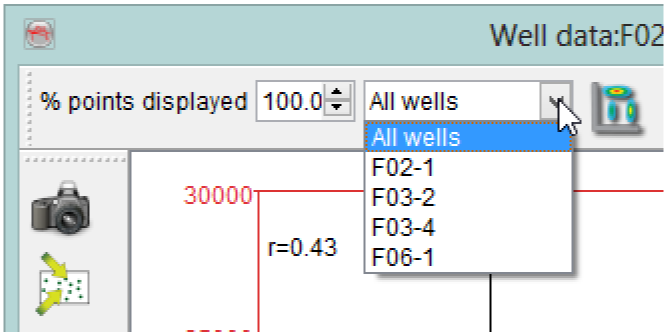
d. Increase the radius around the well e.g. 25 (this will replicate the log values within this radius).

e. Filter Position: *blank* (no sub-selection). It is possible to restrict the extraction area for the attributes.

3. Proceed by pressing *Ok* button.

4. In the pop-up spreadsheet, select any well log as an X-axis (e.g. GR) vs. one/two seismic attributes as Y1/Y2 axis (e.g. Dominant Frequency).

5. Press cross-plot button to plot the selected data . By default, it will plot scattered points of all wells vs. selected attribute(s). You can also create a cross-plot of individual well from the cross-plot window by changing the combo-box:



6. Repeat the same exercise to create log vs log cross-plots by selecting only logs as X and Y1/Y2 axis in the step 4.

3.3.3 Probability Density Functions and Bayesian Classification

The crossplots made previously enable the interpretation of the extracted data. However, there are some cases where the extracted data do not match the application domain and the analysis needs to be extrapolated further:

- The crossplots are made between well logs. The analysis is used to apply a response extracted from the wells, using inverted volumes of the same quantities.
- The size of the data makes it impossible to extract all the points to be analyzed. The crossplot analysis must be done on a sub-selection of the data, and has to be extrapolated to the entire dataset.
- The analysis is done on purpose on a small specific region of the survey, and one wants to know if a similar response exists somewhere else.

The mechanism used to perform these predictions is called Bayesian inversion. The Bayes' Theorem in an inversion context can be summarized by (Kemper, 2010):

> *Posterior distribution is proportional to the Prior distribution multiplied by the Likelihood distribution.*

The prior distribution is extracted from the data using the crossplot tool in a form of Probability density functions (PDFs). The likelihood distribution is a multiplication factor that can be applied to the PDF in order to provide a relative weighting between several PDF functions.

In the following exercise, a Bayesian inversion will be done to forecast if similar bright spots as seen in section 3.3.1 can be predicted elsewhere along the same horizon.

Exercise

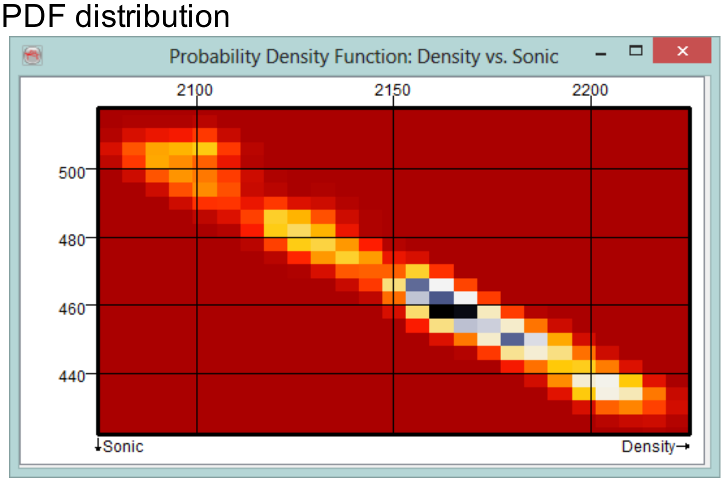
1. Start from the cross-plot data extracted in the exercise of paragraph 3.3.1.

2. We will try to forecast the occurrence of the brightest amplitudes, corresponding to step 10a. To do so, we need to select and remove the points that are outside this sub-selection. Only the desired response should remain.

3. Capture the response by computing the Probability Density function (PDF) of the remaining data. Click on the *P(x)* button. Provide an output name.

4. Perform the same operation for the other cloud (step 10b in section 3.3.1).

5. PDF are sometimes noisy especially when the input dataset is sparse. Use the PDF manager accessible from *Survey* > *Manage* > *Probability Density Function*. There you can browse/edit using the icon or double clicking on the PDF. Then you can either rename the quantities or edit the values displayed in a table. You can view the PDF distribution



and smooth it using the  icon . Press *Ok* and save the smoothed PDF with a new name.

6. The application of the Bayesian inversion requires each input attribute to be processed and stored as a volume.
Create two output cubes (*Processing > Create Seismic Output > Attribute > 3D...*): one for the 24 Hz and one for the 44Hz component. To save processing time, limit the processing range to inline 530 – 750, cross-line 660 – 1040 and Z range 500 – 700ms. Make sure this is done before going further.

7. Launch the Bayesian inversion from *Processing > Create seismic output > Bayesian classification*.

8. Select both previously created and smoothed PDF (to add additional PDF click on More).

9. Provide a weight for each, for example 1 for the first and 0.8 for the second. The weight functions can be constant but also variable and input using volumes. For instance the weight could be a function of the well distance, or the vertical distance to the target.

10. Provide the input volume corresponding to each attribute.

11. Specify the output you would like to receive.

The Bayesian inversion provides several kinds of outputs:

- The “P” is the probability volume associated to each PDF distribution.
- The “Classification: Class” returns an integer corresponding to the most likely PDF at each sample location.
- The “Classification: Confidence” returns the distance between the most likely and second most likely PDF distribution.
- The determination strength gives a number related to the relative position in the most likely position (Histogram count).

12. Display and compare the output volumes on the FS8 horizon. See if other similar bright spots can be recognized. You may also want to load these cubes in a small 3D volume since the processing is volumetric.

3.4 Horizon Tracking

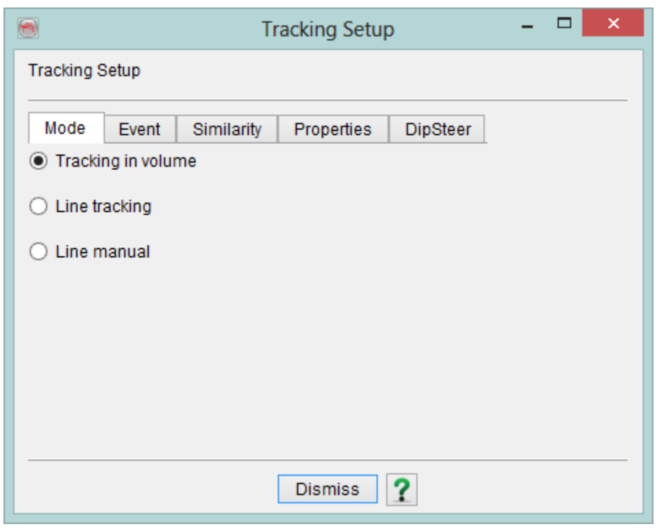
Horizons can be interpreted in different ways. In *OpendTect* it is possible to map seismic events using the horizon tracker.

Exercise

1. Add an inline (use the defulat data, "4 Dip-Steered Median Filter")

2. Right-click "*Horizon*" in the tree and select *New* .... This will launch a tracking setup with the following tabs: Mode, Event, Similarity, Properties.

Mode



Choose the tracking mode: *Tracking in Volume*, *Line tracking*, or *Line manual*.

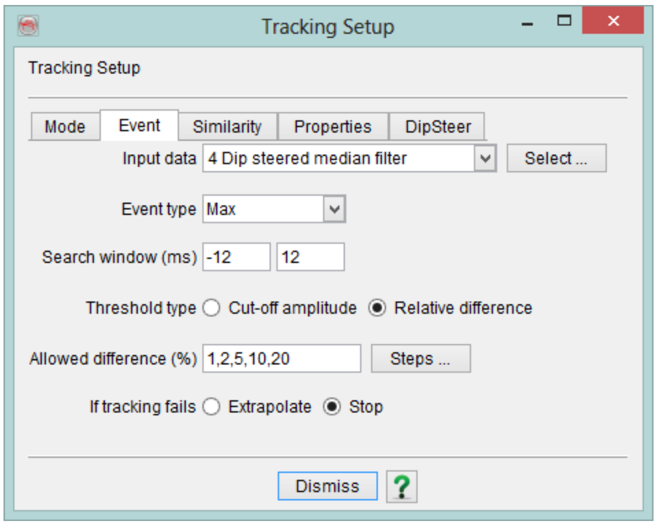
- *Tracking in volume* is used to auto-track a horizon inside a user defined tracking area (3D volume or subvolume). The tracker area can be moved and adjusted inside the survey box. This mode is preferred for most horizon tracking and will be used in this exercise.

- *Line tracking* is used to track a horizon on a line (inline or crossline). This mode gives more control to the interpreter. It is used in difficult areas. In between the seeds, the horizon is tracked along the line. The result is a grid that needs to be filled by either autotracking or interpolation.

- Using the *Line manual* mode, you manually pick a horizon (interpolated line). The workflow is similar to line tracking, with the difference that between seeds a line is user-drawn. This mode is used to cross faults, push through noise zones or interpret unconformities.

> **Note:** Line tracking mode and Line manual mode can be used to interpret horizons on sections inside OpendTect's 3D scene and on sections displayed in an OpendTect 2D viewer.

Event



When *Tracking in volume* or *Line tracking* is selected, you need to define several tracking criteria:

- *Input data:* Select the seismic data on which you are going to track. This can be the original seismic volume, or a filtered seismic volume (preferred) or an attribute.
In this exercise: Select the *Dip steered median filer*.

- *Event type:* Specify the type of event you want to track. The tracker can track negative reflectors (Min), positive reflectors (Max), Z-type zero-crossings (0+-) or S-type zero-crossings (0-+).
In this exercise: Select *Max*.

- *Search Window:* The tracker search in a time window relative to the last tracked sample. The tracker searches for the chosen event type based on amplitude.

- *Threshold type:*

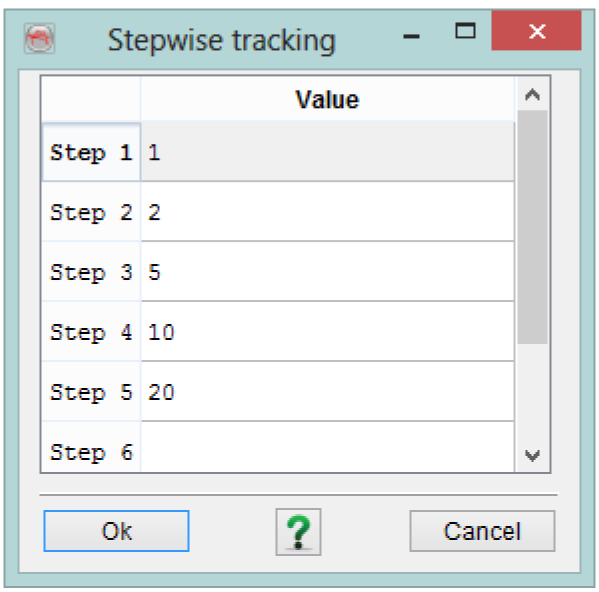
- *Cut-off amplitude*: the absolute amplitude is used as the stopping criteria for the tracker. When the tracker encounters a value below this threshold, it stops tracking. (For a max-event the tracker stops if the value is below this threshold value, and for a min-event when it is above this threshold value).

  Tip: when pointing your mouse at the event, the amplitude value is displayed at the bottom of your screen.

- *Relative difference:* The tracker compares the amplitude of the last tracked point to the amplitude of the point that is candidate for tracking. If the difference exceeds the chosen percentage, the tracker stops tracking.

In this exercise: Use *relative difference*.

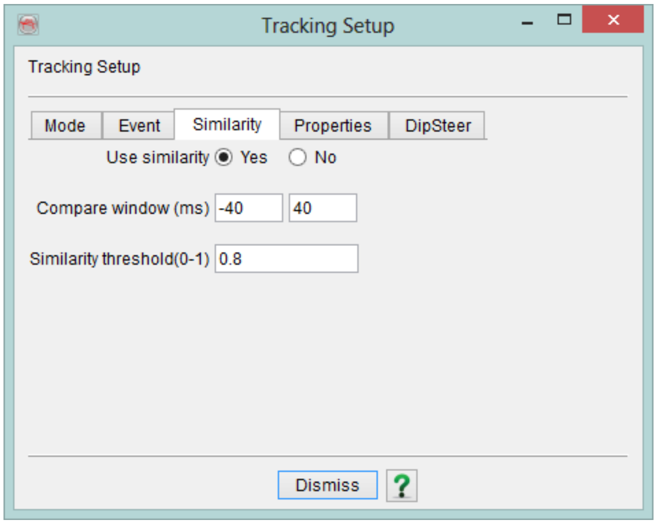
- *Steps...:* Step-wise tracking results in a better tracked horizons. Good parts of the horizon are tracked first, followed by the more difficult areas. The tracker will first track the parts of the horizon that have a low difference to the seeds or parts that have a high amplitude. In subsequent steps the tracker settings become less strict. Therefore, the horizon will be of better quality and needs less editing.
In this exercise: Set subsequent percentage values (incremental: e.g. 1, 2,5,10,20) , or subsequent amplitude values (decremented e.g. 2500,2000,1500,1000,500) .



- *If tracking fails:* If the tracker cannot find a neighboring point (that complies with the specified relative difference or cut-off amplitude), it can either stop tracking or extrapolate the horizon.

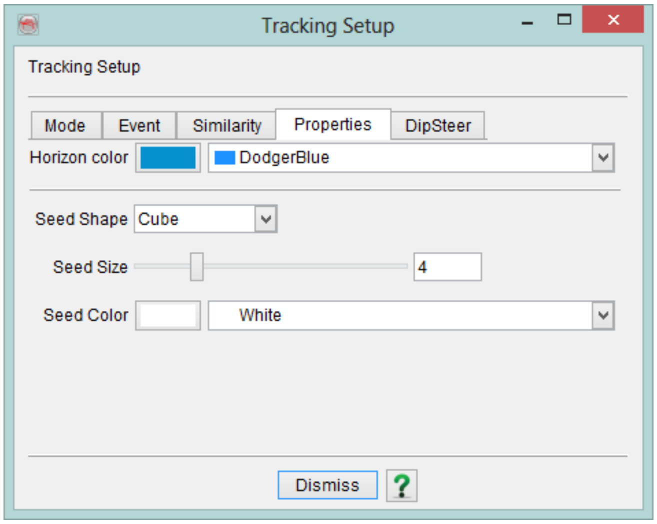
Tip: When the tracker stops tracking before you want it to, adjust the Threshold value and/or Similarity threshold before choosing the extrapolate option.)

Similarity



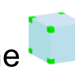
Similarity is a kind of cross-correlation. A part of a trace around the last tracked point is compared to all the trace segments on the neighboring trace around the points that lie within the *Search window* (See user documentation for more detail). The number of comparisons is thus controlled by the *search window*, while the *compare window* controls the length of the trace segments. The measure of Similarity between the trace segments lies between 0 and 1. The tracker will chose the point that has the highest similarity. When the point with the highest similarity has a value below the defined threshold, the tracker stops tracking. Tracking with similarity is more accurate, but it takes more time to compute.

Properties

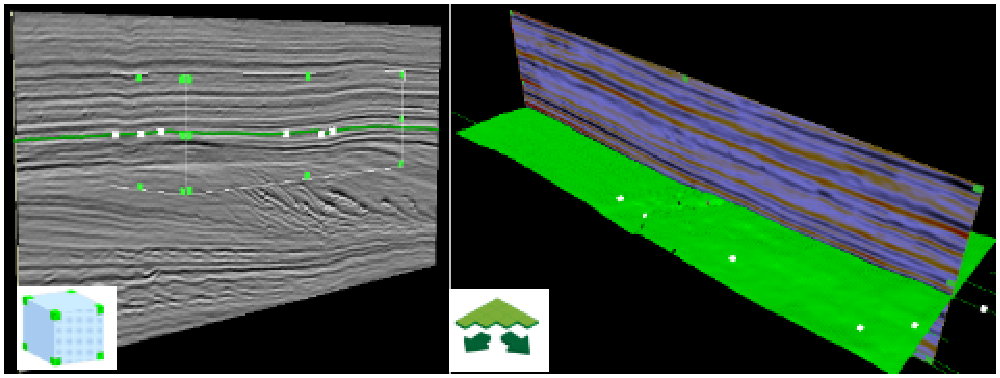


This tab is used to change the properties of the horizon i.e. color, line style, seed shape, seed size etc.

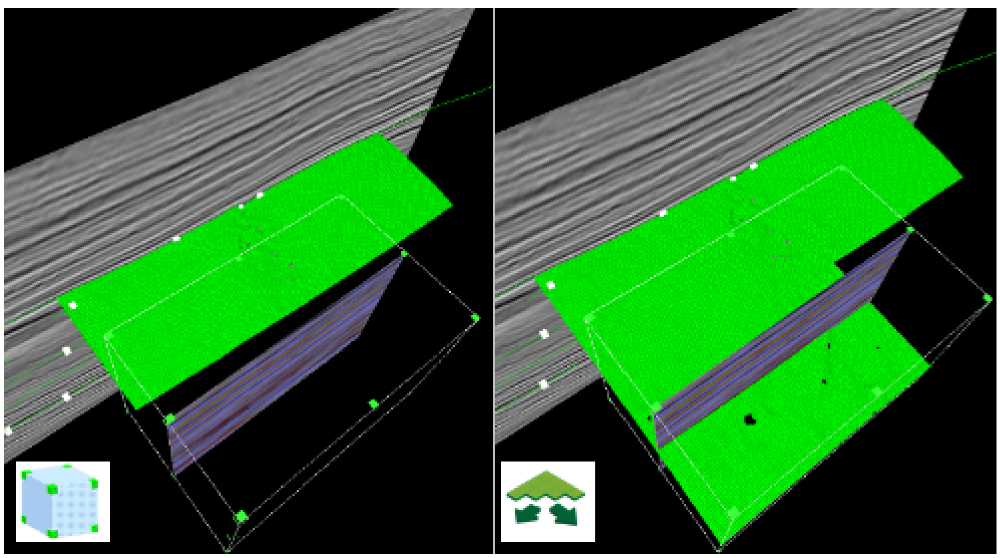
3. After adjusting the parameters in the tracker setup (which can remain open during tracking), start *picking seeds* on a displayed inline/crossline.

4. *Pick* one or more seeds and display the tracking area using the  icon.
Resize the tracking area by dragging the green anchors on the edges of the cube, but do not exceed your computer's memory size or the size of your graphics card memory. If you run out of computer memory, *OpendTect* will crash.

5. *Click* on the auto-track icon . After the input data is loaded inside the tracking area the horizon is tracked



6. After tracking a part of the 3D-horizon, *move* the tracking cube to next place: *click* the top of the tracking cube and *drag*. A small part of the horizon should be inside the new position of the tracking area.



Move the tracking cube to next location. When the Cube is at its desired position, click  again.

3.5 Edit Horizon

When (a part of) a horizon is tracked, the quality can be best checked by using the *display at section only option* .

Click on to adjust the area where the edits are made. Then toggle on QC plane button to show seismic data on an inline/crossline. You can switch them though by using the drop down option of this button. The horizon will be displayed as a line on inline and/or crossline display elements and on the *QC plane*.

> **Tips:** You may drag the QC plane over the tracked horizon to QC further tracking areas. *Shift-click* on the tracker plane to QC in another direction or select another orientation in the tracker toolbar.

If the horizon needs editing, there are several options:

- *Retrack All:* when the horizon is tracked with the wrong settings, change the settings and click on the icon. This first removes all the auto-tracked parts of the horizon while keeping the seeds. Then, the horizon is retracked with the new tracker settings in the tracking area.
- *Polygonal tool:* with the polygon tool, you can delete a part of a horizon to be able to re-track it. First select the polygon selection tool from the tracker toolbar and circle the area to remove. Remove the horizon inside the polygon by clicking the remove icon .
- To fill the hole again :
  - Autotrack will track the hole from the edges
  - Pick a seed on the QC-plain and track from seeds only
  - Interpolate (*<right-click> on Horizon in tree-> Tools-> Gridding...* There are several geometries and algorithms that may be used to grid horizons for differing results. (For full details about this option, see the OpendTect User Doc, Section 4.7.3.1. Grid)

3.6 Fault Interpretation

Faults can be interpreted in several ways in OpendTect. The exercise in this chapter will introduce the fundamental differences between interpreting *FaultStick-Sets* and *Faults*. Saved *Faults* or *FaultStickSets* can be loaded in the tree by right clicking and selecting *Add…*

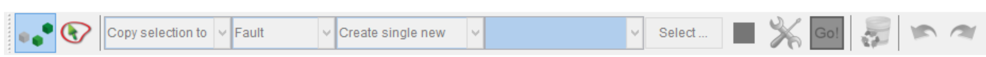
Exercise

1) How to interpret faults

In this exercise, you will interpret a major fault plane in the F3 demo dataset. First, move to **inline 250** where a fault is clearly present throughout almost the entire column.

1. Right click *Fault* in the tree, select *New*...

2. The fault interpretation toolbar at the bottom becomes active, the *edit stick* button is selected by default:



- Pick faults in any order of preference (from top to bottom, middle etc.) by clicking on the seismic section.
- After picking fault sticks, stick nodes can be *dragged* by holding down the left mouse button over a node and dragging it to a new location.
- Individual stick nodes can be removed with Ctrl + left mouse click.
- Multiple fault sticks can be removed by selecting the polygon tool  and selecting one or more seeds. The stick nodes change color (to green) when selected and the polygon will disappear. Thereafter immediately click the recycle icon . Deselection of specific sticks within the selection can be achieved using Ctrl+left click. A single node can be selected using left click and can thereafter be removed in the same manner as above.
- The green *backward*- and *forward arrows* allow for *undo* and *redo* respectively.

3. After inserting seeds on the current seismic inline, *move* the inline

to a new location. For example, set Step to 10 and move inline in any direction.

> **Note:** Your previous interpretation is still visible behind or in front of the moved seismic slice. Often this is considered as a distraction when interpreting. Thus, right-click the fault (New Fault 1 by default) in the tree, select *Display* and choose *Only at sections*.

4. Proceed to *insert seeds* on new inline

5. After interpretation, the new fault can be saved either in the toolbar or in the tree

For saving in the **toolbar**,

a. display fault in full (right click in tree > *Display* > de-select *Only at sections*).
b. Use the polygon tool  to select the whole (or part) of the interpreted fault.
Note: that multiple selections/polygons can be drawn - the currently selected seeds change color.
c. Set *Move selection* to in the first drop-down list, select fault in the second and *Create single new* in the third drop-down list in the toolbar.
d. Give a name in the empty field
e. Set *color* and (optionally) *More transfer settings* 
f. Hit *Go!*

For saving **directly in the tree**,

a. Right-click on the fault
b. Select either *Save* or *Save as*… The latter enables you to specify a name and *Replace in tree*. The whole interpretation (all seeds) is (are) saved when saving a fault in the tree.

2) How to interpret FaultStickSets

FaultStickSets are interpreted similarly to *Faults* (identical toolbars). The fundamental difference is that stick-sets contain fault-sticks that can belong to different faults. The grouping of sticks into faults is done later, in a separate interpretation step. This workflow speeds up the interpretation process greatly.

Exercise

For this exercise, move to **inline 450**. Several small-scale faults are visible in the bottom-left corner, all steep dipping slightly toward the East.

1. Interpret 3-5 fault sticks by inserting seeds.

   Note: When moving to a New Fault, use shift + left mouse click for the first seed. Alternatively, fault sticks can be drawn with a smooth click-and-drag movement.

   When you are finished with one stick, un-click and move the cursor to the start position of the next stick and repeat the process. OpendTect will automatically detect that you are drawing a new stick.
   This process of drawing sticks can be done with a mouse device but it is much easier with a pen-device such as the Cintiq 24HD by Wacom.

2. Individual *seeds* can be moved around and deleted similarly as in the fault interpretation workflow (see section above). The *polygon/recycle* and *arrow* tools work similarly.

3. After interpreting several fault sticks on inline 450, move the slice (e.g. 10 steps) in any direction and draw new fault sticks.

   Note: sticks are not connected by a plane, unlike fault interpretations at this point.

4. Similarly to when interpreting *faults*, it might be beneficial to show the interpretations on the current section only (right click FaultStickSet in tree > *Display> Only at sections*)

5. Select the appropriate fault sticks:

a. Define a *Similarity* attribute (see Chapter 3.2).
b. Add a time-slice to the scene and move the slice such that it intersects the fault-sticks.
c. Apply the Similarity attribute to the time slice. To save time, resize slice to the area around the interpreted fault sticks.

d. Use the polygon tool to select sticks belonging to one fault (note: the color of selected seeds is green, unselected are violet)

3) How to convert FaultStickSets into Faults (Fault planes)

6. Either *Move* or *copy* the selected fault stick set. Then set *Fault* in the second drop-down list and choose *Create single new*. Set name, color and (optionally) *More transfer settings* and hit *Go!*

7. The new fault is *Moved* or *Copied* according to settings to the *Fault* section in the tree.

8. Repeat selection process for all fault sticks

> **Note:** *Faults* and *FaultStickSets* allow for transferring back and forth, with multiple options (*create single new*, *create new in series*, *merge with existing* and *replace existing*).

3.7 Velocity Gridding & Time-Depth Conversion

In this topic, the following exercises will be achieved:

- How to load a stacking velocity function?
- How to grid the stacking velocity into the volume?
- How to display the volume on the fly and batch processing?
- How to batch-processing cubes for depth survey?
- How to batch-processing horizons for depth survey?
- How to set-up the new depth survey?

Exercise

1) How to load a stacking velocity function?

In this exercise, a stored stacking velocity function will be imported in OpendTect. This is done by doing the following:

1. Go to *Survey* > *Import* > *Velocity Function* > *Ascii…* (Locate the file *Velocity_functions.txt* in the Rawdata directory)

2. Click on *Examine* to check the file.

   a. Select the velocity type : *Vrms*.
   See the User documentation to know more about the different velocity types.
   b. The header size is fixed and it consists of 12lines.
   c. The format is: X-Y-Time-Vrms respectively in column 1, 2, 3, 4. Time can be either in millisecond or in second, then chose the correct units.

3. Give the output velocity name and click *Go* and *Dismiss*.

Exercise

2) How to grid the stacking velocity into the volume?

The imported velocity function should be gridded first in order to display it in OpendTect. This can be done using the volume builder module accessible from the  icon:

1. Select the *Velocity gridder* step and add it to the Used steps list with the middle arrow.

2. In the *Edit step* window, choose *Triangulation* as algorithm type.

3. Add a *Velocity source*.
Choose Type: *Stored Function* and select the input function you imported in the previous exercise.

4. Name this step (e.g. *Triangulation of Vrms function*)

5. Store the setup as *Grid velocity function*

6. For this exercise, **do not press *Proceed***. Instead press "*Cancel*" because we want to first display the velocity on-the-fly, once the result is Ok, we go back to start the batch processing of the volume.

Exercise

3) How to display the volume on the fly and do batch processing?

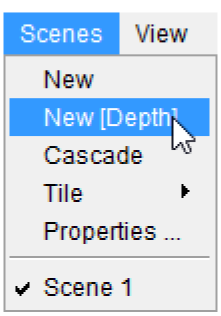
In time scene of time survey:

1. right-click on the element (Inline 425) > *Add Volume processing attribute* and select *Grid velocity function*.

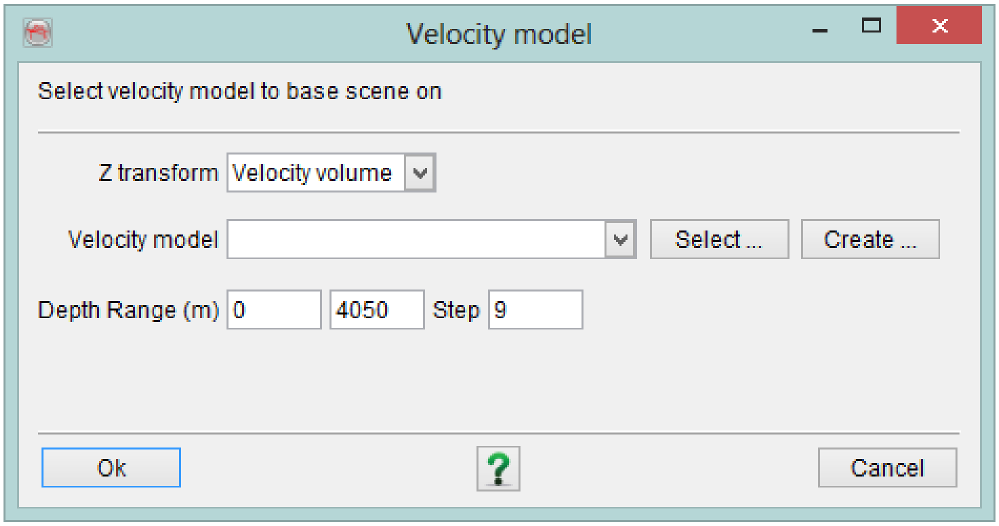
2. To batch process the volume, re-launch the Volume Builder, select the Grid velocity function, give an output name and press Proceed.

In depth scene of time survey:

1. From the main menu open the depth scene by doing the following: *Scenes* > *New [Depth].*



2. A window pops-up asking you to select or create a velocity model.



Note: OpendTect's volume builder is a general-purpose gridder. It is not aware that the volume you created in the previous step is a velocity volume. Therefore, you must now first specify that the gridded volume created before is a *Velocity model*

a. Click on *Create* and *Select* the velocity model.
b. Specify the velocity type (RMS).
c. Press OK and OpendTect will scan the file to compute the depth range for the new scene.
d. Press OK and a scene (depth scene) pops up.

3. Display any stored volume on the inline 425 in the depth scene. You will have to use the corresponding *Tree* in Depth. You will notice that the scene now shows data in depth, which has been converted from time data using the interval velocity you, selected. This is done on the fly.

Conversion of Vrms to Vint:

RMS Velocity can be used for many purposes including T/D conversion, Velocity picking, etc … but there are other applications requiring Interval velocity instead.

Exercise

Do the following to convert one velocity type to another:

1. *Processing* > *Create Seismic output* > *Velocity conversion….*

2. The tagged velocity (Vrms) will be automatically filled as *Input velocity model.* (The velocity is tagged when importing the velocity function).

3. Fill the *Output Cube* as Vint (Interval velocity) > *Proceed*

4. Display the new converted interval velocity and compare it with the rms velocity.

Exercise

4) How to batch-processing cubes for depth survey?

Using the new stored velocity model, cubes from the time domain can be processed and visualized in the depth domain.

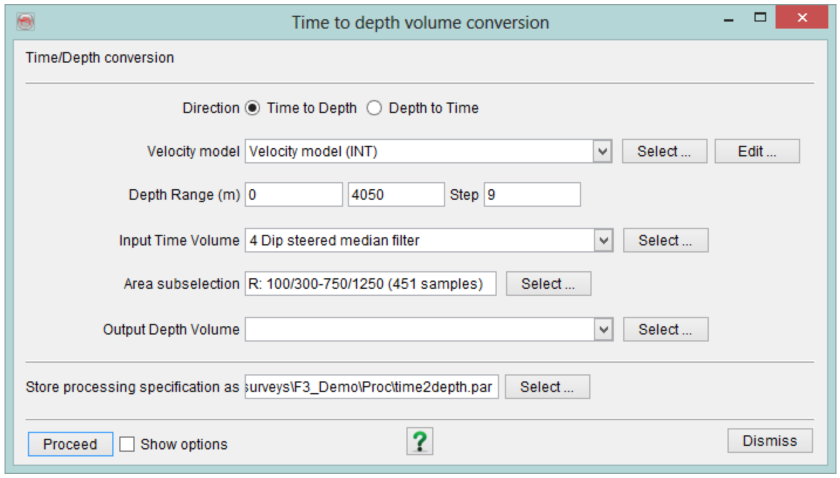
1. To create a depth cube, go to *Processing* > *Create Seismic output* > *Time – depth conversion ….*

2. Select the Velocity Model (in this case, *Velocity Model (INT)*). Click on *edit* and then *scan* to go through the amplitude of the input velocity model.

3. Select the Time volume to be converted.

4. Define the Depth range and the step. In *Volume subselection*, use inline 425.

> **Note:** In general the depth volume range does not change laterally from the original cube (thus InL/XL step stays the same) but the depth Z range can be larger.



5. Give a name to your new depth cube (e.g. D-4_DSMF) and click on *Proceed*. The volume Dip-Steered Median Filter will be converted in depth and stored in the time survey with a tag "D" (like 'depth').

6. To display your new depth cube go to the depth scene, right-click on inline 425 > *Select Attribute* > *Depth Data* > Select the Depth Cube you just created.

5) How to batch-processing horizons for depth survey?

In order to display the horizons in depth survey we will need to first export them from time survey using the velocity model:

1. *Survey* > *Export* > *Horizons* > *Ascii 3D…*
2. Output type: X/Y
3. Output Z: *Transformed* and for Depth conversion, select *Velocity*
4. Velocity cube: Vrms (Z-unit: Meter)

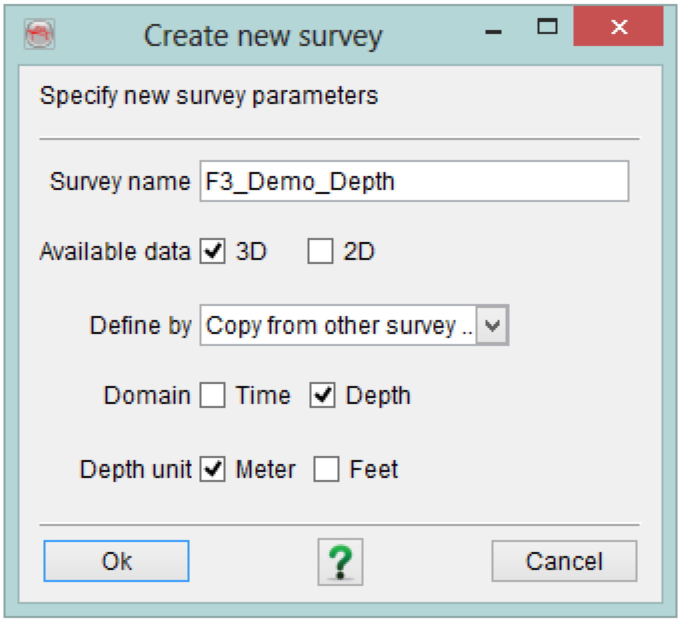
Exercise

6) How to set-up the new depth survey?

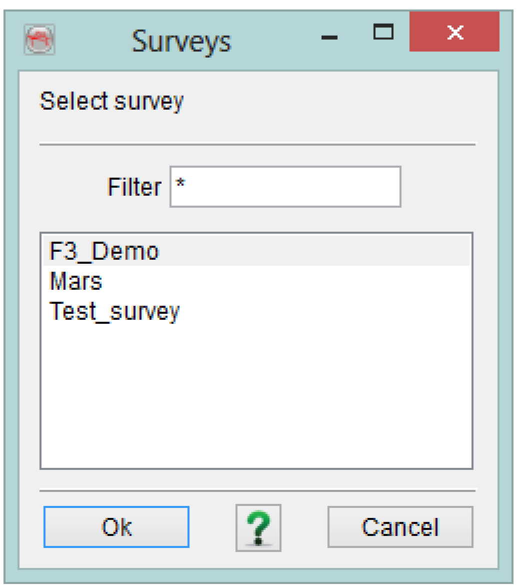
In order to create a new survey:

1. *Survey* > *Select/Setup* > *New*...or click on the icon, then *New*...

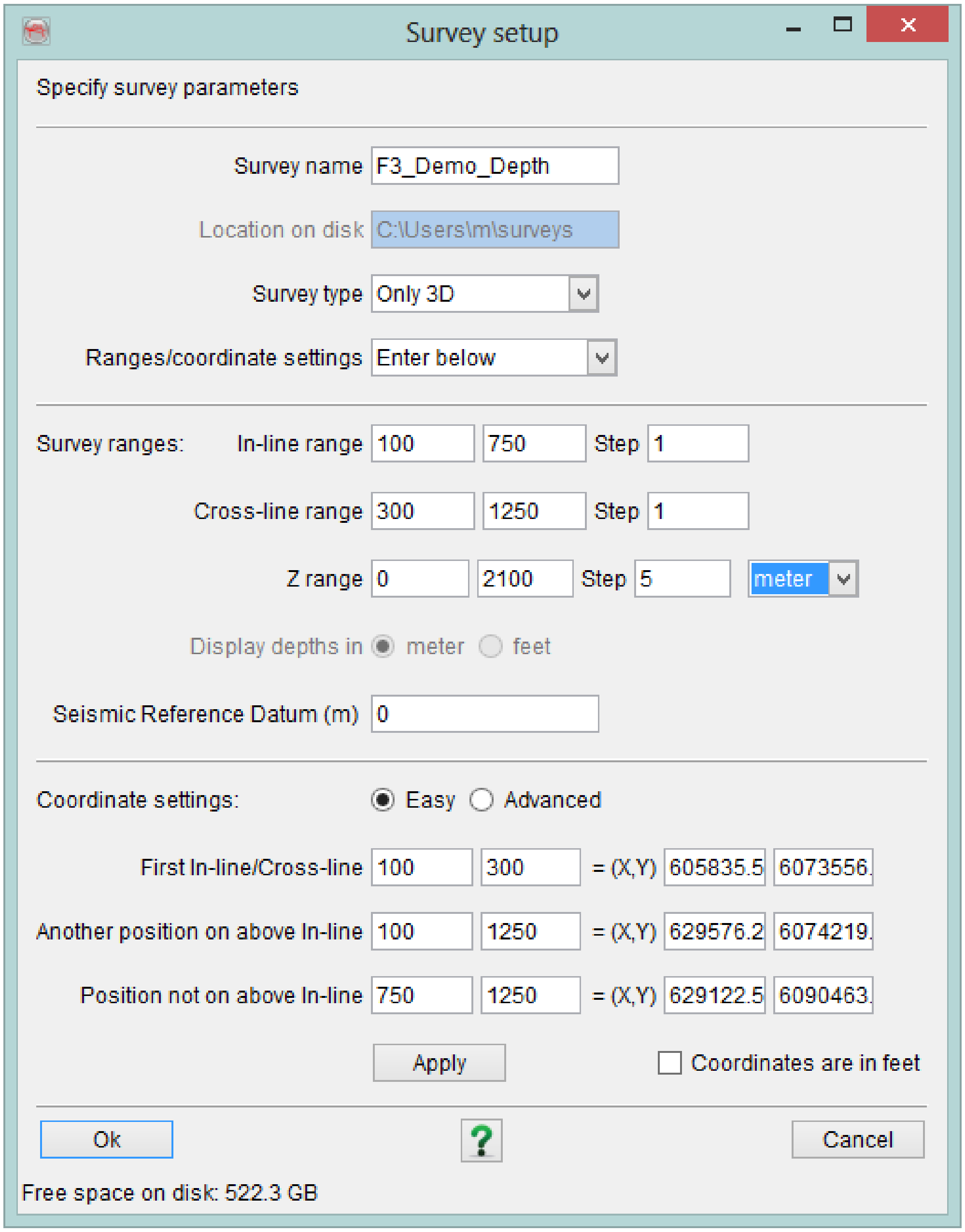
2. Give a name: F3_Demo_Depth



3. Copy from other survey …choose survey: F3_Demo



4. Change the Z range: 0-2100 step 5m > Ok



5. Press *Apply*, then *Ok*

Exercise

7. Import the Seismic in a CBVS format (it's OpendTect format for seismic volumes):

1. *Survey* > *Import* > *Seismic* > *CBVS* > *from file…*

2. Click on *Select*… and browse to the location of F3-Demo (Time survey)

3. Select the depth volume created before *(D-4_DSMF.cbvs*)

4. Keep the default *Use in place* (This means that the physical location of the cube will still remain in time survey)

In the same manner import horizons: 1. *Survey* > *Import* > *Horizon* > *Ascii* > *Geometry 3D…*

Display now your seismic and horizons in depth survey.

4 Dip-Steering

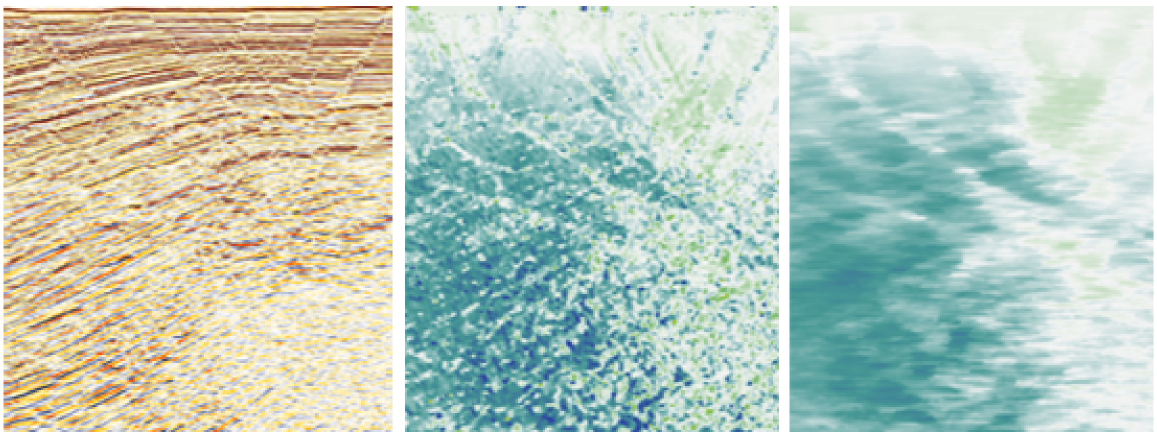
The dip-steering plug-in allows you to create and use a "(Dip-) SteeringCube". A SteeringCube contains the local dip and azimuth of the seismic events at every sample position. This plug-in requires a license-key. You may wish to contact info@dgbes.com to request an evaluation license.

The SteeringCube is used for:

- Structurally-oriented filtering (e.g. dip-steered median filter)
- Improving multi-trace attributes by extracting attribute input along reflectors (e.g. dip-steered similarity)
- Calculating some unique attributes (e.g. 3D-curvature, and variance of the dip).
- Dip-Steered auto-tracking of single horizons or multi-horizons as is done by the algorithm that creates HorizonCubes.

4.1 Detailed vs. Background SteeringCube

In this training, you will be creating several SteeringCubes. The differences between these cubes are in the algorithms used to calculate them and the use of filtering. SteeringCubes named 'Detailed' are unfiltered or gently filtered, while those named 'Background' are heavily filtered. Detailed SteeringCubes contain details such as dip associated faults or sedimentary structures. Background SteeringCubes contain only the structural dip.



Examples of (l-r): Original Seismic (Full stack), Detailed Steering and Background Steering

These Steering Cubes have distinct applications:

Detailed SteeringCube
- Dip & Azimuth attributes
- Curvature attributes
- Guide multi trace attributes (Similarity)

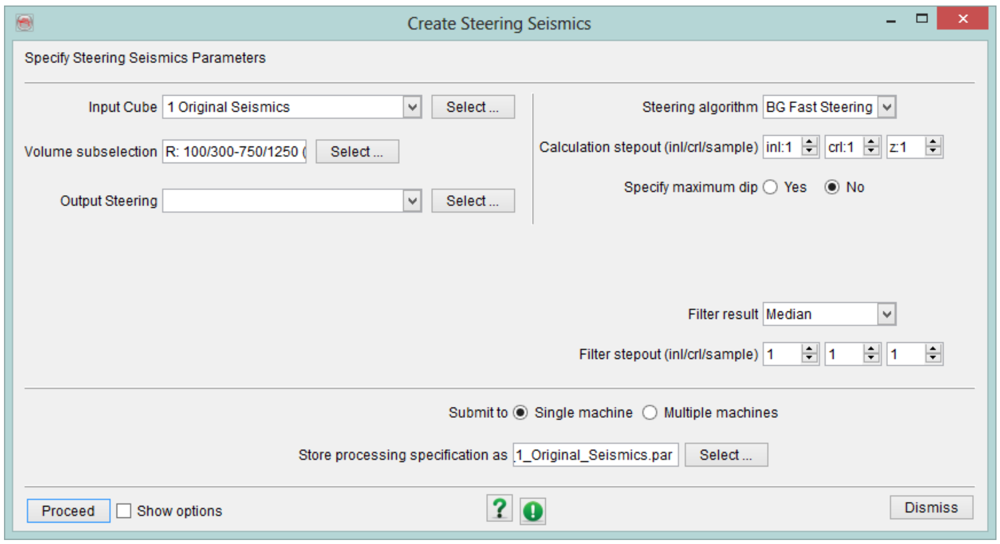
Background SteeringCube
- Dip Steered Median Filter
- Diffusion and Fault Enhancement Filter

More information about the SteeringCube on the dGB Plugins Documentation.

4.2 Detailed SteeringCube Computation

Exercise

1. Bring up the *Create Steering Seismics* window via *Processing* > *Dip Steering* > *3D* > *Create* or press the  button.



2. Select the *Original Seismic* as input and the BG fast steering as Steering algorithm

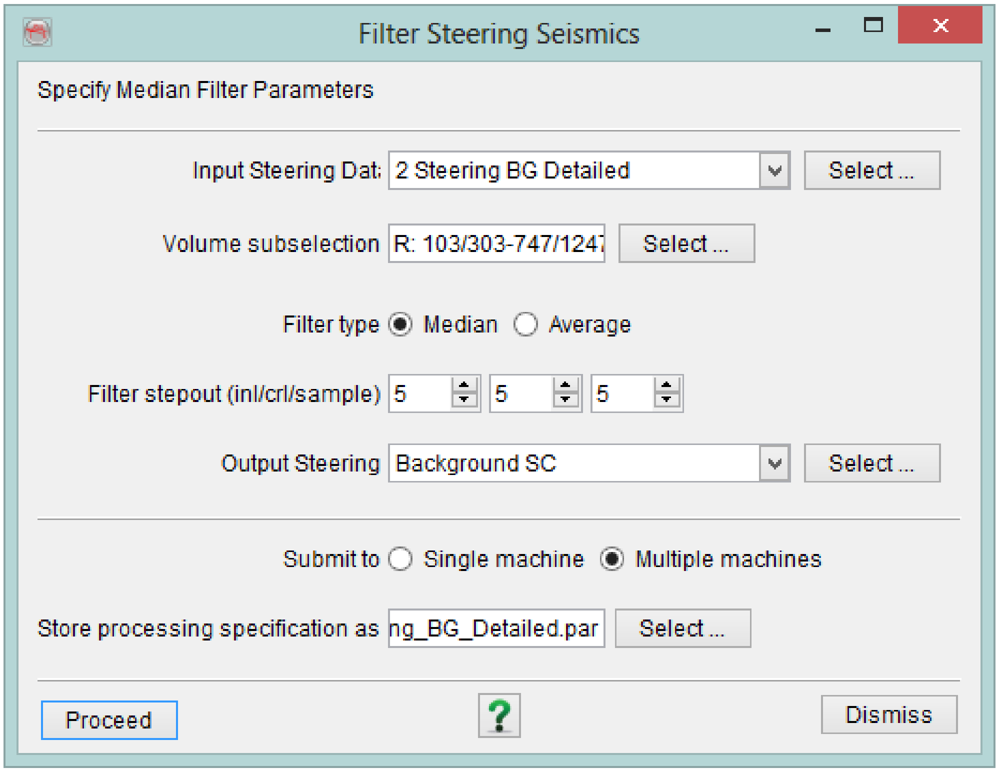
3. Use the default *Calculation stepout* 1, 1, 1. The dip is calculated within a small cube of 3x3x3 samples around each sample

4. A mild median filter with a stepout of 1, 1, 3 is used to remove outliers in the SteeringCube

5. Give the SteeringCube a name (e.g BG111_MF113) and click *Proceed*

4.3 Create Background Steering

1. Bring up the *Create Steering Seismics* window via *Processing > Dip Steering > 3D > Filter...*



2. *Input*: A background Steering is a detailed SteeringCube, filtered with a fairly large horizontal and vertical step-out. Therefore, select the *Detailed Steering* as input.

3. The filter stepout is inl:5/crl:5/sample:0.

> **Note:** this median filter is calculated along a horizontal square (of 11x11 samples), while the median filter used for calculating the *Detailed SteeringCube* was calculated in a vertical elongated block (of 3x3x7 samples).

4.4 Dip Attributes

The dip itself is an important attribute. There are several dip attributes, two of them are often used:

The polar dip or true dip: the dip is measured from the horizontal and the range of the dip is always positive and given in usec/m or mm/m.

The Azimuth of the dip direction is measured in degrees ranging from -180° to +180°. Positive azimuth is defined from the inline in the direction of increasing crossline numbers. Azimuth = 0 indicates that the dip is dipping in the direction of increasing cross-line numbers. Azimuth = 90 indicates that the dip is dipping in the direction of increasing in-line numbers.

Exercise

1. Go to the Attribute engine and select *Dip*
2. Chose *2 Steering BG Detailed* as input
3. Select *Polar dip* for output
4. Click *Add as new* and close the attribute engine (optionally save it)
5. Load *Horizon Demo 1 -> MFS4* by right clicking on Horizon in the tree > *Add…*
6. Compute the Polar dip attribute on the horizon: *Add* > *Attribute* > Select the one you just created i.e. Polar dip available in the Attribute section.
7. Change the color-bar to *Grey Scales*
8. Save the attribute layer by right clicking the attribute in the tree > *Save As Horizon Data*.

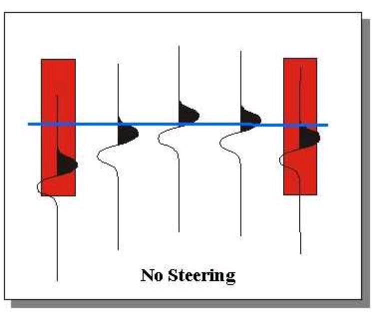
4.5 Dip-Steered Attributes

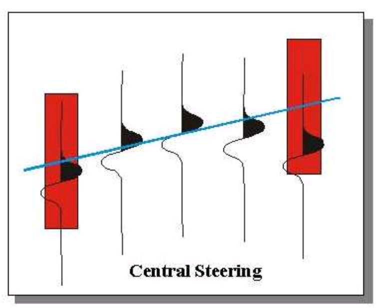
Directivity is a concept in which dip and azimuth information is used to improve attribute accuracy and object detection power.

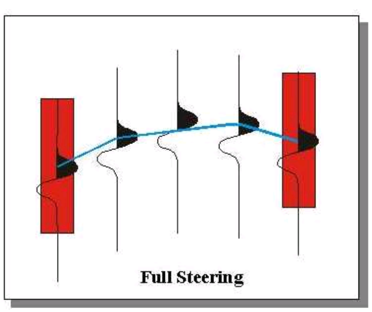
For example, let consider the calculation of a *similarity attribute*. This attribute compares two or more trace segments by measuring their distance in a normalized Euclidean space. Two identical trace segments will yield an output *value of one*, while two completely dissimilar trace segments will return the *value zero*. In a horizontally layered dataset this will work nicely, but in a dipping environment the results will deteriorate. So, instead of comparing two horizontally extracted trace segments we should follow the local dip to find the trace segments that should be compared. The process of following the dip from trace to trace is called *Steering*. It requires a *SteeringCube* as an input.

Steering

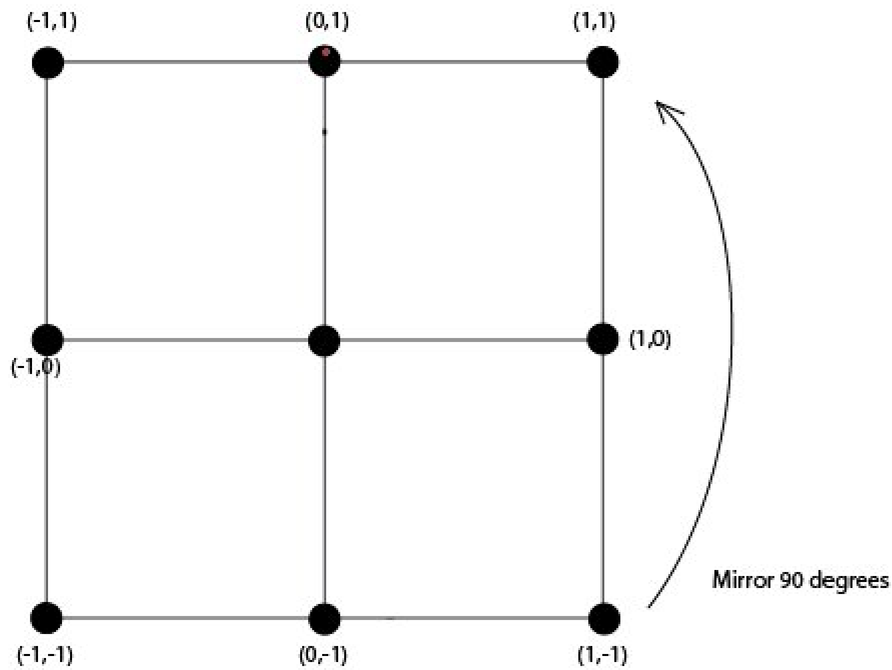
The dip-steering plug-in for *OpendTect* supports two different modes of data-driven steering: Central steering and Full steering.
In *Central* steering the dip/azimuth at the evaluation point is followed to find all trace segments needed to compute the attribute response.
In *Full* steering the dip/azimuth is updated at every trace position.
The difference between '*no steering*', '*central steering*' and '*full steering*' is shown in the following figures. Note that these figures show the 2D equivalent of steering, which in actual fact is a 3D operation.







The trace segments are defined by the time-gate in ms and the positions specified in relative co-ordinates. The extension parameter determines how many trace pairs are used in the computation. This is visualized in the image below.



Definition of trace positions relative to the reference point at (0, 0) (plan view, looking down onto Z)

Extension

With *None* specified, only the trace pairs specified in Trace positions are used to compute the output. *Mirror at 90 degrees* (not available when input is 2D data) and Mirror at 180 degrees means that two similarities are computed: for the specified trace pair and for the pair that is obtained by 90 or 180 degrees rotation. When using *Full block* as extension, all possible trace pairs in the rectangle, defined by inline/cross line step- out, are computed. The attribute returns the statistical property specified in *Output statistic*. For a full description of the *Extension* options, see the *Similarity* attribute entry in the OpendTect User Documentation.

Exercise

Similarity Attribute

1. Fire-up the Attribute engine and select *Similarity*

2. Keep the default time-gate [-28,+28]

3. Select *Extension : Mirror 90 degrees*

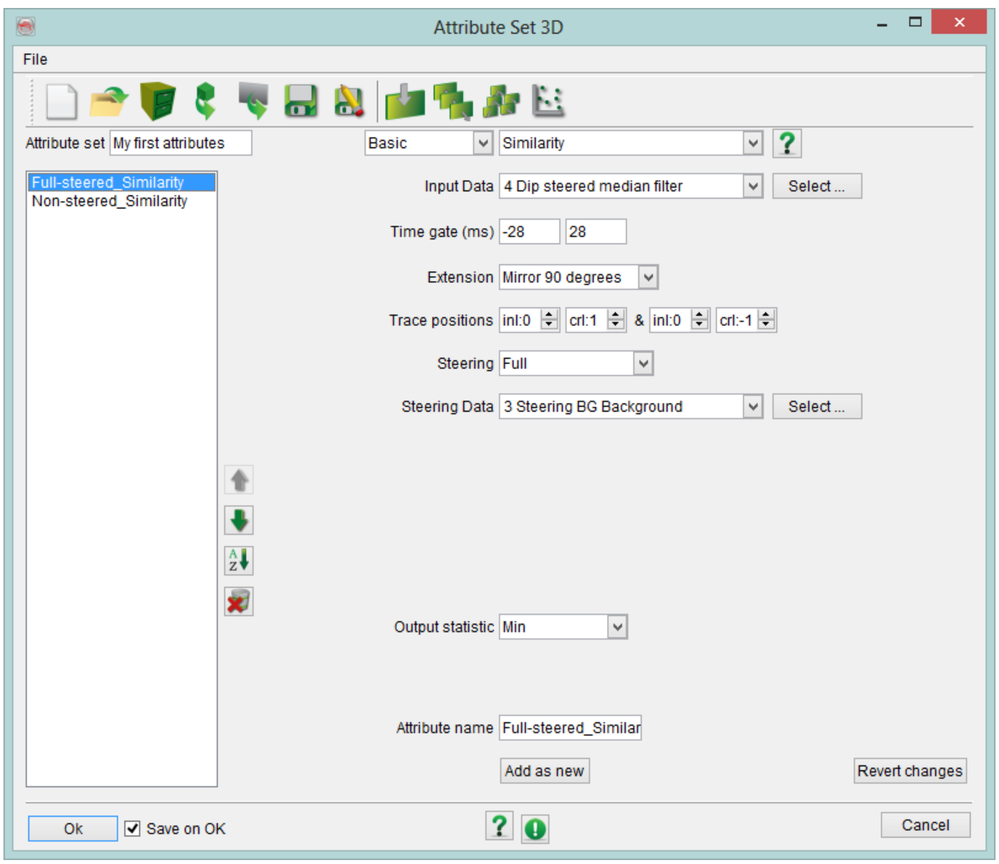
4. Keep the default trace positions (inl:0;crl:1)&(inl0;crl:-1)

5. Select *Min* for *Output statistics*

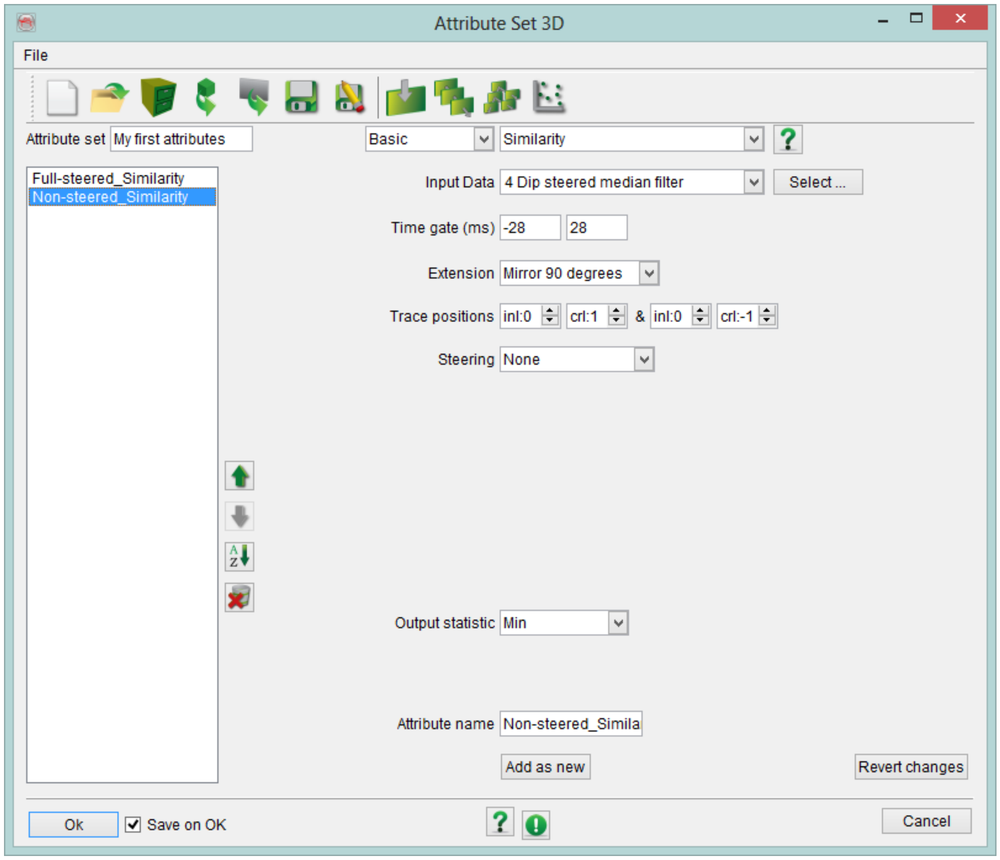
6. Select Steering *Full > 3 Steering BG Background*

7. Give it a name (FS_Similarity) and click *Add as new*

8. In a similar way, define a *non steered Similarity* in selecting *Steering: None* in this case.



Steered Similarity



Non-Steered Similarity

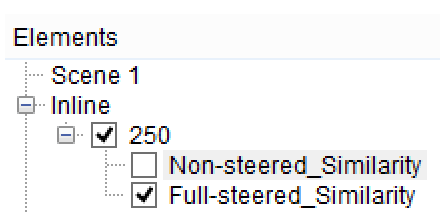
Exercise

Display & Investigate:

1. Display on a single inline (250) the seismic data, the *steered* and *non-steered* similarity attributes

2. Change and flip the color-bars of the similarity attributes

3. What is the influence of dip steering?



4.6 Dip-Steered Median Filter (DSMF)

OpendTect supports quite a few filters to enhance data and reduce noise. Filters applied along the calculated dip and azimuth are called *dip-steered filters* (aka structurally-oriented filters) In the following exercise you will construct *edge-preserving dip-steered filters* that are capable of reducing random noise and enhancing laterally continuous events. The filters collect their input in a curved disk that follows the local dip and azimuth. The dip steered median filter outputs the median value of the input amplitudes at the evaluation point. (See dGB Plugin Documentation for more information)

1) CreateDSMF Filter

To apply a dip-steered median filter to a seismic data set, you need to define an attribute of type "*Volume statistics*":

Exercise

1. Start the attribute engine

2. Select *Volume Statistics* as attribute type

3. Input Data: *1 Original Seismics*

4. Time gate: [0,0]

5. Shape: *Cylinder*

    Note: A time-gate of [0,0] means that effectively the filter input is collected along a disk (cylindrical or round). Full steering means that the disk is curved according to the local dip information.

6. Set the step-out (=radius) to 1x1. (The optimal step-out will be evaluated later).

7. Min nr of valid traces: 1

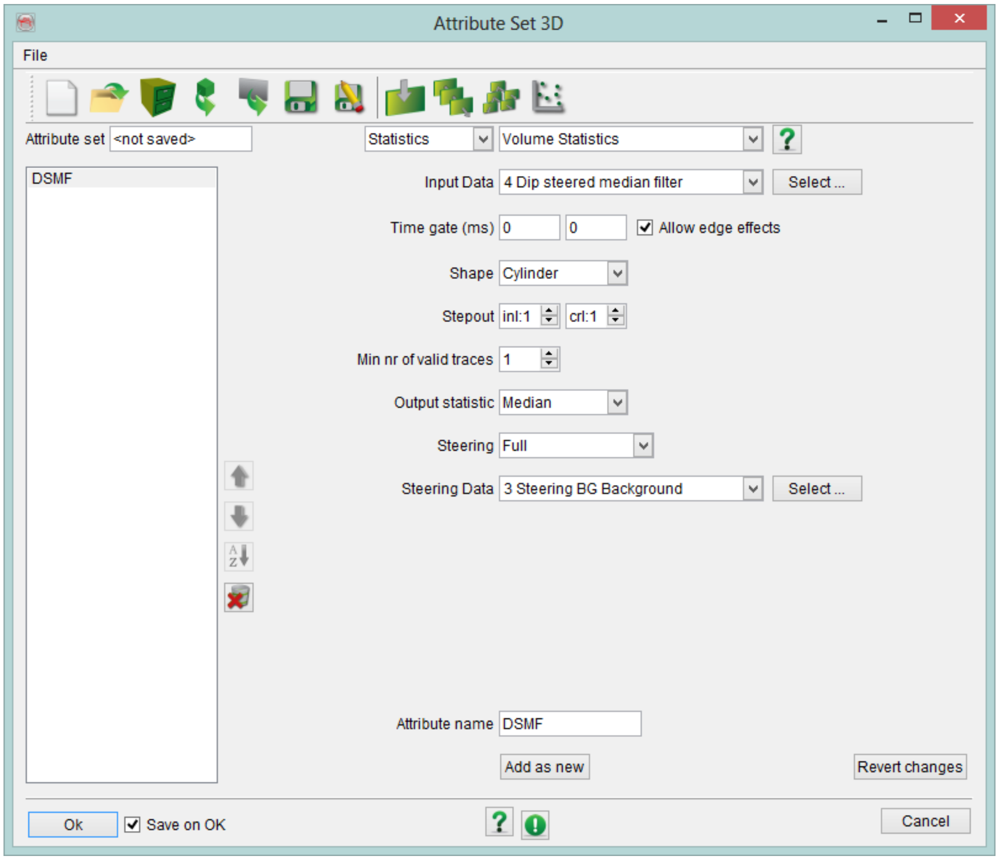
8. Output statistics: *Median*.

9. Steering: *Full > 3 Steering BG background*. You need to use a background SteeringCube

10. Use the attribute evaluation tool  to evaluate the step-out: initial value 0-0, increment 1-1, and 5 slices.

11. Once the computation is done, move the sliders to change the stepout value and see the impact in the scene.

Which step-out is best (removing random noise, but not too much smearing)?



Dip steered median filter (DSMF)

2) Compute Residual

Exercise

To see how much noise is actually removed by the filter, you can subtract the filtered seismic data from the input data. We will do this calculation on-the-fly as follows:

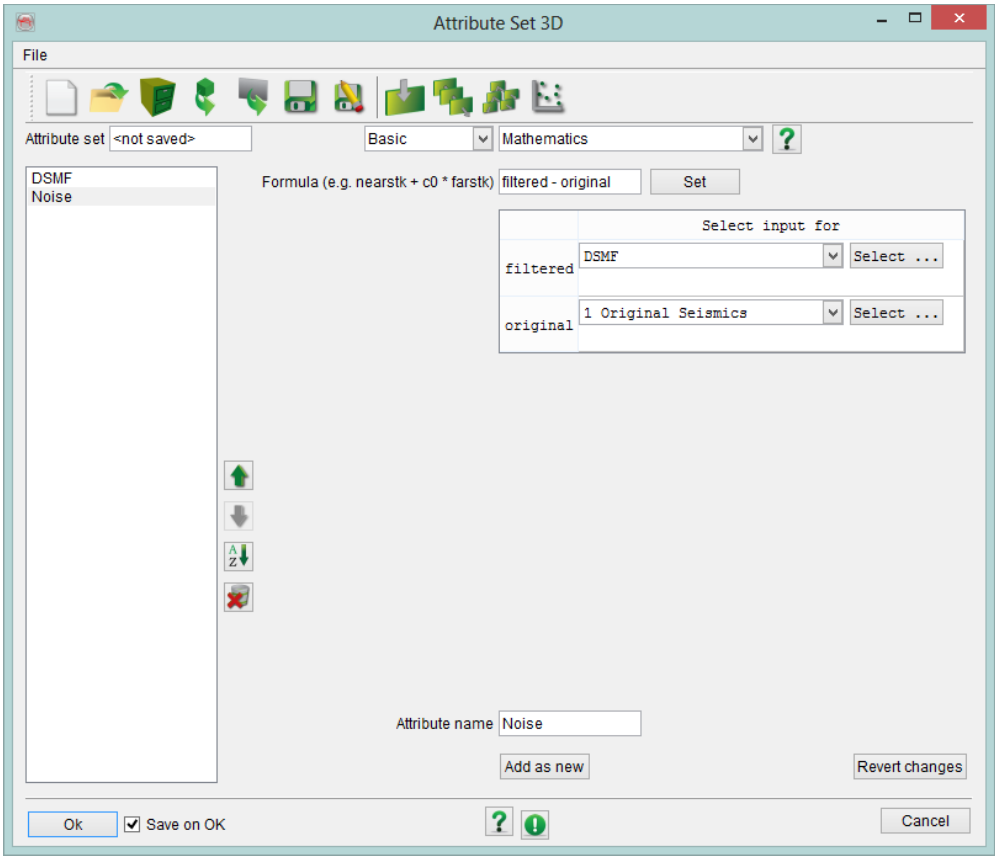
1. Define another new attribute, this time of type *Mathematics*.

2. Define the formula e.g. : *filtered – original*.

3. Specify the previous attribute definition as input for “*filtered*” and the

stored volume "*1 Original Seismics*" for "*original*" and call this attribute "*Noise*".

4. Apply *Noise* to the same section to see what the dip-steered median filter has removed.



Noise

4.7 Dip-Steered Diffusion Filter (DSDF)

The *dip-steered diffusion filter* is used to replace low quality traces by neighbouring traces of better quality. This migration will be performed using a *Similarity* attribute.

To apply a dip-steered diffusion filter to a seismic data set you first need to define *similarity* and *dip-steered median filter* attributes separately. The dip-steered diffusion filter is an attribute of type *Position*:

Exercise

1. Start the attribute engine

2. Optionally, define Similarity or use the attribute set where it is already defined (see section 4.4)

3. Specify Position as attribute type

4. Input seismic: *Similarity* (attribute or cube previously created)

5. Set the step-out (=radius) to 1x1. (The optimal step-out will be evaluated later).

6. Time gate: [0,0]

7. Steering: *Full > 3 Steering BG background*

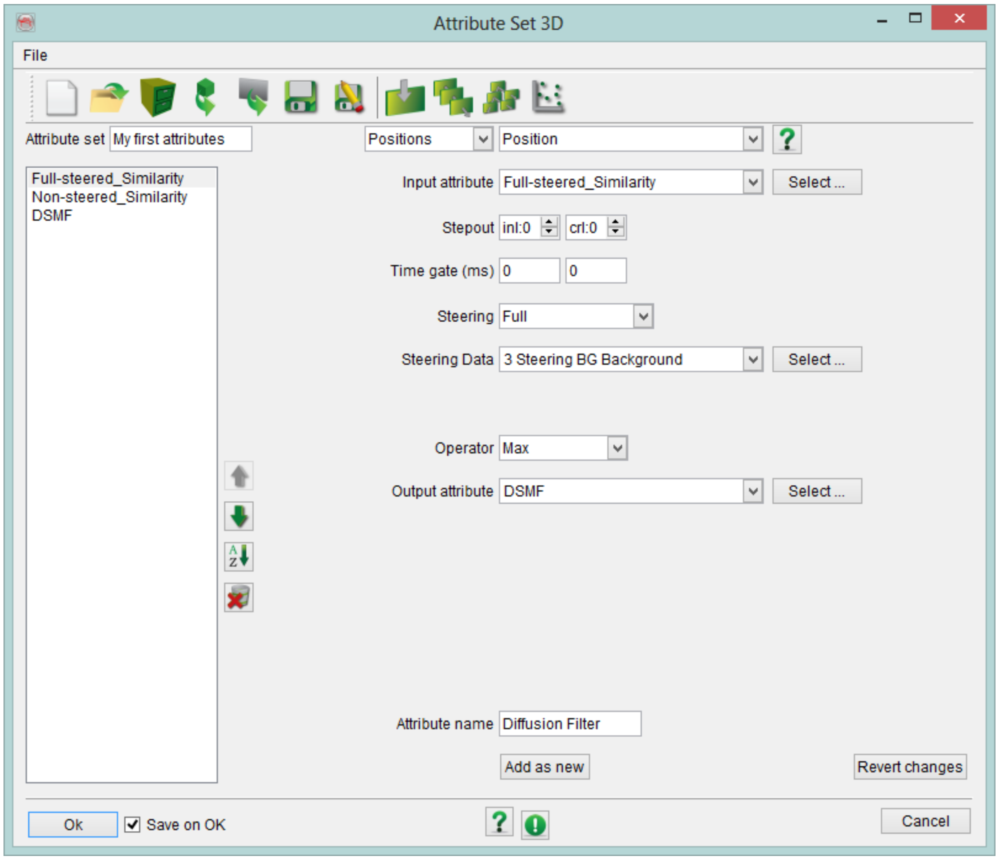
8. Operator: *Max*.

9. Output attribute: *4 Dip-steered median filter* (attribute or cube previously created)

10. Now use the attribute evaluation tool  to evaluate the step-out: initial value 0-0, increment 1-1, and 5 slices.

11. Once the computation is done, move the sliders to change the stepout value and see the impact in the scene.

    Which step-out is best (removing random noise, without creating too many artefacts)?



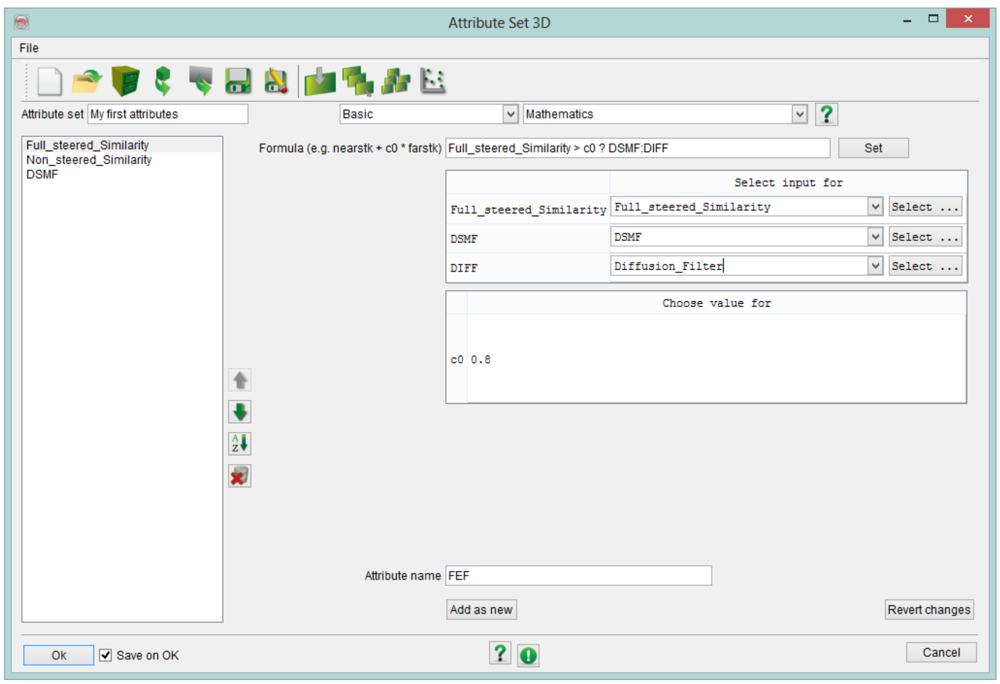
Dip steered diffusion filter

4.8 Fault Enhancement Filter (FEF)

The fault enhancement filter is a combination of dip-steered median filter and diffusion filter, modifying the seismic volume to enhance fault visibility. The filter is released with the software as one of the default attribute sets as either:

- *Fault Enhancement Filter:* all basic attributes needed as inputs for the filtering are shielded and the user can only control the amount of smoothing (dip-steered median filter) versus sharpening (dip-steered diffusion).

- *Fault Enhancement Filter (expert):* the full attribute set definition is shown and can be modified.



Fault Enhancement Filter

Exercise

1. Create a *Fault Enhancement Filter* by retrieving the attribute set with the same name from the default attribute sets 

2. Specify *1 Original Seismics* and *3 BG Steering Background* as inputs

3. Apply the *Fault enhancement filter* to a small area (Z slice 1640ms between inlines 120-400 and crosslines 350-600)

4. Add two Dip-steered Similarity attributes to your attribute set: one with "*1 Original Seismics*" as input and the other with the "*Fault Enhancement Filter*" attribute as input

5. Apply both Similarities to the Z-slice and compare the results

Evaluation of constant C0:

At a given position, if the similarity is higher than the *C0* value, then the *Dip Steered Median Filtered seismic* is used and the *Diffusion filtered seismic otherwise*. Thus *C0* is a critical parameter.

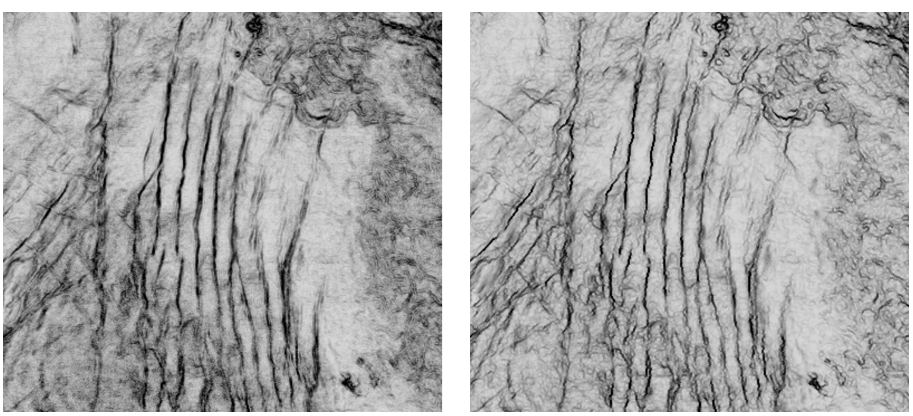
6. If the differences are not clear enough, you may want to improve your Fault enhancement attribute by evaluating the constant *C0*.

7. Open your attribute set and click on  to evaluate the constant *C0*

8. Evaluate different constants starting with an initial value (*C0*=0.1 to *C0*=0.9). Which constant shows the best result? (more faults visible and less noise)

10. Click on 'Accept' to save the constant *C0*.

11. Compare your new Fault enhancement attribute with the similarity attribute computed from the raw seismic data (as shown below)



A comparison between minimum similarity computed from original seismic (left) and fault enhancement filtered seismic (right).

> **Note:** The complete workflow is described in the *How to Manual*: http://www.dgbes.com/index.php/support.html

4.9 Attributes for Faults & Fractures

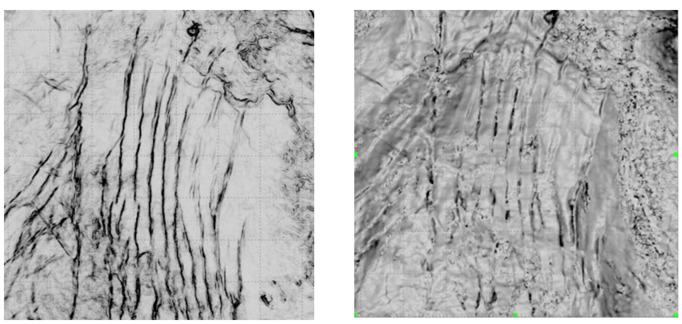
Exercise

1. Load Z slice 1640 between inlines 120-400 and crosslines 350-600.

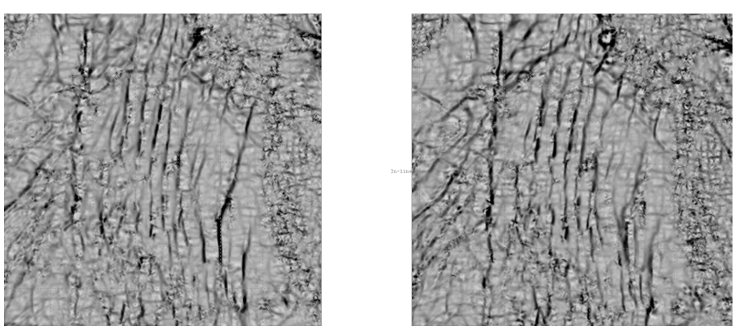
2. Define several attributes (attribute set) that highlight faults.

- Similarity
- Polar Dip
- Curvature (most positive, most negative, curvedness…)
- Similarity (steered and non-steered) on original, DSMF, FEF volumes

3. Display and compare the different attributes. What do they highlight, and why? Which attributes are best under what circumstances, and for which purpose (fault or fractures)? See examples below.



Minimum similarity time slice (left) and Polar Dip (right).



Most Negative Curvature (left) vs. Most Positive Curvature (right)

4.10 Ridge Enhancement Filter (REF)

Meta-attributes, i.e. attributes and filter responses that are combinations of multiple input attributes can be created in *OpendTect* by neural networks or by applying mathematical and logical operations. An example of the latter is the so-called '*Ridge Enhancement Filtering*' attribute set that is delivered with the software as a default set.

The set calculates similarity attributes at 9 locations surrounding the evaluation point. Then it compares the differences between similarity values in 4 directions. The direction perpendicular to a fault usually exhibits the largest difference and is therefore output as the Ridge-enhancement attribute. The effect is a sharper outline of the faults.

> **Note:** with only minor modifications, this attribute can also increase resolution of other attributes like curvature, or volumes as fault probability volumes.

Exercise

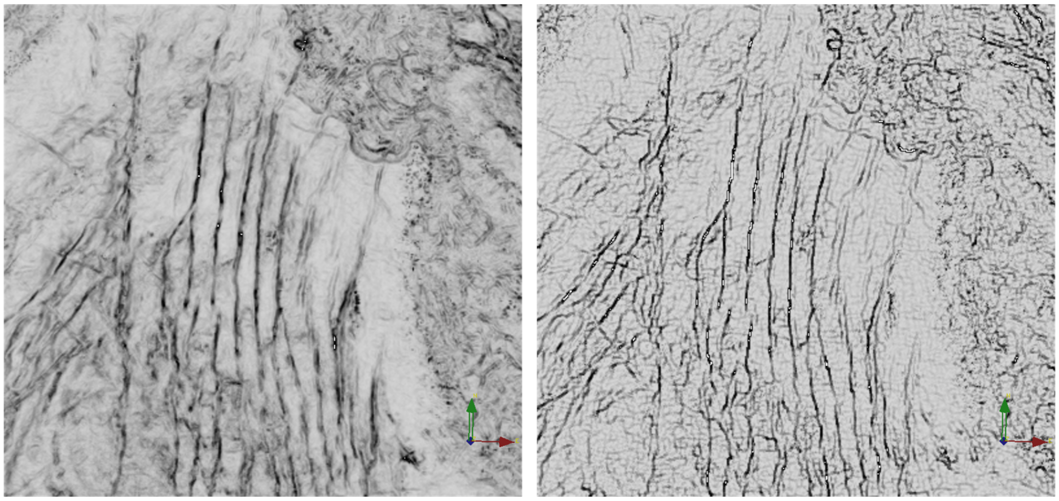
1. Open the attribute engine

2. Open the default attribute set  and select *Ridge Enhancement filter*

3. Select *4 Dip steered median filter* for Input seismic and *3 Steering BG Background* for Input Steering.

4. Store it in the project under the name "*Ridge enhancement filter*". Apply this set to the Z slice of the previous exercise

5. Compare the results with the attributes of the previous exercise.



A comparison (Z-slice1640ms-Section 4.7) of minimum Similarity (left) and Ridge Enhancement Filter (right): linear features have become sharper after applying Ridge Enhancement filtering.

5 Frequency Enhancement (Seismic Spectral Blueing)

Seismic Spectral Blueing (SSB, by ARK CLS) is a technique that uses well data to shape the seismic spectrum to optimize the resolution without boosting noise to an unacceptable level.

The workflow is as follows: An Operator is designed for both SSB using the seismic and well data. Once the operator has been derived, it is converted to the time domain and simply applied to the seismic volume using a convolution algorithm.

Our aim is to design an operator at the zone of interest (target). It is therefore desirable to time gate the selected traces prior to generating well log spectra. Ideally you should use a good interpreted horizon in the target zone to guide the well data (log traces). In this manner, the various gated log traces should have sample values over a similar geology. However, in our case we will just use a window interval instead.

Here is the workflow for how to create and apply these techniques in *OpendTect*:

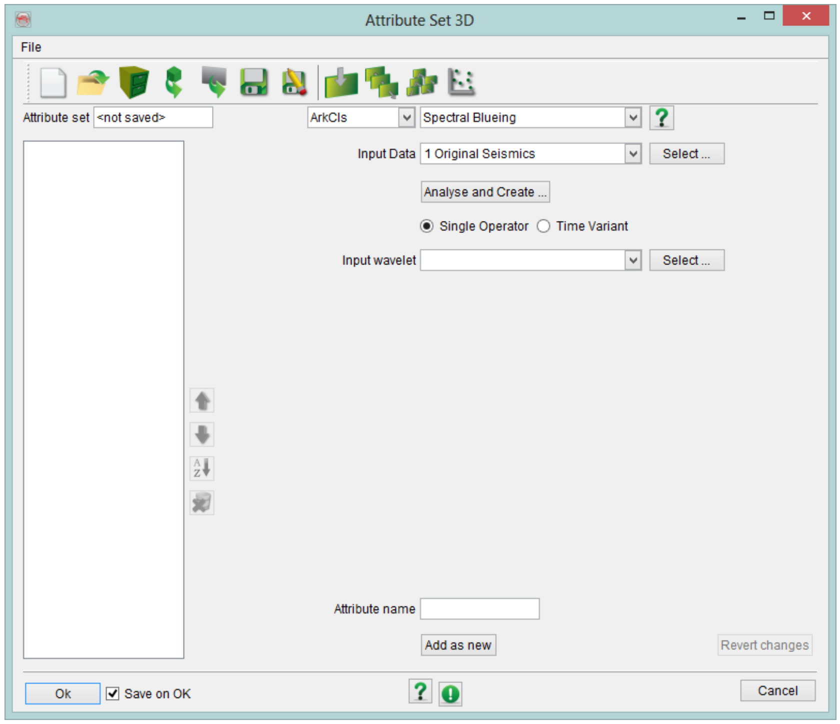
1. Seismic: Amplitude-Frequency plot
2. Smoothing of seismic mean
3. Well: Amplitude-Frequency plot
4. Global trend of well plot
5. Design operator
6. Apply Operator
7. Quality Check

Exercise

1. Launching the Spectral Blueing Module

a. From within *OpendTect* main window click menu *Analysis>Attribute> 3D* or click the  icon to pop up the

Attribute Set Window (figure below)
b. Select Spectral Blueing in the Attribute type list to show the parameters required for this attribute
c. Click *Select*... to the right of the *Input Data* label to pop-up a dialog to allow the input volume to be selected and select *1-Original Seismic*



d. Click on '*Analyze and Create ...*" to launch the SSB Module.

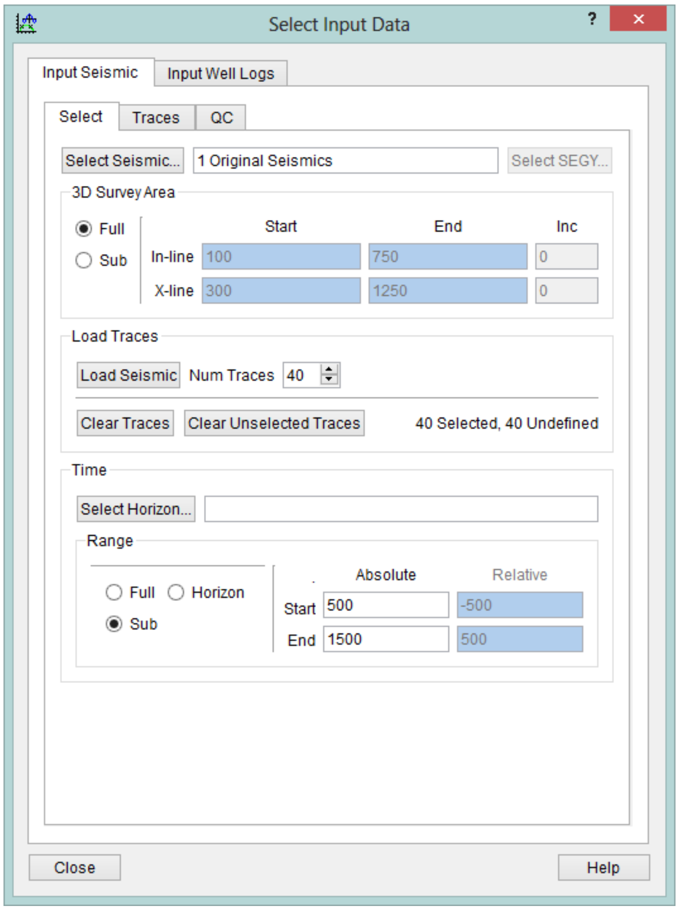
2. Selecting Input Data

To use the SSB application to design an operator, it is first necessary to analyze the seismic and well data spectra. This is achieved by loading some seismic trace data and well log impedance data in time.

a. Selecting Seismic data

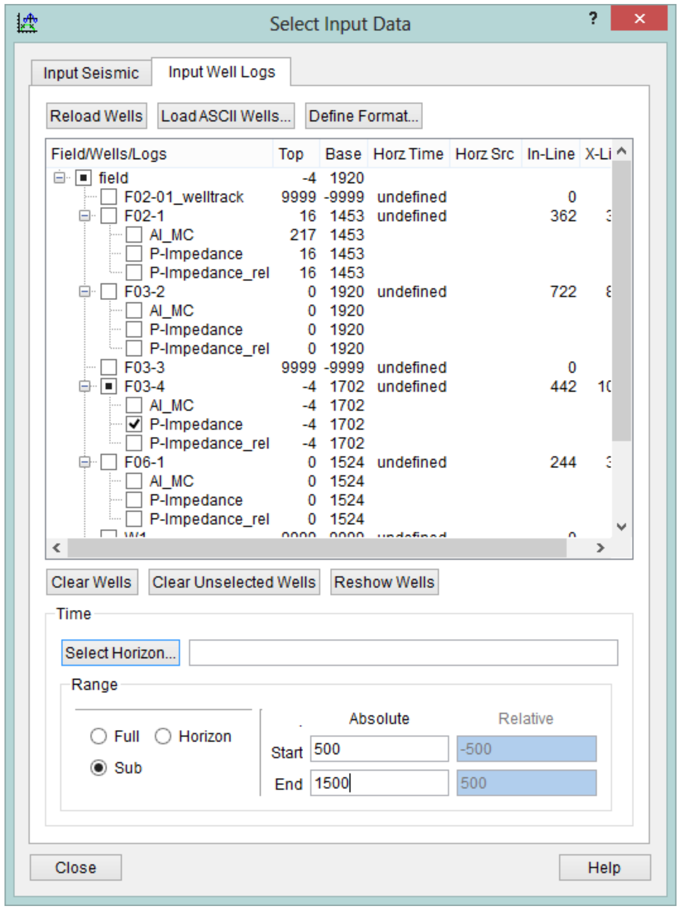
i. Pop up the "*Select Input data*" menu item under the Tools menu bar or click the  icon

ii. Click on *Input Seismic* tab to Select *1-Original Seismic*
iii. "*Load Seismic*" to load the default “40 traces”
iv.. Set the range to *Sub* (Interval length should be 500ms to 1500 ms long)



b. Selecting Well data

i. Click on Input Well Logs tab.
ii. Click 'Load wells', then select the well F3-04. Right-click on the well to generate an Acoustic Impedance log if it is not loaded yet.
iii. As for Seismic, set the range to Sub (Interval length should be 500ms to 1500 ms long), then close the "Select Input Data" window.



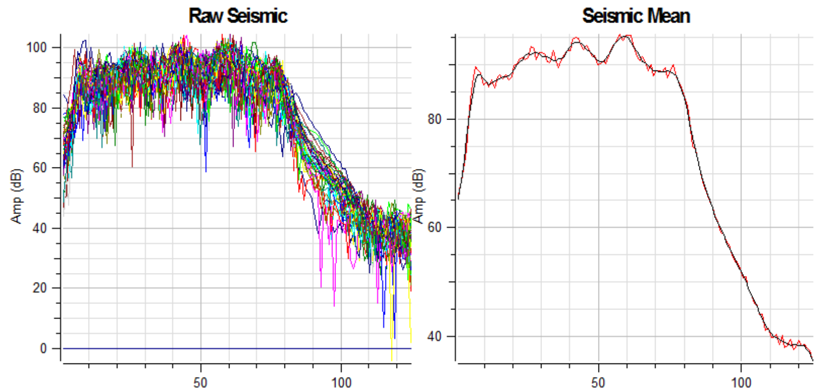
3. Design Operator Dialog

Various parameters exist which allow you to perturb how the operator is generated. These changes occur in real time so you will be able to see immediately the effect of the change you have made.

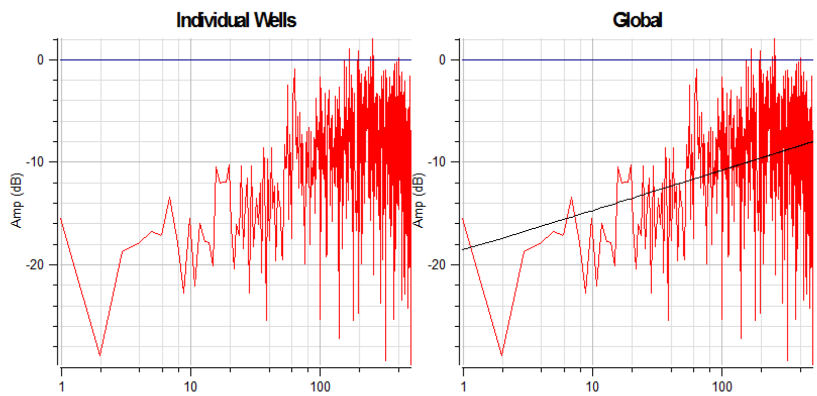
Exercise

a. Pop up the *Design Controls Dialog* by either clicking the Design Controls... menu item under the Tools menu bar or by clicking the  icon.

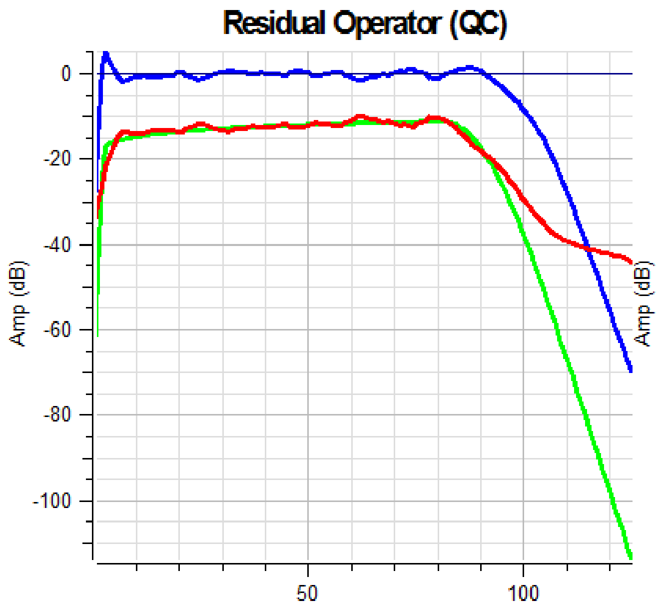
b. Smooth the amplitude-frequency plot of seismic data (seismic mean)



c. Smooth the amplitude-frequency plot of well data

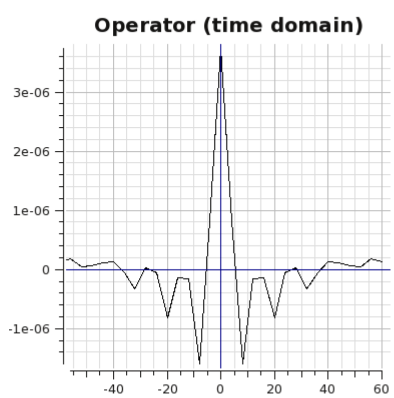


d. Tweak the parameters (low cut, high cut) of the design operator (image below) such that the operator (blue curve) stays 0 in the frequency domain, with a quick drop on both sides. The effect of the parameter tweaking is immediately visible on the seismic display that is updated automatically. Note e.g. the seismic ringing that is introduced when the residual operator is not flat in the low frequencies (Low cut parameter in the 0-8Hz range).



e. If the QC operator has not got the desired shape, parameter settings in the spectral blueing workflow must be changed, until the correct QC operator shape is established

f. Save the operator  by giving it a name.



g. You can optionally save your session  as well. Apply the design operator on the inline 425, compare the result with the original seismic data, if satisfied create a volume output.

6 Flat-Spot Detection

Various methods have been developed to detect locally horizontal seismic events, which do not follow the stratigraphy of the geological layers. These events are potentially Direct Hydrocarbon Indicators, since fluid contacts will most often be perpendicular to the pressure gradient, regardless of the structural dip. Multiples will most often also not follow the local stratigraphy, and are a false positive for these detection methods, since they will also be enhanced should they be horizontal seismic events.

6.1 Optical Stacking

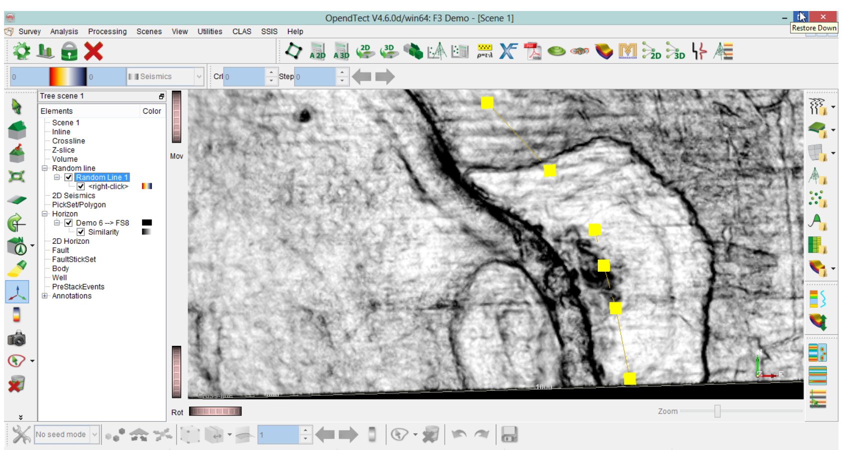
Optical stacking is historically the first method to have been developed. It will stack the seismic traces that are on either side of a 2D profile. It thus starts from the principle that a 2D profile has been made, through the structure by crossing the contour lines perpendicularly. The stratigraphy is then in the profile direction, whereas in the perpendicular direction the events should be flat.

Exercise

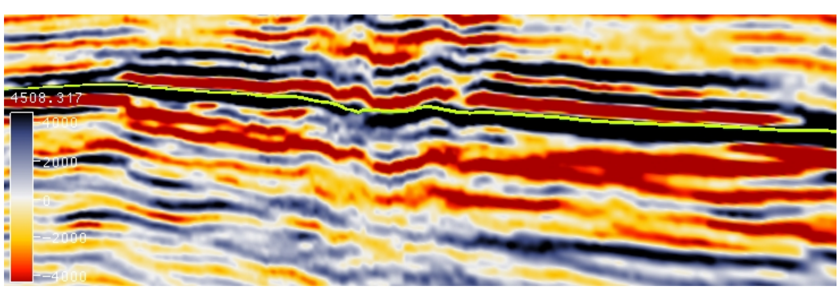
1. Open a surface… right-click on *Horizon > Add... Demo 6-->FS8*

2. Display a *Similarity* attribute on this surface

3. Pick a *Random-line* interactively going through the structure where the amplitude anomaly was previously seen. *Save* the new random line.



4. Display the seismic data along the random line "*4 Dip steered median filter*", with the horizon displayed at section:



5. Define the Optical stacking attribute: Type: Volume statistics; Time gate: [0, 0]; Shape: Optical stack; Stack stepout: 15 (x the bin size of 25m = 375m). Apply it along the profile (remember how to evaluate interactively the stepout).

Discuss the results: What events have been preserved, what events have been enhanced, why?

6.2 Seismic Feature Enhancement

The seismic feature enhancement plugin by Ark-CLS is an improvement of the optical stack. The concept is similar, with the exception that a few traces in the profile direction may also contribute to the stack. The interpretation must thus select one stepout for the perpendicular direction, and a second stepout in the line direction. Furthermore the plugin contains a dedicated user interface to interactively choose the stacking parameters.

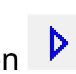
Exercise

1. Start the plugin from the Analysis menu: *ARK CLS Utilities > Seismic Feature Enhancement*. (Note the similarities in the user interface with the *Seismic Spectral Blueing* plugin.)

2. Display the node positions of the random line: Right-click on the random line > *Display > Edit nodes*.

3. In the SFE main window , press the “*Select Data*” icon . Choose the input seismic volume “*4 Dip steered median filter*”, provide an output volume name. Input the same node positions as seen in Step 2 (Or digitize the random line by picking a polygon that you can select as input for the “Traverse”). Close both the *Select Data* and *Edit Nodes* windows.

4. Press now the “Aperture design” icon. Select a similar stepout as in the previous exercise: 375m (normal aperture). Set the traverse parallel aperture size either to 0 (same as optical stack), or leave it to a small value like 75m. Close the window.

5. Apply SFE by pressing the “*Preview SFE*” icon . Look at the Seismic display (zoom forward/backward with *Ctrl+Mouse* wheel).

6. Press *Start* to run the SFE processing and save the result on disk.

6.3 CCB - Fluid Contact Finder

The CCB - Fluid Contact Finder (Common Contour Binning) plug-in enables a seismic detection workflow that stacks seismic traces with respect to the depth of a surface. The objective is to detect subtle hydrocarbon-related anomalies and to pin-point contacts (GWC, GOC, OWC).

It is based on the following principles:

- The seismic traces that penetrate a hydro-carbon bearing reservoir at the same depth (i.e. that lie on the same depth contour line) have identical hydrocarbon columns.
- Stacking traces along these contour lines thus enhances possible hydrocarbon effects while stratigraphic variations and noise are canceled.

This plug-in outputs a new 3D volume with stacked traces along contour lines replacing the input traces, and a CCB stack display (2D section with stacked traces) displayed in a 2D viewer. The CCB stack display has two options: *flattened* and *non-flattened*. The latter is easier for detecting flat spots which are horizontal events in this display. CCB can also be used in pre-stack analysis and for enhancing 4D anomalies (local CCB option).

Exercise

Prospect Identification and Data Preparation

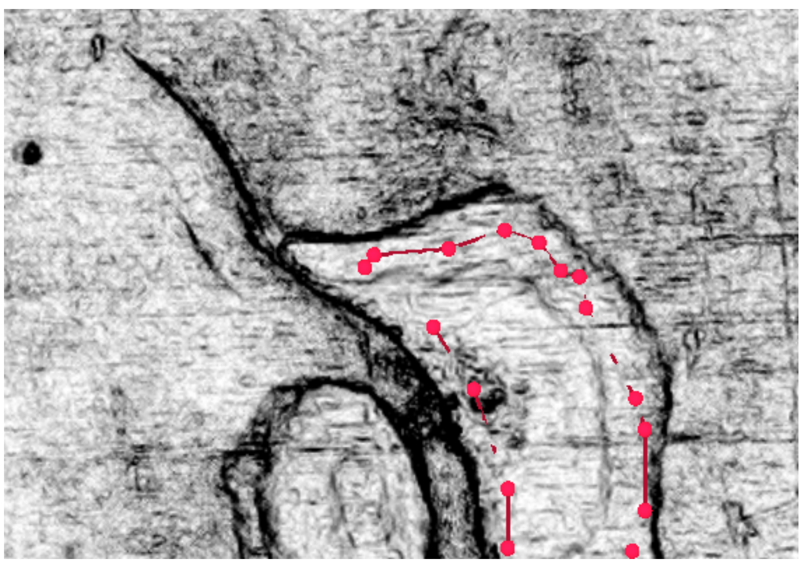
The CCB - Fluid Contact Finder plug-in must be used with precaution since its application to an entire survey would be meaningless. A major preparation step is the identification of the individual structural traps, which normally will have trap-specific fluid contacts. This is especially important in case of an overall structure that is separate in individual compartments by non-communicating faults. Identification of compartments can be done by looking at Z-slices or horizon grids of similarity, using the following workflow:

Delimitation of an area:

1. Open a surface... right-click on *Horizon> Add> Demo 6-->FS8*
2. Display a similarity attribute along this surface:

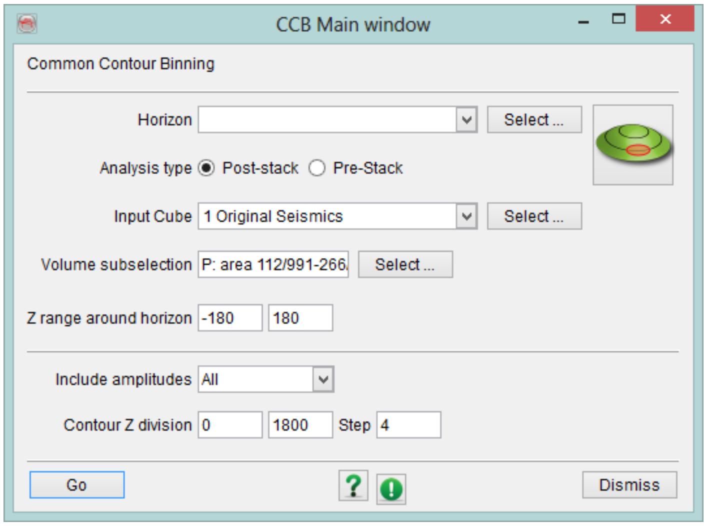
3. Create a new polygon: In the tree scene right-click on “*Pick-Set/Polygon*”, and select *New Polygon*... Provide a name like "CCB-FS8", then Click *Ok*.

4. In interact mode create a polygon around the structural trap located around position inline 200, crossline 1075 on *FS8* by clicking (left mouse button) on the surface. The picked locations appear as dots. Once the polygon is finished right-click in the tree scene on the polygon. Use the option “*Close Polygon*” and “*Save*” to store your polygon.



CCB Application:

5. Open the CCB Main window from the corresponding icon in the OpendTect tools toolbar, or via the *Analysis* Menu.



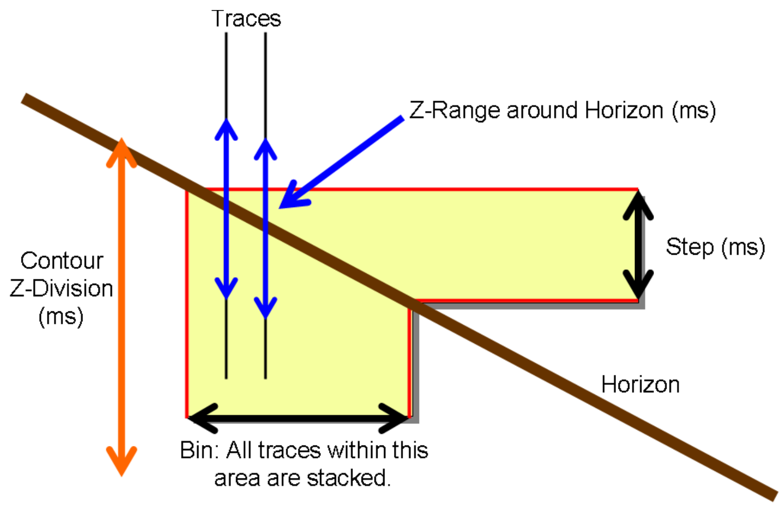
6. Select the *FS8* horizon used to generate the polygon and select the seismic volume.

7. In the Volume Sub-selection window, select the option "*Polygon*" and the previously created polygon.

8. For the first test, the contour Z division can be left as the entire Z survey range. This can be restricted afterward. The step-size defines the contour interval. All traces that lie within the contour interval are stacked, hence the step-size controls the bin-size.

9. The Z range around horizon needs to be defined. This is the interval around the horizon that will be stacked.

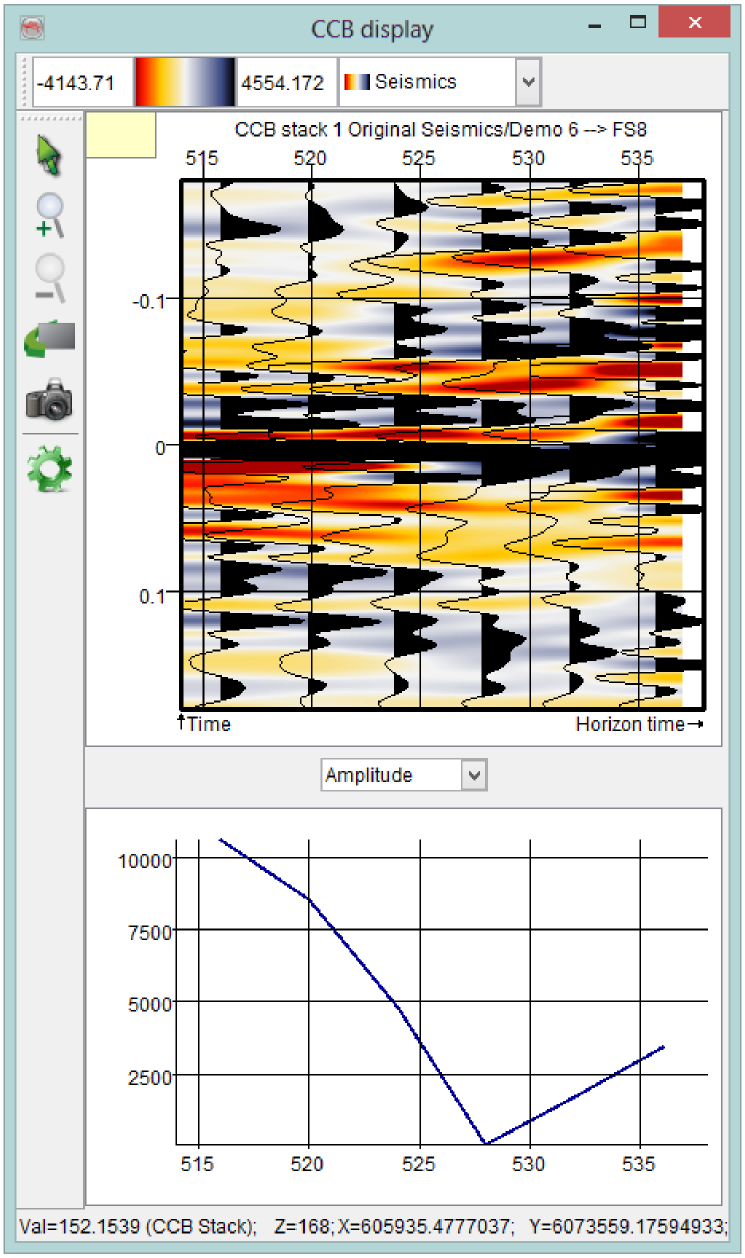
Once this main window is entirely filled pressing the "*Go*" button will launch the extraction and clustering of the seismic data. Once this operation is finished the CCB Analysis window appears with a chart. This chart presents the number of collected seismic traces per bin and the total number of collected traces N:



The CCB analysis window allows launching of the following processes:

- All collected traces of a single bin can be displayed sequentially in a 2D viewer with the option "*Display: Single Z*".
- The stacked traces can be displayed in another 2D viewer. The X-Axis n this display represents contour-time or depth of the bin where the traces were collected. Use option "*Display: Stack*" to do this. Stacking can be normal (sum of all traces divided by the number of traces per bin) or weighted by the RMS value of the seismic traces.
- The stacked traces can be stored in a 3D volume were the original seismic traces are replaced by their corresponding stacked trace.

The CCB main window remains open when performing the CCB analysis. This allows multiple CCB analyses and simultaneous opening of multiple 2D viewers for quick comparisons.



Exercise

Apply local CCB from the so-called attribute with a stepout similar to the optical stacking. Compare the three methods. Which one is best, when?

7 Seismic Object Detection Using Neural Networks

The Neural Networks plug-in to *OpendTect* supports Supervised and Unsupervised Neural Networks. The Supervised Network is a fully-connected Multi-Layer Perceptron (MLP) with one hidden layer. The learning algorithm is back-propagation with momentum and weight decay. Momentum is used as a filtering of the step directions in the gradient decent algorithm, which has a positive effect on training speed. Weight decay is a method to avoid over-fitting when training. Weights are multiplied by a weight decay factor to reduce the weight values, which results in smoother functions with improved generalization properties. The program sets the number of nodes in the hidden layer.

The Unsupervised Network is the Unsupervised-Vector-Quantizer (UVQ). This Network is first trained on a representative set of input vectors (attributes extracted at different locations) to find the cluster centers. Each cluster centre is then represented by a vector. Before the Network is saved, the software sorts the cluster centre vectors on similarity. This has the advantage that in the application phase colors are distributed smoothly over the cluster centers resulting in smoother images which are easier to interpret. In the application phase, each seismic input vector is compared to all cluster centre vectors yielding two possible outputs: Segment and Match. Segment is the index of the winning cluster centre. Match is a measure of confidence between 0 (no confidence) and 1 (input vector and winning cluster vector are identical).

The UVQ Network is used in exercise 7.1 to visualize seismic patterns at one of the mapped horizons. The MLP Network is used in exercises 7.2 and in Chapter 12. In exercise 7.2 a seismic chimney cube is created. Such a cube highlights vertical disturbances in the seismic volume. A chimney cube is used in petroleum system analysis e.g. for the evaluation of charge and seal risk and for fault seal analysis. In the exercise in Chapter 12 a MLP Network is used to predict porosity from seismic data and inverted acoustic impedance using real well information for the training set.

7.1 Waveform Segmentation (UVQ)

The Unsupervised Waveform Segmentation approach reveals areas with similar seismic responses and is used extensively as an easy-to-use and quick interpretation tool. For the method to be successful you need a good reference horizon to work from and preferably a layer-cake setting. Furthermore, it should be realized that due to convolutional effects the results are influenced by variations in the over- and underburden. Variations on the waveform segmentation theme are possible. For example clustering waveforms from near-, mid- and far-stacks incorporates AVO effects. Instead of clustering waveforms it is also possible to cluster on multi-trace attributes such as Similarity and Curvature in the hope of picking up fracture-density patterns.

More quantitative analysis of UVQ results is possible with the aid of (stochastically) modeled pseudo-wells (e.g. de Groot, 1999).

Unsupervised segmentation (clustering) of data can be done in two modes: horizon-based and volume-based. The exercise in this section follows the horizon based (or 2D) approach. A 3D-segmentation scheme is very similar. However, be aware that in 3D only attributes not directly related to the phase at the sample location should be used. If phase sensitive attributes like amplitude are used, the results will look very much like the original seismic data.

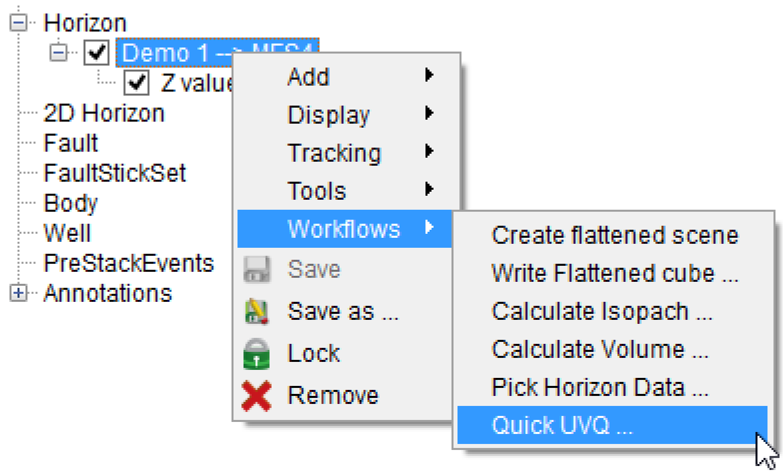
Workflows

They are two ways to create a horizon-based unsupervised segmentation:
The *Standard Method* and by the so-called “*Quick UVQ*”:

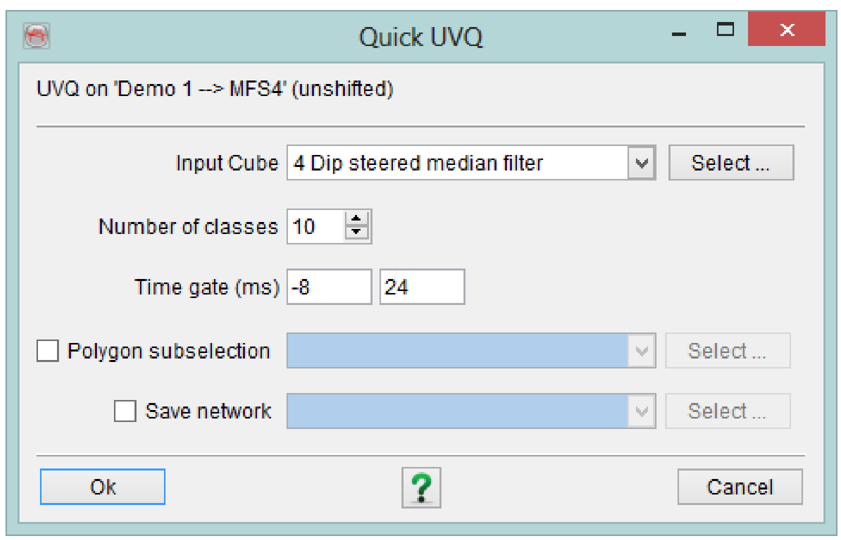
Quick UVQ
The Quick UVQ option can be used to quickly analyze and display the waveform class results under defined window.

Exercise

1. Right-click on *Horizon MFS4 > Work flows > Quick UVQ*:



2. In the pop up window, select the *Input Cube* and specify *Number of classes* (ten) along with analysis window length [-8, +24]. Press *Ok*.



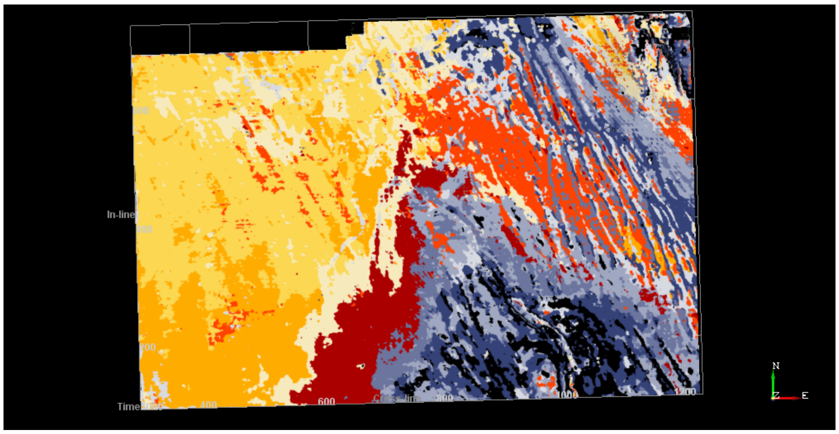
3. A training window pops up in which the network is shown and the Average match between input vectors and class centers. Training can be stopped when the Average match flattens out around 90%.

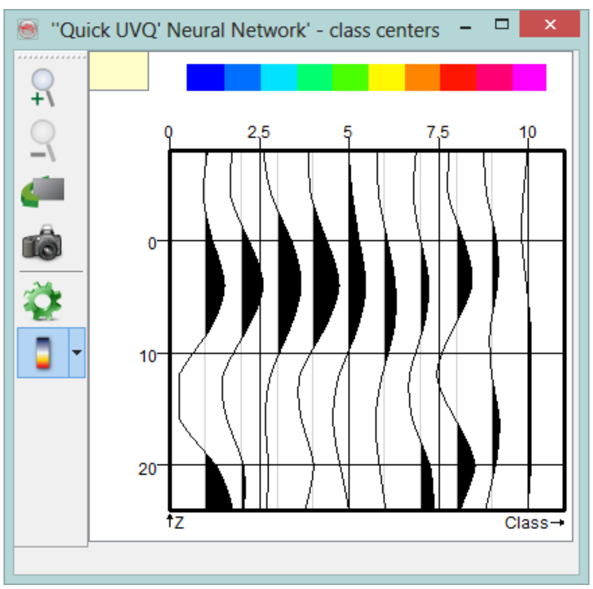
4. Press *Ok* again. A Neural network report window with statistics pops up.

5. Press *Display* to visualize the class centers.

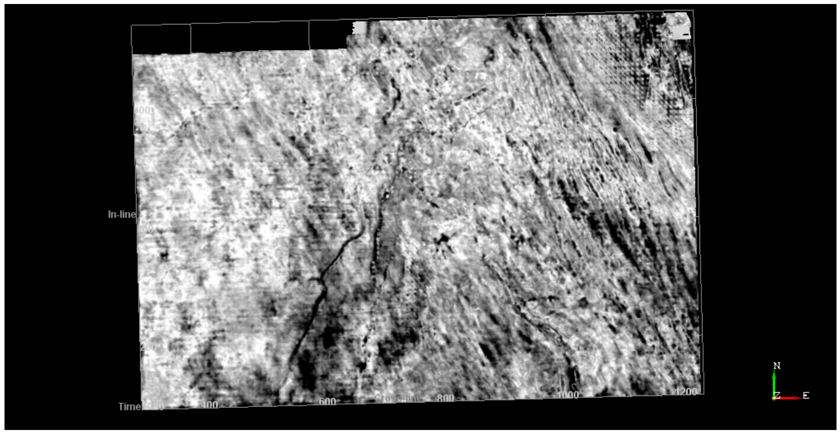
6. Finally the trained Neural Network is automatically applied to all positions along the guiding horizon and outputs *Class* and *Match* grids.

The *Class* and *Match* results can be saved later as a surface attribute.





(a) Quick UVQs segment grid: 10 Classes, windows [-8, +24]ms



(b) Quick UVQs match grid: Classes-10, [-8, +24] ms (black regions are of low average match)

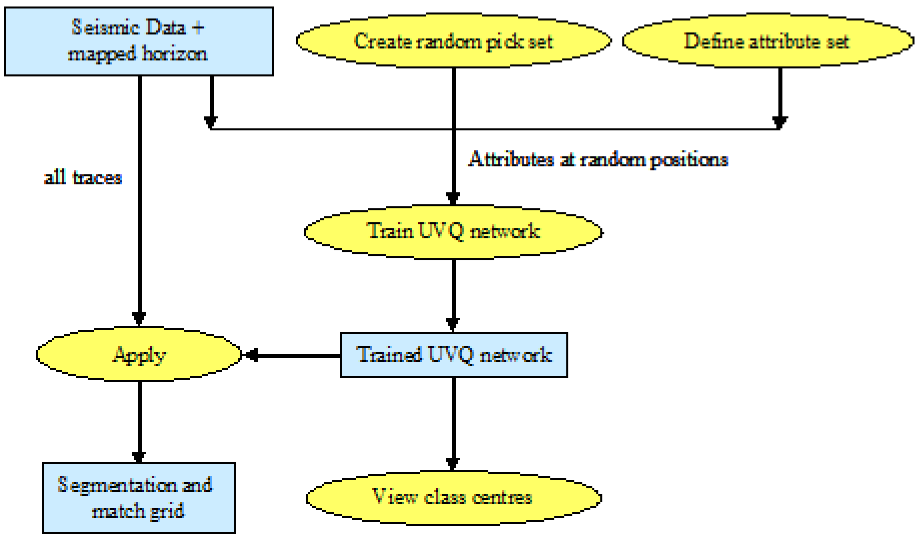
(a and b) shows the results of 2D segmentation at horizon MFS4 using a time gate of [-8, +24]ms. Areas with similar seismic response (similar waveforms) are visualized. Match grids not only gives the idea of average match in seismic waveform, but also an interpreter can use that grid to interpret subtle geomorphological features as represented in above figure.

Standard method

Whilst the results are the same compared to the quick UVQ (except, perhaps, the waveform classes order), the Standard Method gives the user more control over the data. This method can be modified to clustering of waveforms from multiple input volumes, or to horizon-based clustering of other attributes, or to clustering in 3D.

Unsupervised neural network

In this exercise we will apply the workflow of horizon based unsupervised segmentation. The aim is to visualize seismic patterns pertaining to the interval just below the mapped MFS4 horizon. We will do this by clustering seismic waveforms (i.e. seismic amplitudes within a given time interval) that are extracted relative to the horizon. The user can play with two input parameters: the extraction time-window and the number of output clusters. The time-window is determined by the thickness of the geological interval of interest and depends on the seismic phase and bandwidth (with zero-phase data the start time should be set above the horizon when the horizon marks the top of the interval). Usually synthetics and/or log displays are used to determine the optimal time-window. The number of output clusters is typically set to 10. A segmentation result with 10 segments can be visually re-grouped into smaller numbers by simply adjusting the color bar (option Segmentation in Manage colorbar). The workflow is schematically depicted below:



Workflow for UVQ waveform segmentation.

Exercise

1. Click on the *Edit attributes* icon and open the default attribute set *Unsupervised Waveform Segmentation*. Select the seismic volume *4 Dip steered median filter* as input for the attributes.

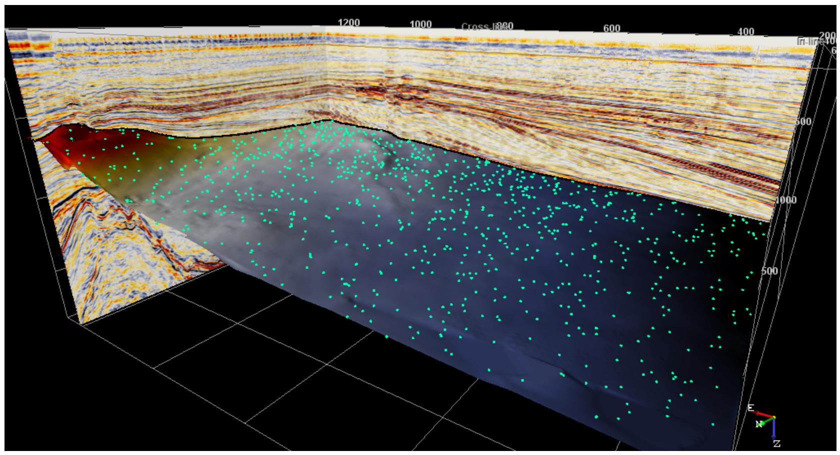
2. Start the Neural Network plug-in by clicking on the 3D icon (3D Neural Network) or by following *Analysis > Neural Networks > 3D...*

3. Click on *Pattern recognition [Picksets]…*

4. Select the *Unsupervised Analysis* method and select a sub-set of all available attributes for input attributes, e.g.

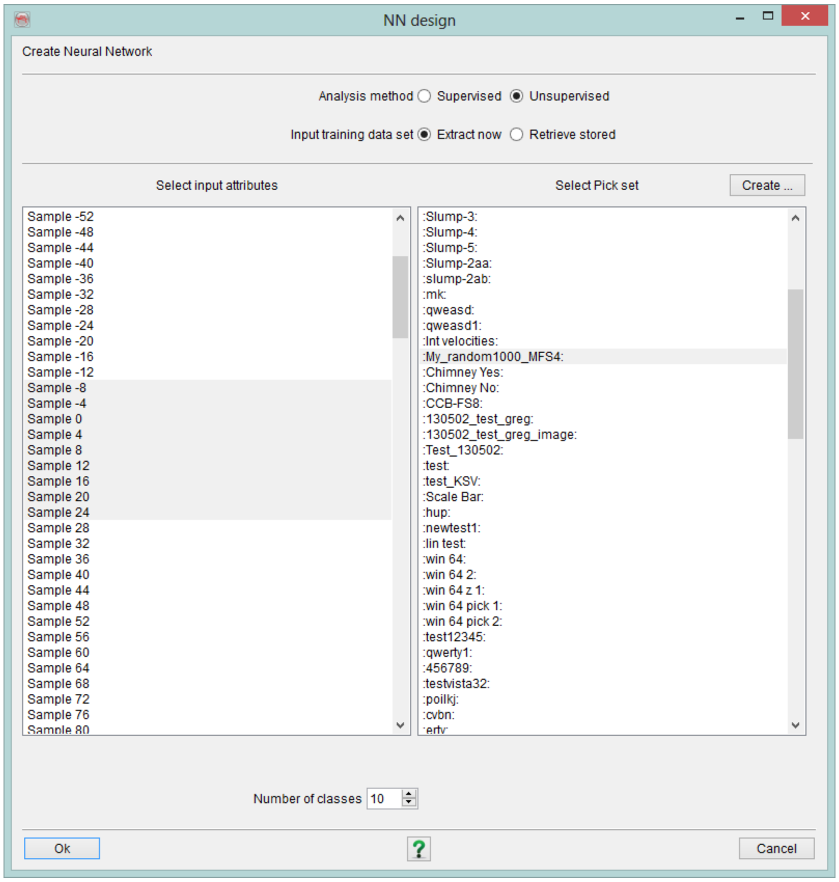
the sample from -8 ms to +24ms.

5. Create a *Pickset* with 1000 randomly chosen positions along the horizon. Call this pick set e.g. *My_random1000_ MFS4* and select this set from the list on the right in the Neural Network window. If you would display this pick set you would see something like in the figure below



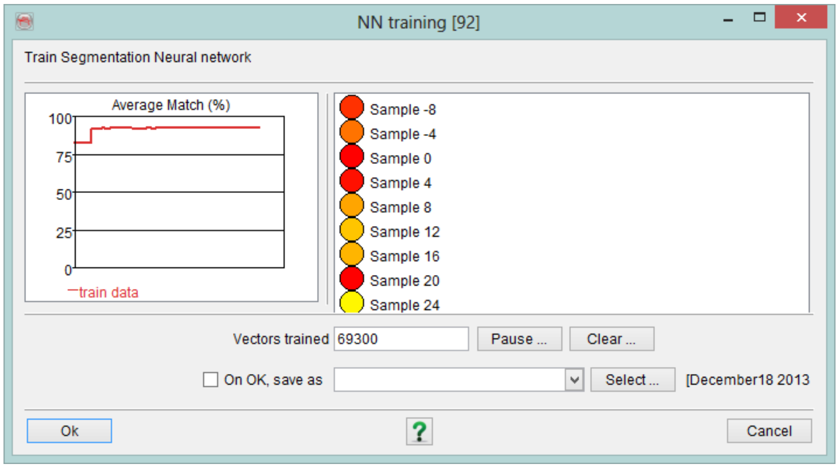
MFS4 horizon 'My_random1000_MFS4' displayed.

6. Now set the number of output classes to 10 (this is the default).



7. Press *Ok* to extract the specified waveforms at the random locations. The data is then displayed in the crossplot spreadsheet for possible further examination.

8. Press *Go* to start training the network. The Neural Network is fully trained (and should be stopped to prevent overtraining) when the average match is about 90% (see figure below).



UVQ network training performance. Training should be stopped when the average match reaches approx. 90%

9. Store the network with a name that makes sense, e.g.: *UVQ_10_[-8,+24]_MFS4* and press *Info* to see some network statistics and to Display the class centers.

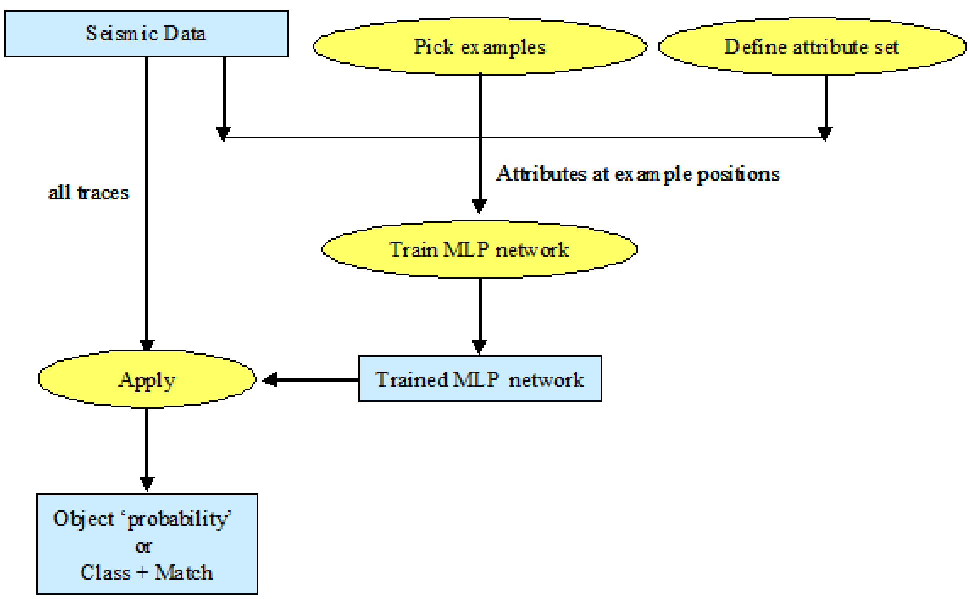
10. Apply the trained Neural Network to the MFS4 horizon by right-clicking on the horizon entry in the tree. Select *Segment* from option in the *Select attribute > Neural Network 3D* menu. This takes some processing time. Hence it is useful to *Save* the result as horizon data. You can later retrieve the saved result via *Horizon > right-click > Select Attribute > Horizon data.*

11. Create a color bar with the same amount of colors as segments, so every segment has its own color.

12. Optionally you can also *Save* the *Match* output. The *Match* will show you where the segmentation is reliable and where not.

7.2 Fluid Migration Path Analysis

The following exercise will take you through the workflow to create a seismic object ‘probability’ cube. In this specific example we aim for a (gas) chimney probability cube, but the workflow can be applied for every seismic object that you want to discriminate from its background, e.g. chimney, salt, faults, anomalies etc. Instead of binary object detection, it is also possible to perform multi-class detection following the same principles. Multi-class detection is typically used for seismic facies classification. Note that this is similar to the previous exercise of UVQ segmentation. Both methods will output seismic facies maps (or volumes) but whereas the UVQ method shows areas (bodies) of similar seismic response that remain to be interpreted, the supervised result reveals areas (bodies) with a geologic meaning. The workflow for supervised detection is schematically shown in the figure below:



Supervised object detection workflow

This workflow can be used to create object ‘probability’ cubes such as the *ChimneyCube* and the *FaultCube* and it can be used to create multi-class outputs such as a *Seismic Facies Cube*.

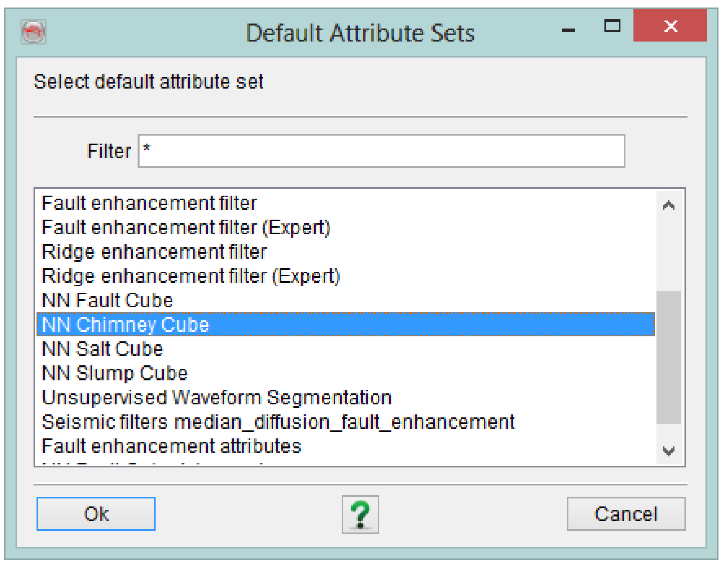
In this case, we will use a workflow towards a *ChimneyCube*: you have to define an attribute set, pick examples of chimneys and non-chimneys (i.e. background response), train the neural network and apply it to the data. Each of these processes is described in detail below.

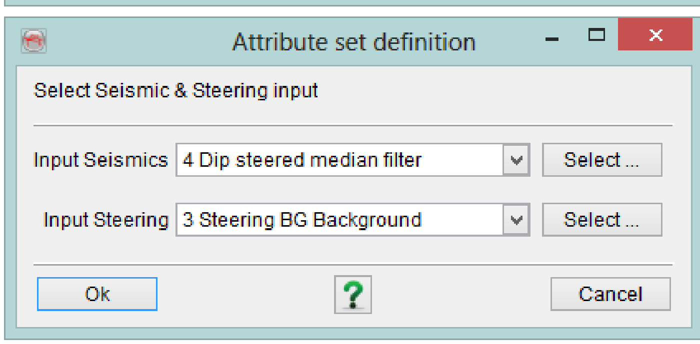
7.2.1 Defining the Attribute Set

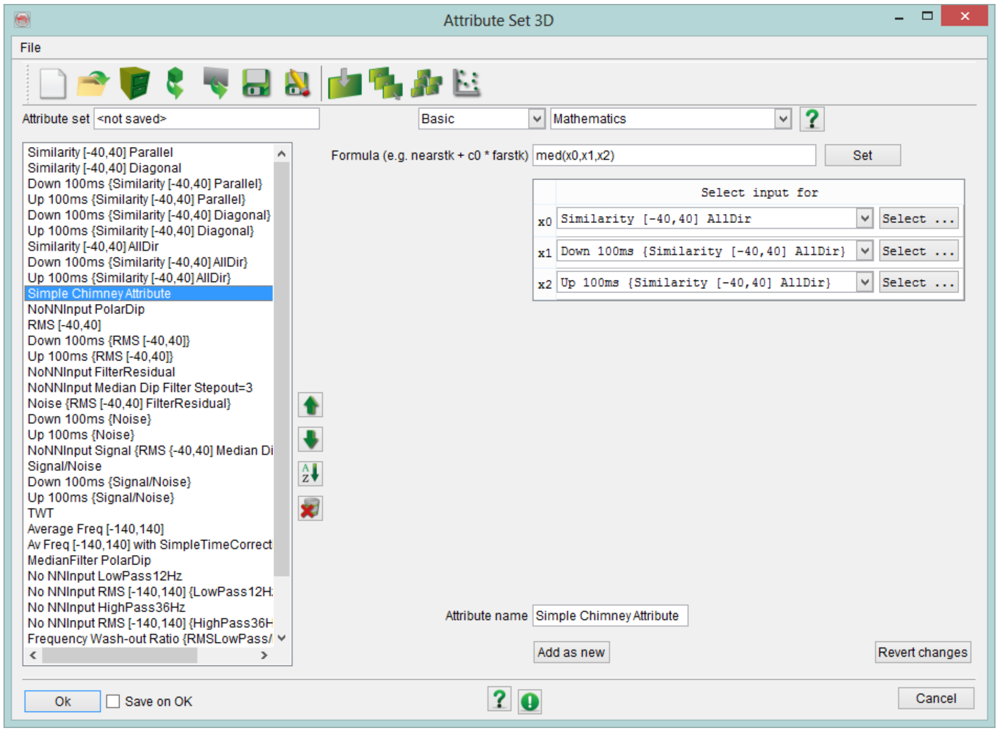
Exercise

1. Open the attribute window from the icon bar by clicking on the attribute icon  .

2. Open up the default attribute set for *NN Chimney Cube* via the  icon. You will get a window to select the input seismic data volume and the steering data volume for the various attributes. Select *4 Dip steered median filter* as input seismic volume and *3 SteeringCube BG background* as input for SteeringCube.







Default attribute set of Chimney Cube

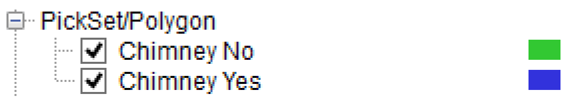
3. The attributes in your set should capture the difference between chimneys and background. Visual inspection of the data shows that chimneys are visible around inline 120 and around inline 690. The chimneys show up as vertical noise trails.

The seismic response in the chimneys is chaotic, with low energies and low trace-to-trace similarity. Thus it makes sense to include attributes such as similarity, curvature, energy and variance of the dip (a measure of chaos) into the attribute set. The vertical nature of chimneys can be captured by extracting the same attribute in 3 vertical extraction windows: above, at and below the evaluation point. This gives the network a chance to separate vertical disturbances from localized disturbances.

7.2.2 Picking Example Locations

To pick chimneys you first have to recognize them. Apart from being vertical and chaotic noise trails, chimneys often exhibit circular shapes in cross-sections on similarity-type Z-slices. Also, chimneys are often associated with seepage-related features such as mud-volcanoes and pockmarks on the (paleo-)sea bottom or with nearby high-amplitude events. The search for chimneys is thus a search through the dataset in which you use the visualization tools and interactive attribute analysis methods that are at your disposal to recognize the chimneys that can be picked. This is of course an interpretation step and as with all interpretations there is an element of bias that will impact the final result.

Picks are organized in *PickSets*. We will create two sets now: one with example locations of a gas chimney and one with example locations of undisturbed seismic data. (see figure a below)



Exercise

1. Add *inline 690* to the tree

2. Right click on *Pickset* in the *OpendTect* elements tree

3. Select New/Load, leave the tick mark at New and provide a name for the pickset you will create now, e.g. Chimney Yes. (As with attribute names, be complete: it helps with organizing your picksets later on).

4. Press *Ok*. When you select the pickset in the tree and provided you are in interact mode , you can pick locations for *Chimney Yes* on the inline. At the bottom of the screen and in the tree, you will see the number of picks in your active pickset.

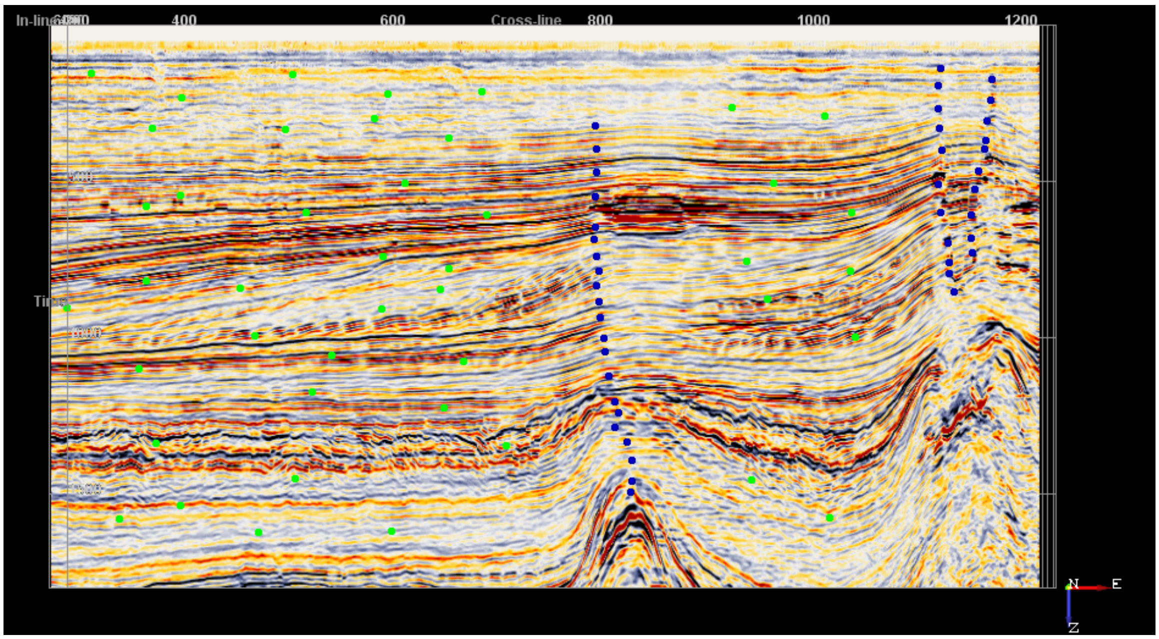
5. To save a pickset, right click on your pickset in the tree, and select *Save*. A new window appears where you can store your pickset. Optionally several sets can be combined into a single group. To save multiple picksets in a single group, select *Save* from right-clicking at *Pickset* one level higher in the tree, and not at the individual pickset.

6. In pick mode you can create picks by left clicking on the screen. Picks are made and plotted on the plane that is nearest to the viewpoint. If you want to rotate the view, use the Scroll buttons along the side of the screen. To delete a pick select the correct pickset, then press and hold the Ctrl key and select the pick.

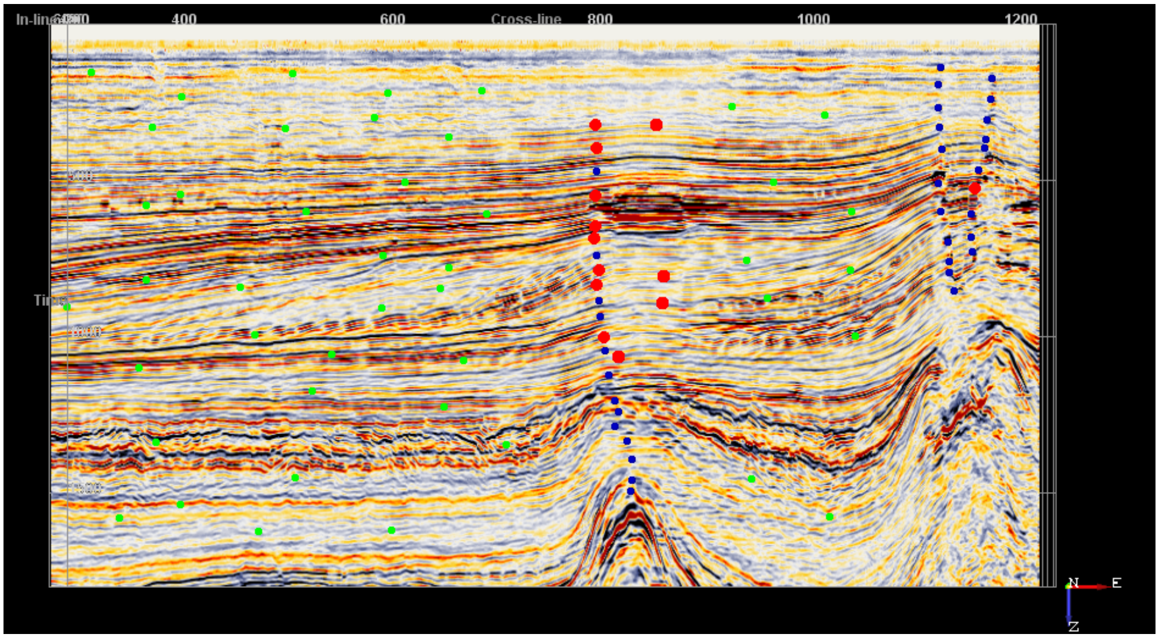
7. Now create a new pickset called *Chimney No* and pick more or less the same number of picks in the seismic data where chimney is not expected. *Save* the two picksets separately.

8. Repeat this process of picking chimneys and non-chimneys on other lines. Use for example the Green arrows to scroll inline 690 to a new position 10 (20, ..) lines away where more examples can be picked. It is recommended to use the option *Display only at sections* when making picks (right-click on the pickset in the tree). Not using this option would clutter your screen with all your picks.

To enhance the quality of your picks, change the attribute(s) you display from time to time. This gives you the opportunity to pick on the best example locations for several different attributes, and gives a better diversity of input to the neural network at a later stage.



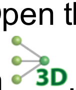
*Input picksets **Chimney Yes** (blue) and **Chimney No** (green) at inline 690.*



*Output **Misclassified Chimney** (red). The Misclassified picksets can be used to enhance the performance of the Neural Network.*

7.2.3 Training and Viewing a Neural Network

Exercise

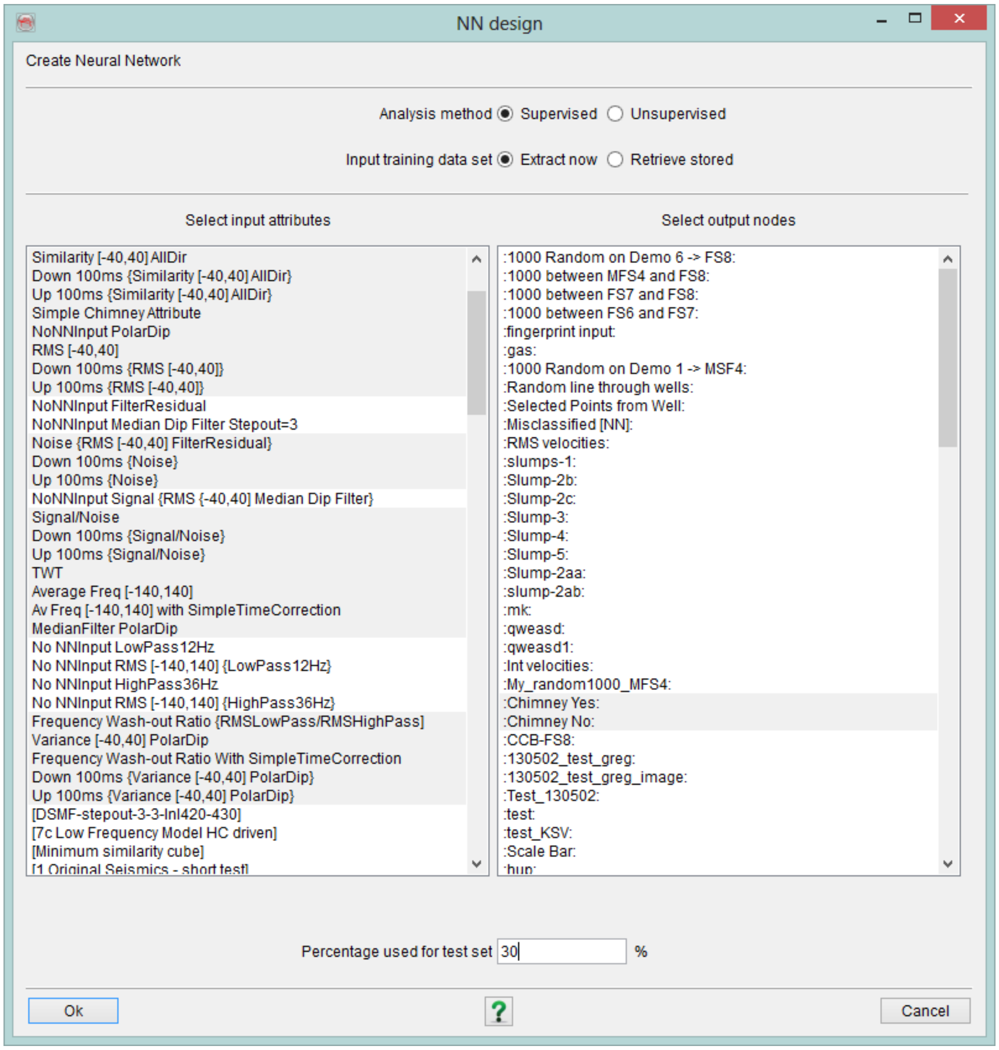
1. Open the neural network window by clicking on the neural network icon , or call the plugin from the *Analysis* > *Neural Network* > *3D...* menu. Press *Pattern recognition [PickSets]*

   Note: If you have many picks and want to use many attributes, you can select to store the extracted data by providing a name. This prevents having to re-calculate everything when you only want to take a few attributes out of your neural network. In that case you would select the *Stored Network* option at the top of the neural network window.

2. The *Supervised* and *Extract* now options are ticked by default. That is what we will use. On the left panel all the attributes defined in the attribute manager are automatically selected. Unselect the attributes beginning with “NoNNInput”.

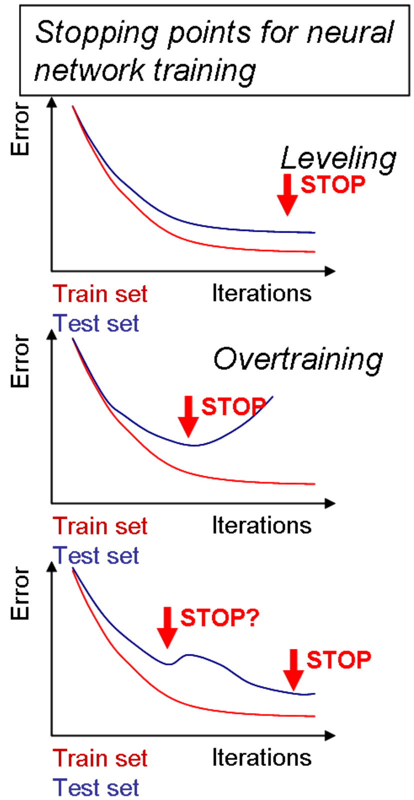
3. On the right you select the two picksets *Chimney Yes* and *Chimney No*.

4. Percentage used for test set: 30%



Supervised neural network

The data set is split randomly into a training set and a percentage for testing. The training vectors are passed through the network and the error is used to update the weights. The test vectors are also passed through the network but the error is only used to check the performance during training and to avoid overfitting. Training is ideally stopped when the error on the test set is minimal. This is the point where the network has the optimal generalization capabilities. (see picture below)



The network will have output nodes: *Chimney Yes* and *Chimney No*. The values of these outputs will be between approx. 0 and 1 (after format scaling).

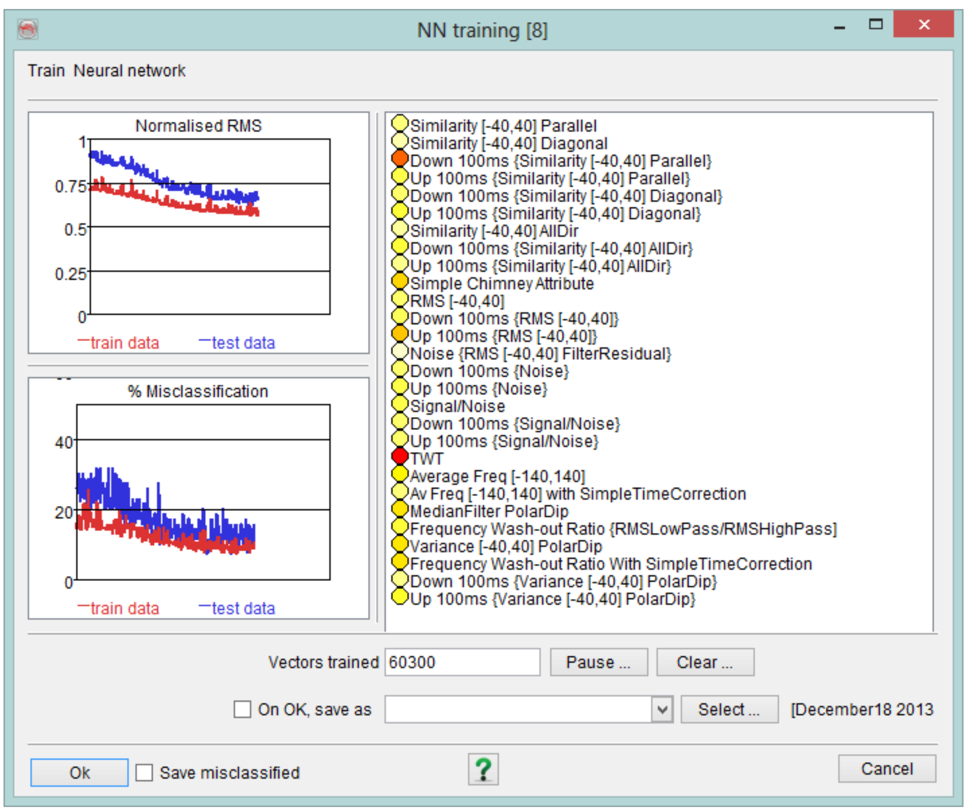
The outputs will also be mirror images of each other: if a position belongs to a chimney the output of *Chimney Yes* will be high while that of *Chimney No* will be low. When we apply the trained network it will thus be sufficient to output only the Chimney Yes response. The closer the value to 1 the more 'probable' it is that the value belongs to the chimney class.

This type of output makes sense only if we are dealing with a two-class problem. With more than two classes (e.g. for seismic facies classification) the option "*Classification*" is selected. The output of the neural network is then replaced by two new output nodes: *Classification* and *Confidence*. The former gives the index of the winning class while the latter is a measure of how confident we are in the result in a range of 0-1 (0 is no confidence, 1 is very confident).

5. Press *Ok*. First, the values of the attributes at the pick locations are extracted. Possibly not all picked locations are valid. For example,

near the edge of the data cube, steering data are not available because of the trace step-out that was used. Steered attributes cannot be calculated there, so picks in that area will not have all attributes defined, and these picks will therefore be ignored. In the spreadsheet you can analyze and edit the attributes by cross-plotting them against each other and (more interesting) against the targets *Chimney Yes* and *Chimney No*.

6. Press *Go* and now the actual neural network training starts (see figure below). Watch the performance, and press *Pause* when you are satisfied. Your network is trained when the misclassification does not decrease anymore, and the RMS error is minimal for both train and test set. You may press clear and start the training again. Note the colors of the input attributes that change during training. The colors reflect the weights attached to each input node and range from white via yellow to red. Red nodes have more weights attached and are thus more important to the network for classifying the data. Colors are very useful to tune a network and throw out attributes that may take up a lot of CPU time without contributing to the final result.

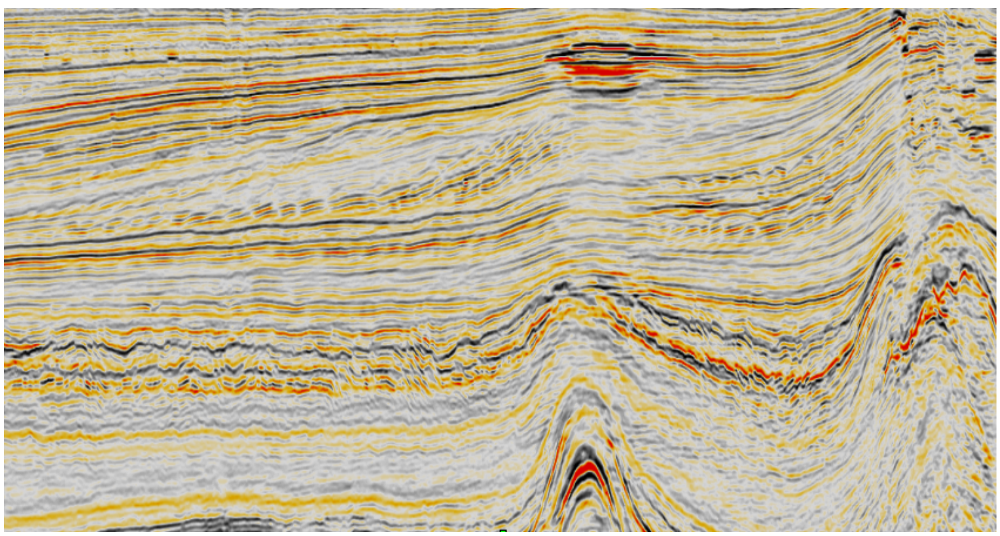


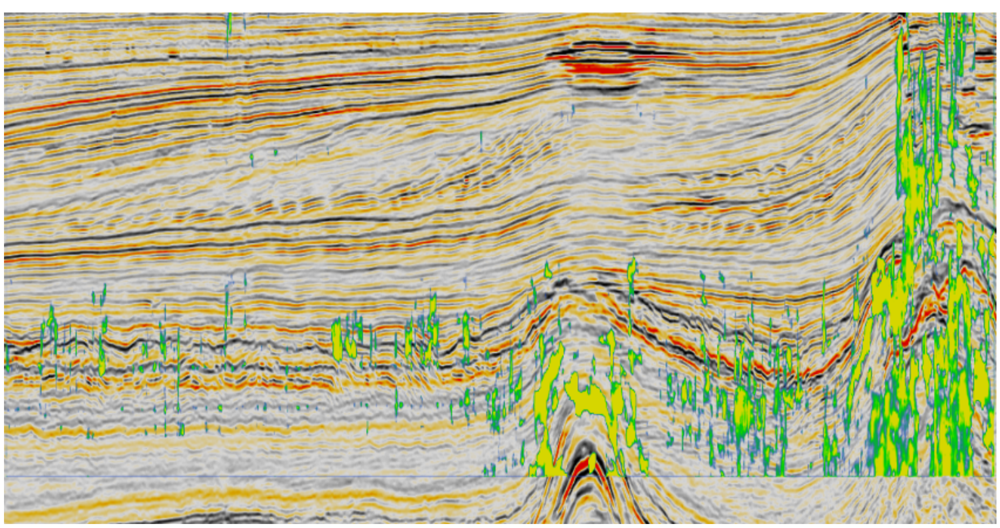
Training performance of the network.

Top left: RMS error vs. training cycles for training and test sets.

Bottom left: The percentage of mis-classification for train and test sets vs. training cycles.
Right: Input attributes with color coding to reveal the importance of each attributes (more red = more important).

7. Press *Ok* to exit the neural network training module, press Store to store the trained neural network and finally exit the neural network manager. You can now test the training performance on your data, e.g. on (part of) inline 690. Right-click on the element in the tree, select attribute, and select the neural network Chimney yes output node. The result may look like the figure below.





Chimney result on Inline 690: filtered seismic (above) with predicted chimney overlay (below). The “Chimney Yes“ neural network output is displayed using the chimney default colorbar. ranges between 0.8 and 1.2.

If you are not satisfied with the results, you can change the location of the picks using the misclassified picksets (the red picksets in the figure b of the section 7.3.2) to enhance the performance of the neural network.

When you are satisfied with the performance of your neural network, you probably want to apply it to the entire volume so that you can analyze the results.

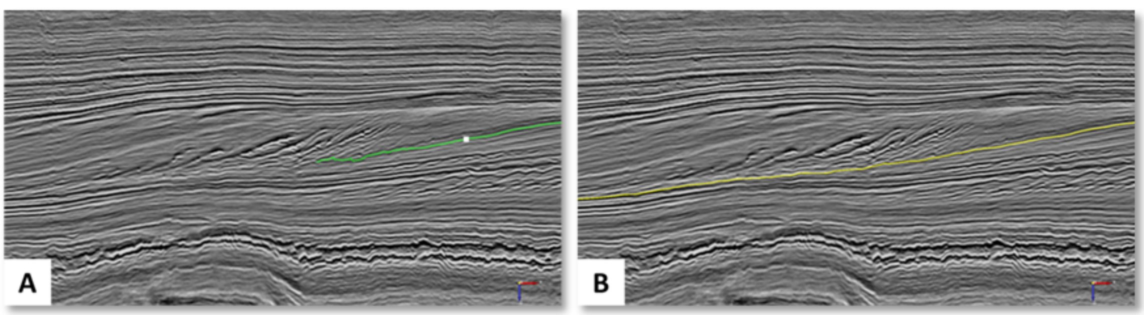
8. Go to *Processing > Create Seismic Output > Attribute > 3D*, select the *Chimney Yes* as quantity to output and give a name for the output volume.

> **Note:** *OpendTect* allows you to process the data on multiple machines. For details, see *Batch Processing* in the *OpendTect Documentation*.

8 HorizonCube

A HorizonCube consists of a dense set of auto-tracked seismic horizons. The auto-tracker tracks the pre-computed dip-azimuth field that is supplied in the form of a (dip-) SteeringCube. The steering data generally determines the quality of the resulting HorizonCube.

In standard seismic interpretation workflows, a coarse 3D structural or sequence stratigraphic model of the sub-surface is constructed from a limited set of mapped horizons. The number is limited because mapping horizons with conventional auto-trackers, based on tracking amplitudes and similarities, is a time consuming practice. In particular, mapping unconformities - primary targets in sequence stratigraphic interpretations - is cumbersome with conventional trackers, as amplitudes tend to change laterally along such surfaces. HorizonCube maximizes the amount of information that can be extracted from seismic data by significantly increasing the number of mapped horizons (figures below).



Seismic section to illustrate the difference between two trackers: conventional vs. dip-steered: (A) Conventionally tracked event based on seismic amplitude and waveform similarity, (B) the same event has been tracked using the dip-azimuth volume (SteeringCube).

The auto-tracker used to track in a dip-field works for both 2D and 3D seismic data. Tracking in a dip field has several advantages: Firstly, the dip field is continuous. Even if amplitudes vary laterally, the dip continues. Second, the dip field can be smoothed before applying the tracker, which enables the controlling of the detail that needs to be captured. The auto-tracker is applied to a target interval and generates hundreds of horizons that are separated on average by a sampling rate. The result is called a HorizonCube. The comparison between conventional amplitude based tracking and dip-steered tracking with SteeringCube is presented in the figure above.

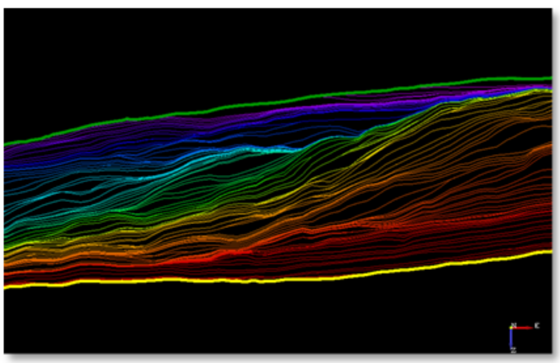
8.1 HorizonCube Types

Two types of HorizonCubes are created in OpendTect:

Continuous HorizonCube:
Contains events (or horizons), as the name implies, that do not terminate. All events are continuous throughout the entire volume. They may come very close together (at unconformities and condensed sections) but they can never cross each other.

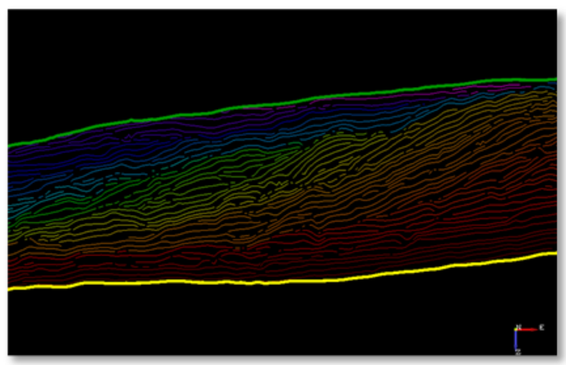
Truncated HorizonCube:
Contains events that terminate against other events.

Both cubes have their own applications for visualization and also for model creation. The advantages are also briefly explained in the following pictures.



Continuous HorizonCube

Applications:
- Low Frequency Models
- Geologic Modeling
- Attribute Visualizations in 3D



Truncated HorizonCube

Applications:
- Sequence Stratigraphic Interpretation
- Wheeler Transformation
- Attribute Visualizations in 3D

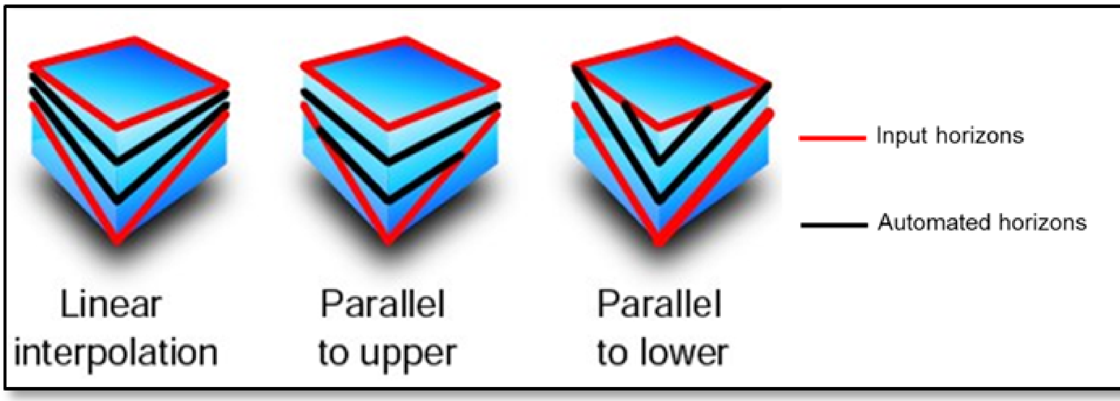
Two types of HorizonCube based on their geometrical configuration.

8.2 HorizonCube Modes

A HorizonCube can be created with two different modes:

Data driven:
The *data driven mode* creates a HorizonCube that is guided by the SteeringCube, in turn computed from the seismic data. Thus it will follow the geometries of seismic reflections. It is the preferred mode to build accurate sub-surface models and interpret the seismic data within a geologic framework.

Model driven:
The model driven mode is a way of slicing the seismic data relative to the framework (input) horizons. There are three model driven sub-modes:



Three different model-driven modes to create a HorizonCube.

8.3 HorizonCube Tools

The following tools are available in OpendTect for performing different manipulations on the HorizonCube:

Edit: Use either error-based or linear-based methods to edit events in a HorizonCube.

Add more Iterations: To fill “gaps” in the HorizonCube.

Merge: Vertically merge HorizonCubes.

Add or Recalculate 2D Line: Modify the HorizonCube by adding more 2D lines or add further horizons and faults.

Modify or Recalculate 3D Sequence: Modify a HorizonCube by adding more horizons/faults.

Extract Horizons: Extract horizons from the HorizonCube (stored as horizon data).

Convert to SteeringCube: Convert the HorizonCube into a dip-azimuth volume (SteeringCube).

Truncate HorizonCube: Operation to remove parts of the HorizonCube based on the event’s density (number of events within a defined time gate).

Get Continuous HorizonCube: Converts the truncated HorizonCube into a continuous HorizonCube.

Grid HorizonCube: Use various algorithms to fill unwanted holes in extracted horizons.

Convert Chronostrat to HorizonCube: Update Chronostrat computed in pre-4.2.0 releases into HorizonCube.

8.4 HorizonCube Applications

The HorizonCube is a step-change technology that opens the door to drastic improvements in understanding the geological meaning contained in seismic data: 3D sequence stratigraphy, seismic geomorphology with data driven stratal slicing, improved geologic models, wells correlation, low frequency modelling for better seismic inversion etc.

Today, seismic interpreters can look forward to the following benefits:

Low Frequency Model Building & More Accurate, Robust Geological Models
In standard inversion workflows, the low-frequency model is considered the weakest link. Now, users can create highly accurate low frequency models by utilizing all the horizons of the HorizonCube, allowing a detailed initial model to be built.

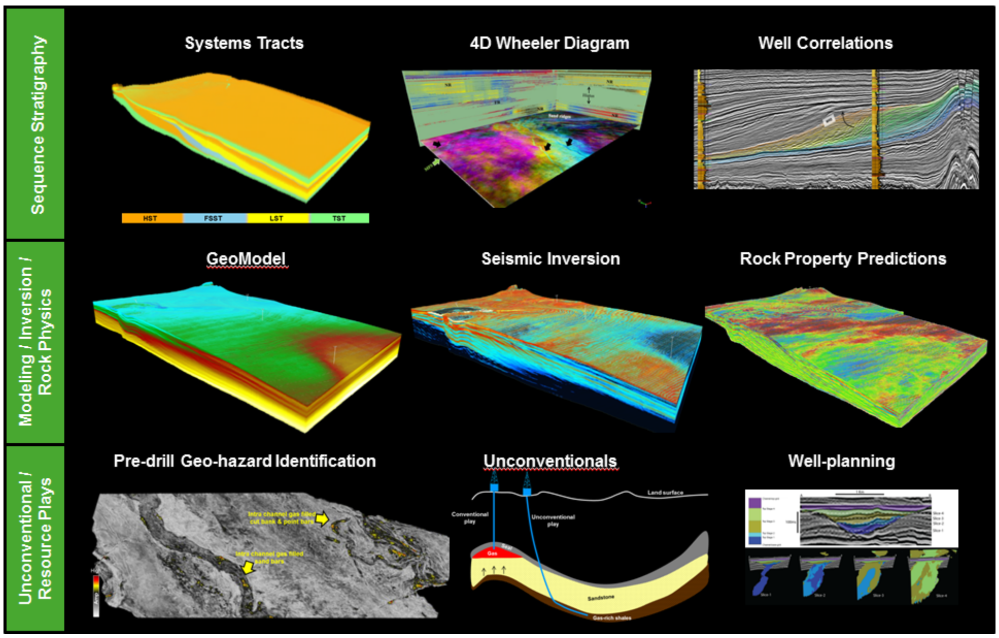
In a similar fashion rock properties can be modelled. Instead of using only a few horizons all horizons of the HorizonCube are used, resulting in greatly improved rock property models.

Rock Property Predictions
The highly accurate low frequency models can be used to create geologically correct Acoustic Impedance (AI) and Elastic Impedance (EI) cubes using OpendTect's Deterministic and Stochastic Inversion plugins. To complete the workflow, the Neural Networks plugin is used to predict rock properties from the Acoustic Impedance volume, avoiding the use of oversimplified linear models which cannot accurately describe most rock property relations.

These advanced tools bring a high degree of precision to traditional seismic workflows, resulting in better seismic predictions and more accurate input into the reservoir management decision-making process.

Sequence Stratigraphy (SSIS plugin)
The SSIS plugin works on top of the HorizonCube plugin. Users can interactively reconstruct the depositional history in geological time using the HorizonCube slider, flatten seismic data in the Wheeler domain, and make full system tracts interpretations with automatic stratigraphic surfaces identification and base-level reconstruction.

Well Correlation (WCP plugin)
The Well Correlation Panel plugin is an interactive tool for correlating well data and for picking well log markers in a consistent manner. The tool supports displaying and manipulating multiple wells with logs, markers, and stratigraphic columns, plus the connecting seismic data (2D lines, or Random lines from 3D volumes) with interpreted horizons, faults, HorizonCube and interpreted systems tracts.



HorizonCube Applications

8.5 Required Inputs

The following section explains the required inputs to process a HorizonCube. Requirements include a pre-computed steeringcube and framework horizons, whilst fault (planes or sticks) are optional.

8.5.1 A Pre-Computed SteeringCube

SteeringCube is a dip-azimuth volume and can be considered as the heart of the HorizonCube.

A good-quality SteeringCube will usually result in an equally good-quality HorizonCube. However, our experience suggests that in order to create a good HorizonCube, one is required to pre-compute possibly 2-3 different SteeringCubes and evaluate them by varying the HorizonCube parameters. The best HorizonCube is then picked by quality controlling the results. Understanding the SteeringCube is thus paramount towards a successful HorizonCube.

The simplest way to understand the SteeringCube is to first knowing the seismic data that you are dealing with. Visualize the seismic data by scrolling the inlines/crosslines or in a volume. Focus on an interval of interest and check the areas of good and bad quality. Get an overview of whether the data quality is poor, fair or good. If it is poor, you can expect a poor SteeringCube and thus in turn a poor HorizonCube output. Another way of looking at the SteeringCube is to look at the geologic complexities. If the data is too complex geologically e.g. contains flower structures, you might not be successful.

In all cases, we suggest various workflows to improve the seismic data. There are three major workflows that have been tested around the globe and are found always a useful step to create a SteeringCube.

1. **Smooth the seismic data** by applying a mild post-stack dip-steered median filter (Chapter 4.6). Such a filter improves the quality of seismic at a sub-volume scale e.g. area of 3 by 3 traces.

2. **Improve the vertical resolution** of the seismic by sharpening the wavelet. We normally use the Seismic Spectral Blueing (a method to enhance the vertical resolution) operation to do this. To read more, please see Spectral Blueing Chapter in this manual.

3. Apply a band pass filter on the seismic data to **discard the high frequency noise**. It is often a valuable step if you are dealing with a high frequency noise and you want to create a HorizonCube which follows the major seismic events only.

Computationally, creating a SteeringCube is a slow process if one is dealing with a dataset of several GB’s. Therefore, it is advisable to pre-process the SteeringCube before you do anything else. You can run such processing by splitting the jobs on multiple machines.

To read more about the best settings and parameters for computing a SteeringCube, please go to the exercises section of this chapter.

8.5.2 Framework Horizons

Framework horizons (2D/3D) are the conventionally mapped horizons (3D grids / 2D horizons) that serve as a geologic constraint to form a vertical boundary for a HorizonCube. Note that at least two framework horizons are needed to form a package/sequence. The HorizonCube is always computed within given two or more packages. So, if one provides three framework horizons, you will get a HorizonCube with two packages only.

The data-driven HorizonCube is dependent on provided framework horizons. It uses them as a relative thickness boundary that cannot be crossed by an automated HorizonCube event. Nevertheless, the automated events may be converged at the framework events. In some cases, such convergences could highlight key geologic features: pinchouts, terminations, levees etc.

Notes and Tips:

- A horizon with holes will result in a HorizonCube with holes. Thus, it is suggested to fill the holes by gridding horizons with undefined areas.
- Two horizons might have different geometries (boundary ranges). In such case the lower boundary would be used as an outer boundary of the HorizonCube.
- Two horizons are also used to define an automated start position (a seed position) to track events. Tracking can in that case be started from the depositional centre which is the position with the thickest isopach value.

8.5.3 Fault Planes & Sticks

Fault Planes (3D) or faultsticksets (2D) are optional input variables that can be used when creating a HorizonCube. Faults serve a structural boundaries along which the throw is automatically computed using the input framework horizons and a given fault plane/stick. In OpendTect, there is an additional data preparation step to make the framework horizons “watertight” with the faults.

There is no limitation on number of faults or sticks. In case no faulting is observed in the dataset, the HorizonCube can be processed without fault data.

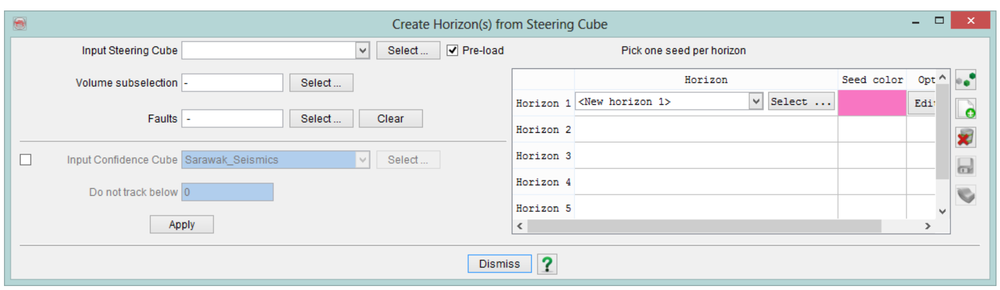
8.6 Track Horizons with SteeringCube

Horizons can be trackedvia several methods in OpendTect. Traditional amplitude tracking can be time consuming, especially if your data is not of the highest quality. The new dip-steered horizon tracker uses the steering volumes to auto-track the bounding horizons. This method is ultrafast, and can produce multiple full survey 3D horizons in a matter of seconds.

Exercise

> **Note:** To speed up the horizon calculation process, preload your steering data: Survey>Pre-load>Seismics…>Add Cube… and select the SteeringCube 2 Steering BG Detailed. Use inline 250, displaying *4 Dip-Steered Median Filter*.

1. Go to *Processing* > *HorizonCube*
2. Select the *Create* option from *Horizons from SteeringCube*



Horizon from SteeringCube window

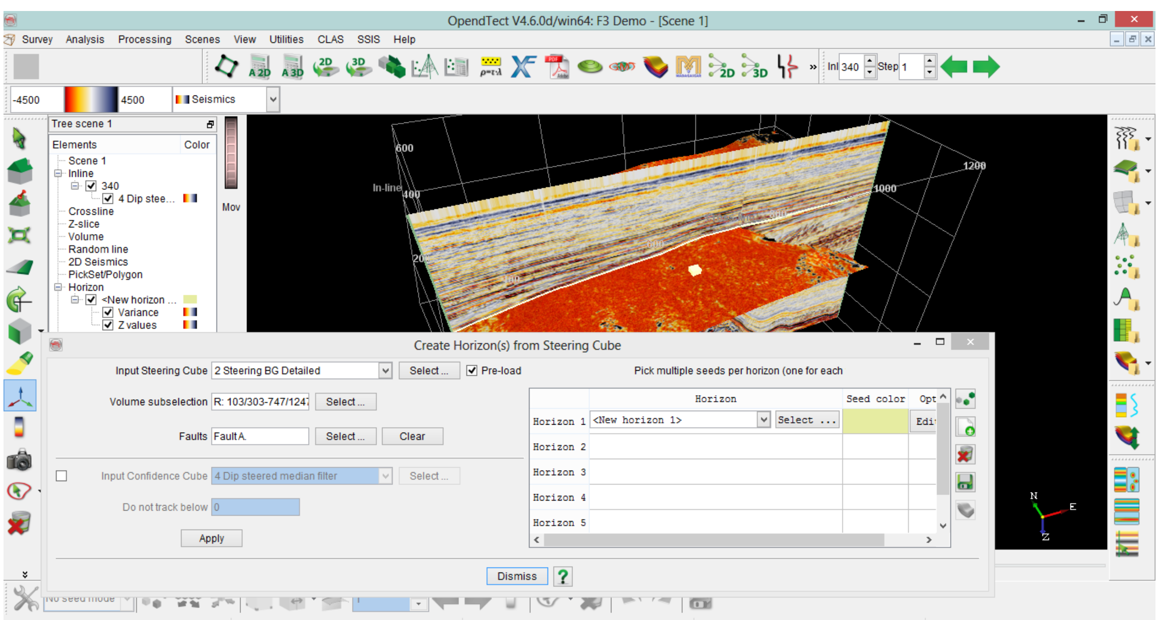
3. Select the SteeringCube you would like to use as input to create your horizons : *2 Steering BG Detailed* in this exercise
4. Select any faults you have in the area. In this case, select *Fault A*
5. Seed picking
    a. Click on the empty *Horizon 1*
    b. Click the *Pick seeds* button . This will turn your pointer into a crosshair

c. Click on only one point on the horizon you wish to track.

> **Note:** If you have faults in your area, you may select one seed per fault block. Optimal results are achieved if you make your seed picks as far away from the fault edges as possible, so as to let the horizons grow organically around the fault.

d. If you would like to track another horizon, click the *Add new horizon* button , and then pick one point on the seismic horizon you wish to track.

e. When you have made one seed pick for each horizon you wish to track, click the *Pick seeds* button to turn the mouse back to a pointer. Click the *Apply* button, and your horizons will auto-track.

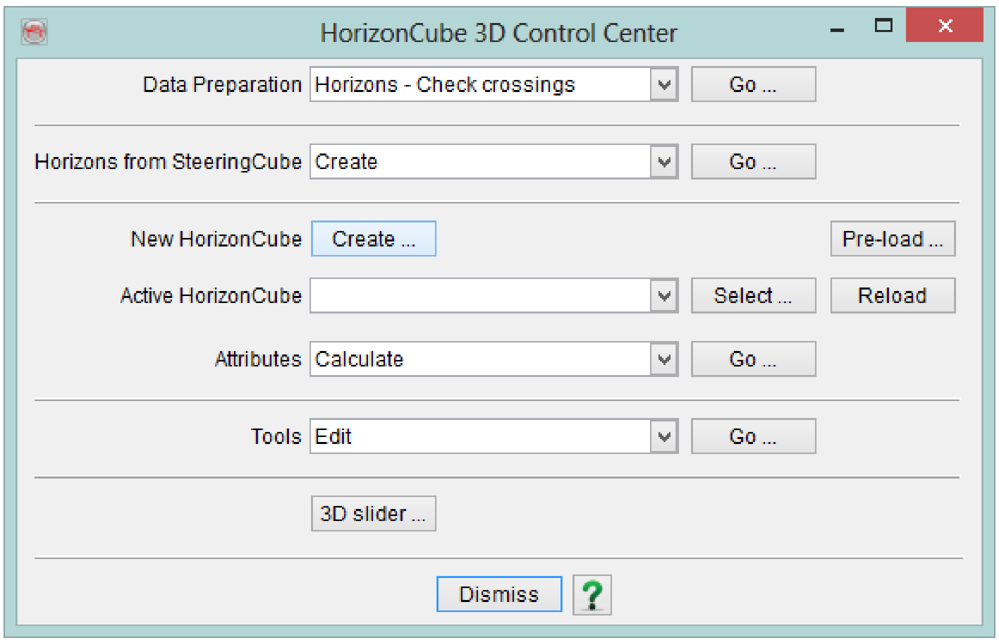


8.7 Creating a HorizonCube

Exercise

> **Note:** to save processing time - especially in the next exercise (adding iterations) - you can limit the processing range in this exercise to inline 400-450.

1. Follow *Processing>HorizonCube* and click on *Create New HorizonCube*



2. Click *Read horizons* and select at least two horizons to be your bounding surfaces.

> **In this exercise:** Select *Demo 0 --> FS4* and *Demo 6 --> FS8* horizons. For multiple horizons selection, use CTRL + Mouse left button click.

This will populate the HorizonCube calculation mode.

3. In this exercise, we would like to create a data driven HorizonCube, i.e that is steered by the SteeringCube.

a. Change the mode to *Data Driven*.

b. Press the *Settings* button

c. In the settings dialog

- select *2 Steering BG Detailed* as input SteeringCube
- The *Start at* drop-down menu has several options. Each of these allow you to define where the initial starting points for each horizon will be located. This can be a very influential step, so be sure to try variations of this option if you are not satisfied with your results.

In this exercise: Set the start at position to be *Centre*.

- The Advanced options are used to edit more settings. There you can decide to create a Continuous or Truncated HorizonCube.

In this exercise: Set the following:

- *Maximum Number of Iterations: 1*
- Leave the rest as default.

d. Click OK.

Note: If you have multiple packages you will notice that the settings you made in the first package have also been applied to the second package. You may change the settings for the second package if you wish. Unselect the *Apply to all packages* option before clicking on *Ok* when defining the settings of the first package.

4. There is one large fault in this survey area, so click the select button next to the faults field, and select *FaultA*
(If there is more than one fault in your area, you may multi-select here as well.)

5. Give a name to your HorizonCube, e.g *HorizonCube BG Detailed*

6. Click on Analyze: this will quickly test all of the settings you have made to see if they would result in a successful HorizonCube. If it does not respond with *All packages passed successfully* then there is

something wrong with your parameters. A brief description of the analysis can help you to locate the problem.

7. If the packages are passed successfully, dismiss this report, and click *Go* on HorizonCube Creator window. A separate window will open up in where you can follow the progress of the HorizonCube processing. You can then dismiss the HorizonCube Creator window.

> **Note:** You can continue to work in OpendTect while this is calculating.

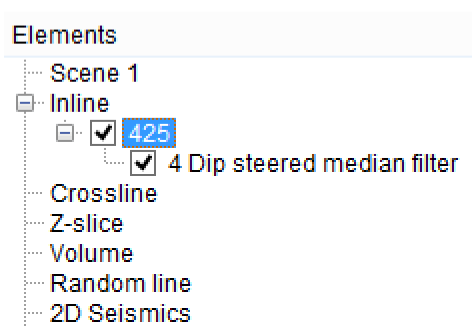
8. Once the processing is complete, i.e when the *Finished Batch Processing* appears in the processing window, you can close this window using the icon .

Displaying the HorizonCube

9. Display Inline 425 in the scene: Tree > *Inline* > *Add*

10. Rick click on the inline name > *Add* > *HorizonCube display*

11. In the HorizonCube selection window, select the *HorizonCube BG Detailed* that you just created.



Adding iterations

This step will add more iteration(s) to an already created HorizonCube. This will fill in any gaps, using the same criteria that were originally used.

1. Follow *Processing>HorizonCube* to access the HorizonCube 3D (optionally 2D) Control Center.

2. In the drop-down *Tool* menu, select *Add more iterations* and click on Go

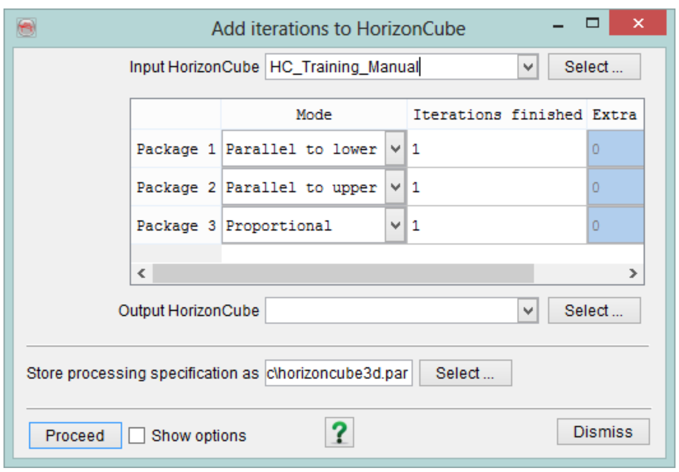
3. In the new window:

a. As input HorizonCube, select the HorizonCube you created in the previous step.

b. The first column tells you how many iteration already processed in this HorizonCube.

c. The second column allows you to change the number of many more iterations you will add in this step. You can add a different number of iterations to the different packages or just add for one. Leave this number to 1 for each package.

d. Save with the same name as before, but at a notation that lets you know how many iterations it will have after this step, e.g. *HorizonCube-i3.*



8.8 Truncate a HorizonCube

The HorizonCube has two output modes: continuous and truncated. These outputs have very different applications. Typical uses for a continuous HorizonCube would be 3D model building, and a Truncated HorizonCube would be used in a Wheeler Scene for viewing depositional stacking patterns. Truncation is based on a user-specified density of events per sample interval. A HorizonCube originally made as continuous can be truncated, and vice versa. We will practice creating a Truncated HorizonCube from a Continuous HorizonCube.

> **Note:** OpendTect v4.6 supports on-the-fly truncation of a HorizonCube display in the Wheeler scene. This feature is called from the *Display > Properties* menu in the tree.

Exercise

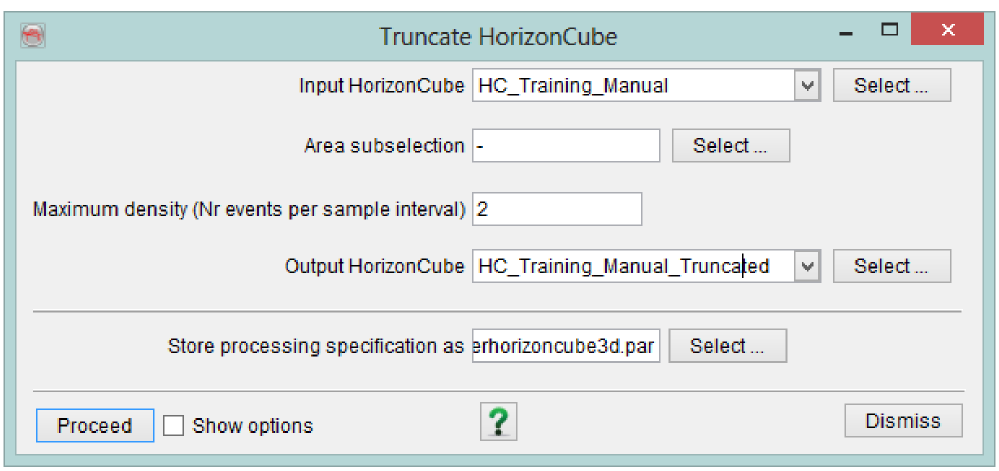
1. Open the HorizonCube 3D Control Center and select *Truncate HorizonCube* in the *Too*l menu

2. Select the original (continuous) HorizonCube as input cube

3. Leave the area sub-selection and minimum spacing as default

4. Name your output cube with a similar name as the original but add a notation that reminds you that this one has been truncated, e.g. *HorizonCube Truncated*

5. Click *Proceed* to process the HorizonCube.



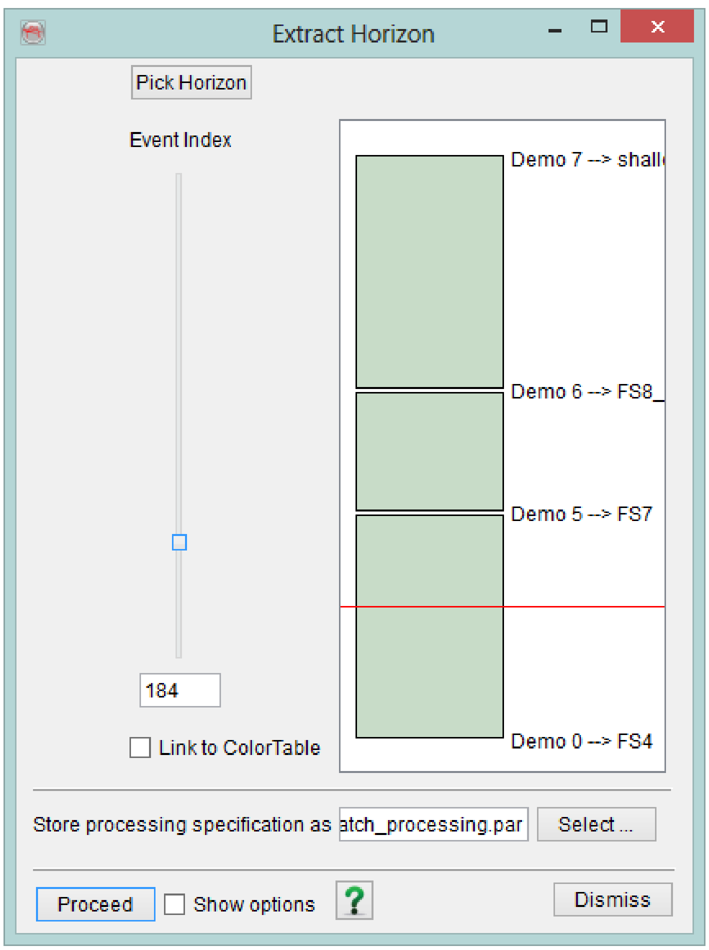
8.9 Extract Horizons

The ultimate goal of the HorizonCube is to have horizons essentially everywhere. These can be used as input for many other advanced features, but often you simply need a well-tracked horizon. You can save any horizon from the HorizonCube as a stand-alone item.

Exercise

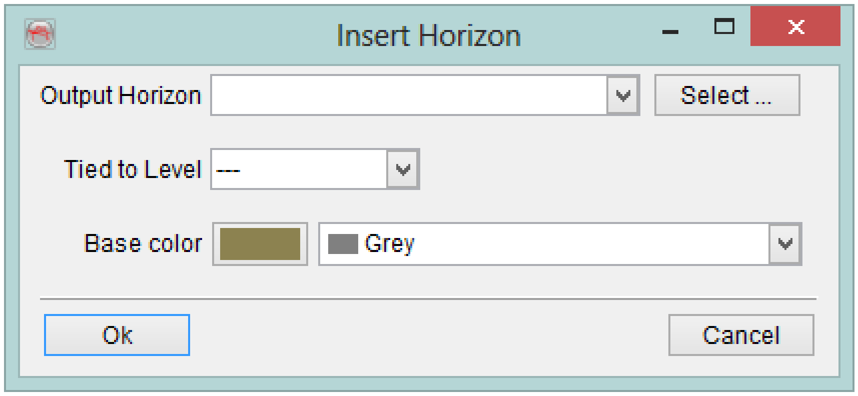
1. Open the HorizonCube 3D Control Center and select *Extract Horizons* in the *Tool* menu

2. Scroll up and down with the slider, watching the HorizonCube in the scene.



3. When you locate a horizon, you would like to extract, click on the *Pick Horizon* button.

4. A second window will appear where you name your new horizon and click *Ok*.

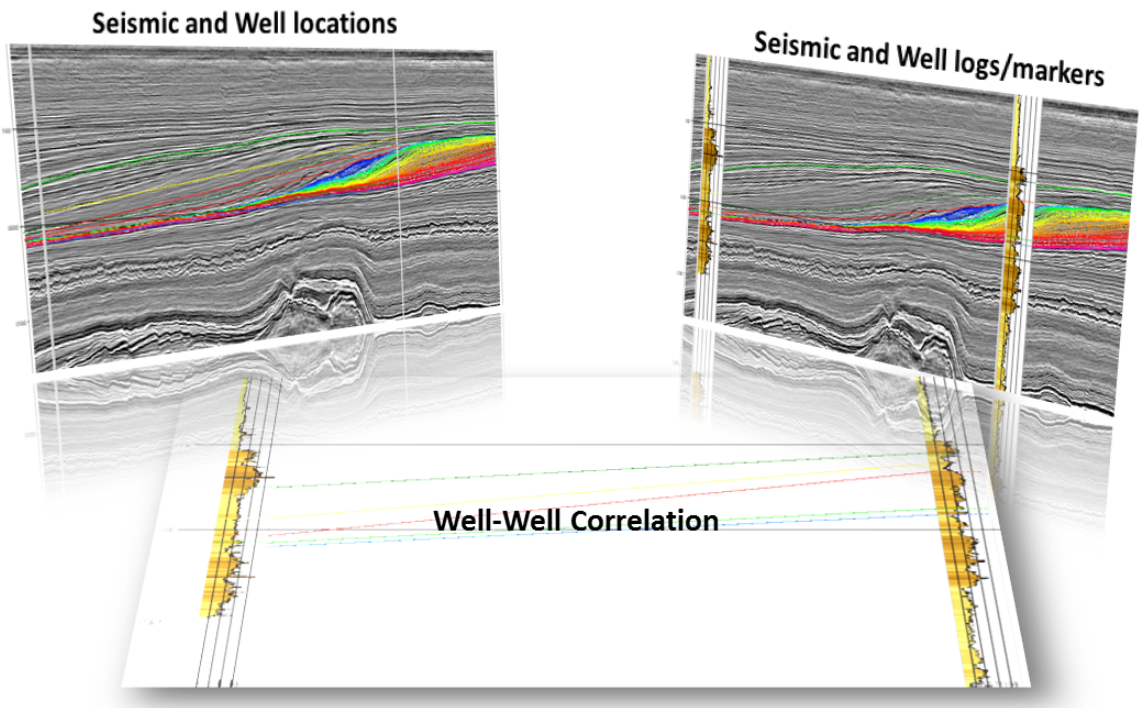


5. Once you have picked and named a horizon, its location is marked with (in this case) a grey line in the *Extract Horizon* window.

6. You may repeat this process for multiple horizons, and when you are finished, click *Proceed*

7. Your horizon(s) is(are) now ready to load.

8.10 Well Correlations Using HorizonCube



A part of sequence stratigraphic interpretation (next chapter) is to integrate the seismic information with the well data. This is done in the *Well Correlation Panel (WCP)*. The panel is an important tool for creating consistent geologic frameworks. It integrates stratigraphy, well logs, markers, mapped regional horizons, seismic and horizons from the HorizonCube in one view. It enables the user to arrive at interpretations that are consistent between the different scales of (regional) geological concepts, seismic data and well logs. Its primary functionality is to pick (and/or QC) well log markers that are defined within the (regional) geological or stratigraphic framework in a consistent manner using seismic correlations to guide the picking. Typically, the user starts with a random seismic transect connecting the wells in a 3D volume. A well correlation panel is constructed along this random track and the *Well Correlation Panel* is launched.

However, if the user wants to use a HorizonCube to guide his/her correlations it can be beneficial to convert the random line into a 2D seismic section and to continue with 2D mapped horizons and 2D HorizonCube. In that case 3D regional horizons are converted to 2D horizons (tree option under 2D Horizon) and a HorizonCube is created along the 2D section. When this is done, the Well Correlation Panel is launched. Here the user picks and QC's markers. To use all supported functionality the user should build a stratigraphic framework that links (regional) well markers to seismic horizons. Both time and depth domain are supported in the WCP module. OpendTect's synthetic-to-seismic matching module is fully integrated and is used to align all wells optimally before picking/editing markers. WCP supports various display modes including but not limited to: wells only; wells plus seismic; equidistant; connecting markers; filling stratigraphy. Unique is the capability to display the dense set of horizons from the HorizonCube and use of the HorizonCube slider to guide detailed correlations.

Exercise

1. Launch the WCP window : *Analysis* > *Wells* > *Well Correlation Panel*

2. Select data type: *2D line*

3. Input data should be selected as "*Well Correlation*" lineset. There is only one *Line* stored in this lineset.

4. At the bottom of the window, select all wells available in the list.

5. The next step is to display the WCP window... press the *Go* button:.

Once you have launched the WCP with the seismic data and the well data displayed as default, the next step is to make a display that you can easily use for interpretation.

6. Change the seismic colour spectrum to *Grey scale*. You can easily do this using the colortable displayed at the top of WCP main window.

7. The next step is to overlay the seismic data with the HorizonCube. Please use the Tree item called HorizonCube to display an existing HorizonCube on top of the seismic data. Right-click on it, and Add HorizonCube display.

8. Now display a Gamma Ray (GR) log on all wells. Use the well properties icon  from the WCP window. In the Log 1 tab, you may select Gamma Ray log with a SandShale colorbar. In the Log 2 tab, you do not select any other log (Select None). Then press the Apply to all wells button to display the Gamma Ray log on all wells already displayed in the panel.

9. Display the wells panel display on top of the seismic i.e. press this icon  that is available at the bottom of the panel. In the pop-up

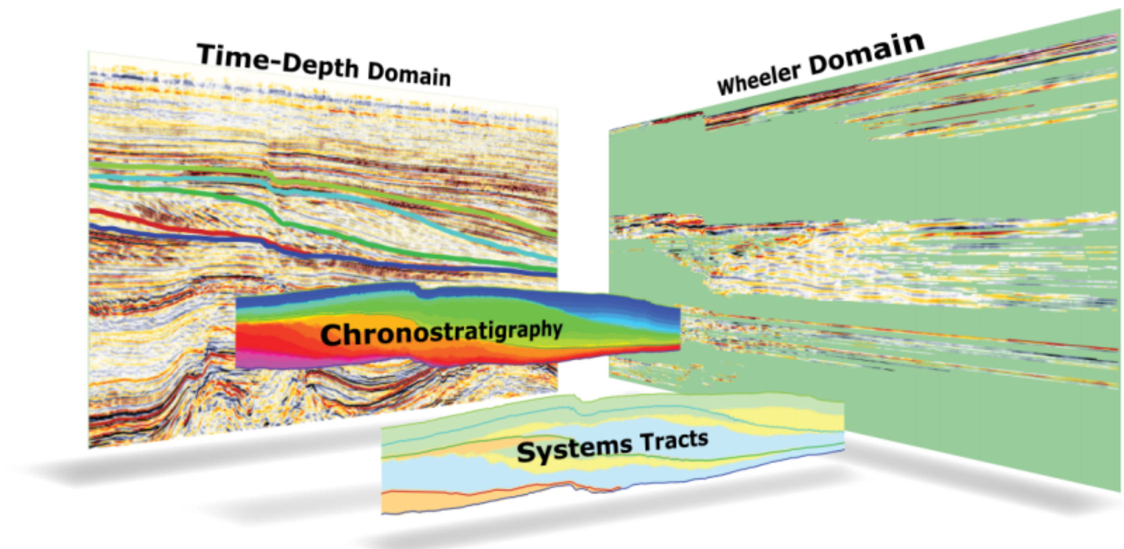
dialog, set check to On top option.

10. Now start interpreting the depositional trends and possible systems tracts boundaries by moving the HorizonCube slider up and down and adding new markers .

> **Note:** The *F03-4* and *F03-2* wells are mainly targeting the coastal plain to near shore type of depositional settings within the shallow interval i.e. between 500- 1000ms. However, the wells *F02-1* and *F06-1* are targeting the slope to deep marine settings for the same interval.

9 Background to SSIS

In essence, sequence stratigraphy is used to provide a chronostratigraphic framework for correlation and mapping and for stratigraphic prediction (Emery and Myers, 1996). Although sequence stratigraphy has proven to be a powerful instrument, and despite major advances in concepts since its introduction in the nineteen-seventies, sequence stratigraphy has not lived up to its potential because of the lack of supporting software tools. OpendTect SSIS, came to the market with the aim of filling this gap.



Wheeler diagrams and wheeler transforms can be powerful tools to aid in sequence stratigraphic interpretations. Non-depositional or erosional hiatuses are visible, the lateral extent of stratigraphic units can be determined at a glance, and a clear understanding of the lateral shift in deposition over time can be established. The Wheeler transform is constructed, by flattening each horizon, thus enabling the user to study seismic data, and its derivatives (attributes or neural network outputs) in the Wheeler domain in three dimensions. Previously, Wheeler diagrams were constructed by hand, making this a time consuming process, which is the reason why this operation was often skipped in a production environment. This is unfortunate because the Wheeler diagram, or Wheeler transform as its seismic counterpart is called, is a very valuable tool to gain insight and to extract additional information.

The Sequence Stratigraphic Interpretation System (SSIS) plugin to OpendTect allows interpreters to automatically create a Wheeler transform in which they can view the depositional history of the area through flattened horizons, showing the stacking patterns including depositional hiatuses and condensed sections. Using this added feature, interpreters can make more informed decisions about seismic facies and lithofacies predictions, thus helping to identifying potential stratigraphic traps.

9.1 Input Requirements

The Sequence Stratigraphic Interpretation System (SSIS) plugin to OpendTect will only be of use if you have already calculated your HorizonCube. If you created a continuous HorizonCube, which would be ideal as input for applications such as basin modeling or rock property predictions, you will need to truncate this to see fluctuations in the Wheeler scene. Both creating a HorizonCube and truncating an existing one are covered in exercises in previous chapters of this training manual.

9.2 Annotating Stratal Terminations - Lap-Out Patterns

While it is not a requirement as part of the workflow to perform this step each time, it is good practice. Annotating the stratal terminations in your data before making your interpretations can speed up the process, provide a reference for why you were making particular sequence assignments, and interpretations on multiple inlines or crosslines can help you check for consistent interpretations across the 3D volume.

Annotations are graphical interpretation tools that are available in OpendTect during the whole workflow. They can be a great help at the start of an interpretation when tracking bounding surfaces, or when making an initial interpretation. The annotations comprise 3 basic tools: Arrows, text boxes, and images. The arrows are intended to indicate lap-out patterns or stratal terminations, but can be used to highlight any feature. Seismic data can be annotated with textboxes and animated with pictures to make communication easier and more direct with colleagues who are working on the same project. This eliminates the need to make annotations in for instance PowerPoint.

Exercise

1. Load inline 375 and click on the '+' next to *Annotations* to expand the selection.

2. Right click on *Arrows* (when using a laptop or a small screen you might have to scroll down), select *Add Arrows Group…* and name the arrow group

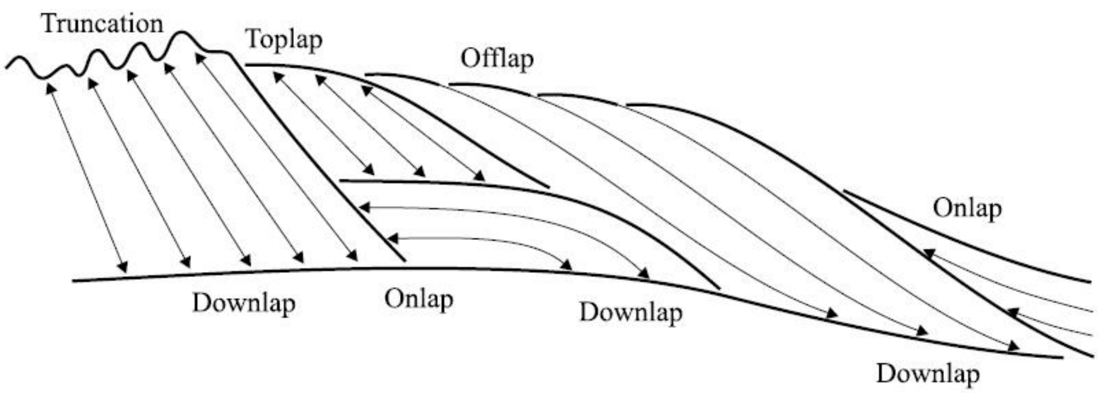
3. Now click on the seismic data where you see a stratal termination or lap-out pattern. The first click adds the arrowhead; the second click adds the direction

    Tip1: For greater control over the direction move away from the arrowhead before making the second click

    Tip2: Terminations are better visible if you use one-sided arrowheads (Properties option in the tree menu)

4. Make a complete interpretation of inline 375 by indicating all stratal terminations, highlighting features with textboxes, etc

The types of stratal terminations are truncation, toplap, onlap, downlap, and offlap. They provide diagnostic features for the recognition of the various surfaces and systems tracts. “Stratal terminations also allow inferring the type of shoreline shifts, and implicitly the base level changes at the shoreline. For example, coastal onlap indicates transgression, offlap is diagnostic for forced regressions, and downlap may form in relation to normal or forced regressions.” (Catuneanu, 2002):



Types of stratal terminations

Stratal Termination	Shoreline shift	Base level
Truncation Fluvial	FR	Fall
Truncation Marine	FR, T	Fall, Rise
Toplap	R	Standstill
Apparent toplap	NR, FR	Rise, Fall
Offlap	FR	Fall
Onlap, fluvial	NR, T	Rise
Onlap, coastal	T	Rise
Onlap, marine	T	Rise
Downlap	NR, FR	Fall, Rise

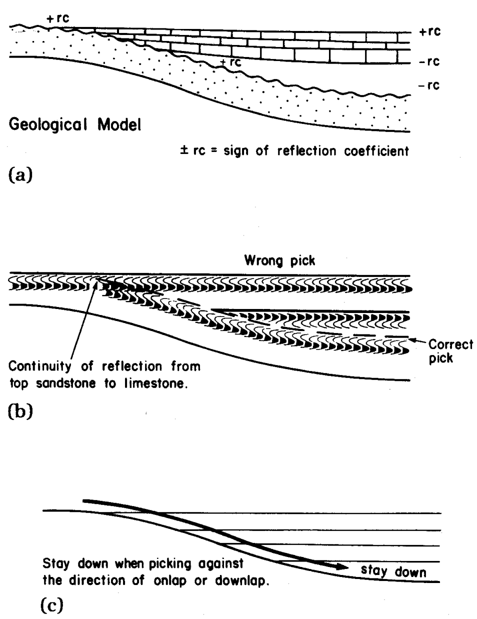


FIGURE 7.14 *Picking criterion—onlap and downlap.* (a) *Geological model: A sandstone of intermediate acoustic impedance is onlapped by shales of low acoustic impedance, and limestone of high acoustic impedance. The reflection coefficient signs are indicated on the diagram.* (b) *Seismic expression: The top sand reflection, the sequence boundary defined by the onlap, changes polarity due to the varying reflection coefficients between the sandstone, limestone, and shale. The apparent continuity between the top sand and top limestone reflections is a potential trap for the unwary interpreter.* (c) *A general rule when following an onlapped sequence boundary is to stay down when picking against the onlap direction.*

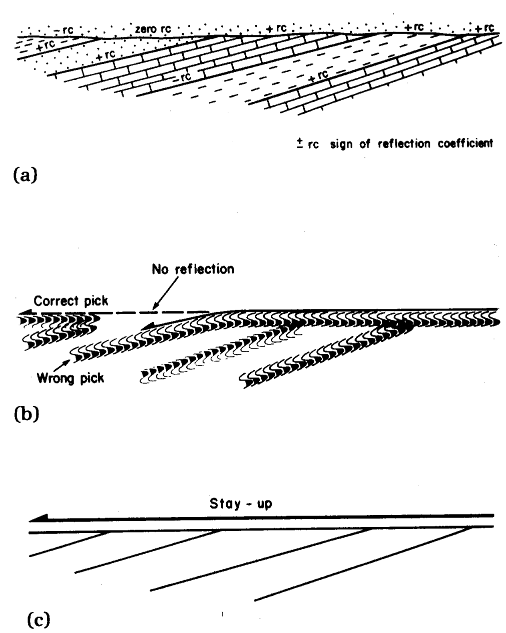


FIGURE 7.15 *Picking criterion—toplap and truncation.* (a) *Geological model: An interbedded sequence subcrops an unconformity overlain by a sand. Signs of the reflection coefficient are indicated. There is no acoustic-impedance contrast between the sands.* (b) *Seismic expression: The unconformity has a positive reflection coefficient to the right, no reflection where it is subcropped by sand, and a negative reflection coefficient to the left. A potential interpretation pitfall would be to take the unconformity pick along the top limestone reflection.* (c) *A general rule when following a surface in the direction of truncation or toplap direction is to stay high.*

Selecting unconformities

9.3 The HorizonCube Slider

The HorizonCube slider is a very useful tool to investigate your data and to make detailed observations of the depositional history of your sedimentary basin.

Exercise

1. Load the original (continuous) HorizonCube onto inline 425 with right click on the name *425* in the tree > *Add* > *HorizonCube display*

2. Click on the HorizonCube Slider icon , and a new window will open with a slider for the top and the bottom directions.

3. If you start to pull the toggle on the top slider down, you will see the upper horizons disappear. If you pull this all the way to the bottom, and then slowly begin to drag this upwards, you will see the horizons building upwards. View this on your data, and familiarize yourself with the behavior.

4. Display this on a crossline at the same time and consider the stacking patterns.

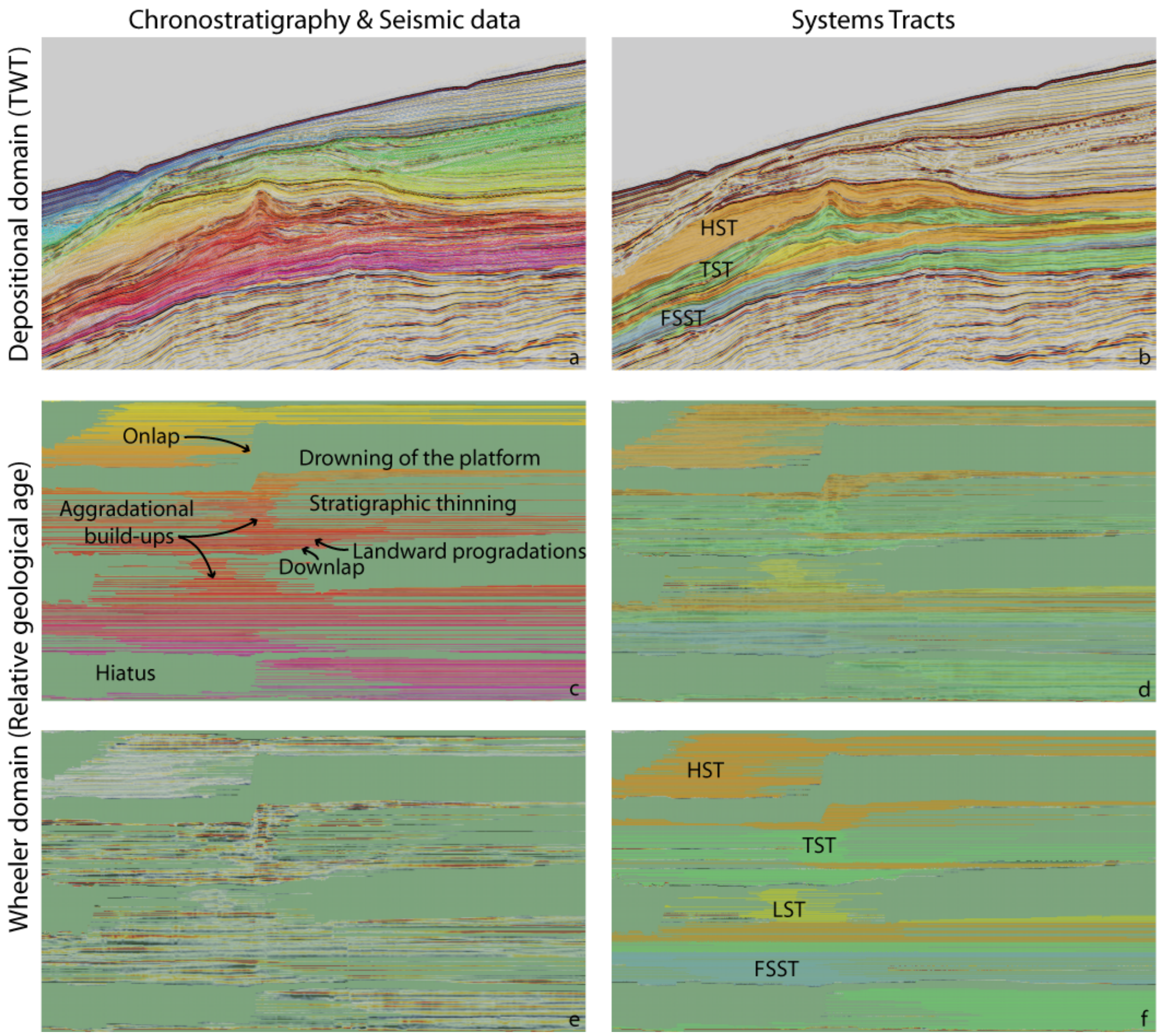
9.4 The Wheeler Transform

The Wheeler transform is automatically generated when you calculate your HorizonCube. Using this as a tool in making your system tracts interpretations puts the interpreter at an advantage since the stacking patterns, hiatuses, and erosional features become so apparent.

Data is best studied simultaneously in the Wheeler domain and in the normal or depositional domain. In the depositional domain, structural features are visible but other features stay hidden. Several of these features are exposed in the Wheeler domain, but this domain lacks the structural aspect. One of the most apparent features in the Wheeler transform is that hiatuses are visible. Both non-depositional events and erosional truncations can be distinguished (see figure c below).

Stratigraphic thinning or condensed sections can also be identified in the Wheeler transform. During deposition of condensed sections, sedimentation rates are very low causing stratigraphic events to merge below seismic resolution so that they cannot be auto-tracked. Therefore, even though stratigraphic thinning or condensed sections might not be true hiatuses, they do show up in the Wheeler transform (and the original Wheeler diagram) as such (see figure c below).

Additionally, the lateral extent of stratigraphic units or individual chronostratigraphic events can be determined with ease in the Wheeler transform. This can be a daunting task in the depositional domain, especially when no HorizonCube is available. The Wheeler domain is thus ideal for the study of the development of deposition over time, helping to answer such questions as “how does deposition shift (laterally) over time?”, “what is the lateral and temporal distribution of the packages?”.



Depositional domain a) HorizonCube b) Systems tracts interpretation. Wheeler transforms: c) HorizonCube d) Semi-transparent systems tracts overlaying the seismic data e) Seismic data f) Systems tract interpretation.

Exercise

1. Follow *SSIS> Add Wheeler Scene*

2. A new scene with a new tree opens up. Load the same inline (425) into the new Wheeler scene. Add seismic data (*4 Dip Steered Median Filtered Seismic*) and add the continuous HorizonCube.

3. Viewing a continuous HorizonCube in the Wheeler scene is not very interesting so the first thing to do is to truncate the HorizonCube display.

a. Right-click in the tree on the HorizonCube entry and select *Display> Properties*.
b. Toggle Truncate HorizonCube on and test truncating with different densities (e.g. 2, 10, 20) and chose the one you like best.

4. Maximize the Wheeler scene so that it is all that you see in your window. Use the HorizonCube slider to scroll up and down through your data in the Wheeler display. Notice the areas of non-deposition, and the condensed sections toward the deeper part of the basin.
Do you see the prograding complex?

5. Now you will view the HorizonCube in the Wheeler scene and the normal scene simultaneously.
Go to *Scenes> Tile > Vertical*. This will stack one scene on top of the other, and you can use the HorizonCube slider again, this time viewing the two scenes simultaneously.

Additional Note:

In the Wheeler scene, flattened seismic data can be displayed by adding elements (inline, crossline, and Z slice) in the tree. Such transformation is done on the fly. All attributes and neural network outputs are calculated in the normal domain first and then transformed to the Wheeler domain. Because of this transformation, quickly scanning through your Wheeler is only possible after creating a stored Wheeler Volume (*SSIS> Create Wheeler Output 3D*).

9.5 Making SSIS Interpretations

To make systems tracts interpretation you need the HorizonCube and a systems tracts model. Several models are supported in the SSIS plugin, and it is very simple to create your own model.

Choice of System Tracts Model
Within the sequence stratigraphic community several different sequence models are currently used, each with its own set of terminologies for systems tracts and stratigraphic surfaces and with their own position of the sequence boundary (Catuneanu, 2002). The software is not bound to any one of these models, since systems tracts terminology and the position of a sequence boundary are user-defined variables.

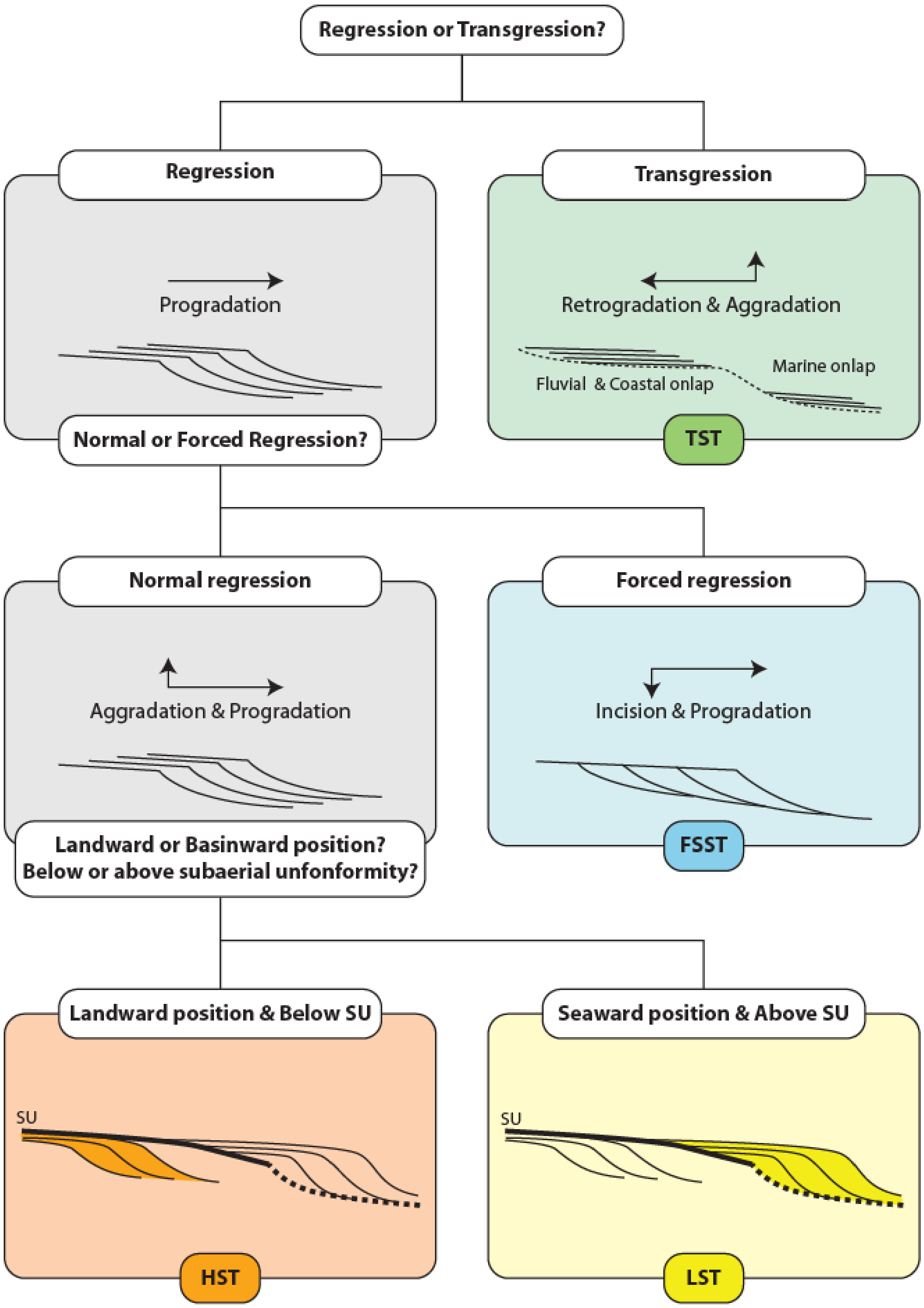
A systems tracts interpretation is based on user defined geo-time intervals. A systems tract is thus bounded by two chronostratigraphic events selected by the user. All intermediate chronostratigraphic events are assigned to the interpreted systems tract. Similar to the HorizonCube, an overlay of interpreted systems tracts can be made on inlines and crosslines.

This flexibility also allows sequences to be sub-divided into user defined depositional packages, with an individual color and name for each package, when systems tract interpretation is impossible or difficult.

Default System Tracts Model
As standard, we subdivide a full sequence into four systems tracts: Falling stage systems tract (FSST), Lowstand systems tract (LST), Transgressive systems tract (TST) and Highstand systems tracts (HST) (Figure below). The interpretation is based on the following basic principles:

- A transgression is a landward shift of facies and shoreline, while a regression is a seaward shift of facies and shoreline. (Catuneanu, 2002).
- A transgression or transgressive systems tract is characterized by a retrogradation and aggradation. This occurs when base-level is rising and more accommodation space is created than is consumed by sedimentation.
- Regressions can be subdivided into normal and forced regression:
    - a. During forced regression base-level is dropping, forcing the system to prograde. Forced regression is characterized by progradation and incision (erosion).
    - b. During normal regression base-level is rising but the consumption of accommodation space by sedimentation exceeds the creation of accommodation space by the base-level rise. Normal regression occurs during the first and last stages of base-level rise and is characterized by progradation and aggradation. The lowstand systems

tract and highstand systems tracts are both normal regression deposits.



Using the tiled view of both the normal and Wheeler scenes, an interpreter can quickly produce a rough interpretation based on viewing one line, and then view the interpretation in other areas to QC.

Exercise

1. Using the arrows created on inline 425 in the annotations exercise you will make a first pass SSIS Interpretation.

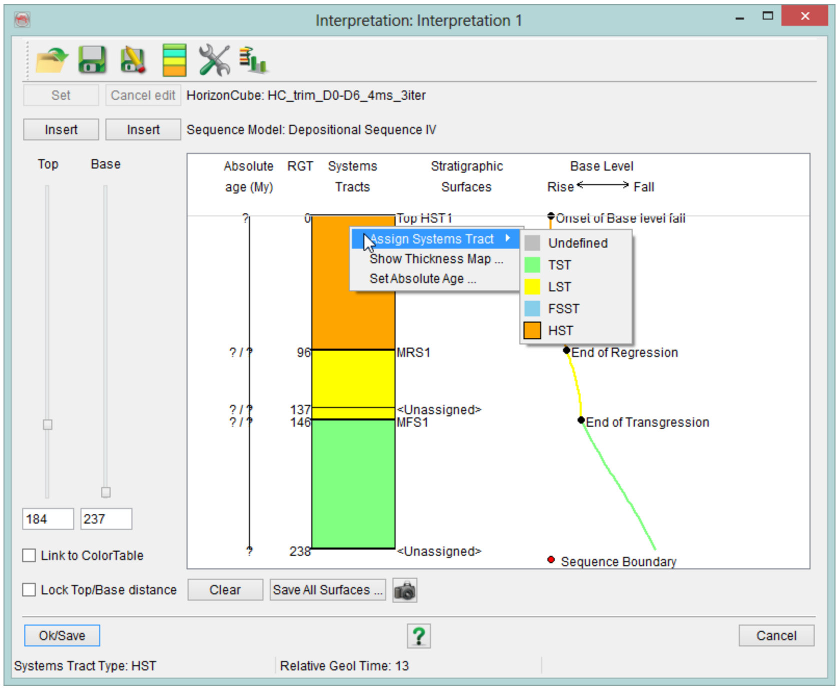
2. Toggle on your arrows group, found under the annotations section in the tree.

3. Open the SSIS interpretation window by clicking this button 

4. A blank interpretation window will open, with the familiar HorizonCube Sliders on the left side, and interpretation column, base level curve, and timeline in the white pane on the right.

5. First, open the Sequence Models selection window to view your options, by clicking the tools icon  in the SSIS Interpretation window.

   a. View the options of the sequence models available. For this exercise, the default model (Depositional Sequence IV) will be used.
   b. Close out this window when you have finished viewing the options. (**Note:** The sequence models are setup in *OpendTect* according to the hierarchal description of Catuneanu, 2002.)



6. To begin your interpretation, you will first use the HorizonCube sliders. Slide the top slider all the way to the bottom while watching the Wheeler and normal scenes. Slowly drag it up until you find a breaking point that would indicate a different system tract. Perhaps you have already marked this with one of the arrows?

7. Once you have located a position where you would like to insert a boundary when using the top slider, click the *Insert* button located above the top slider.

8. You will see a newly inserted *<Unassigned>* boundary inserted on the systems tracts column. You may now assign a system tract to this area by right clicking in the area below the newly inserted boundary. If you are not sure what system tract you would like to assign, you may skip this step or assign as undefined at this time, and come back later and make assignments. (The stratigraphic surface will be assigned according to the selected sequence model.)

9. Following the same procedure, identify other systems tracts and interpret the entire package.

10. Add the systems tract display to inline 425 in the normal domain (right-click '425' in the tree > add Systems tracts display)

11. When you are done, press the *Ok/Save* button to save your

interpretation.

Saving Surfaces

If you want to save the identified stratigraphic surface as output horizon, right click on the identified stratigraphic surface (on right panel) and select Save as surface option. Give output name to that surface and load it via Horizon element in the tree. Additionally, you may save all of your interpreted surfaces at once by selecting the Save all surfaces button.

Exercise

1. Choose one of your newly interpreted horizons, and right click on the surface name, select Save as Surface.

2. You may provide a new name for your surface in the Output Surface field, and select *Ok*.

3. Go to the tree in the normal scene, right click on *Horizons* and load the horizon you just saved. (Depending upon the speed of your computer, this could take a while. If your computer is slow, select only a subvolume to process, limiting the range between inlines 375-425.)

9.6 Stratal Slicing

Stratal Slicing (aka proportional slicing) is a technique that constructs the intermediate horizons at fixed intervals between two horizons. It is an excellent tool to quickly analyze 3D seismic data by slicing through all available data.

In this section we will create a stratal slicing display in the Wheeler domain.

Workflow:

1. Track or import two horizons

2. Calculate the HorizonCube (model driven only, dip steering not required)

3. Create wheeler volume

4. Load volume in Wheeler scene

> **Note:** Before starting the exercise, we assume that the two main horizons have been checked, if it is not the case, do the following in *OpendTect* SSIS menu: Go to *Processing*> *HorizonCube* then in the HorizonCube 3D Control Center, select *Horizons - Check crossings... and/or Horizons - Fill holes* in the drop-down menu *of Data Preparation*.

Exercise

1. In the HorizonCube 3D Control Center, click on Create in front of New HorizonCube.

2. *Read* three horizons: *Demo 5, Demo 6* and *Demo 7.*

3. Assign a model to each package that is best representing the geology: choose between linear interpolation, parallel to upper of lower. Closely observe the lap-out patterns.

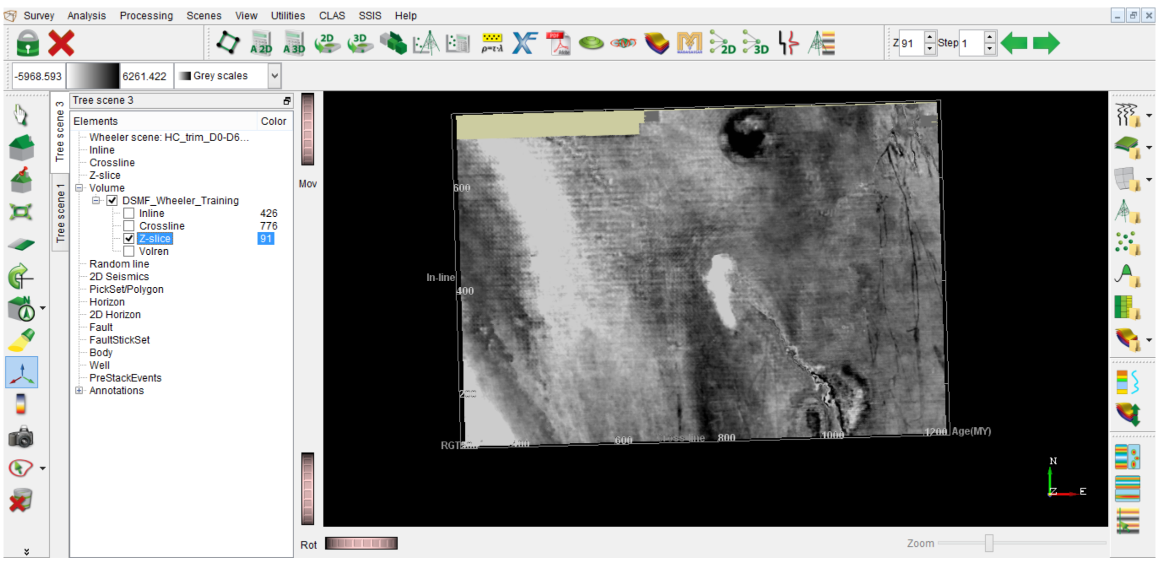
4. After the batch process of the HorizonCube has been completed, select the HorizonCube that you just created as *Active HorizonCube* in the HorizonCube 3D Control Center.

5. You can now either compute the Wheeler transformed data on-the-fly by loading what you want to view in a Wheeler scene (next step), or you can first create a Wheeler Cube as follows: *SSIS > Create Wheeler Output 3D.*

A window pops up. Your HorizonCube is automatically loaded in the *Input HorizonCube* field. Now, select the "*4 Dip steered median filter*" as Input Data and give a Wheeler Cube name in the *Output Wheeler Cube*. Click on *Proceed* to start the creation of the Wheeler Cube.

6. To view this, add Wheeler Scene as follows: *SSIS > Add Wheeler Scene*. Add the Volume in the Wheeler Scene. Show only the z-slice sub element of the Volume. (Uncheck inline, crossline, volren)

7. You can then click and drag the z-slice through the volume. (tip: lock the volume to prevent accidental repositioning):



Stratal slicing in the Wheeler domain

9.7 References

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10 Data Preparation

The following sub-chapters describe several ways in which data can be prepared prior to seismic interpretation proper.

10.1 Synthetic-to-Seismic Matching

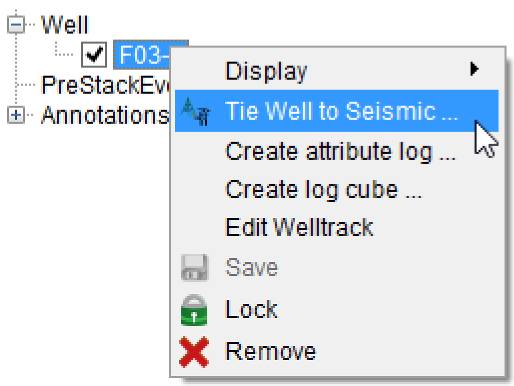
Tying a seismic volume to well data is a major task in interpretation projects. It is typically done at the start of a project to determine which seismic events correspond to which geologic markers.

Exercise

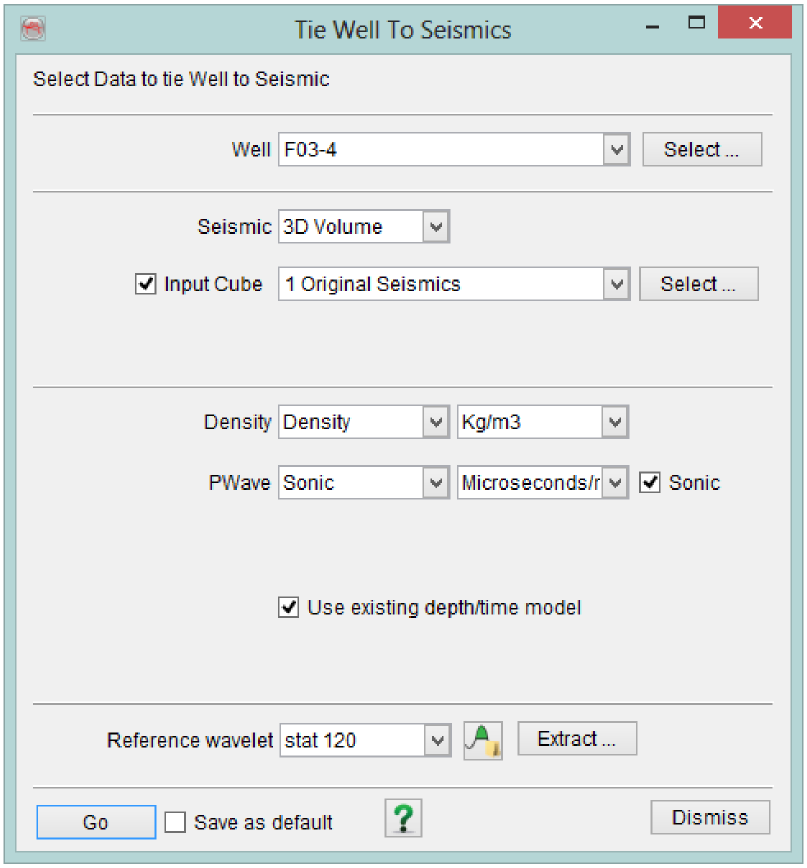
We will assume that all data (inputs for the tie) have been prepared already. The inputs are:

- 3D seismic Volume
- an initial wavelet
- well data (either sonic and density logs, or an impedance log, and geologic markers)
- (Seismic horizons are optional)

1. Load well *F03-4*, right-click on it and select *Tie Well to Seismic*.



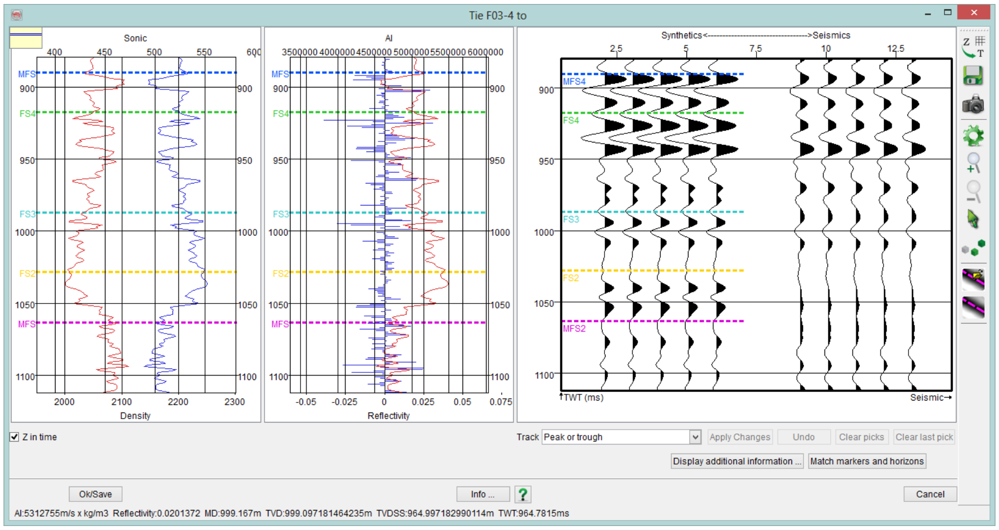
2. This will open the *Tie Well to Seismic* window. Fill the requested fields as shown below.



Select the stat120Hz wavelet as the reference wavelet. This wavelet approximates the bandwidth of the seismic data. This can be easily checked by comparing the Amplitude Spectrum from a seismic section over the target interval (accessible from right-click in the tree) with the spectrum of the stat120Hz wavelet (press the corresponding icon in Manage wavelets). Instead of approximating the wavelet with the stat120 type or a Sync type of wavelet, it is also possible to create a *statistical wavelet* from the data by pressing the *Extract* button.

> **Note:** the data is *reverse polarity* (ie: an increase in impedance gives rise to a trough.)

3. Click on Go to pop up the well tie display panel:



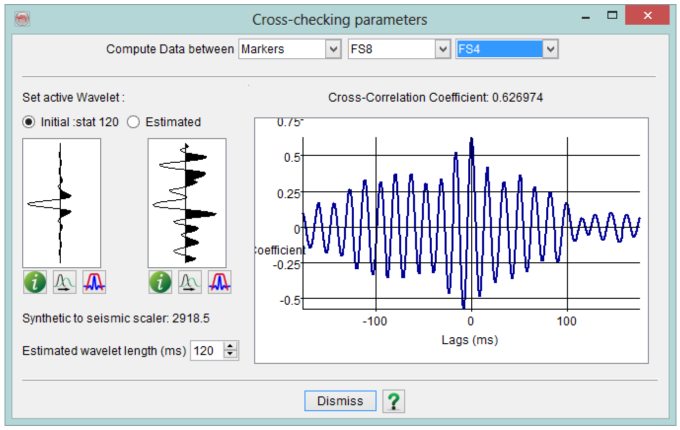
4. Optionally, the current (loaded) time-depth curve can be fine-tuned by stretching and squeezing the curve. It is achieved by picking matching events on both the seismic and synthetic traces (activate pick mode with the  icon). To see which events match load the already mapped horizons Demo 1 until 7. Zoom in (middle-mouse scroll button) and pan (left-mouse click-and-drag) until you have a display to pick matching events. After picking the events, press Apply Changes to reflect the changes. You can Undo the previous step.

5. *Additional information* can be also displayed:

The estimated (*deterministic*) wavelet can be viewed and optionally saved.

The *Cross-checking parameters* can be checked and used to get the best correlation.

- Compute the wavelet between two levels (e.g. start-end of data and one of the provided markers). Your computation interval should be defined regarding the interval of interest.



- Press the *Save Estimated Wavelet* button to save the wavelet. Write the appropriate wavelet name in the Output wavelet.

10.2 Fast-Track Inversion (Seismic Coloured Inversion)

Seismic Colored Inversion (SCI, by ARK CLS) enables rapid band-limited inversion of seismic data.

The workflow is as follows: An Operator is designed for SCI using the seismic and well data. Once the operator has been derived, it is converted to the time domain and simply applied to the seismic volume using a convolution algorithm.

Our aim is to design an operator at the zone of interest (target). It is therefore desirable to time gate the selected traces prior to generating well log spectra. Ideally you should use a good interpreted horizon in the target zone to guide the well data (log traces). In this manner, the various gated log traces should have sample values over a similar geology. However, in our case we will just use a window interval instead.

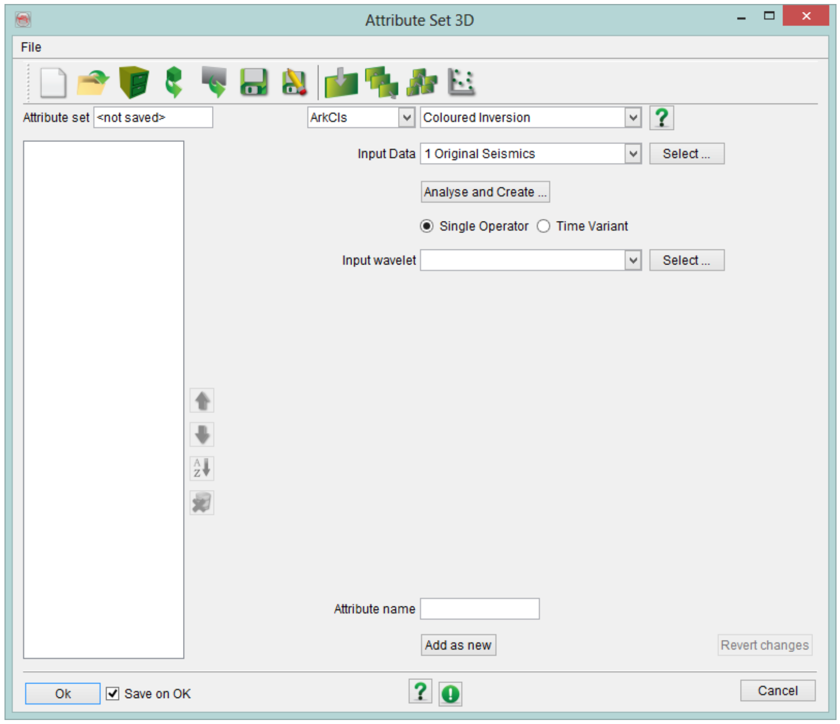
Here is the workflow on how to create and apply these techniques in *OpendTect*:

1. Seismic: Amplitude-Frequency plot
2. Smoothing of seismic mean
3. Well: Amplitude-Frequency plot
4. Global trend of well plot
5. Design operator
6. Apply Operator
7. Quality Check

Exercise

1. Launching the Seismic Coloured InversionModule

a. From within *OpendTect* main window click menu *Analysis>Attribute> 3D* or click the A 3D icon to pop up the Attribute Set Window (figure below)
b. Select Coloured Inversion in the Attribute type list to show the parameters required for this attribute
c. Click *Select...* to the right of the *Input Data* label to pop-up a dialog to allow the input volume to be selected and select *1-Original Seismic*



d. Click on '*Analyze and Create ...*' to launch the SCI Module.

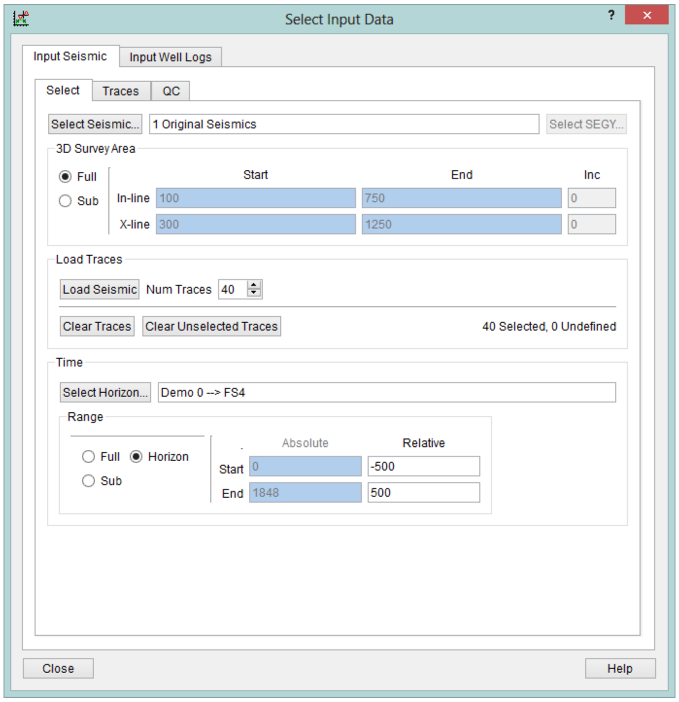
2. Selecting Input Data

To use the SCI application to design an operator, it is first necessary to analyze the seismic and well data spectra. This is achieved by loading some seismic trace data and well log impedance data in time.

a. Selecting Seismic data

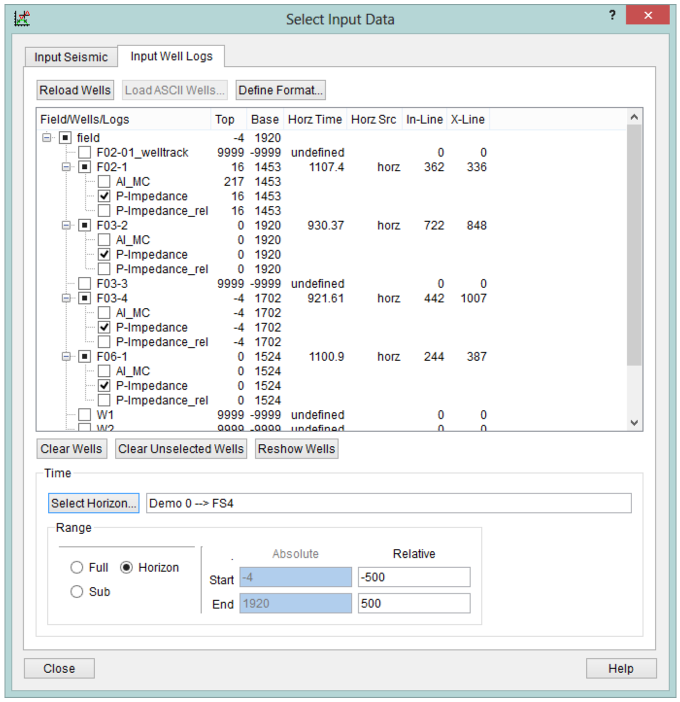
i. Pop up the "*Select Input data*" menu item under the Tools menu bar or click the  icon
ii. Click on *Input Seismic* tab to Select *1-Original Seismic*
iii. Click "*Load Seismic*" to load the default “40 traces”
iv.. *Select Horizon Demo 0 --> FS4* and toggle the *Range* to *Horizon* (Interval length should

now display as 'Relative' and be -500ms to +500 ms)



b. Selecting Well data

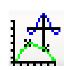
i. Click on Input Well Logs tab, then select several wells with AI or P-Impedance. Right-click on the well to generate an Acoustic Impedance log if it is not loaded yet.
ii. The previously selected horizon should be selected, toggle the *Range* to *Horizon* (Interval length should match that of the seismics, that is 'Relative', -500ms to +500 ms long), then close the "Select Input Data" window.



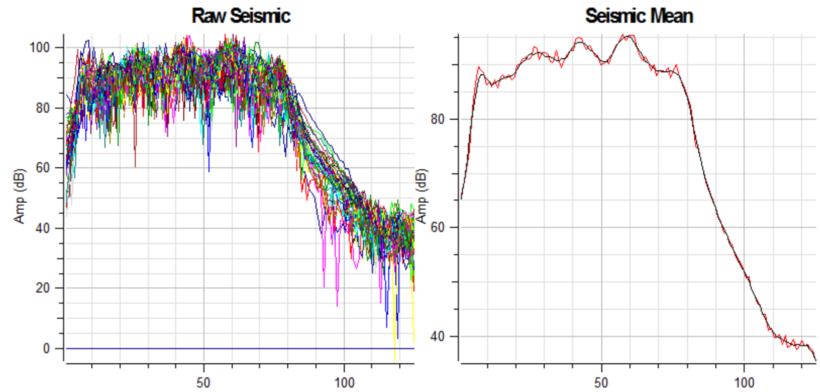
3. Design Operator Dialog

Various parameters exist which allow you to perturb how the operator is generated. These changes occur in real time so you will be able to see immediately the effect of the change you have made.

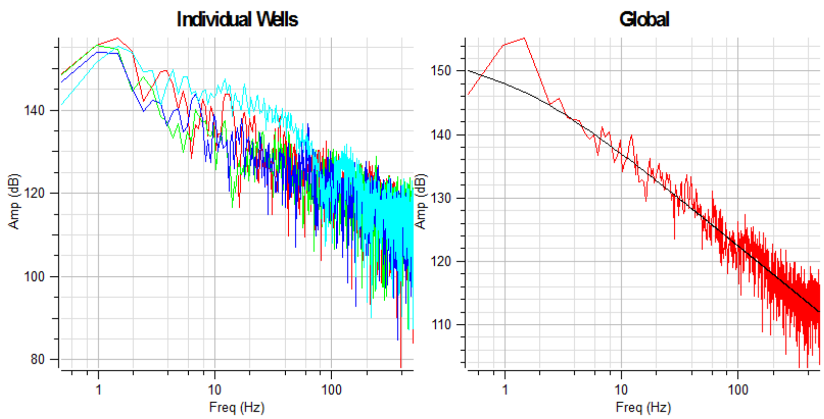
Exercise

a. Pop up the *Design Controls Dialog* by either clicking the Design Controls... menu item under the Tools menu bar or by clicking the  icon.

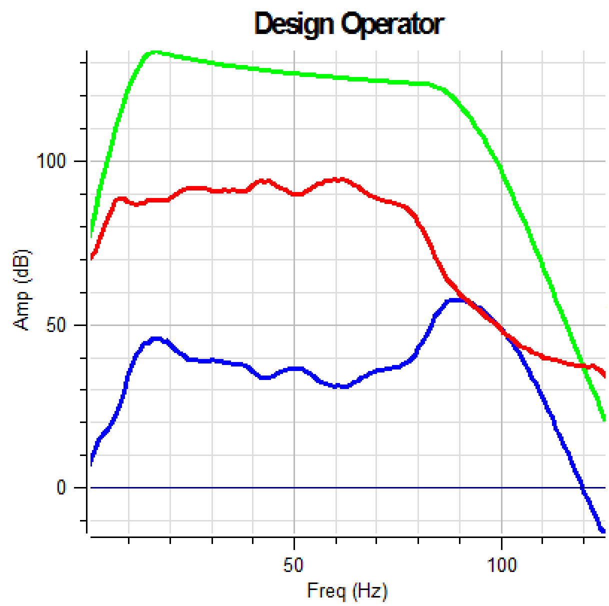
b. Smooth the amplitude-frequency plot of seismic data (seismic mean)



c. Smooth the amplitude-frequency plot of well data

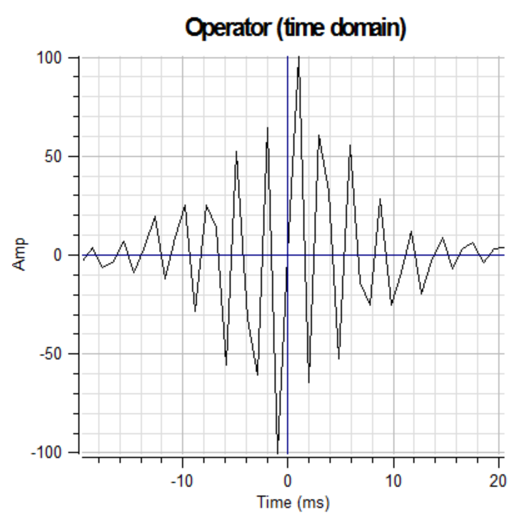


d. Tweak the parameters (low cut, high cut) of the design operator (image below) such that the operator (blue curve) stays 0 in the frequency domain, with a quick drop on both sides. The effect of the parameter tweaking is immediately visible on the seismic display that is updated automatically. Note e.g. the seismic ringing that is introduced when the residual operator is not flat in the low frequencies (Low cut parameter in the 0-8Hz range).



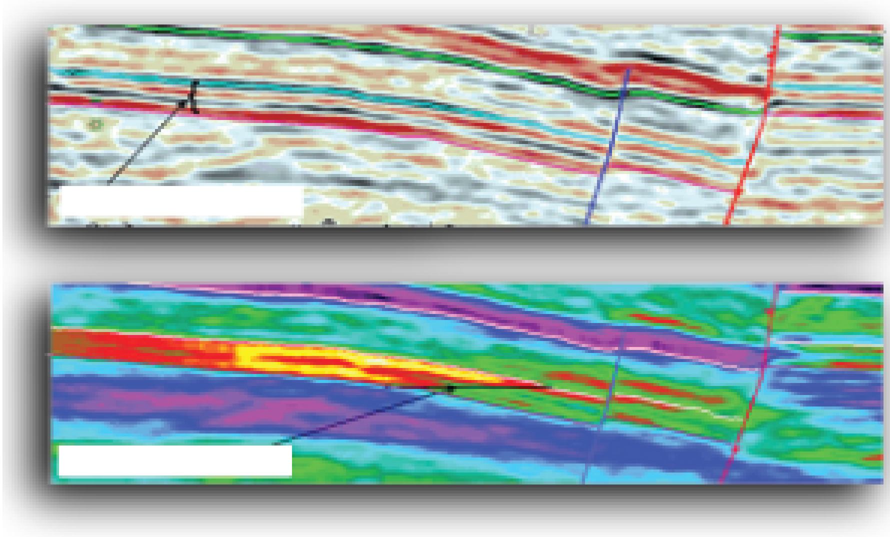
e. If the QC operator has not got the desired shape, parameter settings in the seismic coloured inversion workflow must be changed, until the correct QC operator shape is established

f. Save the operator  by giving it a name.



g. You can optionally save your session  as well. Apply the design operator on the inline 425, compare the result with the original seismic data, if satisfied create a volume output.

h. Compare the SCI attribute with the raw seismic data as shown in this example below.



Original seismic (top) and Colored inversion (base)

10.3 Variogram Analysis

Variogram parameters are necessary inputs for both the first step of the inversion, the creation of the prior impedance model, and for the deterministic stochastic inversion itself. A variogram describes the spatial continuity. The inversion model will be constructed in three zones or layers bounded by two horizons. These horizons are represented in the wells by the FS8 and FS4 markers.

Both horizontal and vertical variograms will be computed for the packages above FS8, between FS8 and FS4, and below FS4.

Horizontal variograms

Horizontal variograms are computed from grids (attributes) stored on horizons. The attribute used for this analysis is the inversion target, impedance maps. Nevertheless one should not forget that stationarity is a basic assumption in variogram analysis. Stationarity implies that the variograms analysis should be performed on trendless data. An average impedance map extracted from a broadband mean impedance volume is very unlikely to show no trends, thus it represents an improper intput. The closest maps that can be produced, and that does not contain trend(s) are attribute maps extracted from relative impedance volumes.

Exercise

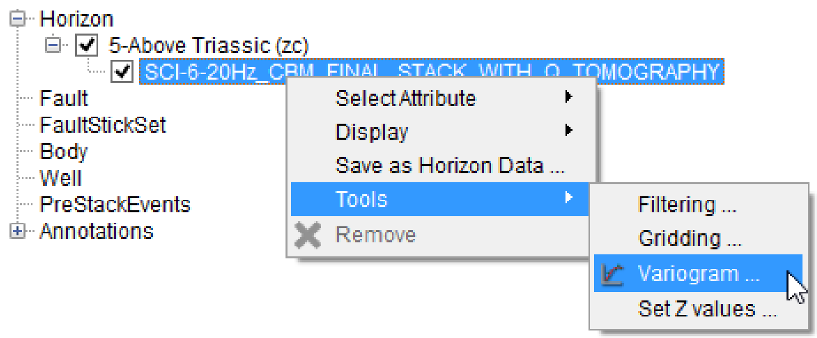
Apply the following steps to build your input for the horizontal variograms analysis:

1. Run *Seismic Coloured Inversion* on the input seismic volume.
2. Extract average SCI maps from the SCI volume:
    - Map at least the top and/or the base of several layers by tracking the zero-crossing in the SCI volume.
    - Extract an attribute map using either the volume statistics attribute (no stepout, only a time gate, minimum or maximum), or the event attribute: multiple events, maximum within a time gate, output the amplitude. Optionally you can use the stratal amplitude: *Processing > Create Horizon Output >Stratal Amplitude*.
3. Run the horizontal variogram tool:

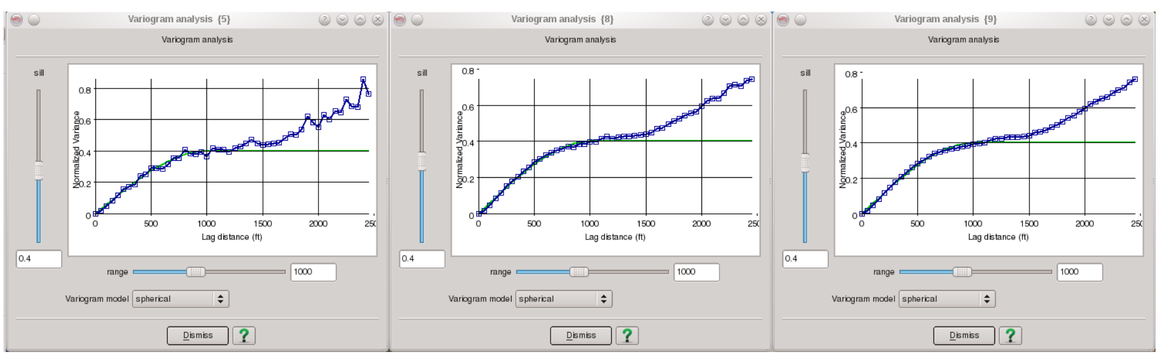
a. Load the horizon holding the surface data in the tree

b. Load the surface data

c. Select the “Variogram” option in the algorithm of the right click menu



You can change the maximum range (maximum distance allowed between the pairs for the analysis). Each lag will be analysed using a random subselection of pairs. In the variograms window (see below) you can set the synthetic variogram (green) by setting its model, range and sill that bests fit your data (blue curve). Mind the impact of the number of pairs per lag on the smoothness of the data extracted curve.



Examples of horizontal variograms from the Stratton field. The fold increases from left to right, with respectively 1000, 10000 and 100000 points per lag distance.

Vertical Variograms

Vertical variograms need to be extracted similarly. Although volume attributes could be used, well log measurements represent a more reliable input. The vertical variogram tool extracts its input from well logs using the well-attrib crossplot tool. The log data is resampled at the variogram processing step and de-trended prior to the variogram computation itself. The variogram analysis is performed in the time domain since the inversion is performed in this domain. As a result the wells used to extract the log data must be properly tied before performing the variogram analysis.

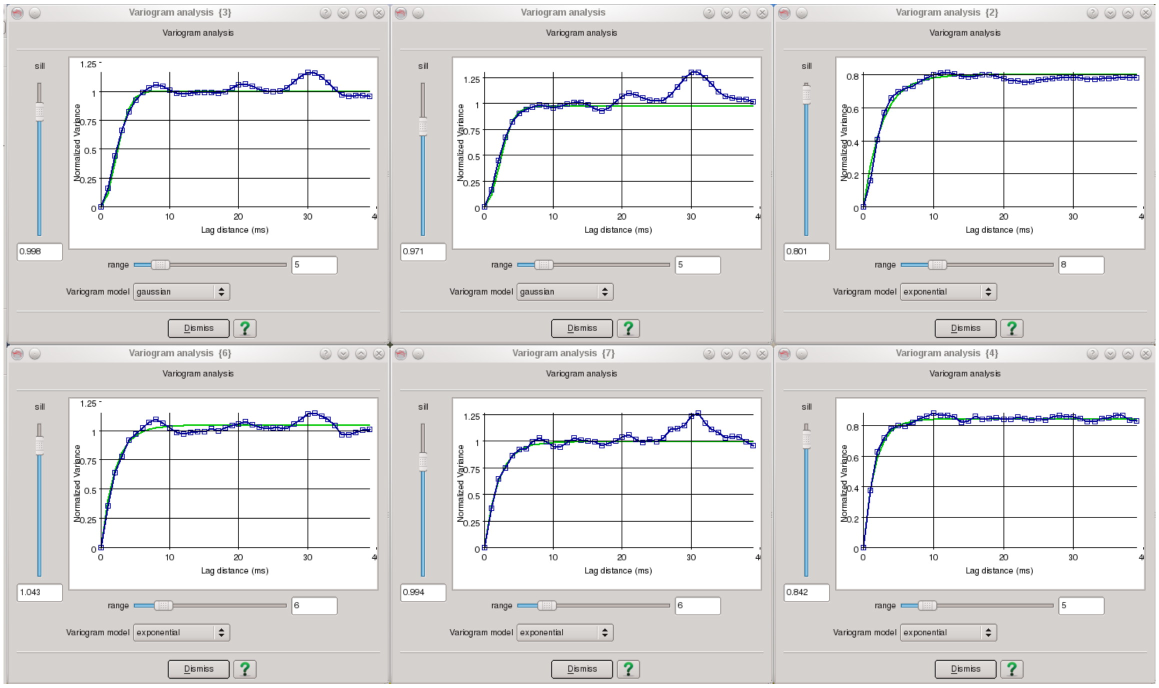
Exercise

1. Extract P-Impedance logs using the *Well-Attribute Crossplot* module in the *Analysis* menu. Remember that the data is extracted at the survey sampling rate. It is recommended to lower the survey sampling rate to 1ms during the variogram analysis.
Select the wells to be used for the data extraction, and the P-Impedance log. Set the "*Radius around wells*" to 0 and choose "*Nearest sample*" as "*Log resampling method*".

2. The extracted data will be shown in the crossplot table window. Select your P-Impedance log and press the variograms icon in the toolbar (top right).

The input parameters are very much comparable to the horizontal variograms analysis. The main difference is the number of available data points. Variogram analysis requires a minimum number of pairs per lag distance and lots of data must be input in order to obtain a representative variogram.

The analysis can be performed well by well to get an idea of the variability, but it is advised to estimate the final variogram range from all wells. If not enough data was collected you can either lower the minimum number of pairs or increase the size of the interval used for the log extraction.



Examples of vertical variograms from the Stratton field.
From left to right: above, in and below the target interval [mfrio C38].
The data was extracted using an average filter (top) or the nearest sample (bottom). Mind the impact of the filter on the variograms shape for the very first lag distances.

11 MPSI Inversion

The deterministic inversion plugin inverts the seismic data using an a priori impedance model. The output is an estimate of the mean impedance at each sample location. The prior model is created first using stochastic parameters extracted from the data. Then a 2D error grid volume is constructed to get spatially variable constraints. Finally the model, error grid, seismic volume and wavelet are used to create the mean impedance volume.

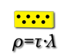
The MPSI stochastic inversion starts after the deterministic inversion. Many realizations of the impedance inversion are computed starting from the mean impedance volume using the stochastic model parameters input in the a priori model building step, and a user-defined NScore transform. Several utilities can then be used to convert the realizations into geobodies or probability volumes.

11.1 Deterministic Inversion

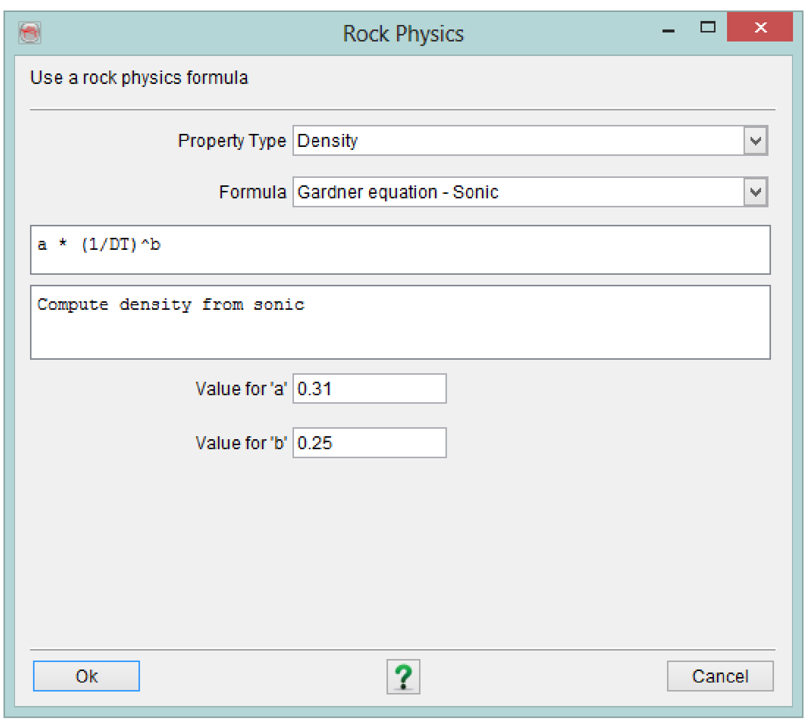
Exercise

For this exercise, please follow the steps presented in the MPSI manual. A few comments only will be given here.

Wells preparation: It is of uppermost importance to have a fully prepared log database. There should be no spikes in the logs, and it is recommended to have extended the logs upwards and downwards such that they cover the Z range where the a priori model will be used. Also since the model is created in the time domain the wells must be tied to the seismic before the inversion. Finally the logs must be in the same units and it is preferable that each log is called with the same name in all wells.

OpendTect comes with an extensive *Rock Physics library* to create logs from existing logs. The rocks physics module is called from the *Manage Wells* utility by pressing the *Create* button, followed by the Rock Physics icon . This icon is now also located in the *OpendTect* toolbar (top of the screen).

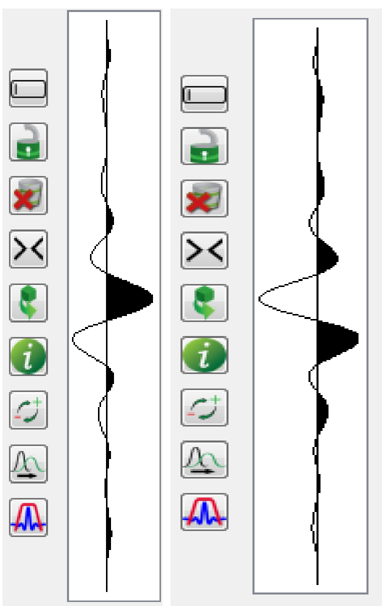
The utility supports creating new logs and filling in holes in existing logs. (An example of the latter is given below where Gardner's equation is used to replace undefined values in the Density log.)



Some useful equations in the context of MPSI inversion are:

- Gardner's equation for computing density from a sonic log.
- Castagna's equation for computing Shear sonic from a sonic log.
- Krief's equation for computing Shear sonic from a sonic log.
- Poisson's Ratio.
- Acoustic impedance from density and sonic.
- Elastic impedance from density and shear sonic.
- Extended elastic impedance for the angle χ (in radians).

Wavelet polarity: The wavelet polarity is always subject to many mistakes. One should always set the polarity of the wavelet in the MPSI deterministic inversion attribute to Normal, and set the wavelet polarity using the wavelet manager. In the figure below the wavelet on the left has a positive amplitude at t=0ms. This is a true (almost) zero phase wavelet. The wavelet on the right is the opposite, it has a trough at t=0ms, so it is a reversed zero phase wavelet.



Left: **Zero phase wavelet.** Convolving this wavelet with reflectivity series from the wells will associate peaks (+ve, positive amplitudes) in your seismic survey with a local impedance increase.

Right: **Reversed zero phase wavelet.** The real phase of this wavelet is +/- 180 degrees. Convolving this wavelet with reflectivity series from the wells will associate troughs (-ve, negative amplitudes) in your seismic survey with a local impedance increase.

The ideal workflow for setting the wavelet polarity should be the following:

1. Extract the statistical wavelet from the seismic survey. If you know the polarity of your dataset, set directly the phase to either 0 or 180. 0 will provide a wavelet like the left example, 180 will create a wavelet like the right example.

2. Tie the wells to the seismic data. If the polarity is correctly set and the well is tied with a good match, then the cross-correlation graph will show a large positive value at zero lag. If the polarity is wrongly set you should see a strong negative amplitude at zero lag, or offset from the zero lag if the previous interpreter tied the well assuming the wrong polarity.

3. Correct the polarity if needed in the wavelet manager using either the “Reverse polarity” button or the “Rotate phase” button.

4. Apply the MPSI attribute with the polarity flag set to “Normal”. The option “Reverse” reverses the wavelet polarity on the fly without changing the stored wavelet on disk. This is not recommended.

Scaler extraction: The computation of the scaler is the most difficult part of the impedance inversion, after the generation of the wavelet.

The following guidelines should always be honoured:

- The scaler varies with the frequency content of the a priori model. Ideally the scaler should be computed on unfiltered a priori models. Thus all smoothing parameters from the 3Dmodel attribute should be toggled off during the scaler computation. Smoothing can be turned on again for running the inversion by setting the scaler to the computed value.
- The scaler should always be set with ‘relaxed’ constraints, set to 0.1, 0.1.
- The scaler is computed over the Z range of the working area. The survey Z range is thus far too large, and you must lower the Z range of the working area to your target area for the computation of the scaler. This option is available in the View menu.
- The scaler is by default extracted along the wells. Sometimes this data is not suitable for the scaler extraction, and one needs to compute the scaler from a subselection of the points. Note that both use the a priori model as

input for computing the synthetic seismic, and not the impedance logs from the wells.

Scaler too low: The inverted impedance will have very strong vertical variations, and the corresponding synthetic seismic error will be very similar to the input seismic volume, both in the time domain and in the frequency domain.

Scaler too high: The inverted impedance will be very similar to the a priori model, and the corresponding synthetic seismic error will show low overall amplitudes.

LN Error correction: This option applies a lognormal correction to the AI log when converting the synthetic seismic error to impedance errors. The automatic computation transformation goes sometimes wrong and one must then toggle off this option or manually set to value. A symptom to be kept in mind is that a wrongly set LN error correction can shift the mean impedance value over the target.

Block size: The block size determines the blockyness of the output impedance. A large block size will have poor resolution but a better estimate of the mean impedance. The block size should ideally be set to 1. Using a larger value may increase the reliability of the mean impedance estimate, but will return a rather blocky output that can be more difficult to interpret.

Pre-processing: This function is used to reduce the runtime of the attribute. However the pre-processing must be re-done everytime the scaler, well constraints, block size or inversion range (Z range of working area) is changed. As a rule it should not be used during the testing phase, but after the parameters have been finalized and before the batch processing.
Even so, for small targets it can be more efficient to compute the matrices on the fly than to read them from disk. An approximation is to use the pre-processing when the inversion window is larger than 500 samples.

Exercise

Quality control of the inversion:

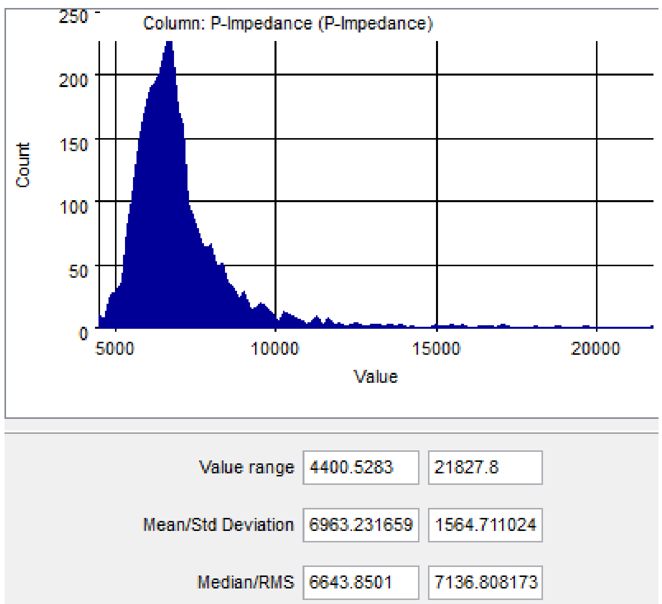
- QC that the synthetic seismic error has an RMS amplitude lower than 10% of the RMS of the seismic.
- When inverting with relaxed constraints, QC that the inverted impedance correlates with the impedance logs using the cross-plot tool. Optimize the cross-correlation as a function of the scaler and LN Error correction.

- Extract the histogram from the inverted impedance volume and measurement impedance log using the well-attrib crossplot tool, around/in the inversion target. QC that the mean and standard deviation are similar. A shift in the mean indciates an LN Error problem while a change in the standard deviation is indicative of a problem with the scaler.

11.2 Stochastic Inversion

The parameters to set for the stochastic inversion are rather limited. One must enter low and high bounds for the stochastic impedance generation. However the statistics shown in the log window are computed from the entire Z range, and are certainly not fit for the purpose of the inversion.

Better minimum and maximum values should be extracted using the well-attrib crossplot module in the range of the impedance inversion. The histogram will return minimum, maximum, average and standard deviation values for the level of interest.



The figure above shows an example of a P-Impedance histogram extracted at the inversion level. The distribution is well behaved except for the high end of the histogram, very much stretched towards large impedances. This could be the result of the presence of many high impedance spikes. If not then it is still not recommended to use the maximum value as parameter for the stochastic inversion.

The lower and high bounds should be within +/-2 or maximum 3 standard deviations from the mean impedance value.

12 Rock Properties Prediction Using Supervised Neural Networks

In the exercise that follows, we will convert seismic information to porosity using a neural network inversion workflow.

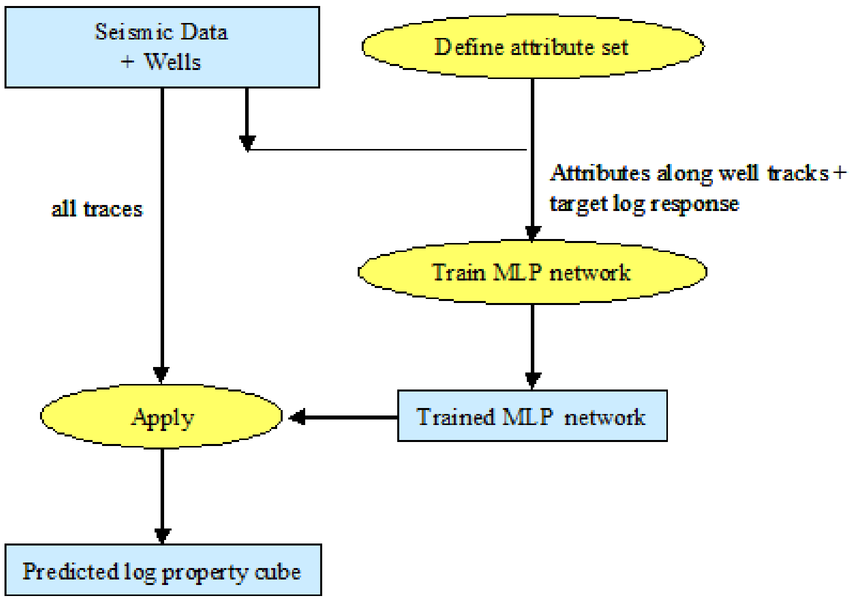
As in the chimney cube exercise (see Chapter on Seismic Object Detection, Fluid Migration Path Analysis), we will use a supervised neural network to establish the (possibly non-linear) relationship between seismic response and porosity. The main difference from the previous exercise is that we will now use well information to construct the training (and test) sets.

The input consists of acoustic impedance values from the AI volume and the reference time, i.e. the two-way time at the extraction point. The reference time is included to capture a possible porosity trend with depth (time).

Theoretically we only need the AI value at the evaluation point as input to the neural network but this assumes that the inversion process has completely removed the wavelet and that there is perfect alignment of AI and log responses along the entire well track. To compensate for potential inaccuracies we will extract more than just the AI value at the evaluation point. Instead we will extract AI in a 24ms time window that slides along the well tracks. The corresponding porosity values from the depth-to-time converted and resampled logs serve as target values for the neural network.

12.1 Workflow

Porosity prediction is a relatively easy process. The workflow is schematically shown below:



Log property prediction workflow
This workflow can be used to create log property cubes such as a porosity cube and a Vshale cube.

Exercise

To perform the exercise the following steps must be followed:

1. Start by selecting the *Inversion attributes* set from the defined attribute sets (*Analysis > Attributes > 3D.. > File > Open set* or click on the icon followed by).

2. Look at the attributes in the set and note that we extract amplitudes from the AI cube in a time gate of -12 to +12ms relative to the evaluation point. Click *Ok* to dismiss the window.

   Note: reference time is defined in the attribute set.

3. Open the neural network plug-in and select *Property prediction*

[Well Data]

4. Select the *Input Attributes* (default is all defined attributes from the selected attribute set)

5. Select *Target: Porosity*. Select all 4 available wells

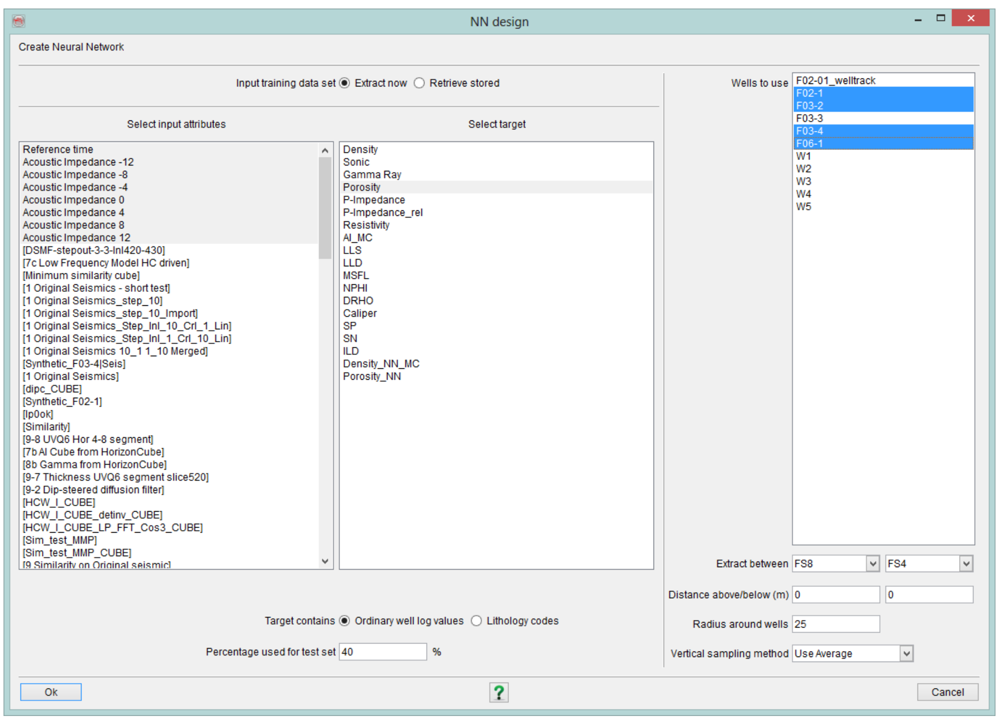
6. Select logs from *F02-1*, *F03-2*, *F03-4* and *F06-1* to create the training set within the target zone

7. Start of data is top *FS8* and End of data is *FS4*. (Distances above and below are both *0*)

8. *Radius around wells:* Indicates the distance out from the well centre where the selected input attributes are calculated for each depth of extraction. All traces within the radius are selected. For example, to utilize only the nearest trace, leave this field blank or enter a zero.

9. Choose *Average* for Vertical sampling rate. This means that the target porosity is calculated over all well log values within a window of + and - half a sample rate.

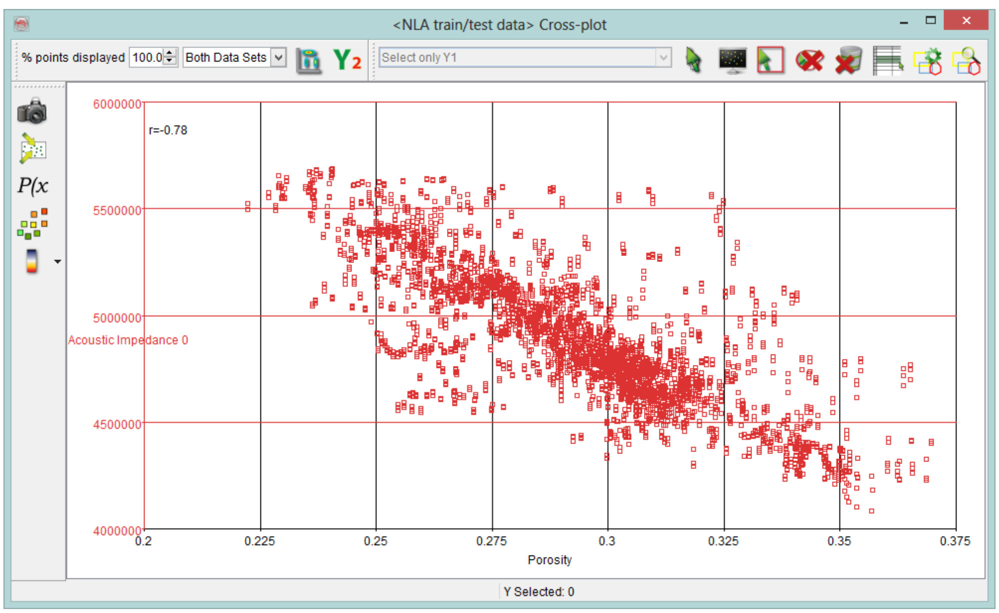
10. Select 40% of all examples to be used as *test set* and press *Ok*.



The software has extracted all specified input attributes and target values over the specified range along the well tracks and randomly divided the data into a training set and a test set. In the cross-plotting facility, the data can be examined and where necessary edited.

11. To make a cross-plot of Acoustic Impedance versus Porosity (figure below)

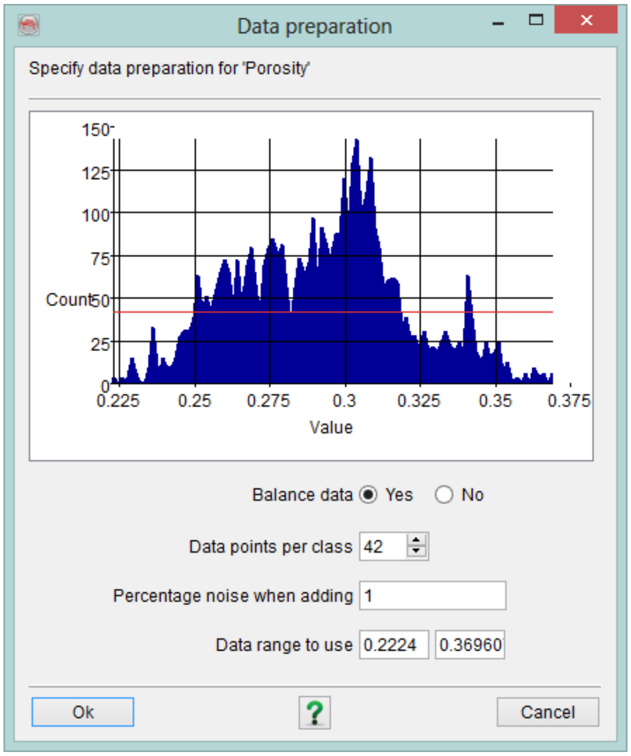
> a. click on the Header of the *Porosity* column and press the *X* icon.
> b. click on the *AI 0* column, and press *Y+* followed by the *Cross-plot.*  icon. The crossplot window will popup.
> c. Use the green arrows (in the previous window) to move the Y column to see how the other input attributes plot against porosity and perhaps press the *Distribution* icon to see how the data are distributed. The cross-plotting utility also allows us to edit the data. For example, we can remove outliers, which will improve subsequent neural network training.
> d. In this case, no editing is needed, so dismiss the cross-plot window and press *Go* to continue.



Porosity versus AI cross-plot

12. In the next step you have the option to balance your data. Balancing is a recommended pre-processing step if the data is not properly sampled (see figure below). The process helps the network to find the relationship we seek instead of finding a relationship that is driven by

the sample distribution.

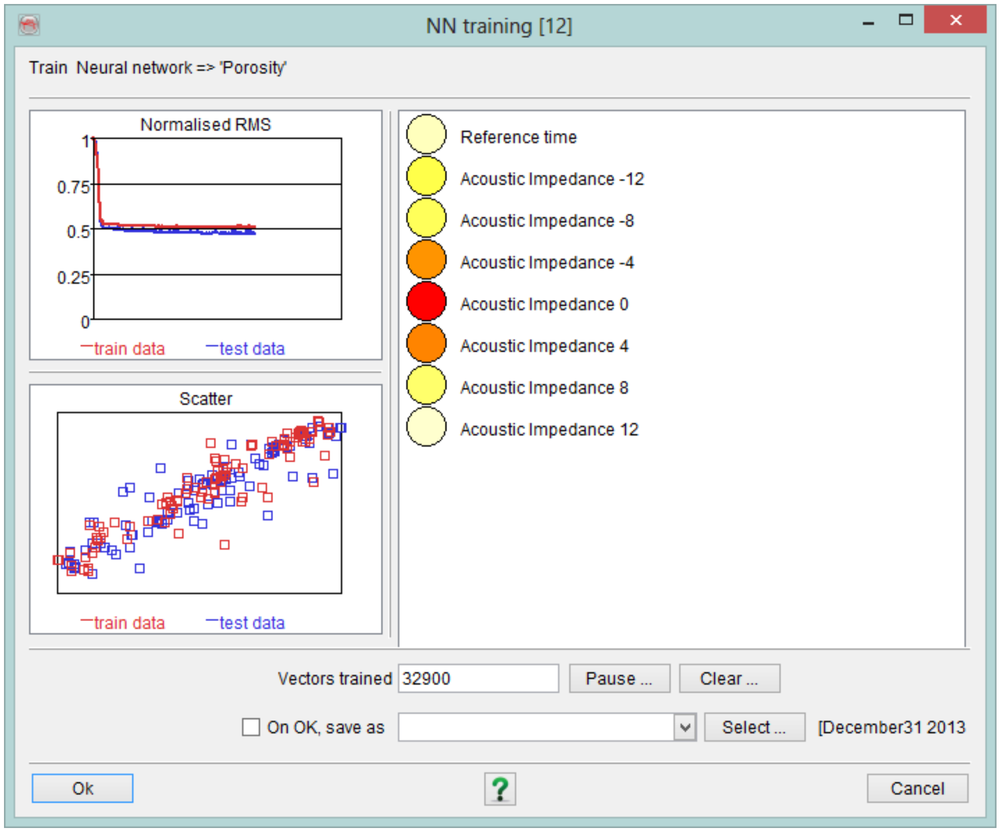


Data preparation of the training dataset.

Imagine that the range of porosities varies between 2% and 30% but that 90% of the data has porosities between for exemple 18% and 20%. The trained network will then probably also predict only values between 18% and 20% as such a network will have the smallest prediction error over all the samples in the training set. The aim of balancing is to give the network equal amounts of training samples over the entire range. This is done by dividing the distribution chart into a user-defined number of classes. The desired number of classes is set. Classes that are over-sampled are re-sampled by randomly removing samples. The number of samples in under-sampled classes is increased by randomly selecting a sample, adding 1% of white noise and adding the noisy sample to the training set. This process is repeated until all classes have the same number of samples. In this case we are lucky that our dataset is nicely sampled as we have learned in the previous cross-plotting phase. To continue, press *Ok*.

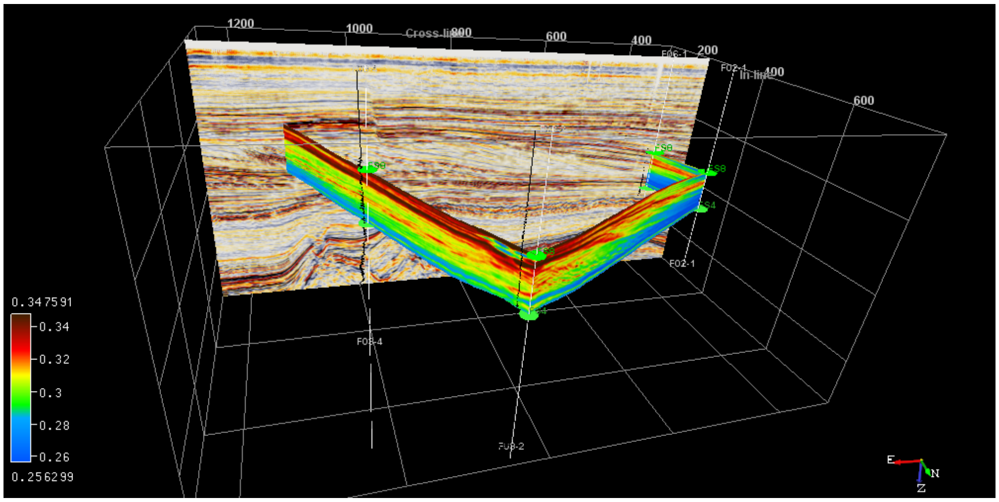
13. The network training started automatically. Stop training when the error on the test set is minimal (see below). The cross-plot in lower-left corner plots predicted target values against actual values for train and

test sets. For an explanation of the error curves and the color scheme of the input nodes see the previous exercise. Press *Ok* and *Store* the network.



Neural Network training performance window

14. To create a porosity cube, save the network in the *Create Seismic output* > *Attribute* > *3D...* window, or apply it first on a part of an inline, or a horizon so you can check the results. Note that all results are only valid within the target zone. The final result may look like the result in the figure below:



Porosity prediction result on random line through 4 wells. The displayed log is the actual porosity trace.

12.2 References

De Groot, P., 1999 Seismic Reservoir Characterisation Using Artificial Neural Networks. 19th Mintrop seminar, Muenster, Germany

Berge, T.B., Aminzadeh, F., de Groot, P. and Oldenziel, T., 2002 Seismic inversion successfully predicts reservoir, porosity, and gas content in Ibhubesi Field, Orange Basin, South Africa. The Leading Edge, April

13 Project Workflows

So far we have been working on the F3 survey which had already been setup. The seismic data were preloaded, the SteeringCube with other derived cubes like Chimney Cube were already calculated.
When you start your own survey you will have to load and calculate these data yourself. In this exercise you learn how to setup a new survey and import seismic data, horizons, and wells and you learn how to calculate a SteeringCube (This has also been explained earlier).

Note that there are several commercial plugins that support easy project setup and data IO to and from SeisWorks/OpenWorks, GeoFrame-IESX and Petrel. If you do not have access to these plugins you can always load data from standard formats such as SEGY, LAS and ASCII. How to do this is the subject of the following exercises.

The raw data for our new survey are located in a folder called *Raw_Data* in the F3 survey.

13.1 Setup Survey and Load SEG-Y Data

Exercise

1. Select the "*Select/Setup..*" option under the Survey menu or click on the Survey icon  .

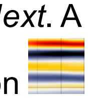
2. Select *New* button to setup a new survey.

3. In the next window, name the new survey and select the survey type (*2D only*, *3D only* or *both 2D and 3D*)

4. The survey ranges (or coordinates) can be filled manually, copied from GeoFrame/Petrel, set for 2D only, copied from another survey or created by scanning a SEG-Y file, which is the way we will do it in this exercise. Select "*Scan SEG-Y file(s)..*" from "Define by", specify the domain and press *Ok*.

5. Select the Input SEG-Y file (F3/Raw Data/Seismic data/Seismics_ data.sgy).

6. Under Manipulate you can inspect and change headers. The window shows a dump of the EBCIDIC header, the binary header and the first trace header. You can scroll through the trace headers with the Trc scroller. A plot of trace headers for a number of traces can be made by pressing the corresponding icon. Optionally binary header information can be changed and trace headers can be modified by specifying mathematical formulae in the middle column. Close the window with *Cancel*.

7. Leave the remaining fields as default and press *Next*. A report of the first 100 traces is given. Press the *Display traces* icon  to see the first 100 traces. Press *Dismiss* when satisfied.

8. You are now in the *Determine SEG-Y revision* window. Modern SEG-Y files are Revision 1 but unfortunately not all SEG-Y files that are claimed to be Rev-1 adhere to the standards. This is why we need all these tools to examine and possibly override header information. Select "*[No]: The file is NOT SEG-Y Rev.1 - treat as legacy (i.e. Rev 0)* ", then click *Next* in the Wizard to proceed.

9. In the SEG-Y scan window you can optionally override the start

time, sampling rate and the SEG-Y co-ordinate scaling. Press *Go* to scan the entire file. A report is generated in which you find among others inline and crossline ranges and amplitude ranges with scaling parameters that can be used in case you wish to save the seismic file in 16, or 8-bit format. Press *Dismiss* and *OpendTect* will fill in all the parameters it needs in the Survey Setup window.

10. Click *Ok* to select the survey you have just setup and *OpendTect* will prompt you to load the seismic file that has just been scanned. Click *Yes*, specify an output file name and press *Go* to load the seismic data in *OpendTect*. On import completion, you will see an information window giving some details of the cube. Click *Ok* to dismiss this, once read.

11. Finally, load an inline (from the tree) to check the data. You will probably want to change the vertical scale. Go to *View* and adjust the Z-scale (fit to scene, if desired) and safe this scale as default.

13.2 Create a SteeringCube

(for Dip-Steering license-holders)

Exercise

1. Several attributes need steering data to work.
To create a *SteeringCube* select *Processing > Dip Steering >3D> Create...* .

2. Select the *Quantity to Output* as *'1 Original Seismics'*.

   Note: It will take a reasonably fast computer about an hour to calculate the whole SteeringCube. In order to save time select a small *Volume subselection*.

3. Appropriately name the *Output Cube*.

4. Consult the dGB index for the differences between supported Steering algorithms. In this case we select the fast *BG Fast steering* algorithm to save time. Keep the default settings.

5. Now specify whether you want to process the SteeringCube on a *single machine* or on *multiple machines*. If multiple machines are available choose this option. The next windows are self-explanatory and will start your process.

6. When the SteeringCube is created, check the result by displaying the SteeringCube itself. (*Inline > SteeringCube > Crossline dip*)

13.3 Import Horizon

Exercise

1. Choose *Survey > Import > Horizon > ASCII > Geometry3D* then select the horizon Input Ascii file (e.g. */Raw Data/Surface data/F3-Horizon-FS6.xyt* -- for example, you are free to choose any of the horizons).

2. Examine the file to determine the header contents and to check details for the *Format Definition*. Optionally, *Scan Input File* and choose if you wish to *Fill undefined parts*.

3. Name the *Output Horizon* and toggle "*Display after import*". Press *Ok* and the horizon will be imported and displayed.

13.4 Import Well Data

Exercise

1. First import the well track by choosing *Survey* > *Import* > *Wells* > *Ascii* > *Track*

2. Select the *Well track file* (e.g */RawData / WellInfo /F02-01_well-track.txt*) and examine it by clicking on the *Examine* button. Define the *Format Definition* (col-1: X, col-2: Y, col-3: Z and col-4: MD). The units are in meters.

3. Select the *Depth to time model file* (e.g. */RawData/ WellInfo/F02-01_TD_TVDSS.txt*) and *Examine* the file. *Define* the *Format Definition* for the Depth to time model (col-1: Depth-m, col-2: TWT-msec). Check the file header.

4. *Is this checkshot data?*: Yes

5. *Advanced* options are optional.

6. Name the output well and press *Go* to import the track file.

7. After the well track is loaded display the well in the survey by right clicking *Well* in the tree, next click *Add*.

8. To import the logs files click on the *Manage Well Data* icon then *Import* or *Survey* > *Import* > *Wells* > *Ascii* > *Logs*

9. Press the *Import* button, then select las file (e.g.*/RawData/WellInfo/F02-01_logs.las*), toggle *TVDSS* and click on *Ok*.

10. When the logs are imported, show the logs by right clicking the well in the tree > *Display* > *Show* > *Logs*. Now select which log file you want to display by right click on the Well *Display* > *Properties* > *Left log (or right log)*. Select log...

11. To add markers click on the *Manage Well Data* icon, and click the *Edit Markers* icon. It is also possible to add markers manually. In this exercise, we will import markers from an existing file by pressing *Read New*.

12. Select the input file (*/RawData/ Well Info/F02-01_markers.txt*) and

Define the *Format Definition* (Col-1: MD and col-2: Name).

13. Now select a color for each marker by double-clicking on the appropriate row in the *Color* column. When finished, press *Ok*.

14. Show the markers on the well by right clicking on the well in the tree *Display* > *Properties* > *Markers*. Toggle on the desired markers and set the marker size etc. You may wish to use these settings to *Apply to all wells*.

14 Optional Items

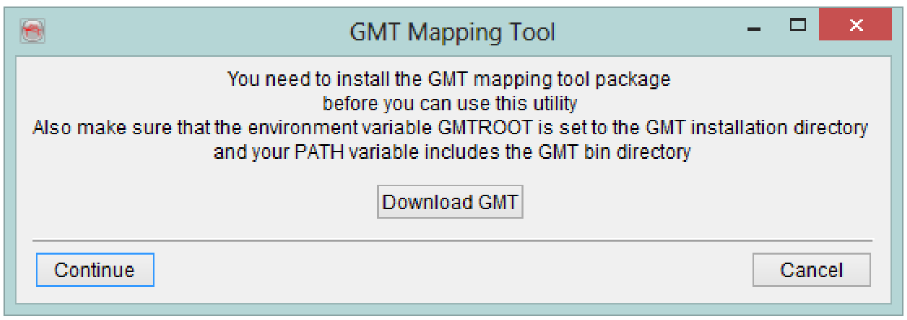
In the sub-sections below, please find some additional items that may be of interest.

14.1 Generic Mapping Tools (GMT)

GMT is an open source collection of tools for manipulating geographic and Cartesian data sets and producing Encapsulated Postscript (eps) file illustrations ranging from simple x-y plots via contour maps to artificially illuminated surfaces and 3-D perspectives views.

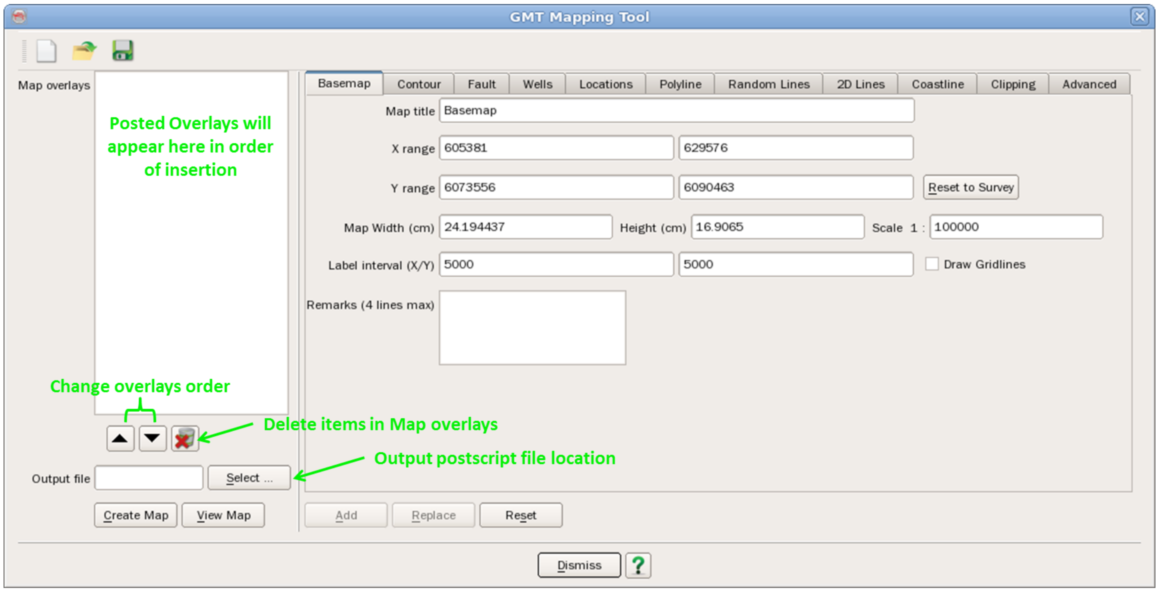
In this chapter, we will shortly explain the GMT plugin and we will create different maps in *OpendTect*:

To launch GMT tools, click on the icon in OpendTect main toolbar. The first time you launch the GMT mapping tools, a warning message will pop-up: a mapping tool package needs to be installed in order to run it. This can be downloaded from the GMT web site: http://gmt.soest.hawaii.edu/projects/gmt/wiki



> **Note:** if OpendTect fails to create a map with GMT, check whether the environment variable GMTROOT is set to the directory in which GMT was installed and whether the PATH variable includes the GMT bin directory. (Per default: GMTROOT c:\programs\GMT4 and PATH …c:\-programs\GMT4\bin…). Environment variables in Windows 7 can be set from *Computer* > *System Properties* > *Advanced System Settings*.

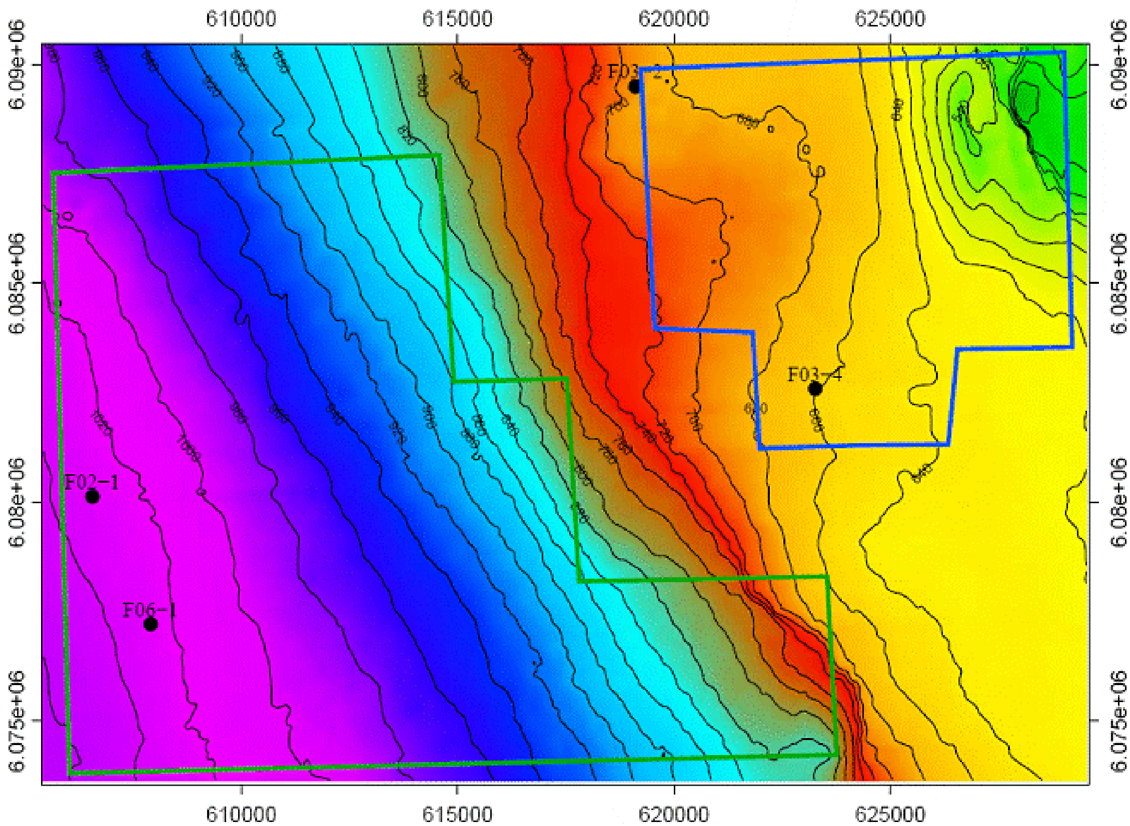
After successful installation of GMT package, the GMT user interface will be started:



When creating postscript maps, the several tabs allow to specify the respective settings:

- *Basemap:* used to set the scale of map and other map settings. You do not need to add it in the map overlays. This is the first and mandatory step into the creation of maps
- *Locations:* used to post pickset data (e.g. proposed well locations) in the map overlay
- *Polyline:* used to add polygons (e.g. lease boundaries) in the map overlay
- *Contours:* used to make a horizon contour map
- *Coastline:* used to draw coastal lines
- *Wells:* used to post wells in the map
- *2D Lines:* used to post the OpendTect 2D-Line(s) in the map
- *Random Lines:* used to post the Random Line(s) in the map
- *Clipping:* used to set up polygonal clip path
- *Advanced:* used to customize the GMT commands

Time Contour Map at Demo 4 Horizon

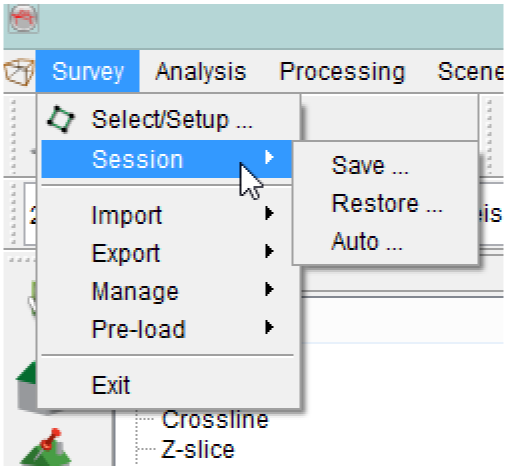


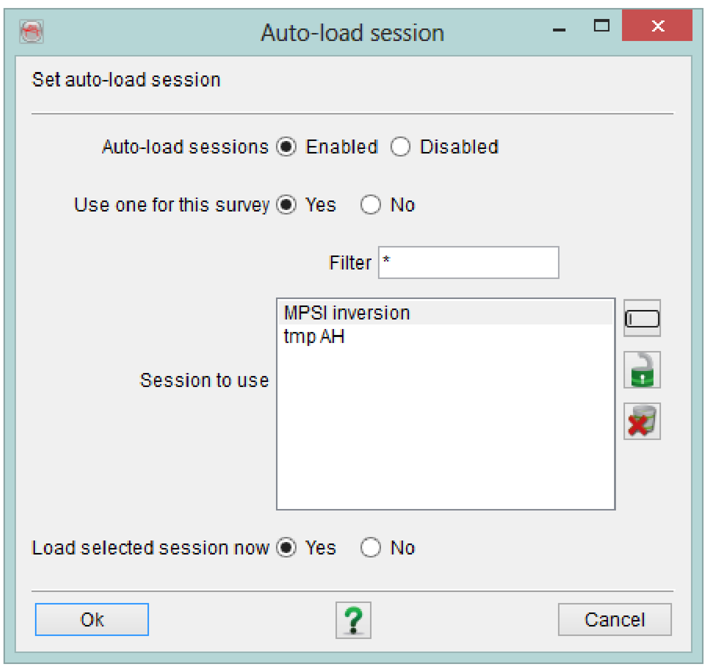
A typical example of a time Contour Map with well locations

Note: GMT4 (downloaded June 2012) had issues creating legends. The error message “pslegend.exe has stopped working” can be ignored by pressing *Cancel*. The map will be created without the legend.

14.2 Save & Restore Session

Use *Survey > Session > Save…/Restore…/Auto…* to restart your interpretation at a later moment. The graphic scene(s), elements in the tree(s), current attribute set and neural network are all saved and restored.





When clicking *Auto… > Enable*, the Auto-load session (by choosing one session amongst the available ones) the session will restore itself automatically the next time you start OpendTect.

Warning:

Elements that contain attributes that were calculated on the fly can only be restored if the attribute definition is still valid at the time of saving the session. If not, you will get a warning message stating that the attribute cannot be restored.

Tip:
Attribute calculations take time. A Session restore will go much faster if you retrieve the data from disk instead of recalculating it on the fly. So, before you save a session think whether you can retrieve the data from disk (e.g. a horizon attribute can be saved as *Horizon data* with the parent horizon. The same display can thus be restored much faster if you save the attribute first and then select it from Horizon data before saving the session).

Personal Notes