Introduction To OpendTect & OpendTect Pro

OpendTect

Created by

dGB Earth Sciences

dGB Earth Sciences - OpendTect version 6.6

Training Manual
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About this manual

This training manual is prepared for geo-scientists who want to learn how to use OpendTect seismic interpretation software. The OpendTect suite of software tools consists of two parts: a free (open source) part and a commercial (closed source) part that is protected by license managing software. The free part consists of a base system called OpendTect that can be optionally extended with free plugins. The commercial software consists of a software layer on top of OpendTect called OpendTect Pro that offers extra functionality for professional seismic interpreters.

OpendTect Pro can be further extended with a range of commercial plug-ins for special work flows. This manual teaches both parts. Theory and background of some of the more advanced work flows are given but the focus is on hands-on exercises that are executed on “F3 Demo”, a 3D seismic data set from offshore the Netherlands. Manual and data set are released free-of-charge for self-training. The same material is used by dGB Earth Sciences, the company behind OpendTect, in commercial training classes.

To follow the free exercises in Part 1 of this manual you need to install OpendTect and download F3 Demo. To follow the commercial exercises in Part 2 you need to install OpendTect Pro and all of the commercial plug-ins. For details, please follow the instructions for F3 Demo Training on the website.

OpendTect is supported on Linux (64 bits), Mac OS X 10.14 (Mojave) and 10.15 (Catalina) and Windows 10 & 11 (64 bits). The latest version of OpendTect + plug-ins can be downloaded from the Download page. The full instructions for installation can be found via the Install page and in the Administrator's Manual:

- Installing OpendTect on Windows
- Installing OpendTect on Linux
- Installing OpendTect on Mac OS X

OpendTect itself runs without license keys but the commercial plug-ins are protected by FlexNet license managing software. Entitlement is stored in FlexNet license keys that are checked whenever you run one of the commercial plug-ins. A warning message is given in case you are not entitled to run the software (e.g. when a colleague grabbed the last license before you). F3 Demo is a special data set. No license checks are made if you work on this data set. In other words all exercises in this manual can be performed without license keys.

The training manual consists of two parts:

Part I – Free Software

- OpendTect
  - Set up a survey & data loading
  - Basic interaction
  - Attribute analysis & cross-plots
  - Well to Seismic Tie
  - Interpretation of horizons & faults
  - Time-Depth conversion

Part II – Commercial Software*

- OpendTect Pro
  - Set up a survey and get data from Petrel
  - Basemap interaction
  - Grab and share 3D pdf images
  - Seismic facies tracking (Thalweg tracker)
  - AVO attributes & Angle stacks
- Attributes & filters
  - Structurally oriented filters & attributes (Dip-Steering)
  - Frequency enhancement (Spectral Bluing)
  - Flat spot enhancement (Fluid Contact Finder)
  - Object detection (Neural Networks)
- HorizonCube & sequence stratigraphy
  - Global Interpretation (HorizonCube, Well Correlation Panel)
  - Sequence stratigraphic interpretation (SSIS)
- Seismic Predictions
  - Band-limited inversion (Colored Inversion)
  - Full-bandwidth inversion (Deterministic Inversion)
  - Stochastic inversion (MPSI)**

**Not all commercial extensions are introduced in this manual. For training of SynthRock (stochastic pseudo-well modeling & HitCube inversion) and Velocity Model Building (pre-stack NMO & RMO picking) please contact dGB. For XField (potential field – gravity & EM - modeling) please contact the developers ARK CLS.*

***Multi-Point-Stochastic-Inversion is introduced in this manual. For a more complete (commercial) training class please contact dGB.*

Licenses

The OpendTect suite of software products is released under a triple licensing policy:

- GNU / GPL license – grants access to the free (open source) part only.
- OpendTect Pro license – grants access to both parts free (open source) and commercial (closed source).
- Academic license – grants access to both parts to Universities for education and R&D only.

Under the GNU / GPL license, OpendTect is completely free-of-charge, including for commercial use.

The OpendTect Pro license gives access to OpendTect Pro and the (closed source) plug-ins. Licenses can either be bought (permanent license) or rented on a monthly or annual basis. The closed source parts of OpendTect are protected by FlexNet license keys.

		GPL License		Pro License	
Feature	**Description**	**Access**	**Support**	**Access**	**Support**
OpendTect	• Data visualization • Horizon tracking • Fault interpretation • Basic Attributes • Spectral Decomposition • RGBA • Time-Depth conversion … etc	✓	✗	✓	✓
Free Plugins	• Colop • AVOAttrib. • LTFAttrib. • MLV filter • RSpecAttrib. • ExternalAttrib. … etc	✓	✗ *Not developed by dGB*	✓	✗ *Not developed by dGB*
Opendtect Pro	• PetrelDirect • Basemap • PDF 3D • Ray-tracer • Thalweg tracker … etc	✗	✗	✓	✓
Commercial Plugins	• Dip Steering • Neural Networks • HorizonCube • SSIS • Colored Inversion • CLAS … etc	✗	✗	✓	✓

Under the academic license agreement Universities can obtain free licenses for OpendTect Pro and the commercial plug-ins for R&D and educational purposes.

For more information please visit the website at the Download page.

About F3 Demo dataset

Google maps showing the location of the F3 Demo dataset (brown-filled rectangle)

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 (exercise 2.3.1 Dip-Steering) 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).

The F3 Block is available, along with other datasets, via the Open Seismic Repository on the TerraNubis website.

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.

Support Options

There are several ways of getting help with OpendTect's interactions and workflows.

User Mailing List

There is an active User Community. The users mailing list 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.

Support

For support questions please contact OpendTect's support team at: support@dgbes.com

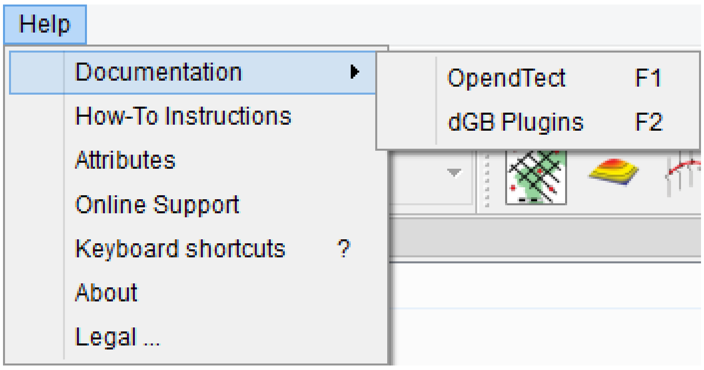
Social Media

There are OpendTect user groups on Facebook and LinkedIn.

Documentation

All user-documentations can be accessed online as either HTML or PDF, or via Help menu in the UI.

Via the software



The help menu

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

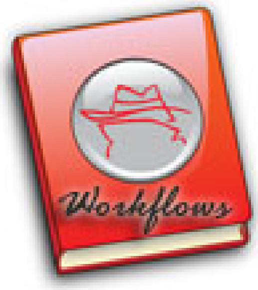
User Documentation

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

Plugins Documentation

A documentation for all commercial plugins in OpendTect.

How-to Manual



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

At videos.opendtect.org the user can find different demo, training workflow and webinar videos like: Survey Setup & Load SEG-Y, Horizon tracking, Machine Learning webinars, Fault planes, SSIS interpretation, Dip steered median filter, Chimney Cube etc…

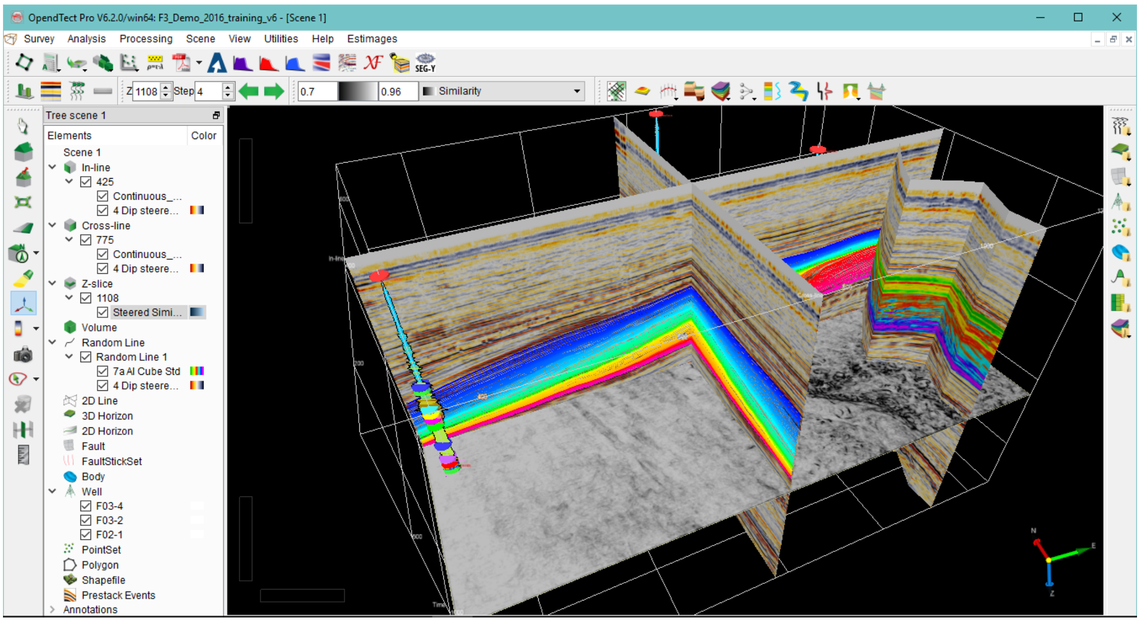
1 Part I: Free Software

1.1 About OpendTect

What is supported?

OpendTect version 6.6 supports all tools you expect to find in a seismic interpretation system. Key features include:

- 2D, 3D Post-stack & Pre-stack seismic data
- 2D & 3D viewers
- Volume rendering & RGB(A) blending
- Seismic attributes & cross-plots
- Spectral decomposition
- Movie-style parameter testing
- Distributed computing
- Rock-physics library
- Horizon trackers
- Faults
- Well-tie
- Depth Conversion
- Geobodies and … a lot more …



As stated before all functionality listed above is available free-of-charge when OpendTect is run under the open source GNU/GPL license. This system can be extended with other free software systems and several open source plugins. dGB developed links to Madagascar and GMT (see below). Several open source plu-

Free 3rd Party Plugins.

Madagascar

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

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.

1.2 Set up a Survey & Load Data

In this Chapter you will learn how to set up a new survey (a project) and how to load seismic data, horizons and well data using industry-standard file formats such as SEGY, LAS and ASCII.

In many oil companies setting up surveys and loading data is done by specialists. OpendTect Pro users who want to use OpendTect in combination with Petrel* can simply copy the Petrel project information to setup the OpendTect survey (Exercise 2.1.1a). They can then either work directly on the Petrel data store, or they can copy data from Petrel into OpendTect and back to Petrel when they are finished. The first option saves disk space but ties the Petrel license. The second option saves money as it allows you to work with many OpendTect interpreters on a project without tying the Petrel license. In addition to the PetrelDirect link in OpendTect Pro there are also several commercial plug-ins that support easy project setup and data IO to and from SeisWorks/OpenWorks**, GeoFrame-IESX*** data stores.

Since not everybody needs (or wants) to know how to do this it is possible to skip this entire Chapter. F3 Demo is already set up for OpendTect, hence there is no need to start from scratch. Simply go to the next Chapter to start your training.

The raw data for our new survey are located in a folder called Raw_Data in the F3 Demo directory.

** Is a mark of Schlumberger.*
*** Registered Trademark of Landmark Graphics Corporation.*
**** Registered Trademark of Schlumberger.*

1.2.1 Survey Definition

What you should know about OpendTect surveys

- A survey is defined by a 3D grid of Inline, Cross-line numbers and Z sample rate in time, or depth.
- Inline, Cross-line numbers are linked to X,Y rectangular coordinates via a single linear transformation.
- Surveys can be set-up for 3D seismic only, for 2D seismic only and for 2D and 3D seismic data.
- The Z dimension (time or depth) as defined in the survey setup determines the primary display axis in OpendTect. Data in the other dimension can be visualized in new (3D visualization) scenes in which the data is transformed on-the-fly using a given velocity field.
- 3D seismic must fall inside the defined survey boundaries.
- It is possible to load 3D seismic data sets with varying orientations and sample rates inside one survey. All data sets are mapped onto the defined grid.
- 2D seismic lines can stick outside the defined survey boundaries. The grid dimensions as defined in the survey setup are used in gridding operations, e.g. when creating a 3D horizon from a 2D horizon.

Surveys can be set up in different ways

1. **Manually:** You enter the required information such as the specification of the 3D grid and the inline, cross-line to X, Y co-ordinate transformation by hand. The latter is specified:
    a. Either in the form of two linear functions.
    b. Or, as three points (usually the corner points of the survey outline). Two of the points must lie on the same inline. OpendTect derives the linear transformation functions from the specified points.
2. **SEGY Scan:** SEGY data usually contains inline, cross-line and X,Y co-ordinate information in the trace headers. As not all SEGY data adheres to the standard (SEGY Revision1) OpendTect supports tools to help you analyze and where needed correct SEGY files.
3. **Copy from another survey.**.
4. **Set up for 2D only:** For 2D seismic surveys OpendTect only requires X, Y co-ordinates to be correct. You can set it up with a fake inline, cross-line grid.
5. **Using Commercial Tools:** There are commercial links to SeisWorks/OpenWorks, GeoFrame-IESX and Petrel.

1.2.2 SEG-Y Scan Setup & Load

What you should know about SEG-Y

- SEG-Y is the industry standard seismic data format that was defined originally as a tape format.
- It consists of a EBCIDIC Header with general information like data format, trace length and sample rate, followed by a binary Header (descriptive data typed in by the seismic processor – not very trustworthy) and seismic traces. Each trace consists of two parts: a trace header followed by trace data.
- Not all SEG-Y files (especially older files) adhere to the standard definition, which is called SEG-Y – Rev. 1 (Revision 1).
- Before loading SEG-Y data you must verify that the information OpendTect needs (inline, cross-line and X,Y co-ordinates) is stored in the trace headers where OpendTect expect these.
- If not, you specify where the information is located. If the information is not present at all you can create the information using OpendTect's trace header manipulation tools.
- If you run into problems, please check this page from the user doc with possible solutions: UserDoc.

What you should know about SEG-Y in OpendTect

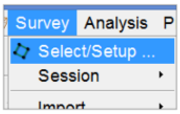
- OpendTect can work directly on SEG-Y data files.
- The advantage is that there is no data duplication.
- To use this option OpendTect must scan the SEG-Y file to construct a table with inline, cross-line information from the trace headers.

1.2.2a Survey Setup & Load SEG-Y

Required licenses: OpendTect.

Exercise objective:

Set up a new OpendTect survey and load 3D seismic data from SEGY using the SEGY scan wizard.



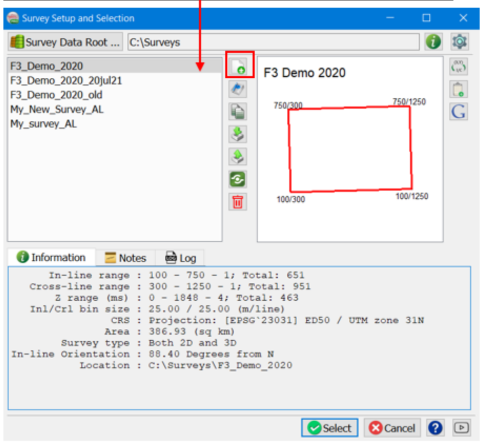
Workflow:

1. **Go to** Survey > Select/Setup…

   or **click** on the Survey Setup icon .

2. **Click** on the New Survey icon .

List of all Surveys in this Survey Data Root directory.



When starting OpendTect for the first time, you arrive directly in the Survey Setup & Selection window.

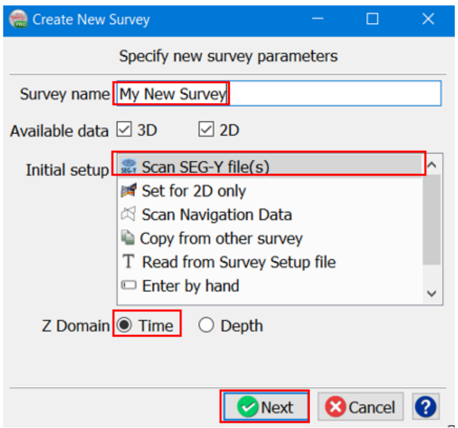
Workflow cont'd:

3. **Specify** a Survey name and

   (a) **select** Scan SEG-Y file(s),

   (b) **set** Time for Z Domain,

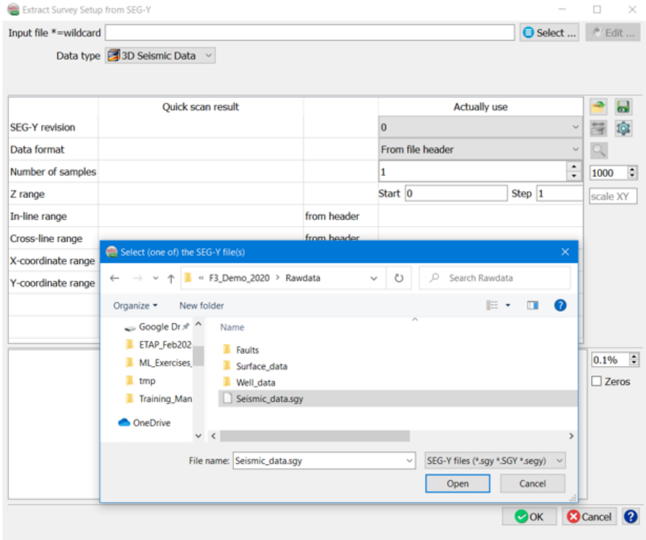
   (c) **Press** Next.



OpendTect display scenes are in Time or Depth. Transformation is done on-the-fly using a given velocity model. In the Survey Setup you choose the primary Z Domain. In the case of depth survey, Z Domain should be *Depth*.

Workflow cont'd:

4. **Go** to the Rawdata directory of F3 Demo and **Select** the Input SEG-Y file: \Raw data\Seismic_data.sgy.

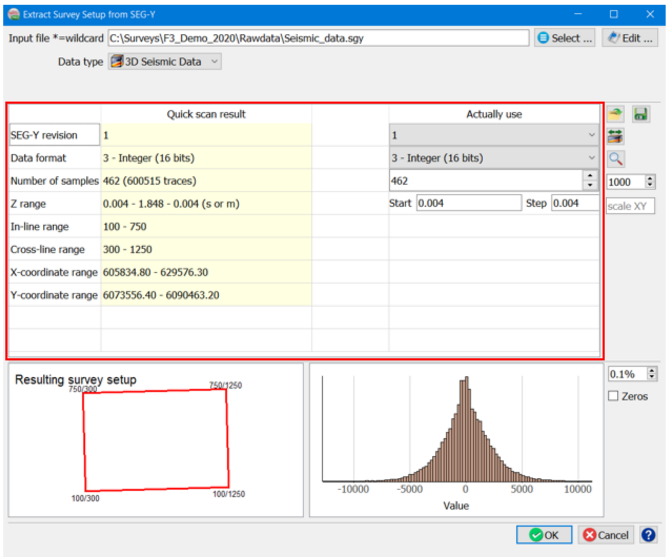


Workflow cont'd:

5. The import wizard makes a quick scan of the SEG-Y volume and automatically fills-in relevant parameters for survey set-up and import.

If needed, the parameters required for SEG-Y import (under the *Actually Use* column) can be changed manually.

The bottom part shows the extracted geometry of the survey and the histogram of seismic amplitudes from the quick scan of the input SEG-Y volume.

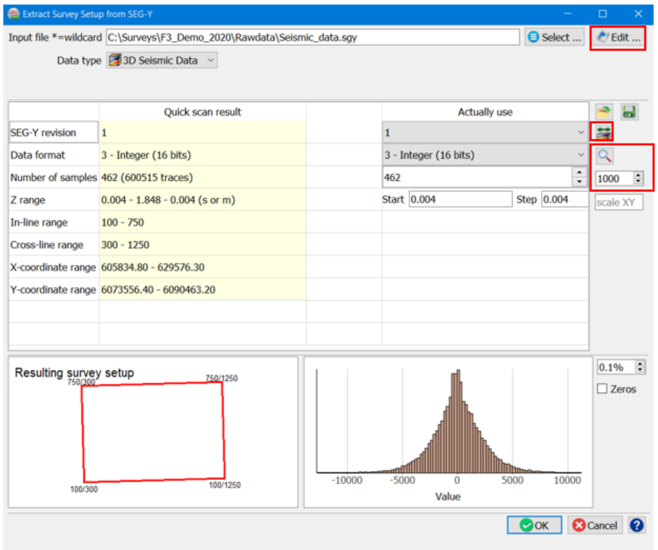


Workflow cont'd:

6. Optionally, **click** on the icon to scan the entire input SEG-Y file.
7. **Click** on the icon to examine in detail, first '1000' traces (changeable) of the file.

Edit option can be used if the SEG-Y file needs to be modified. You can update binary headers and trace headers using mathematical formulae and information from other headers.

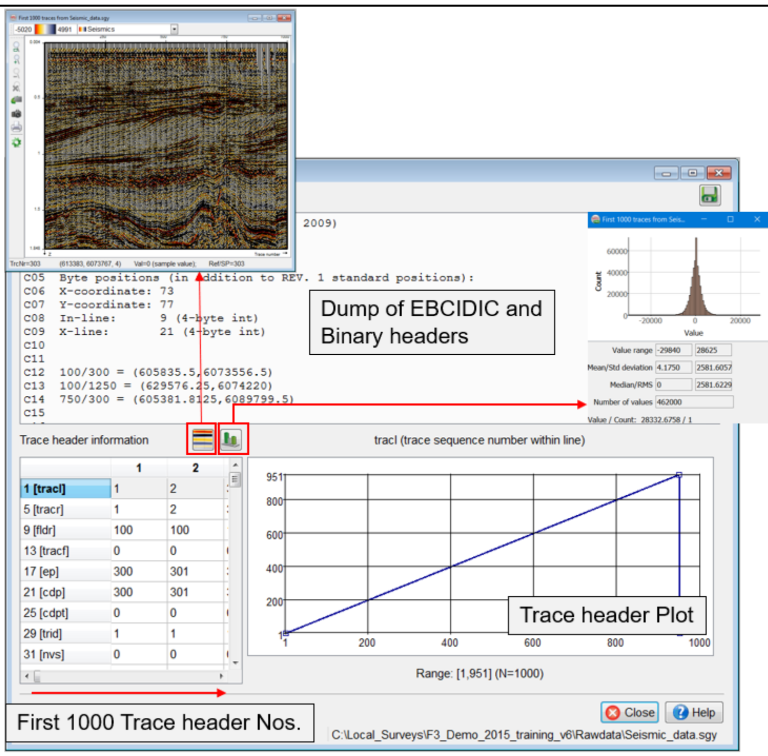
Scanning the entire SEG-Y file is useful when the survey geometry extracted from the quick scan looks doubtful.



Workflow cont'd:

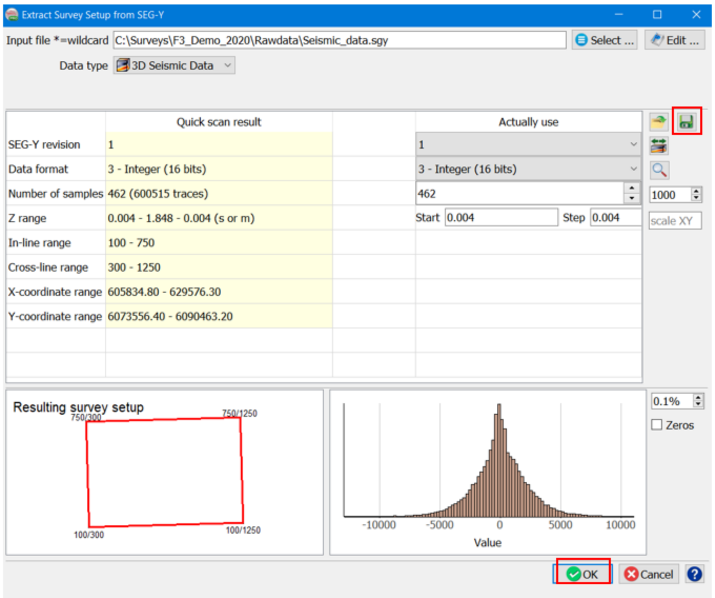
8. Examiner window: **Use** this to find out what is inside the file.
9. **Check** the Inline, Crossline and X/Y coordinates : **find** the corresponding byte and **observe** the associated plot.
10. Optionally, **check** Seismic viewer and histogram windows.

Trace header name + byte position.



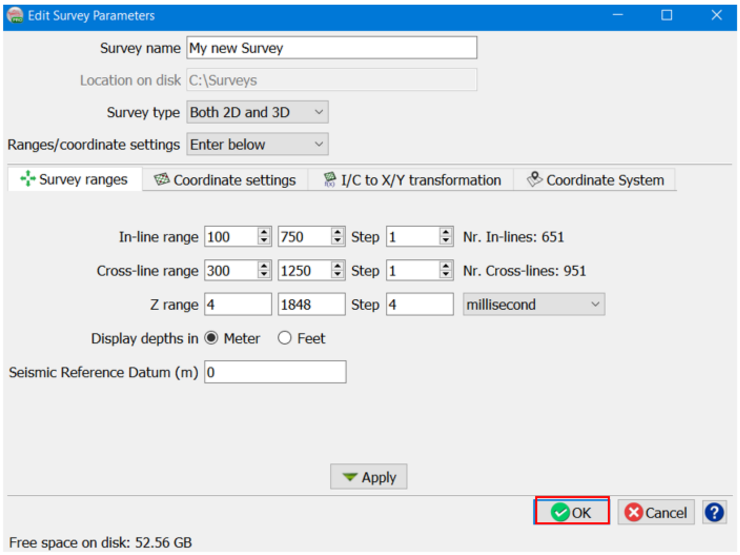
Workflow cont'd:

11. **Click** on OK. Optionally, **click** on the icon to save the import set-up parameters.



Workflow cont'd:

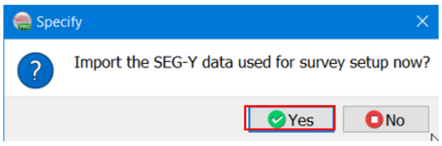
12. Survey definition is set now. **Click** on OK to proceed further.

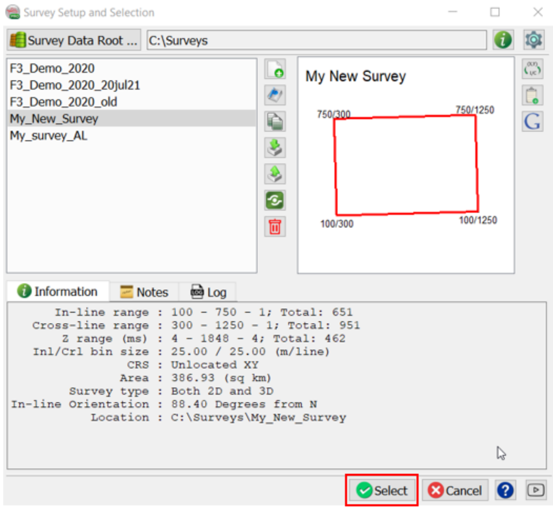


Workflow cont'd:

13. **Go** inside the newly created survey by either **double-clicking** on it or **clicking** on Select.

14. **Press** Yes when asked to import the SEG-Y file used to set-up the survey.



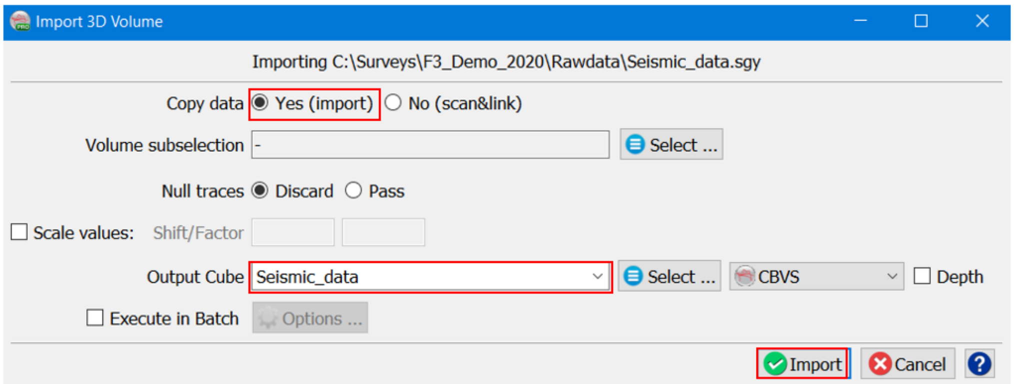


Workflow cont'd:

15. **Keep** the default Yes (import) toggled on, in front of Copy data. Optionally, it is possible to make a link to the input SEG-Y file in OpendTect.

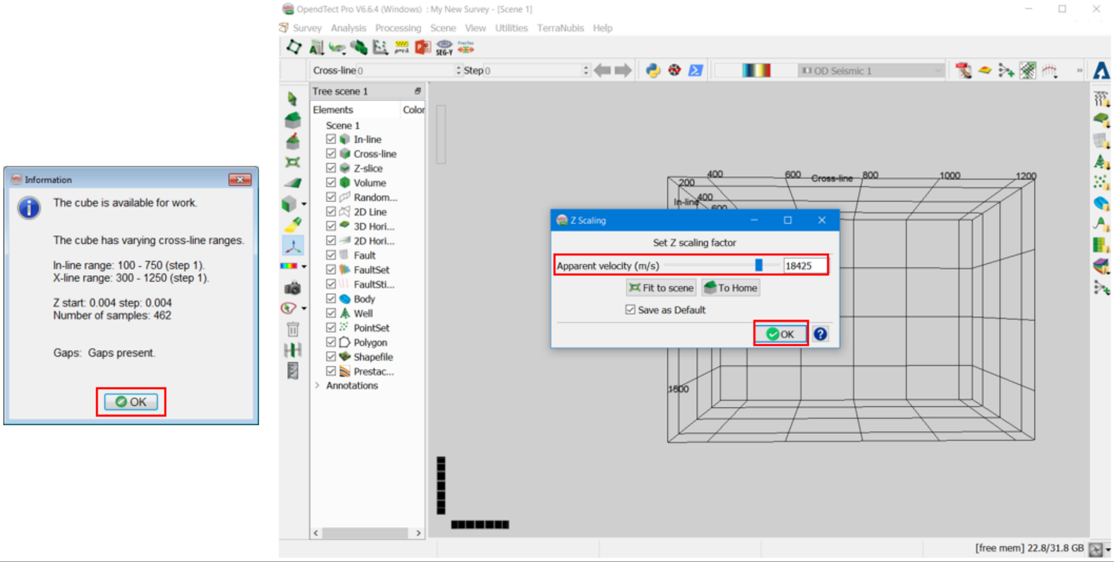
16. **Specify** an Output Cube name (by default name of the input file is copied here).

17. **Press** Import.



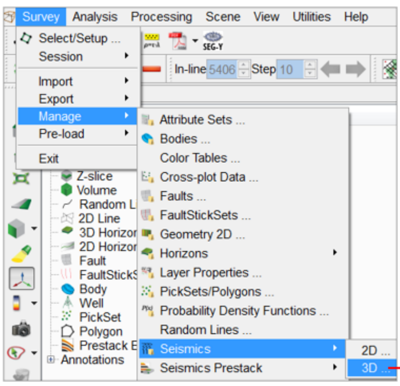
Workflow cont'd:

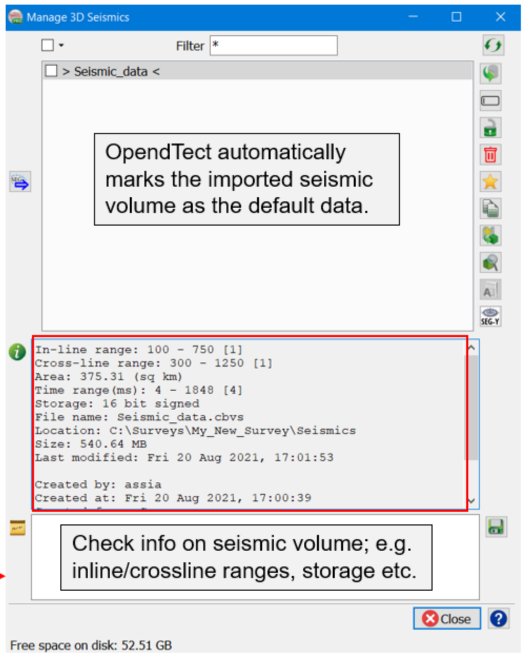
18. Once the import is finished, **press** OK on the notification window. Next, OpendTect will automatically open the option to change the Z-scaling of the newly created survey. **Move** the slider to set an appropriate Z scaling factor and **press** OK.



Workflow cont'd:

19. **Check** in the seismic manager the newly imported cube; Survey > Manage > Seismic > 3D.

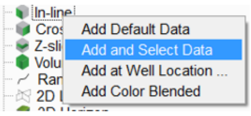




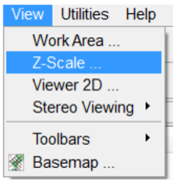
Workflow cont'd:

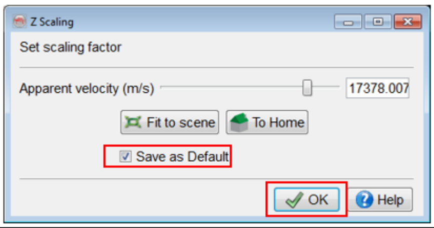
Tips:
- Changing the default Z-scale setting manually at any time
- Saving color settings with the loaded data set
- Manually making a seismic cube the default data set

Changing the Z-scale at any time:



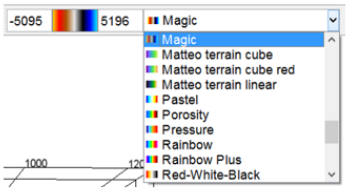
1. Add an inline:
   - **Right-click** in the tree on Inline > Add and Select Data.
   - **Left-click** on the selected seismic data or **press** OK in the window that pops-up after step 1.
2. **Go to** View > Z-scale.
3. **Use** the slider to change Z. **Toggle on** Save as default and **press** OK.



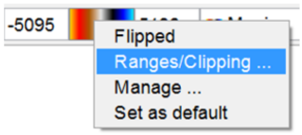


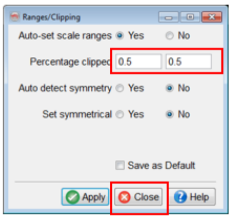
Workflow cont'd:

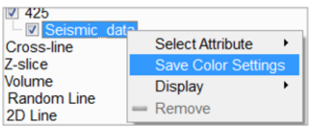
Saving color settings with stored volumes:

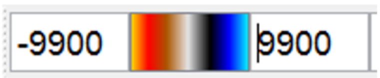


1. **Select** a color bar.
2. **Right-click** on the color-bar and **select** Ranges/Clipping.
3. **Change** the Percentage clipped and **Apply** a few times. When satisfied **Press** Close.
4. By default, clipping is used meaning every line will be scaled slightly different. To set the extreme values: **manually overwrite** the values next to the color bar and **press** Enter.
5. **Right-click** on an attribute in the tree and **select** Save Color (& scaling) Settings to save it as default for this attribute.



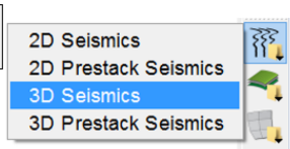






Workflow cont'd:

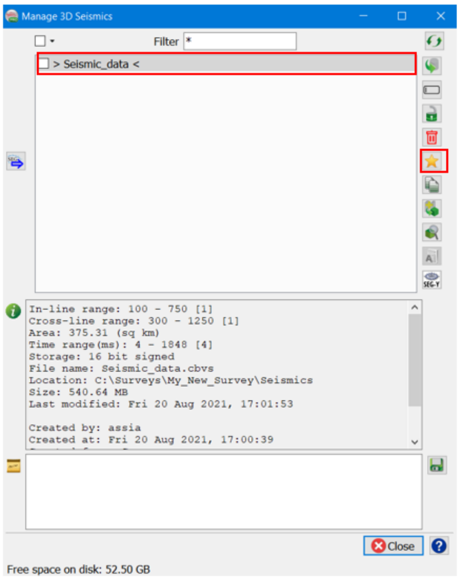
This is just for information purpose and is not part of the current exercise.



Manually setting a default data set :

1. **Press** the Manage Seismic icon and **Select** 3D Seismics or **go to** Survey > Manage > Seismics > 3D.

2. **Select** a Seismic data set from the list and **click** on the Default icon. The default file is marked by the >< symbol.



The advantage of having a default data set is that it saves many clicks to select data in various places in OpendTect. For example in this exercise we used option "Add and Select " to see the data. We then had to select the data. From now on we can use "Add default data" for in-lines, crosslines and Z-slices.

1.2.2b Load SEG-Y

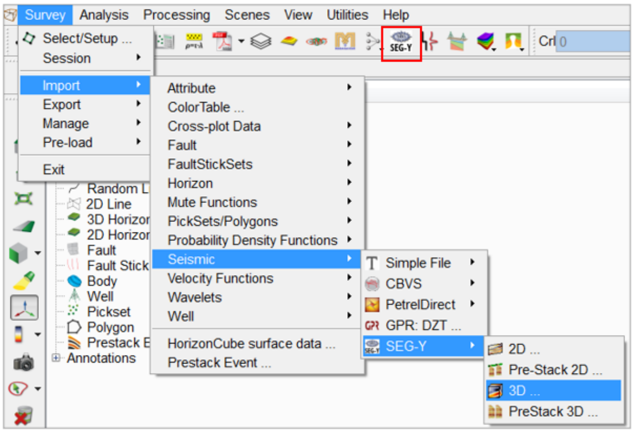
Required licenses: OpendTect.

Exercise objective:
Load a seismic SEG-Y volume in OpendTect.

Workflow:

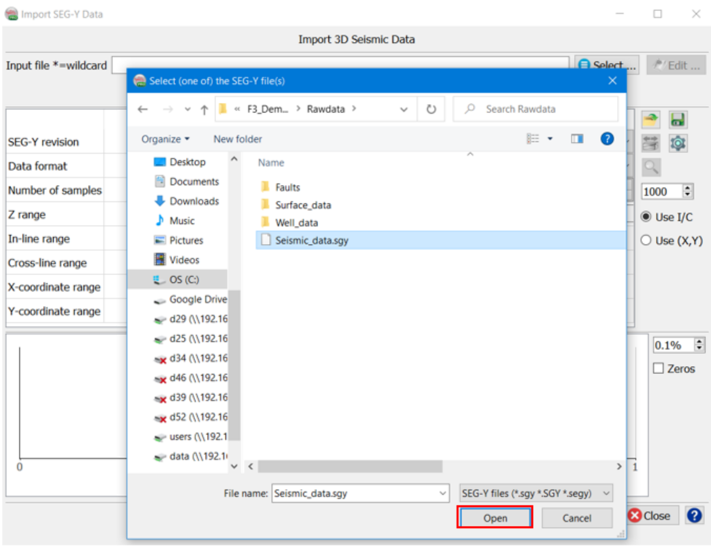
1. **Go to** Survey > Import > Seismic > SEG-Y > 3D

   or **click** on the SEG-Y import icon in the OpendTect main toolbar.



Workflow cont'd:

2. **Go** to the Rawdata directory of F3 Demo and **Select** the Input SEG-Y file: \Raw data\Seismic_data.sgy.

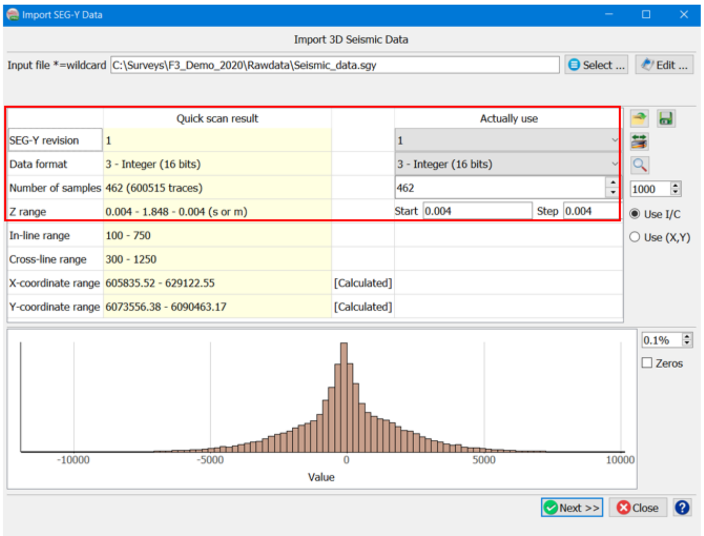


Workflow cont'd:

3. The import wizard makes a quick scan of part of the seismic volume and automatically fills in relevant parameters required for import.

If needed, the parameters required for SEG-Y import (under the *Actually Use* column) can be changed manually.

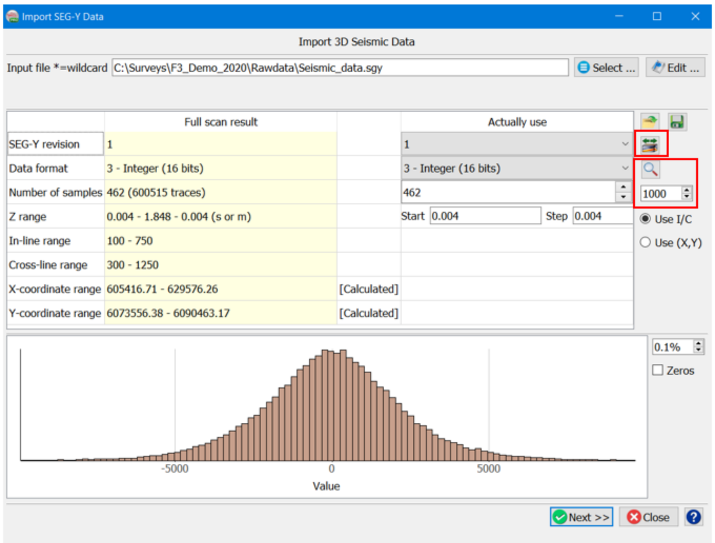
In the bottom part, histogram of seismic amplitudes of traces used for the quick scan can be seen.



Workflow cont'd:

4. Optionally, click on the  icon to scan the entire input SEG-Y file.

5. **Click** on the  icon to examine in detail, first '1000' traces (changeable) of the file.



Now in the bottom part, histogram of seismic amplitudes of all the traces in the input SEG-Y volume can be seen.

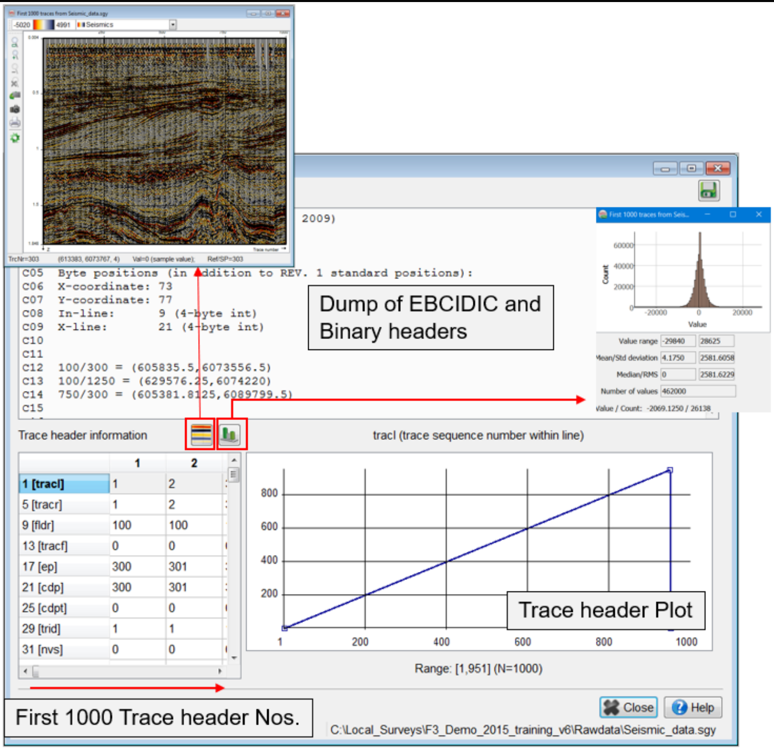
Workflow cont'd:

6. Examiner window: **Use** this to find out what is inside the file.

7. **Check** the Inline, Crossline and X/Y coordinates : **find** the corresponding byte and **observe** the associated plot.

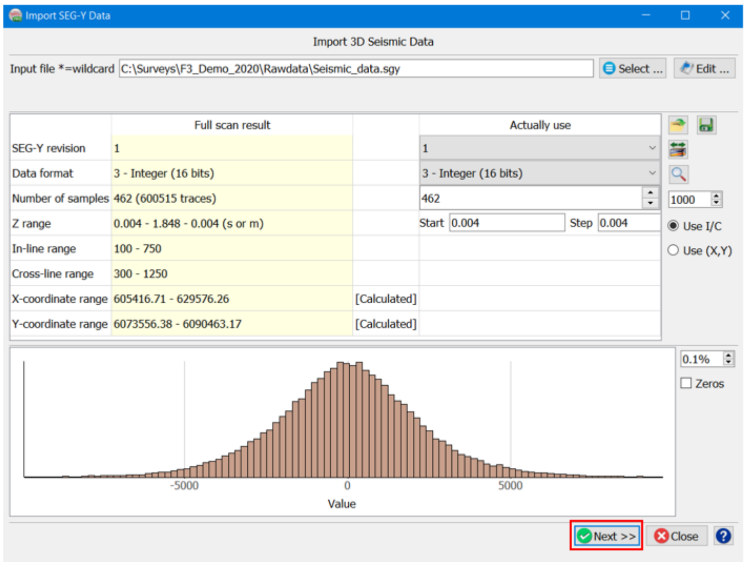
8. Optionally, **check** Seismic viewer and histogram windows.

Trace header name + byte position



Workflow cont'd:

9. **Click** on Next in the Import SEG-Y Data window.

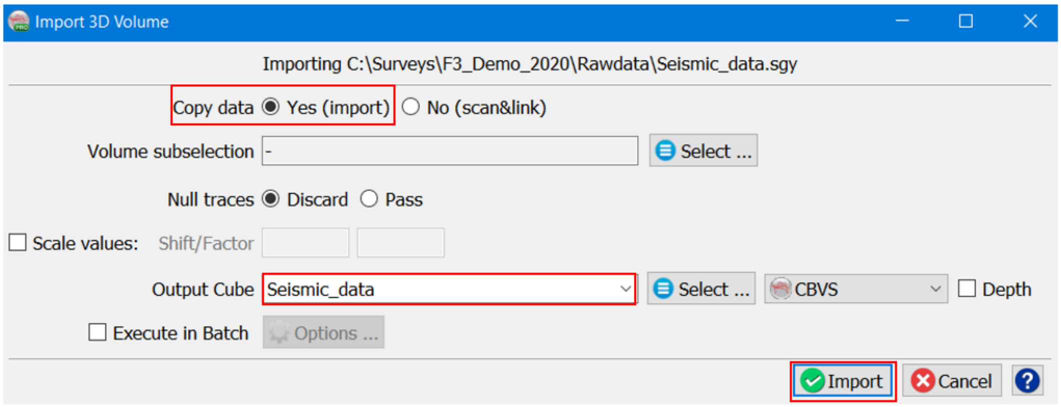


Workflow cont'd:

10. **Keep** the default Yes (import) toggled on, in front of Copy data. Optionally, it is possible to make a link to the input SEG-Y file in OpendTect.

11. **Specify** an Output Cube name (by default name of the input file is copied here).

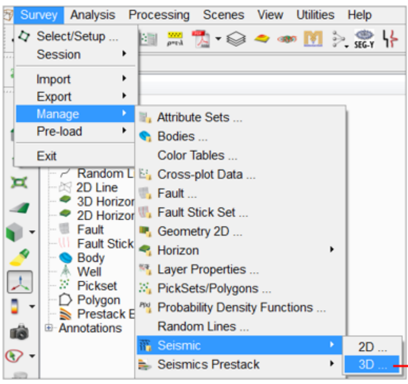
12. **Press** Import.

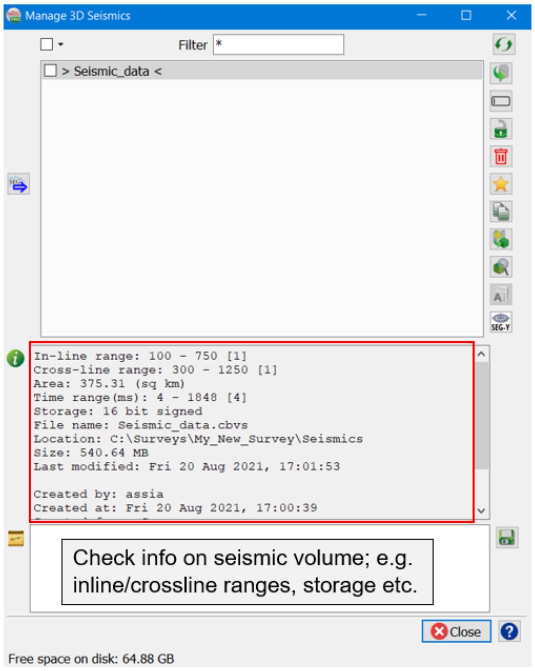


Workflow cont'd:

13. **Close** the Import SEG-Y Data window.

14. **Check** in the seismic manager the newly imported cube; Survey > Manage > Seismic > 3D.





1.2.3 Import Horizon

What you should know about OpendTect horizons

- There are two kinds:
  - 2D horizons (from 2D seismic)
  - 3D horizons (from 3D seismic)
- Each kind has two types:
  - Geometric grids
  - Attribute grids
- Attribute grids are stored as “Surface Data” with the geometric grid to which they belong.

1.2.3a Horizon

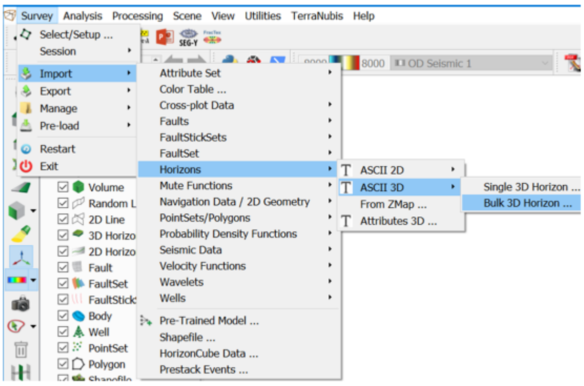
Required licenses: OpendTect.

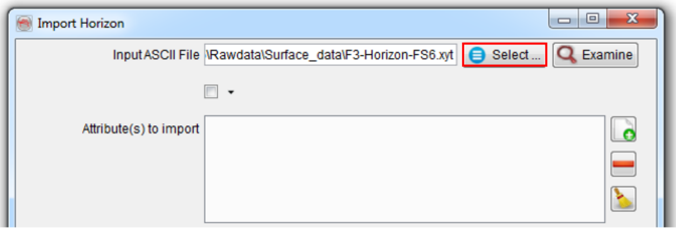
Exercise objective:

Import (geometric) horizons from ASCII files.

Workflow:

1. **Go to** Survey>Import>Horizon>ASCII> Geometry 3D.
2. In the Import window, **select** the horizon as Input Ascii file: \Rawdata\Surface_data\ F3-Horizon- FS6.xyt for example.





Workflow cont'd:

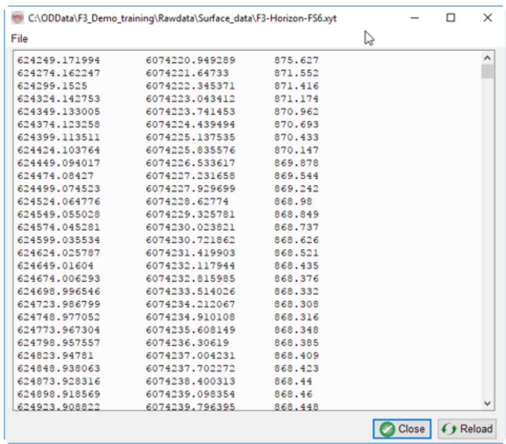
3. **Examine** the file to determine the header contents and to check details for the Format Definition.

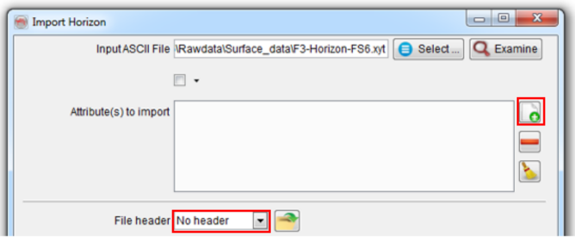
Keep this window open to fill in the Format Definition.

4. **Specify** the header size (number of lines): here, **set** it to No header.

Optionally define attribute(s) to be loaded as Horizon Data in the same time as the geometry : use the icon. You can add as many attribute as you need. They will be listed and you can decide to select them for loading.

Attributes can also be imported and added to an already existing horizon by choosing: Survey > Import > Horizon > Attribute 3D...



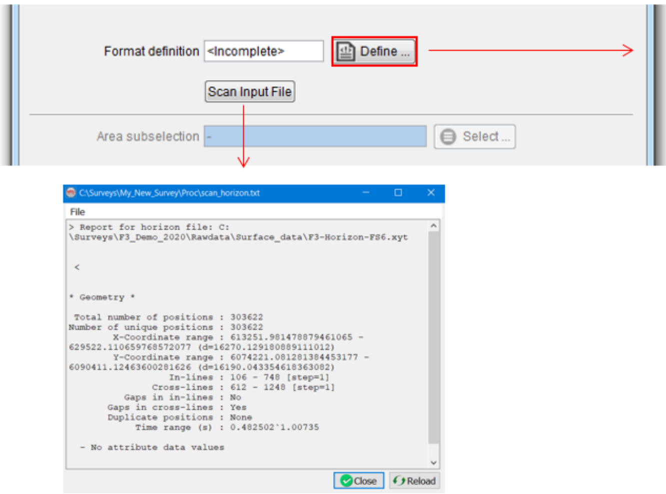


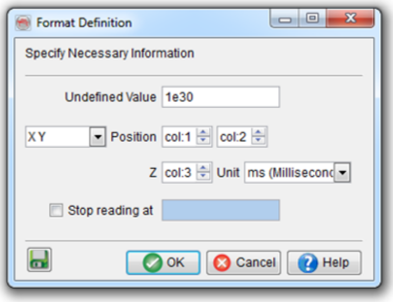
Workflow cont'd:

5. To set the Format Definition, **click** on Define : **assign** to each quantity the corresponding column in the file.

6. Optionally, **click** on Scan Input File to test the loading parameters.

7. **Close** the scan report





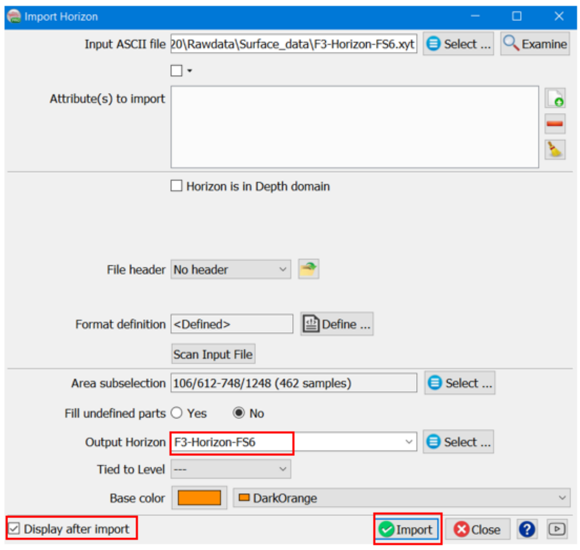
Workflow cont'd:

8. **Specify** if the undefined parts should be filled: select No.

9. **Name** the Output Horizon and **select** a color for display.

10. To automatically load the horizon in the 3D scene, **toggle on** the "Display after import" option.

11. **Press** Import.



1.2.4 Import Well Data

What you should know about well data:

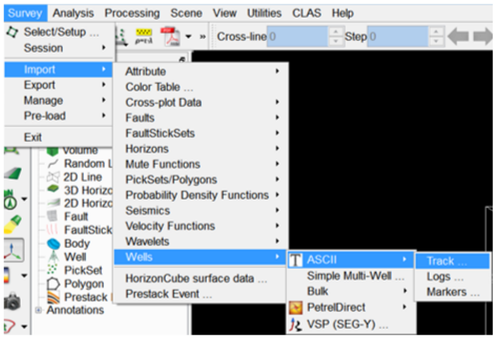
- Wells are defined by a well name and a well track.
- Optionally the following information can be added:
  - Time-Depth Curves.
  - Markers.
  - Logs.
- Time-Depth curves can be modified (stretched and squeezed) in the Well-tie module (synthetic-to-seismic matching module).
- New logs can be created in the Well manager using OpendTect's Rock-physics library and math & logic manipulations.

1.2.4a Well Data

Required licenses: OpendTect.

Exercise objective:

To load well data from ASCII and LAS files.

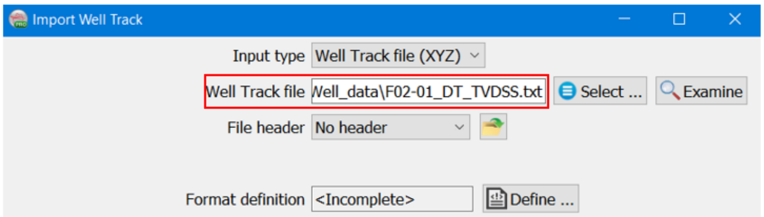


Workflow:

1. First **import** the well track by choosing Survey > Import > Wells > ASCII > Track.

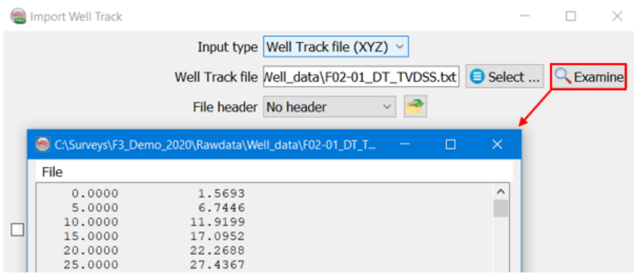
2. **Select** the Well track file: /Rawdata/Well_data/F02-01_welltrack.txt for example.

If you select Directional or Vertical Well, you can manually add the well head coordinates.

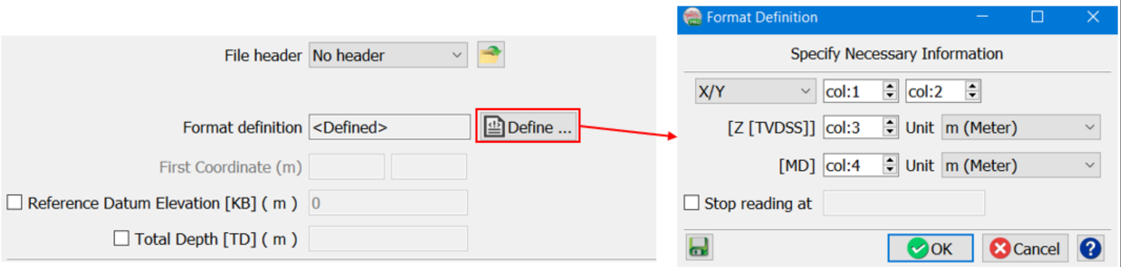


Workflow cont'd:

3. **Click** on the Examine button.



4. **Define** the Format Definition for the well track: col-1: X, col-2: Y, col-3: Z and col-4: MD. The default units are in meters, but can be modified from the drop-down menu.

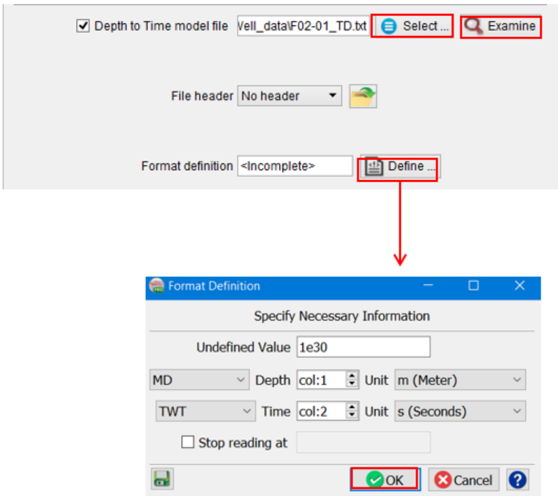


Workflow cont'd:

5. **Select** the Depth to time model file: /Rawdata/Well_data/F02-01_TD.txt.

6. **Examine** the file.

7. **Define** the Format Definition for the Depth to time model; col-1: Depth in m, col-2: TWT in sec.



If you uncheck the Depth to Time model file, you will be able to add a constant velocity model for this well.

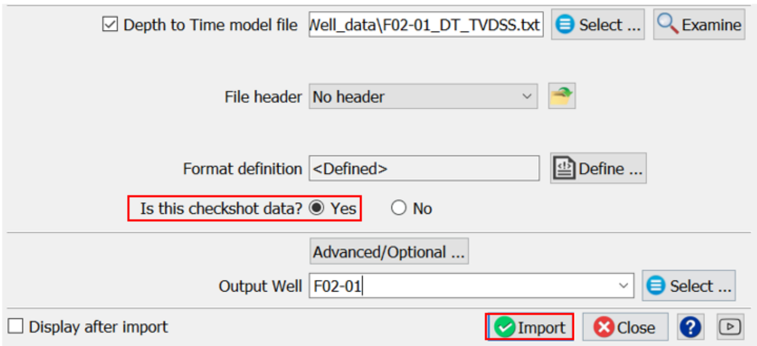
Workflow cont'd:

8. Is this checkshot data? **Tick** yes.

Advanced options are optional

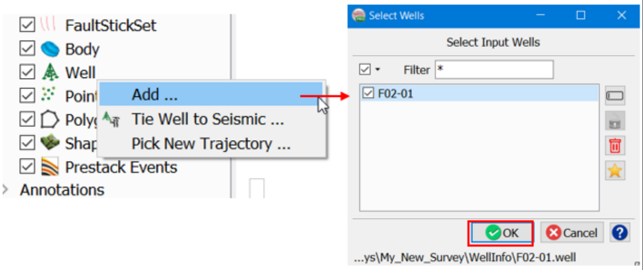
9. **Provide** an output name.

10. Once done, **press** the Import button.

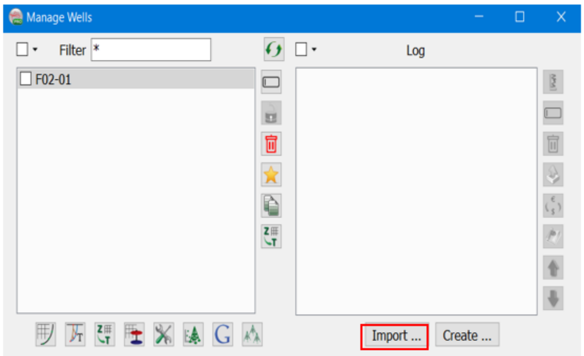


Workflow cont'd:

11. Display the well in the survey: **right click** on Well > Load and **select** your well.



12. To import the logs files: **click** on the Manage Well Data icon and **click** on Import. Alternatively, **follow** Survey > Import > Wells > ASCII > Logs.



Workflow cont'd:

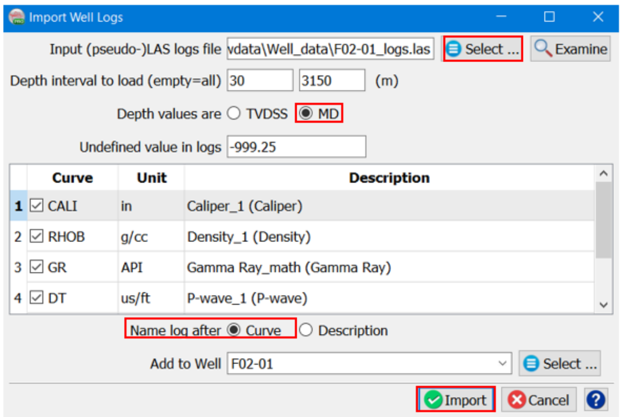
13. Press the Import button, then **select** las file: /Rawdata/Well_data/F02-01_logs.las.

14. Toggle MD.

15. Highlight all logs needed to import

16. Select Curve in the name after log

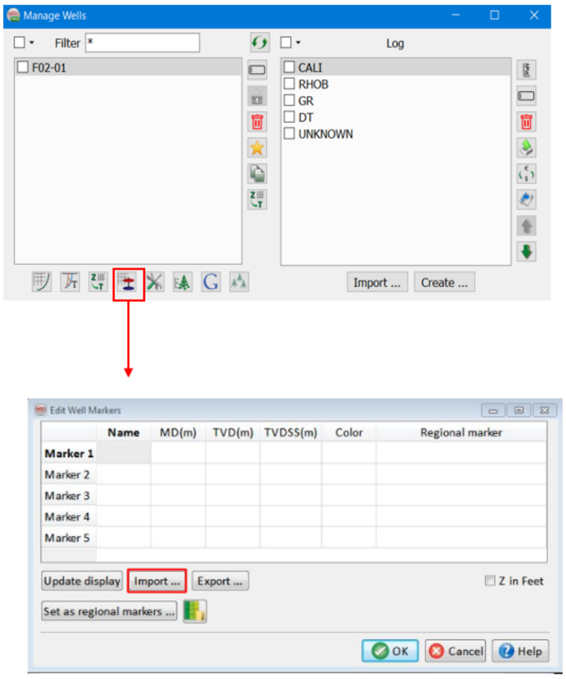
17. Click on Import.



Workflow cont'd:

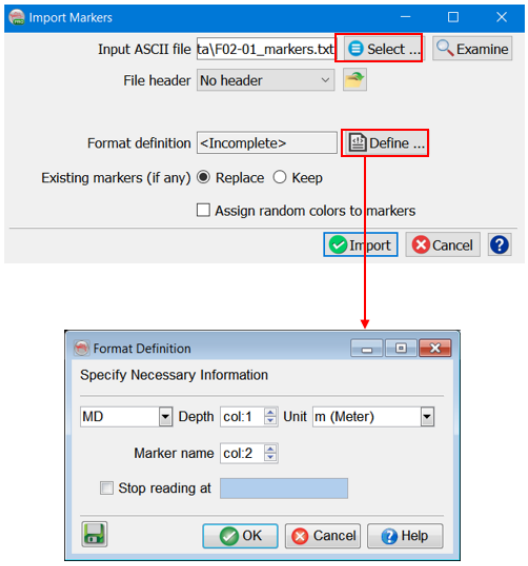
18. In the well manager, **click** the Edit Markers icon.

In this exercise, we will **import** markers from an existing file. It is also possible to add markers manually.



Workflow cont'd:

19. **Select** the input file: /RawData/ Well _data/F02-01_markers.txt.



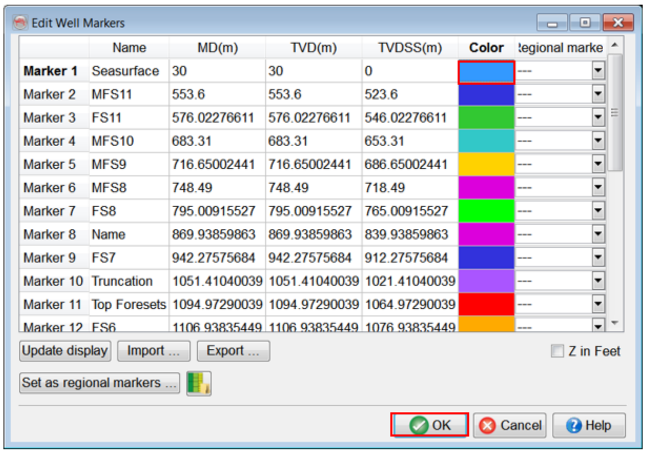
20. **Define** the Format Definition:

Workflow cont'd:

21. **Select / Modify** a color for each marker by **double-clicking** on the appropriate row in the Color column.

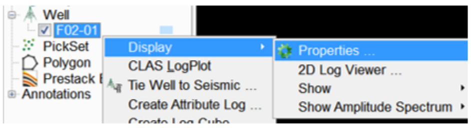
22. **Press** OK.

23. Once done, **close** the dialogs and return to OpendTect scene.

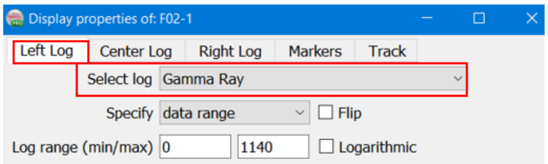


Workflow cont'd:

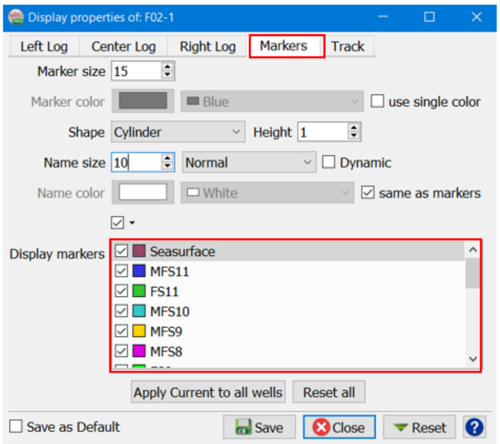
24. In the scene, **display** the log and/or markers on the well : **right click** on the well in the tree and **follow** Display >Properties.



25. In the left- , center- or right-log tab, **select** the log to display and the properties.

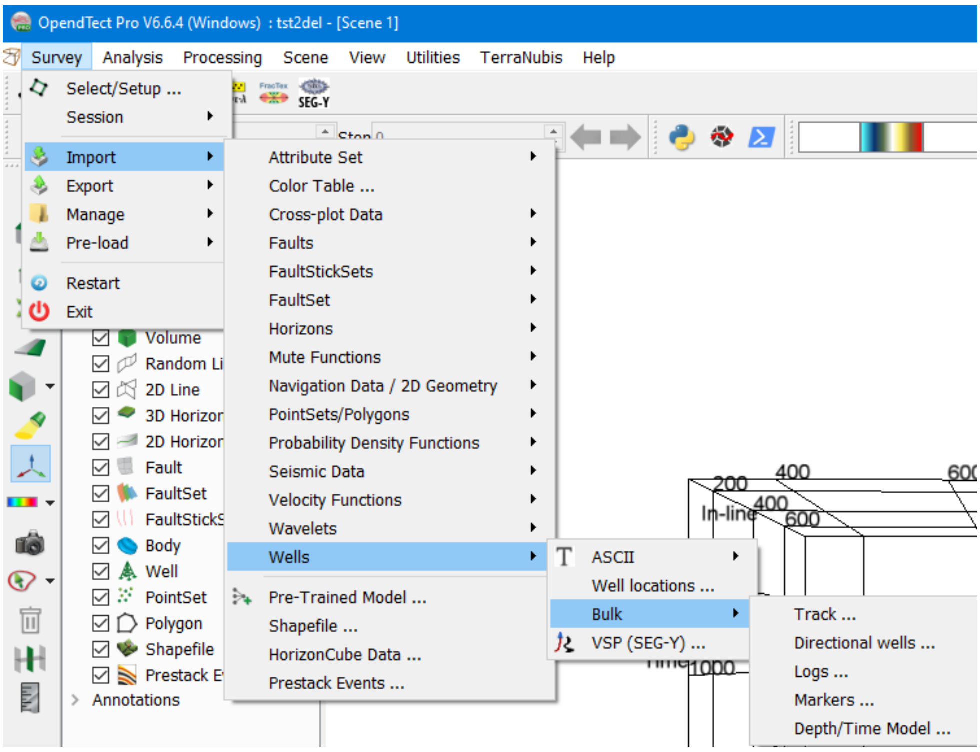


26. **Open** the Markers tab: **toggle** on the desired markers and **set** the marker size etc.



1.2.5 Multi-Well Import

Different options are available to import multiple wells in OpendTect



- **Import > Wells > Bulk...**
  - Track: if the track information of more than one well is in the same file, use this option. The names of the wells need to be in a column.
  - Directional wells: allows for the import of multiple well tracks following the same principle as for Bulk Well track. In this case, after reading the file, the well tracks are listed in a table that can be QC-ed and edited prior to actual import.
  - Logs: allows for the simultaneous loading of several LAS files.
  - Markers: as for well track.
  - Time/Depth Model: as for well track.

Important notice: when you have finished with this Chapter do **NOT** continue in the survey you have just created but return to the original F3 Demo data set as this data set is much richer.

1.3 Basic Interaction

This Chapter deals with basic interactions. You will learn how to display seismic data on in-lines and cross-lines, how to move lines in the 3D scene, how to zoom in and rotate a scene and how to create random lines.

What you should know about the user interface

- OpendTect supports multiple 3D scenes.
- Each scene has its own Z-axis (time, depth, flattened on a single horizon, Wheeler-transformed).
- There are three interaction modes for 3D scenes, each has its own cursor:
  1. **Position mode** for positioning & moving display elements (arrow cursor)
  2. **View mode** for zoom, rotate and pan (hand cursor)
  3. **Interpretation mode** for picking and editing data points (cross cursor).
- Each Scene has its own tree from which data objects are added to the scene and from where they can be manipulated.
- The tree does **NOT** show the entire data base of all stored data in the survey as in some other software systems. The tree *shows which elements have been loaded or processed on-the fly*. These elements reside in memory and are available for visualization and further manipulations.
- Most display elements (lines, horizons, slices) have multiple layers for comparing and co-rendering information.
- Data for display can be loaded from stored files, or processed on-the-fly.
- If you have the memory: use it! **Pre-load** seismic data to speed up visualization and on-the-fly processing.
- Display elements can be manipulated in the 3D scene (right-click menu) or from the tree (right-click menu).
- Seismic sections displayed in the 3D scene also be displayed in separate 2D (flat) viewers.
- If you have an OpendTect Pro license: use the **basemap**to interact with the system.
- Functionality can be accessed via Menus, Icons and short-keys.

Short-keys and Mouse-controls

OpendTect supports a range of short-keys to speed up various interactions. Mouse controls and a number of short-keys can be modified from the Utilities menu, option Settings --> Keyboard shortcuts. The default settings of the most important short-keys and mouse-controls are given in the table below. This table is also available from the menu Help with the option "Keyboard shortcuts.

View Mode

Pan	Middle Click + Drag
Rotate	Shift + Middle Click + Drag
Zoom in/out	Scroll Wheel
	Ctrl + Middle Click + Drag

Position Mode

Activate element		Left Click
De-activate element		Left Click outside active element
Draggers – applied to Active Inline, Crossline, Z-slice or Random Line		
Browse/Resize Volume perpendicular-to-plane		Left Click + Drag in Active Volume
Resize		Left Click + Drag (green) Anchors
Rotate (if possible)		Ctrl + Left Click + Drag
Move	perpendicular-to-plane	Left Click + Drag
	parallel-to-plane	Shift + Left Click + Drag

Basemap

Add	Inline	i
	Crossline	c
	Random line	r

Main Short keys

Show all Shortkeys		Shift + ?
Save selected object		Ctrl + s
Save as selected object		Shift + Ctrl + s
Undo /Redo		Ctrl + z / Ctrl + y
Toggle / Print 3D graphics stats		g / G
Pop up Command Controller		Ctrl + r
Toggle between "in full" / "at section" selected item display		v
inline/crossline/z-slice	Forward	x
	Backward	z

S P A C E

Interpretation Mode

Pick seed		Left Click
Remove seed/pick		Ctrl + Left Click on seed/pick
Activate Polygon Selection		y
Multi Selection		y + Ctrl + Left Click
Move Single Selection		Left Click + Drag
Fault stick	New	Shift + Left Click
	Finish	Double Left Click
	Select (to edit)	Ctrl + Left Click on existing fault stick (outside seeds)
		Left Click on existing seed

Horizon Tracking

Tracking menu	Ctrl + Right Click
Autotrack	k
Retrack	Ctrl +k
Lock / Unlock	l / u
Clear Selection	a
Delete Selection	d

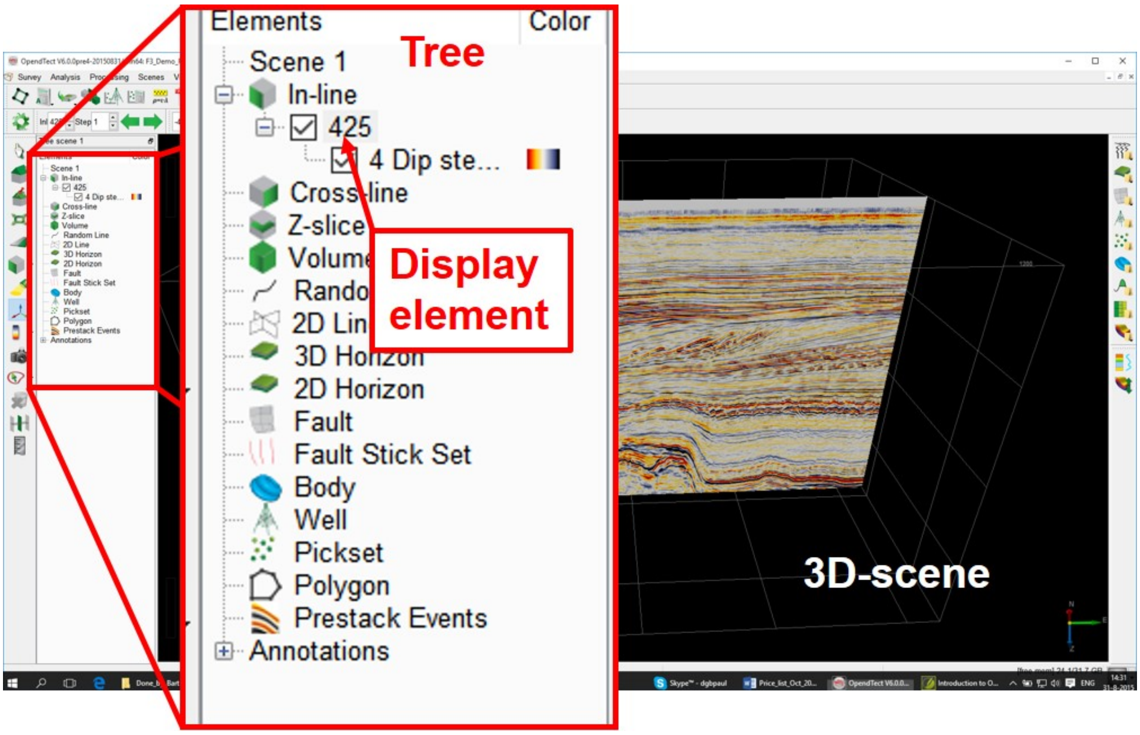
OpendTect Pro

1.3.1 Tree, Scene & Elements

Each 3D scene has a tree and each tree controls a set of display elements: In-lines, Cross-lines, Horizons, Wells etc. Via the tree a user controls what is displayed in the 3D scene. (OpendTect Pro users can also do this via the basemap.) Display elements can be toggled on and off and display parameters can be changed from the tree menu, which is opened by right-clicking on the element.

Section elements such as In-line, Cross-line can be filled up to 8 layers deep with data for co-rendering. The layers can be moved up and down in the tree. For co-rendering the user can change the layer's transparency and / or change the opacity curve of the chosen color bar.

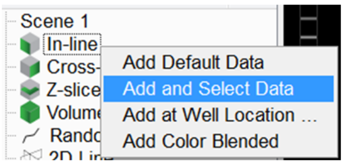
Display elements can be filled with stored data and data that is calculated on-the-fly. The latter option is used to test attributes and to evaluate their parameters before (optionally) computing an attribute volume in batch mode. This way of working improves efficiency.



1.3.1a Display An Inline

Required licenses: OpendTect.

Exercise objective:
Display an inline in the 3D scene.

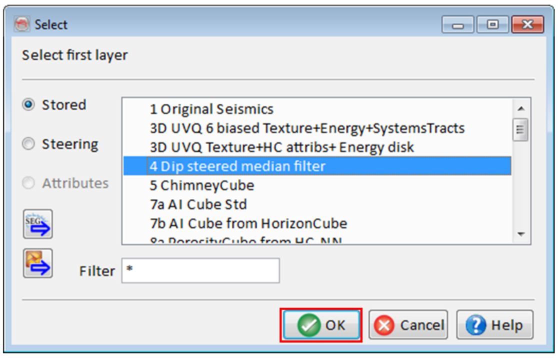


Workflow:

1. **Right-click** on Inline in the tree and **select** Add and Select Data.

2. In the pop up window, **select** 4 Dip steered median filter.

3. **Click** OK to display data in the scene.



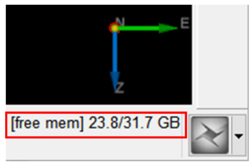
Visualization and processing goes faster when you load the relevant data set(s) into memory. If you do not have sufficient memory to load an entire volume load only the part you intend to work on. Another way to reduce memory consumption is to re-scale data to 8-bit during pre-load.

1.3.1b Pre-load Data

Required licenses: OpendTect.

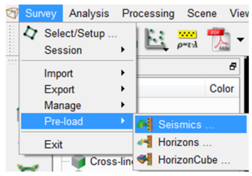
Exercise objective:
Pre-load data

In the lower-right corner of the main window you can see how much memory is free.

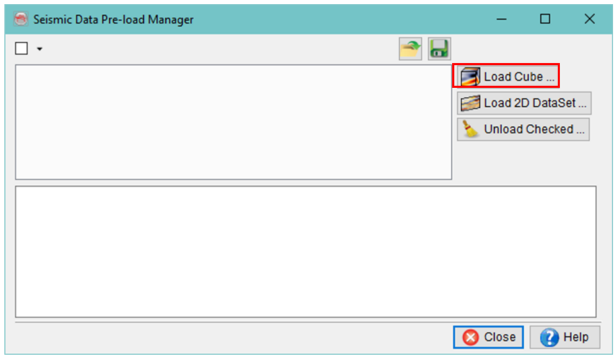


Workflow:

1. Use it only if you have sufficient memory. To **Pre-load** a stored seismic cube **go to** Survey > Pre-load > Seismic.



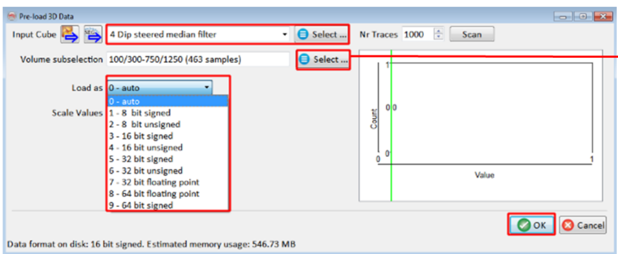
2. **Click** on Add Cube.

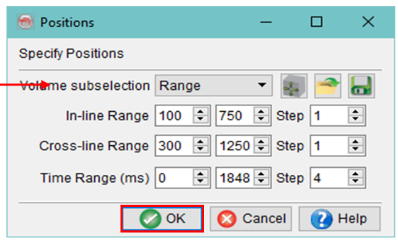


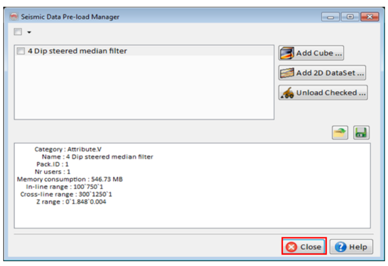
Workflow cont'd:

3. **Select** *4 Dip steered median filter* as input cube. Optionally, **specify** a volume subselection and the loading format. **Press** OK.

To reduce memory consumption:
1) load in a smaller volume range
2) load in a different format e.g. as 8-bit







1.3.2 View, Position and Interpretation Mode

OpendTect distinguishes three possible modes of operation for the 3D scene:

- **Position Mode** for (re-)positioning, moving and resizing display elements. The cursor in this mode is an **arrow**.
- **View Mode** for rotating, panning and zooming. The cursor in this mode cursor is a **hand**.
- **Interpretation Mode** for picking and editing data points. The cursor in this mode is a **cross**.

Use  or   icons to toggle between Position and View modes.

Use  or icon to toggle between Interpretation and View modes.

1.3.2a Position, Zoom, Pan, Rotate

Required licenses: OpendTect.

Exercise objective:

Learn how to zoom, pan, & rotate a 3D scene and how to move a seismic line.

Workflow:

1. **Click** on shift + the mouse wheel and drag to **rotate** your display. To **pan** the scene (i.e. move the scene horizontally & vertically) **press** the scroll wheel (keep it pressed on) and **move** the mouse.

2. **Zoom** in and out by scrolling the mouse wheel. Or **press** Ctrl + the mouse wheel (keep it pressed on) and **move** the mouse back and forth.

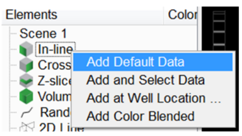
Workflow cont'd:

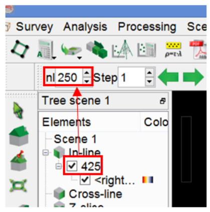
Positioning elements

3. **Click** on In-line in the tree > **Add Default Data**.

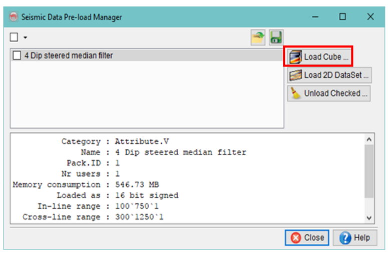
4. **Select** the inline in the tree by clicking on the line number 425**.**

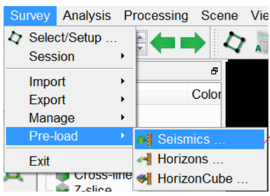
5. **Fill in** 250 (the new inline position) line number in the Slice Position toolbar.





Use available memory: **pre-load** 2D, 3D, pre-stack seismic, Horizon and HorizonCube for quicker access.
Survey > Pre-load > Seismics





Workflow cont'd:

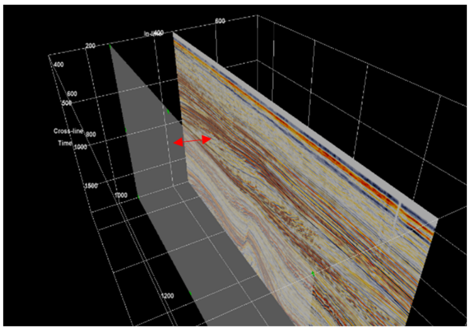
Positioning elements

6. **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.

7. **Left click** (keep the button pressed) on the inline in the scene and **drag** it to the desired location and let it go.

8. To undo **press Ctrl + Z**.

If the seismic is pre-loaded the display is uploaded instantaneously, movie-style.

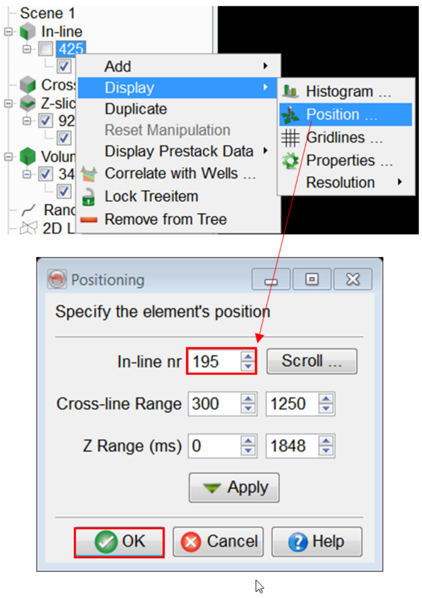


Workflow cont'd:

Positioning elements

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

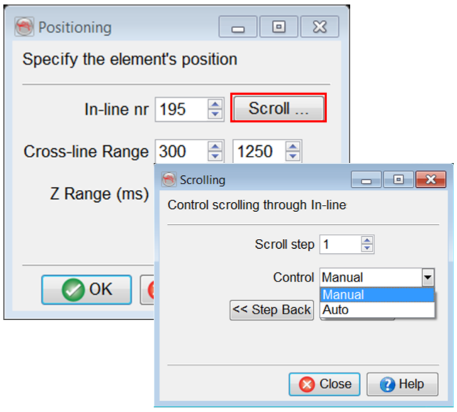
10. **Position** the inline at 195 and **click** OK.



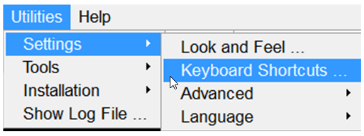
Workflow cont'd:

Positioning elements

11. Scrolling: **Right-click** on an In-line number and **select** Display > Position. **Press** Scroll. Elements are moved either manually (**select** Control Manual) or automatically (**select** Control Auto).



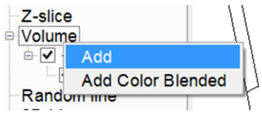
12. Default keyboard short cuts to move a slice backwards/forwards are x and z. To change this **go to** Utilities > Settings > Keyboard shortcuts.



Workflow cont'd:

Positioning elements

13. In the element tree **right-click** on Volume and **select** Add. This will insert an empty element in the tree.

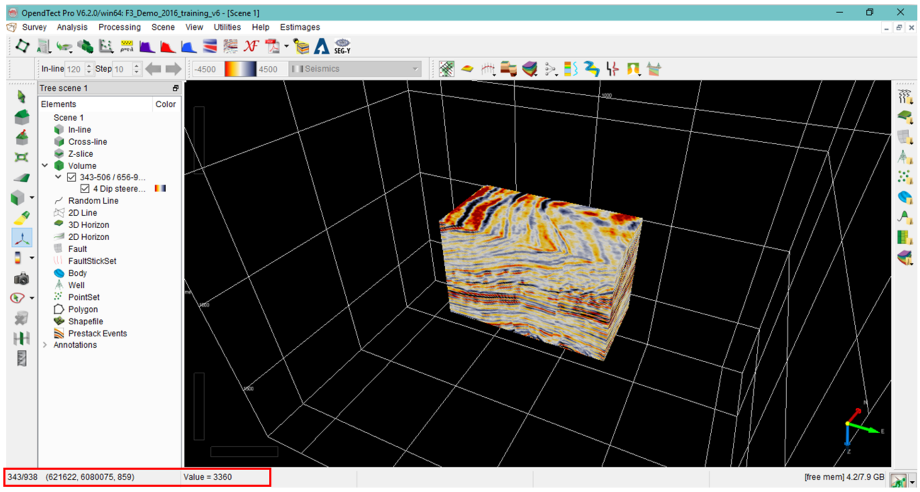


14. **Select** a stored volume: **right-click** on <right-click> and **go to** Select Attribute > Stored Cubes > 4 Dip steered median filter.

15. **Left-click and drag** an in-line/cross-line/z-slice, you can then go quickly through the entire volume.

Workflow cont'd:

Look at what you have from all sides. Note that the data values are read out and displayed in both methods (view mode and position mode), these values are displayed at the bottom of the screen.
Show crossline 1000 in a similar manner.



Workflow cont'd:

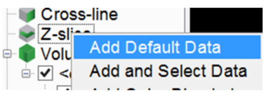
Show a part of a Z-slice at 700 ms TWT

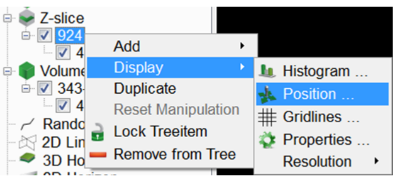
16. **Right-click** on Z-slice > Add Default Data.

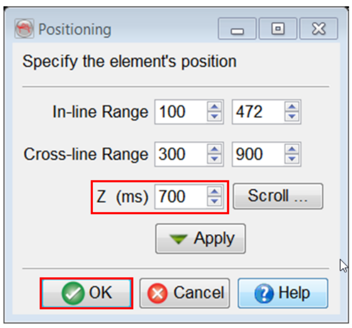
17. **Rotate** the view so you see the Z slice from above. Shift + Middle Click + Drag.

18. **Make** the frame smaller by dragging the green handle points of the frame. (If the handles are not apparent **click** on the relevant slice to 'activate' them).

19. **Right-click** on the Z-slice number > Display > Position. **Change** Z (ms) to 700 and **press** OK.





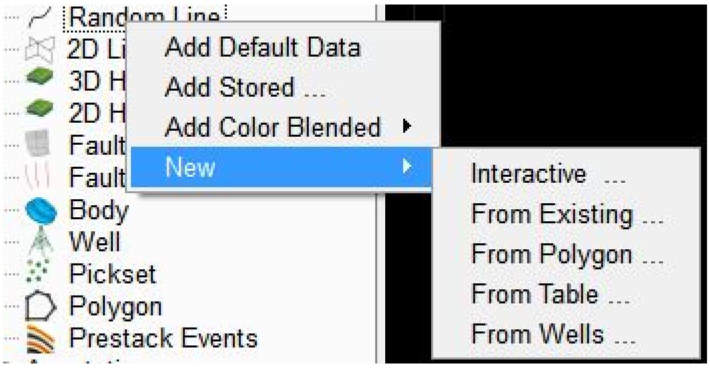


1.3.3 Random lines

What you need to know about random lines

- Random lines can me moved **(left-click + drag**) and rotated (**Ctrl left-click + drag**) through a volume.
- For movie-style inspection of the data it is recommended to load the data into memory **(pre-load** exercise 1.3.1b)
- Random lines can be created in different ways:
  - **Easiest:** Add default data to get a line positioned in the center of the volume and start moving rotating
  - **Drawn** on time-slices or horizons (OpendTect Pro users can do this in the basemap).
  - **Through wells:** A random line can be created by connecting the selected wells. 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.
  - **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 random line in defining its nodes in a table. Each node is defined by its x/y coordinates and Inline/Crossline information.

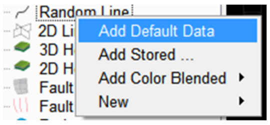
- Random lines can be optionally saved in the data base.



1.3.3a Random Line

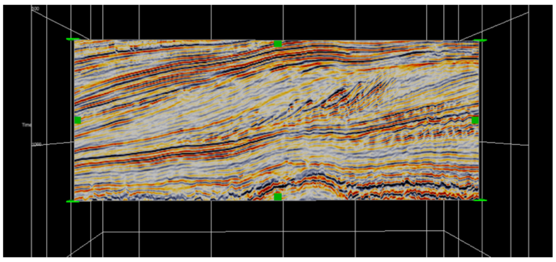
Required licenses: OpendTect.

Exercise objective:
Add a random line and move & rotate this through a 3D seismic volume.



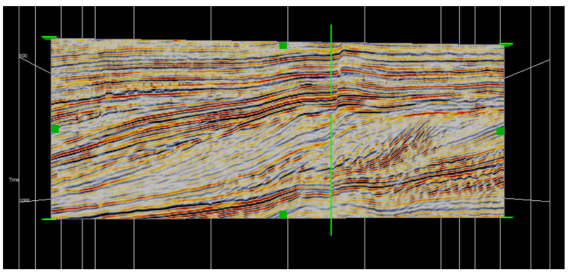
Workflow:

1. **Pre-load** the stored *4 Dip steered median filter* cube (see exercise 1.3.1b).
2. Add a random line: **right-click** on the tree item (OpendTect Pro users can also do this from the basemap).
3. Resize the display element: **left-click + drag** on the green anchors (this is optional but for the sake of this exercise let's do it).



Workflow cont'd:

4. Push the line through the seismic volume: **left-click + drag**.
5. Rotate the line: **Ctrl left-click + drag**.
6. Push the line through the volume in the new direction: **left-click + drag**.

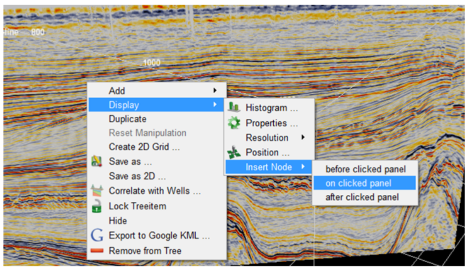


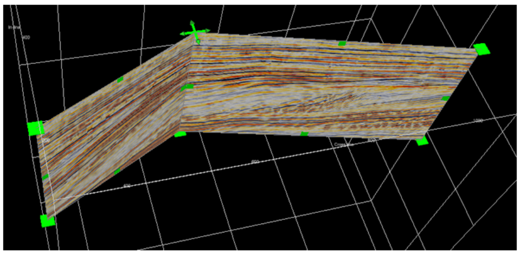
Workflow cont'd:

7. Insert a node: **right-click** on the element in the scene, or the entry in the tree and

8. Use the green anchors to position the node: **left-click + drag**

9. As before, now push and rotate the crooked line through the volume using **left-click + drag** and **Ctrl left-click + drag**, respectively.

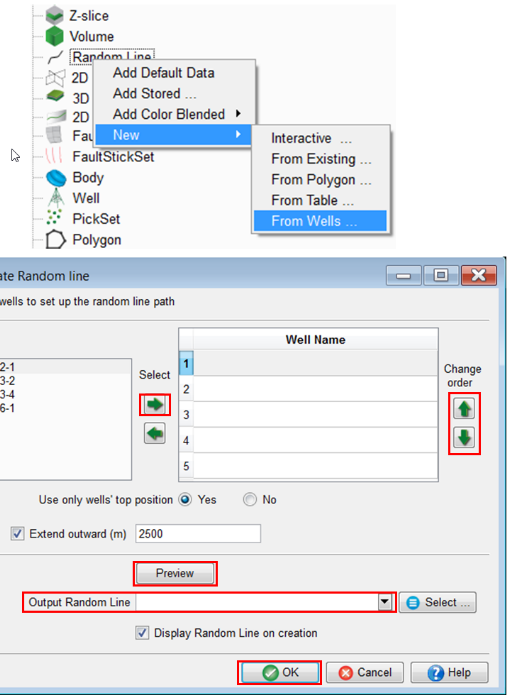




1.3.3b Random Line Through Wells

Required licenses: OpendTect.

Exercise objective:
Create a random line through existing wells.



Workflow:

1. **Right-click** on Random line > New > From Wells.

2. **Select** all four available wells and **change** the well's order accordingly: F03-4, F03-2, F02-1, F06-1, using *Change order* arrows.

3. **Press** the Preview button to see the updated geometry in the scene.

4. **Give a name** to the newly created Random line and **click** OK.

1.3.4 Save & Restore Session

Use Survey > Session > Save…/Restore…/Auto load… 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 load, choose Enable and then Use one for this survey. Select one session amongst the available ones. The session will restore itself automatically the next time you start OpendTect.

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.

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).

1.4 Seismic Interpretation

In this Chapter you will learn basic interpretation tasks such as tying wells, tracking horizons and interpreting faults.

1.4.1 Well-to-Seismic Tie

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.

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

- 3D seismic Volume
- An initial wavelet (if there is none, you can create either synthetic or stochastic wavelets, in OpendTect)
- Well data (either sonic and density logs, or an impedance log, and geologic markers)
- (Seismic horizons are optional)

1.4.1a Well Tie

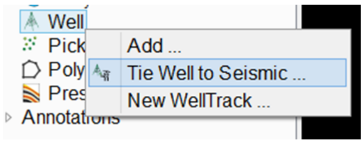
Required licenses: OpendTect.

Exercise objective:

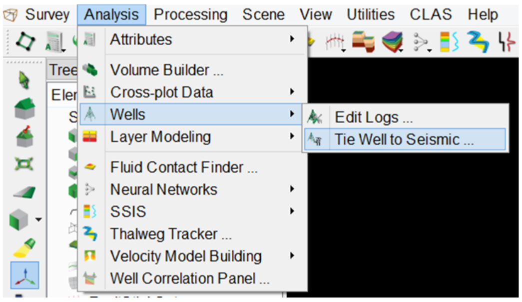
Tie a well to the seismic and extract a deterministic wavelet.

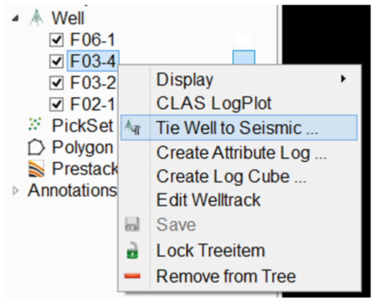
Workflow:

1. **Right-click** on Well in the tree > Tie Well to Seismic…



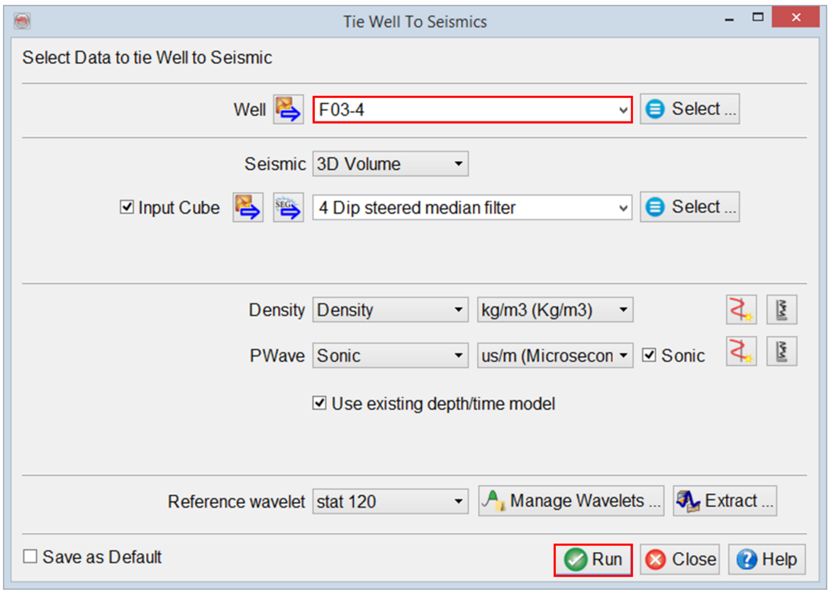
Tip:
Well to seismic tie module can be also launched via:
- Analysis > Wells > Tie Well to Seismic…
- Right-click on a well name in the tree > Tie Well To Seismic…



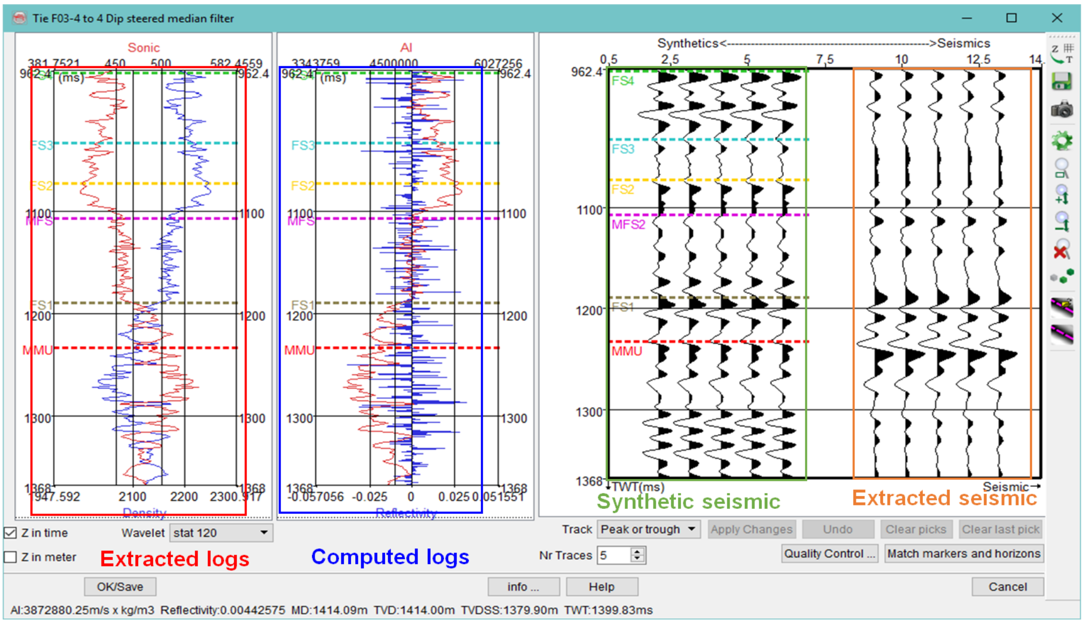


Workflow cont'd:

2. In the Tie Well to Seismic window: **choose** F03-4 well, **check** the options to be as shown below and **click** Run.



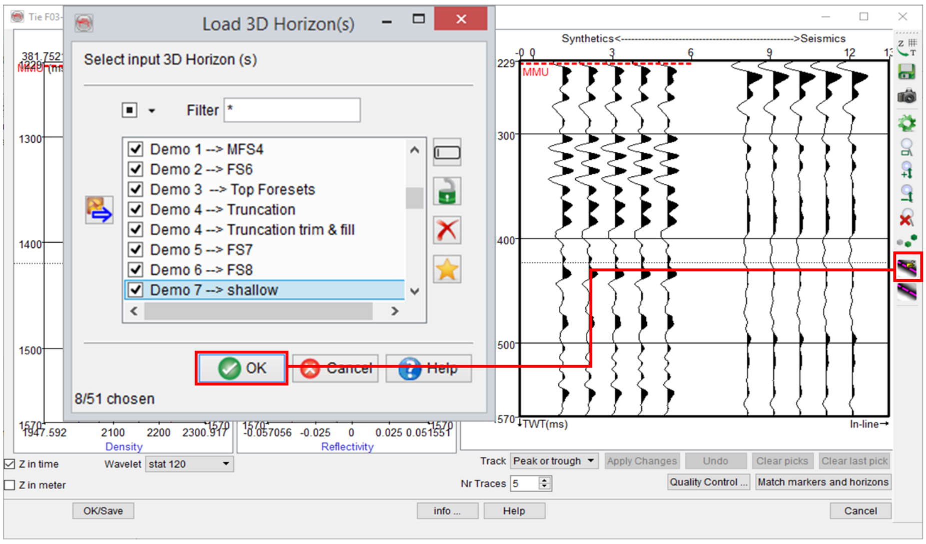
Workflow cont'd:



Markers are loaded by default.

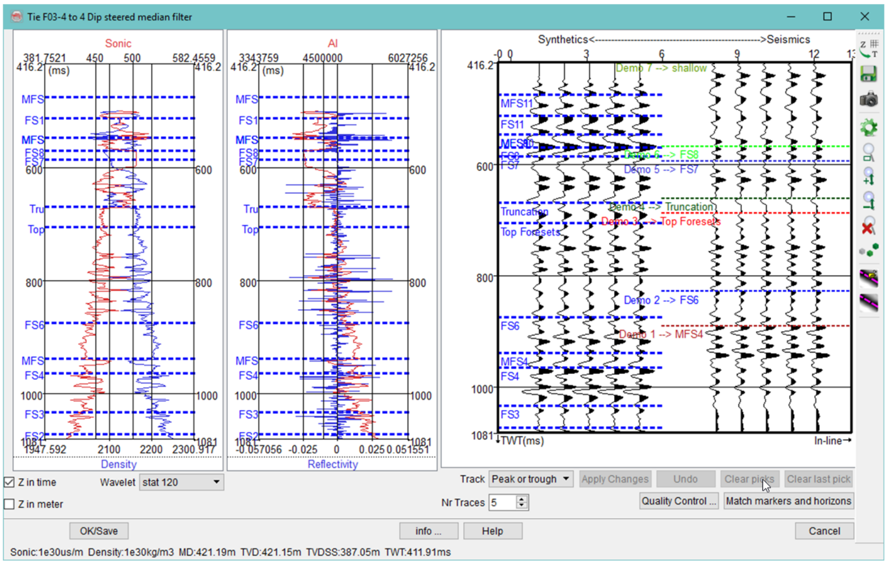
Workflow cont'd:

3. Click on icon to load already mapped horizons to be displayed on the extracted seismic traces: Check horizons from *Demo 1* to *Demo 7* and click OK.



Workflow cont'd:

4. **Zoom in** using middle-mouse scroll button and **pan** by pressing middle-mouse button: **hold** and **drag** up/down until you have a display to pick matching events.

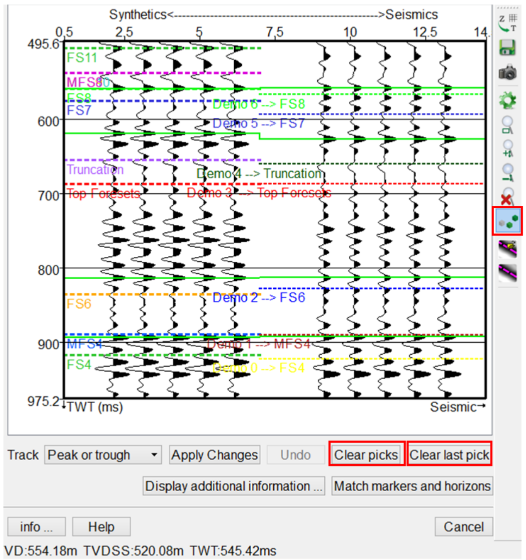


Workflow cont'd:

5. **Activate** pick mode with the icon 

6. **Pick** matching events on the extracted seismic then synthetic traces (or synthetic then extracted seismic).

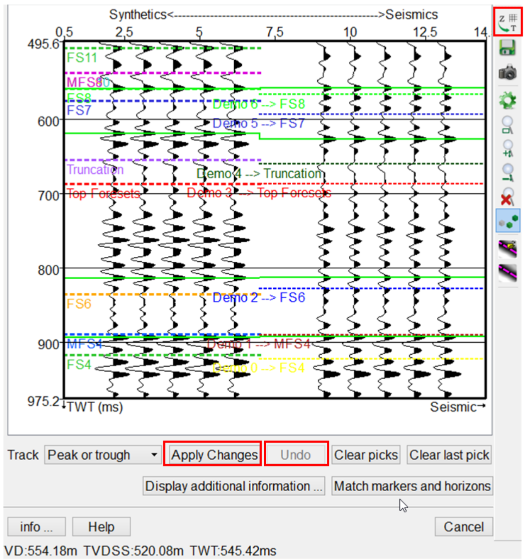
7. Optionally, to **change** your picks: **click** Clear picks or Clear last pick if needed.



Workflow cont'd:

8. After picking the events, **click** Apply Changes to reflect the changes.

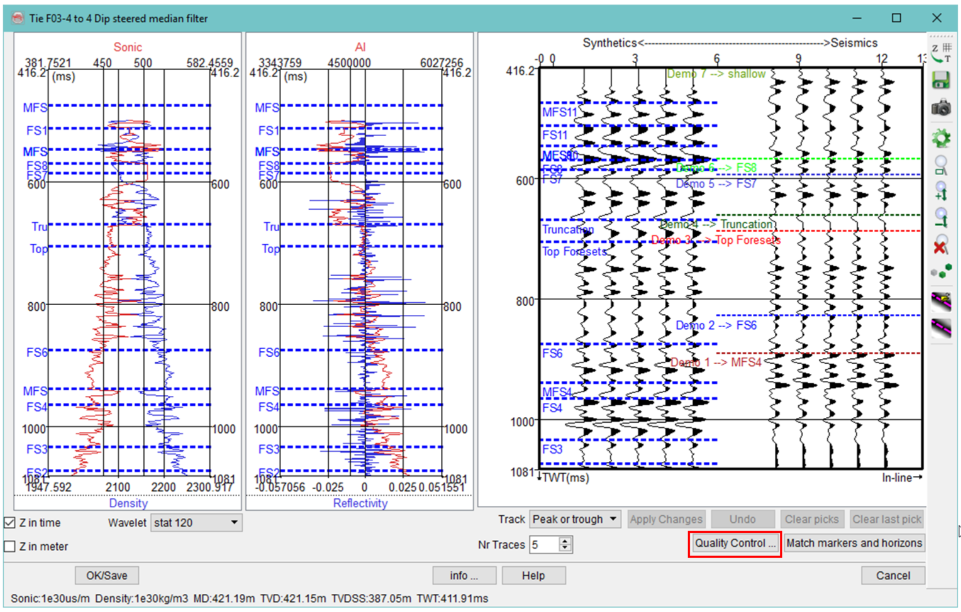
9. If not satisfied with the result, **click** Undo to revert the most recent step.



As only the previous step can be reverted using Undo button, it is recommended to save intermediate T/D (Time/Depth) curves by clicking on the icon and exporting to a text file.
Saved T/D curves can be (re-)imported at any time via the same window or via Well Manager.

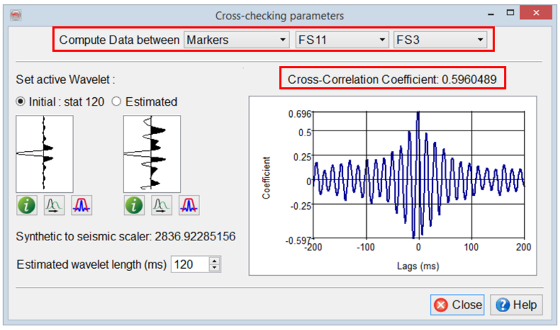
Workflow cont'd:

10. Click on Quality Control to check the Cross-Correlation Coefficient.

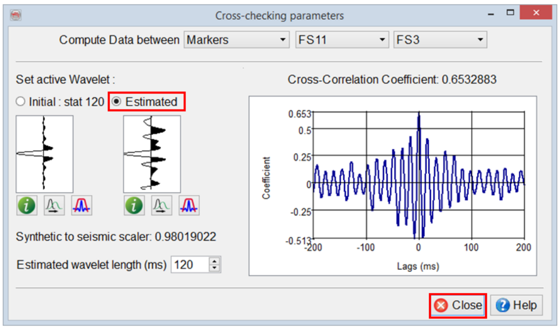


Workflow cont'd:

11. **Choose** Compute Data between Markers and **select** top and bottom markers, for example FS11 and FS3, to define a window of interest.
Note that Cross-Correlation Coefficient, the graph and the Estimated wavelet are immediately updated.



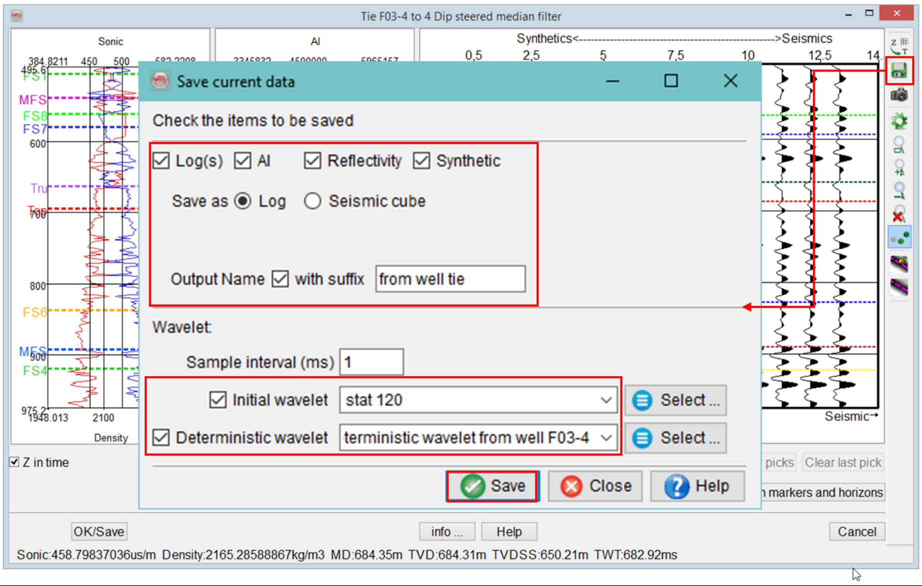
12. Optionally, **switch** to Estimated (deterministic) wavelet option: **see** that the synthetic traces change in the main Tie Well to Seismic window. The scaler applied to the seismic has also changed and should be close to 1.



Workflow cont'd:

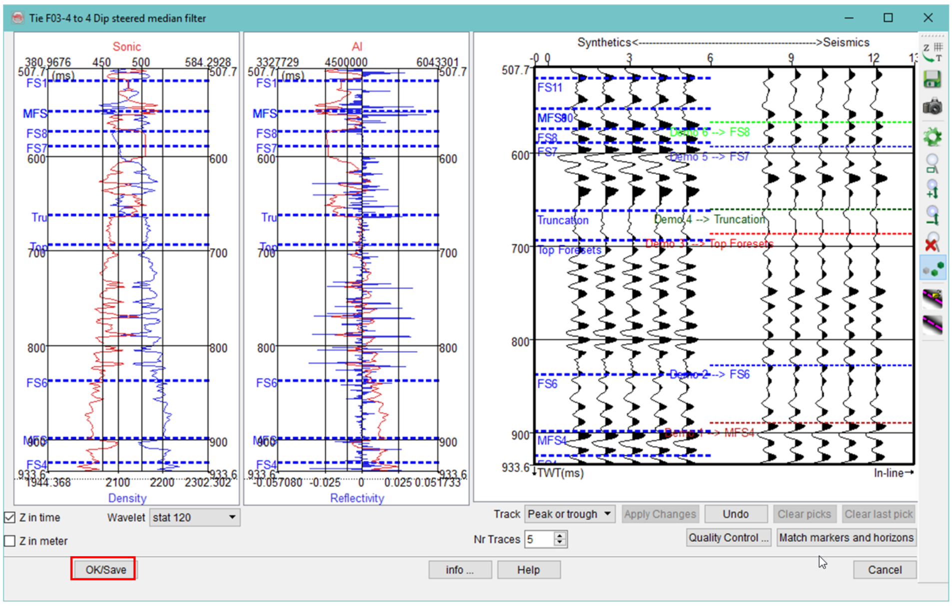
Click on icon to save:

- Acoustic Impedance, Reflectivity and Synthetic as well logs or as seismic cubes.
- The initial (loaded) and/or estimated wavelet.



Workflow cont'd:

13. Click on OK/Save button to save the T/D curve as an active T/D model of the tied well.



1.4.2 Horizon Tracking

What you should know about horizon tracking in OpendTect

There are several horizon trackers in OpendTect to support a variety of work flows using 2D and 3D viewers. The following trackers exist:

- **3D auto-tracker.** This interactive tracker is the primary tool for tracking horizons in OpendTect. It operates in the 3D scene and tracks amplitude differences along maxima, minima or zero-crossings. Optionally, the tracker also tracks using similarity or correlations and using seismic dip (only if you have a Dip-Steering license). The tracker supports two methods: comparing with (picked) seed traces and comparing with parents (neighbors). The seed trace option is used in a work flow in which the user continuously points additional seeds and QC's the tracked results. First areas with the largest confidence are tracked before the constraints are relaxed and the exercise is repeated. Typically multiple passes are made through the entire data set. Any remaining holes are filled in later stage using a gridding algorithm (e.g. OpendTect dip-steered gridder, see below). The advantage of this work flow is that the horizon is QC-ed while you are interpreting and that you save time on editing. In cases where the event is easy to track the parent method in which positions are compared against neighbors is preferred. The tracker extends the horizon further out from the starting positions but the risk of loop-skipping increases.
- **2D auto-tracker.** This interactive tracker is similar to the 3D tracker. The main difference is that it operates only along seismic sections. The lines are either displayed in the 3D scene, or in a flat (2D) viewer. Use this tracker to interpret 2D seismic data and/or to interpret 3D seismic lines in a grid, e.g. to interpret every 10th inline and crossline.
- **2D line drawing.** This option is used to manually pick horizons in areas where auto-tracking is not feasible.

- **3D dip-steered tracker.** This tracker requires a dip-steering license. It creates a single horizon from multiple picked seed positions by inverting the dip field (given in the form of a Steering Cube). This tracker can be used e.g. to create a quick geologic model with minimal input from the interpreter.
- **3D dip-steered gridding.** This tool requires a dip-steering license. This gridder interpolates holes in a horizon using a inverse-distance solution that honors the dip field (given in the form of a Steering Cube). The gridder is typically used to fill in holes left by the 3D auto-tracker and to fill in areas that were not interpreted (2D auto-tracker).
- **Thalweg Tracker.** This tracker requires an OpendTect Pro license. It tracks bodies and horizons either by adding one single position at the time (following the Thalweg: the path of least resistance) or by adding positions to the edges (margin tracking). It is used for seismic facies tracking, e.g. for mapping channels, see exercise 2.1.4 in Part 2.

1.4.2a 3D Auto-track

Required licenses: OpendTect.

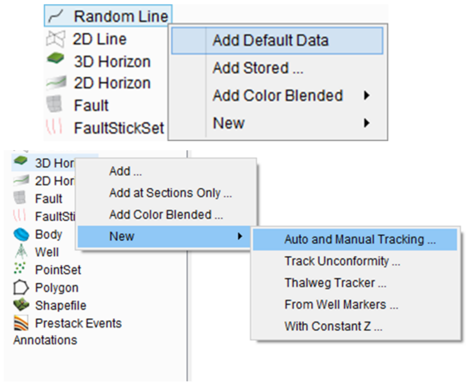
Exercise objective:

Interpret a horizon using 3D auto tracking

Workflow:

Survey > Pre-Load > Seismic…
For details on pre-loading see Exercise 1.3.1b.

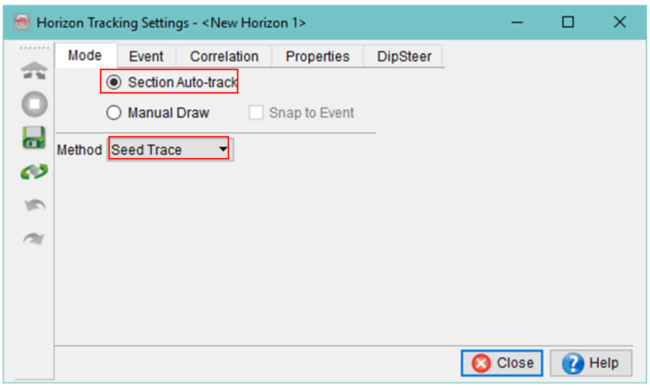
1. **Pre-load** *4 Dip steered median filter.*
2. **Right-click** on Random Line > Add Default Data. The data displayed is *4 Dip steered median filter* in the middle of the survey.
3. **Right-click** on 3D Horizon in the tree > New > Auto and Manual Tracking.
4. The Horizon Tracking Setup control center pops up (next slide).



You can interpret on inlines, crosslines and random lines, in the 3D scene and 2D viewer.

Workflow cont'd:

5. **Choose** the tracking mode: Section Auto-track (from seeds) and **Select** Seed Trace as tracking method.



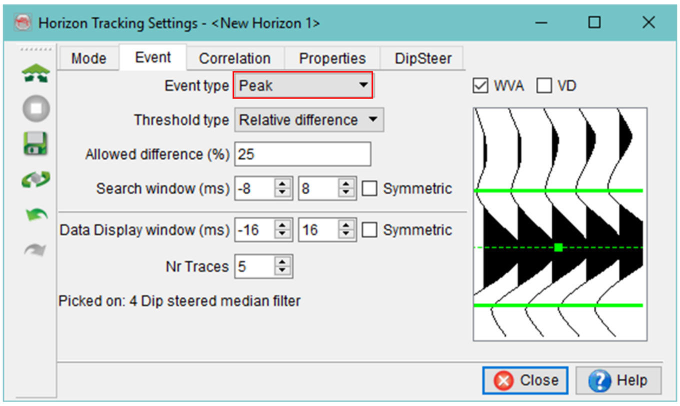
Method:

- Seed trace: compares amplitudes against the seed reference (recommended for most horizons)
- Adjacent parent: compares amplitudes against the last tracked position (increased risk of loop-skips; recommended for easy horizons).

Workflow cont'd:

6. **Click** on the Event tab.

7. **Select** event type Peak and leave the search window as default for now.



Display after picking a seed

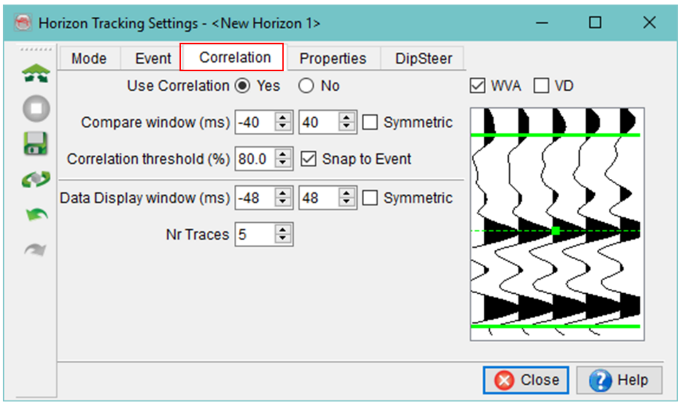
- Use the green lines in the waveform display to change the search window
- It is possible to change the event type during the interpretation

Workflow cont'd:

8. **Click** on the Correlation tab.

9. **Set** the use Correlation toggle to Yes.

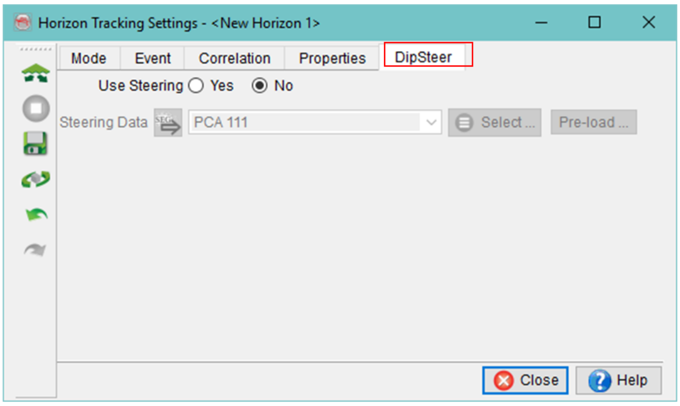
10. **Set** the Correlation threshold to 60%.



Tracking with correlation is more accurate, but it takes more time to compute.

Workflow cont'd:

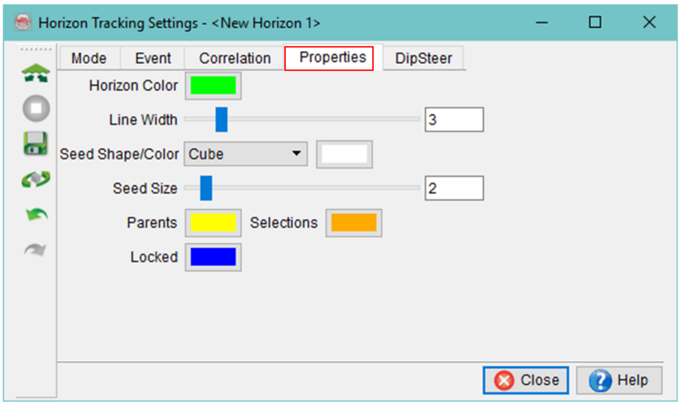
11. Set the selection of Steering to No.



This option is only available if you have a dip-steering license.
It ensures that the correlation window follows the seismic reflectors by steering the window along the pre-calculated dip. This option lowers the risk of loop-skips, especially in areas with steep dips.

Workflow cont'd:

12. Optionally **edit** the display properties.

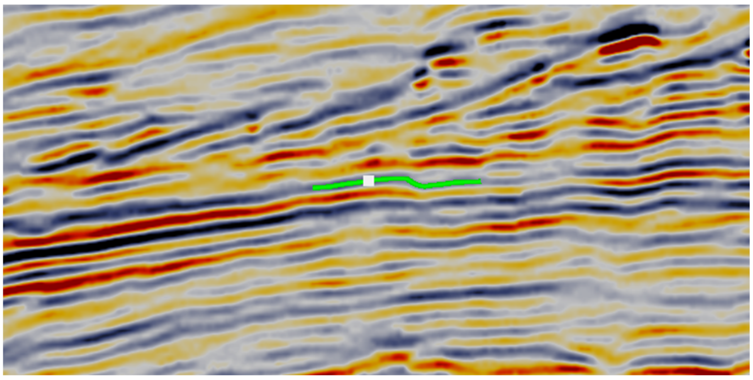


We recommend the Horizon Tracking setup window to stay open during the entire interpretation session. Parameters can thus be adjust at all times. To re-open the window, use the icon in the toolbar in the lower section of OpendTect main window.

Workflow cont'd:

13. **Pick** a seed on a Max event (as selected earlier) on the displayed random line.

14. **Click** on the Auto-Track icon in the Horizon Tracking Setup window.



In horizon picking mode, the cursor is a cross. You need to have the horizon active in order to interpret. You can make it active by clicking on it in the 3D scene or on its name in the tree.

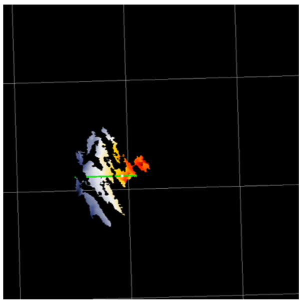
Workflow cont'd:

15. **QC** the auto-tracked horizon patch:

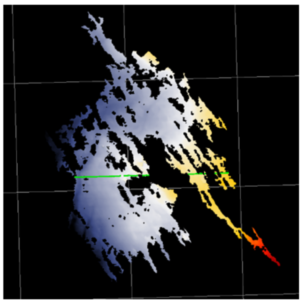
- **a.** **Select** the new horizon in the tree.
- **b.** **Set** the display of the horizon to "sections only": **press** the shortcut v/V key.
- **c.** **Move** the random line through the patch: **click** and **drag** the line.

16. If the horizon patch looks OK but is rather small: **change** the amplitude correlation parameters and redo.
In this case, **change** the correlate window to [-20, 20] ms.

17. **Click** on the Retrack-All icon in the Horizon Tracking Setup window.



Correlation window [-40;40]ms

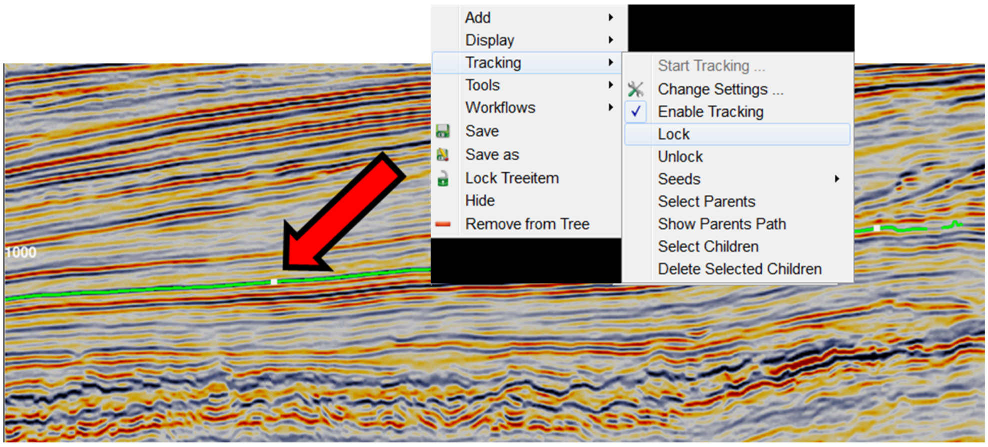


Correlation window [-20;20]ms

Workflow cont'd:

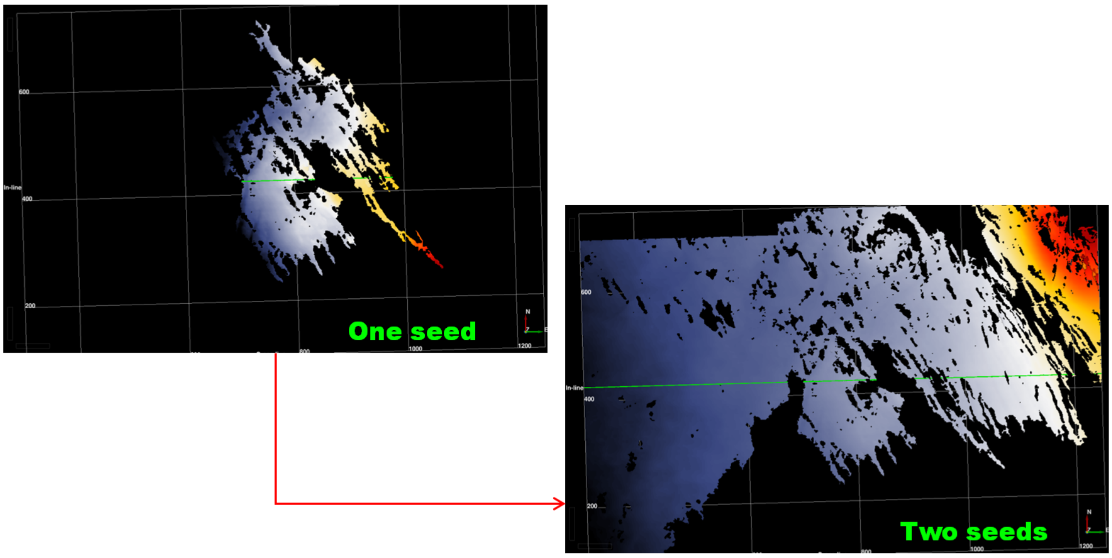
18. When satisfied with a patch, **right-click** on it > Tracking > Lock, so that it can no longer be changed. Alternatively, **Ctrl + right-click** on it > Lock.

19. To continue, **pick** another seed in an empty area and repeat the exercise.



Workflow cont'd:

20. **Click** on the auto-track icon to track more from the new seed (previously auto-tracked horizon patch remains untouched).



Workflow cont'd:

21. **Repeat** this workflow (add seeds, auto-track, QC, lock) until you have filled the entire area with horizon patches of good confidence.

22. Now **lower** the constraints in the amplitude and correlation tabs.

23. **Repeat** steps 21 and 22 until the tracker cannot fill in holes any further without making mistakes.

What to do when something went wrong?

There are three ways to change the results:

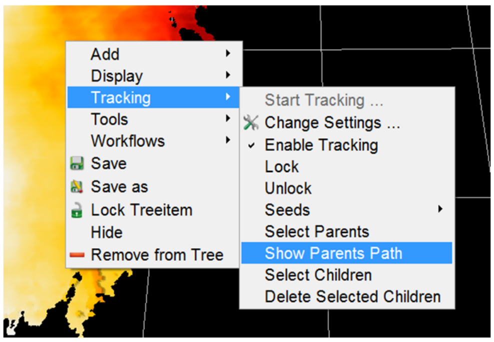
- Use Undo and Redo icons, or CTRL-Z / CRTL-Y shortcuts.
- Select the area to remove with the selection  icon and press the  delete icon.
- Use the tracking history to remove all positions (children) following the last good position (parent). How to do this is explained next.

Workflow cont'd:

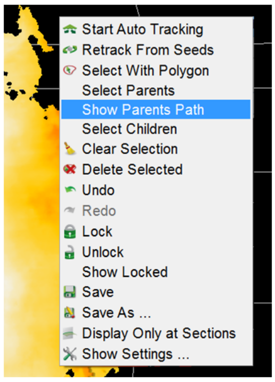
How to see the tracking history

24. **Right-click** in the 3D scene on a bad position on the auto-tracked horizon and **Go** to Tracking > Show Parents Path.

25. Alternatively, **ctrl + right-click** on the bad position on the auto-tracked horizon and **select** Show Parents Path.



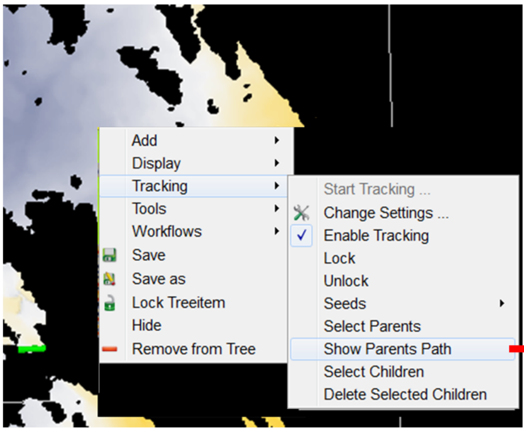
OR

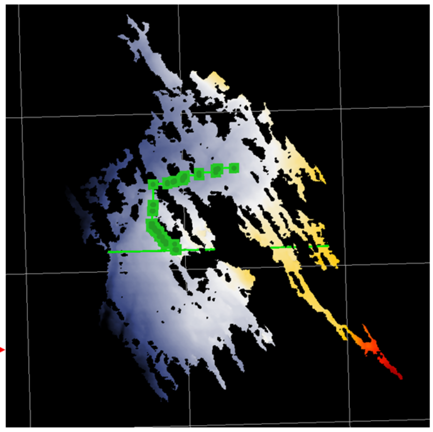


Ctrl + right-click pops up the dedicated menu containing all the tools required for 3D horizon tracking. This menu minimizes the need to use the horizon tracking set-up window, e.g. for auto-tracking or re-tracking from seeds.

Workflow cont'd:

26. The nodes of the random line that appears in the 3D scene shows the tracking path to the selected position (Parents Path).



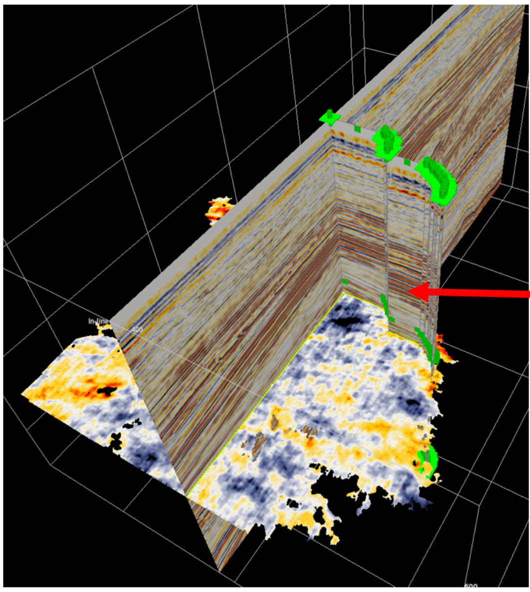


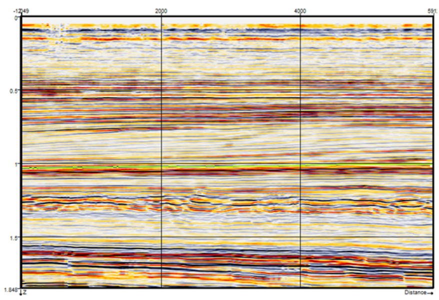
Each node (in Green) of the random line, corresponds to a parent seed.

Each parent path is added in the tree under the Random line item and can be saved.

Workflow cont'd:

27. Additionally, the Parents Path random line is automatically displayed in a 2D viewer.

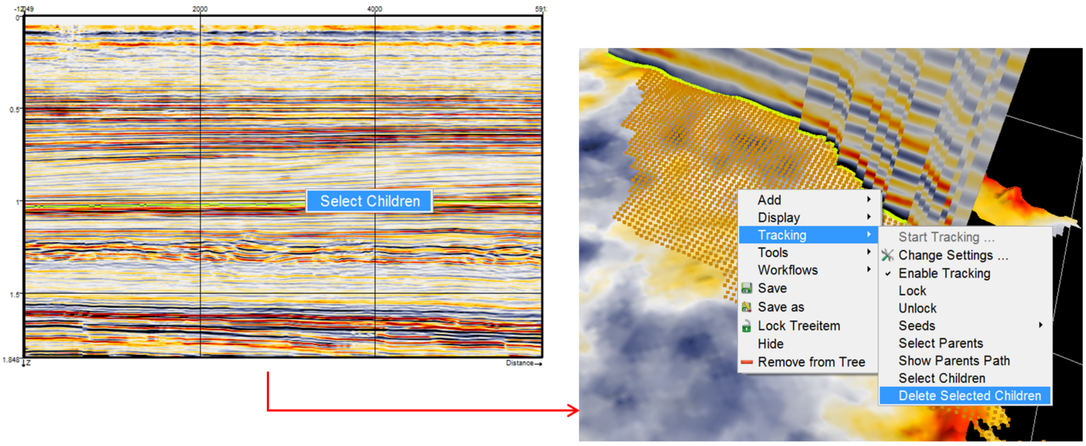




Workflow cont'd:

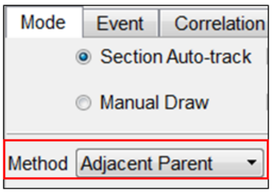
28. **Locate** the parent position where the interpretation went off-track: **Ctrl + right-click** on this position on the horizon patch (or in the 2D viewer) and **select** Select Children.

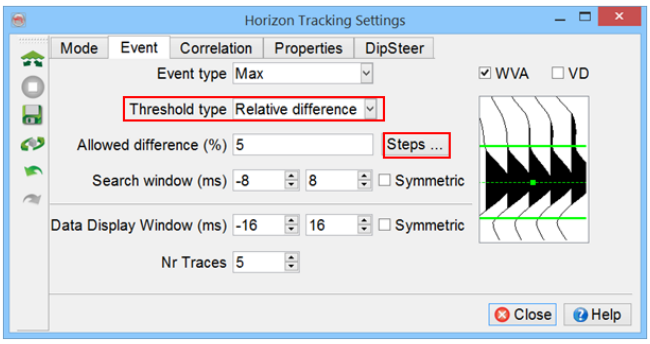
29. The samples tracked from this bad parent position are highlighted in the scene. Either, **right-click** on them > Tracking > Delete Selected Children or **Ctrl + right-click** on them > Delete Selected.



Workflow for "fast" auto-tracking using "Adjacent Parent" tracking method

1. **Select** Adjacent Parent method in the Mode tab.
2. **Go** to the Event tab and **Select** Relative difference as Threshold type.
3. **Define** the allowed differences by clicking on Steps …



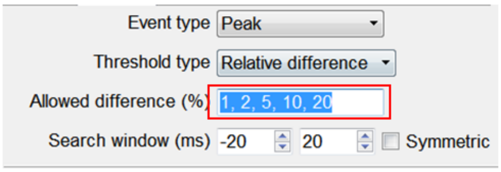


Patches tracked with the Adjacent Parent method tend to be much larger than with the Seed Trace method, especially if you use multiple steps (next slide)

Workflow cont'd:

4. **Specify** the allowed differences (in %) as shown on the picture. In this example any sample of the horizon is tracked in at-most 5 steps.

In the first step only 1% difference between neighbors is allowed. If the program is able to find a new sample in the neighborhood with less than 1% amplitude difference, that sample is included in the horizon and tracking moves on. Otherwise, the amplitude difference criteria of next steps are utilized.
Be aware that loosening the constraints too much may result in loop-skips.



Adjust the amplitude and correlation parameters in case the tracker stops tracking too soon.

5. **Follow** steps 8-29 of the previous workflow based on the Seed Trace method.

1.4.2b Tracking In 2D Viewer

Exercise objective:

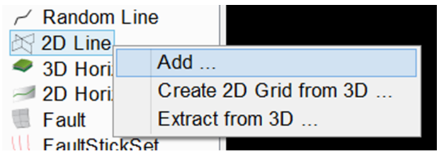
Interpret a 2D horizon using a 2D viewer

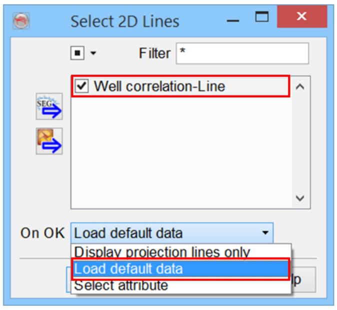
Workflow:

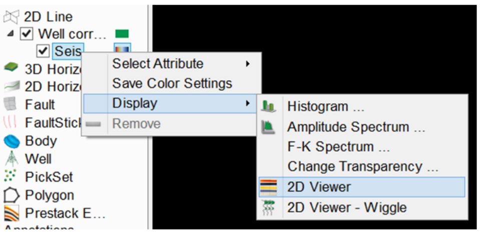
1. **Add** a 2D line to the 3D scene: **right-click** on 2D line and **go** Add.

2. **Select** the Well correlation - Line and **change** the action to Load default data.

3. Once the 2D line is loaded, **right-click** on the attribute name (i.e. Seis) in the tree and **go** Display > 2D viewer.

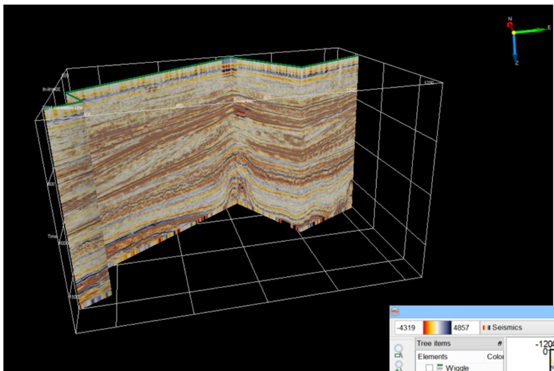






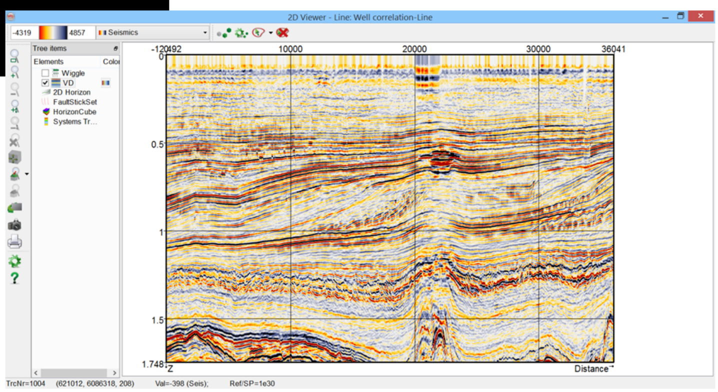
In a 2D viewer, you can interpret 2D and 3D seismic.

Workflow cont'd:



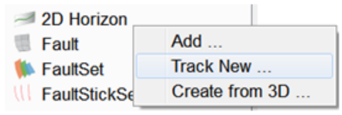
3D scene

2D viewer



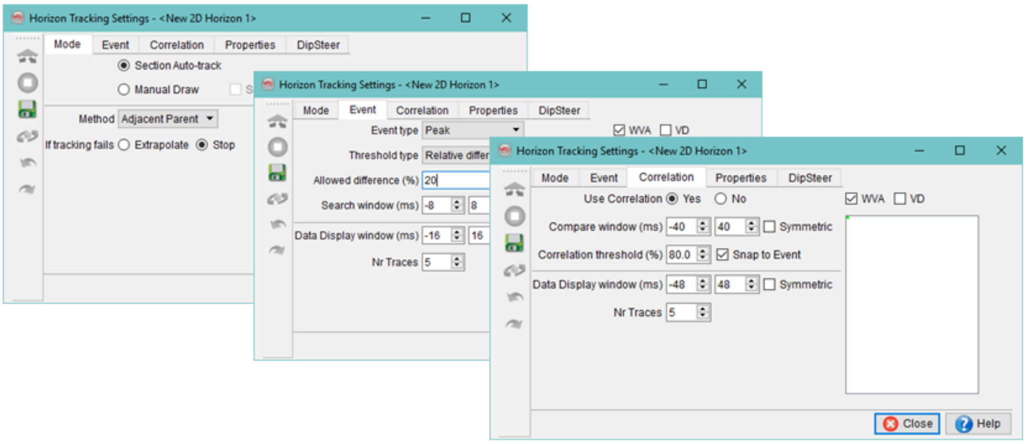
Workflow cont'd:

4. In the 2D viewer, **right-click** on 2D horizon and **select** Track new.



5. In the Horizon tracking settings, **leave** the parameters as default.

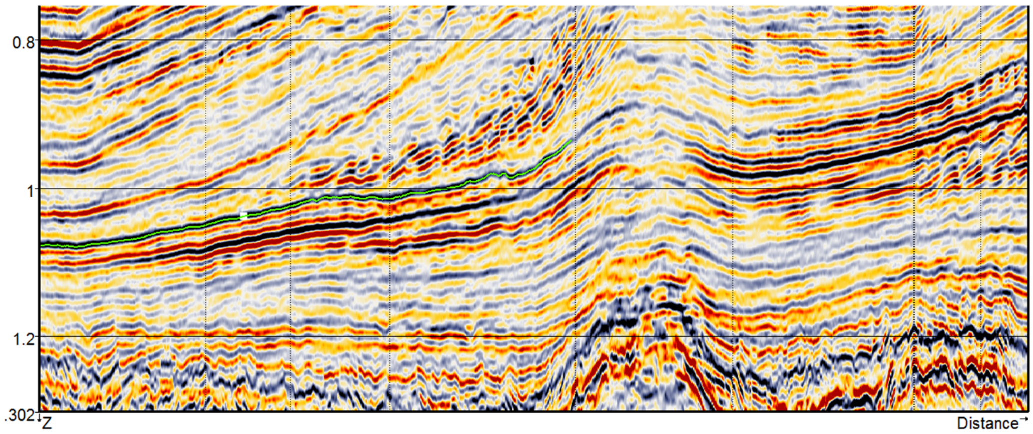
6. Optionally, **close** the Horizon tracking setting window



Workflow cont'd:

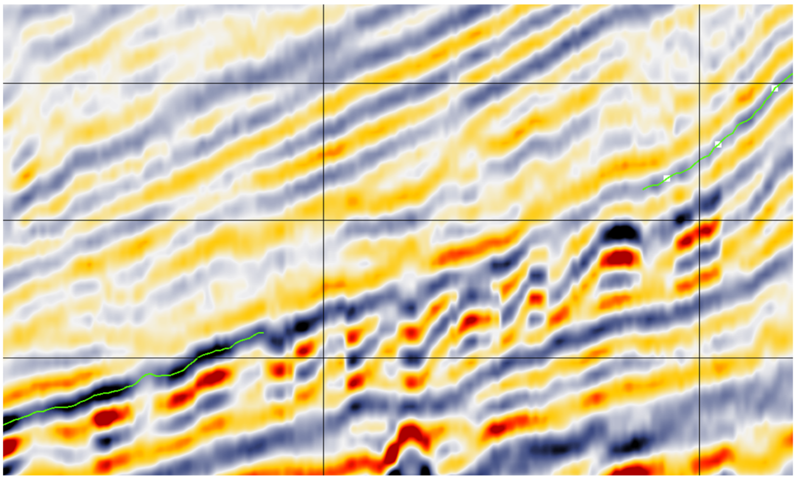
6. **Pick** a seed on a Max event (as selected earlier) on the line.

7. **Interpret** the full line.



Workflow cont'd:

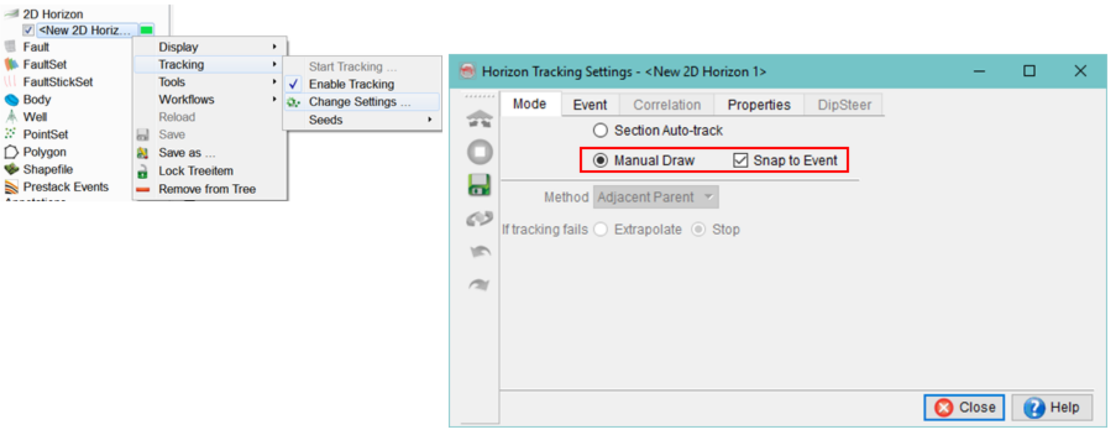
8. In some areas the horizon does not propagate well and you may want to switch to the manual drawing mode.



Workflow cont'd:

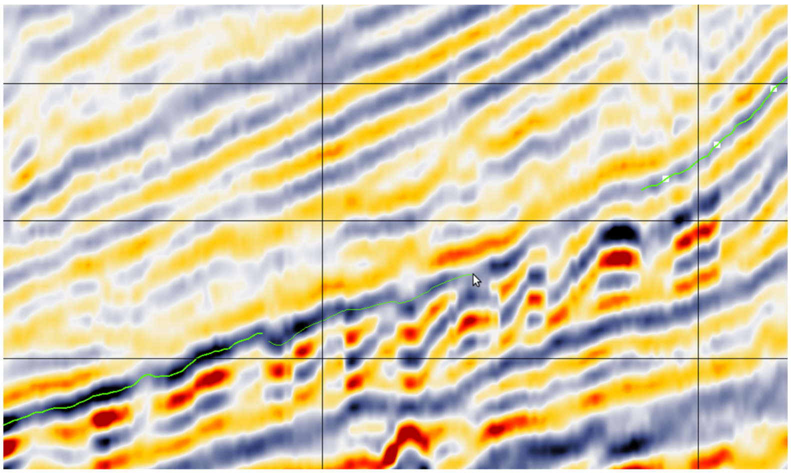
9. **Re-open** the horizon tracking settings: **right-click** on the *<New 2D Horizon>* and Tracking > Change Settings.

10. **Change** the tracking mode to Manual Draw and **select** the Snap to event option. The event type is defined as previously.



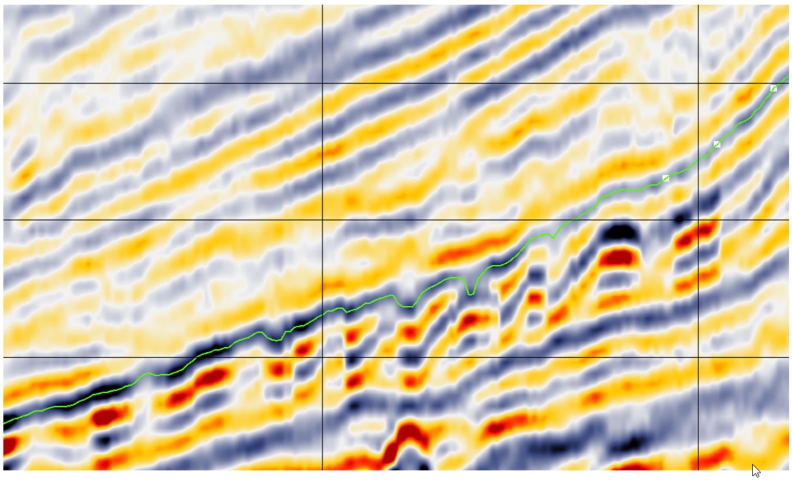
Workflow cont'd:

11. **Draw** the line where you want to interpret.



Workflow cont'd:

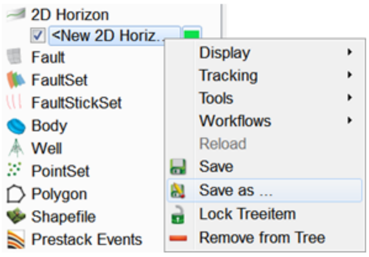
12. Once you are done, **release** the left-click button from your mouse: the line will be automatically converted into the horizon and snapped to the Max event.

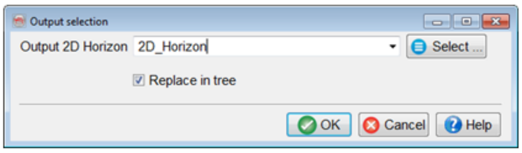


Workflow cont'd:

13. When satisfied of the interpretation, **save** the 2D horizon: **right-click** on the *<New 2D Horizon>* in the 2D viewer tree and **select** Save as (at this point Save and Save as are equivalent) and **specify** an output name.

14. **Close** the 2D viewer. The 2D line and the newly interpreted 2D horizon are displayed in the 3D scene.





Note: A 3D horizon as well as Fault stick sets can also be interpreted in the 2D viewer.

Workflow cont'd:

3D horizon interpretation using a 2D viewer

1. The horizon type you are interpreting is 3D horizon.

2. The tracking modes are similar but on the contrary to the 2D tracking, the auto-tracking option is ON while tracking a 3D horizon in a 2D viewer.

3. For auto-tracking the horizon, recommendation is to use the Seed trace method in combination with the section auto-track option (see previous exercise 1.4.2a for more details).

4. In the 2D viewer, while tracking a 3D horizon, you can switch inline/crossline by either typing the line number or using the arrows and the step to interpret a grid like you would do in the 3D scene.

1.4.3 Fault Interpretation

What you should know about faults in OpendTect

- We distinguish between fault sticks and fault planes.
- Fault planes can be mapped directly from line to line (only advisable for large faults that can be recognized easily).
- Alternatively, faults sticks are picked and stored in a fault stick set from which fault planes are created by manually grouping the sticks.
- In the current version (5.0) you can pick horizontal and vertical fault sticks but you cannot combine sticks from different orientations.

1.4.3a Fault Planes

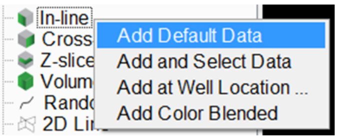
Required licenses: OpendTect.

Exercise objective:

Pick a major fault plane.

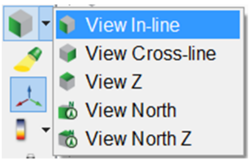
Workflow:

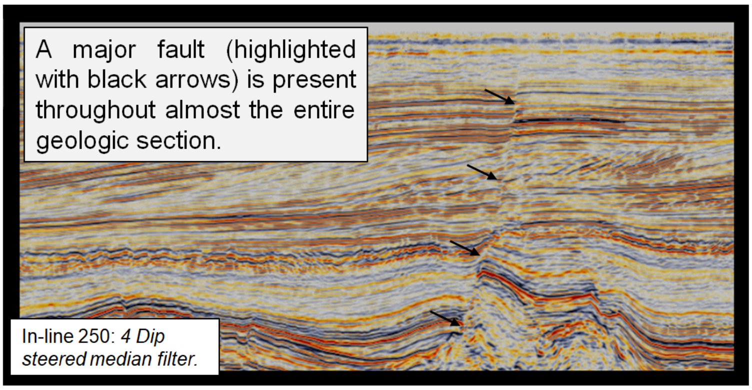
1. **Right-click** on In-line in the tree > Add Default Data; *4 Dip steered median filter*.



2. **Change** In-line position and step: **enter** manually 250 and 10 in the Inline and Step fields, respectively, of the navigation toolbar.

3. **Click** on  to have an In-line view.

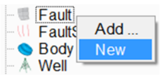




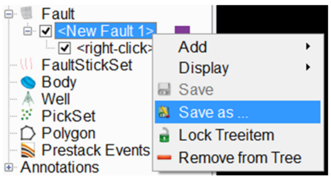
In-line 250: *4 Dip steered median filter.*

Workflow cont'd:

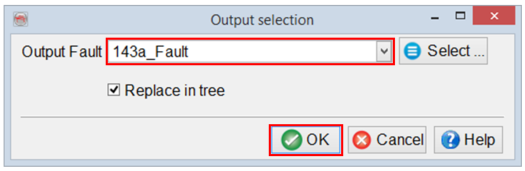
4. **Right-click** on Fault in the tree > New.



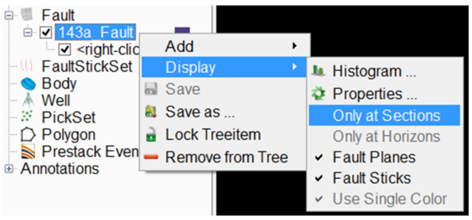
5. **Right-click** on the newly added Fault > Save as…



6. **Enter** an Output Fault name and **click** OK.



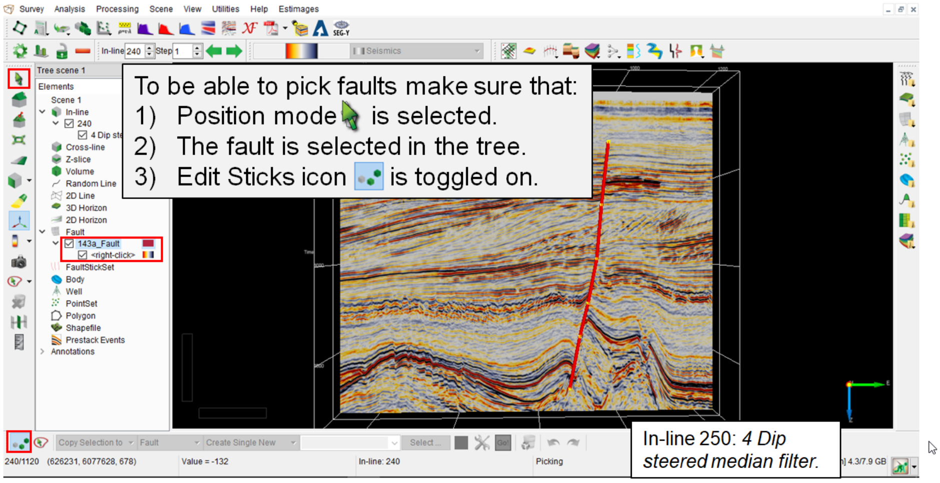
7. **Right-click** on the saved Fault name > Display > **toggle on** Only at Sections.



Workflow cont'd:

8. **Pick** the fault on the first In-line: either **Left-click + drag** or **Left-click** to pick and **double-click** to end a stick.

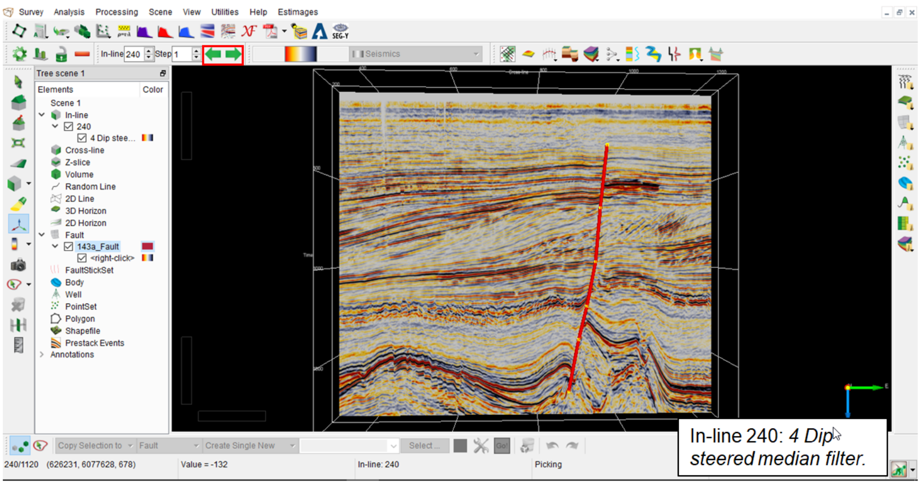
9. **Edit** as needed: **Left-click + drag** seeds, **Ctrl + Left-click** to remove seeds, or **Ctrl + Z** to undo the last action, or **Ctrl + Y** to redo.



Workflow cont'd:

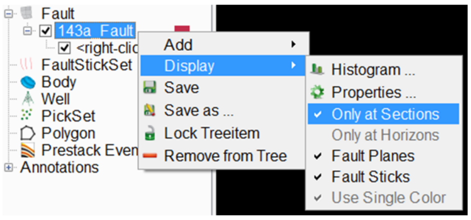
10. **Move** the In-line to a new location (for example 240): **Click** on in the navigation toolbar or use short keys (Z and X by default) to move the In-line backward and forward.

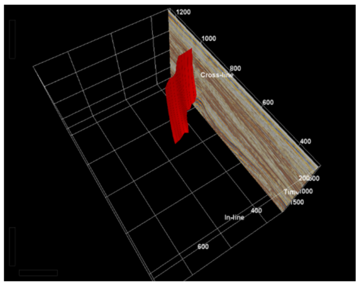
11. **Repeat** steps 8, 9 and 10 for every 10th inline in the range 100-250.



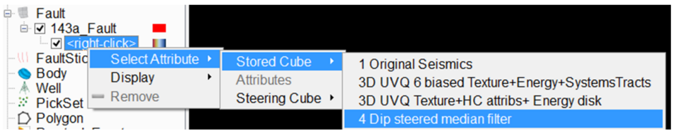
Workflow cont'd:

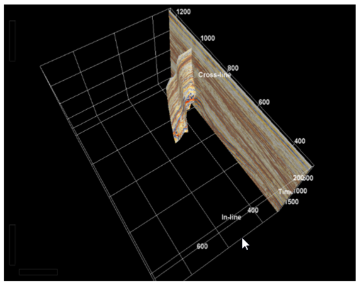
12. **Right-click** on the fault name in the tree > Display > **toggle off** Only at Sections, to see the fault plane in 3D. (Shortcut key: v)





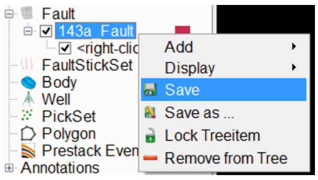
13. Optionally **display** the seismic data along the fault. **Right-click** > Select Attribute > Stored Cubes > *4 Dip steered median filter.*



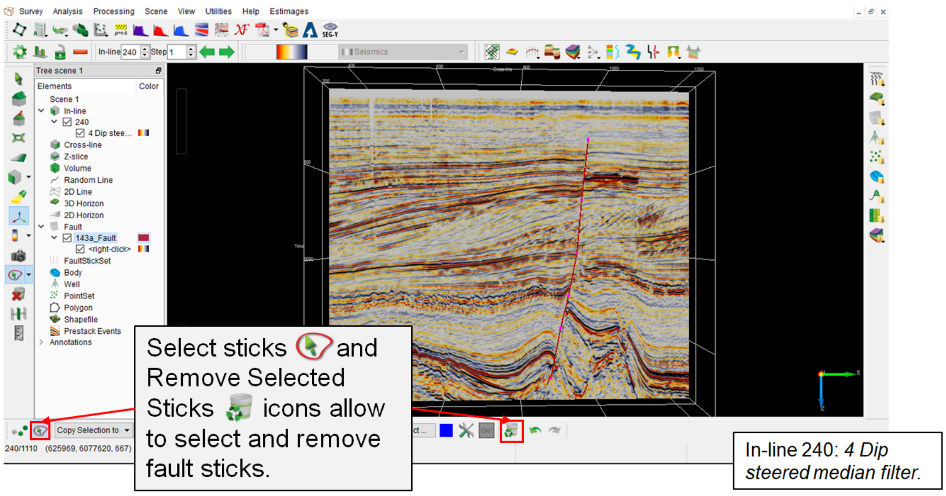


Workflow cont'd:

14. Don't forget to **Save** your work regularly.



15. To delete sticks from a fault plane, **use** Select and Remove icons as shown below.



1.4.3b Fault Sticks

Required licenses: OpendTect.

Exercise objective:

Pick a set of fault sticks and group these into fault planes.

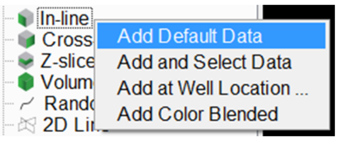
Workflow:

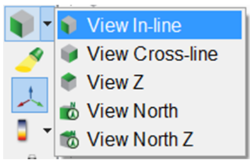
1. **Right-click** on In-line in the tree > Add Default Data; *4 Dip steered median filter*.

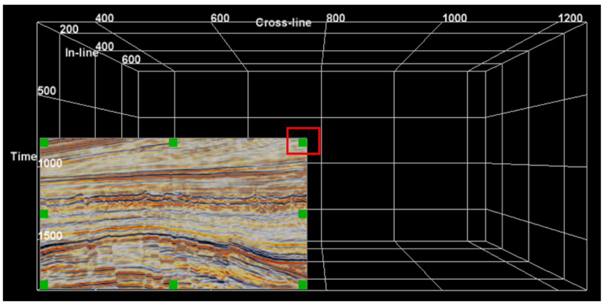
2. **Drag** inline position to 110 in the Position mode .

3. **Click** on to have an inline view.

4. **Reduce** the displayed area to the faulted part as shown in the picture: **Left-click + drag** the green square in the upper right corner.



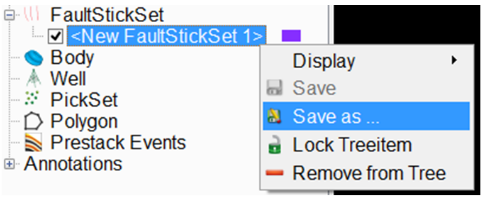




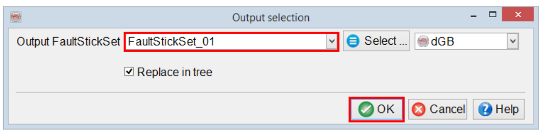
Workflow cont'd:

5. **Right-click** on FaultStickSet in the tree and **select** New.

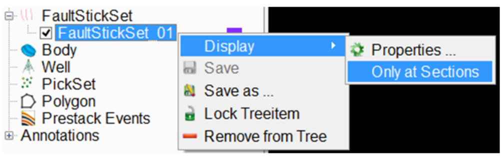
6. **Right-click** on the newly added FaultStickSet > Save as…



7. **Enter** an Output Fault Stick Set name and **click** OK.



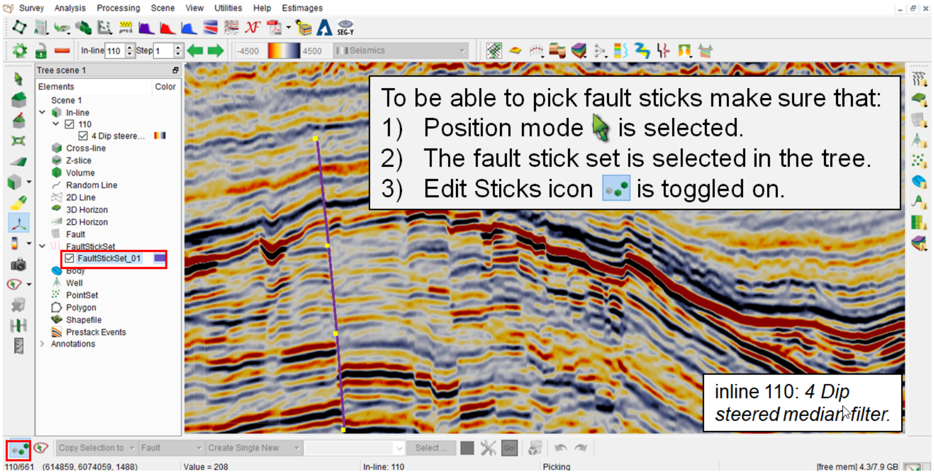
8. **Right-click** on the saved FaultStickSet name > Display > Only at Sections.



Workflow cont'd:

9. **Pick** the first fault stick: either **Left-click + drag** or **Left-click** to pick and **double-click** to end a stick.

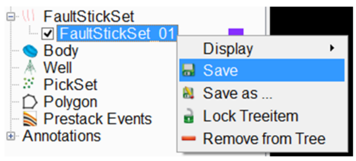
10. **Edit** as needed: **Left-click + drag** seeds, **Ctrl + Left-click** to remove seeds, or **Ctrl + Z** to undo the last action, or **Ctrl + Y** to redo.

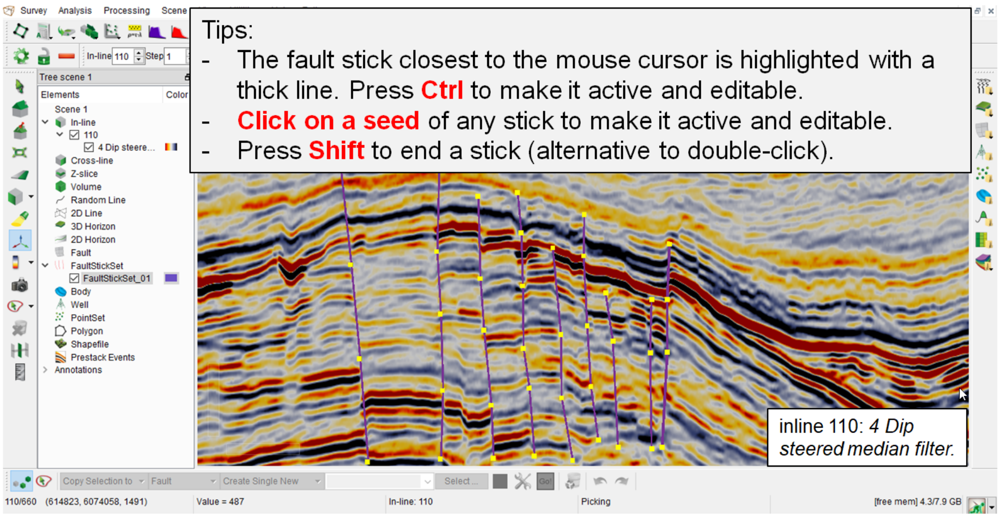


Workflow cont'd:

11. **Save** your work regularly.

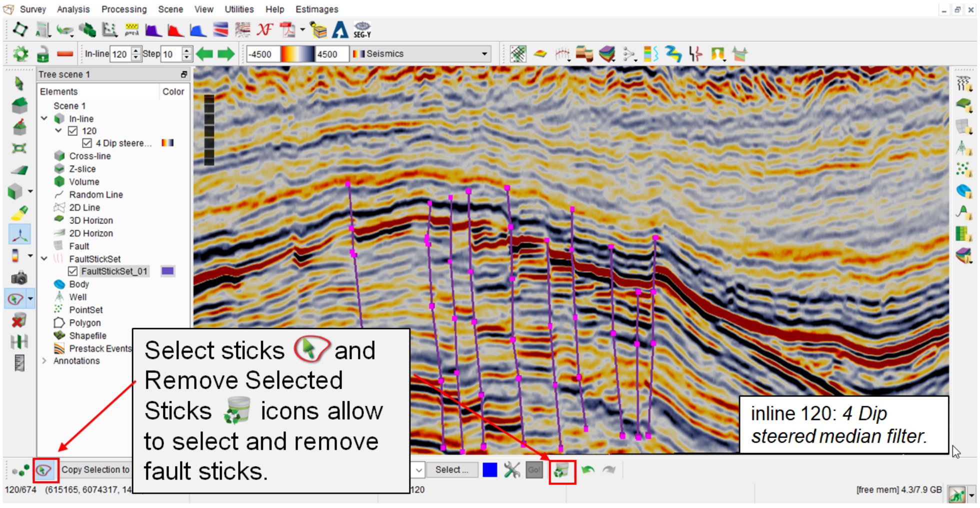
12. **Interpret** several fault sticks on inline 110.





Workflow cont'd:

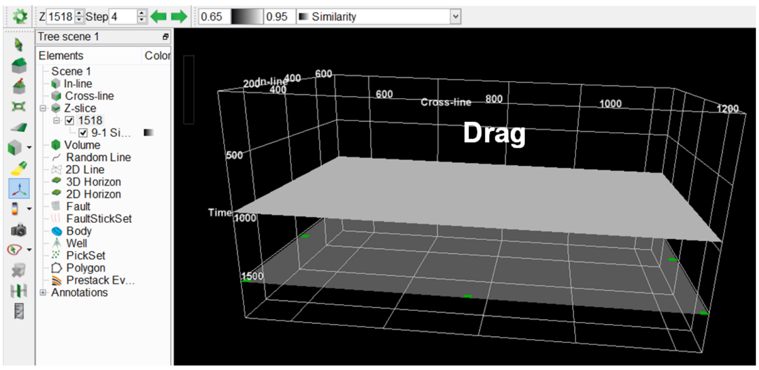
13. **Move** to inline 120: **Click** on [arrow icons] in the navigation toolbar or use short keys (Z and X by default) to move the inline backward and forward. **Continue** the interpretation for several inlines, e.g. with a step of 10.

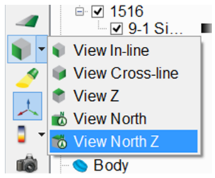


Workflow cont'd:

14. **Add** an empty Z-slice* to the scene and **Drag** it to 1500 ms. **Click** on [icon] to have a North oriented top view and resize with the green anchors to cover more or less the area you interpreted.

We have finished picking sticks. In the next phase sticks will be grouped into planes. To facilitate this process we will display a fault discontinuity attribute on a time-slice through the sticks.

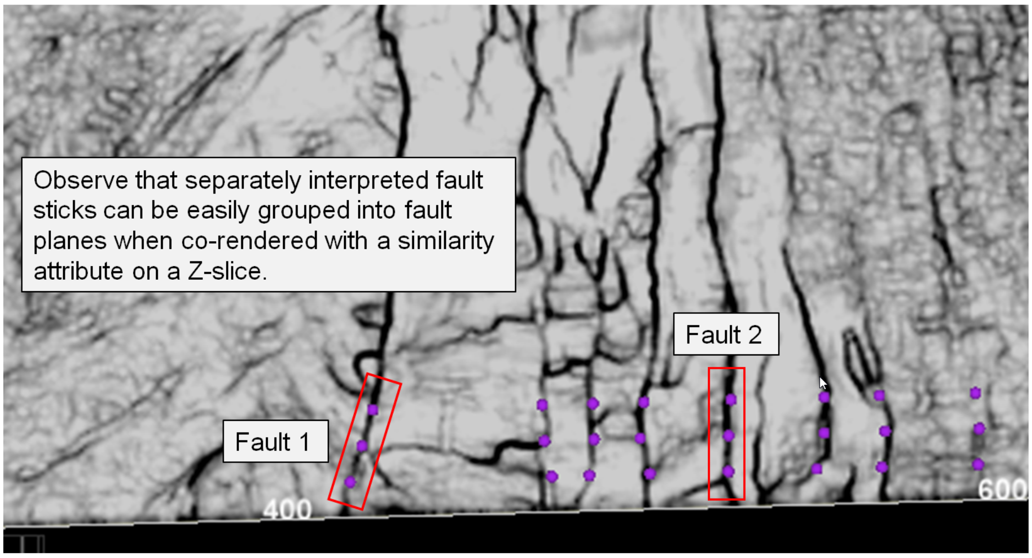




*Positioning an empty slice is faster than positioning a slice with data. With pre-loaded data the speed difference is negligible.

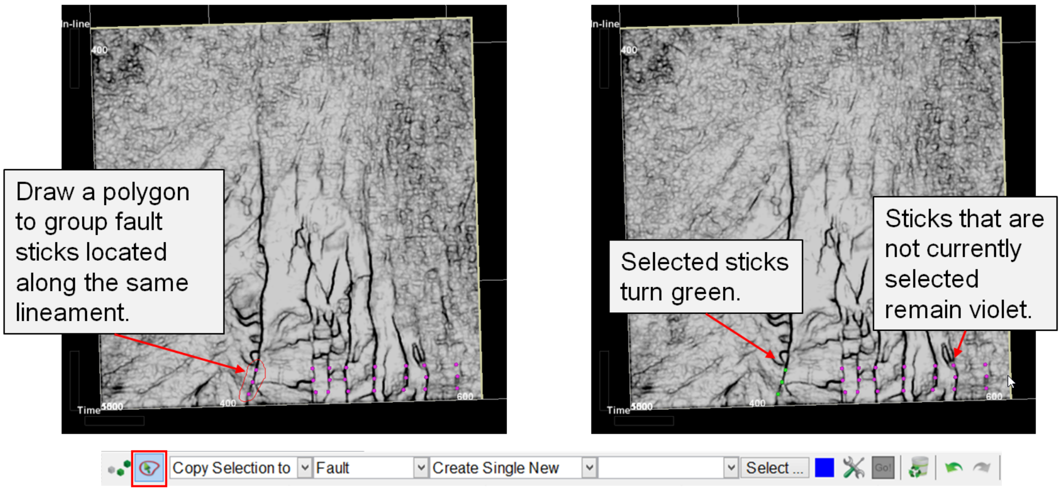
Workflow cont'd:

15. **Add** *9-1 Similarity on FEF seismic* from Stored attribute list.



Workflow cont'd:

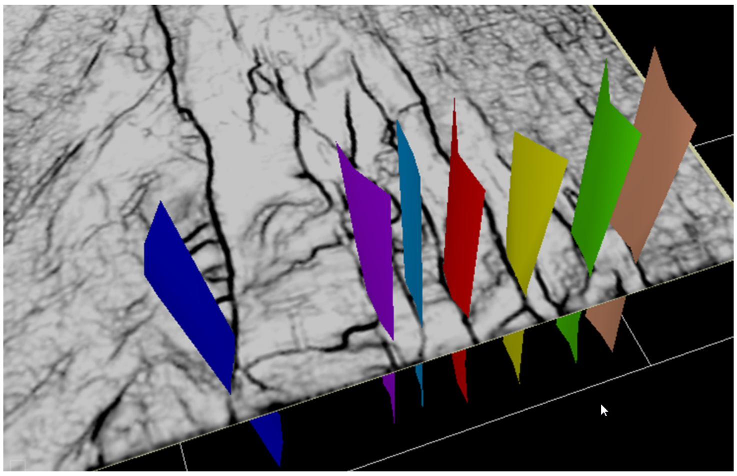
16. **Select** sticks located along the same lineament by clicking on icon and:
   - **Ctrl + Left-click** to select/de-select sticks one by one;
   - **Left-click + drag** to select/de-select a group of sticks;
   - **Ctrl + Left-click + drag** around several groups of sticks for multi-group selection.



Workflow cont'd:

17. **Choose** Copy Selection to > Fault > Create Single New and type in a new name in the toolbar. Optionally choose a fault color. Then **click** .

18. **Repeat** previous two steps to create more fault planes.



1.4.4 Velocity Gridding & Time-Depth Conversion

What you should know about Velocity Gridding and TD conversion

- Time-Depth conversion is performed on-the-fly by transforming the Z-axis of the scene using a given velocity field.
- Velocities are given in the form of:
  - Velocity volume.
  - The TD curve of the specified well.
  - A user-defined linear velocity function.
- 3D velocity volumes can be created in the Volume Builder.

What you will learn in this Chapter

- How to load a stacking velocity function.
- How to grid stacking velocities and create a 3D velocity volume.
- How to display the volume on the fly and batch processing.
- How to batch-process cubes for depth survey.
- How to batch-process horizons for a depth survey.
- How to set-up a new depth survey.

1.4.4a Stacking Velocities

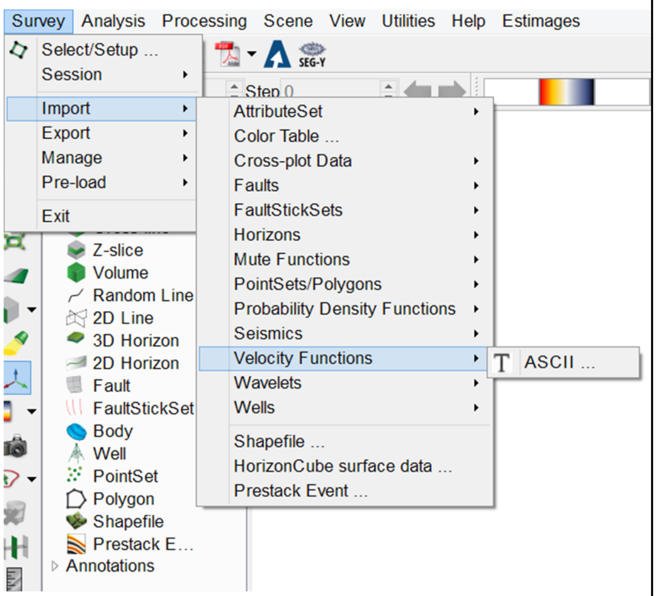
Required licenses: OpendTect.

Exercise objective:

Import stacking velocity functions.

Workflow:

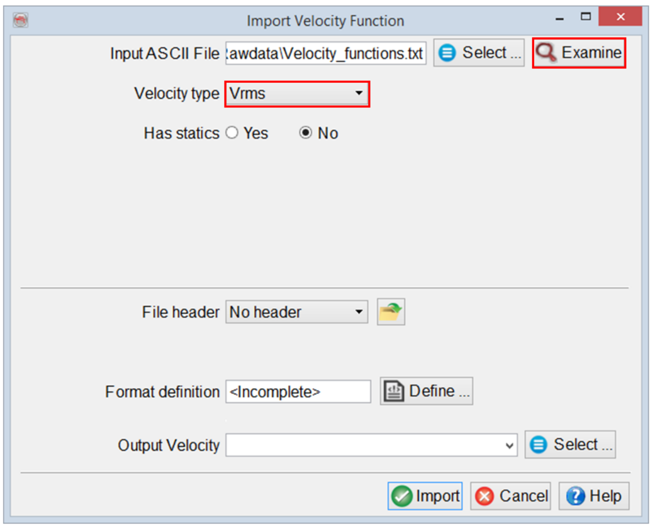
1. **Go to** Survey > Import > Velocity Functions > ASCII… to import a velocity function.



Workflow cont'd:

2. **Locate** the file *Velocity_functions.txt* in the *Rawdata* directory and **Examine** the input file.

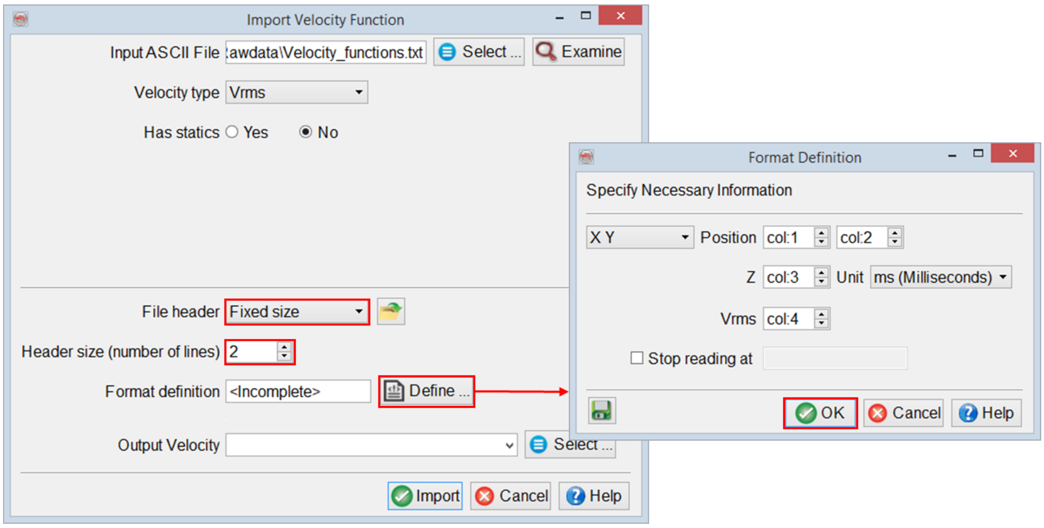
3. **Select** the velocity type: Vrms.



Workflow cont'd:

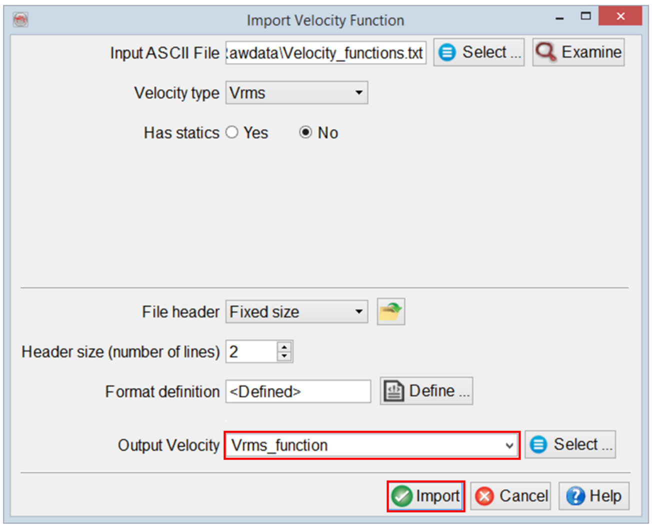
4. **Set** File header to Fixed size consisting of 2 lines.

5. **Define** the format as X-Y-Time-Vrms respectively in column 1, 2, 3, 4.



Workflow cont'd:

6. **Specify** an Output Velocity name as it would appear in OpendTect, e.g. *Vrms_function*, and **click** Import.



1.4.4b Grid Stacking Velocities

Required licenses: OpendTect.

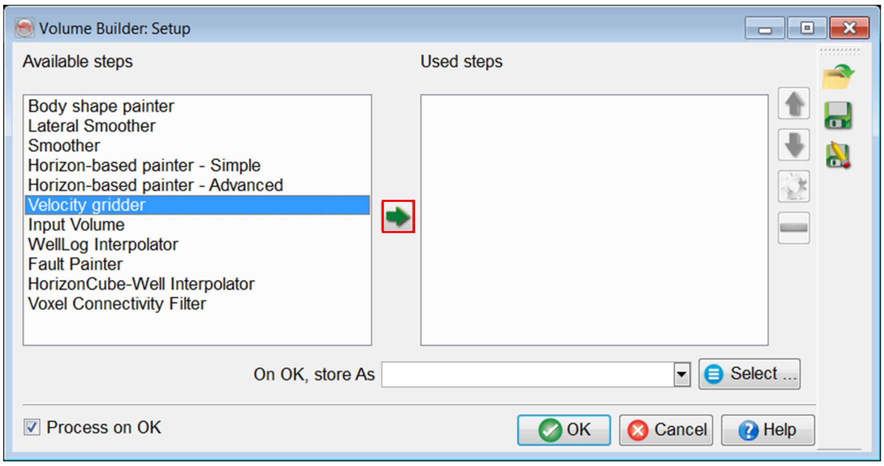
Exercise objective:

Specify the gridding workflow to grid the stacking velocity functions.

Workflow:

1. **Launch** the volume builder module accessible from the icon .

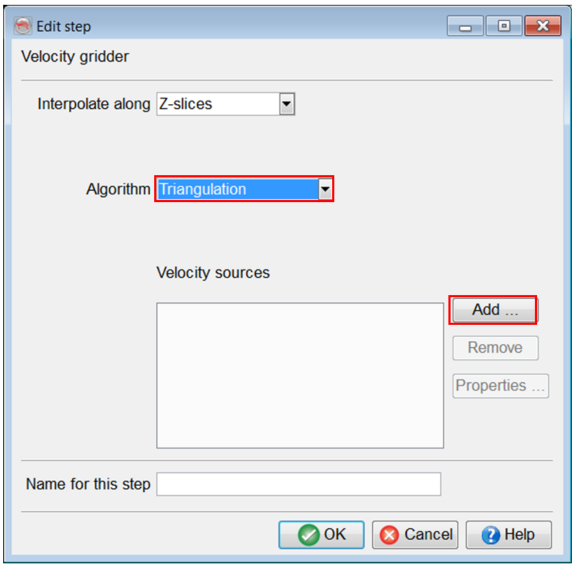
2. **Select** the Velocity gridder step and **add** it to the Used steps list with the middle arrow.



Workflow cont'd:

3. In the following window, **choose** Triangulation as an algorithm type.

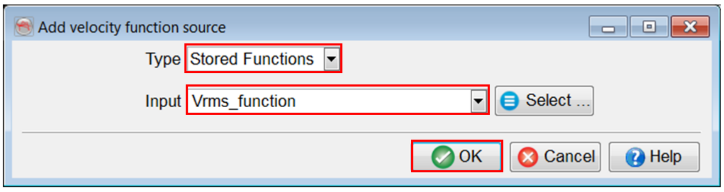
4. **Add** velocity source.



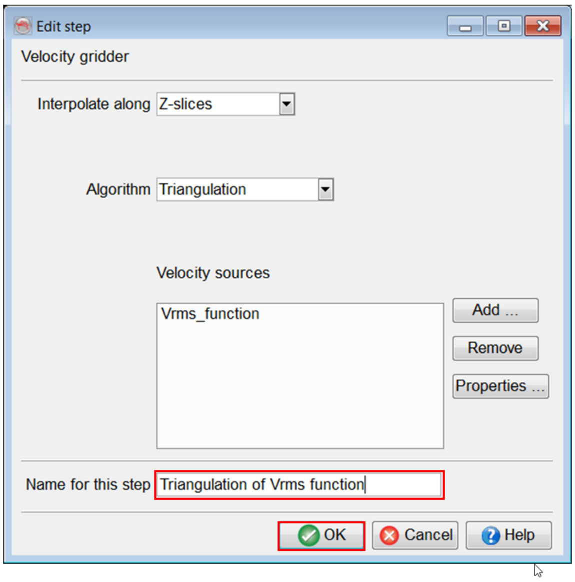
Workflow cont'd:

5. **Choose** Type: Stored Functions and select the input function *Vrms_function* that was imported in the previous exercise.

6. **Click OK** to proceed.



Workflow cont'd:



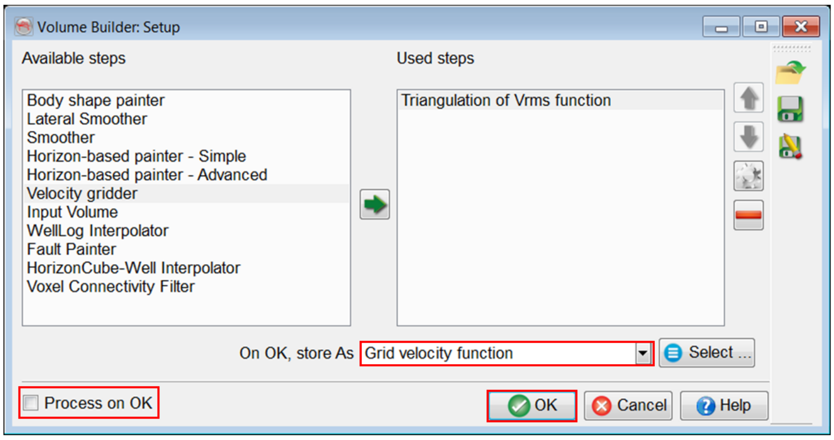
7. **Name** this step (e.g. *Triangulation of Vrms function*).

8. **Click** OK**.**

Workflow cont'd:

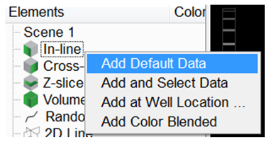
9. **Store** the setup as *Grid velocity function*.

10. **Toggle off** Process on OK and **press** OK.

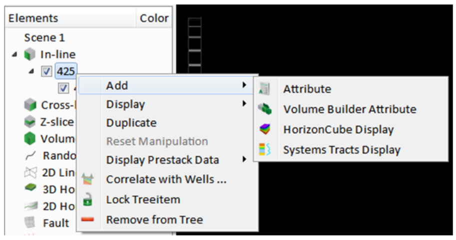


Workflow cont'd:

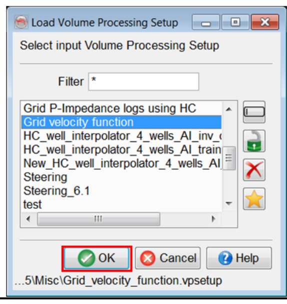
11. **Add** default inline to the scene.



12. **Right-click** on it > Add > Volume Builder Attribute.

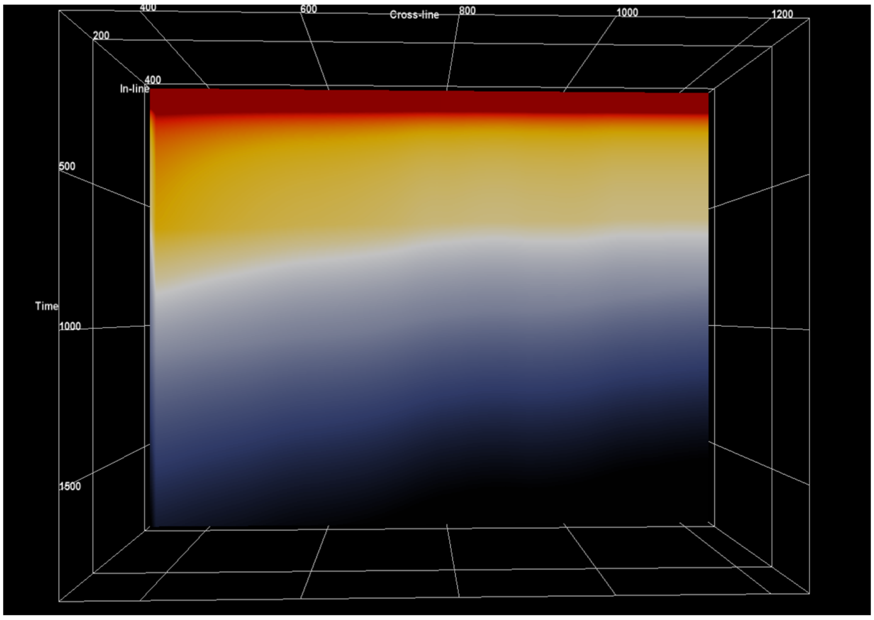


13. **Select** *Grid velocity function* and **press OK** to display the attribute on-the fly.



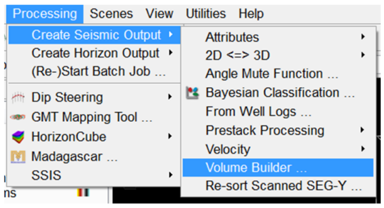
Workflow cont'd:

The result should be similar to the one shown below

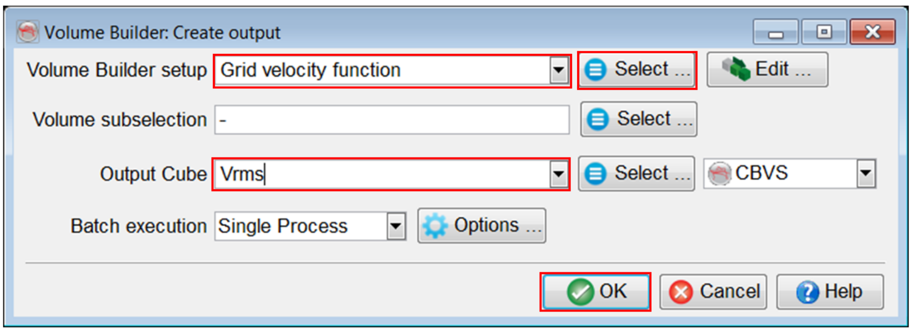


Workflow cont'd:

14. **Go to** Processing > Create Seismic Output > Volume Builder.



15. In the pop up window, **select** *Grid Velocity function* for Volume Builder setup and **specify an output name**, e.g. *Vrms*, and **press** OK to start batch processing.



1.4.4c TD Conversion On-the-fly

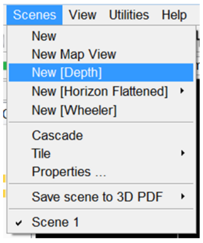
Required licenses: OpendTect.

Exercise objective:

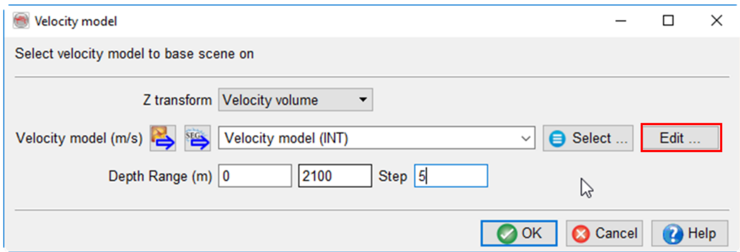
Create a depth scene and perform velocity conversion.

Workflow:

1. **Go to** Scenes > New [Depth].

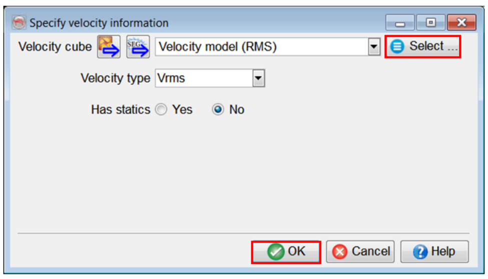


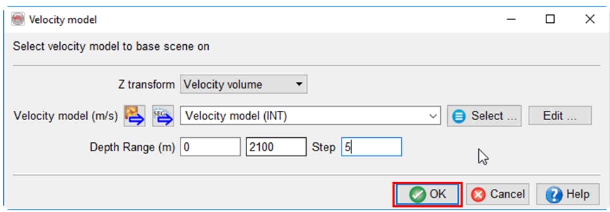
2. A window pops-up asking you to select or create a velocity model. **Click on** Edit…



Workflow cont'd:

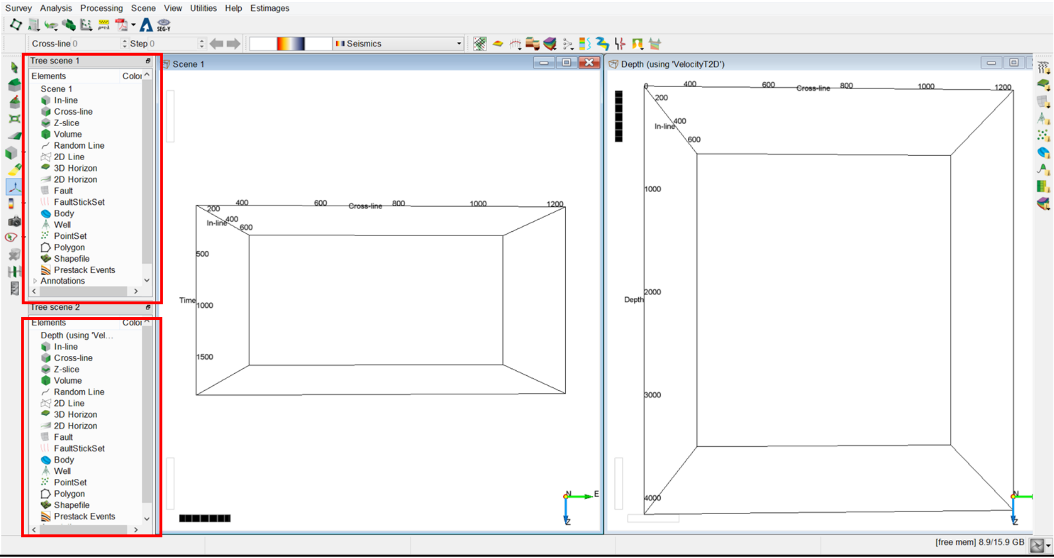
3. **Select** the velocity cube i.e. *Velocity model (RMS)* and **specify** the velocity type (RMS).
4. **Press** OK and OpendTect will scan the file to compute the depth range for the new scene.
5. **Press** OK in the Velocity Model window and a new depth scene will appear.





Workflow cont'd:

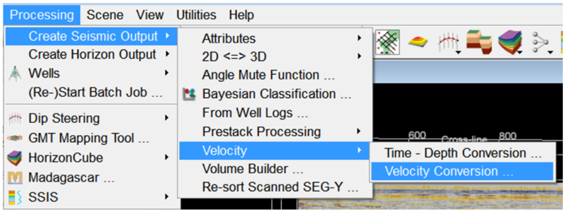
6. In the depth scene, **display** any stored volume on the inline 425. You will notice that the scene now shows data in depth, which has been converted from time data using the interval velocity you, selected. This is done on-the-fly.



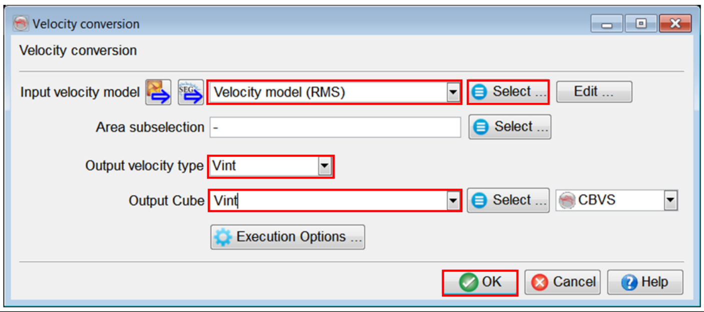
Workflow cont'd:

Conversion of Vrms to Vint

7. **Go to** Processing > Create Seismic output > Velocity > Velocity conversion…

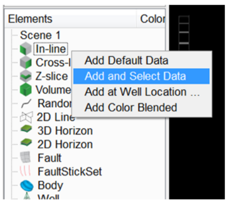


8. **Fill** the fields as shown below and **click** OK.

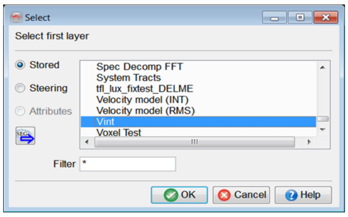


Workflow cont'd:

9. **Right-click** on an inline in the scene > Add and Select Data.

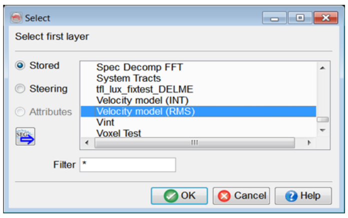


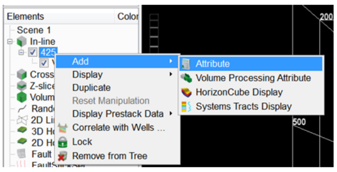
10. **Select** the new converted interval velocity.



11. **Right-click** on an inline 425 in the scene > Add > Attribute.

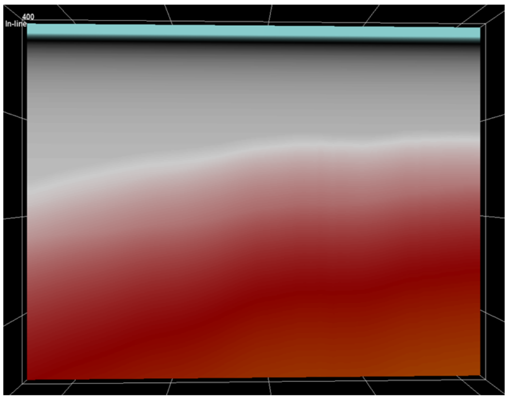
12. **Select** the rms velocity to compare.



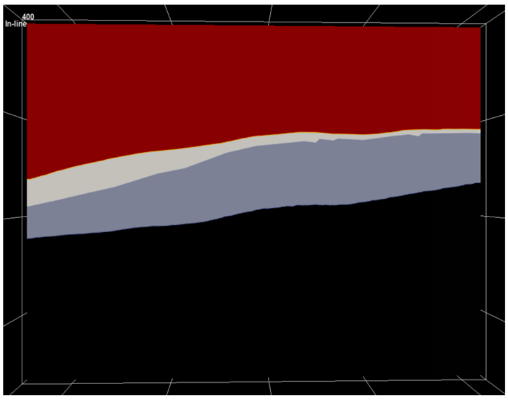


Workflow cont'd:

Velocity model (RMS)



Velocity model (INT)



1.4.4d TD Volume Conversion In Batch

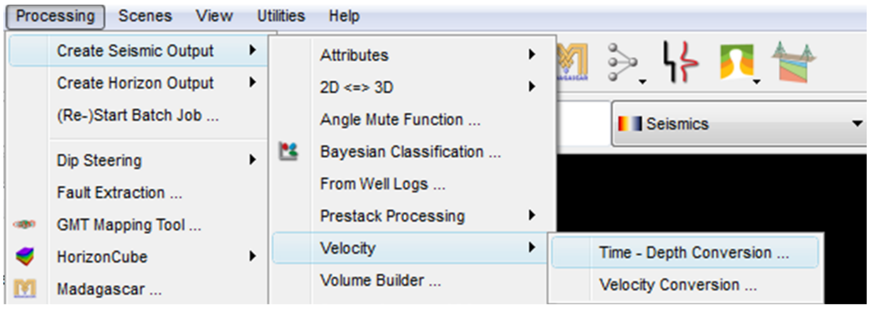
Required licenses: OpendTect.

Exercise objective:

Use the velocity volume to time-depth convert volumes in batch mode.

Workflow:

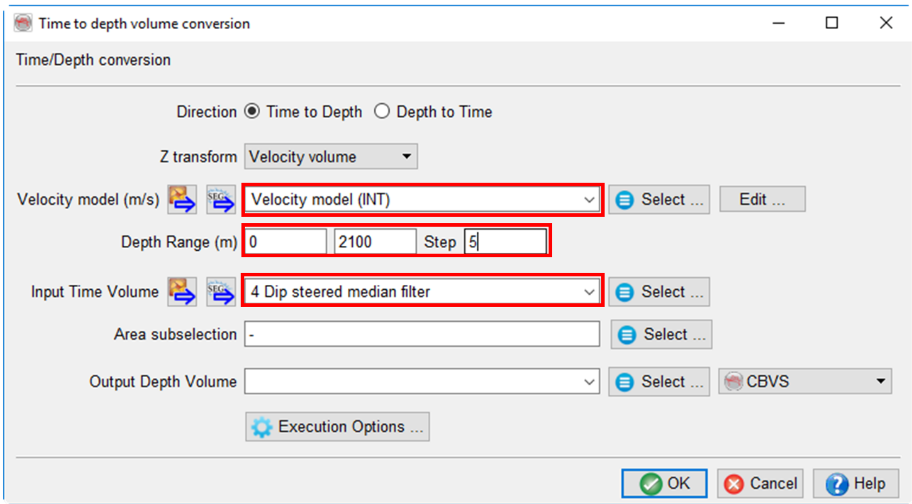
1. **Launch** the time-depth conversion dialog.



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

Workflow cont'd:

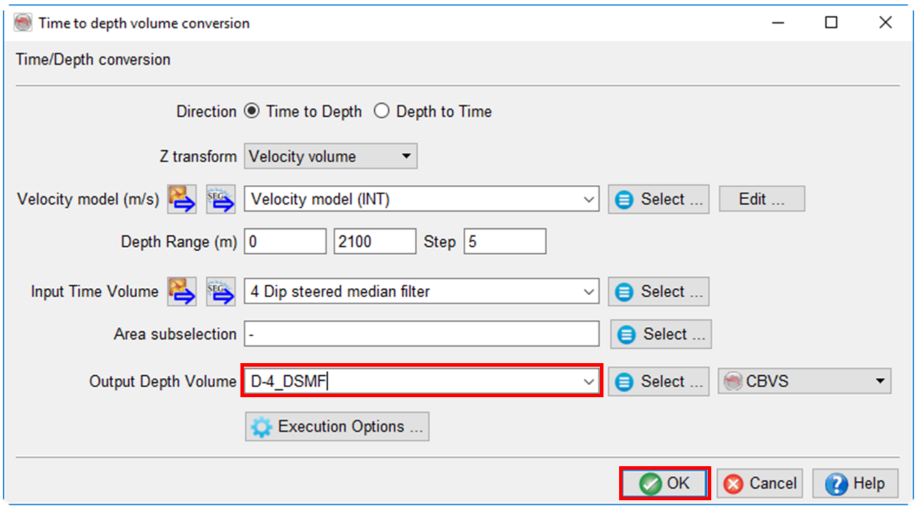
2. **Select** the Velocity Model (in this case, Velocity Model (INT)).
3. **Define** the depth range and the step
4. **Select** the Time volume to be converted



Workflow cont'd:

5. **Specify** the new output depth volume (e.g. D-4_DSMF).

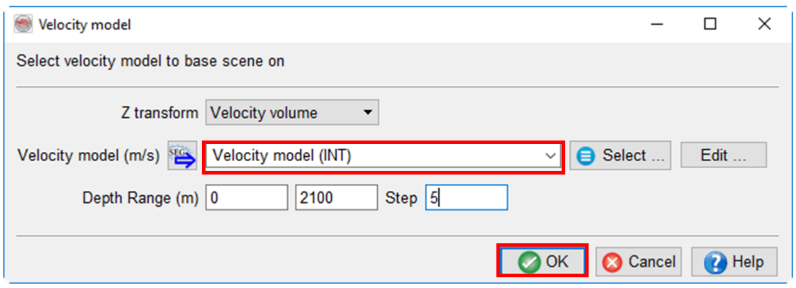
6. **Click** on OK. The volume will be saved in depth and stored in the time survey



Workflow cont'd:

7. To **display** the new depth volume, go to the depth scene. **Click** on the scenes, **Select** New [Depth].

8. A new window will pop up, **Make** sure all inputs are correct, and then **Press** Ok.

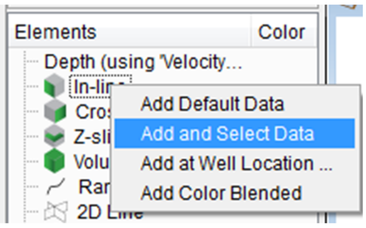


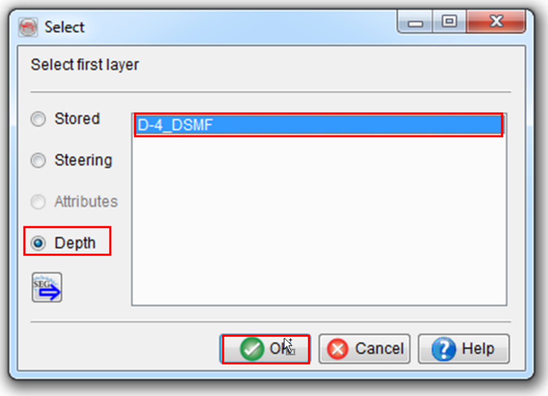
Workflow cont'd:

9. Right click on inline > Add and Select data

10. In the pop-up dialog, **Select** the depth volume.

11. **Hit** Ok, and a new depth volume will be displayed





1.4.4e TD Horizon Conversion In Batch

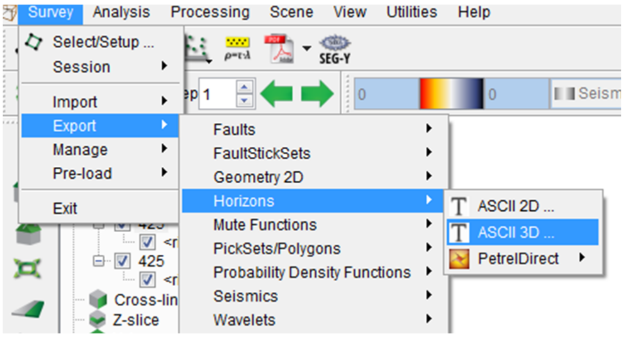
Exercise objective:

Use the velocity volume to time-depth convert horizons in batch mode.

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

Workflow:

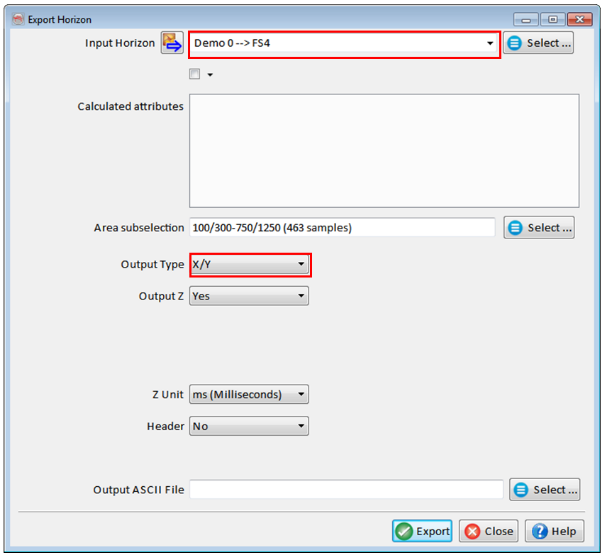
1. **Go to** Survey > Export > Horizons > ASCII 3D.



Workflow cont'd:

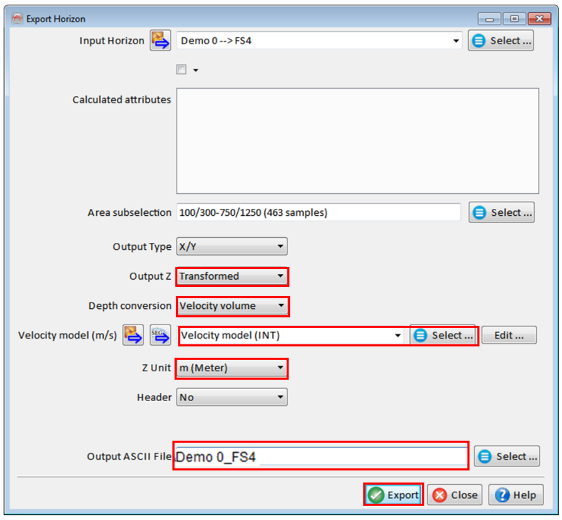
2. **Select an input** *Demo 0 --> FS4.*

3. **Set** the output type to X/Y.



Workflow cont'd:

4. **Specify** output Z: Transformed.
5. Depth conversion**: Velocity volume.**
6. **Select** a velocity model (volume).
7. **Z-units:** set them to meter.
8. **Give it a name** and **Export** (by default it will be store in the survey main directory).



Note that if you have already calculated attributes in time survey, you select some or all to be exported in the white rectangle.

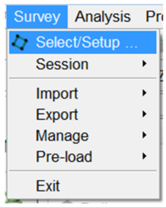
1.4.4f Setup Survey For Depth Converted Data

Exercise objective:

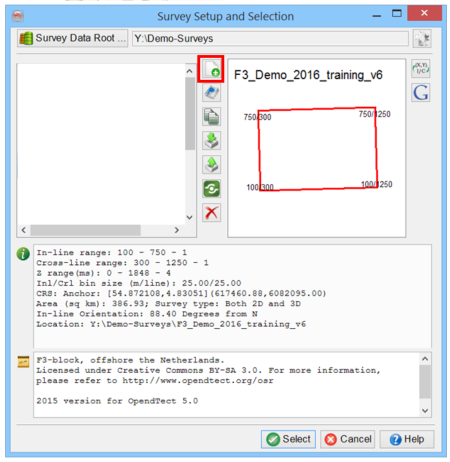
Set up a new depth survey to work with depth converted data (e.g. seismic, horizons etc.).

Workflow:

1. **Go to** Survey > Select/Setup…> or click on this icon.



2. **Click** on icon in the Survey Setup and Selection window.



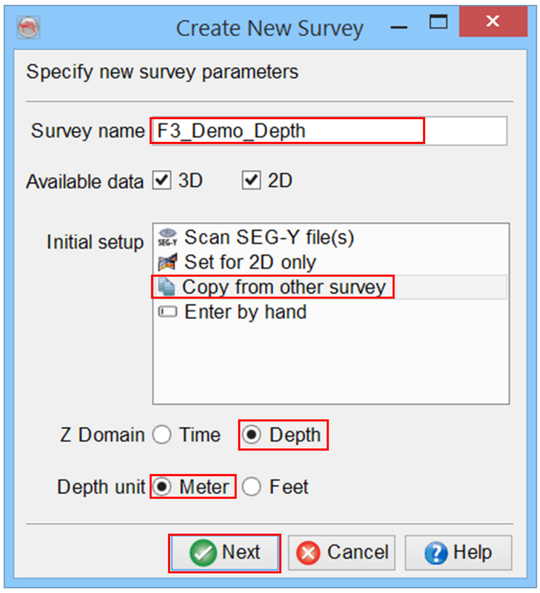
Workflow cont'd:

3. **Give a name** to the new depth survey: *F3_Demo_Depth*.

4. **Choose** Copy from other survey.

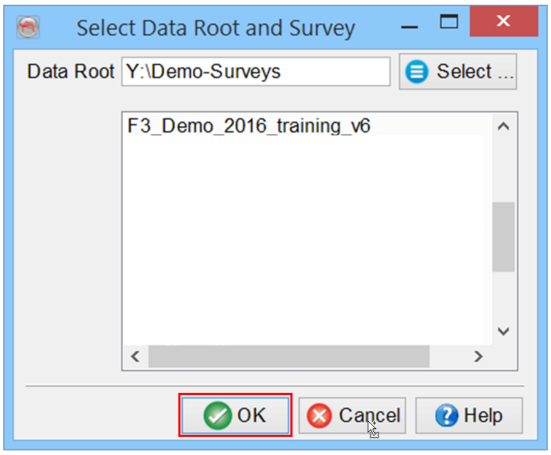
5. **Select** Depth for Z Domain and Meter for units.

6. **Click** Next.



Workflow cont'd:

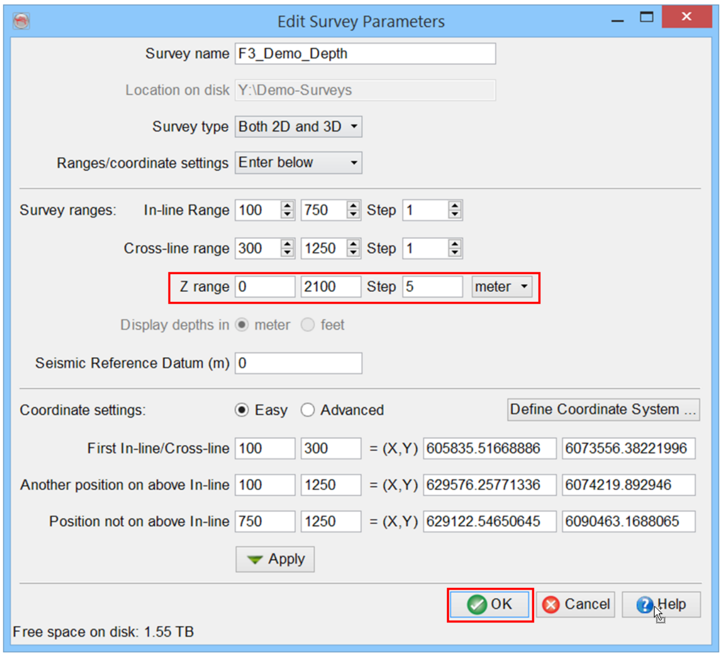
7. **Choose** the time survey and click OK.



Workflow cont'd:

8. **Change** the Z range: 0-2100, step 5 in meters.

9. **Click** OK to create the survey.

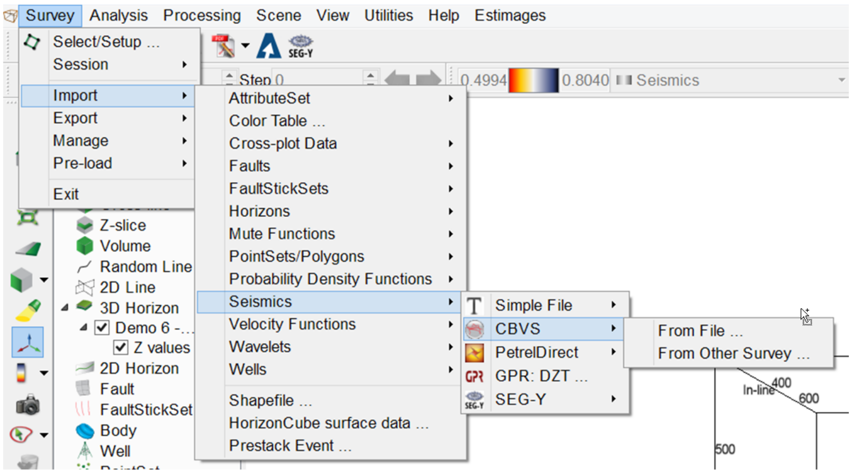


1.4.4g Import TD Converted Volumes And Horizons

Exercise objective:
Import the newly time-depth converted volumes and horizons into the new depth survey.

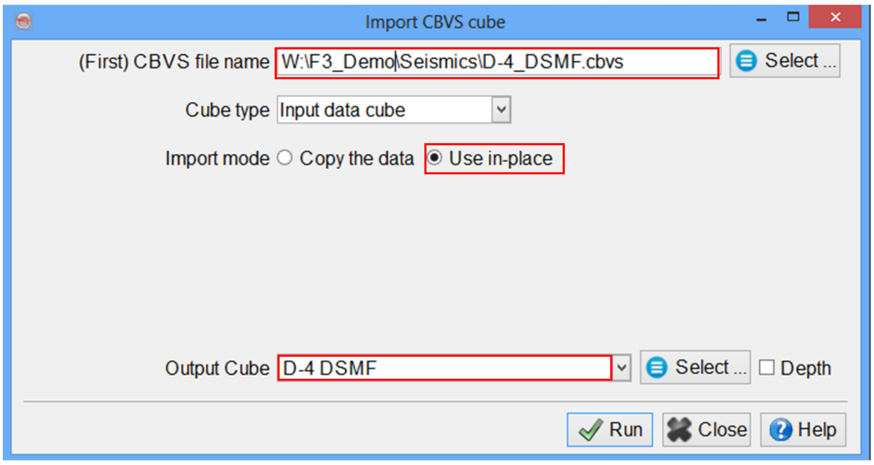
Workflow:
Here we assume that the time-depth converted seismic volume is saved in OpendTect's native CVBS format, in the time survey. We are working now in the depth survey.

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



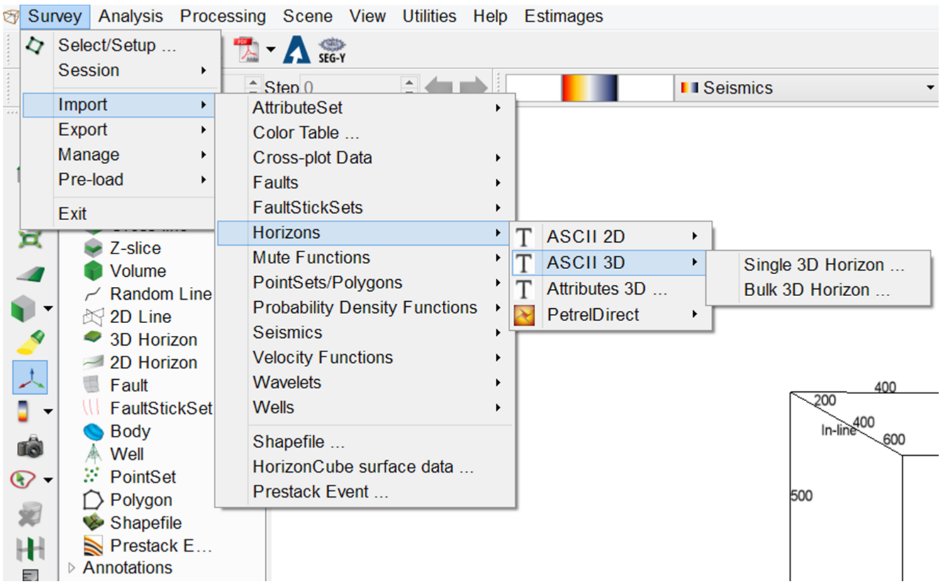
Workflow cont'd:

2. **Click** on Select and browse to the location of F3-Demo (Depth survey).
3. **Select** the depth volume that was created in the exercise *1.4.4.e* (D-4_DSMF.cvbs).
4. **Keep** the default Use in place option (which means the physical location of the stored volume will remain in the time survey).



Workflow cont'd:

Similarly, **import** horizons: Survey > Import > Horizons > ASCII > Geometry 3D…

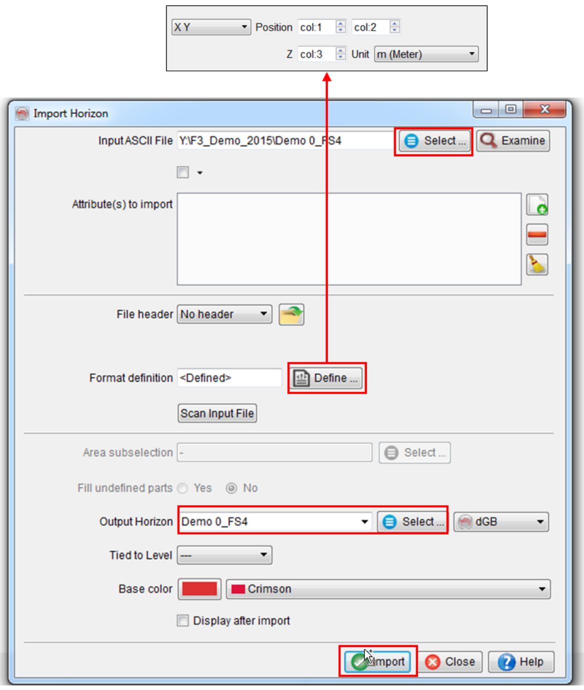


Workflow cont'd:

5. **Click** on Select and browse to the location of FS4 horizon.

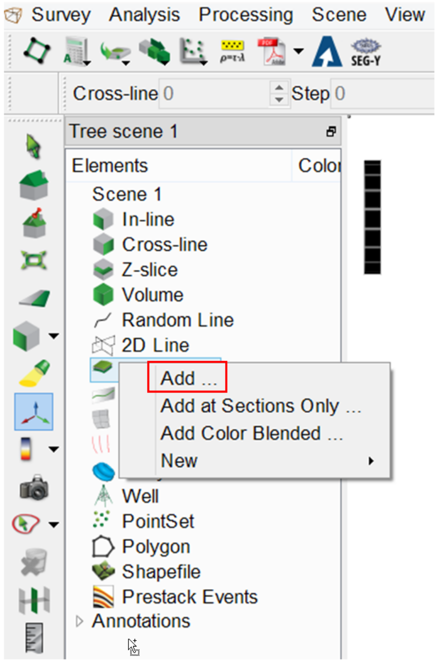
6. **Press** on Define to specify the necessary information for import, relating columns with X,Y and Z.

7. **Give** the output horizon a name and **press** import.



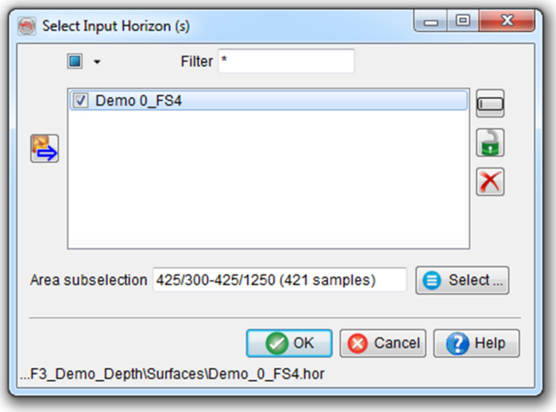
Workflow cont'd:

8. **Right-click** on 3D Horizon > Add.



Workflow cont'd:

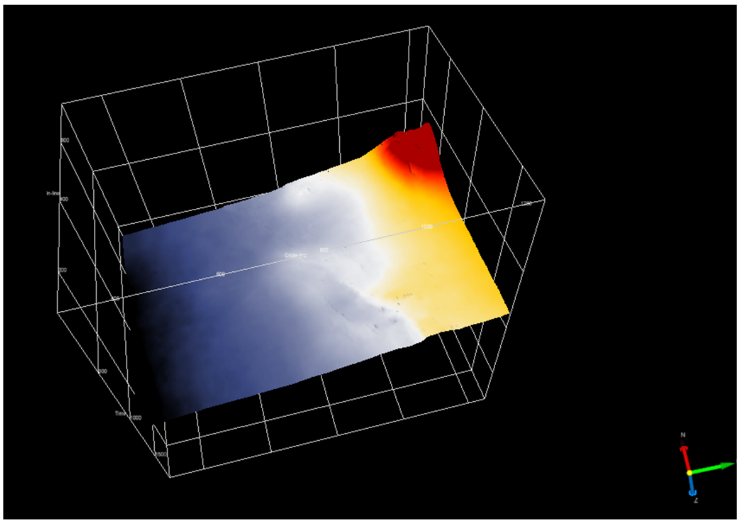
9. **Select** the just imported FS4 Horizon.



10. **Press** OK.

Workflow cont'd:

11. FS4 Horizon is displayed in full in the Depth survey.



1.5 Attribute Analysis & Cross-plots

What are seismic attributes?

Seismic attributes are all the measured, computed or implied quantities obtained from the seismic data. The two main reasons for using seismic attributes:

1. **Visualization (qualitative)**
    - To remove extraneous information in the hope of revealing trends or patterns not visible in the original data.
2. **Data integration (quantitative)**
    - To obtain information carriers from different sources that can be integrated by statistical methods.

What you should know about Attributes in OpendTect

1. Attributes can be computed from post-stack 2D and 3D data and from pre-stack data.
2. Attribute definition and computation are two separate steps:
    - Step 1: Define how to compute the (2D or 3D) attribute in the corresponding “Attribute Set” window (input > algorithm > parameters > output).
    - Step 2: Compute the algorithm either on-the-fly on the display element of choice (inline, crossline, Z-slice, horizon, sub-volume, point-sets, fault plane, 3D geobody), or in batch mode to create an attribute volume (via the Processing menu).
3. Attributes can be chained (output attribute 1 is input to attribute 2).
4. You can create your own attributes using chaining, mathematics and logical manipulations.
5. Attribute parameters can be tested in a movie-style manner.
6. Attribute time gates (vertical window) and step outs (lateral step in multi-trace attributes) are specified relative to any evaluation point (x, y, z) where the attribute is to be computed (Step 2, see above).
7. A time-gate of 30ms that is defined as [-10, 20] means the software will extract data from a time-gate between 10ms above the evaluation point to 20ms below the evaluation point. The extracted data is resampled to sample rate defined in the survey.
8. Filters are a just another group of attributes, hence are treated as attributes.

What attributes are supported?

Since it is possible to create one's own attributes using chaining, math & logic the number of attributes supported in OpendTect is without limit. To put order in the attribute maze, dGB supports an Attribute Table on their website. The table maps attributes versus application domains and is ordered in attribute classes.

Please note that will find both free and commercial attributes described in the table. OS (Open Source) labels attributes offered in the free functionality.

Amplitude-based	
Attributes	**Information**
Energy	• **Description:** sum of Amplitudes Squared in a time-gate • **Plugin:** OS, OD • **Stratigraphic:** highlights packages with different reflection strengths • **Siliciclastics:** energy may correlate with lithology & porosity • **Fluids:** enhances Bright Spots • **Other:** use Sqrt output option to control output dynamic range • References
Scaling	• **Description:** various functions to correct amplitudes vs. time • **Plugin:** OS, OD • **Structural:** scaling can be tuned to facilitate structural interpretation • **Fluids:** AGC time-gates smaller than 500ms should be avoided in quantitative interpretation • **Other:** do not apply in workflows that require preservation of original amplitudes • References
Event	• **Description:** quantifies the shape of an event or relative distance between events • **Plugin:** OS, OD • **Structural:** useful to determine horizon quality • **Stratigraphic:** useful inputs for 3D NN facies classifications • References
Stratal Amplitude	• **Description:** returns statistical property (min, max, sum etc.) of an attribute in an interval defined along one horizon or between two horizons • **Plugin:** OS, OD • **Stratigraphic:** useful to characterize intervals • References
Frequency-based	

The application domains (organized in columns) are:

- Structural
- Stratigraphic
- Siliciclastic
- Carbonates
- Fluids
- Noise
- Others

The attribute classes (rows) are:

- Amplitude based
- Frequency based
- Multi-trace based
- Impedance based
- Dip & azimuth based
- Processing & Filters
- Meta-attributes
- HorizonCube & SSIS
- Pre-stack attributes

The following list shows which attributes are useful for a specific task.

- **Noise reduction:**Dip Steered Median Filter, Frequency Filter, Gap Deconvolution
- **Frequency enhancement (spectral balancing):**Seismic Spectral Blueing
- **Fault detection:**Similarity, Fault Enhancement Filter, Ridge Enhancement Filter, Curvature, Dip, Variance, Fault Extraction
- **Fracture prediction:**Curvature, Azimuthal AVO, Fracture, Inversion to Anisotropic Parameters
- **Layer thickness estimation:**Spectral Decomposition, Instantaneous Attributes
- **Porosity estimation:**Deterministic Inversion, NN Rock Properties Prediction
- **Net-pay:**Seismic Coloured Inversion, Stratal Amplitude, Net-pay
- **HC presence detection:**AVO Attributes, Frequency Attenuation, Energy ((far-near) x far), Sweetness, Fluid Contact Finder, Seismic Feature Enhancement
- **HC saturation estimation:**Gas Chimneys, Three Term Inversion?
- **Oil vs. Gas prediction:**Gas Chimneys, Three Term Inversion, NN Classification, Spectral Decomposition
- **Predicting Clastic Lithofacies (sand-silt-shale):**
    - **Simple:**Energy ((far-near) x far), Frequency, Phase
    - **Advanced:**Waveform Segmentation, Volumetric Segmentation, Fingerprint, Deterministic Inversion, NN Rock Properties Prediction
- **Predicting Carbonate Lithofacies:**Waveform Segmentation, Volumetric Segmentation, Fingerprint, Deterministic Inversion, NN Classification
- **Mapping seismic geomorphology:** Lithology (see above): Similarity (indicates erosional incision), Dip Attributes, Spectral Decomposition

1.5.1 Bright Spot Detection and Visualization

What you should know about bright spot detection OpendTect

Bright spots are seismic anomalies that are often related to hydrocarbons. How the seismic response varies as a result of a change in fluid-content depends on the geologic setting and rock-physics / fluid properties. Forward modeling helps to increase the understanding of the seismic behavior as a function of changes in rock and fluid properties. such understanding is important for selecting the optimal attributes and tools for qualitative and quantitative analysis of bright spots.

OpendTect offers a range of pre- and post-stack analysis tools to investigate bright spots, especially in the domain of commercial plugins. Examples are seismic inversion plugins and hydrocarbon anomaly enhancement techniques such as Fluid Contact Finder and Seismic Feature Enhancement.

Seismic attribute analysis is a simple and effective tool to enhance bright spots and to study their areal extent in 3 dimensions. In the exercise a gas-related bright spot is visualized in 3D using volume rendering of the energy attribute. The volume rendered object can be saved as a 3D object for further study, e.g. to compute the body's volume.

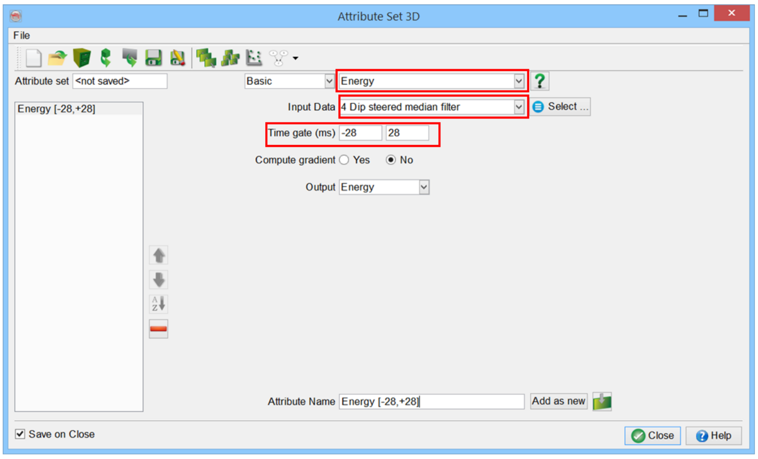
1.5.1a Bright Spot

Required licenses: OpendTect.

Exercise objective:
Isolate an amplitude anomaly (bright-spot) using attribute analysis and visualize the anomaly in 3D using volume rendering

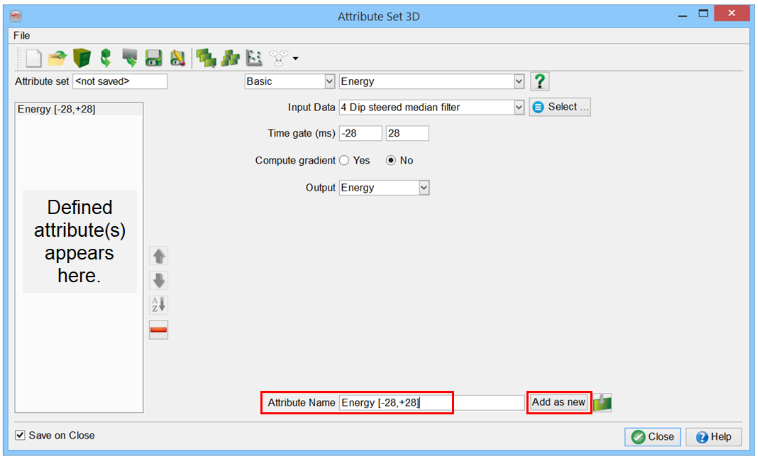
Workflow:

1. **Launch** the attribute set window: **click** on the Attribute 3D icon and **select** 3D.
2. **Define** the Energy attribute with default parameters.



Workflow cont'd:

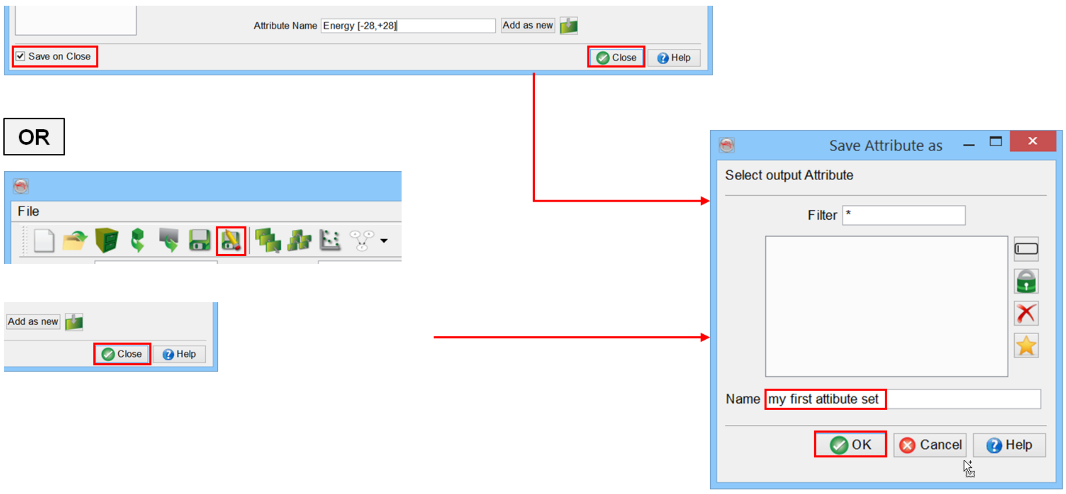
3. **Provide** an attribute name as Energy [-28,+28] and **press** Add as new.



There are no restrictions 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.

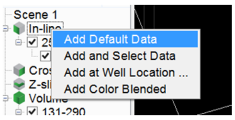
Workflow cont'd:

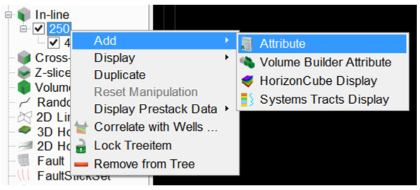
4. **Tick** the Save on Close box and **press** Close.
   Alternatively, **press** the Save as icon and **press** Close.
5. **Provide** a (new) name for the attribute set like *my first attribute set* and **press** OK.

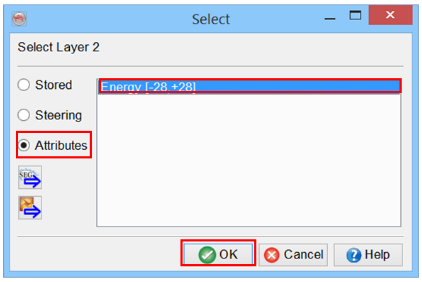


Workflow cont'd:

6. In the tree, **right-click** on In-line and **select** Add Default Data.
7. **Change** the inline position to 250: **select** the inline in the tree and **type** the position using the position toolbar.
8. **Add** an extra attribute layer to inline 250: **right-click** on the inline number in the tree and **go** Add > Attribute.
9. The attributes available are organized in three categories: Stored, Steering and Attributes (from the active attribute set and calculated on-the-fly).
   Go to the Attributes section, **select** your attribute *Energy [-28,+28]* and **click** Ok.

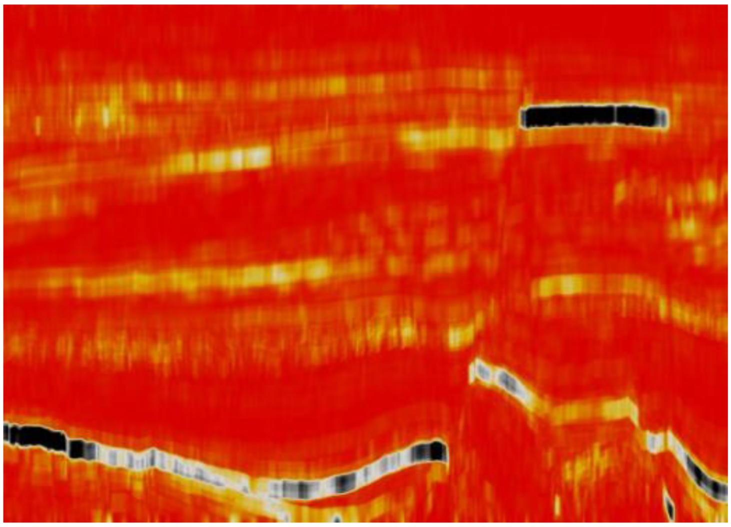






Workflow cont'd:

Results should look like this.

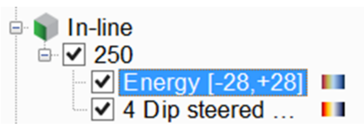


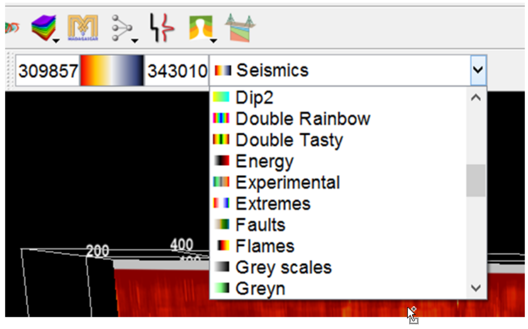
Workflow cont'd:

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.
The color-bar is displayed by default above the 3D scene and can be edited by selecting a new color-scheme.

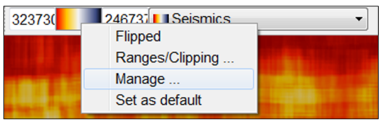
1. **Click** on the attribute from the tree and **change** the color-bar.
   Try: Chimney, Faults and Grey scales.





Workflow cont'd:

2. **Right-click** on the color bar: **select** Manage…



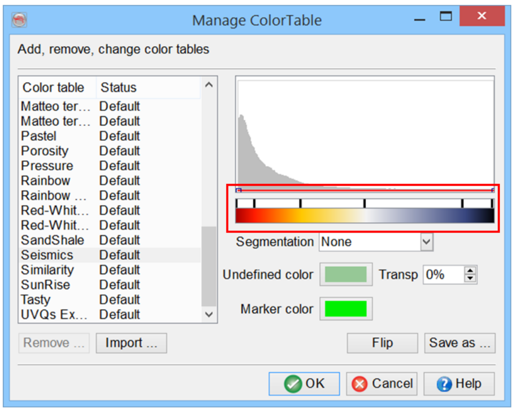
Edit color markers

from the main window

The color can be edited by double clicking on one black marker below the histogram. To add a new marker, double click at the position you want, select the appropriate color and click Ok. Drag the marker to change its position. Right-click on a marker and chose Remove color to delete it.

From the table

Right-click in the white section of the color-bar displayed under the histogram and chose Edit markers… In the table that pops up, the colors and position of every marker can be edited: for a specific marker, you can type in a new position and change the color by double-clicking on the used color. When right-clicking on a marker, you can either delete the selected marker or add a new one above or below.



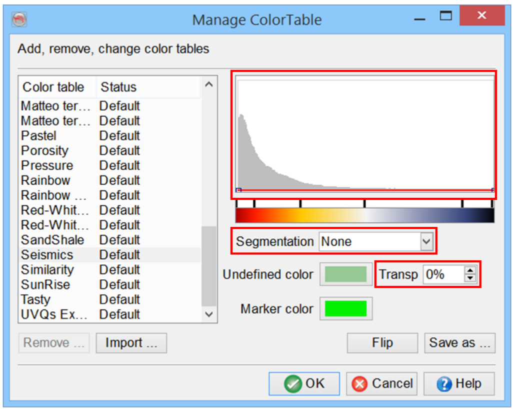
Workflow cont'd:

Segmented vs Continuous

The color-bar can be continuous or segmented. When changing the Segmentation from None to fixed, you define the number of the segment. Segmented color-bars are in particular used when displaying a discrete attribute, for example a Neural Network result: one color corresponding to one class.

Transparency

The red line in the histogram represents the transparency: changing the transparency line alters the parts of the spectrum that are displayed. Drag the seeds up to modify the transparency. You need to have a seed at each extremity of the histogram: add new seeds by double-clicking on the red line and drag the seed laterally and vertically. To remove a seed, do ctrl+click on the seed.



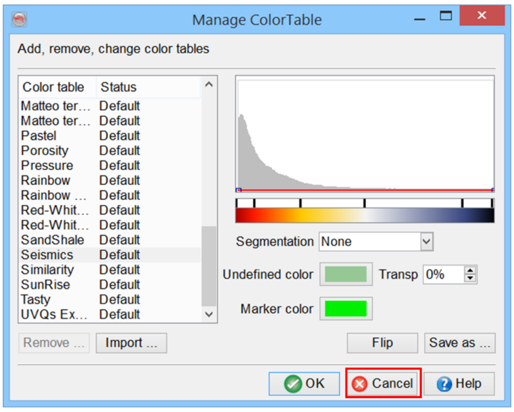
Workflow cont'd:

3. **Press** Cancel to close the color-bar manager.

The undefined color is the color that will be used for undefined values. You can adjust its transparency.

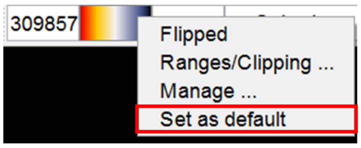
The changes you are making are applied in the same time in your scene: you can actually QC the color-bar edition.

Once you are done with the color-bar editing, you can save it with another name or overwrite the color-bar you were using (not recommended) by just clicking OK and Continue. If you do not wish to save the modifications, click on Cancel.

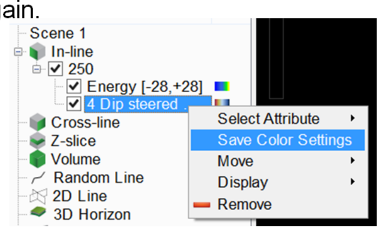


Workflow cont'd:

4. **Right-click** on the color-bar and **select** Set as default: it will set the specific color bar by default for all the attributes to be displayed that do not have a specific color bar attached to them.



5. Optionally, **right-click** on a stored attribute (volume) in the tree and **select** Save Color Settings to save the color-bar and the color range: it will be used when loading this specific attribute again.

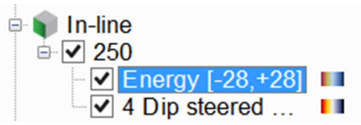


The color-bar right-click menu allows you to flip the color bar, change the Ranges/Clipping (to set the scaling values symmetrical around zero), Manage the color bar, Set as default.

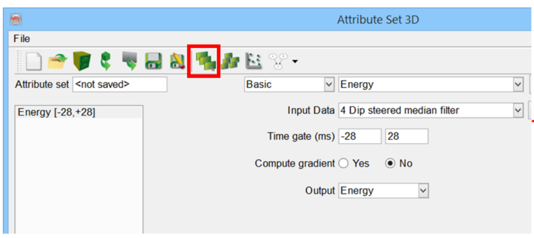
Workflow cont'd:

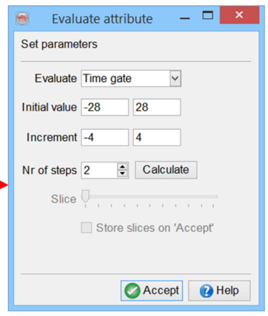
Evaluate attribute parameters

Now we are going to evaluate the Time gate parameter of the energy attribute by interactively (movie-style) evaluating its parameter settings:



1. **Open** the Attribute Set window: **click** on the Attribute set icon  and **select** 3D.
2. **Activate** the *Energy [-28,+28]* attribute displayed on inline 250 in the tree.
3. In the Attribute Set window, **select** the *Energy* attribute again and **press** the Evaluate attribute icon .





Workflow cont'd:

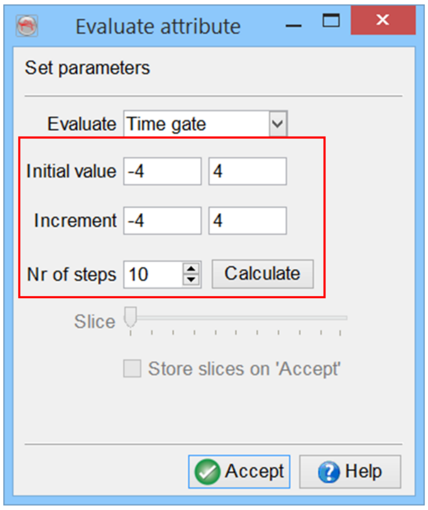
4. **Select** the parameter to evaluate: Time gate (in this case, there is only one type of parameter to evaluate so it is selected by default).

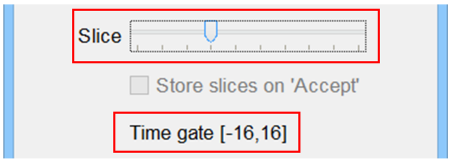
5. **Provide** the parameters for the time gate as shown in the image on the right.

6. **Press** the Calculate button.

7. The slider becomes active once the on-the-fly processing is finished. **Move** the slider to see the results for a certain slider position, corresponding to a time gate in this case: **observe** the changes in the 3D scene (see the following slides, for instance).

If an attribute is defined using a time gate and/or a step out, these parameters can be evaluated the same way.

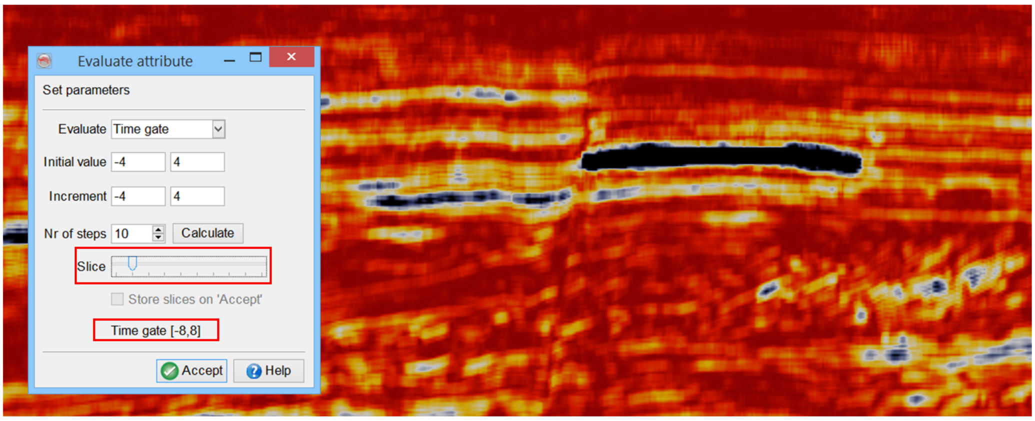




Workflow cont'd:

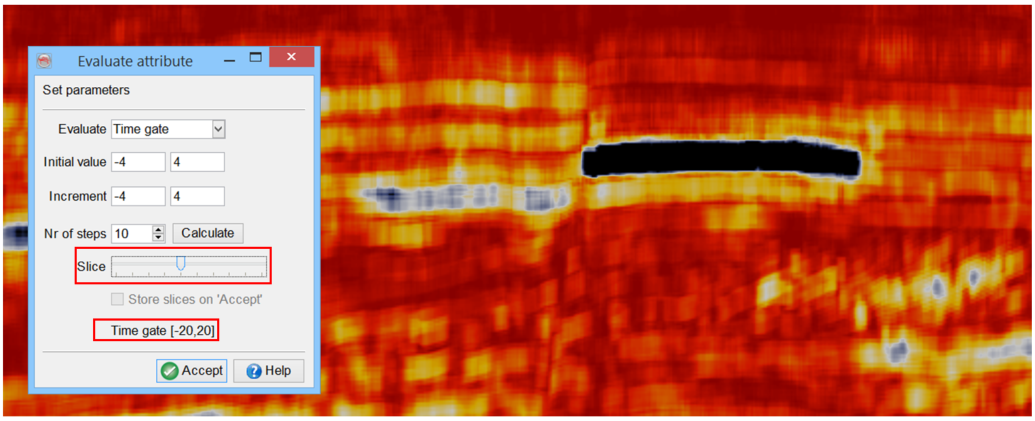
8. **Evaluate** the attribute by moving the slider position.

Time gate [-8,+8]ms



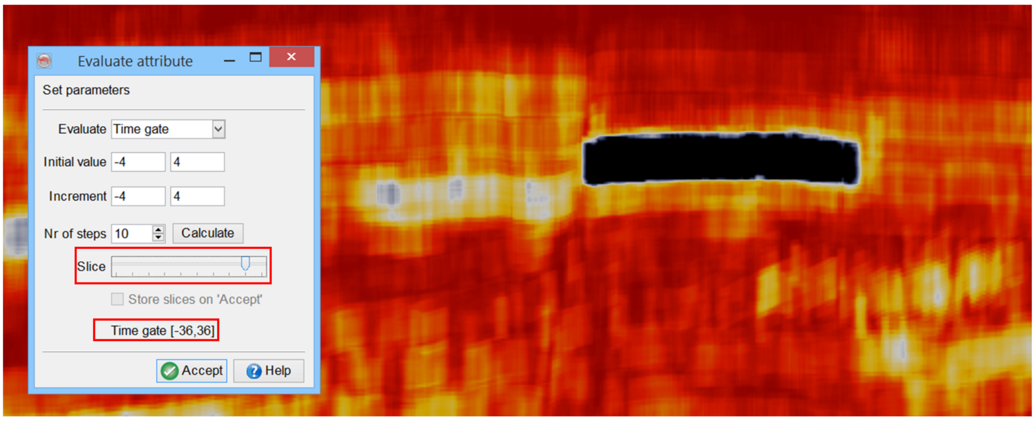
Workflow cont'd:

Time gate [-20,+20]ms



Workflow cont'd:

Time gate [-36,+36]ms



If you Accept at this point, [-36,36]ms will become the time gate of the attribute that you were evaluating. In this manner, you decide the optimum time gate.

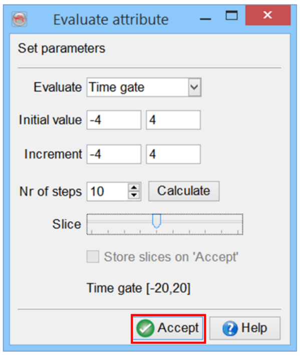
You may also say that this might be a too large time gate for this feature when compared with a narrow time gate e.g. [-16,16]ms.

Workflow cont'd:

9. Once the best time gate has been decided, **press** Accept to update the attribute with the selected time gate.

10. **Update** the attribute name according to the selected time gate

11. Optionally, **click** on the icon to save the attribute set window or **tick** the Save on close box, and **close** the window.

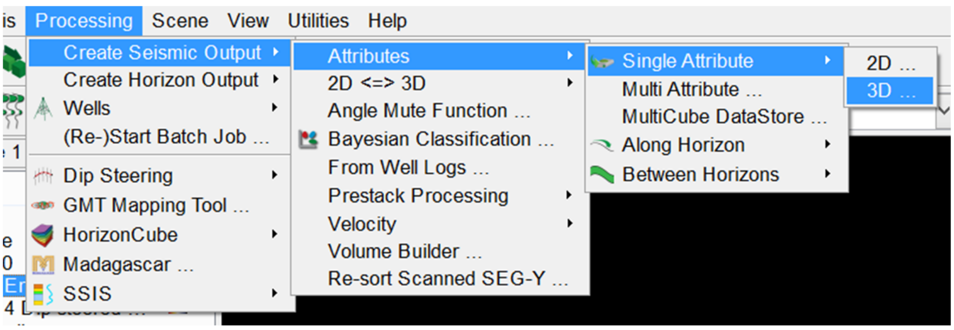


Workflow cont'd:

Create a seismic output

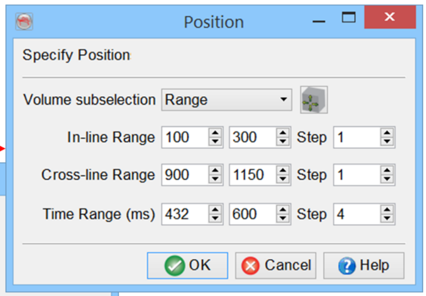
So far, everything was done in memory. We are now going to calculate and store the Energy attribute on disk as an OpendTect volume.

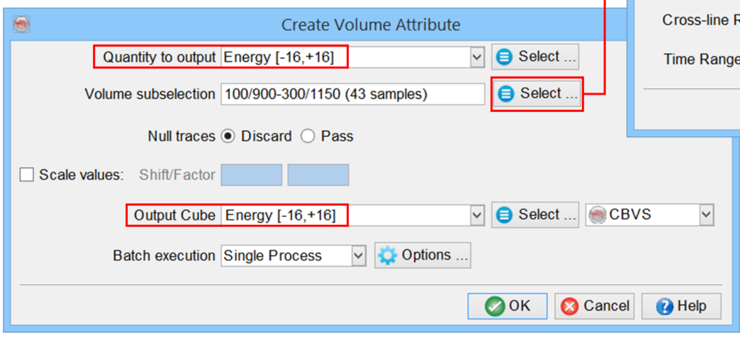
1. **Click** on the Create Seismic Output icon and **select** 3D or **go to** Processing > Create > Seismic Output > Attribute > Single Attribute > 3D



Workflow cont'd:

2. **Select** *Energy* as the Quantity to output.
3. **Select** a volume sub-selection:
   Inline range: 100 – 300, Crossline range: 900 – 1150, Time range: 432 - 600 ms
   Press OK.
4. **Press** OK to start the processing.





By default the processing is single-machine, To speed up, you can use the multi-machine processing (requires plugin).

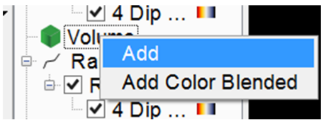
Workflow cont'd:

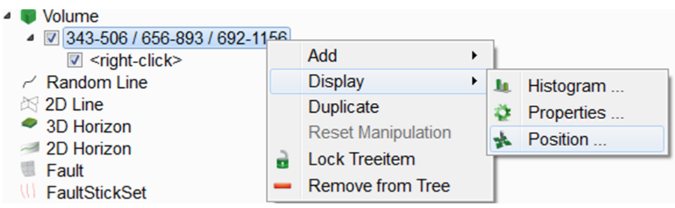
Volume Rendering

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

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

2. **Position** the volume: **Right-click** on <343-506 / 656-893 / 692-1156> and **go to** Display > Position.

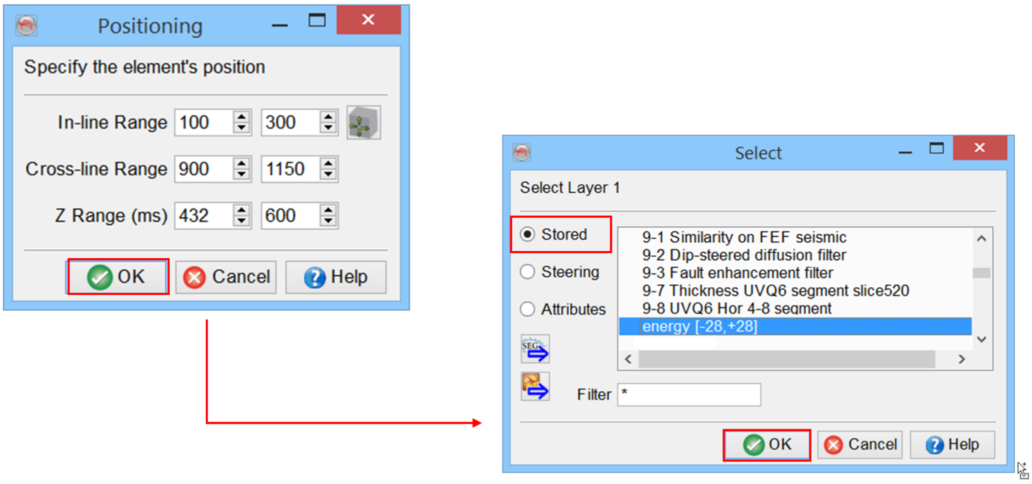




Workflow cont'd:

3. It will launch a position dialog: **fill in** the ranges:
   Inline range: 100 – 300, Crossline range 900 – 1150, Time range: 432 – 600ms.
   Press OK.

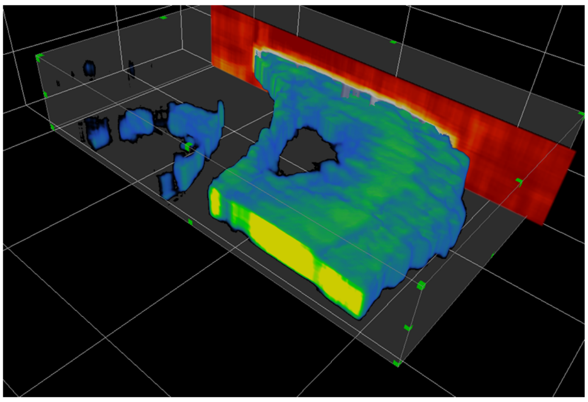
4. **Select** *Energy* from the window in the Stored category and **Press** OK again.



Workflow cont'd:

5. **Change** the color-bar to Chimney and optionally **adjust** the color range.

6. In Position mode  , **left-click** (keep pressed) and **drag** to re-position the surfaces of the volume or just **scroll** through in this manner to view the contents.



Attributes calculated on the fly can be displayed using the volume rendering. For large volumes, it is recommended to store them prior displaying to save time.

1.5.2 Spectral Decomposition

What you should know about 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 spectrum of a seismic trace. It can be done either by using Fast Fourier Transformation (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 a mother wavelet which is extended and compressed for computing the time-frequency spectra. It is equivalent to a 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.

1.5.2a Spectral Decomposition

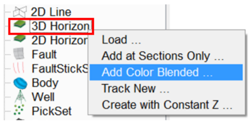
Required licenses: OpendTect.

Exercise objective:

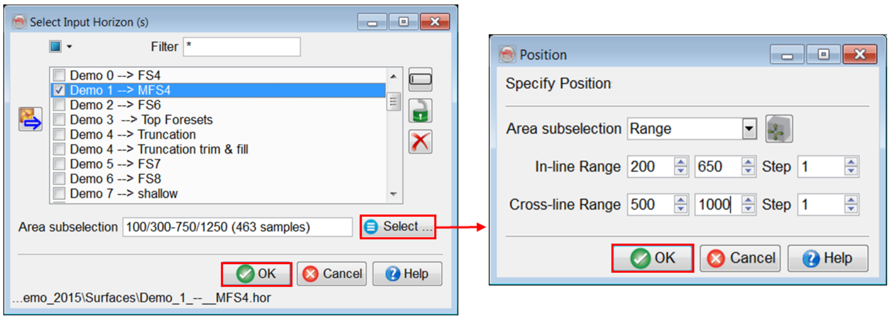
Study paleo-geomorphological features by displaying 3 iso-frequencies simultaneously with color stacking.

Workflow:

1. **Right-click** on 3D Horizon in the tree and **click on** Add color blended…
   Choose horizon *Demo 1->MFS4* from the list of horizons.

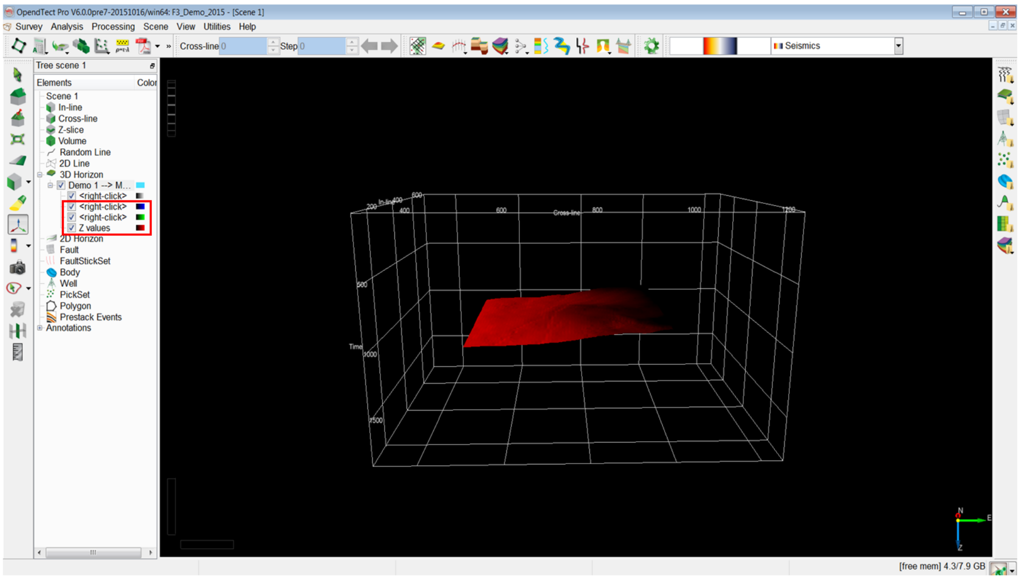


2. Optionally, to speed up the exercise, **click** Select for area sub-selection and **set** inline range to 200-650; crossline range to 500-1000.
   Press OK to apply the changes and then **click** OK to display the horizon.



Workflow cont'd:

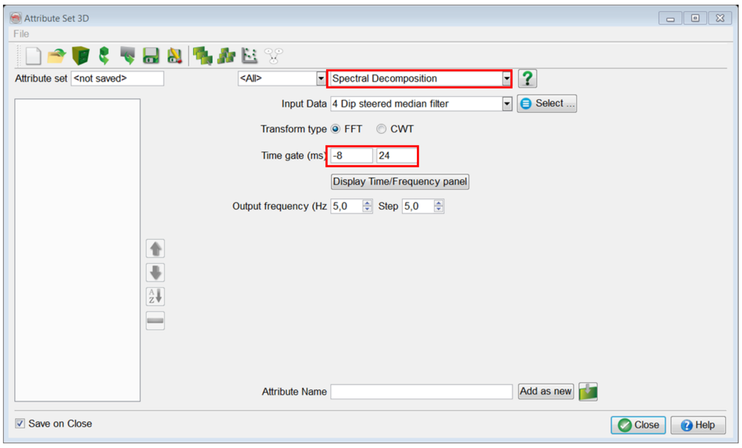
In the tree, the horizon appears with 4 separate attribute layers. The three lowest attribute layers represent the RGB channels (see color flags next to each layer). Three attributes can thus be blended into a single display.



Workflow cont'd:

3. To define 3 different attributes that will be loaded to the RGB channels of the horizon, **open** an attribute set 3D: **click** on the icon.

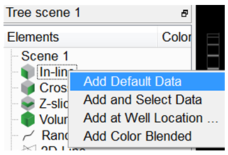
4. **Select** Spectral Decomposition as attribute and **set** the time gate to [-8,24]ms.



When the extraction of an attribute 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 geological features above and 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.

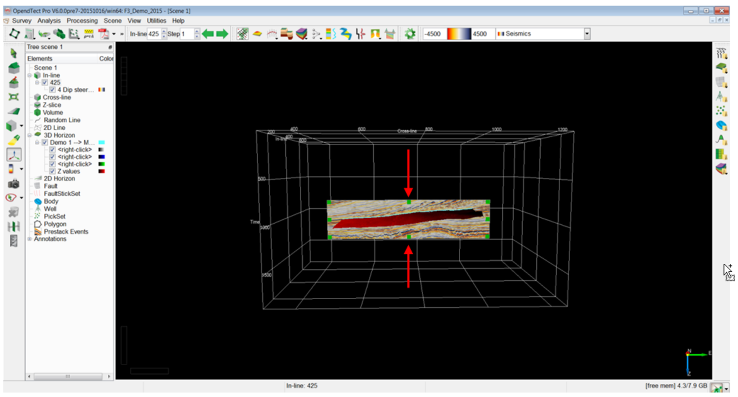
Workflow cont'd:

5. **Right-click** on Inline in the tree > Add Default Data
   Inline 425 will be added to the scene.



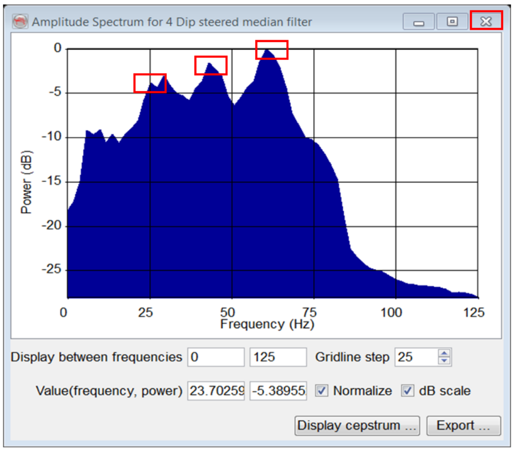
6. **Reduce** Z ranges of the section, so that it just covers the horizon interval: **select** the inline and **drag** the green anchor vertically.

7. **Right-click** on the *4 Dip Steered Median Filter* attribute and **select** Display > Amplitude Spectrum...



Workflow cont'd:

8. Within the amplitude spectrum, **identify** the frequencies to be used as the low, middle and high frequencies: the low frequency can be selected as being the first peak (e.g. 24Hz), while the high frequency as the last peak (e.g. 64 Hz).
   After choosing the frequencies, **close** Amplitude spectrum window.

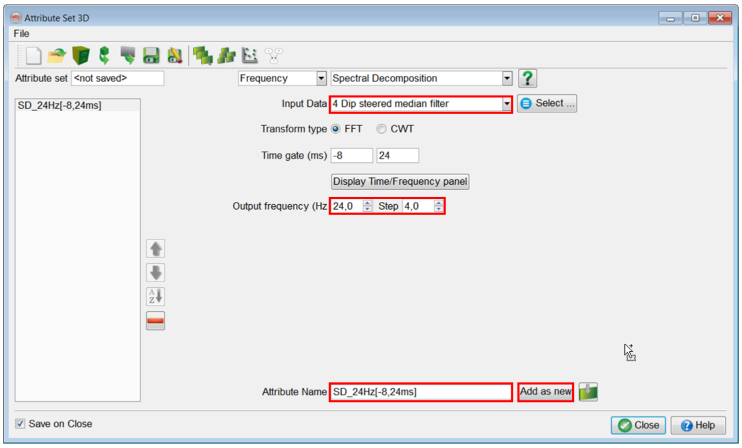


Workflow cont'd:

9. Back to the attribute set window: **create** the first Spectral Decomposition attribute and **set** the input data to *4 Dip Steered Median Filter*.

10. **Set** output frequency to 24Hz with a step of 4Hz.

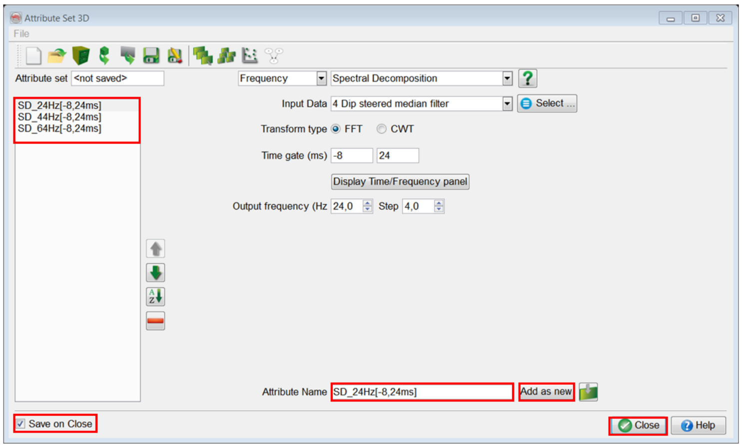
11. **Give** a name to a new attribute, e.g. *SD_24Hz[-8,24ms]*, and **press** Add as new.



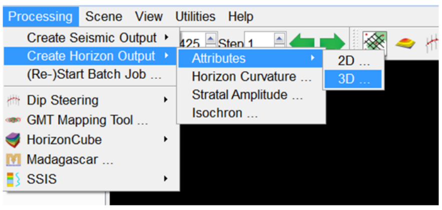
Workflow cont'd:

12. In the same manner, **create** the other two attributes for middle (44Hz) and high (64Hz) frequencies: **change** the output frequency value and the attribute name respectively. **Click** Add as new every time when a new attribute was defined.

13. **Click** on Close.
Optionally, **give** a name to the new attribute set, e.g.: *Spectral Decomposition* (if Save on Close is toggled on).



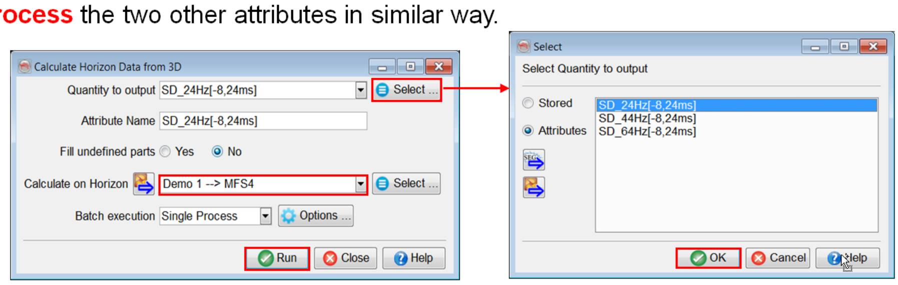
Workflow cont'd:



14. To convert your attributes into Horizon Data. **go** to Processing > Create Horizon Output > Attributes > 3D.

15. **Select** the *SD_24Hz_[-8,24]ms* attribute to output and the *Demo1->MSF4* horizon on which it will be output and **press** Run**.**

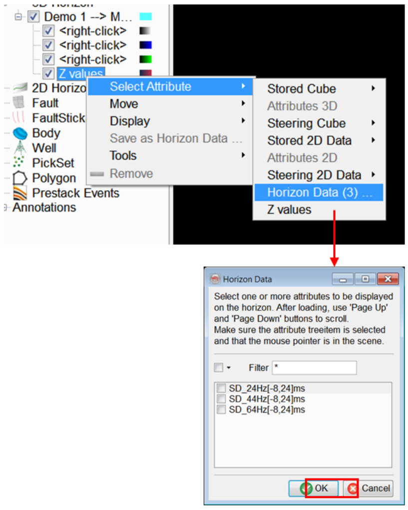
16. **Process** the two other attributes in similar way.



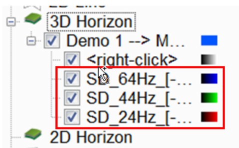
Saving as Horizon Data is faster than calculating on the fly along a horizon. Moreover, the process is done in batch, so can be preferred simultaneously for other Horizon Data.

Workflow cont'd:

17. **Display** the three new Horizon Data on *Demo1-> MFS4*: **right-click** the text adjacent to the red channel > Select attribute > Horizon Data and **select** *SD_24Hz_[-8,24]ms.*

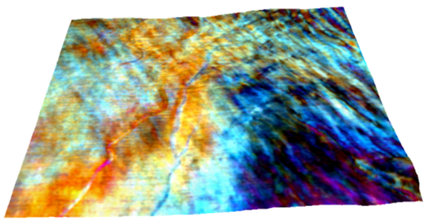


18. In the same manner, **select** *SD_44Hz_[-,24]ms* data for the green channel and **select** *SD_64Hz_[-8,24]ms* for the blue channel.



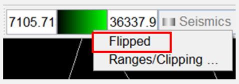
Workflow cont'd:

19. When blending the three inputs, the results should be similar to the one shown on the figure.



Some extra steps:

- Try to flip the green channel : **right-click** 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? Which paleo-geomorphological features can you interpret? What can you conclude in terms of depositional environments, water depth, litho-facies, and direction of currents?

Workflow cont'd:

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

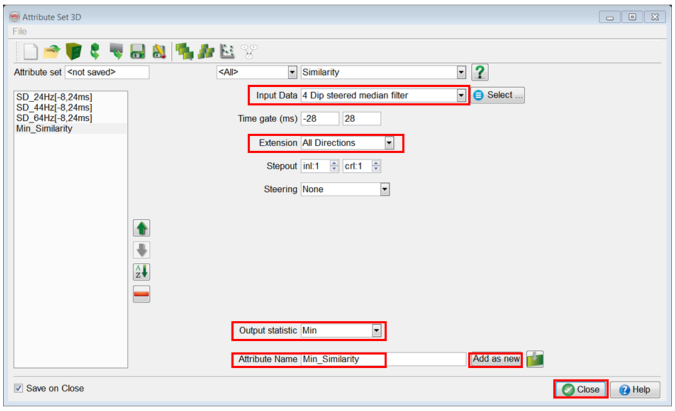
20. To define 'Similarity' attribute and add it to the fourth layer, **open** the Attribute set 3D window with the icon and **select** Similarity.

21. **Select** Extension: All Directions.

22. **Select** Min for Output statistics.

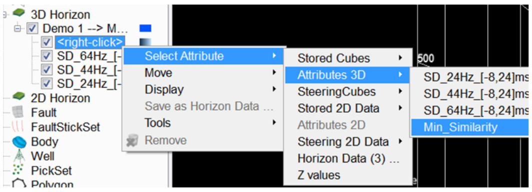
23. **Give** it a name (*Min_Similarity*) and **click** Add as new.

24. **Close** the Attribute set window.



Workflow cont'd:

25. **Right-click** on the fourth element on *Demo1--> MFS4* > Select attribute > Attributes 3D and **select** *Min_Similarity*.



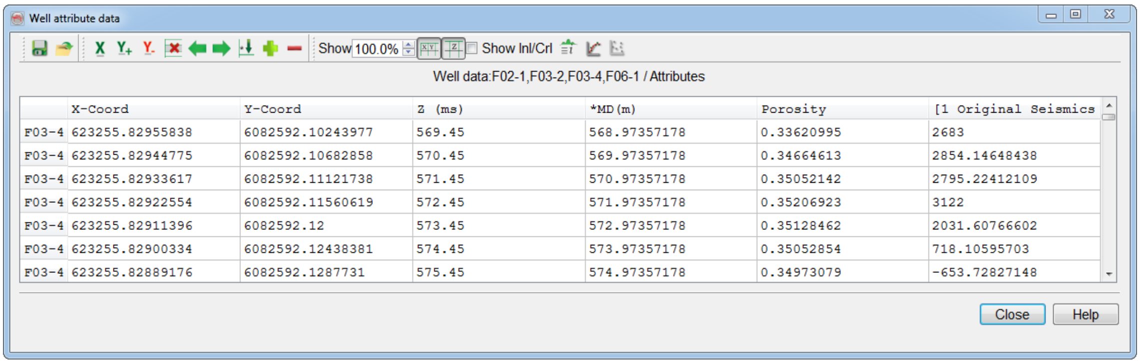
What do you notice? Do you see any structural features (faults, fractures)?

Extra Step: After processing several frequencies to a seismic volume, use PgUP and PgDN to toggle between the processed frequencies for the different channels.

1.5.3 Cross-plots

What you should know about cross-plots in OpendTect

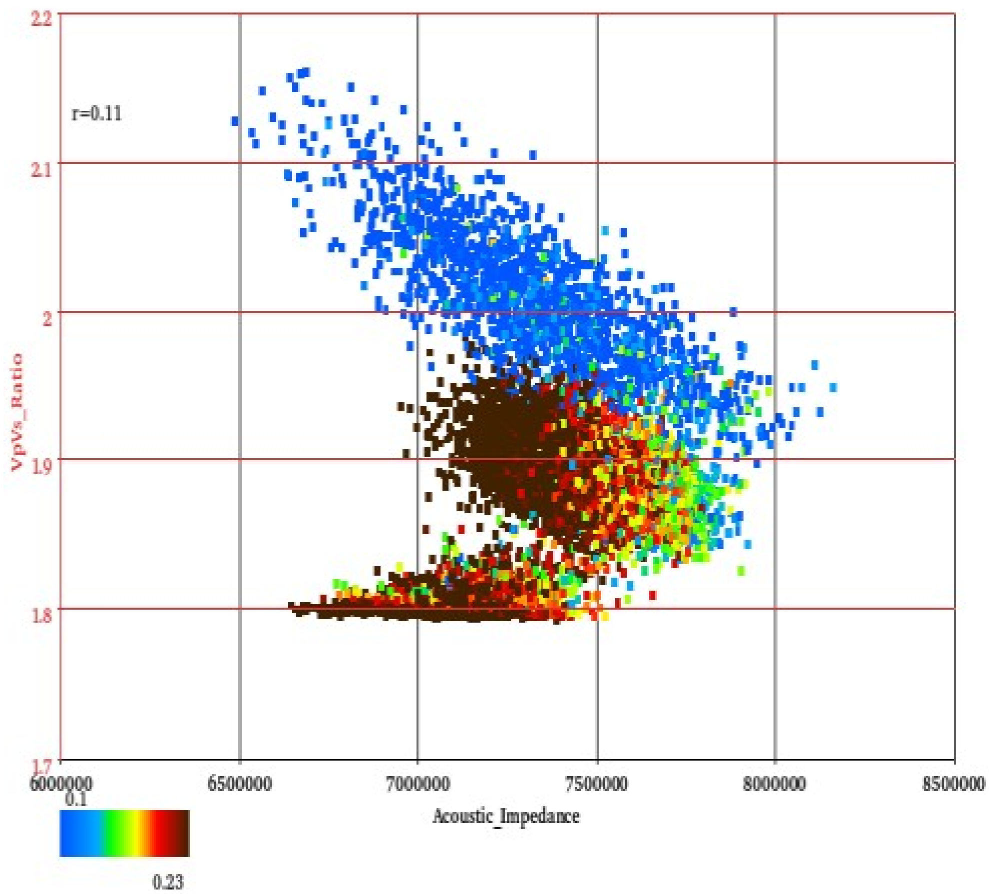
The cross-plot tool in OpendTect creates 2D cross-plots for analyzing relationships between seismic data and well data. Two types of cross-plots are typically analyzed: seismic attributes vs. seismic attributes and seismic attributes vs. well logs. The data points are extracted in a given volume or in 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.



	X-Coord	Y-Coord	Z (ms)	*MD (m)	Porosity	[1 Original Seismics
F03-4	623255.82955838	6082592.10243977	569.45	568.97357178	0.33620995	2683
F03-4	623255.82944775	6082592.10682858	570.45	569.97357178	0.34664613	2854.14648438
F03-4	623255.82933617	6082592.11121738	571.45	570.97357178	0.35052142	2795.22412109
F03-4	623255.82922554	6082592.11560619	572.45	571.97357178	0.35206923	3122
F03-4	623255.82911396	6082592.12	573.45	572.97357178	0.35128462	2031.60766602
F03-4	623255.82900334	6082592.12438381	574.45	573.97357178	0.35052854	718.10595703
F03-4	623255.82889176	6082592.1287731	575.45	574.97357178	0.34973079	-653.72827148

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 pointsets for Neural Network prediction
- ASCII file output
- Quick cross-plot snapshots



2.2
2.1
2
1.9
1.8
1.7
r=0.11
VpVs_Ratio
6000000
6500000
7000000
7500000
8000000
8500000
Acoustic_Impedance
0.1
0.23

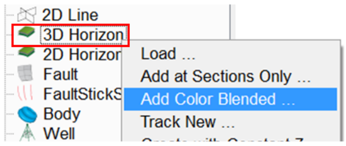
1.5.3a Attributes - Attributes

Required licenses: OpendTect.

Exercise objective:

Analyze the attribute response of the bright-spot amplitude anomaly by cross-plotting the iso-frequency attributes

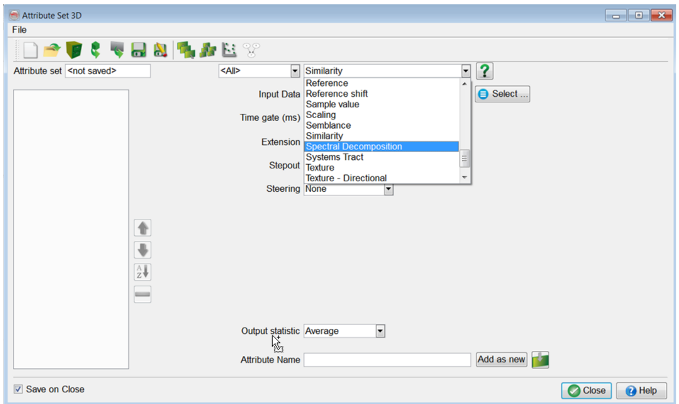
Workflow:



1. **Right-click** on 3D Horizon in the tree and **click** on Add color blended…
   Choose horizon *Demo-6 -> FS8* from the list of horizons.

2. **Launch** the Attribute Set 3D window: **click** on the  icon.

3. **Choose** Spectral Decomposition from the list of attributes.

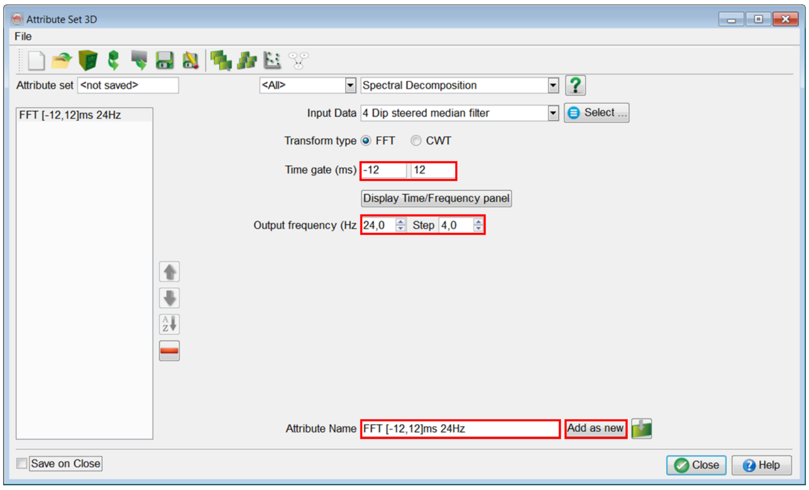


Workflow cont'd:

4. **Change** the time gate to [-12,12]ms.

5. **Change** output frequency to 24Hz with a step of 4Hz.

6. **Give** it a name, e.g. *FFT [-12,12]ms 24Hz*, and **press** Add as new.

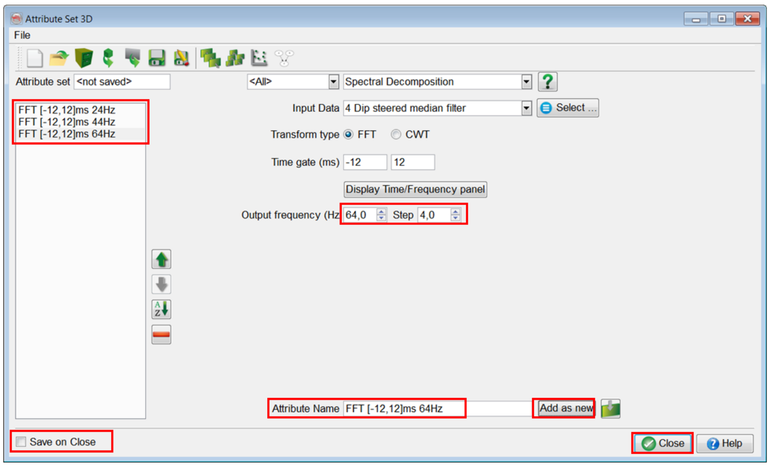


Workflow cont'd:

7. In similar way **define** two more Spectral Decomposition attributes of 44Hz and 64Hz.

8. **Give** them appropriate names, e.g. *FFT [-12,12]ms 44Hz* and *FFT [-12,12]ms 64Hz*, each time **pressing** Add as new.

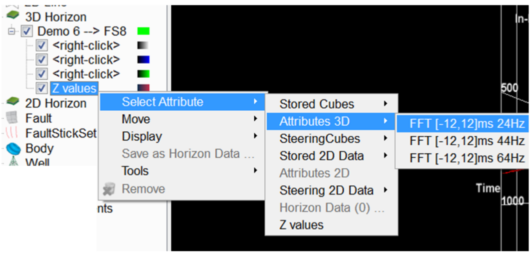
9. **Uncheck** Save on Close and **press** Close.



Optionally save the attribute set. In this case "Save on close" should be checked.

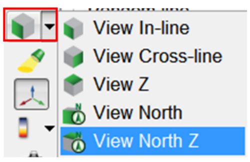
Workflow cont'd:

10. Apply these three attributes on the horizon (red-24Hz, green-44Hz, and blue-64Hz): **right-click** on the red channel and **go** Select attribute > Attributes 3D > *FFT [-12,12]ms 24Hz*.



11. In the same manner **select** for the green (44Hz) and blue (64Hz) channels.

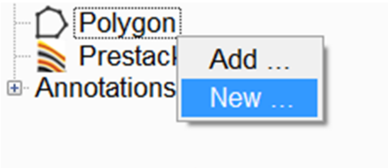
12. **Click** on the View icon and **select** View North Z to observe the result.

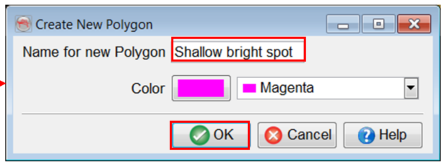


Workflow cont'd:

13. **Right-click** on the Polygon in the tree > New.

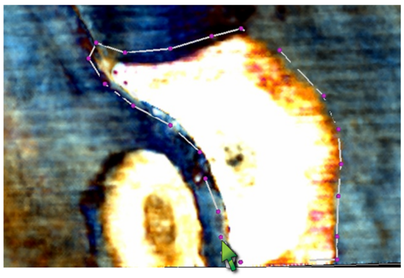
14. **Type in** the name *Shallow bright spot* and **Press** OK.



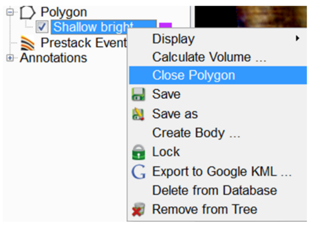


Workflow cont'd:

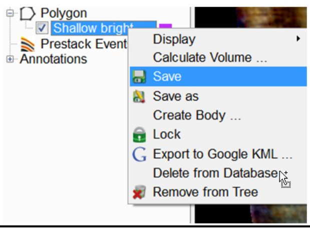
15. **Use** left mouse button to outline a polygon.



16. When finished, **right-click** on this newly added polygon in the Tree and **select** Close Polygon.

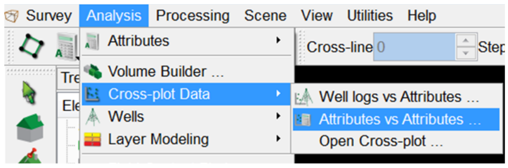


17. **Right-click** again on the polygon name and **Save**.

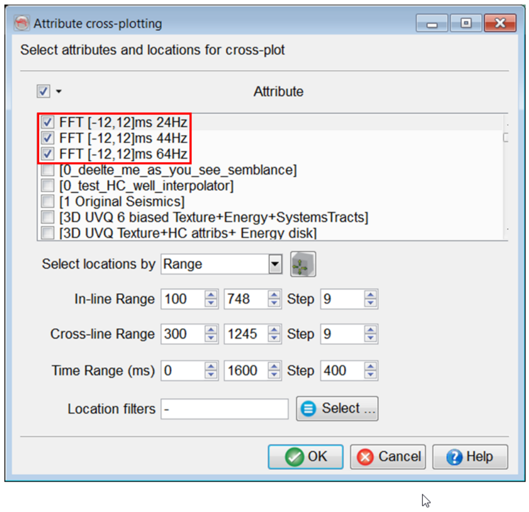


Workflow cont'd:

18. **Go** to the menu Analysis > Cross-plot Data > Attributes Vs Attributes… or **click on** the cross-plot icon.



19. **Select** the three attributes just created.



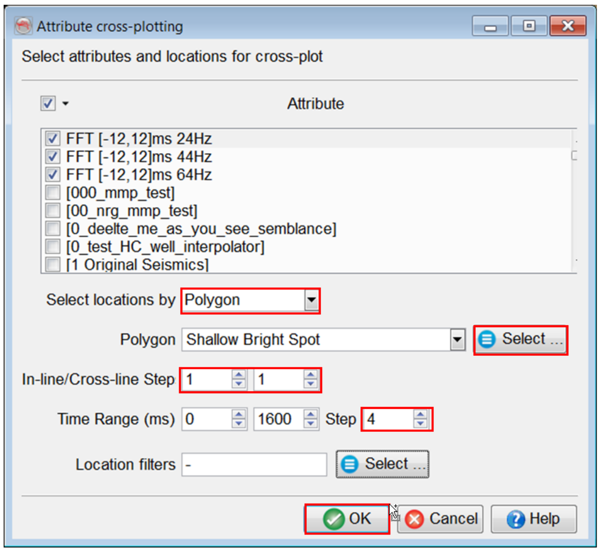
Workflow cont'd:

20. **Select** location by – Polygon.

21. **Select** *Shallow Bright Spot* polygon.

22. **Change** Inline & Cross line steps to 1 and time step to 4ms.

23. **Click** Select for Location filter.

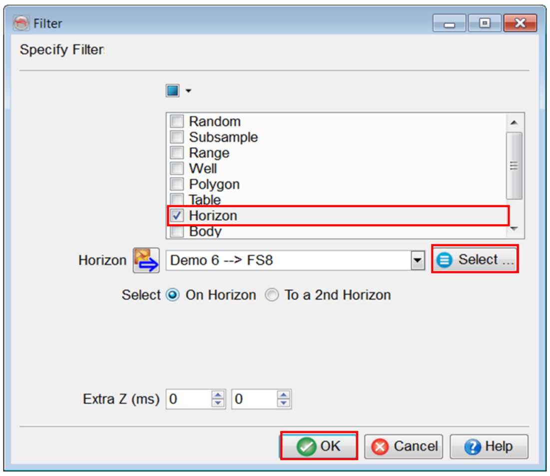


Workflow cont'd:

24. **Check** the Horizon option.

25. **Select** the horizon *Demo6 -> FS8*.

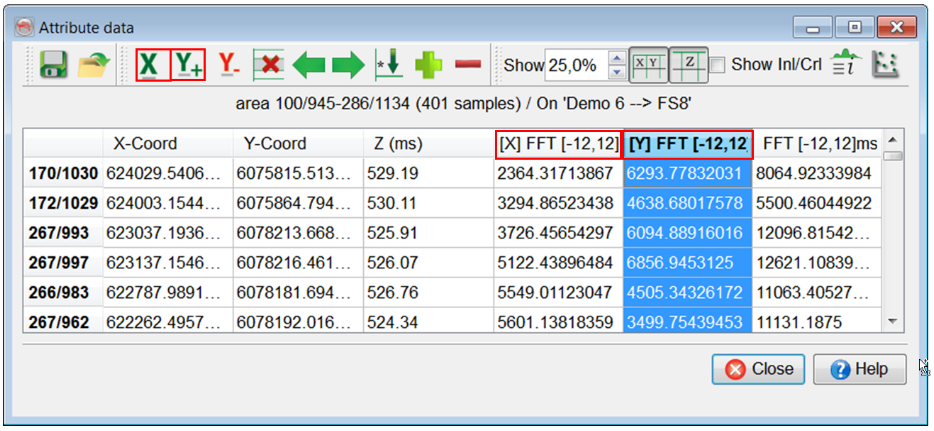
26. **Click** OK in both windows to proceed.



Workflow cont'd:

27. In the pop-up spreadsheet, **select** *FFT [-12,12]ms 24Hz* to be displayed along X-axis: **click** on *FFT [-12,12]ms 24Hz* column and then **click** on **X** icon.

28. **Assign** *FFT [-12,12]ms 44Hz* to Y-axis: **click** on *FFT [-12,12]ms 44Hz* column and then **click** on Y_+ icon.

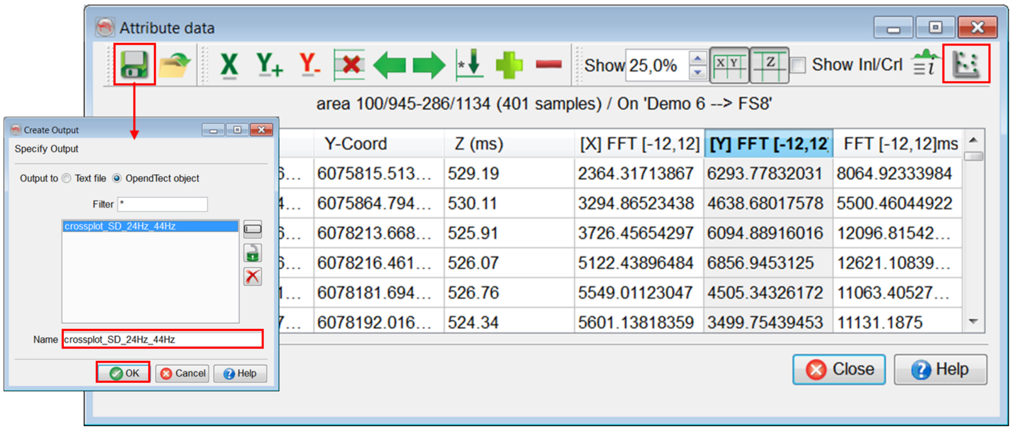


Workflow cont'd:

29. Optionally add more attributes to the Y-axis by selecting a column and pressing Y+ icon. Or remove the selection by pressing Unselect icon. Y-

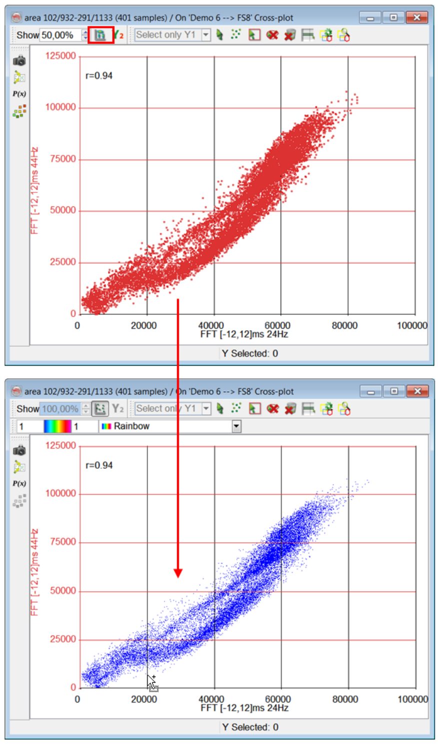
30. **Click** on the Save icon to save the crossplot data and **provide** a name and **click** OK.

31. **Press** Cross-plot icon to plot the selected data.



Workflow cont'd:

32. To have a better feel of the data's behavior **toggle** the density plot button in the scattered cross-plot window.

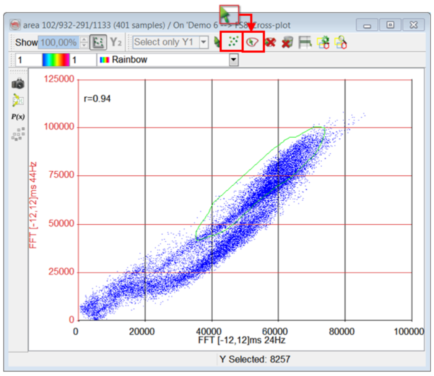


Workflow cont'd:

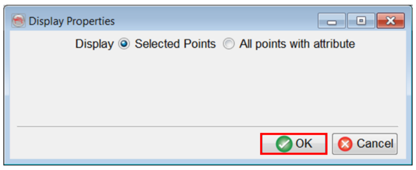
33. **Click** on icon to reverse the selection tool.

34. Using the selection tool **draw** a free-hand polygon, as shown in green color on the figure.

35. **Click** Show points in 3D scene button

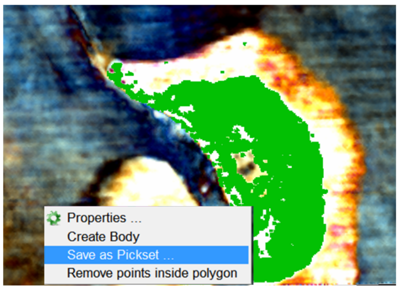


36. In the pop-up window **choose** an option Selected Points to display the selected scattered data and **Press OK**.

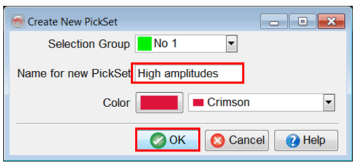


Workflow cont'd:

37. In the scene, **right-click** on the green colored displayed picks > Save as Pickset…

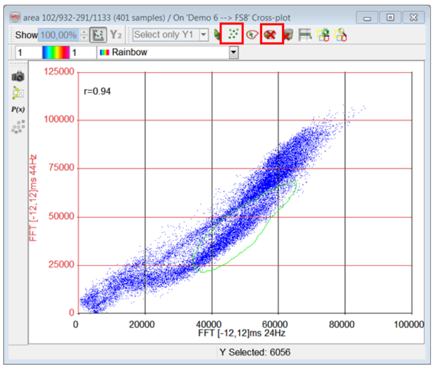


38. **Give it a name**, e.g. *High amplitudes*, and **press** OK.



Workflow cont'd:

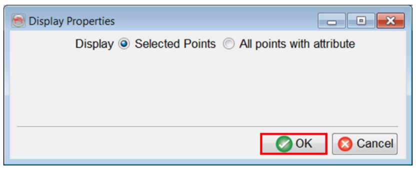
39. In the Cross-plot window **click** on icon to remove the previous selection.



40. **Draw** a new polygon as shown on the figure.

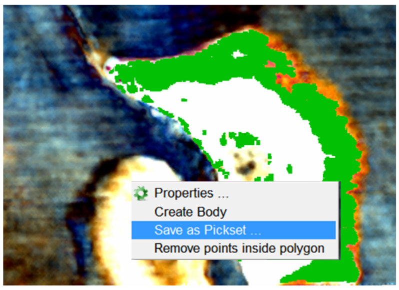
41. **Click** Show points in 3D scene button

42. **Choose** an option Selected Points to display the selected scattered data > **Press** OK.

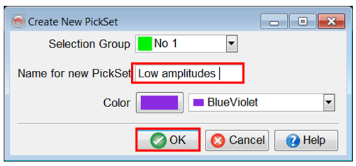


Workflow cont'd:

43. In the scene, **right-click** on the green colored displayed picks > Save as Pickset…



44. **Give it a name**, e.g. Low amplitudes and **press** OK.

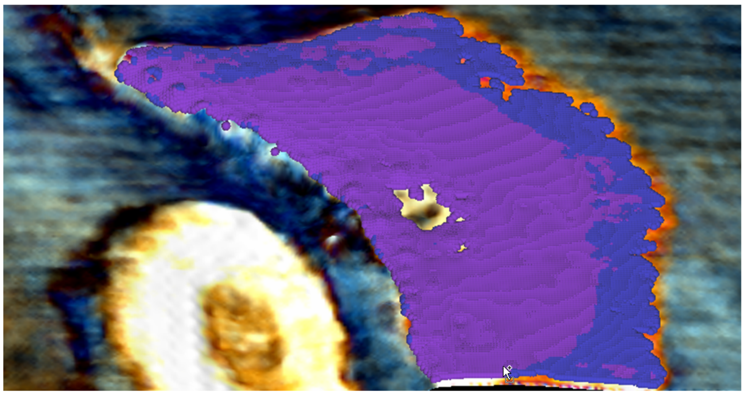


Workflow cont'd:

Some extra steps:

- The scattered data selected in the previous figure can be displayed as pick sets. Note that the separation of frequency highlights two different regions of the bright spot.

- 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 to cross-plot all three attributes together FFT 24Hz, 44Hz and 64Hz.



1.5.3b Attributes - Wells

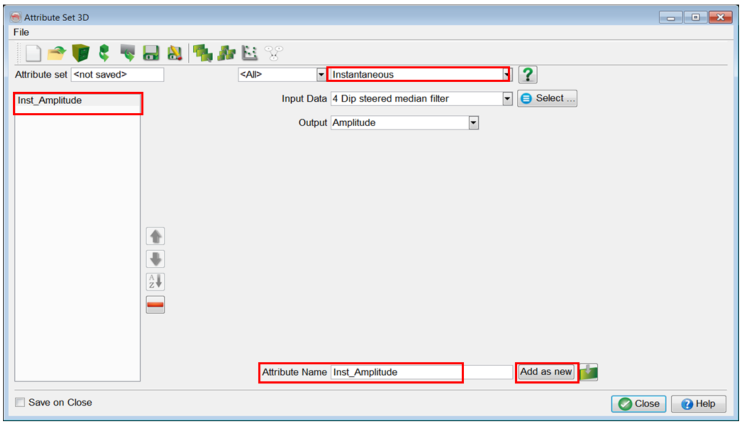
Required licenses: OpendTect.

Exercise objective:

Analyze relationships between seismic attributes and well logs using cross-plots.

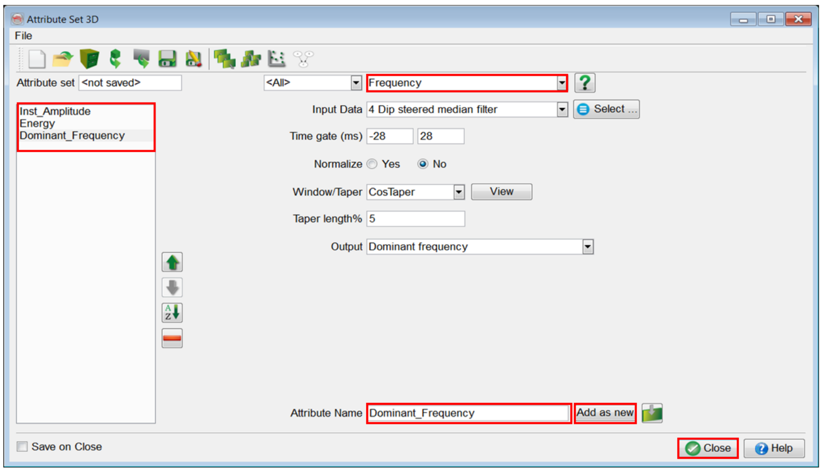
Workflow:

1. **Launch** the Attribute Set window  > 3D or **follow** Analysis > Attributes > 3D.
2. **Define** Instantaneous Amplitude attribute: **Select** Instantaneous from the list of attributes and keep all the default parameters for this exercise.
3. **Type in a name**, e.g. *Inst_Amplitude*, and **Add as new**, so that the attribute appears in the list of defined attributes on the left-hand side.



Workflow cont'd:

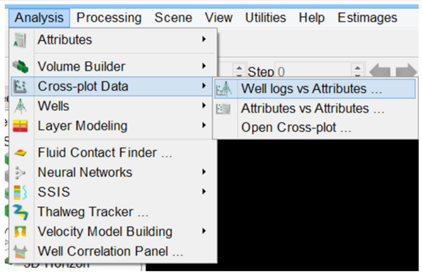
4. In similar way **define** two more attributes: Energy and Dominant Frequency (Listed under "Frequency" option in the attribute list), using all the default parameters.
5. **Close** the window.



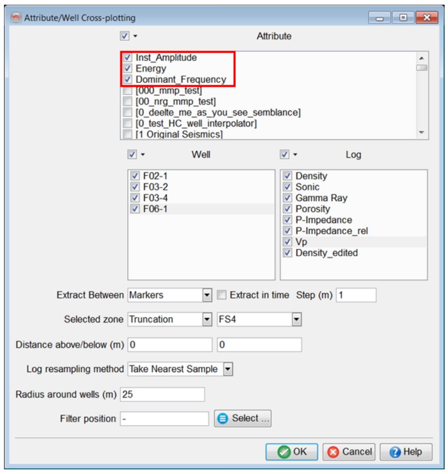
If the Save on Close box is ticked, the attribute set will be automatically stored when closing. When closing an unsaved attribute set, you will the have the option to store it.

Workflow cont'd:

6. **Go to** the menu Analysis > Cross-plot Data > Well logs Vs Attributes… or **click** on the cross-plot icon.



7. **Select** the three defined attributes in the Attribute section.



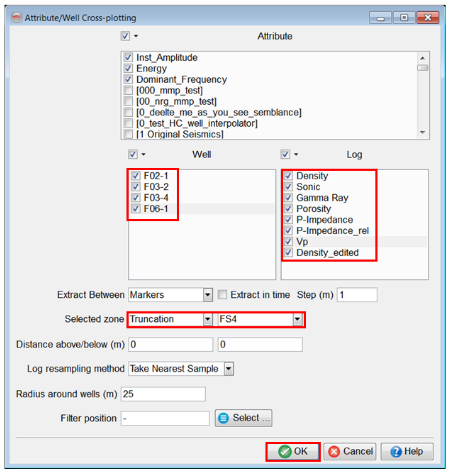
Workflow cont'd:

8. **Select** all available wells and logs.

Use Ctrl+A shortcut to select all items from the list or tick the box on top of the item list.

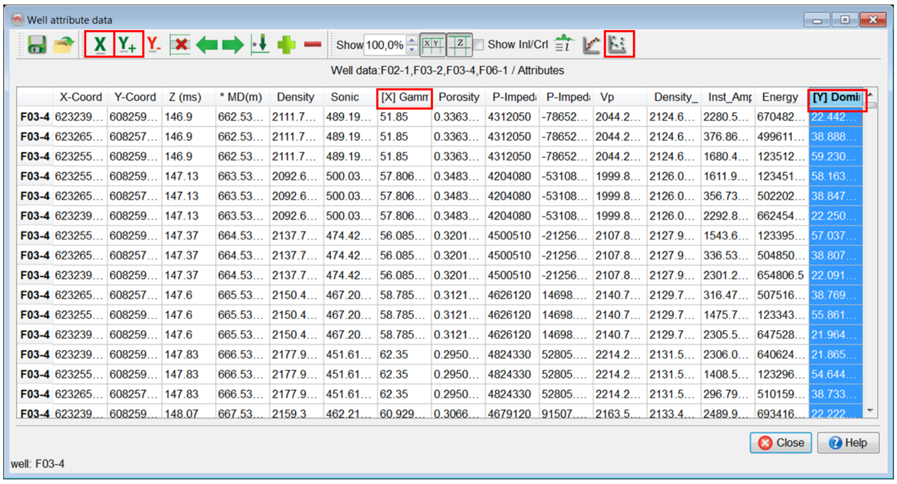
9. **Extract** between the Truncation and FS4 markers.

10. **Press** OK button to proceed.



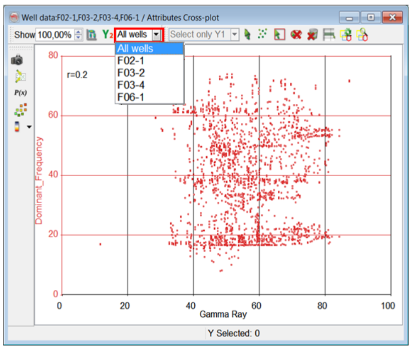
Workflow cont'd:

11. In the pop-up spreadsheet, **select** GR log to be displayed along X-axis: **click** on GR log column and then on **X** button.
12. **Assign** Dominant frequency attribute to Y-axis: **click** on Dominant Frequency column and then on **Y+** icon.
13. **Press** Cross-plot button to plot the selected data.



Workflow cont'd:

14. By default, it will plot scattered points of all wells vs. selected attribute(s). **Select** one well from the combo-box to cross-plot an individual well.



Additionally:
Repeat the steps 12 to 14 by selecting exclusively logs for the X axis and for the Y axis. Optionally select consecutively two logs to be displayed on the Y axis. The second log will be displayed as Y2.

When selecting different X and Y quantities in the table, the crossplot display window will be automatically updated. Use the ⬅ and ➡ arrows to change the Y column to the next (or previous) column.

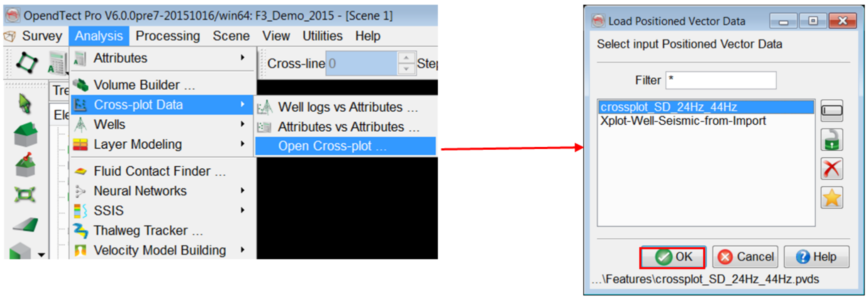
1.5.3c Bayesian Inversion

Exercise objective:

Perform a Bayesian inversion to predict whether a similar bright spot as the one we have studied exist elsewhere along the same horizon.

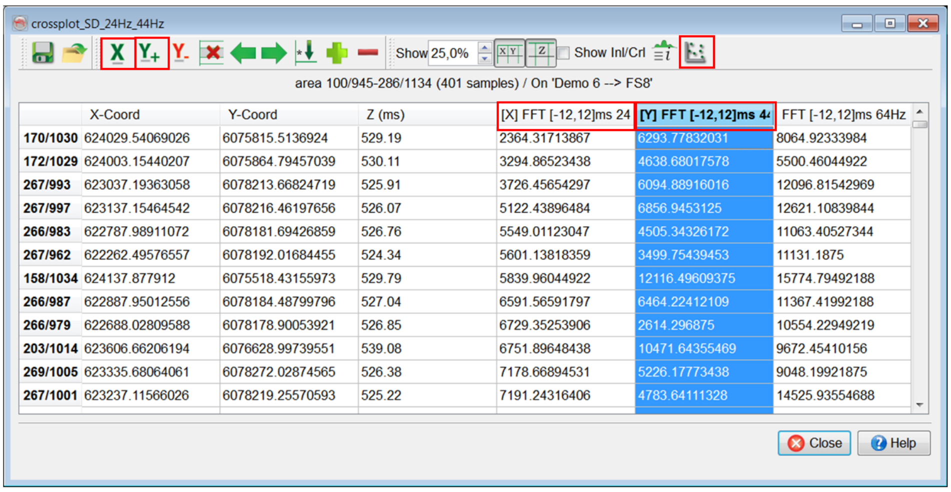
Workflow:

1. **Open** the cross-plot data saved in the exercise 1.4.3: Analysis > Cross-plot Data > Open Cross-plot.
2. **Select** the cross-plot data and **click** OK.



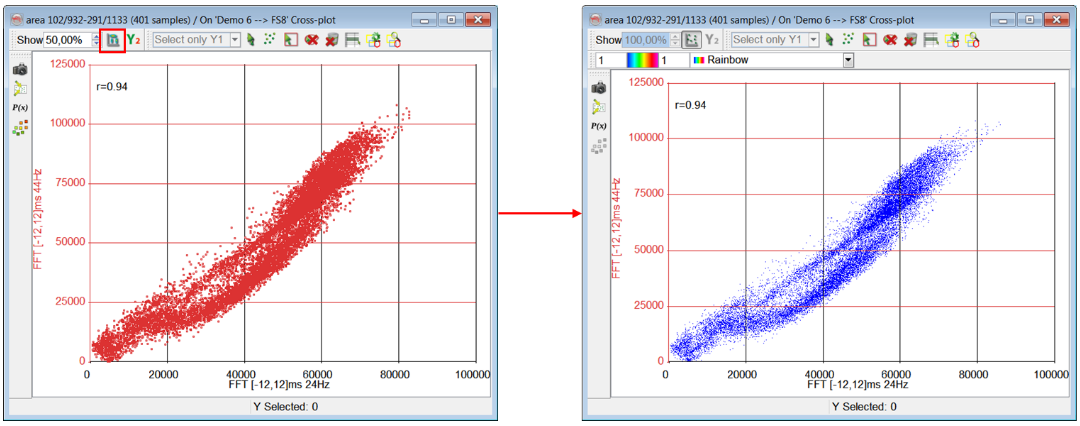
Workflow cont'd:

3. In the spreadsheet, select *FFT [-12,12]ms 24Hz* to be displayed along X-axis: **click** on *FFT [-12,12]ms 24Hz* column and then on button.
4. **Click** on *FFT [-12,12]ms 44Hz* column and then on icon.
5. **Press** Cross-plot button to plot the selected data.



Workflow cont'd:

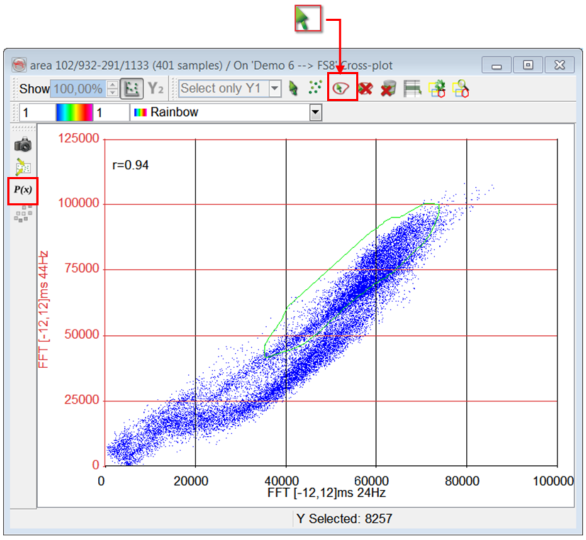
6. To have a better feel of the data's behavior **toggle** the density plot button in the scattered cross-plot window.



Scattered cross-plot **Density cross-plot**

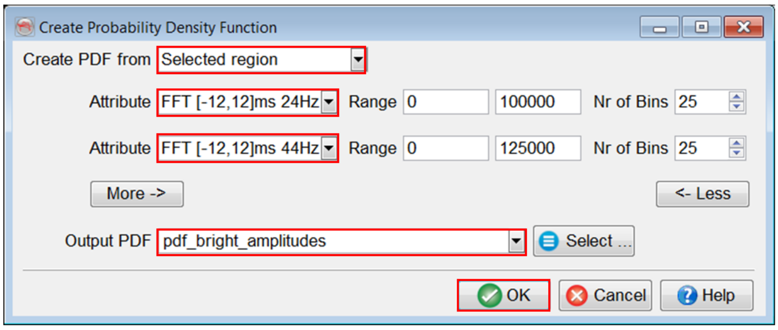
Workflow cont'd:

7. **Click** on icon to reverse the selection tool.
8. Using the selection tool **draw** a free-hand polygon, as shown in green color on the figure.
9. **Click** on Create Probability Density Function (PDF) icon ***P(x)***.



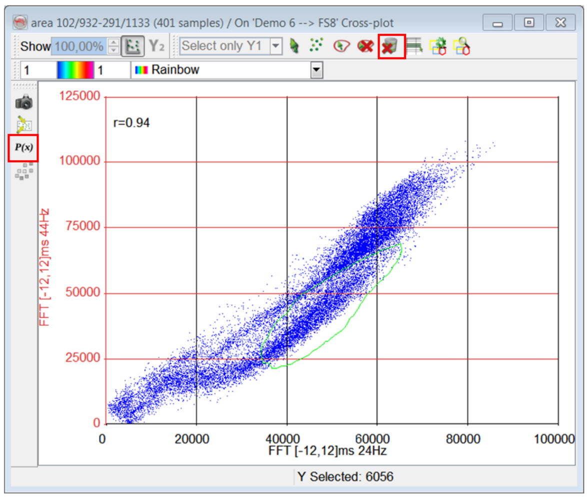
Workflow cont'd:

10. In the pop-up window **choose** an option Selected Region.
11. **Select** Spectral Decomposition attribute 24Hz and 44Hz.
12. **Provide** an output name, e.g. *pdf_bright_amplitudes*, and **click** OK.



Workflow cont'd:

13. In the Cross-plot window **click** on [icon] to remove the points inside the selected area.
14. **Draw** a new polygon as shown on the figure (left mouse button down and drag).
15. **Click** on Create Probability Density Function (PDF) icon ***P(x)*** .

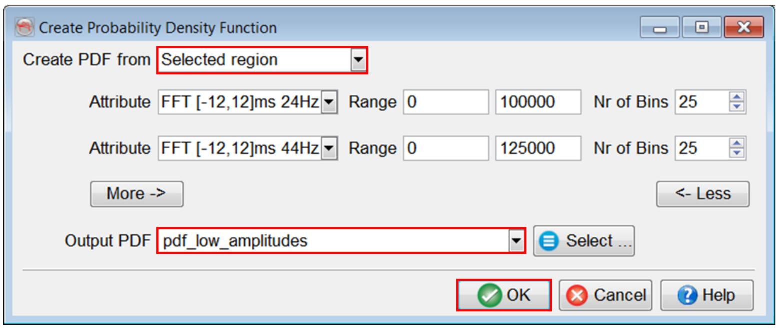


Workflow cont'd:

16. In the pop-up window **choose** an option Selected Region.

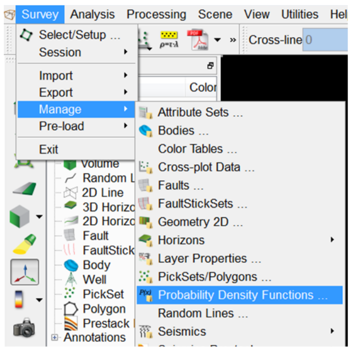
17. **Provide** an output name, e.g. *pdf_low_amplitudes*, and **click** OK.

18. **Close** the cross-plot windows.

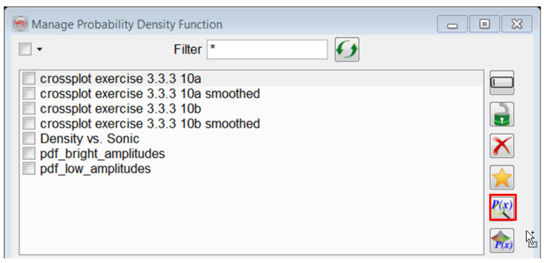


Workflow cont'd:

19. **Go to** Survey > Manage > Probability Density Functions.



20. There you can **browse/edit** PDFs : **click** on using the icon  or **double click** on the PDF.



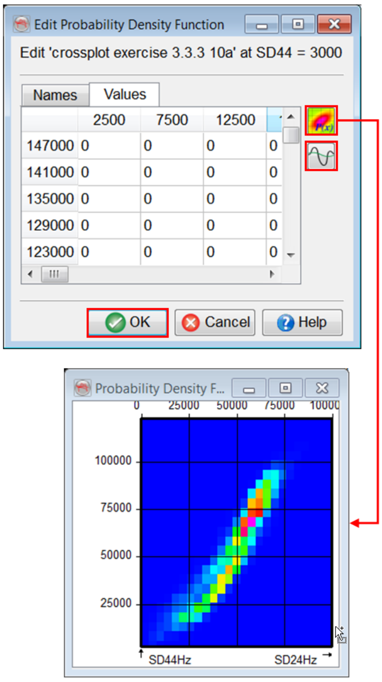
Workflow cont'd:

21. **View** the PDF distribution by clicking the icon in the Values tab.

22. **Smooth** the function using the icon .

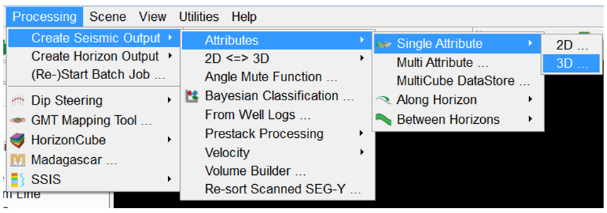
23. **Press** Ok and **save** the smoothed PDF with a new name or overwrite the existing file.

24. In the same way **smooth** the second PDF and **close** the Probability Density Function manager window.

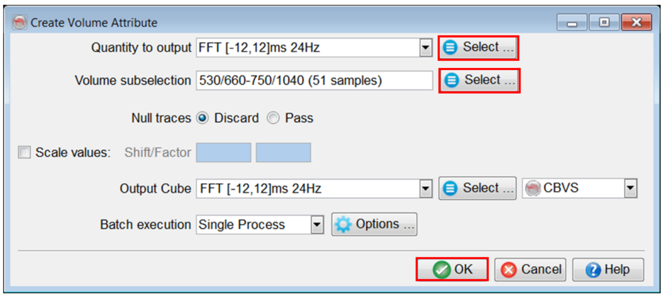


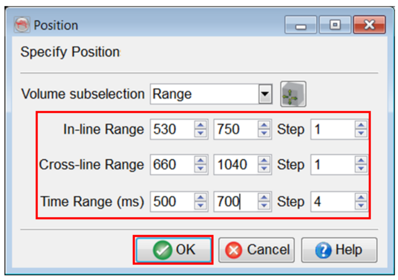
Workflow cont'd:

25. Go to Processing > Create Seismic Output > Attributes > Single Attribute > 3D...



26. **Select** Spectral Decomposition attribute of 24Hz and **limit** the processing range to in-line 530 – 750, cross-line 660 – 1040 and Z range 500 – 700ms to save processing time. **Click** OK to start batch processing.

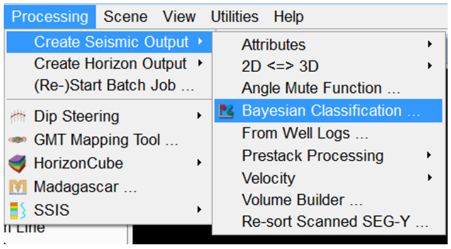




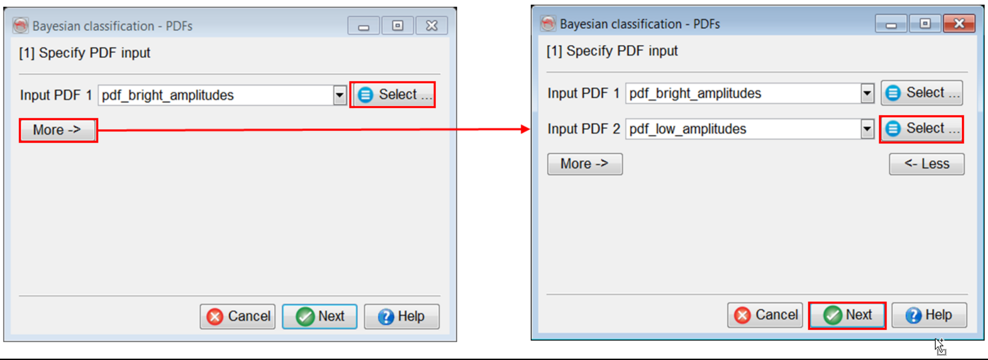
27. In the same way **process** Spectral Decomposition attribute of 44Hz.

Workflow cont'd:

28. **Go to** Processing > Create seismic output > Bayesian classification to launch the Bayesian inversion.

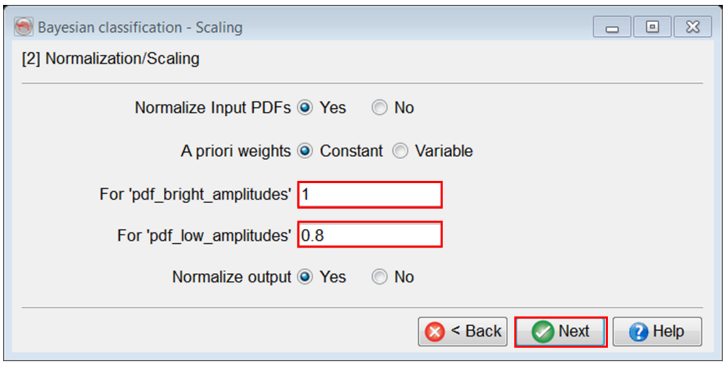


29. **Select** both previously created and smoothed PDF (to add additional PDF **click on** More).



Workflow cont'd:

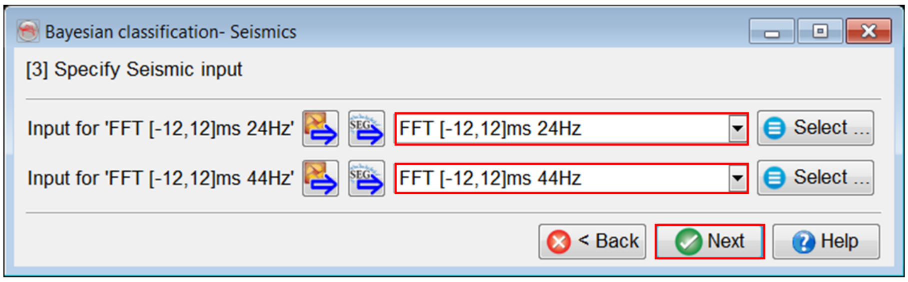
30. **Provide** a weight for each: 1 for the first and 0.8 for the second. Then **press** Next.



The weight functions can be constant as well as variable that can be input in form of volumes. For instance the weight could be a function of the well distance, or the vertical distance to the target.

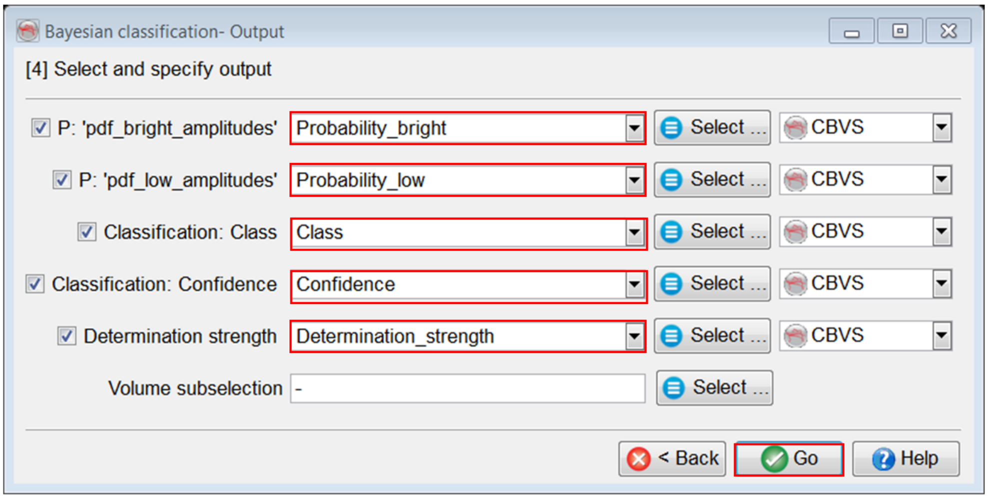
Workflow cont'd:

31. **Select** input volumes corresponding to each attribute.



Workflow cont'd:

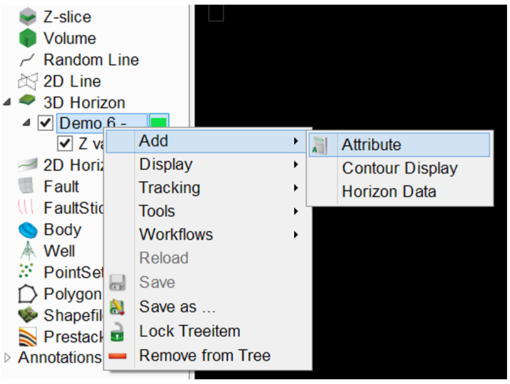
32. **Check** the outputs you want to generate, **provide** the desired names and **hit** Go.



Workflow cont'd:

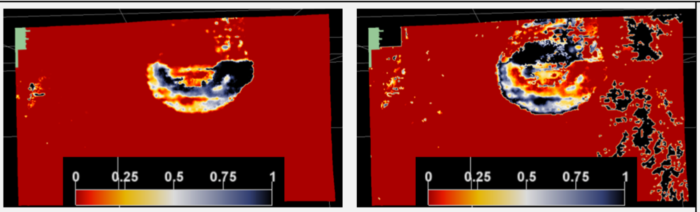
33. **Right-click** on 3D Horizon in the tree > Load > **Select** *Demo6* --> *FS8* horizon to display.

34. **Right-click** on the *Demo6* --> *FS8* horizon in the tree > Add > Attribute and **select** one of probability attributes from the list.

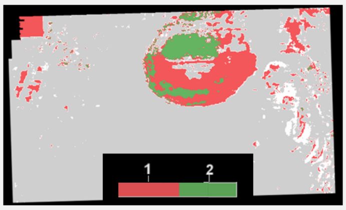


35. One by one **display** all five attributes that were output. See if other similar bright spots can be recognized. **Change** the color bars if need be.

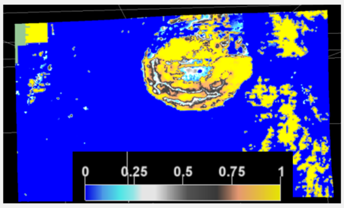
Workflow cont'd:



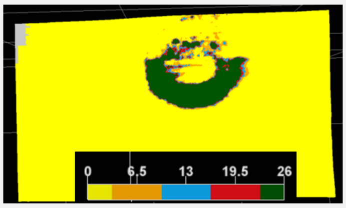
The "P" is the probability volume associated to each PDF distribution.



The "Classification: Class" returns an integer corresponding to the most l 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).

2 Part II: Commercial Software

Under a commercial, or academic license agreement OpendTect, the open source seismic interpretation platform, can be extended with a range of closed source extensions. These extensions are protected by FlexNet license keys. All extensions, also the ones developed by other vendors are licensed through dGB.

For purchase/maintenance fees please contact dGB via info@dgbes.com.

As stated before the exercises in this manual can be executed without license keys as OpendTect does not check license keys when the survey you work on is F3 Demo.

2.1 OpendTect Pro

What you should know about OpendTect Pro

OpendTect Pro is a commercial layer (closed source, FlexNet license key protected) that extends the free OpendTect software with extra functionality. All commercial plugins require an OpendTect Pro license to run.

Among others OpendTect Pro offers:

- PetrelDirect, a two-way seamless connection to Petrel;
- An interactive basemap with mapping functionality;
- PDF3D plugin for sharing 3D images (see below);
- A Thalweg tracker for tracking seismic facies;
- An accurate ray-tracer for AVO attributes and Angle Stacks.

2.1.1 PetrelDirect

What you should know about PetrelDirect

PetrelDirect is a two-way data connectivity solution that enables OpendTect to work directly on a Petrel data store. Data can either be linked (no data duplication) or copied. The advantage of copying data is that usage of the Petrel license is restricted to a minimum. Apart from linking / copying data PetrelDirect can also be used to set up an OpendTect survey.

The following features are supported with full two-way access:

- 3D seismic volumes
- 3D horizons and horizon attributes
- 2D seismic lines
- Fault stick sets
- Wavelets

One-way access: Petrel > OpendTect is supported for:

- Wells: tracks, logs, markers (time/depth curves and/or checkshot data is automatically transferred with the track if present)
- 3D Seismic pre-stack data.

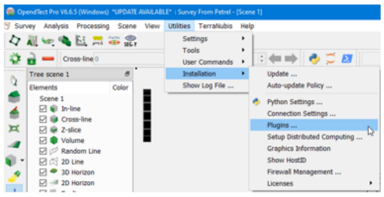
2.1.1a Set up PetrelDirect Plugin

Required licenses: OpendTect Pro.

Exercise objective:

To check the setup and verify that the PetrelDirect plugin is installed in OpendTect and Petrel*.

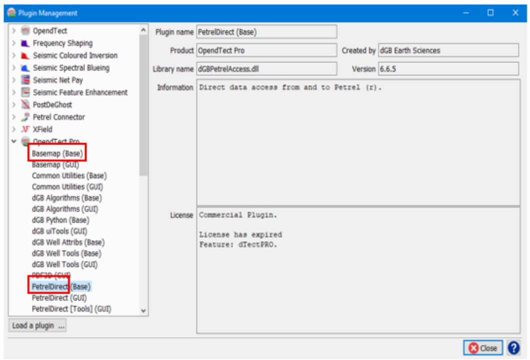
The PetrelDirect plugin allows OpendTect Pro users to seamlessly exchange data with the Petrel* data store of a running Petrel* project. The data exchange exercise between Petrel and OpendTect can be replicated only if the PetrelDirect Plugin is installed and OpendTect Pro and Petrel licenses are available.



OpendTect:

1. The PetrelDirect plugin is a part of OpendTect Pro. Once OpendTect Pro is installed, **Start** OpendTect

2. **Verify** that the PetrelDirect plugin is installed and license is active: OpendTect > Utilities > Installation > Plugins > OpendTect Pro. **Select** *PetrelDirect*



* *Petrel is a mark of Schlumberger*

Petrel*:

To be able to use PetrelDirect functionality in Opendtect Pro, *Data access for OpendTect (dGB) plugin* must be installed in Petrel*. Installation can be done either via Windows installer (.msi file) or Plugin Installer Package (PIP file).

Via Windows installer (.msi file):

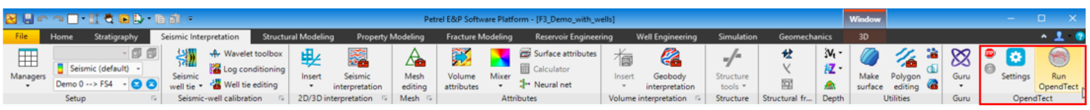
The Windows installer does both the first-time plugin installation and an update of already installed plugin to a newer version without any extra actions.

1. **Download** the .msi file from the dGB's download page in the OpendTect Pro plugin for Petrel*

2. **Run** the .msi file and follow the instructions.

3. **Start** Petrel*

4. **Go** to the *Seismic Interpretation tab* and observe that OpendTect toolbar is present:



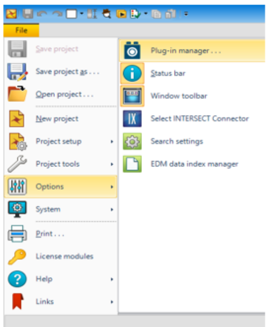
* *Petrel is a mark of Schlumberger*

Petrel*:

To be able to use the PetrelDirect functionality in Opendtect Pro, *Data access for OpendTect (dGB) plugin* must be installed in Petrel*. Installation can be done either via Windows installer (.msi file) or Plugin Installer Package (PIP file).

Via Plugin Installer Package (PIP file):

For the plugin to update to a newer version, any old version must be uninstalled first:

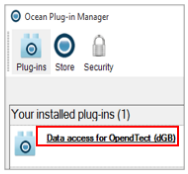


1. **Start** Petrel*

2. In Petrel* main window: **go** to File > Options > Plugin Manager:

3. In Ocean Plugin Manager window: **uninstall** the old version of *Data access for OpendTect (dGB) plugin* by selecting it and **clicking** the *Uninstall* button.

4. **Close** Petrel*

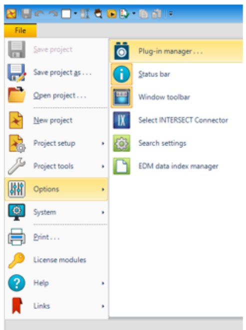


* *Petrel is a mark of Schlumberger*

Petrel*:

To be able to use PetrelDirect functionality in Opendtect Pro, *Data access for OpendTect (dGB) plugin* must be installed in Petrel*. Installation can be done either via Windows installer (.msi file) or Plugin Installer Package (PIP file).

Via Plugin Installer Package (PIP file):

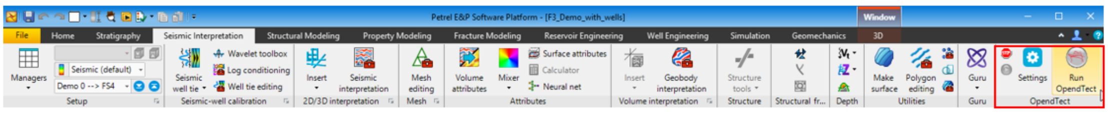


For a first-time installation, or once the plugin version is uninstalled:

1. **Download** the PIP file from the dGB's download page in the OpendTect Pro plugin for Petrel*.
2. **Start** Petrel*
3. In Petrel* main window: **go** to File > Options > Plugin Manager:

In *Ocean Plugin Manager* window:

4. **Click** on *Install plugin* button
5. **Locate** the PIP file and **click** *Open*
6. Once the installation is finished, **click** *Close* in both windows
7. **Restart** Petrel*
8. **Go** to *Seismic Interpretation tab* and check that the OpendTect toolbar is present



* *Petrel is a mark of Schlumberger*

Link OpendTect and Petrel* projects

PetrelDirect status button helps monitor the status of the connection to Petrel*. Clicking the button will open the settings window. The drop-down menu next to it allows to directly control the status of the connection:

- - disabled (drop-down menu next to it allows to *Enable* connection)
- - uninitialized (connection is enabled, i.e. will be activated once PetrelDirect is used; drop-down menu next to it allows to either *Disable* connection or *Initialize now*)
- - active (drop-down menu next to it allows to *Disable* connection)

If the connection is enabled and left initialized, the PetrelDirect status will become active once Petrel is used

1. Start Petrel* and **Select** the Project of interest.

2. Start OpendTect. At startup, the Petrel connection is disabled (in the lower right corner of the main OpendTect window). **Select** *Enable* from the drop-down menu. When the connection is enabled, the PetrelDirect status icon becomes active

3. Select *Initialize*. The icon turns indicating that the connection has been established between Petrel and OpendTect.

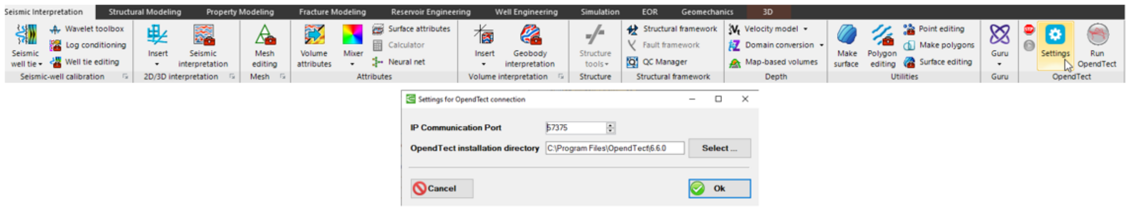
* *Petrel is a mark of Schlumberger*

Choosing the preferred Communication Port (TCP/IP)

Petrel:

By default the plugin should use the TCP/IP port 57375; if this port is not available or accessible, it can be changed in two ways:

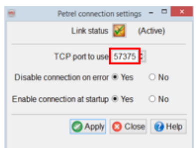
1. From the Petrel plugin user interface, which is available under the 'Seismic interpretation' tab in the Petrel* ribbon.



2. By adding an environment variable DTECT_PETREL_PORT, and setting the value to the preferred port number which is available for access.

OpendTect:

The Petrel* connection setting can be set and modified in the PetrelDirect status window. The TCP port number must be the same as the port number specified on the Petrel* side. The default value of 57375 should work in most cases.



* *Petrel is a mark of Schlumberger*

2.1.1b Set up Survey using PetrelDirect

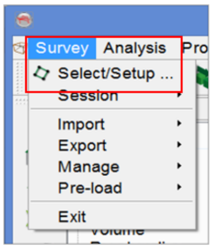
Required licenses: OpendTect Pro.

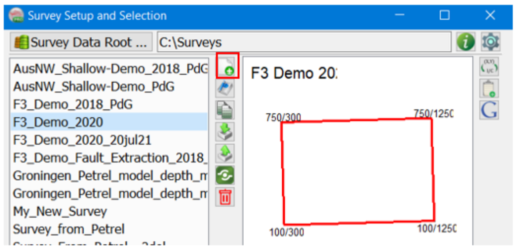
Exercise objective:

To show how an OpendTect survey can be quickly set up from an existing Petrel* project using PetrelDirect.

Workflow:

1. **Choose** Select/Setup option under the Survey menu or **click** on the Survey Setup icon .
2. **Click** on the *Create New Survey* icon in the *Survey Setup and Selection* window.





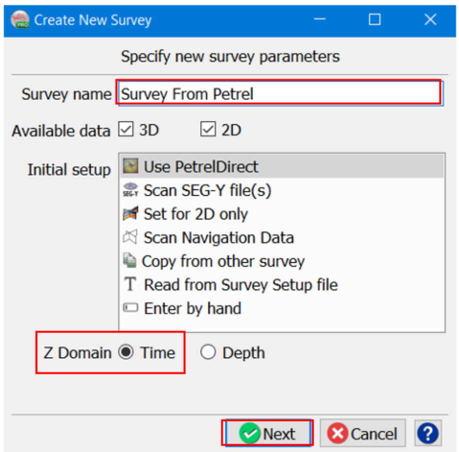
* *Petrel is a mark of Schlumberger*

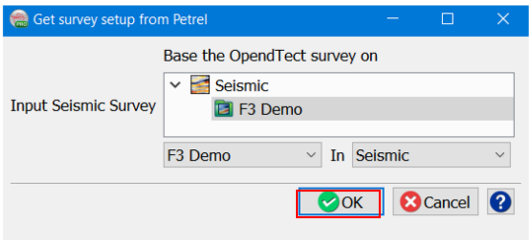
Workflow cont'd:

3. **Specify** a Survey name; **select** Use PetrelDirect; **Set** Time for Z Domain and **press** Next.

4. **Select** a seismic data set from the Petrel project to set up the OpendTect survey

5. **Press** OK.

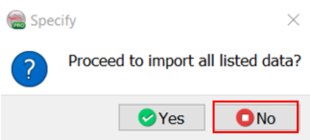


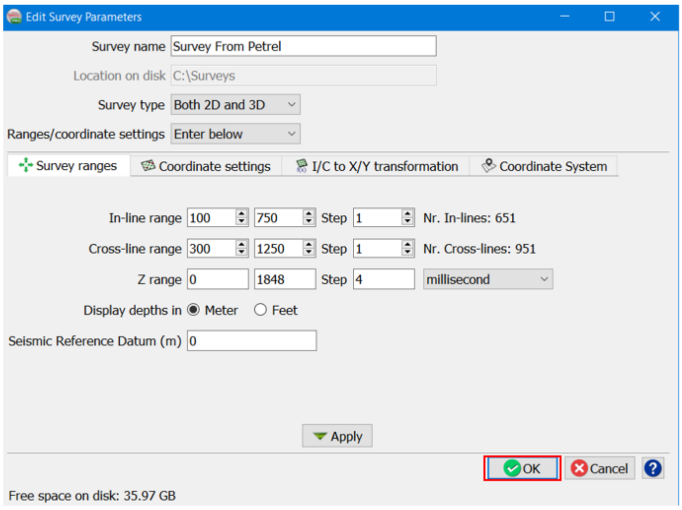


Workflow cont'd:

6. You would see the survey information filled-in automatically from the selected Petrel* project set-up. **Press** OK to set-up the survey.

7. A pop-up message asking if you want to proceed with the data import. **Select** No, if you don't want to proceed with bulk data import from Petrel.





2.1.1c Import data from Petrel using PetrelDirect

Required licenses: OpendTect Pro.

Exercise objective:

Import data from Petrel* to OpendTect using PetrelDirect.

Introduction

PetrelDirect is an OpendTect Pro feature for direct data transfer between OpendTect and Petrel* projects. Reading data from a Petrel* project is available in various OpendTect workflows via insert icon , which allows to either access data directly from a Petrel* data store via links or physically data copy to an OpendTect project:

Link to Petrel*:

• no data duplication;

• data is available only when the Petrel* project is running and PetrelDirect connection is active (i.e. Petrel* license is tied).

OpendTect copy:

• physical copy data in OpendTect format;

• no restrictions on data access (i.e. Petrel* license is not tied and data is accessible to all users).

Either method gives full potential for manipulation, interpretation and processing. Writing data to a Petrel project is also available in various OpendTect workflows by choosing PetrelDirect output format.*

PetrelDirect support the following objects:

- **Full two-way access (Petrel* <> OpendTect):**

Faults and FaultStickSets, 3D horizons, 2D and 3D seismic, Wavelets, Wells (tracks, time-depth models and logs)

- **One way access (Petrel* > OpendTect):**

2D horizons, 3D prestack seismic, Wells (markers)

Batch processing for importing objects is now available for Faults, FaultSticks, Horizons and Seismic Cubes.

A check box to use the original name is provided which should be checked in case the same needs to remain identical to the object in the Petrel project. Any name entered into the field adjacent to this will be used as the 'base name' for the objects.

The following exercises will cover some examples of data exchange between Petrel and Opendtect .

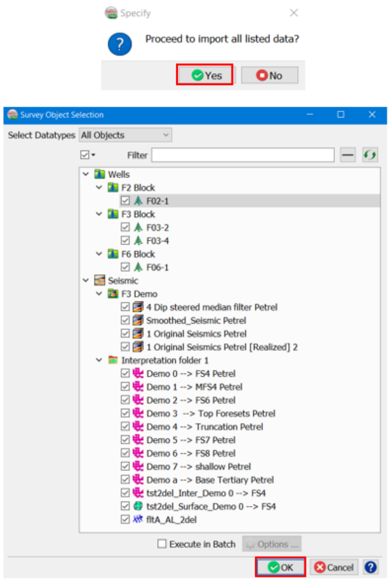
Exercise objective:

Use PetrelDirect to import **all data** in one go from Petrel* to OpendTect at Survey creation.

Workflow:

1. Perform the same steps as in Exercise 2.1.1b to set up an OpendTect survey using PetrelDirect, except the last step. At the pop-up message asking if you want to proceed with the data import, **Select** Yes, to proceed with bulk data import from Petrel.

2. **Select** All Objects in the Datatypes and **Hit** OK. For a large amount of data you can use the 'Execute in Batch' option.



Note that 'Datatypes' and 'Filter' can be used to list and select only the data of interest to be loaded.

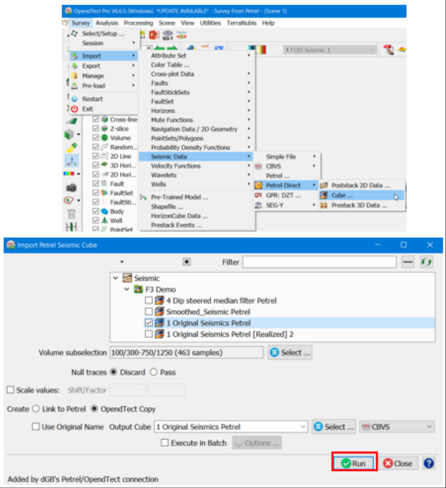
* *Petrel is a mark of Schlumberger*

Exercise objective:

Use PetrelDirect to import **3D seismic** from Petrel* to OpendTect.

Petrel* 3D seismic cube can be accessed in OpendTect by clicking on PetrelDirect insert icon in the following places:
• *Manage 3D Seismics* window (*Survey > Manage > Seismics > 3D...* or click on icon in the *Manage Data* toolbar)
• *Select* window when adding a seismic attribute display at In-line/Cross-line/Z-slice/3D Horizon in the 3D scene
• Other workflows, including attribute definition and processing, etc.
Petrel seismic data must have compatible geometry with OpendTect survey set up. The easiest way to achieve this is to get survey set up from Petrel* when setting up a survey and choose an appropriate Petrel* seismic survey folder as the geometry source.*

Workflow:



1. **Perform** the same steps as in Exercise 2.1.1b to set up an OpendTect project using PetrelDirect.

2. **Select** Survey < Import < Seismic Data < PetrelDirect < Cube. **Select** the Seismic cube from the *Import Petrel Seismic Cube* window.

3. **Create** either *Link to Petrel** or *OpendTect Copy*. Note that the *Link to Petrel option,* requires Petrel License to be able to use the seismic in OpendTect.

4. **Keep** the default parameters. **Tick** *Use Original Name Output Cube* and **Hit** Run.

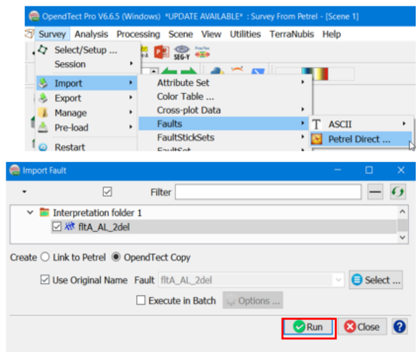
* *Petrel is a mark of Schlumberger*

Exercise objective:

Use PetrelDirect to import **Faults** from Petrel* to OpendTect.

Petrel* fault interpretation can be accessed in OpendTect as Faults by clicking on PetrelDirect insert icon in the following places:
•*Manage Fault* window (*Survey > Manage > Faults...* or click on icon in the *Manage Data* toolbar)
•*Select Input Fault(s)* window when adding Fault(s) to the 3D scene, 2D viewer or Basemap by right click on *Fault* in the tree > *Add*)
This workflow is similar to import FaultStickSets from Petrel to OpendTect.

Workflow:



1. **Perform** the same steps as in Exercise 2.1.1b to set up an OpendTect project using PetrelDirect.

2. **Select** Survey < Import < Faults < PetrelDirect. **Select** the Fault from the *Import Fault* window.

3. **Create** either *Link to Petrel** or *OpendTect Copy.* Note that the *Link to Petrel option,* requires Petrel License to be able to use the Fault in OpendTect.

4. **Keep** the default parameters. **Tick** *Use Original Name Output Cube* and **Hit** Run.

Note that OpendTect does not support crossing fault sticks (a fault plane cannot cross itself). If faults were picked on inlines, crosslines and horizontal slices, only the largest subset of the three will be used to import the faults. Manual editing (removing unwanted sticks) is possible after import and might be required in some cases.

* *Petrel is a mark of Schlumberger*

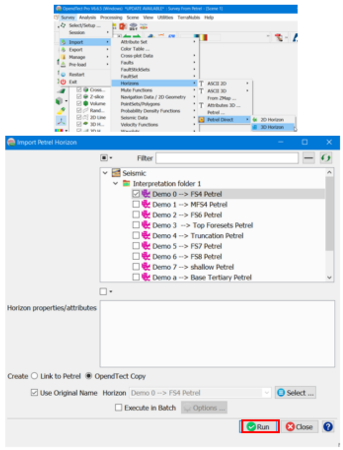
Exercise objective:

Use PetrelDirect to import **3D Surfaces** from Petrel* to OpendTect.

Petrel 3D horizons and surfaces can be accessed in OpendTect by clicking on PetrelDirect insert icon in the following places:
- *Manage 3D Horizons* window (*Survey > Manage > Horizons > 3D*... or click on icon in the *Manage Data* toolbar)
- *Select Input Horizon(s)* window when adding 3D Horizon to the 3D scene, 2D viewer or Basemap by right click on *3D Horizon* in the tree > *Add*)
- Other workflows, including 3D Horizon gridding and filtering, creating flattened scene, etc.

This workflow is similar to import 2D Horizon from Petrel to OpendTect.

Workflow:



1. **Perform** the same steps as in Exercise 2.1.1b to set up an OpendTect project using PetrelDirect.
2. **Select** Survey < Import < Horizon < PetrelDirect< 3D Horizons. **Select** the Horizon (s) from the *Import Petrel Horizon* window.
3. **Create** either *Link to Petrel** or *OpendTect Copy.* Note that the *Link to Petrel option,* requires Petrel License to be able to use the Horizon in OpendTect.
4. **Keep** the default parameters. **Tick** *Use Original Name Horizon* and **Hit** Run.

OpendTect project is based on a particular 3D survey set up. Petrel 3D horizons associated with 3D seismic surveys which geometries are different and Petrel* surfaces based on grids which are different are snapped to an OpendTect grid during import.*

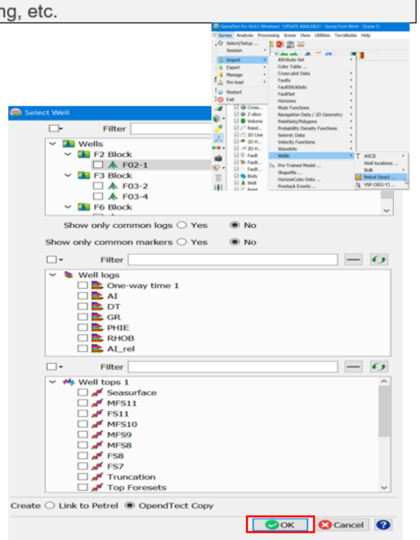
* *Petrel is a mark of Schlumberger*

Exercise objective:

Use PetrelDirect to import **Wells** from Petrel* to OpendTect.

Petrel well data (deviation survey, time-depth model, logs and well tops) can be accessed in OpendTect by clicking on PetrelDirect insert icon in the following places:
- *Manage Well* window (*Survey > Manage > Wells...* or click on icon in the *Manage Data* toolbar)
- *Load Well(s)* window when adding well(s) to the 3D scene or Basemap by right click on *Well* in the tree > *Add*)
- Other workflows, including well-to-seismic tie, Log attribute definition and processing, etc.

Workflow:



1. **Perform** the same steps as in Exercise 2.1.1b to set up an OpendTect project using PetrelDirect.
2. **Select** Survey < Import < Wells < PetrelDirect. **Select** the Wells(s) from the *Import Petrel Well* window.
3. **Create** either *Link to Petrel** or *OpendTect Copy.* Note that the *Link to Petrel option,* requires Petrel License to be able to use the Wells in OpendTect.
4. **Keep** the default parameters and **Hit** OK.

Selection of well logs and markers can be done using the Filters, Show only common logs/markers switch, then Select buttons.

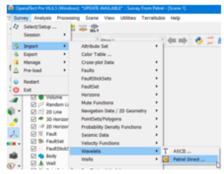
* *Petrel is a mark of Schlumberger*

Exercise objective:

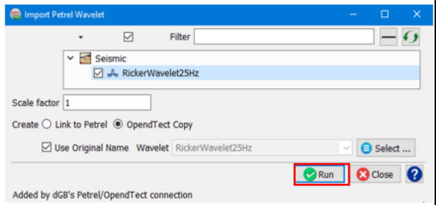
Use PetrelDirect to import **Wavelet** from Petrel* to OpendTect.

Petrel* wavelets can be accessed in OpendTect by clicking on PetrelDirect insert icon in the following places:
• *Manage Wavelets* window (*Survey > Manage > Wavelets* or click on icon in the *Manage Data* toolbar)

Workflow:



1. **Perform** the same steps as in Exercise 2.1.1b to set up an OpendTect project using PetrelDirect.
2. **Select** Survey < Import < Wavelets < PetrelDirect. **Select** the Wavelets (s) from the *Import Petrel Wavelet* window.
3. **Create** either *Link to Petrel** or *OpendTect Copy.* Note that the *Link to Petrel option,* requires Petrel License to be able to use the Wavelet(s) in OpendTect.
4. **Keep** the default parameters *and* **Hit** Run.



* *Petrel is a mark of Schlumberger*

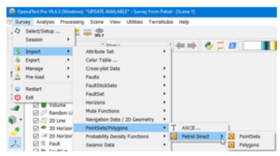
Exercise objective:

Use PetrelDirect to import **Pointsets and Polygons** from Petrel* to OpendTect.

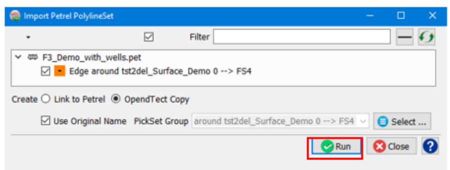
Petrel pointsets and polygons can be accessed in OpendTect by clicking on PetrelDirect insert icon in the following places:

• Manage Pointset/Polygons Windows (*Survey > Manage > Pointsets/Polygons*... or click on the icon in the *Manage Data* toolbar). When adding from PointSet/Polygon manager, user will have a selection box to choose which kind of object they want to import from Petrel*
• *Load Pointsets (Polygons)* window when adding pointsets (polygons) to the 3D scene or Basemap by right clicking on *Pointsets (Polygons)* in the tree > *Add*). The relevant dialog box pops up.

Workflow:



1. **Perform** the same steps as in Exercise 2.1.1b to set up an OpendTect project using PetrelDirect.
2. **Select** Survey < Import < Pointsets/Polygons < PetrelDirect < Polygons (or Pointsets). **Select** the Polygons (s) from the *Import Petrel Polygons* window.
3. **Create** either *Link to Petrel** or *OpendTect Copy.* Note that the *Link to Petrel option,* requires Petrel License to be able to use the Polygons/Poinsets in OpendTect.
4. **Keep** the default parameters, Use Original Name *and* **Hit** Run.



* *Petrel is a mark of Schlumberger*

2.1.2 Basemap

What you should know about the basemap

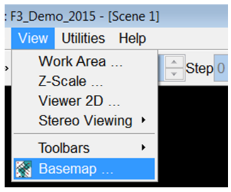
The basemap utility in OpendTect Pro is a new module for interacting with the data while presenting a clear overview of the interpretation exercise at hand. From the basemap the user populates a 3D scene with data elements (inlines, cross-lines, random lines, 2D seismic lines, Z-slices, horizons, wells, etc.) and / or pops up 2D viewers. The module also features options for gridding / contouring and for creating final maps. As the module is brand new in version 6.0 some functionality will evolve as the product matures over time.

2.1.2a Basemap

Required licenses: OpendTect Pro.

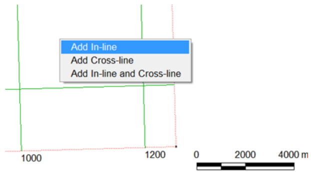
Exercise objective:

Use the Basemap to populate/manipulate the 3D scene.

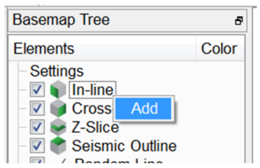


1. **Pre-load** *4. Dip steered median filter* (optional, see Exercise 1.3.1b for details).

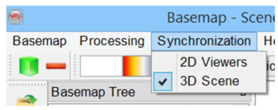
2. To open the basemap, **click** on the icon or **go to** View > Basemap.



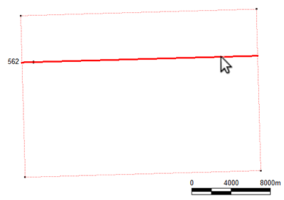
3. **Add** an inline to the basemap and the 3D scene*. This can be done in 3 ways:
   a) **Press** (once) **keyboard I** and drag the line to the correct position : the line number is shown in the tree and in the lower left corner.
   b) **Move** the cursor in the basemap to the correct position; **right-click** and **Add Inline**.
   c) **Right-click** in the basemap tree > Add.



The basemap can be used: 1) to populate a 3D scene; 2) to pop up 2D viewers; and 3) as standalone utility, e.g. when creating output maps. All options are controlled from the Synchronization menu.



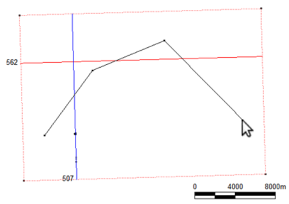
Workflow cont'd:



4. **Move** the inline to a new position: **hover** over the inline until it shows up in bold; **left-click** and **drag** to the new position*.

5. **Add** a crossline with **pressing** (once) keyboard C.

6. **Add** a random line **pressing** keyboard R; **Left-click** to add corner points and **double-click** to end the line.

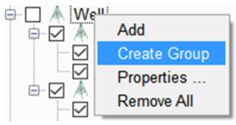


To insert a new node after the random line is drawn:
Hover over the random line until it shows up in bold and then **shift + click**.
To delete a node **ctrl + click** on it.

*If the basemap is synchronized with the 3D scene (as in this exercise) you can also re-position elements using all options supported in the 3D scene, e.g. Inl 562 Step 1 .

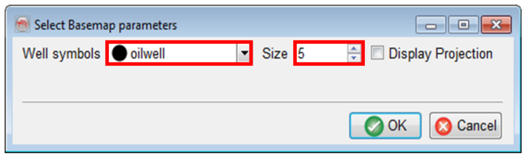
Workflow cont'd:

7. **Right-click** on Well in the basemap tree and **select** Create Group.

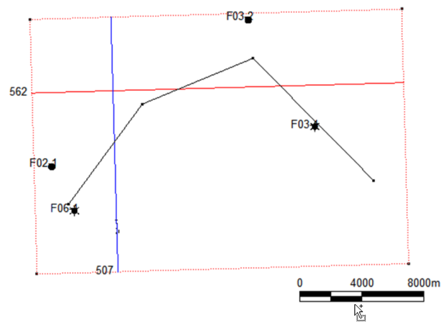


8. **Add** *F02-1* and *F03-2* to the group.

9. **Right-click** on the Group and **select** Properties.
For the sake of the exercise let's assume these wells are oil wells: **select** the corresponding Well symbol and **change** size to 5.

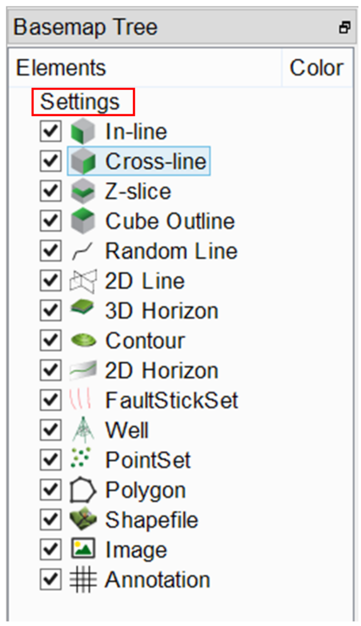


10. **Repeat** the exercise for *F03-4* and *F06-1*: **Give** another well symbol to these two, say oil and gas.

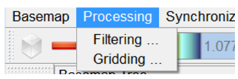


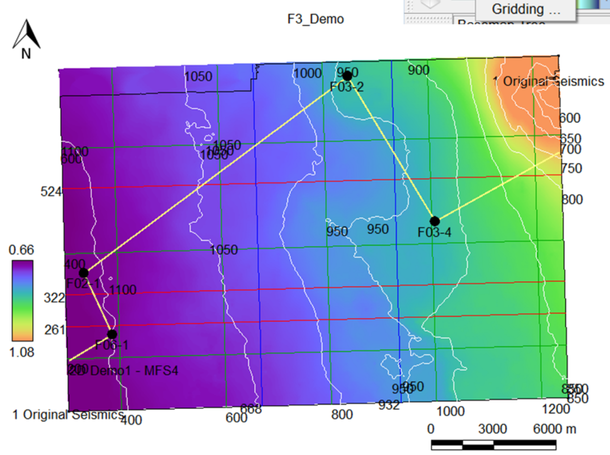
Workflow cont'd:

11. **Add** other elements (horizon, contour, shapefiles, …) and **change** the basemap settings (**right-click** on Settings).



12. To create final maps you can process your horizon before printing: under the **Processing** menu you will find options for filtering or gridding.





2.1.3 PDF3D

What you should know about PDF3D

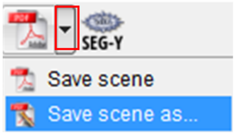
The PDF3D plug-in supports the capture of a 3D scene in OpendTect and to save the captured information in PDF format. The 3D PDF file can then be viewed, rotated, zoomed, and manipulated in Adobe's free Acrobat Reader software that is installed on most computers. PDF3D thus greatly improves communication of complex seismic interpretations. The PDF3D plug-in to OpendTect allows volume sections, horizons, wells and interpretation features to be embedded within a secure technical report.

2.1.3a PDF3D

Required licenses: OpendTect Pro.

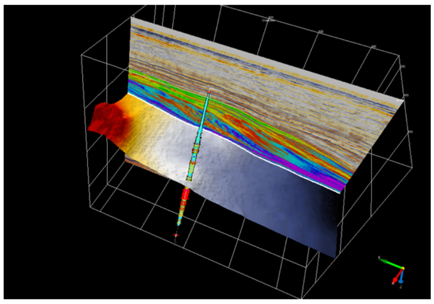
Exercise objective:

Grab a 3D scene with PDF-3D for sharing via Acrobat Reader

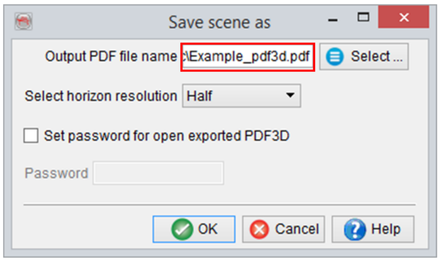


Workflow:

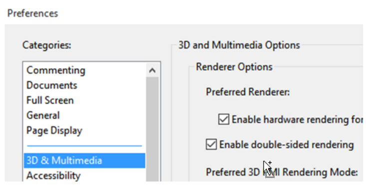
1. Prepare the scene you wish to capture and **press** the drop down sign adjacent to PDF-3D icon. **Select** Save scene as…



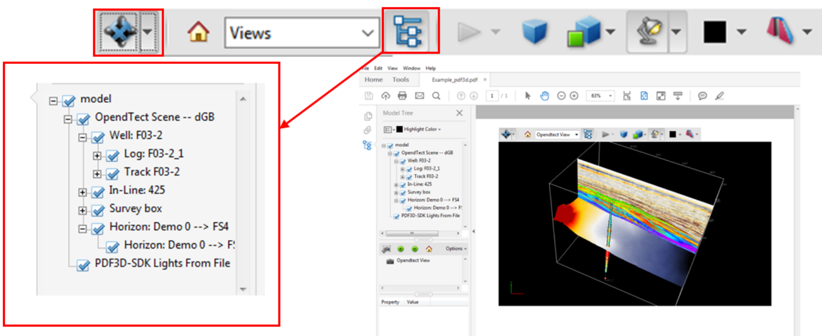
2. **Specify** the Output PDF file name (e.g. *Example_pdf3d)* and **select** Half the resolution for the horizons.



Workflow cont'd:



3. **Open** the file in Acrobat Reader v8 (or higher).
4. Ensure that double-sided rendering is enabled.
5. **Use the left most icon** on the toolbar to zoom, pan, rotate etc.
6. **Use the tree** to toggle elements on and off.



2.1.4 Thalweg tracker

What you should know about the Thalweg tracker

A Thalweg is a geologic term to describe the path of a river as it flows through a valley (Thalweg is a German word; Thal means valley and Weg is path). A Thalweg tracker operates in a similar way: it follows the path of least resistance. It does this by adding only the best matching position per iteration. The tracker can be used to track 3D bodies and / or horizons and is typically used for detailed seismic facies mapping e.g. for tracking channels.

The Thalweg tracker tracks samples in an input seismic cube based on certain user-specified constraints. Initially the user points a single seed position. The seed is considered to be a cube of unit size and the next sample to be tracked is chosen from all available samples along the 'faces' of the seeds. In the first iteration, all six neighboring samples along the six faces of the initial seed act as candidates for tracking. Only the best matching position is added. In the next iteration, all samples neighboring the two currently accepted positions now act as candidates and again only the best matching position is added. This process continues until it is no longer possible to add candidates that meet the tracking constraints.

A Thalweg tracker adds only one position per iteration. If you choose to accept more than one position per iteration, the Thalweg tracker becomes a margin tracker. Thalweg and margin trackers are typically used sequentially. For example in the exercise hereafter we first use the Thalweg tracker to track a channel. Once the channel is found we change the settings to track the channel margins.

The output of a Thalweg tracker is a Point Set that is typically converted into a "snapped" horizon. All tracking attributes can be saved with the horizon tracked in this way. The tracking attributes can also be used for further analysis in the Crossplot tool.

2.1.4a Thalweg Tracker

Required licenses: OpendTect Pro.

Exercise objective:

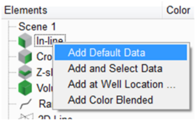
Track a channel (and its associated margins) using the Thalweg tracker.

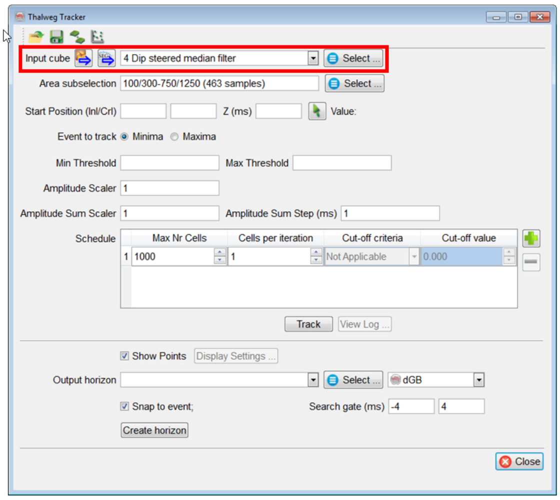
Workflow:

1. **Add** an inline with default data in the scene.

2. **Launch** the Thalweg tracker from the Analysis menu (Analysis > Thalweg tracker) or **click** on icon.

3. The default data volume for this survey will appear automatically in the Input Cube field.



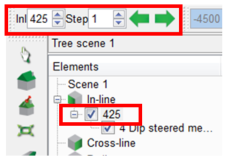


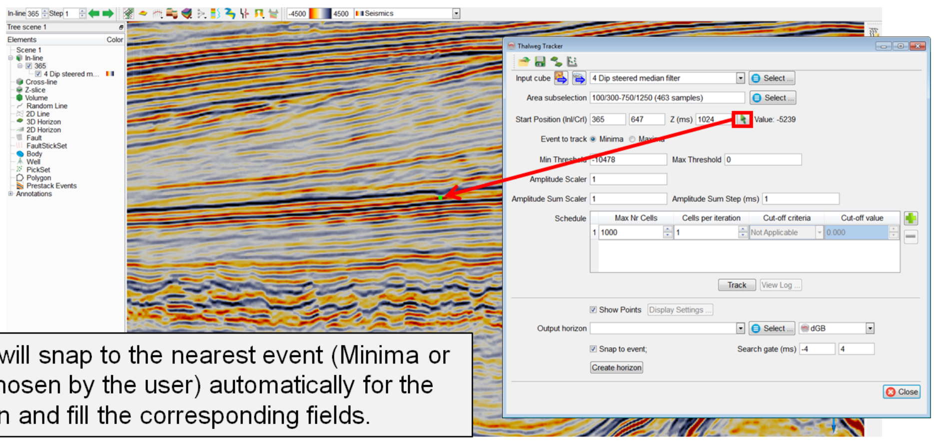
The Thalweg tracker is not a conventional tracker: it is using a weighted voxel approach to track seismic facies.
Hence it is not limited to map channels.

Workflow cont'd:

4. **Move** the inline to 365: **click** on the inline 425 and **type in** 365 in the Slice Position toolbar, or **use** the basemap and **drag** the inline to the wanted position.

5. **Pick** an event: **press** icon and **pick** a seed at crossline 647 at 1024ms.





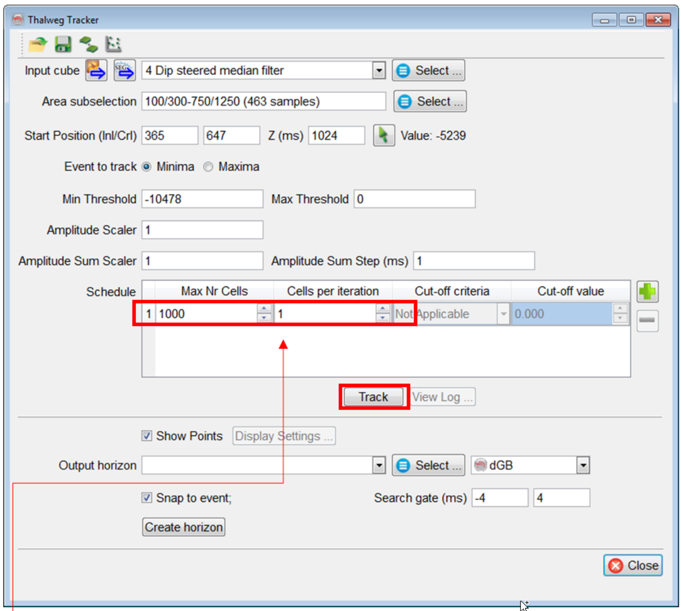
The software will snap to the nearest event (Minima or Maxima, as chosen by the user) automatically for the picked position and fill the corresponding fields.

Workflow cont'd:

6. **Keep** default values for Amplitude Scaler, Amplitude Sum Scaler and Amplitude Sum Step (ms).

7. Schedule: **set** the values as shown in this screenshot.

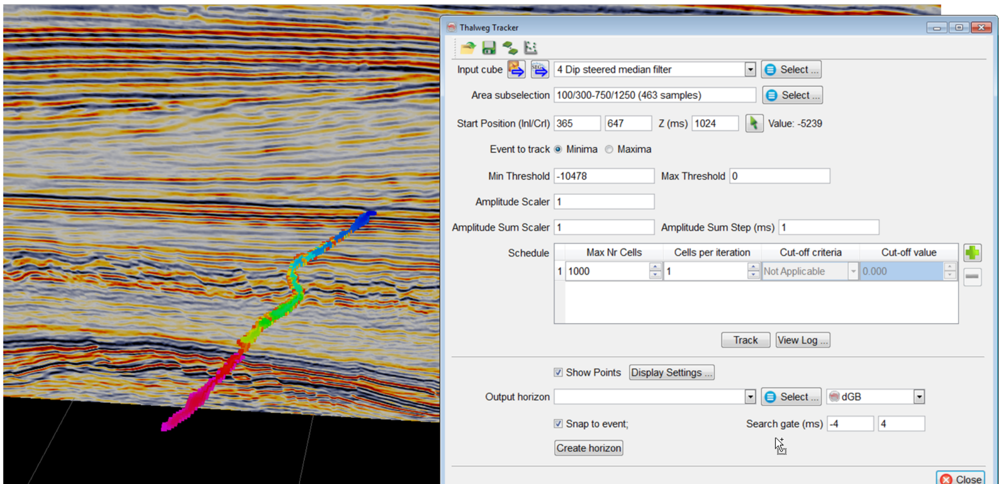
8. **Press** the Track button to start reading the input volume and tracking.



The first row of the schedule table represents the thalweg settings e.g. Max Nr Cells = 1000 and Cells per iteration = 1.

Workflow cont'd:

9. Once the processing is finished, it will display the result as color-coded points.

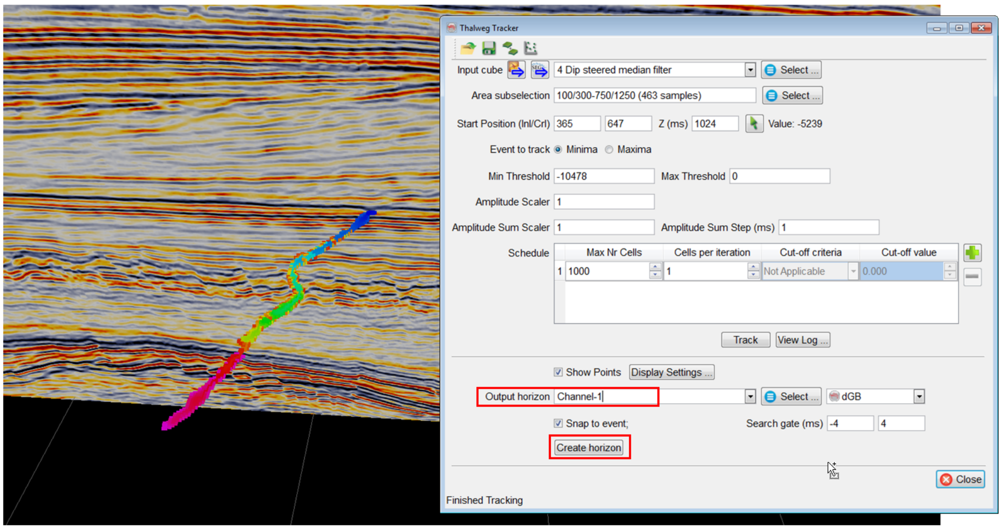


Output of the extracted channel.

Workflow cont'd:

10. If you are satisfied with the results, **specify** the Output horizon name. Optionally, **toggle on** Snap to event, to output a horizon snapped to the nearest Minima or Maxima in a user defined Search gate (default is [-4 +4] ms).

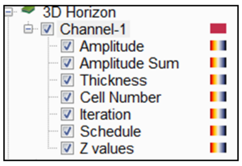
11. **Press** the Create horizon button.

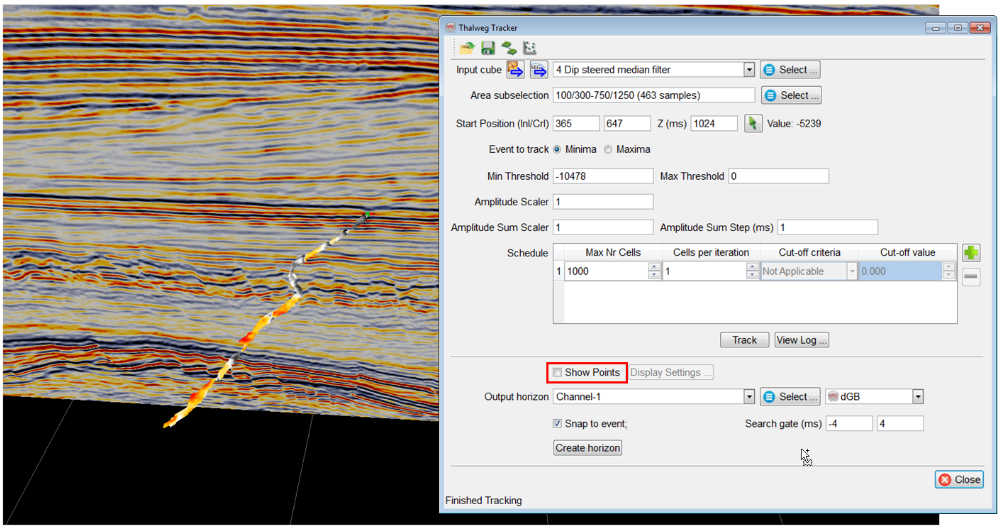


Workflow cont'd:

12. The horizon will appear in the tree as well as in the scene.

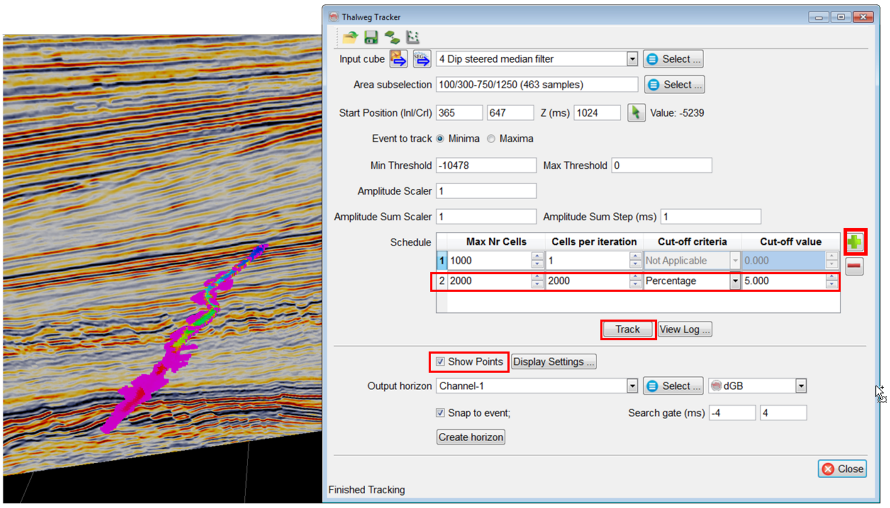
13. **Turn off** the Show points display.





Workflow cont'd:

14. To track the margins of the channel, **add** a second schedule step and set the parameters as shown in the figure. **Turn on** Show points and **press** the Track button to obtain the Thalweg and its associated margins.

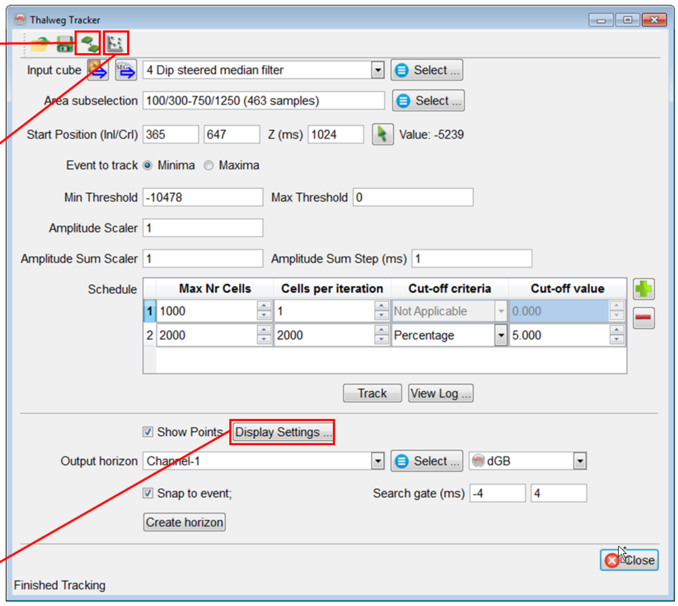


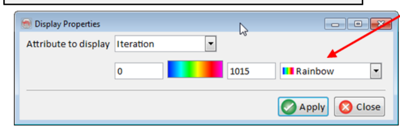
Workflow cont'd:

Several horizons can be created and **merged** into a single horizon.

Crossplot is a utility to perform analysis on the extracted dataset (e.g. if you use an acoustic impedance (AI) volume, you can analyze iterations with AI data).

Display Settings control the display and color coding of the points of various extracted attributes along the Thalweg.





2.1.5 Raytracer

What you should know about the Raytracer

OpendTect Pro's ray-tracer is a 1D ray-tracer that computes the angle of incidence at various interfaces in an elastic, horizontally-layered earth model. The ray-tracer is used among others by the SynthRock plug-in to compute pre-stack synthetics (P, S, and multiples). OpendTect Pro users do not need a SynthRock license to make good use of the ray-tracer. Ray-tracing is used in the conversion from offsets to angles e.g. when computing mute functions, angle stacks and AVA attributes.

2.2 Commercial Plug-ins

OpendTect supports free and commercial plug-ins. The latter are only available under the OpendTect Pro license. Commercial plug- ins are used for specialized and advanced tasks. dGB and 3rd party vendors ARKCLS, Estimages, The Visual Wavefield Project, Geo 5 and LTrace provide commercial plug-ins for OpendTect.

Unless you are working on the F3 Demo training data set commercial plug-in require FlexNet license-keys. You may wish to contact info@dgbes.com to request an evaluation license.

Users can create their own commercial OpendTect Pro system by picking and choosing the plug-ins they need. Logical sets of plug-ins have been combined into packages for typical G&G tasks. These packages are licensed at discounted prices. The following packages are available:

- **Geophysics: Attributes & Filters** This package contains OpendTect Pro and the following plug-ins: Dip Steering, Neural Networks, Faults & Fractures, Fluid Contact Finder, Seismic Spectral Blueing, Seismic Feature Enhancement, and Workstation Access.
- **Geology: Sequence Stratigraphy.** This package Contains OpendTect Pro and the following plug-ins: Dip Steering, HorizonCube, SSIS, Well Correlation Panel, Seismic Spectral Blueing, Neural Networks and Workstation Access.
- **Geophysics: Inversion & Rock Properties.** This package contains OpendTect Pro and the following plug-ins: Dip Steering, HorizonCube, Deterministic Inversion, Stochastic Inversion, Seismic Coloured Inversion, Seismic Spectral Blueing, Seismic Net Pay, SynthRock, Neural Networks, and Workstation Access.
- **Geoscience.**This package contains OpendTect Pro and the following plug-ins: Dip Steering, HorizonCube, SSIS, Well Correlation Panel, Neural Networks, Faults & Fractures, Fluid Contact Finder, SynthRock.

This manual follows a similar sub-division for training the commercial parts of the software:

- Attributes & Filters.
- HorizonCube & Sequence Stratigraphy.
- Seismic Predictions.

Before starting the training exercises let’s first give short descriptions of the commercial plug-ins per software vendor.

2.2.1 dGB Plug-ins

As well as creating the open-source OpendTect software itself, dGB Earth Sciences also develops closed-source plug-ins for OpendTect. See: dGB website.

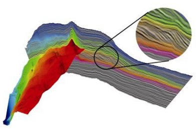
Dip-Steering

The dip-steering plug-in 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*

HorizonCube

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).



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.

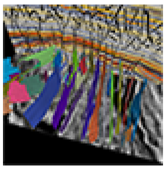
Well Correlation Panel

The *Well Correlation Panel* plug-in 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.

Neural Networks

The *Neural Network* plug-in 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.).

Faults & Fractures



The *Faults & Fractures* plug-in supports special attributes, filters and tools for analyzing faults and fractures. Included are among others: Thinned Fault Likelihood, Smoothed Seismic, Un-faulting, automatic fault-plane extraction, fracture density and fracture proximity. In combination with dip-steering also: dip-steered attributes and filters (SOF), and curvature attributes.

Sequence Stratigraphic Interpretation System (SSIS)

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

Fluid Contact Finder

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

Velocity Model Building

The VMB plug-in 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).

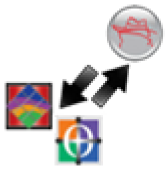
SynthRock

The SynthRock plug-in 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.

2.2.2 ARK CLS & Earthworks Plug-ins

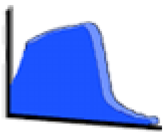
ARK CLS make the following commercial plug-ins for OpendTect. See: ARK CLS website.

Workstation Access



The *Workstation Access* plug-in is used for direct data access to and from OpenWorks/SeisWorks and GeoFrame-IESX.

Seismic Spectral Blueing



The *Seismic Spectral Blueing* plug-in 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.

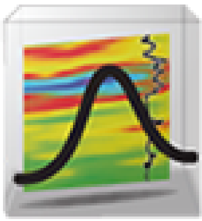
Seismic Colored Inversion

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

MPSI Deterministic 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.

MPSI Stochastic Inversion



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.

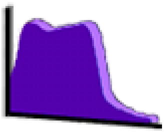
Seismic Net Pay

The *Net Pay* plug-in 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.

Seismic Feature Enhancement

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

Frequency Shaping



Frequency Shaping is an innovative technique that integrates well data into your seismic analysis. Two operators are simultaneously derived using acoustic impedance logs and reflectivity, once applied to the seismic data they effectively broaden the amplitude spectrum of the seismic data at both ends, low and high.

Spotlight

Spotlight adds quantitative interpretation capabilities to the standard SCI workflow by rapidly combining up to 4 different coloured seismic datasets into a single cube that resembles the behaviour of a given elastic attribute. The relationship between the input data and the desired output is established from prior well log analysis.

2.3 Attributes & Filters

OpendTect's attribute engine can be extended with various plug-ins that allow computation of advanced attributes and filters. As OpendTect's user interface is built dynamically, information about plug-ins (and certain attribute options in the user interface) is only visible if the plug-in is installed and a valid license key is available. (As stated before this is no issue when working on F3 Demo).

In this Chapter you will learn how to:

- Remove random noise (Dip-Steering).
- Sharpen edges (Faults & Fractures, Dip-Steering).
- Visualize faults (Faults & Fractures, Dip-Steering).
- Extract fault bodies (Faults & Fractures)
- Extract Fault planes (Faults & Fractures)
- Enhance the vertical resolution (Spectral Blueing).
- Enhance amplitude anomalies (Optical Stacking (free), Fluid Contact
- Finder, Seismic Feature Enhancement).
- Visualize seismic patterns (Neural Networks).
- Create a Chimney Cube (Neural Networks).

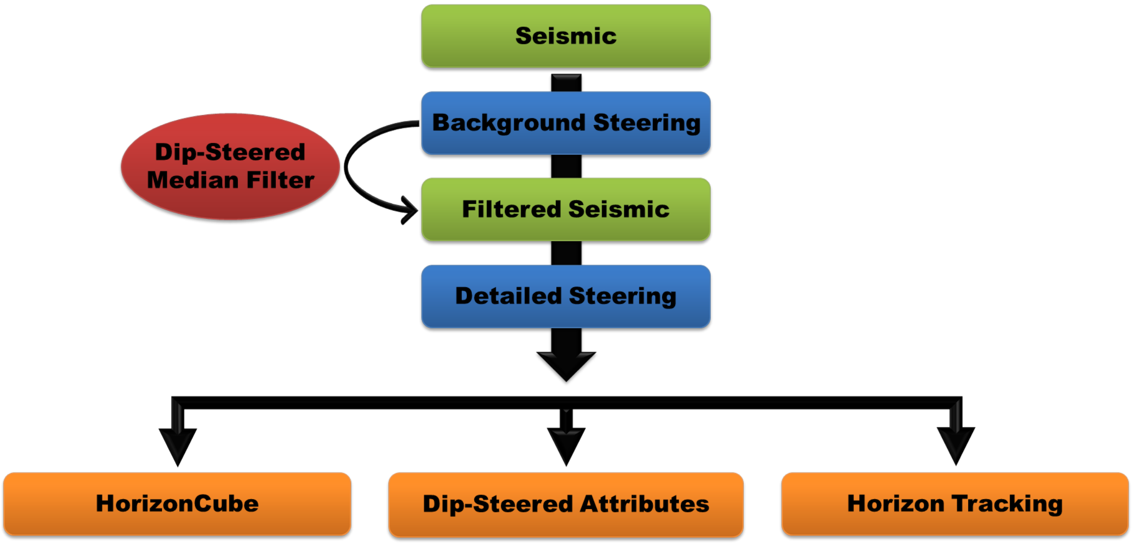
2.3.1 Dip-Steering

What you should know about Dip-Steering

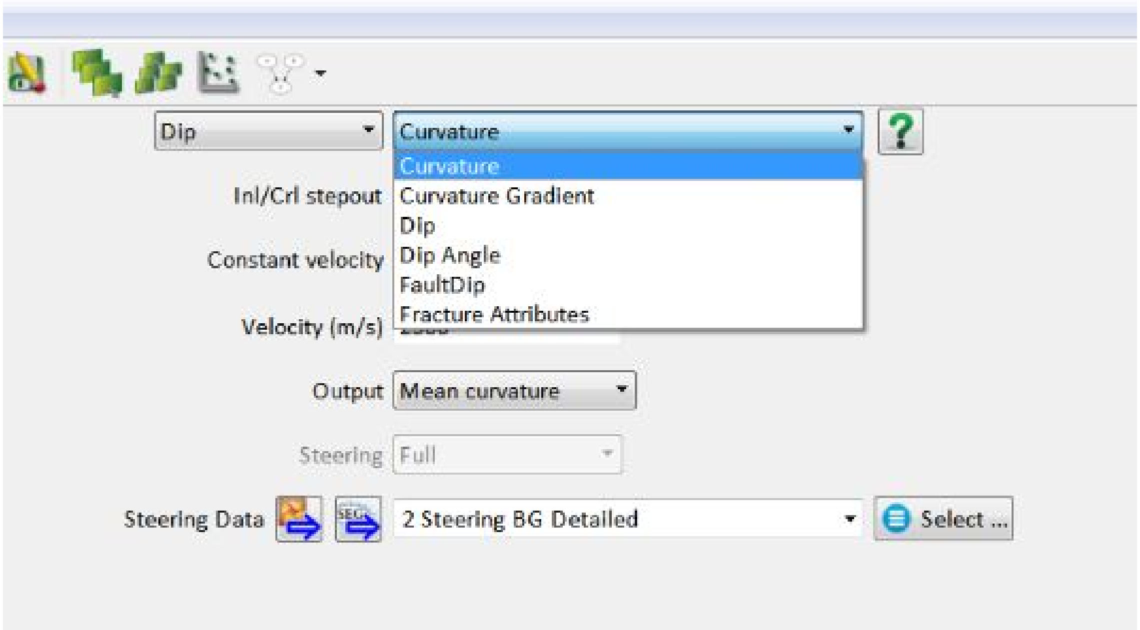
The dip-steering plug-in allows you to create and use a (Dip-) SteeringCube. A SteeringCube contains at every sample position the dip in the inline- and cross-line directions of the seismic events. These dips can be displayed as overlays on seismic sections. Please note that you should display the cross-line dip on an inline and the inline dip on a cross-line (right-click menu in the tree). In 2D, the SteeringCube contains the apparent dip in the line direction.

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 HorizonCube.



From a SteeringCube several valuable attributes can be computed. Most of these attributes, which require SteeringCube are grouped under type *Dip* inside OpendTect's attribute set.



For example, OpendTect supports computation of a whole family of **volume curvature attributes**. These attributes are useful in the interpretations of fractures, geo-morphological features and drainage patterns. Other attributes that can be computed from a SteeringCube are:

- 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.

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 called '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 (left to right): Original Seismic (Full stack), Detailed Steering and Background Steering

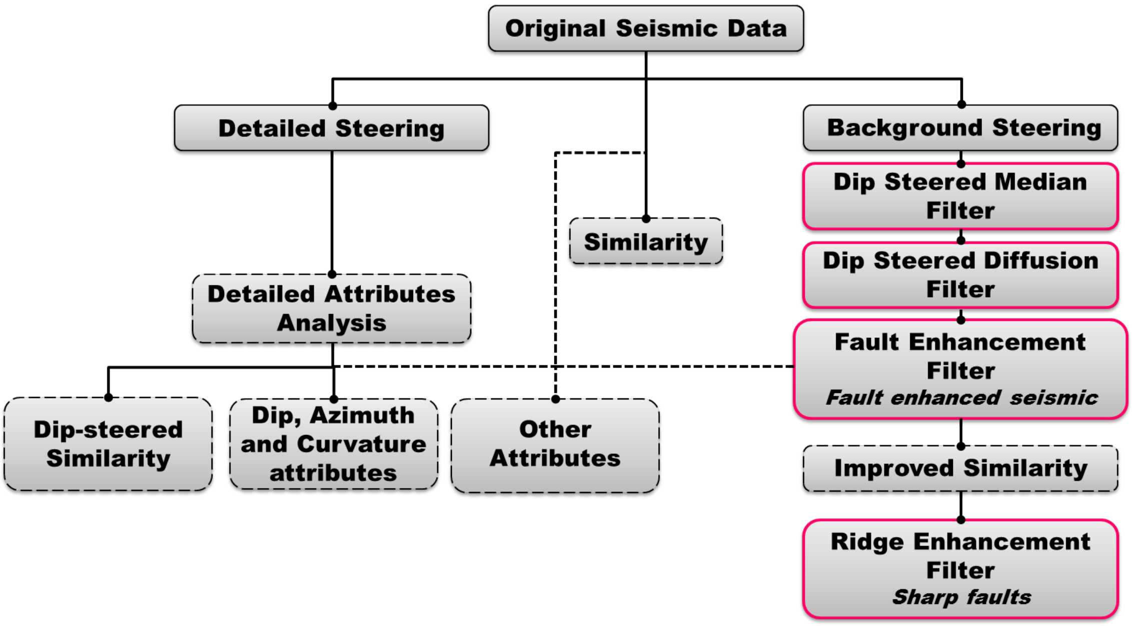
These Steering Cubes have distinct applications:

Detailed SteeringCube

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

Background SteeringCube

- Dip Steered Median Filter
- Diffusion and Fault Enhancement Filter
- Ridge Enhancement Filter



In OpendTect there are two different algorithms available for creating SteeringCubes (e.g. BG Fast Steering and FFT). Coming few exercises will be carried out using the BG Fast Steering algorithm (based on the phase of seismic signal). More information about the SteeringCube can be found in the dGB Plug-ins Documentation: UserDoc.

2.3.1a Steering Cube

Required licenses: OpendTect Pro, Dip Steering.

Exercise objective:

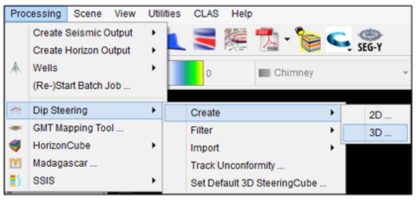
Compute a SteeringCube.

Workflow:

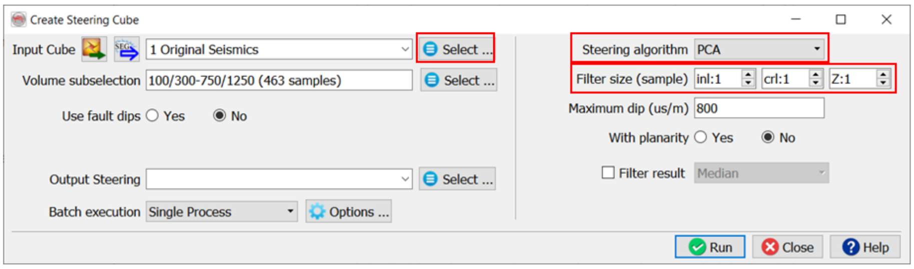
1. **Bring up** the Create Steering Seismics window: **Processing > Dip Steering > Create > 3D.**

2. **Select** *1 Original Seismics* as input.

3. **Keep** the default calculation stepout for the PCA steering algorithm 1,1,1.

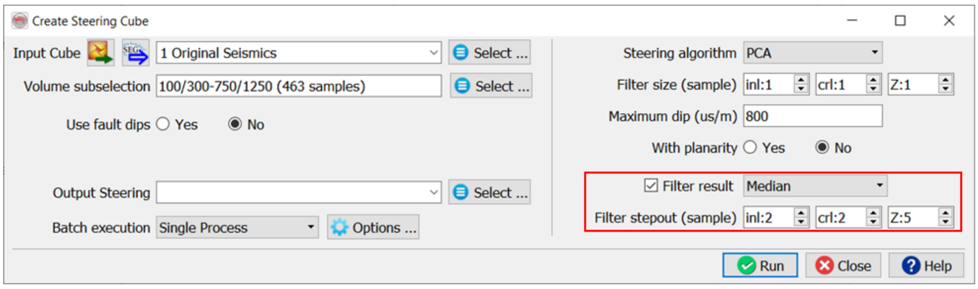


With a calculation stepout of 1,1,1; the dip is computed within a small cube of 3x3x3 samples around each sample in consideration.



Workflow cont'd:

4. **Specify** a stepout of 2,2,5 to apply a median filter on the raw dips.



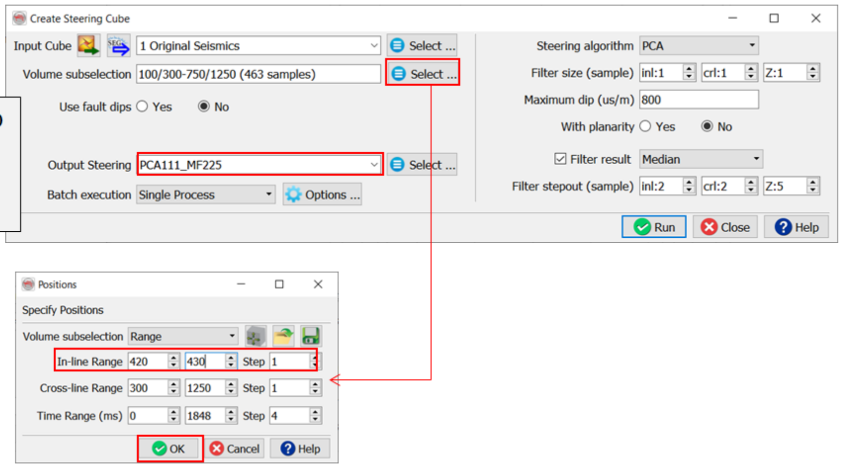
When adding **Planarity**, the output steering cube contains an additional Planarity component along with the Inline Dip and Crossline Dip. The Planarity attribute returns the quality of the steering cube and is used by Unconformity Tracker, Inversion + tracker and for HorizonCube creation.

Workflow cont'd:

5. **Set** Volume Subselection for only 10 in-lines, e.g. between 420-430, to save time run this process .

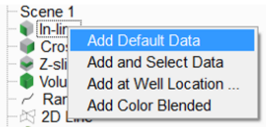
6. **Give** the output SteeringCube a name (e.g. *PCA111_MF225*) and **click** OK.

Tip: It's recommended to use the SteeringCube parameters in its name, as done in this exercise.

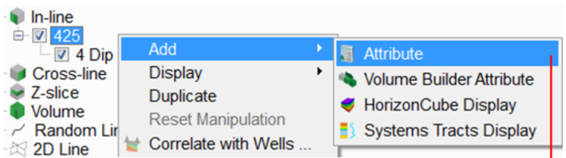


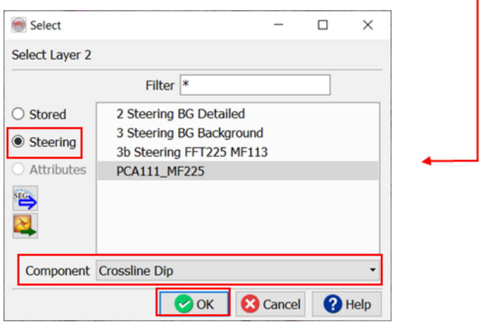
Workflow cont'd:

7. **Add** default data (i.e. *4 Dip steered median filter*) by **right-clicking** on inline 425.



8. Once again **right-click** on inline 425 to display the Detailed SteeringCube (**select** *PCA111_MF225* from Steering tab).

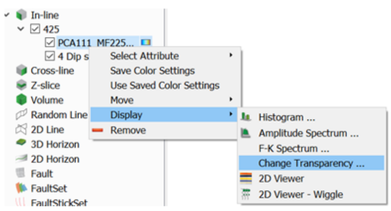


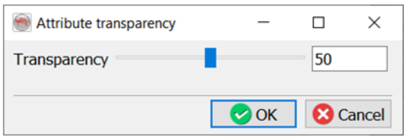


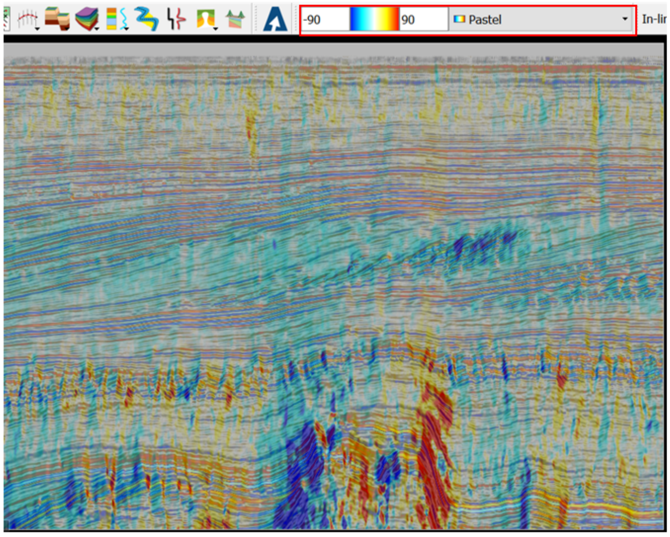
Tip: It's recommended to display the Crossline dip component of the SteeringCube on an inline and vice-versa.

Workflow cont'd:

9. **Use** the *Pastel* color-bar.
10. To co-visualize seismic and cross-line component of dip, **right-click** on the PCA111_MF225 in the tree > Display > Change Transparency and **set** the transparency to 50%.

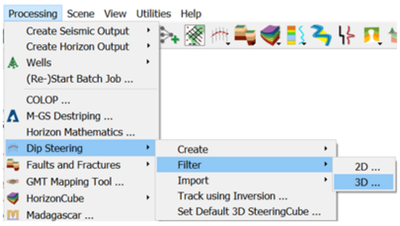


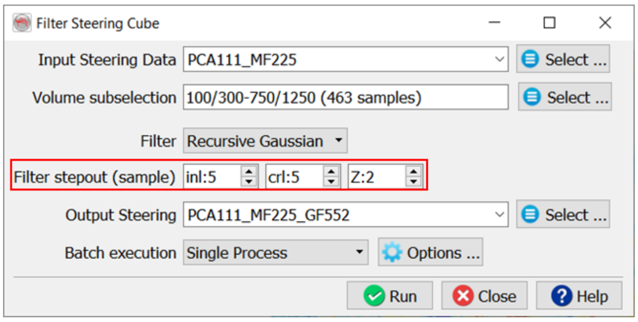




Workflow cont'd:

11. Additional step: **Go to** Processing > Dip Steering > Filter > 3D and apply Recursive Gaussian filter using the stepout of 5, 5, 2 to achieve smoothly looking results.





Tip: **Recursive Gaussian filter** is extremely fast and is available for all OpendTect Pro users. If you're using a free version of OpendTect, for additional smoothing we recommend applying the **Average filter**, instead of the Median one. Median filter was already applied during the steering cube computation to remove spikes (step 5 of this exercise).

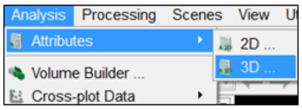
2.3.1b Dip & Azimuth

OpendTect Pro, Dip-steering

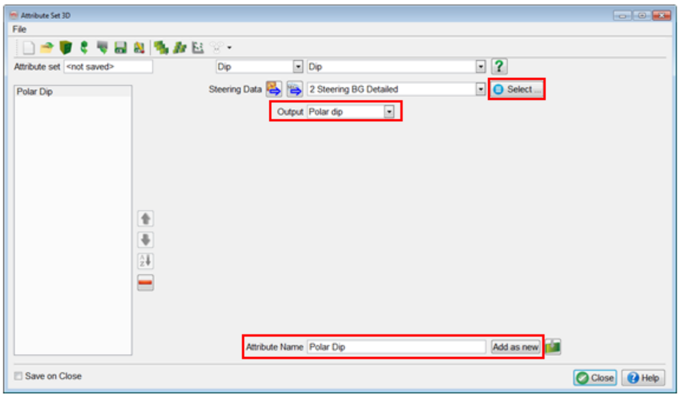
Exercise objective:

Compute Dip and Azimuth attributes from a SteeringCube.

Workflow:

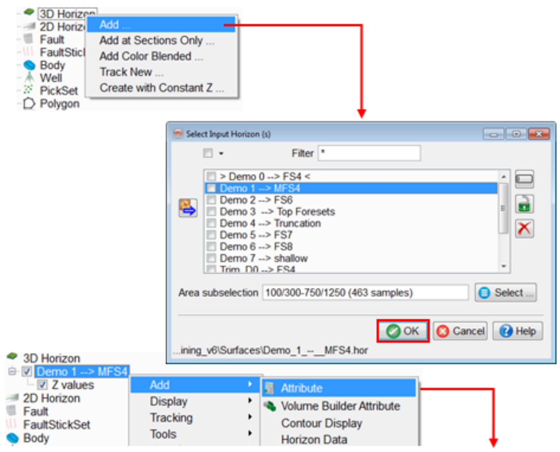


1. Go to the Attribute engine: Analysis > Attributes > 3D or click on the icon > 3D
2. In the attribute set window, select Dip attribute.
3. Select *2 Steering BG Detailed* as input and Polar dip as output.
4. Specify a name for the attribute (e.g. *Polar Dip*) and Add as new (optionally save it).

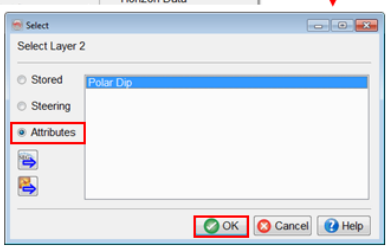


Workflow cont'd:

5. In the 3D scene, Load horizon *Demo 1 --> MFS4* by right-clicking on 3D Horizon in the tree.



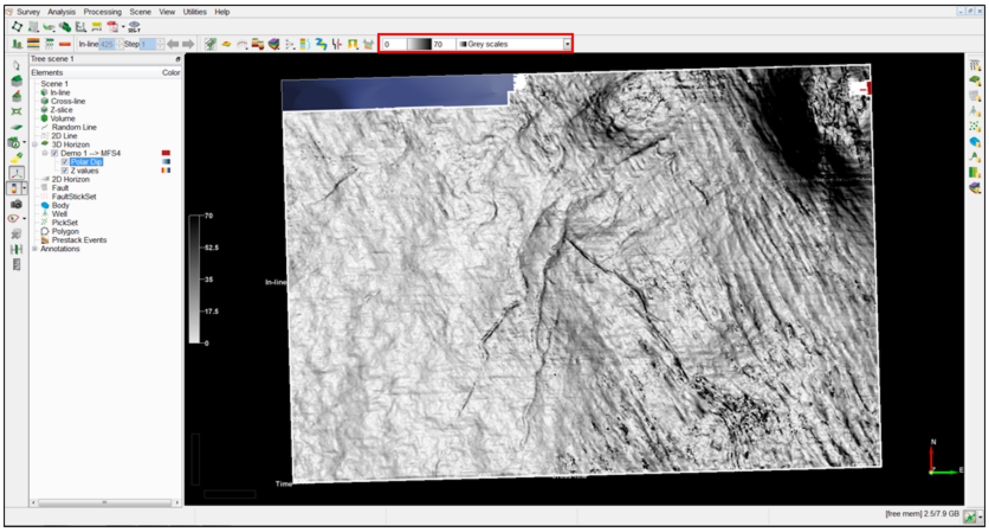
6. In the tree, right-click on the loaded horizon and follow Add > Attribute : select the Polar dip attribute. The attribute is calculated on-the-fly.



Alternatively, you could process the *Polar Dip* attribute as horizon data and afterwards add it (see the section on Spectral Decomposition).

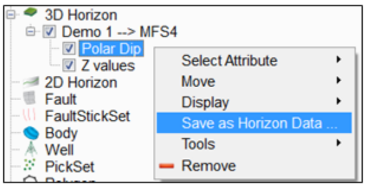
Workflow cont'd:

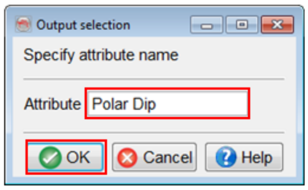
7. **Change** the colorbar to *Grey scales* and the range to 0 to 70.



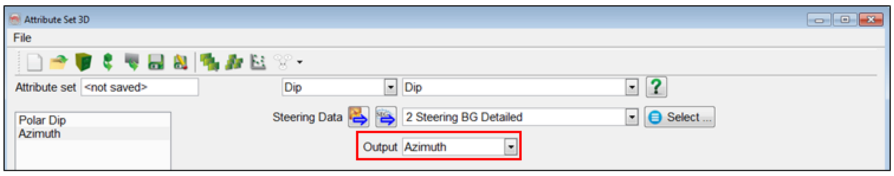
Workflow cont'd:

8. **Save** the attribute to the disk by **right-clicking** on it's name (i.e. *Polar Dip*), and selecting Save as Horizon Data.





Try displaying the *Azimuth* attribute in the same way as *Polar Dip*. What differences do you see between the two?



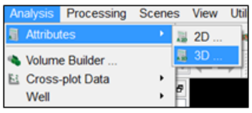
2.3.1c Dip-steered Similarity

Required licenses: OpendTect Pro, Dip-steering.

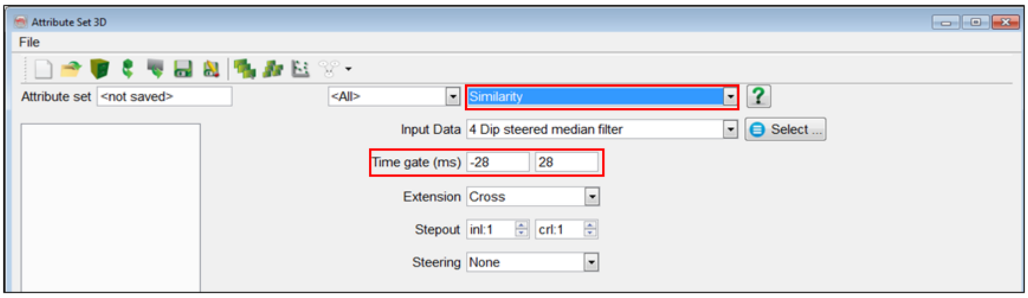
Exercise objective:

Compute a Similarity attribute with and without dip-steering.

Workflow:

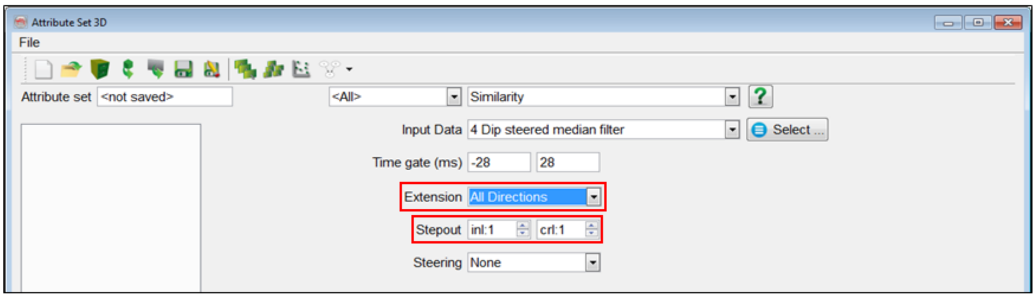


1. **Go** to the Attribute engine: Analysis > Attributes > 3D or **click** on the icon > 3D.
2. In the attribute set window, **select** Similarity attribute.
3. **Keep** the default Input Data *4 Dip steered median filter* and default time gate [-28 +28] ms.



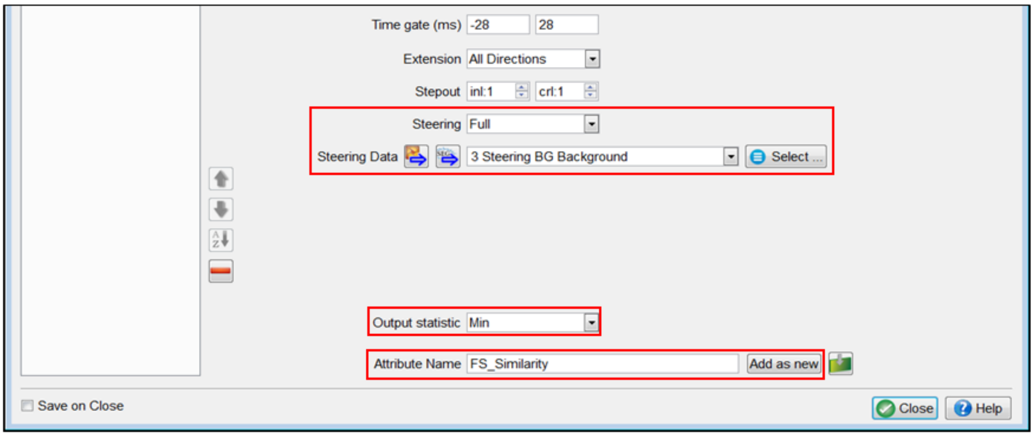
Workflow cont'd:

4. **Select** Extension: All Directions.
5. **Keep** the default stepout, i.e. inl:1; crl:1.



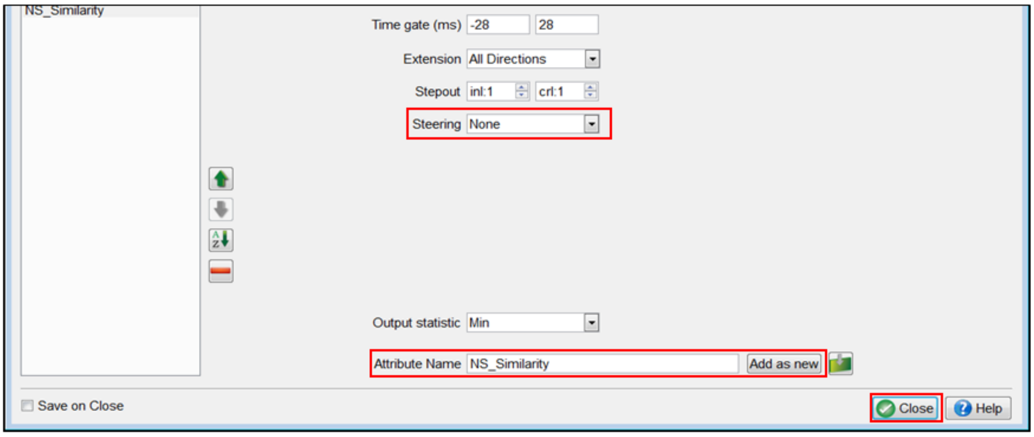
Workflow cont'd:

6. **Specify** Steering: Full and **select** *3 Steering BG Background*.
7. **Choose** Output statistics: Min.
8. **Give** a name (e.g. *FS_Similarity*) and **Add as new**.



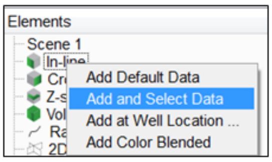
Workflow cont'd:

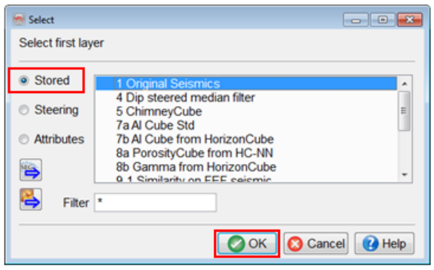
9. In a similar way, define a non-steered Similarity attribute by **selecting** Steering: None.
10. **Give** it a name (e.g. *NS_Similarity*) and **Add as new**. Optionally save the attribute set. **Click** on Close.



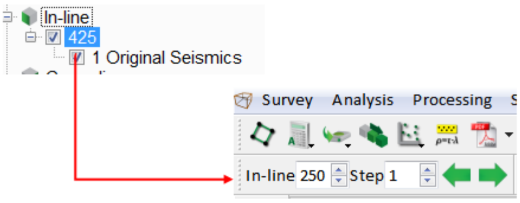
Workflow cont'd:

11. **Display** seismic data on inline 425 by **right-clicking** on In-line > Add and Select Data.
    Under the Stored tab **select** *1 Original Seismics*.



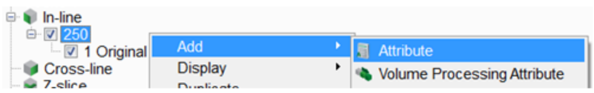


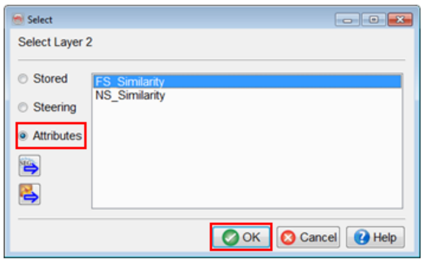
12. **Select** inline number 425 in the tree, **go** to the top toolbar, **change** it to 250 and **press** enter.



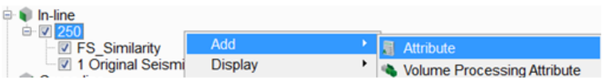
Workflow cont'd:

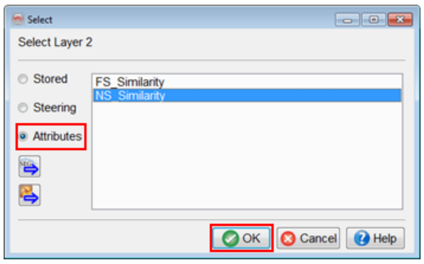
13. **Load** first the steered similarity attribute (i.e. *FS_Similarity*) by **right-clicking** on inline number 250 > Add > Attribute.





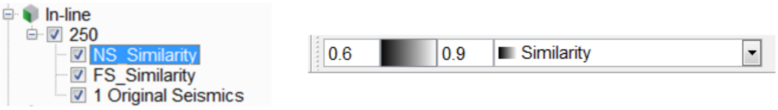
14. Similarly, **load** the non-steered similarity attribute (i.e. *NS_Similarity*).





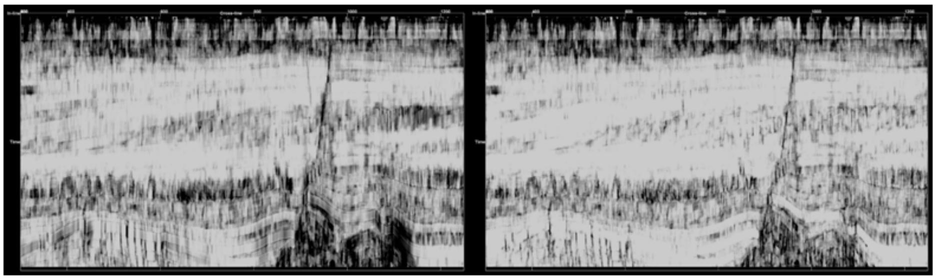
Workflow cont'd:

15. Change the color-bars of both the similarity attributes to *Similarity*.



16. Compare the two similarities by ticking on and off the upper attribute (here NS_Similarity).

What is the influence of dip-steering?



Inline 250: Non-Steered Similarity (left) and Steered Similarity (right)

2.3.1d Dip-steered Median Filter

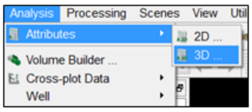
Required licenses: OpendTect Pro, Dip-steering.

Exercise objective:

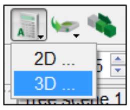
Remove random noise from the seismic data using Dip-Steered Median Filter (DSMF).

Workflow:

1. **Go** to the Attribute engine: Analysis > Attributes > 3D

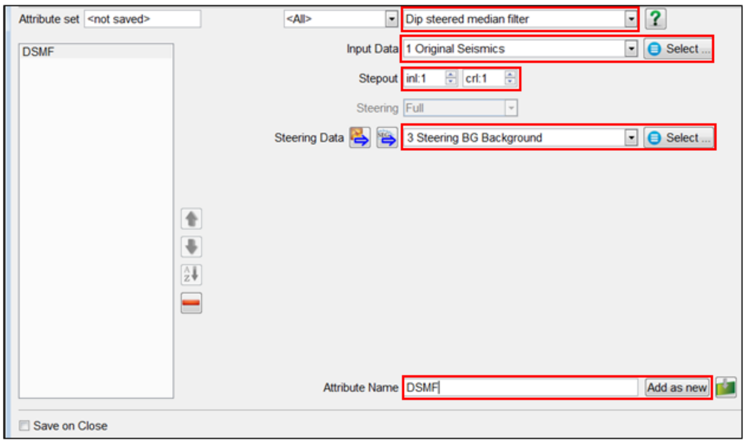


   or **click** on the icon > 3D.



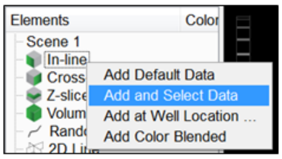
Workflow cont'd:

2. **Select** the attribute: Dip steered median filter.
3. **Select** Input Data: *1 Original Seismics*.
4. **Set** the step-out to 1, 1 (the optimal step-out will be evaluated later).
5. **Select** the Steering Data: *3 Steering BG background*.
6. **Give a name** (e.g. *DSMF* for Dip Steered Median Filter) and **Add as new**. Keep this attribute set window open.

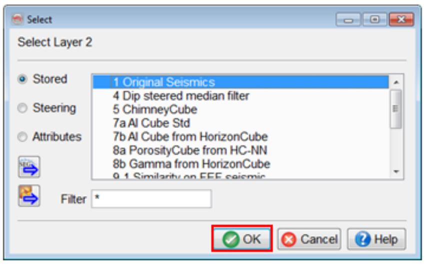


Workflow cont'd:

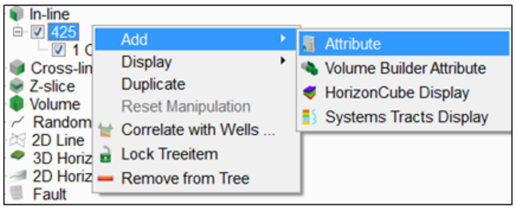
7. Now in the scene, in the tree, **right-click** on In-line and choose Add and Select Data.



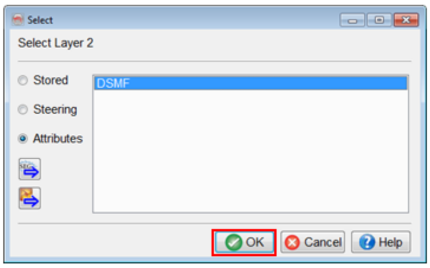
8. **Select** *1 Original Seismics* from Stored tab and **press** OK.



9. In the tree, **right-click** on inline number (i.e. 425): Add > Attribute.



Workflow cont'd:



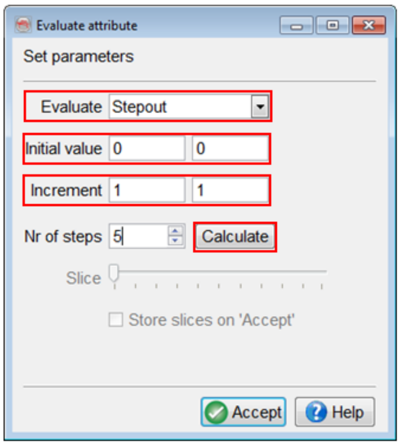
10. **Select** *DSMF* from Attributes tab.

11. **Go back** to the Attribute Set window and **click** the attribute evaluation tool icon to evaluate the step-out.

12. **Specify** Evaluate: Stepout.

13. **Set** the initial value "0-0", increment "1-1", and Nr of steps "5".

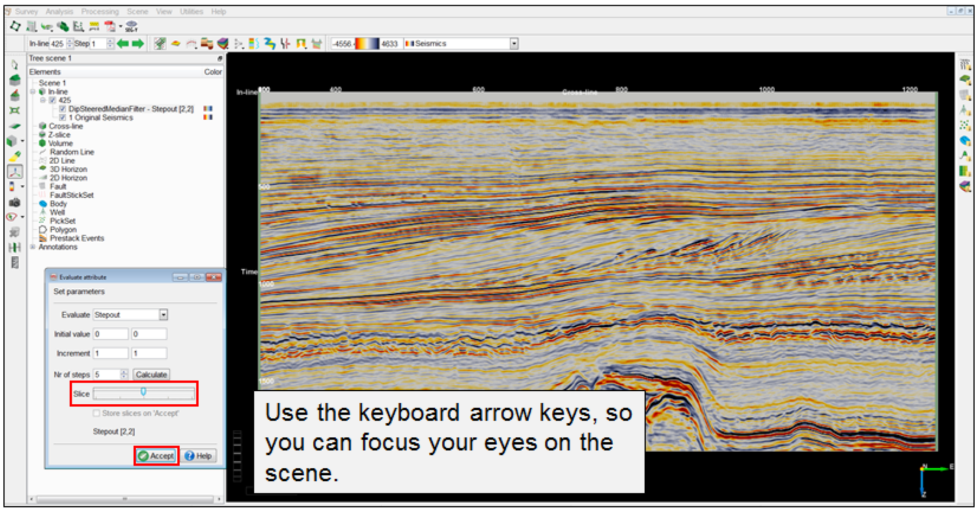
14. **Press** Calculate.



Workflow cont'd:

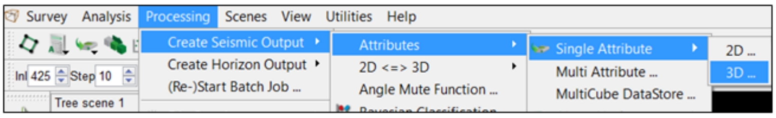
15. Once the computation is done, **move the slider** to change the stepout value and see the impact in the scene.

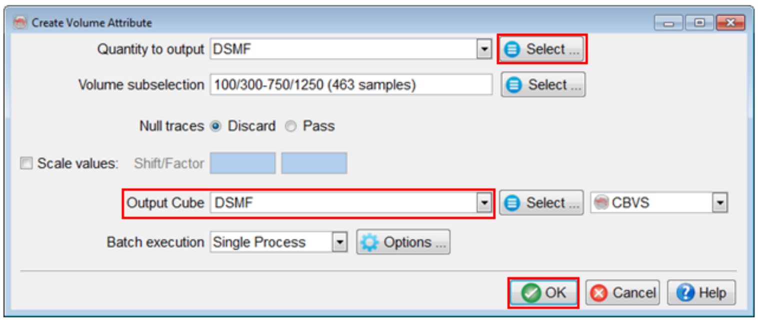
16. Assess which step-out is best (removing random noise, but not too much smearing)? Once chosen, **press** Accept and **close** the attribute set window.



Workflow cont'd:

17. If you are satisfied with the parameters, you may want to process the attribute definition as a volume. **Follow**: Processing > Create Seismic output > Attributes > Single attribute > 3D or **click** on the icon.





The processed attribute volume will appear as a Stored Cube (in Seismic Manager).

2.3.1e Mathematics

Required licenses: OpendTect.

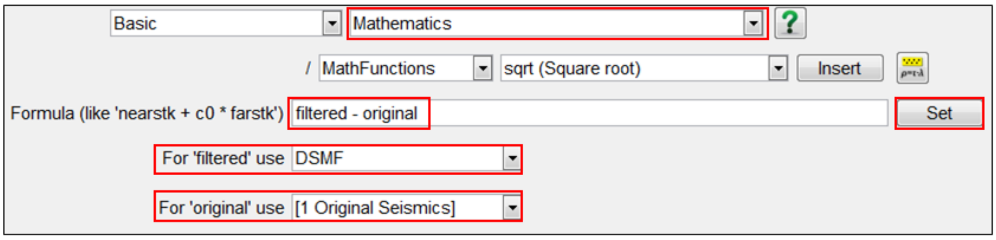
Exercise objective:

Analyze the noise removed by the Dip-Steered Median Filter using the Mathematics attribute.

Workflow:

Note: This exercise uses the attribute set from the previous exercise.

1. **Define** a new attribute (in addition to DSMF of previous exercise) of type Mathematics and **write** the formula: 'filtered – original' and **press** Set.

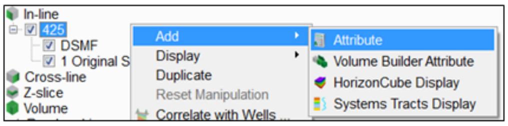


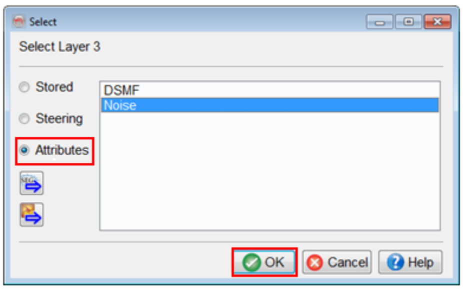
2. **Use** the previous attribute definition (i.e. *DSMF*) for filtered and the stored volume *1 Original Seismics* for original. **Give** the attribute a name (e.g. *Noise*) and **Add as new**.

Workflow cont'd:

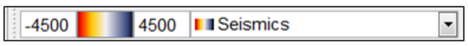
3. **Right-click** on inline number 425: Add > Attribute.

4. **Select** the Noise attribute.



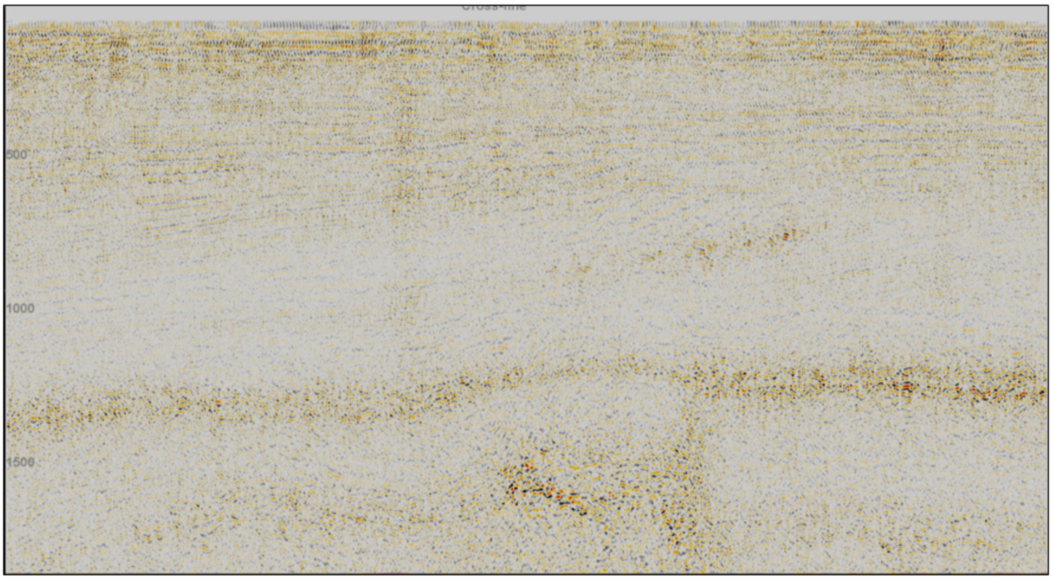


Use the same color-bar for original seismic, DSMF seismic and Noise for a fair comparison.



Workflow cont'd:

Your result should look like this.



2.3.1f Dip-steered Diffusion Filter

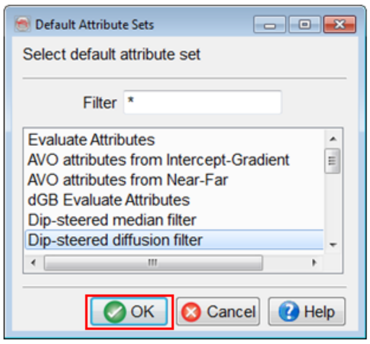
Required licenses: OpendTect Pro, Dip-steering.

Exercise objective:

Enhance low-quality seismic data near faults using a Dip-Steered Diffusion Filter.

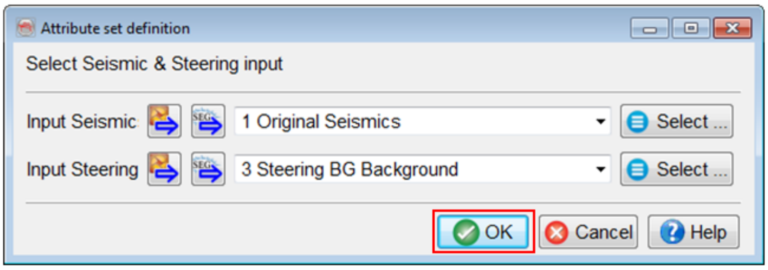
Workflow:

1. **Start** the attribute engine .
2. **Open** the Default Attribute set.
3. **Select** Dip-steered diffusion filter and **press** OK.



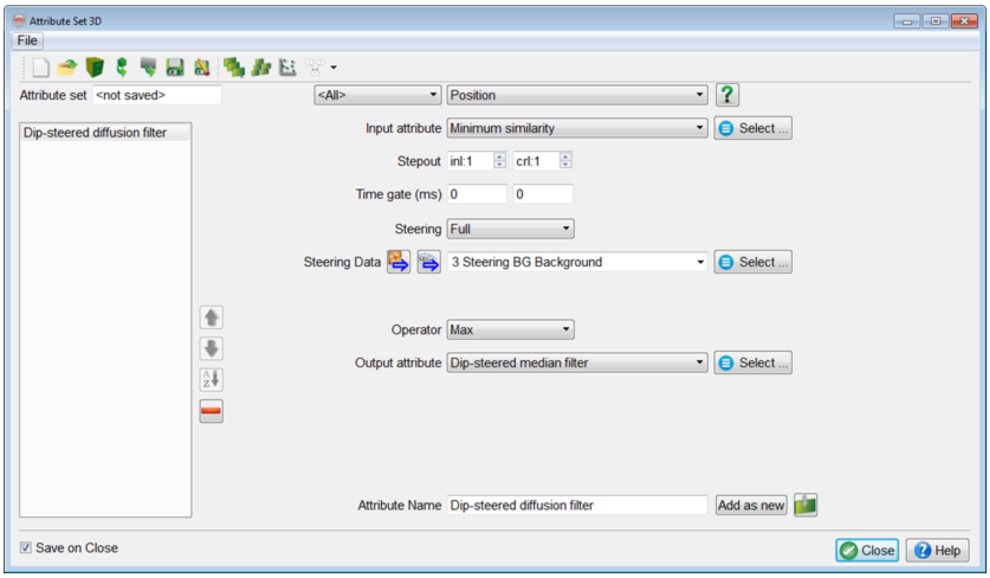
Workflow cont'd:

4. In the pop-up window **set** *1 Original Seismics* as input seismic and *3 Steering BG Background* as input steering, and **press** OK.



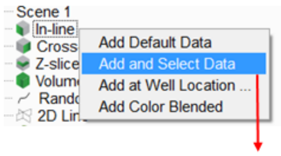
Workflow cont'd:

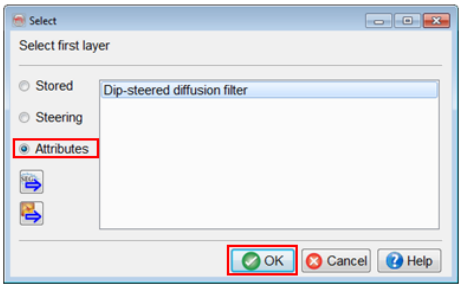
5. The attribute is defined.



Workflow cont'd:

6. **Keep** the attribute set 3D window open and **add** the *Dip-steered diffusion filter* attribute in tree on inline 425.





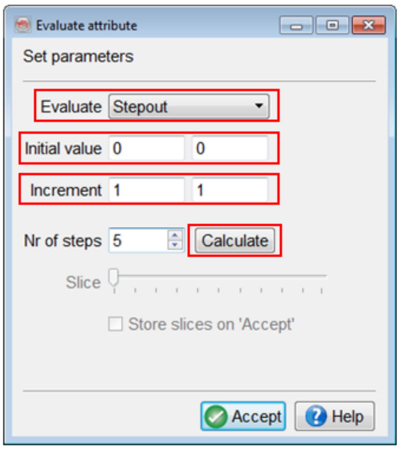
Workflow cont'd:

7. **Go back** to the attribute set 3D window, and **click** on the attribute evaluation icon to evaluate the step-out of the *Dip-steered diffusion filter* attribute.

8. **Specify** Evaluate: Stepout

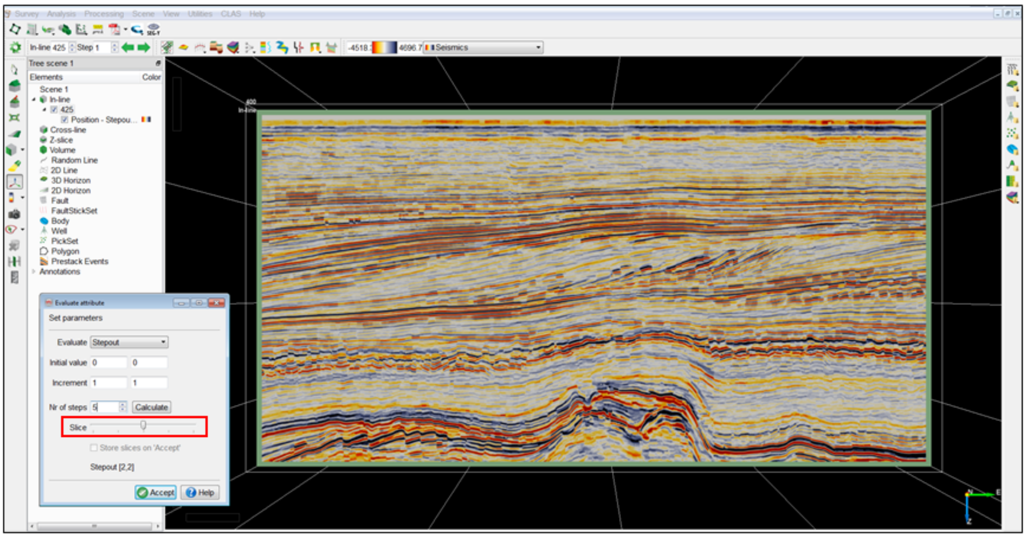
9. **Set** the initial value "0-0", increment "1-1", and Nr. of steps "5".

10. **Press** Calculate.



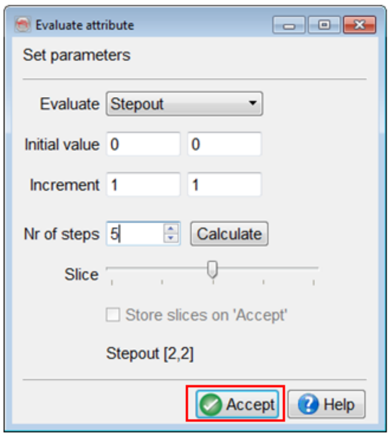
Workflow cont'd:

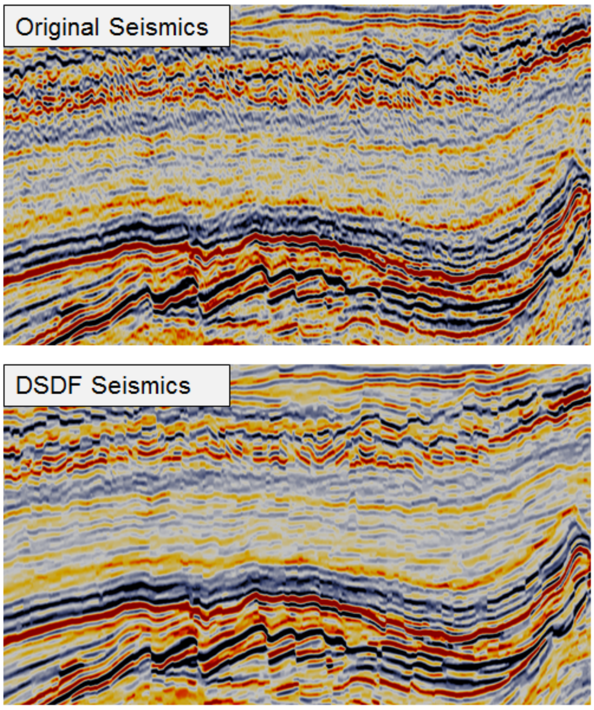
11. Once the computation is done, **move the sliders** to change the stepout value and see the impact in the 3D scene.



Workflow cont'd:

12. Evaluate which step-out is best (removing random noise without creating too many artefacts)? Once chosen, **press** Accept and **close** the attribute set window.





2.3.1g Dip-steered Fault Enhancement Filter

Required licenses: OpendTect Pro, Dip-steering.

Exercise objective:

Remove noise and sharpen edges/faults with the Fault Enhancement Filter (FEF).

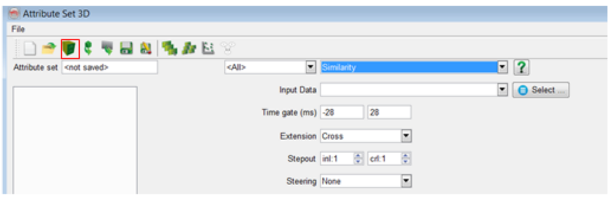
The Fault Enhancement Filter is a combination of dip-steered median filter and diffusion filter, modifying the seismic volume to enhance fault visibility.

Based on a similarity threshold, the data is smoothed (DSMF) away from the faults and sharpened (DSDF) at the fault location. The filter is released with the software as default attribute sets in two forms:

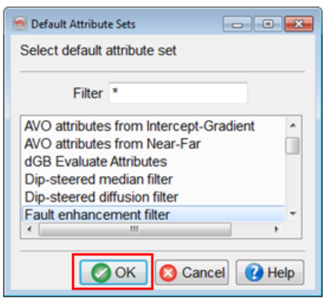
- *Fault Enhancement Filter*: All basic attributes needed as inputs for the filtering are shielded and the user can only control the amount of smoothing (dip-steered median filter) versus sharpening (dip-steered diffusion).
- *Fault Enhancement Filter (expert)*: The full attribute set definition is shown, which can be modified.

Workflow:

1. **Start** the 3D attribute set window by clicking on .
2. **Click** on default attribute set icon .

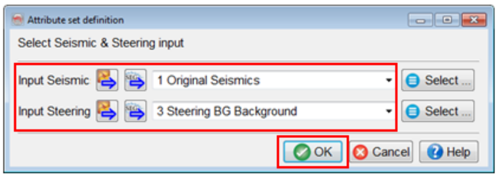


3. Select Fault enhancement filter and **press** OK button.



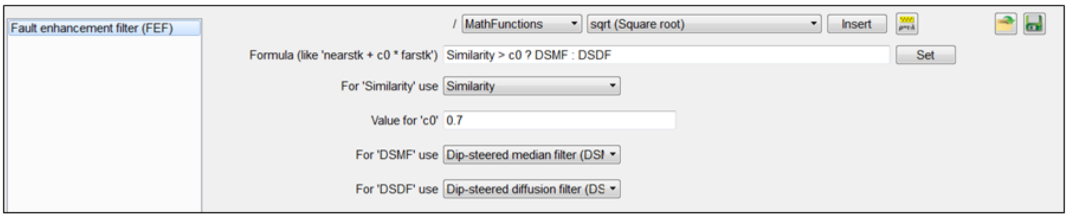
Workflow cont'd:

4. **Select** the *1 Original Seismics* as input seismics and *3 Steering BG Background* as input steering and **press** OK.



5. This will create a fault enhancement filter attribute for you.

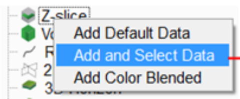
6. Keep this window open and proceed to the next step.

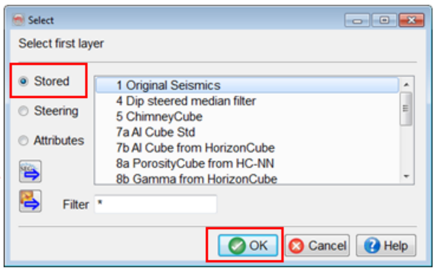


Workflow cont'd:

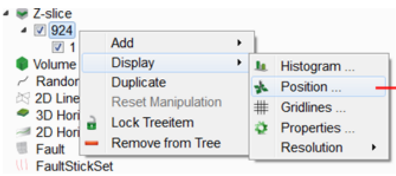
7. **Load** the default seismic data to a small area of the Z-slice at 1640 ms, between inlines 120-400 and crosslines 350-600.

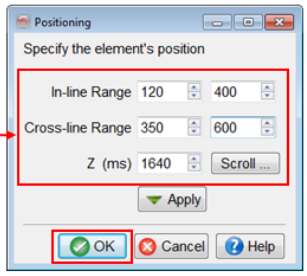
   - **Right-click** on Z-slice in the tree to add stored *1 Original Seismics*.





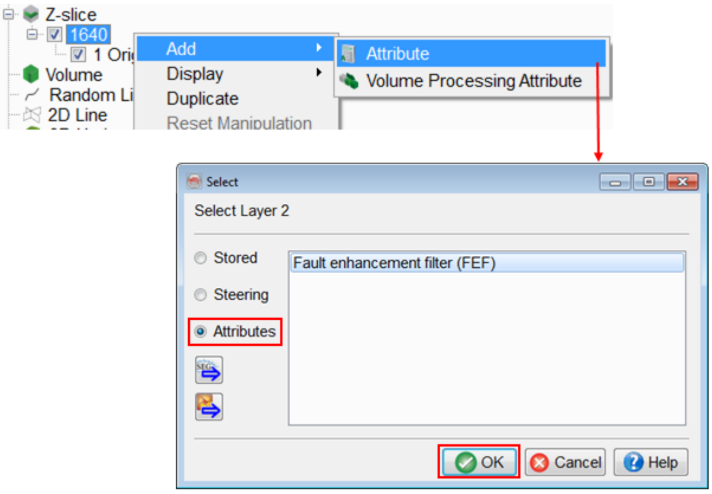
   - Once it is loaded, again **Right-click** on Z-slice number 924 to change its position.





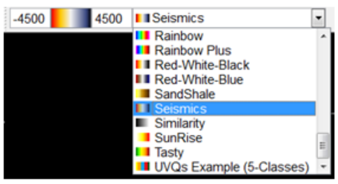
Workflow cont'd:

8. **Apply** the Fault Enhancement Filter to the constrained Z-slice at 1640 ms.
   - **Right-click** on Z-slice number 1640 to **add** the *FEF* attribute.

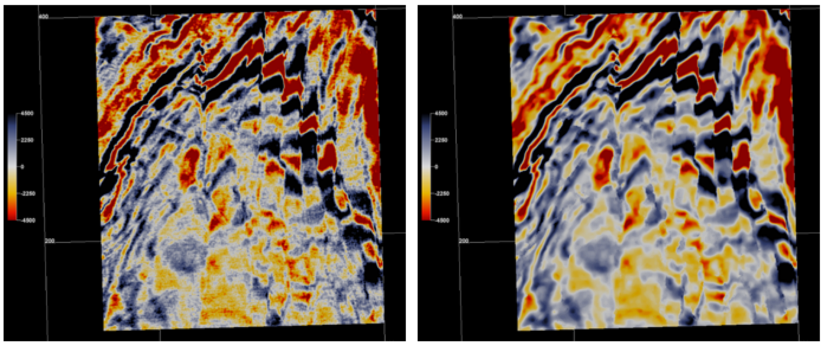


Workflow cont'd:

9. **Compare** *1 Original Seismics* with the *FEF* attribute on the constrained Z-slice 1640 ms. Make sure to use the same colorbar range for both.



Did you get clear enough differences between original seismics and FEF?



Original Seismics (left) and FEF Seismics (right) displayed on Z-slice at 1640 ms.

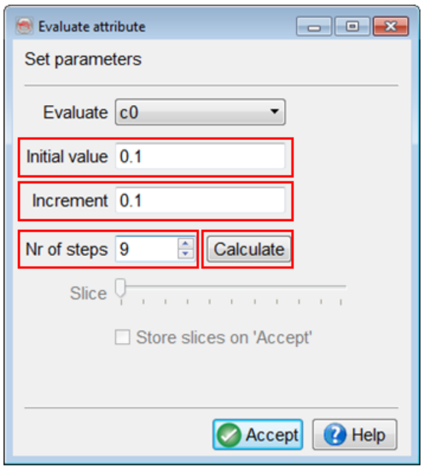
Workflow cont'd:

<u>Evaluation of constant c0</u>

A critical parameter of the Fault Enhancement Filter is c0. If the similarity value is higher than the c0 value, then the *Dip Steered Median Filtered Seismic* is used and otherwise the *Diffusion Filtered Seismic* is used.

10. **Go back** to the attribute set window, and **click** on the attribute evaluation icon to evaluate the constant c0.

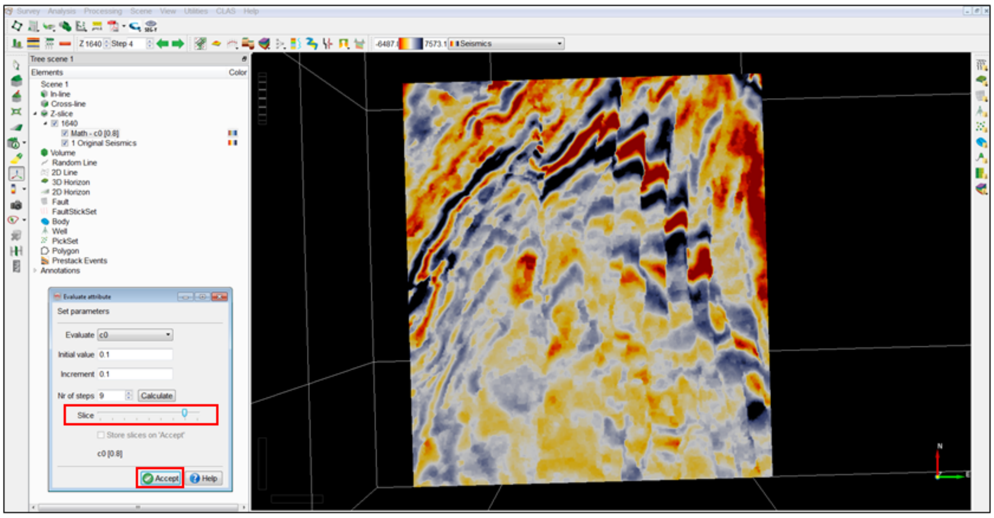
11. **Use** Initial value: 0.1, Increment: 0.1, Nr. of steps: 9 and **press** calculate.



Workflow cont'd:

<u>Evaluation of constant c0</u>

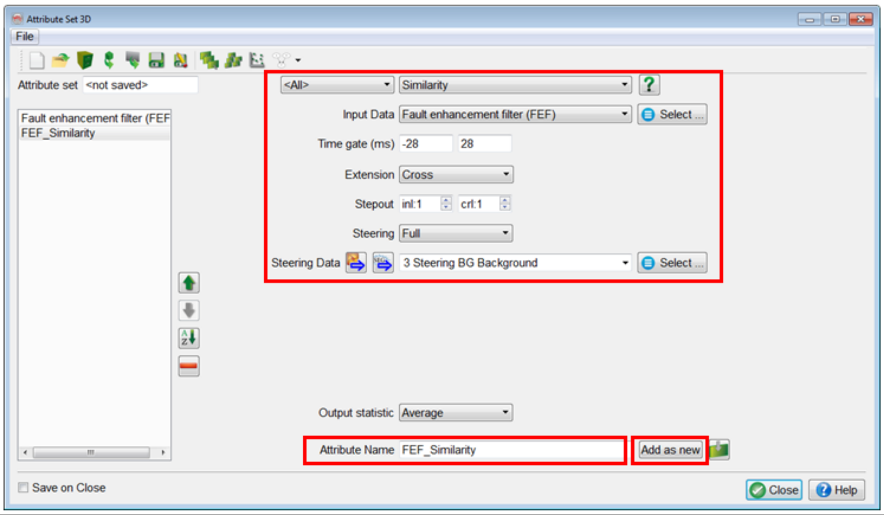
12. **Move** the slider to assess which constant shows the best results (more faults visible and less noise)? **Press** accept to save the constant c0.



Workflow cont'd:

Fault Enhanced Similarity

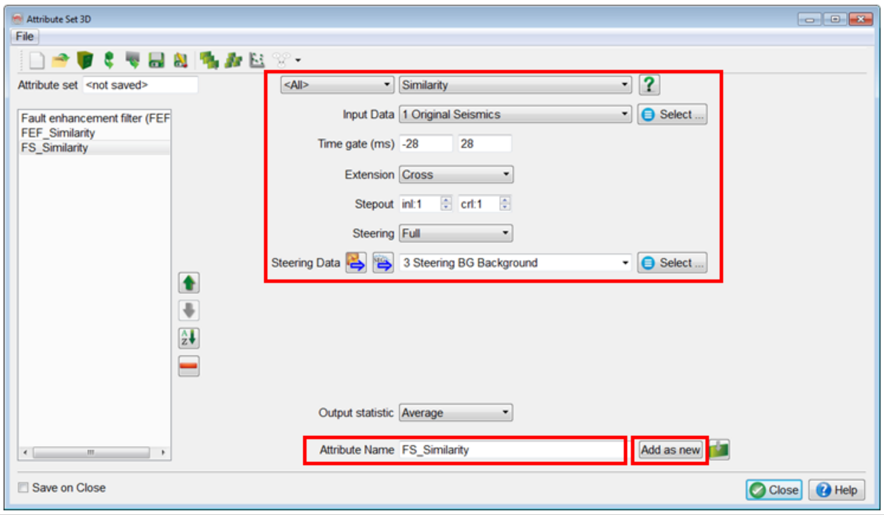
13. **Open** the Attribute set window and **create** a new dip-steered similarity attribute using the *FEF* attribute as input. **Use** the default values for rest of the parameters. **Name** it *FEF_Similarity* and **Add as new**.



Workflow cont'd:

Fault Enhanced Similarity

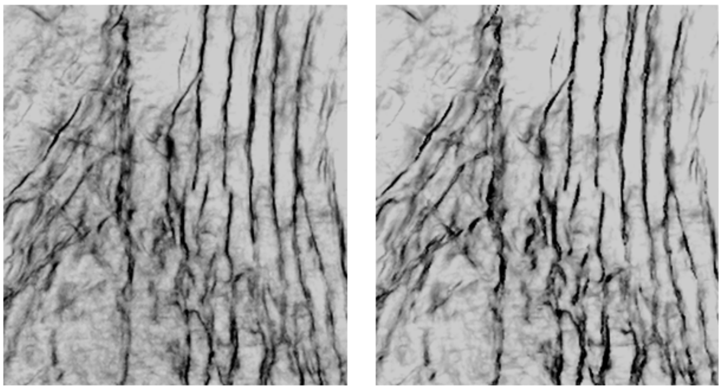
14. **Create** yet another dip-steered similarity attribute using the *1 Original Seismics* as input. **Use** the same parameters as the previous step. **Name** it *FS_Similarity* and **Add as new**.



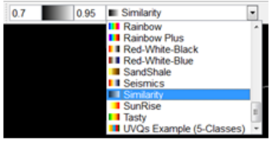
Workflow cont'd:

Fault Enhanced Similarity

15. **Apply** one-by-one the *FS_Similarity* (calculated using original seismic) and the *FEF_Similarity* (based on the Fault Enhancement Filtered seismic) to the constrained Z-slice at 1640 ms.

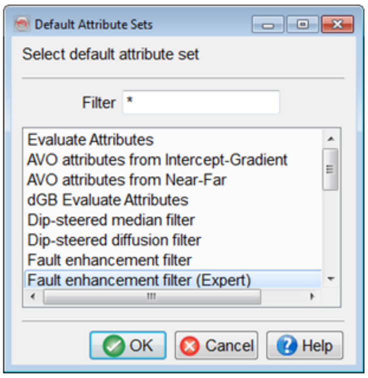


Dip-steered similarity from Original Seismics (left) and FEF Seismics (right)



Don't forget to use identical *Similarity* colorbars!

Tip: Both *Fault Enhancement Filter* and *Fault Enhancement Filter (expert)* can be accessed from the 'Default Attribute Set' using the Drawer  icon from the row of icons at the top.



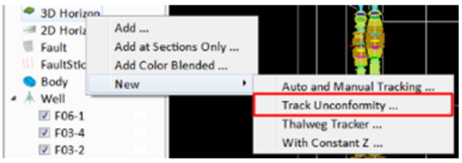
2.3.1h Unconformity Tracker

Required licenses: OpendTect Pro, Dip-Steering.

Exercise objective:
Create two horizons: 1) a seismic event constrained by a few manually picked positions; 2) an unconformable event constrained by well markers.

Workflow:

1. **Pre-load** the default seismic data set (4 Dip steered median filter).
2. **Add** an in-line (Add Default Data)
3. **Add** the stored Random Line called: "Random Line through wells"
4. **Add** all 4 wells
5. **Go** to 3D Horizon > New > Track Unconformity …



Traditional trackers follow amplitude and phase. Unconformities do not exhibit consistent amplitude / phase behavior and can thus not be tracked with a conventional tracker. The unconformity tracker flattens the dip field using a constrained inversion-based algorithm. Constraints are given in the form of picked positions and (optionally) a confidence weight volume.

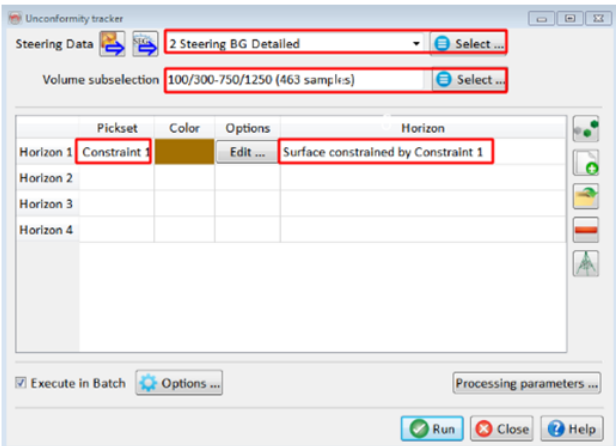
Workflow cont'd:

6. In the Unconformity tracker window, **select** the input steering cube for the tracking: 2. Steering BG Detailed.

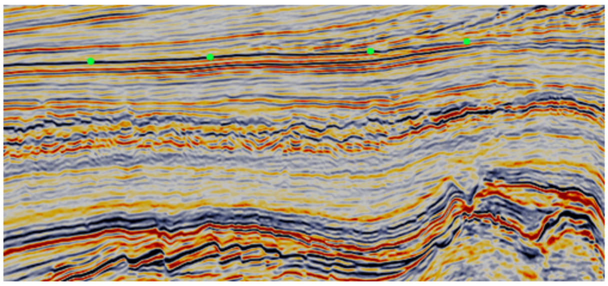
Ideally, use a detailed steering cube (see Exercise 2.3.1a) calculated on enhanced seismic.

7. Optionally, **limit** the output extend by using the Volume sub-selection.

8. Optionally, **change** the names of Pickset and Horizon by double clicking on the respective fields.



Workflow cont'd:

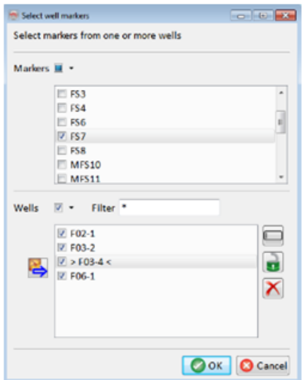


9. **Click** on the Pick Seeds icon and pick a few points (minimum 3) on the event you want to track.

10. Optionally, **pick** more points on in-lines and cross-lines. Alternatively, open an existing pick set with interpreted points by clicking on the corresponding icon:

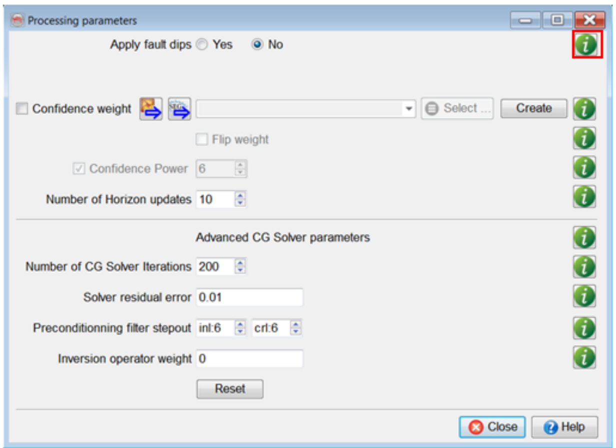
11. For the second horizon **press** the wells icon and select the FS7 marker from all wells.

	Pickset	Color	Options	Horizon
Horizon 1	Constraint 1		Edit ...	Surface constrained by Const
Horizon 2	FS7		Edit ...	Surface constrained by FS7
Horizon 3				



Workflow cont'd:

12. **Select** Processing parameters … and read the information for each of the parameters.*



* A good "Confidence weight" volume example is the Planarity volume.

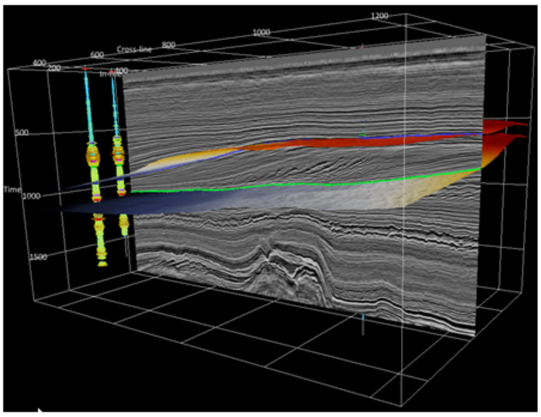
Workflow cont'd:

13. **Close** the Processing parameters window and start processing by pressing Run

14. When the batch process is finished **Close** the window and **Add** the new horizons to the tree.

15. **Add** a random line to **QC*** the horizons.

16. Improvements can be made by (if needed): adding more picks; adding a confidence weight volume and by changing the inversion parameters.



*Tips: Change the color bar of the random line to grey scale; Show the horizons at sections only; Change the line thickness (Horizon -> Display -> Properties); Move and rotate the random line to check whether the horizon is following the events properly.

2.3.2 Attributes for Faults & Fractures

What you should know about Faults & Fractures in OpendTect

The Faults & Fractures plug-supports a collection of attributes, filters and tools for visualizing, manipulating and analyzing faults and fractures. Some of the tools in this plug-in can be found elsewhere in the system, e.g. in the attribute engine, others are only available through this plug-in. In combination with dip-steering the plug-in offers additional dip-steered and dip-derived attributes and dip-steered filters (Structurally Oriented Filters) such as fault enhancement filter and dip-steered median filter.

Important fault attributes are:

- Thinned Fault Likelihood (developed by the Colorado School of Mines)
- Dip-steered similarity (best applied after fault enhancement filtering)
- Polar dip (directly computed from a (dip-)SteeringCube)

Special fracture attributes are:

- Curvature attributes (points up flexure of reflectors without fault throw)
- Fracture proximity (measures the distance to the nearest fault / fracture)
- Fracture density (measures the number of faults / fractures within a user-defined radius)

2.3.2a Thinned Fault Likelihood

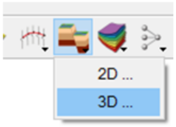
Required licenses: OpendTect Pro, Faults & Fractures.

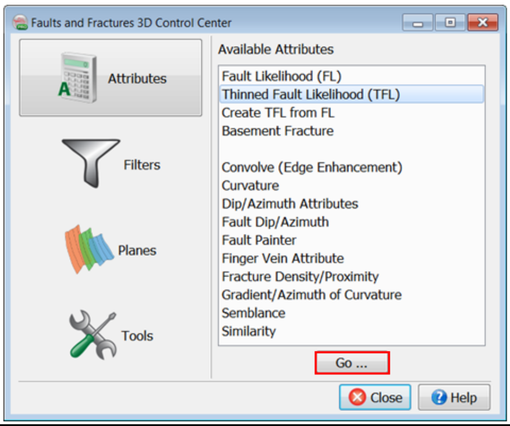
Exercise objective:

Create Thinned Fault Likelihood attribute.

Workflow:

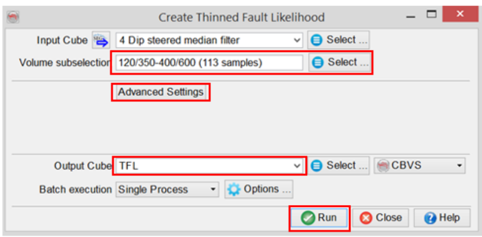
1. **Launch** the Faults and Fractures Control Center by clicking this icon.
2. **Select** 3D
3. **Select** the Thinned Fault Likelihood attribute from the list and **press** Go…



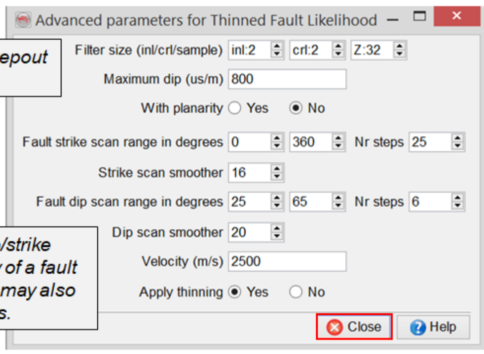


Workflow cont'd:

3. **Specify** the Input Cube *4 Dip steered median filter*.
4. To speed up the process **set** Volume sub-selection to inline 120-400, crossline 350-600, z range 1400-1848.
5. **Choose** *Advanced Settings* to view the parameters.
6. **Keep** the default parameters, as shown in the image on the right and Close the advanced parameters dialog.
7. **Provide** an Output Cube name, e.g. Thinned Fault Likelihood, and **press** Run.



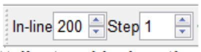
Keep a large Z stepout (recommended)



Smoothing along dip/strike increases the continuity of a fault plane. Over smoothing may also enhance outliers.

Workflow cont'd:

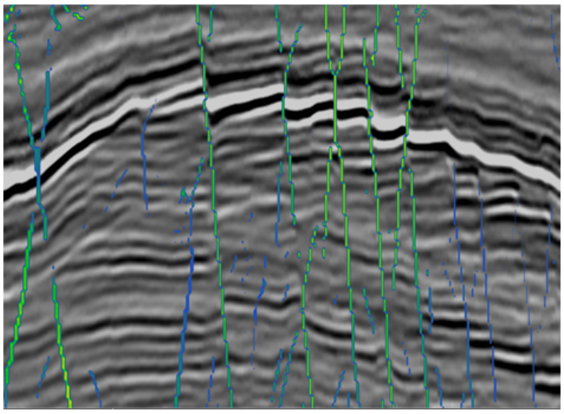
8. When processing is finished, **display** the Thinned Fault Likelihood on inline 200.
   - **Right-click** on inline > Add Default Data.
   - **Change** the inline number to 200.



   - **Right-click** on inline nr. (i.e. 200) > Add Attribute; Under the Stored section, **select** Thinned Fault Likelihood.

9. **Apply** semi-transparent color bar (e.g. Chimney) on it for better visualization.

10. The result should be similar to the one shown below.

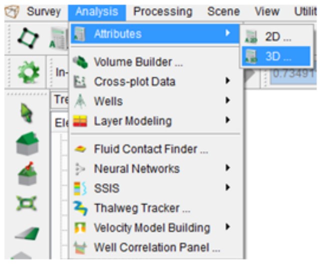


2.3.2b Volume Curvature And Others

Required licenses: OpendTect Pro, Dip-steering.

Exercise objective:

Compute and compare various attributes that pick up faults and fractures.



Workflow:

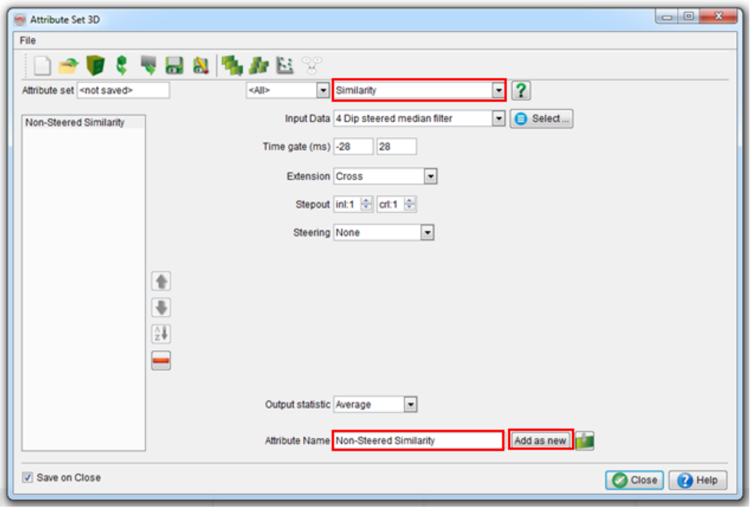
1. **Start** the 3D attribute engine: **Analysis > Attributes > 3D**.

Workflow cont'd:

2. **Select** Similarity attribute from the list of attributes.

3. Keep all the parameters by default and give it a name, e.g. *Non_steered_Similarity.*

4. **Press** Add as new.

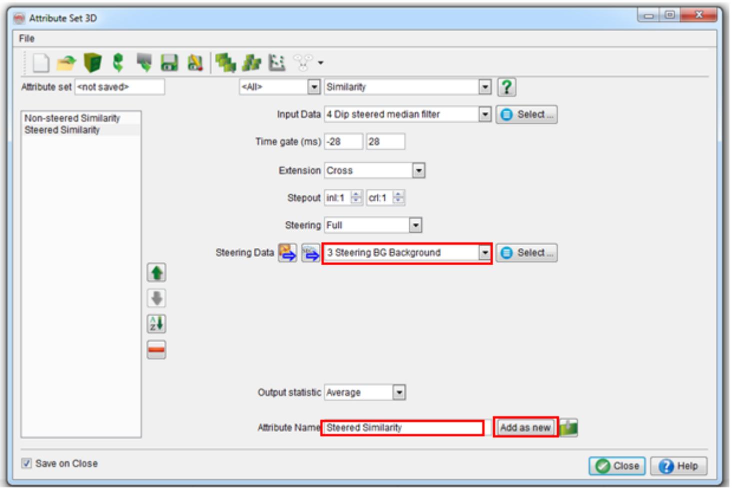


Workflow cont'd:

5. **Change** Steering to Full with *3 Steering BG Background*.

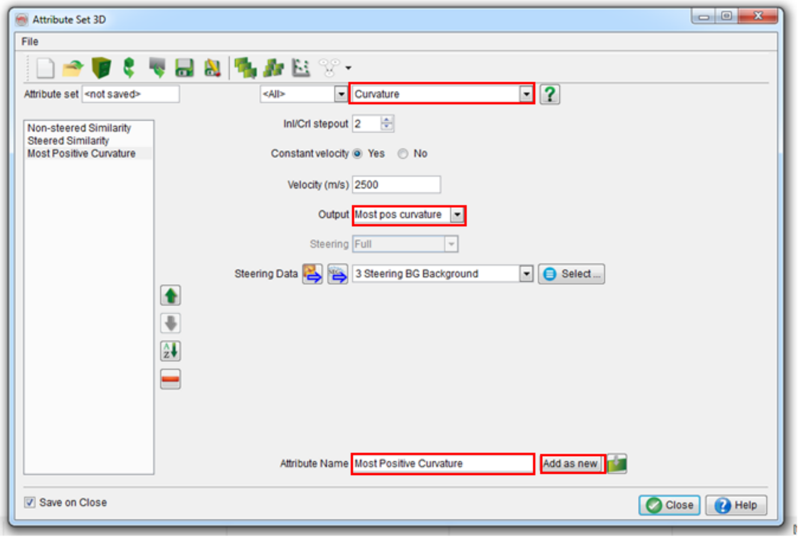
6. **Type in a new name**: *Steered Similarity*.

7. **Press** Add as new.



Workflow cont'd:

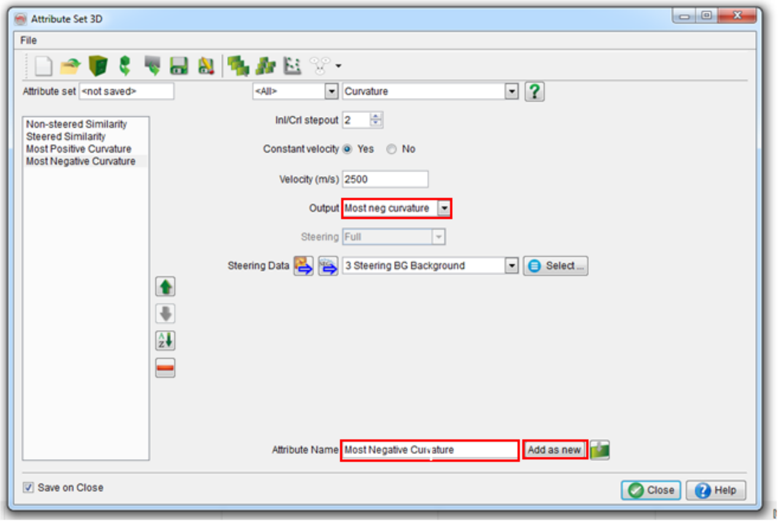
8. **Select** Curvature from the list of attributes.
9. **Change** output to Most pos curvature and **type in a new name**, e.g. *Most Positive Curvature*.
10. **Press** Add as new.



Workflow cont'd:

11. **Change** Output to Most neg curvature and **type in a new name**, e.g. *Most Negative Curvature*.

12. **Press** Add as new.

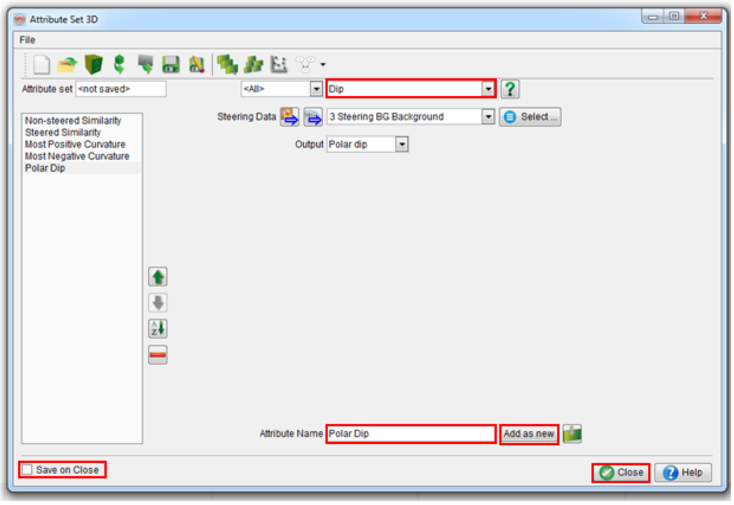


Workflow cont'd:

13. **Select** Dip from the list of attributes.

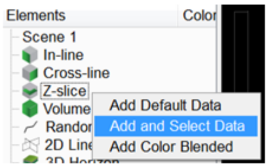
14. **Change** Output to Polar dip and **type in a new name**, e.g. *Polar Dip*.

15. **Press** Add as new, **Un check** Save on close and **Close** the window.

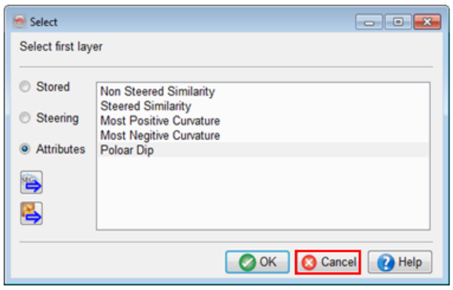


Workflow cont'd:

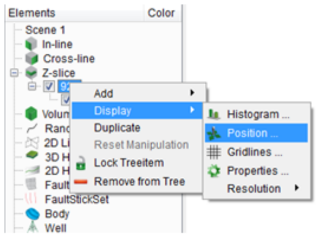
16. **Right-click** on Z-slice in the tree **> Add and Select Data**.



17. As visualization of the full z-slice will take some time, we will limit the inline and crossline ranges. So, **press Cancel** in the pop-up window.

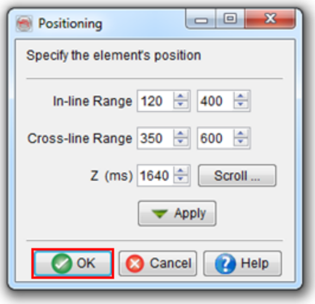


18. **Right-click** on the Z-slice number in the tree > Display > Position.



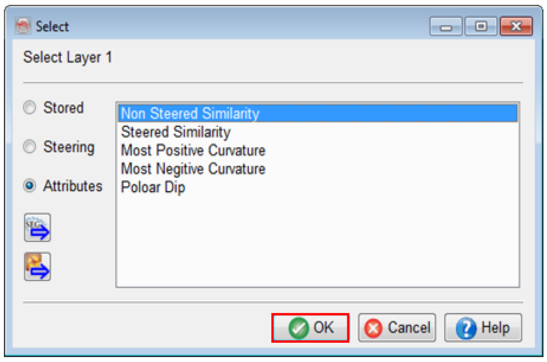
Workflow cont'd:

19. **Position** Z slice 1640ms between inlines 120-400 and crosslines 350-600 and **press OK**.

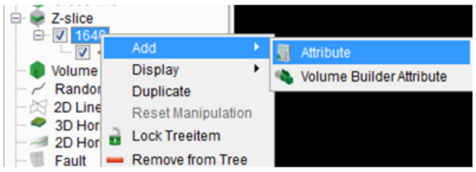


20. In the pop-up window **select** *Non-steered Similarity* from Attributes tab.

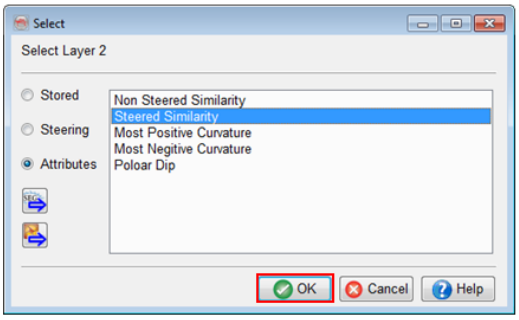
21. **Press OK** to display it in the scene.



Workflow cont'd:



22. **Right-click** on the Z-slice 1640 in the tree > Add > Attribute.



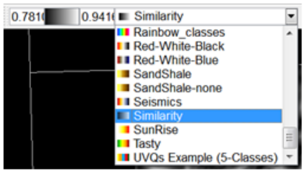
23. In the pop-up window **select** *Steered Similarity* from Attributes tab.

24. **Press OK** to display it in the scene.

25. In similar way **display** the rest three attributes.

Workflow cont'd:

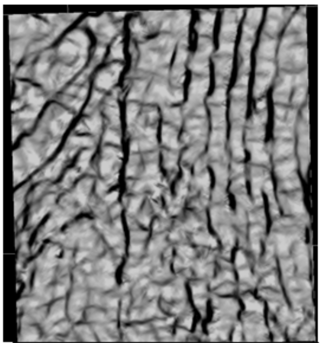
26. Now you can compare them by checking/unchecking the attributes.



27. **Click** on an attribute in the tree to make it active and change the color bar to *Similarity.* Do the same for all the attributes.

28. The result should be similar to the one shown below. 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)?

Steered Similarity



Most Negative Curvature

2.3.2c Bodies

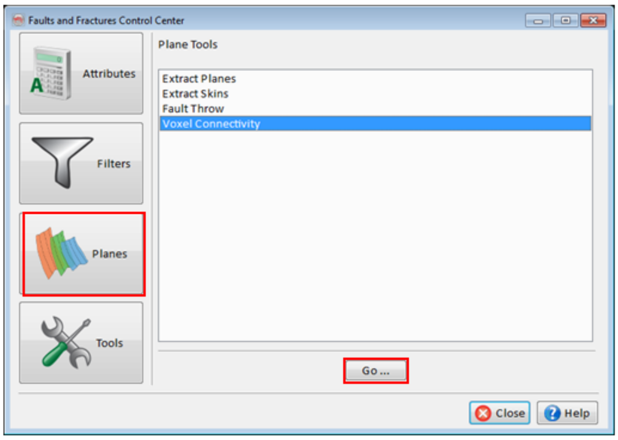
Required licenses: OpendTect Pro, Faults & Fractures.

Exercise objective:

Create and rank fault bodies from a fault discontinuity attribute volume.

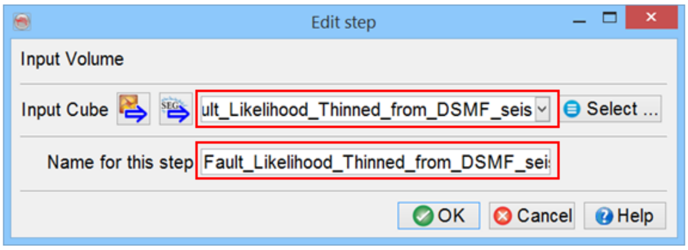
Workflow:

1. **Click** on the Faults and Fractures icon  .
2. In the Faults and Fractures control center: **Select** Voxel Connectivity tool in the Planes module.
3. **Press** Go.



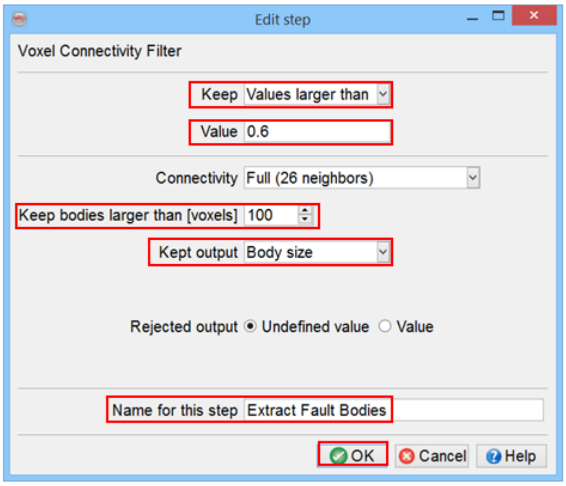
Workflow cont'd:

4. **Define** the first step:
   a. **Select** *Fault_Likelihood_Thinned_from_DSMF_seis* as Input Cube
   b. **Give** a Name for this step and **click** Ok.



Workflow cont'd:

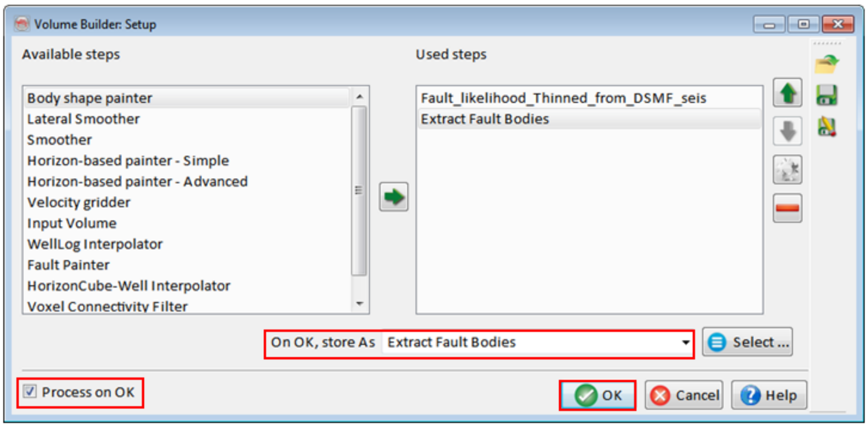
5. **Define** the second step:
   a. **Select** the Voxel Connectivity Filter step and click on .
   b. In the Edit step window, **Keep** Values larger than 0.6.
   c. **Set** the body size threshold to 100.
   d. **Set** the Kept output to Body-size.
   e. **Give** a Name for this step.
   f. **Click** on OK.

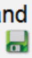
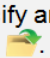


Voxel Connectivity Filter is a special tool to create continuous bodies based on the amplitudes in a stored volume. A voxel is defined as the volume around one sample. It is thus linked to the survey bin size and sampling rate.

Workflow cont'd:

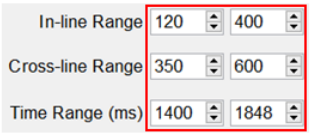
6. In the next Volume builder main window, **give** a name to the Volume builder setup.
7. Make sure the box Process on OK is **toggled on** and **press** OK.

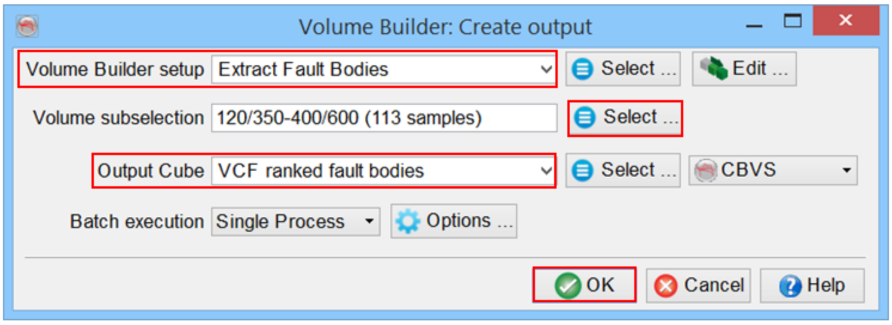


If the Process on OK box is toggled on, pressing OK will prompt you to save the Volume Builder setup and specify an output volume name. You can also save and retrieve setups with the icons:  and . Processing is then started from the Processing menu, option Volume Builder ...

Workflow cont'd:

8. In the Create output window, the active Volume Builder setup is selected by default.
9. **Reduce** the volume to process: **press** Select and **specify** Inline, Cross-line and Time ranges as shown.
10. **Specify** a name for the Output cube and **press** OK.

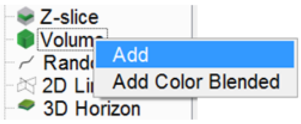


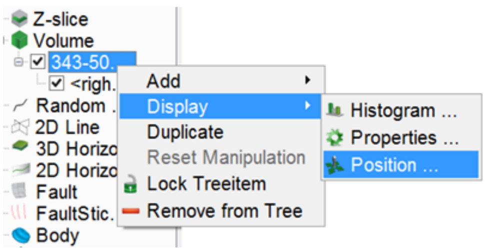


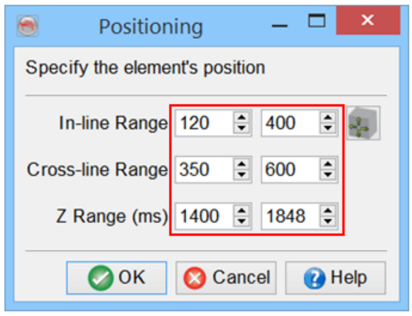
Workflow cont'd:

11. To display the created volume, **click** on Volume in the tree and **select** Add to add a volume viewer to the 3D scene.
12. Click on the new tree item and go to Display > position. **Set** the viewer to the ranges specified in the previous slide either using the menu.

    Alternatively use the icon.



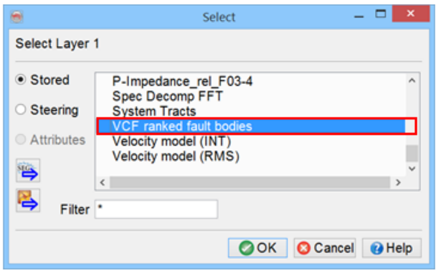


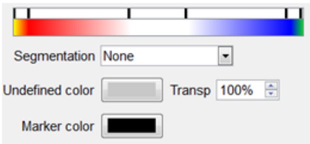


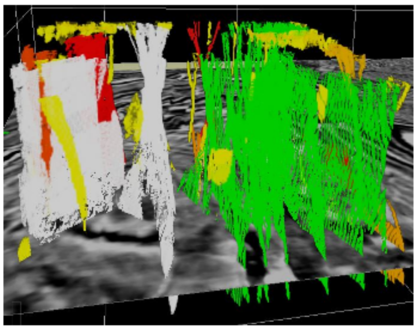
Workflow cont'd:

13. **Select** the volume you just created in the pop up window and **click** Ok.
14. **Select** a color bar (e.g. *Extremes*). Adjust transparency as needed and ensure that undefined values are displayed with 100% transparency.

To edit the colorbar: see Exercise 1.2.2







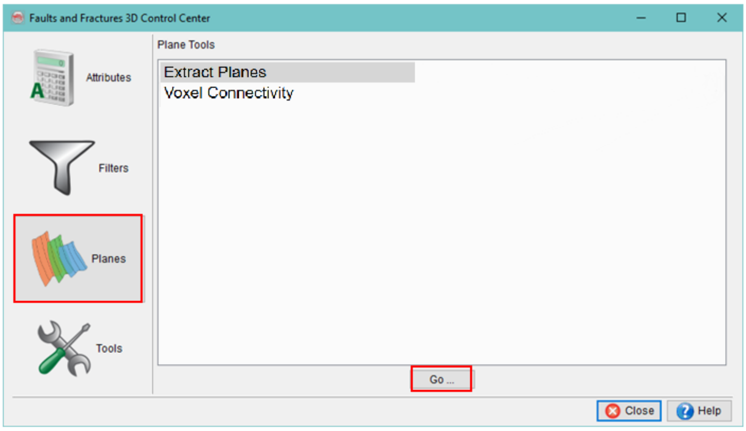
2.3.2d Planes

Required licenses: OpendTect Pro, Faults & Fractures.

Exercise objective:
Extract fault planes from a Fault Likelihood volume.

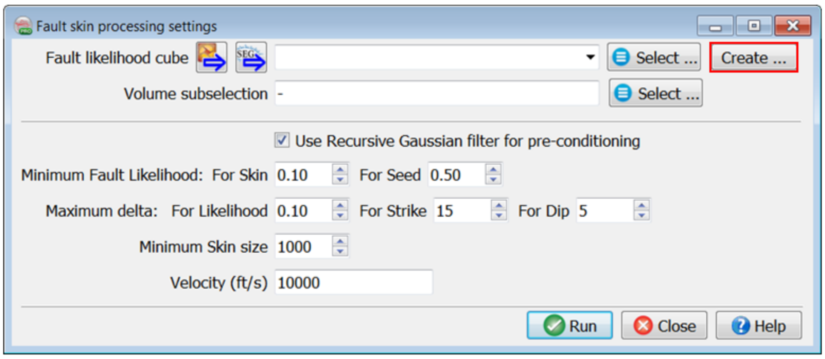
Workflow:

1. **Click** on the Faults and Fractures icon .
2. In the Faults and Fractures control center: **Select** Extract Planes under the Plane category.
3. **Click** on Go.



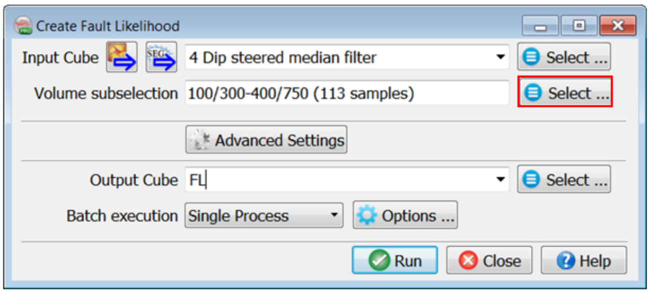
Workflow cont'd:

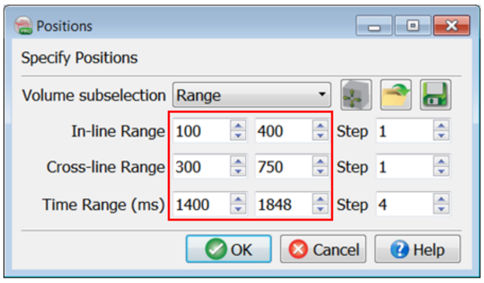
4. In the Fault Skin Processing settings window **create** an input Fault Likelihood cube.



Workflow cont'd:

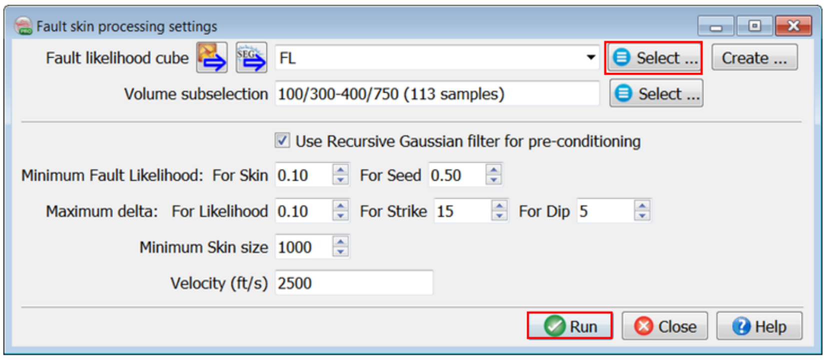
5. Select 4 Dip steered median filter cube and keep the processing parameters by default.
6. Restrict the volume subselection to inline 100-400, crossline 300-750, z range 1400-1848.





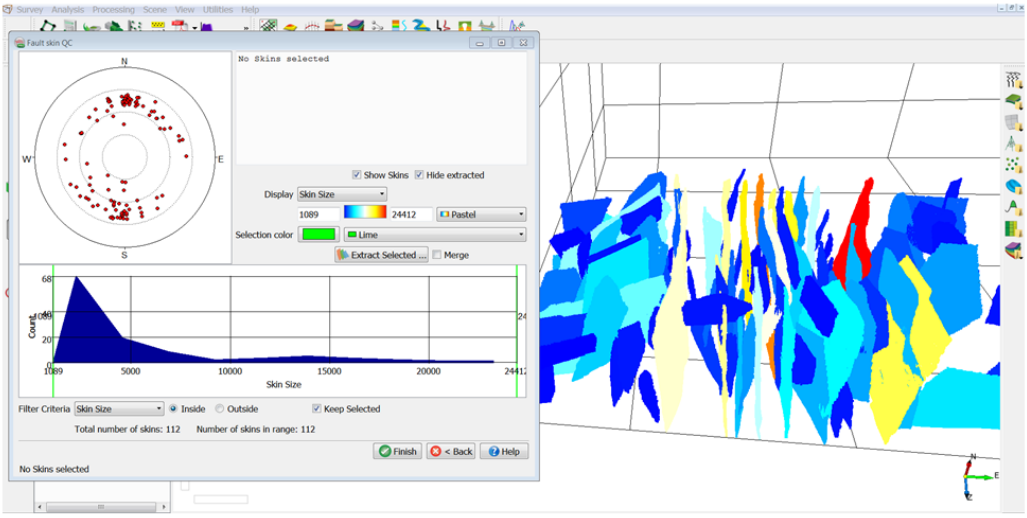
Workflow cont'd:

7. **Select** the processed Fault Likelihood volume.
8. Press **Run** to extract fault skins.



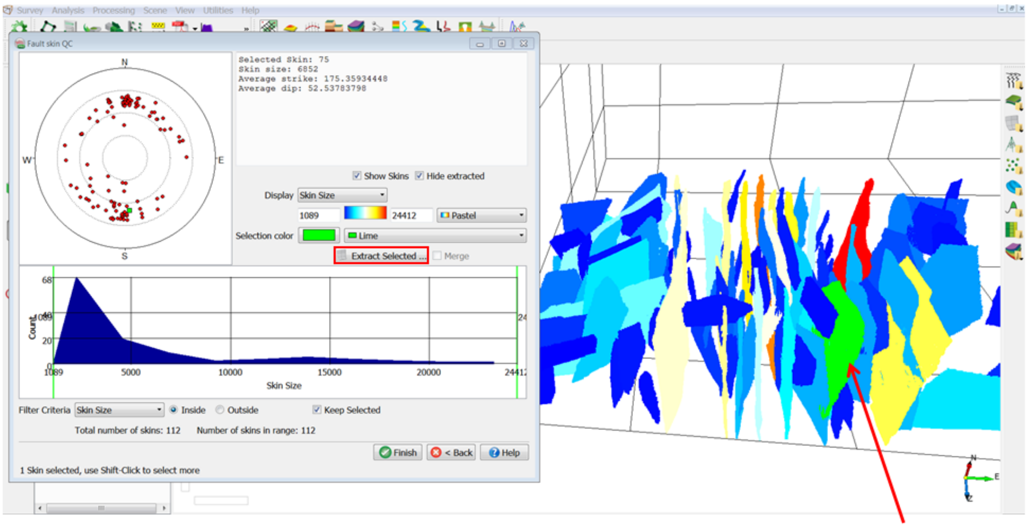
Workflow cont'd:

9. A set of fault skins is now displayed in the 3D scene along with Fault skin QC window.



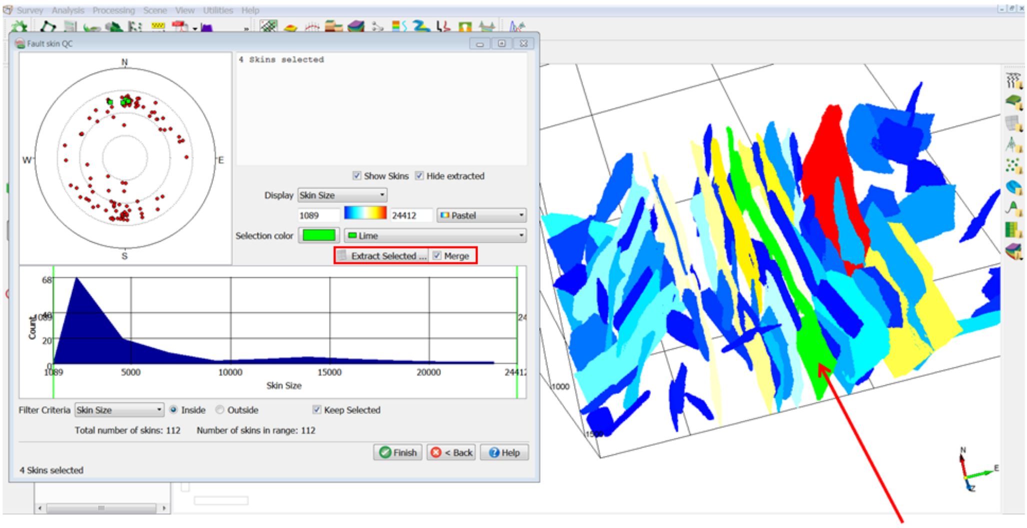
Workflow cont'd:

10. Select an individual fault by clicking on a skin (it turns green) and Extract Selected as an individual fault plane.



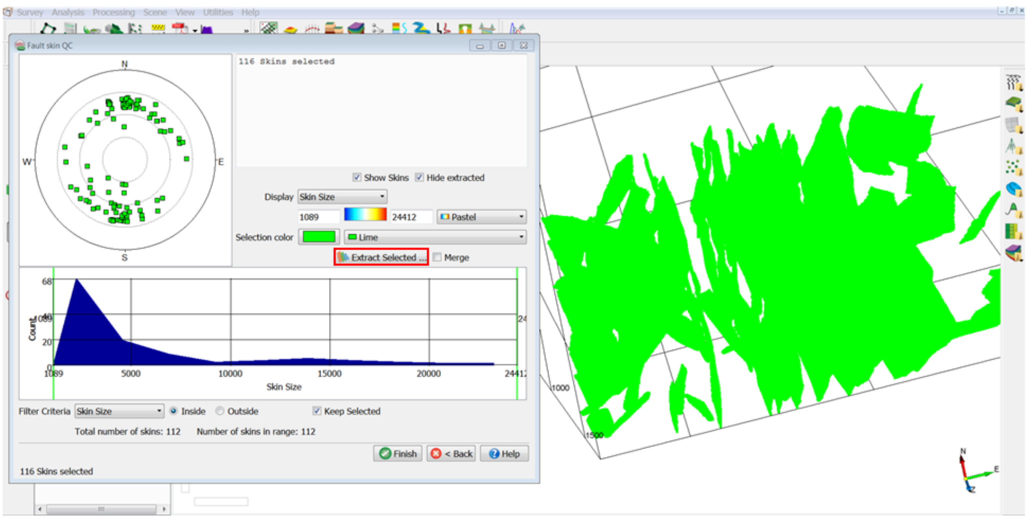
Workflow cont'd:

11. Select several skins using Shift + left mouse click.
12. Check the Merge option and extract the skins as one fault.



Workflow cont'd:

13. Select all skins using Ctrl+A.
14. Extract all skins as a Fault Set.



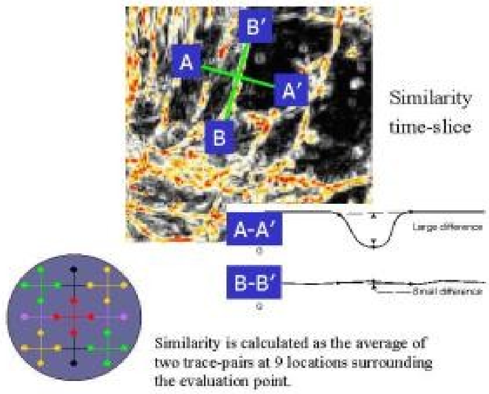
2.3.3 Ridge Enhancement Filter (REF)

What you should know about the Ridge Enhancement Filter

The *Ridge Enhancement Filter* is a post-processing filter for fault attribute volumes, such as *Similarity*. It sharpens the attribute response such that faults are more clearly visible.

The '*Ridge Enhancement Filter*' is delivered with the software as part of the default attribute set.

The set calculates similarity attributes at 9 locations surrounding the evaluation point. Then it compares the differences between similarity values in 4 horizontal 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.



The default attribute set is based on Similarity. With only minor modifications, this attribute can also increase resolution of other attributes like curvature, or volumes as fault probability volumes.

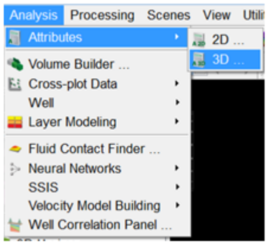
2.3.3a Ridge Enhancement Filter

Required licenses: OpendTect.

Exercise objective:
Compute the Ridge-enhancement filer attribute for improved fault visualizations.

Workflow:

1. **Start** the 3D attribute engine: Analysis > Attributes > 3D.

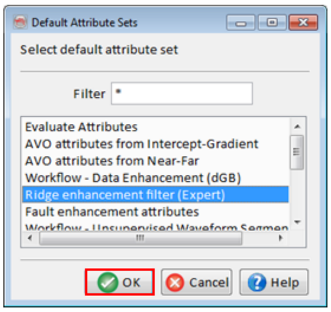


Workflow cont'd:

2. **Open** the default attribute set .

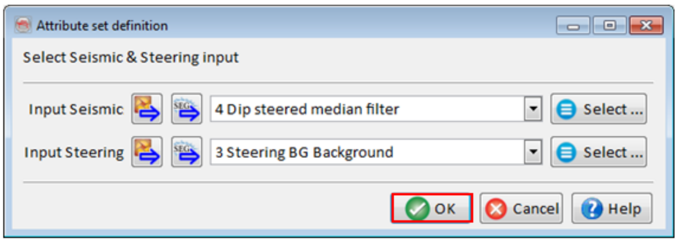
3. **Select** Ridge Enhancement filter (Expert).

4. **Press** OK.



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

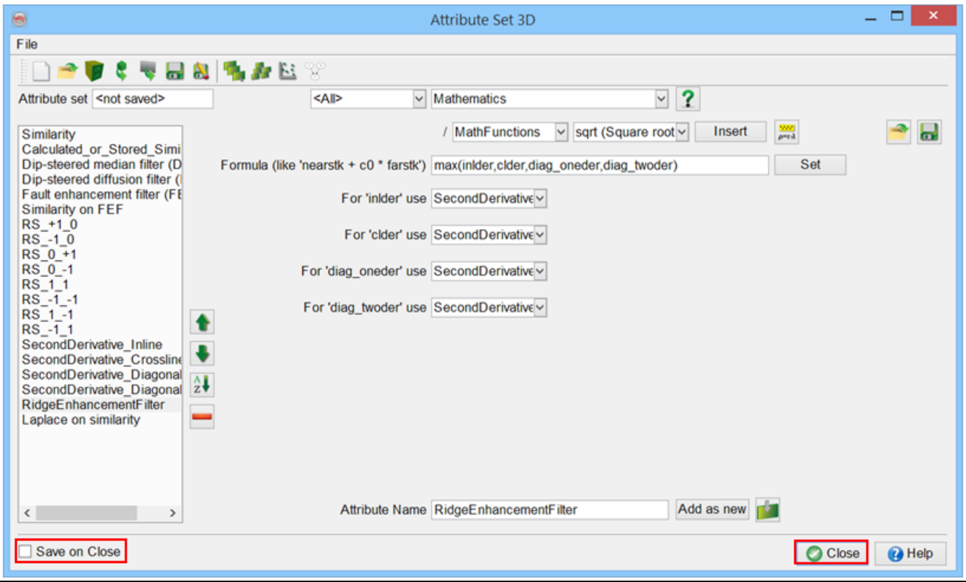
6. **Press** OK.



Workflow cont'd:

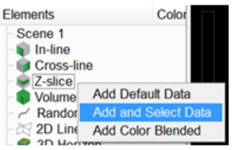
7. **Keep** everything default with the default name *Ridge enhancement filter*.

8. **Uncheck** Save on close and then **Close** the window.

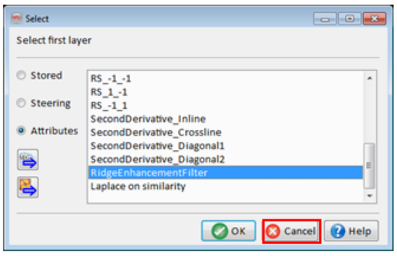


Workflow cont'd:

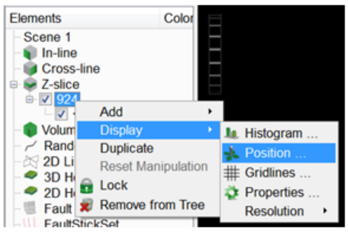
9. **Right-click** on Z-slice in the tree > Add and Select Data.



10. As visualization of the full z-slice will take some time, we will limit the inline and crossline ranges. So, **press** Cancel in the pop-up window.

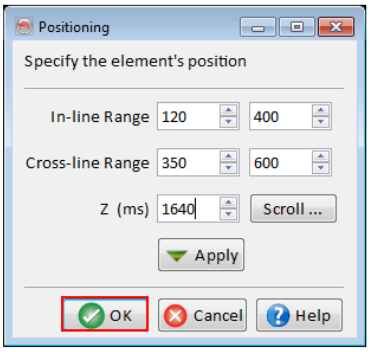


11. **Right-click** on the Z-slice number > Display > Position.

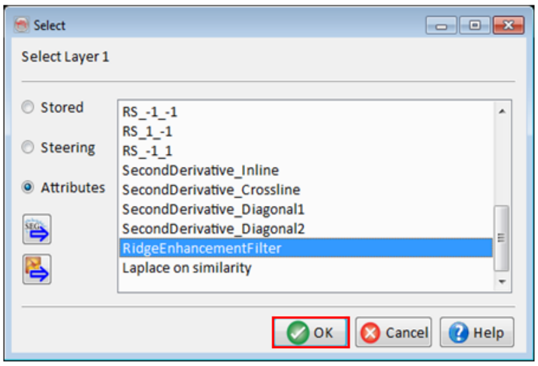


Workflow cont'd:

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



13. In the pop-up window **select** *Ridge enhancement filter* from Attributes.

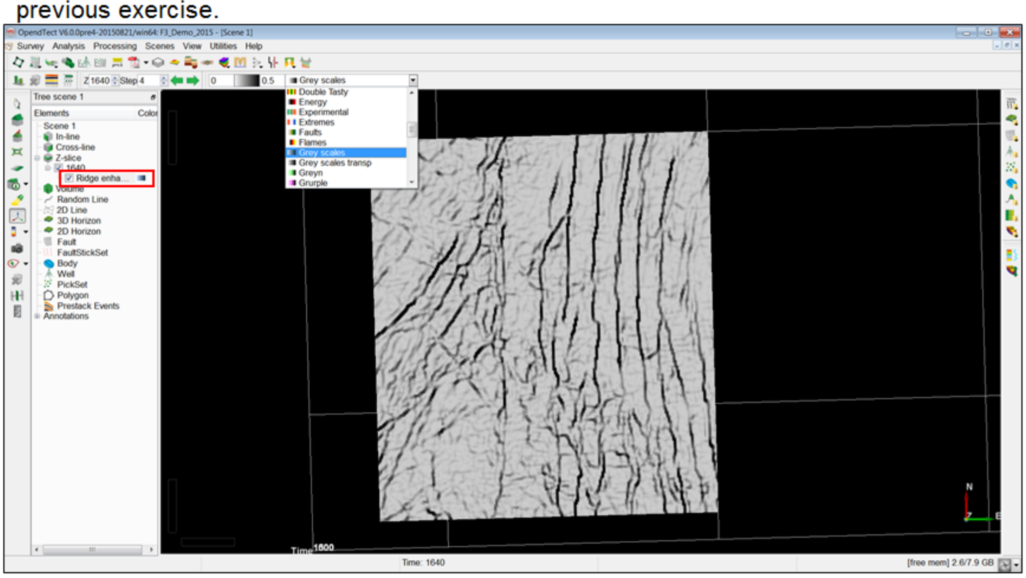


14. Press OK to display it in the scene.

Workflow cont'd:

15. Once the slice is displayed, **click** on its attribute in the tree to activate it and **change** the color bar to Grey scales.

16. The result should be similar to the one shown below. Compare it with the attributes of the previous exercise.



2.3.4 Frequency Enhancement (Spectral Blueing)

What you should know about 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 SSB using both the seismic and well data. This operator aims to shape the seismic amplitude spectrum such that it becomes similar to that of the well reflectivity spectrum. Once the operator has been derived, it is converted to the time domain and simply applied to the seismic volume using a convolution algorithm. As the SSB technique uses both seismic and well data, one of the main prerequisites of this workflow is to have good quality well-to-seismic ties.

Typically, the aim is to design an operator at the zone of interest (target). It is therefore best to identify a time gate for this interval before proceeding ahead with the SSB workflow. Ideally one should use a good interpreted horizon in the target zone to guide the seismic traces and well data (log traces). In this manner, the various gated log traces should have sample values over a similar geology. However, for this training exercise, 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

2.3.4a Spectral Blueing

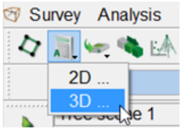
Required licenses: OpendTect Pro, Seismic Spectral Blueing.

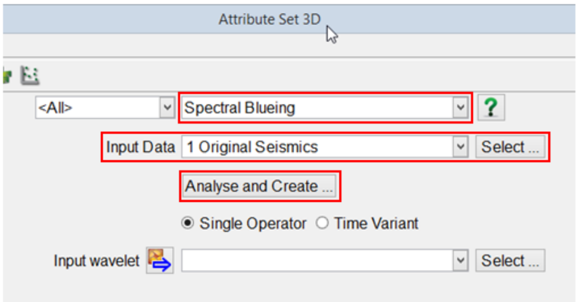
Exercise objective:

Increase the vertical resolution of the seismic data with Seismic Spectral Blueing (SSB) technique.

Workflow:

1. **Go** to the Attribute engine: Analysis > Attributes > 3D or **click** on the icon > 3D.
2. **Choose** Spectral Blueing attribute from the drop-down list.
3. **Select** *1 Original Seismics* as Input Data.
4. **Keep** the default Single Operator option selected.
5. **Click** Analyze and Create ... to launch the SSB Module.

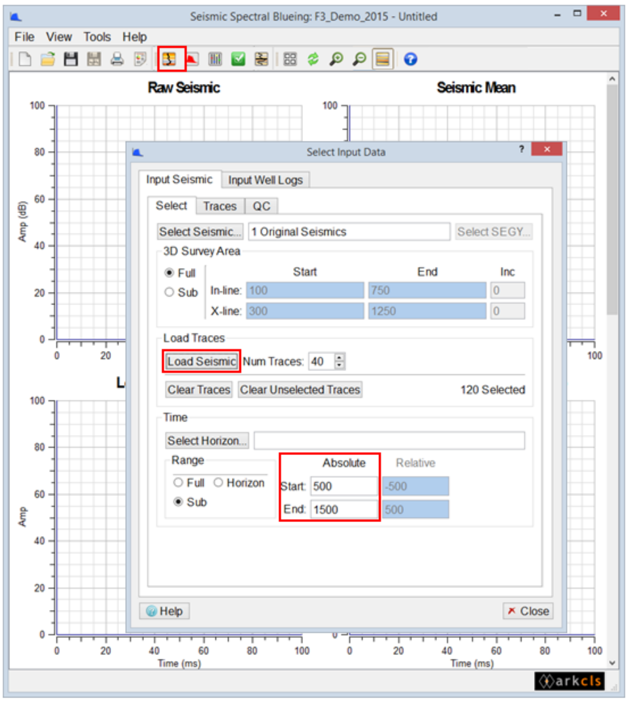




Workflow cont'd:

In order to design an SSB operator, it is mandatory to analyze the seismic and well data spectra by loading some seismic traces and time converted acoustic impedance well logs.

6. **Click** on the icon to pop up the Select Input Data window.
7. **Keep** *1 Original Seismics* as selected seismic.
8. **Click** Load Seismic to load 40 random traces from the selected seismic.
9. **Keep** the default Sub option for Time Range and **enter** 500 (Start) and 1500 (End).



Workflow cont'd:

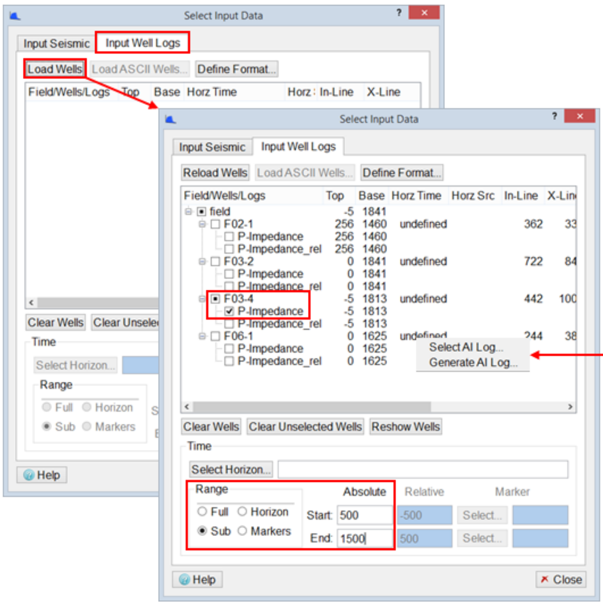
10. **Switch** to Input Well Logs tab.

11. **Click** Load wells.

12. **Select** the well *F3-04* and the *P-Impedance* log.

13. **Keep** the default Sub option for Time Range and **enter** 500 (Start) and 1500 (End).

14. **Close** the Select Input Data window.

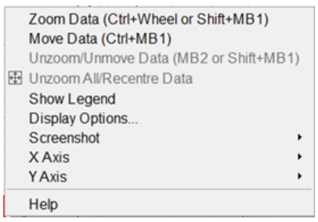


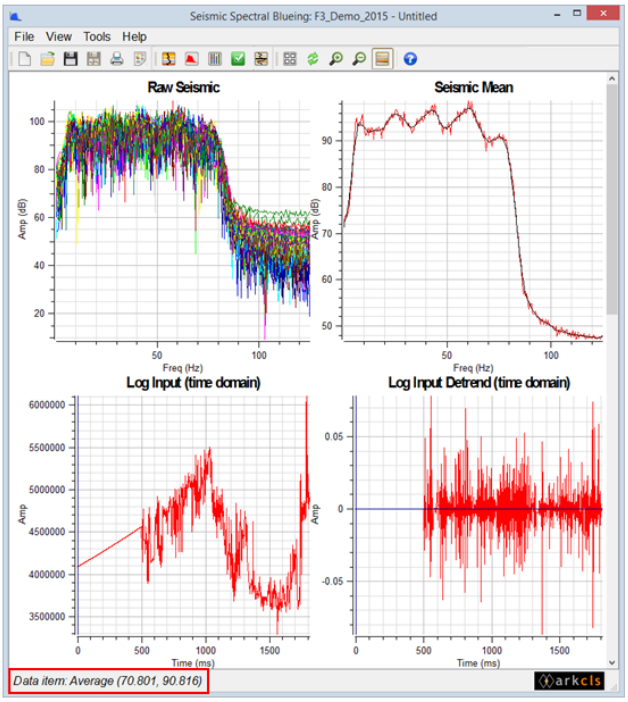
Right-click on a well either to select another or to generate a new acoustic impedance log if it is not available.

Workflow cont'd:

15. Once the seismic and well data are loaded, you can see various curves displayed in different plots.
Take your time to scroll through this window: **left-click** on any curve and in the lower left corner find out what does it represent.

16. **Right-click** on any plot to see a menu that allows to change various display options, show a legend, etc.





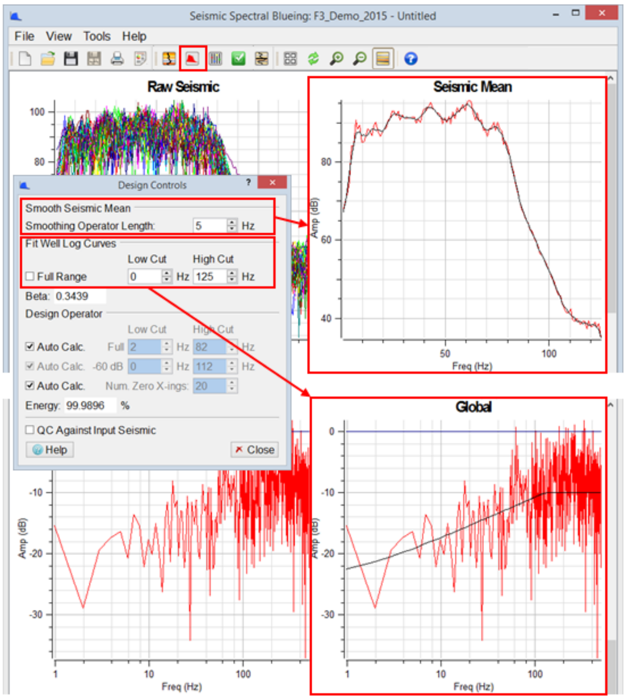
Workflow cont'd:

17. **Click** on [icon] to pop up the Design Controls dialog.

18. **Smooth** the average amplitude-frequency spectrum of seismic data displayed on the Seismic Mean plot.

19. **Uncheck** the Full Range option for Fit Well Log Curves and **enter** 125 Hz as the High Cut frequency, thus limiting it to the Nyquist frequency of input seismic.

20. **Observe** changes on the Global plot.



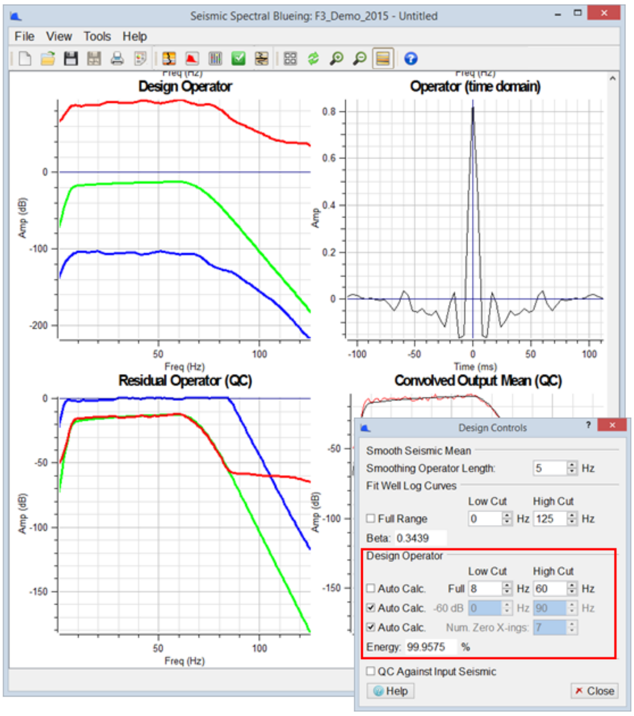
Workflow cont'd:

21. **Tweak** the Low and High Cut parameters of the Design Operator such that the residual operator (blue curve on the Residual Operator QC plot) stays 0 in the frequency domain, with a quick drop on both sides.

22. **Save** the operator [icon] by giving it a name. This operator is saved as a wavelet.

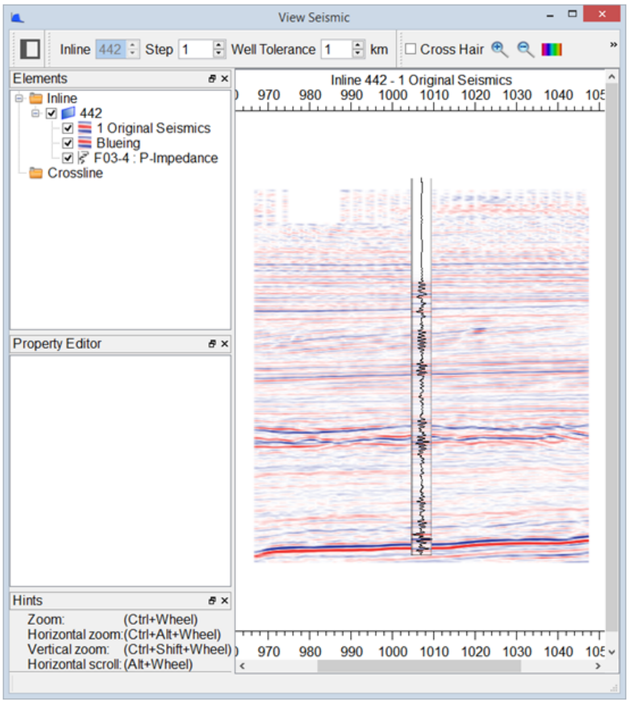
23. **Save** [icon] your session (optional).

The SSB operator is stored as a wavelet and can be visualize in the wavelet manager.



Workflow cont'd:

The effect of the parameter tweaking of the Design Operator is immediately visible in View Seismic window which can be popped up by clicking on [icon] and is updated automatically.

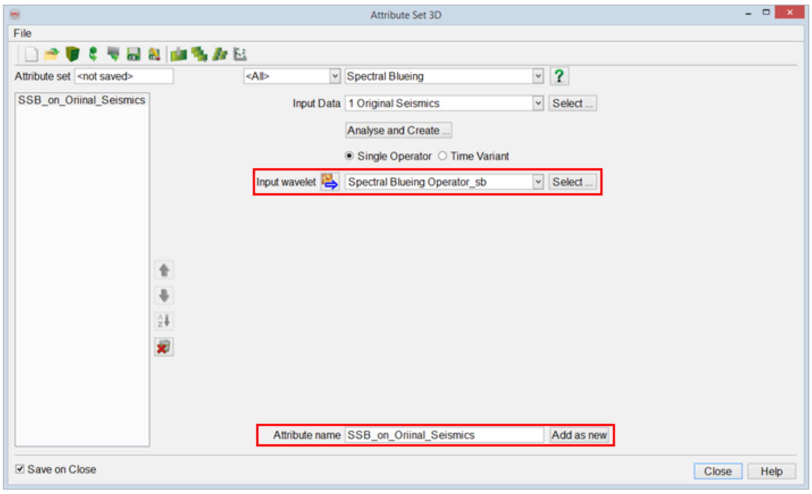


Workflow cont'd:

24. **Close** the SSB module and **return** to the Attribute Set 3D window.

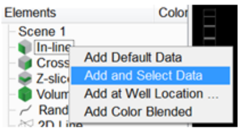
25. **Check** if the newly-saved operator is selected.

26. **Specify** the Attribute Name and **Click** Add as new.

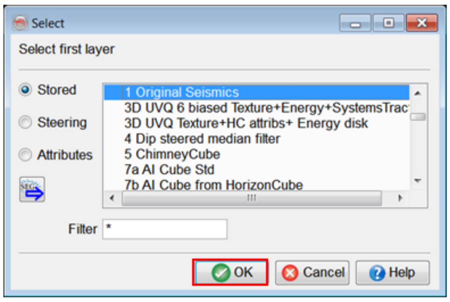


Workflow cont'd:

27. **Right-click** on In-line in the tree and **chose** Add and Select Data.

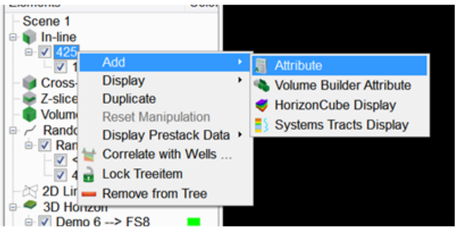


28. **Select** *1 Original Seismics* from Stored tab and **press** OK.

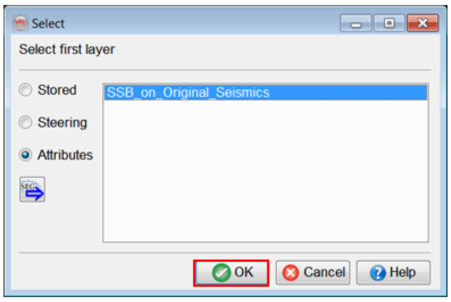


Workflow cont'd:

29. **Apply** the SSB attribute on inline 425 and **compare** the result to the original seismic data: **Right-click** on In-line 425 in the tree and **follow** Add > Attribute.

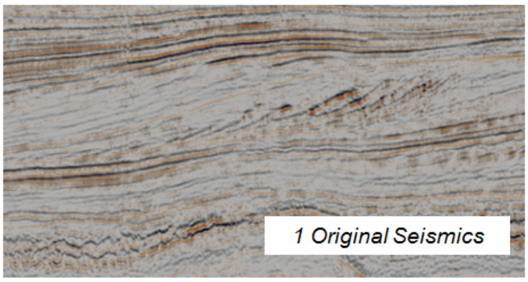


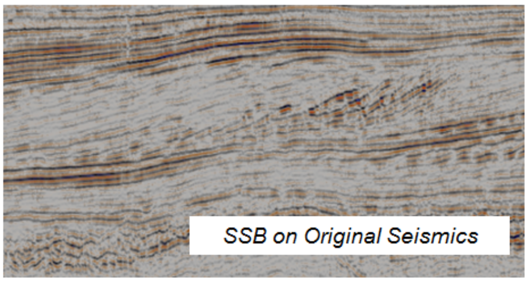
30. **Select** *SSB_on_Original_Seismics* from Attributes tab and **press OK**.



Workflow cont'd:

30. The results should be similar to the ones shown below.

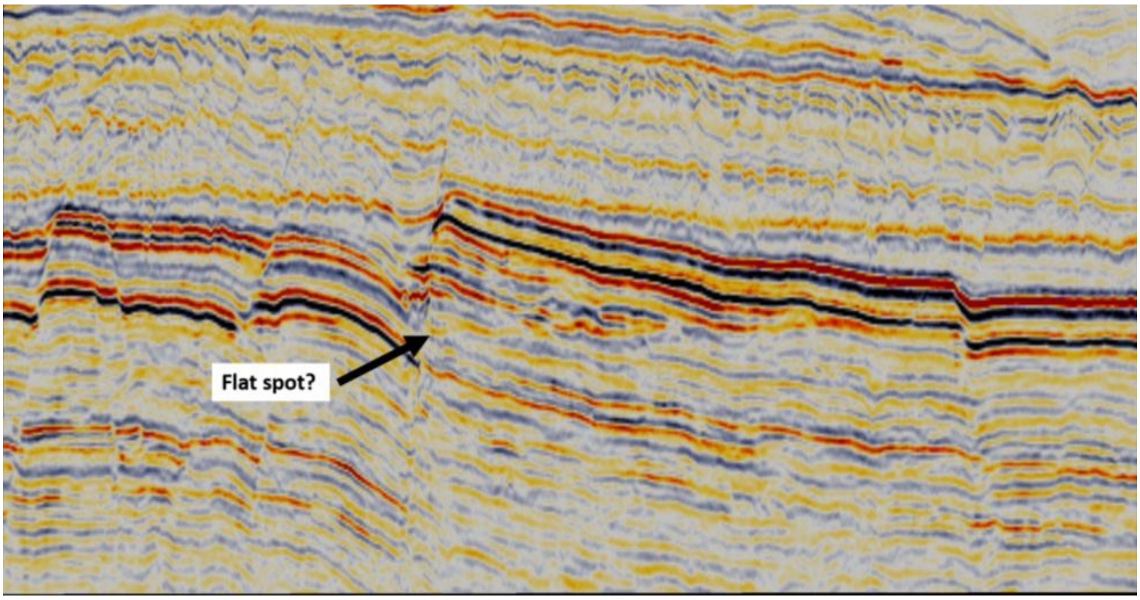




31. **Compare** the original seismic and the SSB seismic: **tick on** and **off** the overlaying attribute in the tree.

2.3.5 Flat-Spot Detection

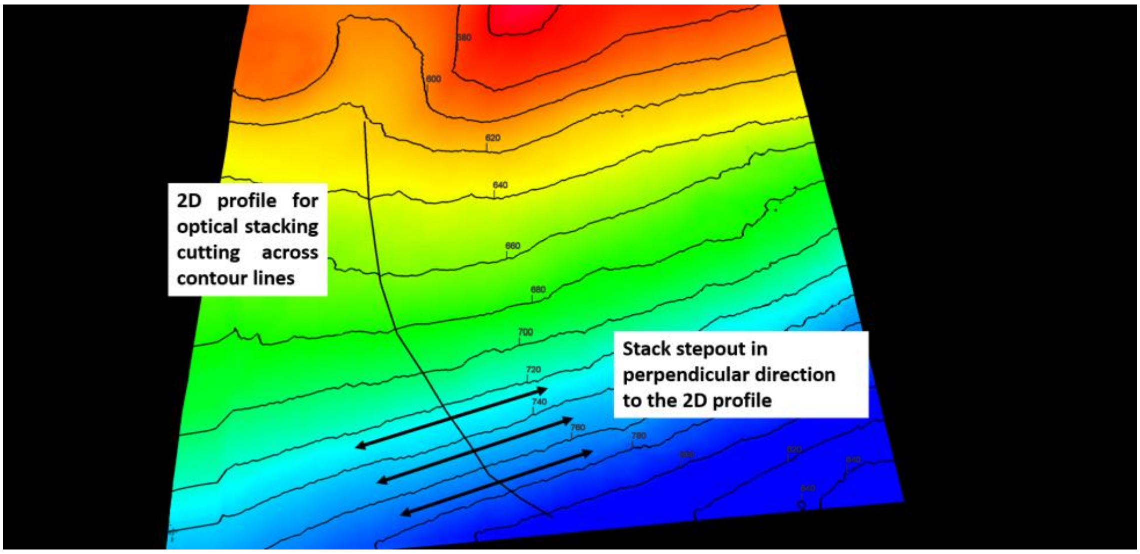
Various methods have been developed to detect locally horizontal seismic events, which do not follow the stratigraphy of the geological layers. These events are potentially Direct Hydrocarbon Indicators, since fluid contacts will most often be perpendicular to the pressure gradient, regardless of the 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.



Optical Stacking

What you should know about Optical Stacking

Optical stacking is released as a free (open source) attribute in OpendTect. Historically optical stacking was the first stacking method to enhance hydrocarbon anomalies that emerged in seismic interpretation software systems. Optical stacking stacks seismic traces that are on either side of a 2D profile. The 2D profile should ideally be oriented such that depth contour lines are crossed perpendicular to the line direction. The traces in the stacking direction can be expected to have similar fluid effects (same hydrocarbon columns) hence subtle hydrocarbon effects are enhanced.



2.3.5a Optical Stacking

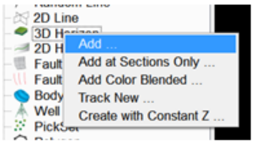
Required licenses: OpendTect.

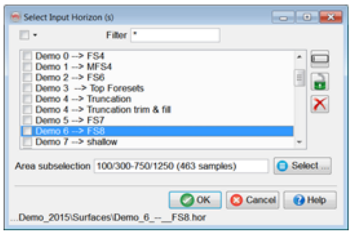
Exercise objective:

Enhance the amplitude anomaly on a random line with optical stacking.

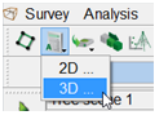
Workflow:

1. **Right-click** on 3D Horizon in the tree > Add... and **select** *Demo 6 --> FS8*.



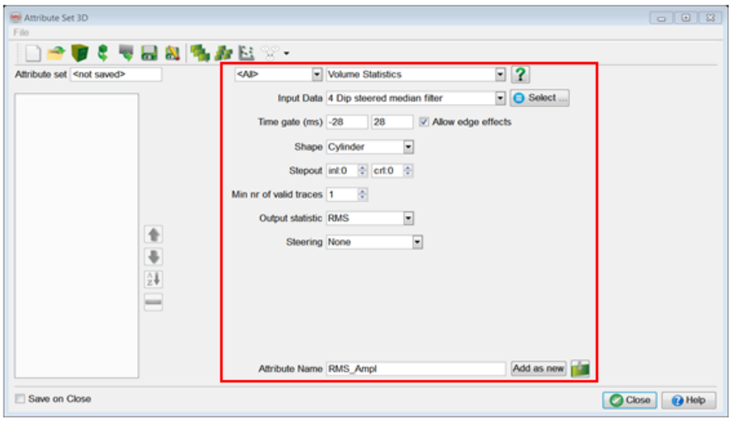


2. **Launch** the Attribute Set 3D window.



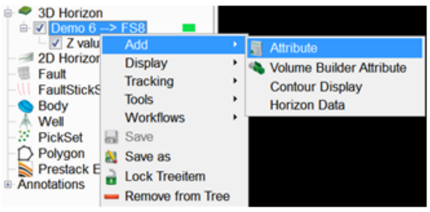
3. **Choose** Volume statistics attribute from the drop-down list.

4. **Specify** parameters as shown on the image to define an RMS amplitude **give** it a name and **press** Add as new.

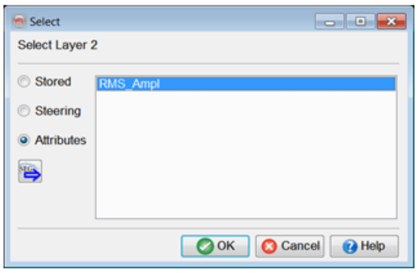


Workflow cont'd:

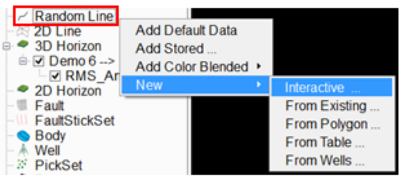
5. **Right-click** on *Demo 6 --> FS8* > Add > Attribute.



6. **Choose** the RMS amplitude and **click** OK. Optionally, change the color bar for RMS amplitude to Rainbow Plus.

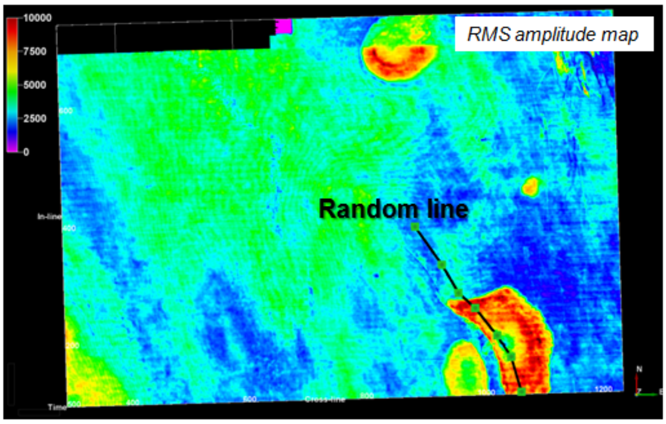


7. **Right-click** on Random Line in the tree > New > Interactive ...

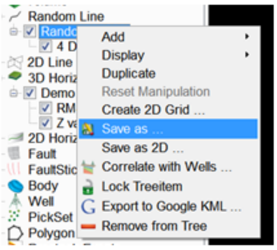


Workflow cont'd:

8. **Pick** a random line going through the structure where the amplitude anomaly is seen. Using the left mouse button, click on the map to insert a node.

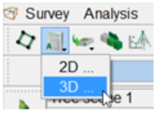


9. **Right-click** on a newly picked random line in the tree > **Save as …** and type in a new name.



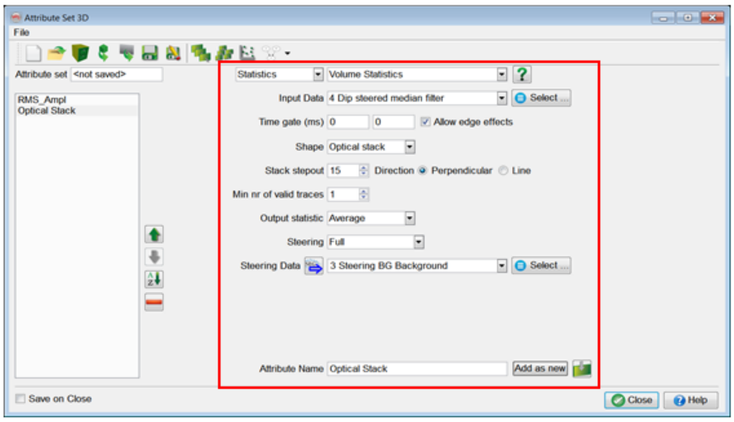
Workflow cont'd:

10. **Launch** the Attribute Set 3D window.



11. **Choose** Volume statistics attribute from the drop-down list.

12. **Specify** the following parameters to define an optical stack: *4 Dip steered median filter* as Input Data, [0, 0] Time gate, Optical stack Shape, Stack stepout of 15, Full Steering by *3 Steering BG Background*.



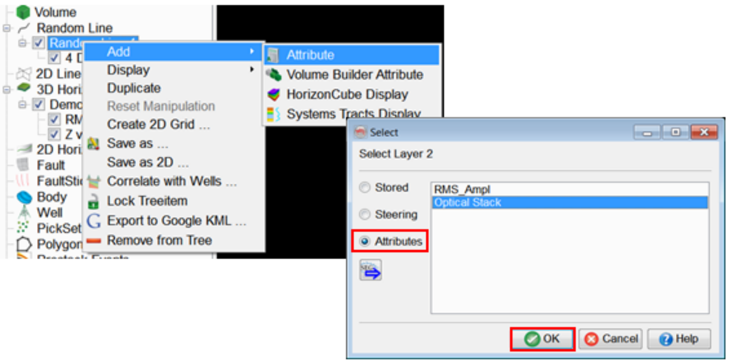
Stack stepout of 15 is equal to 375m at the bin size of 25m.

Workflow cont'd:

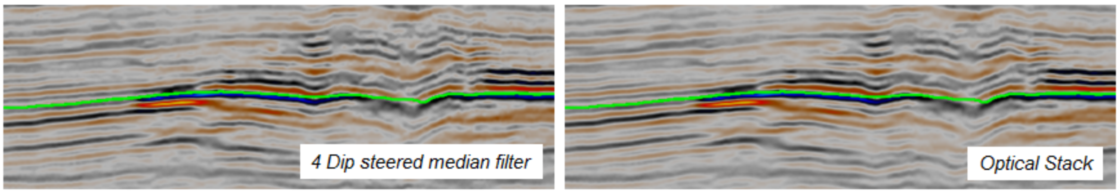
13. **Right-click** on the random line in the tree > Add > Attribute

14. **Choose** the optical stack attribute from the Attributes list and **click** OK.

15. Optionally **evaluate** the Stack stepout parameter.



Compare the optical stack attribute to the input seismic data.
Discuss the results: What events have been preserved, what events have been enhanced, why?



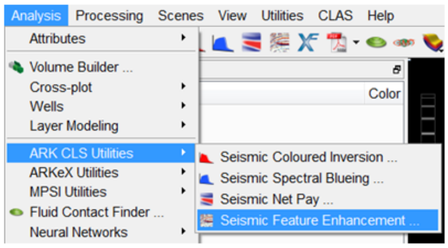
2.3.5b Seismic Feature Enhancement

Required licenses: OpendTect Pro, Spectral Feature Enhancement.

Exercise objective:
Enhance the amplitude anomaly on a random line with Seismic Feature Enhancement (SFE).

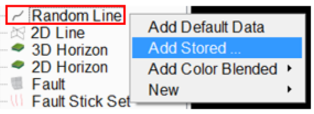
Workflow:

1. **Go to** Analysis > ARK CLS Utilities > Seismic Feature Enhancement.

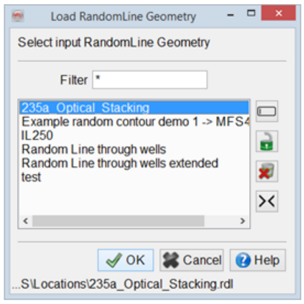


2. **Keep** all the SFE windows open and go to the OpendTect main window.

3. **Right-click** on Random line in the tree > Add Stored ….

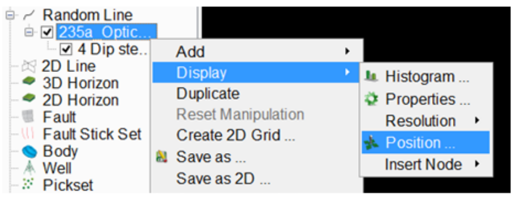


4. **Choose** the random line created in the previous exercise 2.3.5a and **click** OK.

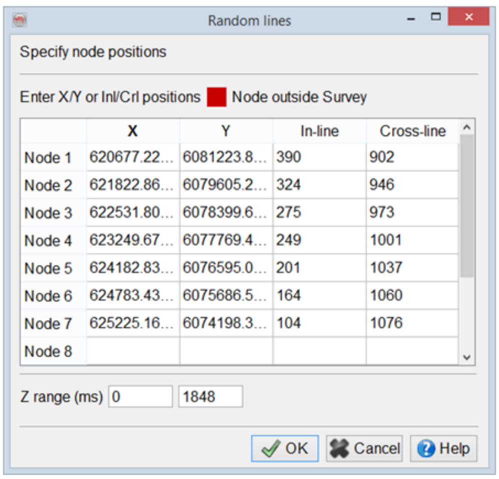


Workflow cont'd:

5. **Right-click** on the random line name in the tree > Display > Position.



6. **Keep** the Random lines window open. This window lists In-line and Cross-line positions of all nodes of the selected random line. You will need this information in one of the next steps.

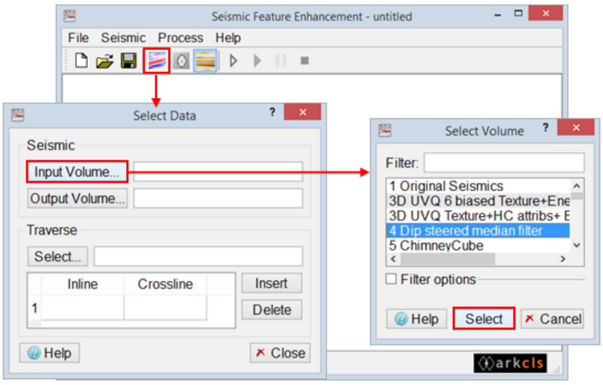


Workflow cont'd:

7. **Go** back to the SFE main window and **Click** on Select Data icon .

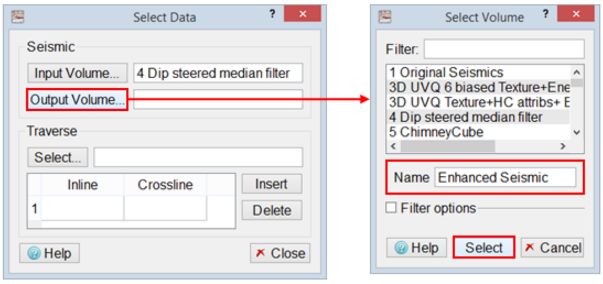
8. **Click** on Input Volume in the Select Data window

9. **Choose** *4 Dip steered median filter* in Select Volume window and **click** Select.



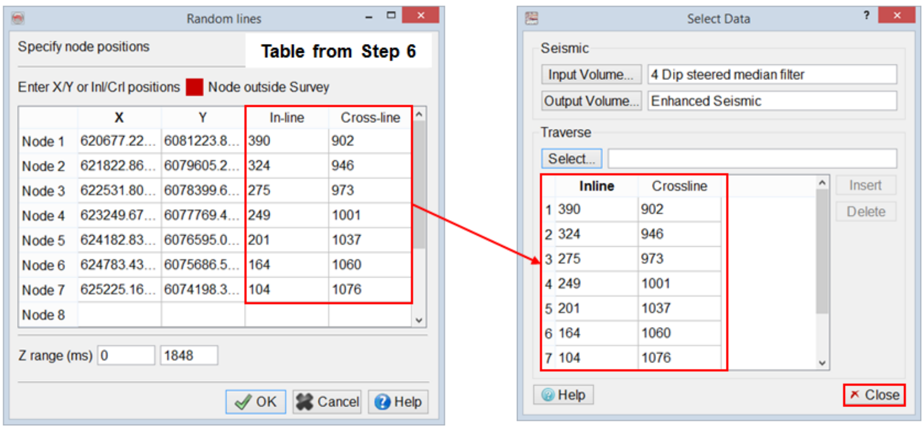
10. **Click** on **Output Volume** in the Select Data window.

11. **Enter** a new name of the output dataset and **click** Select.



Workflow cont'd:

12. **Enter** manually the random line node positions in the Traverse section from Step 6.



13. **Close** the Select Data window.

14. **Close** the Random lines window.

Alternatively, digitize the random line by picking a polygon that you can select as input for Traverse by clicking on Select button.

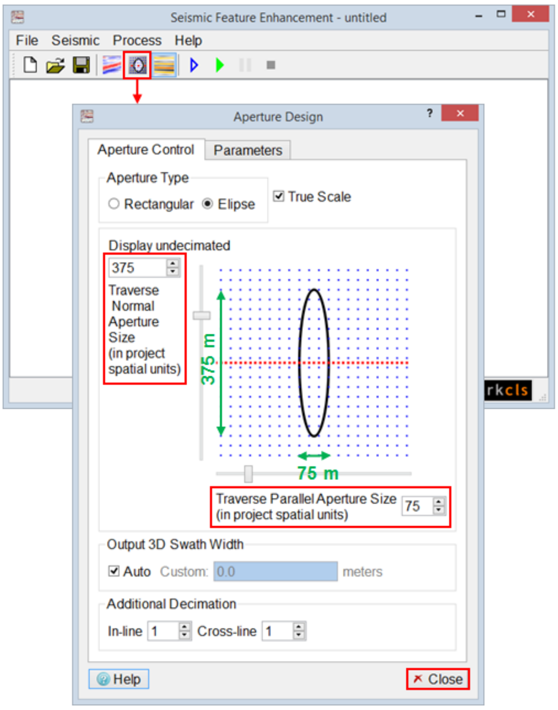
Workflow cont'd:

15. **Click** on Aperture Design icon  in the main SFE window.

16. **Enter** 375 m and 75 m as Traverse normal and parallel aperture sizes.

17. **Close** the Aperture Design window.

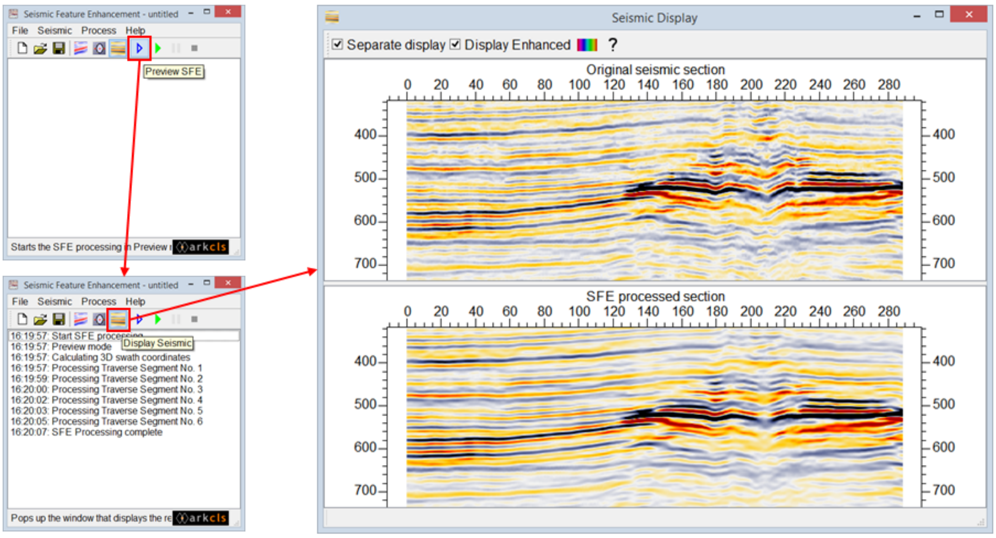
All traces inside the ellipse are stacked and the result is output at the center of ellipse.



Workflow cont'd:

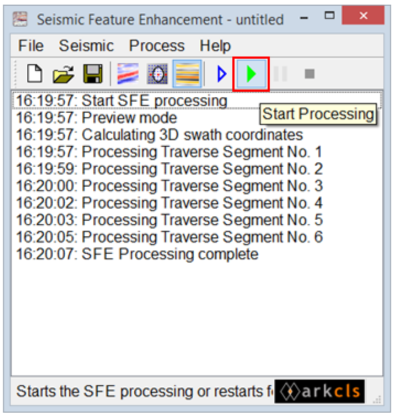
18. **Preview** SFE results by clicking on  icon in the main SFE window.

19. **Display Seismic** by clicking on  icon if it is not displayed yet.

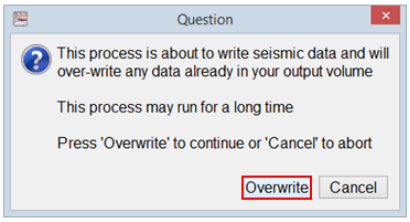


Workflow cont'd:

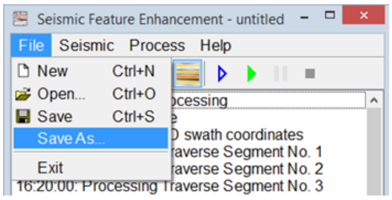
20. **Start Processing** by clicking on [▶] icon in the main SFE window.



21. **Click** Overwrite to output SFE results along the traverse.



22. Optionally, **follow** File > Save As … to save your session.



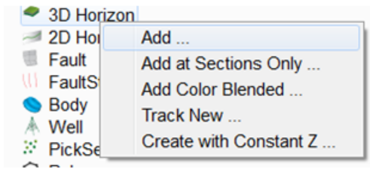
2.3.5c Fluid Contact Finder

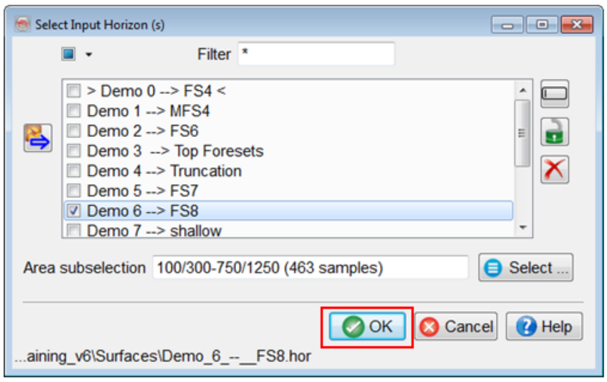
Required licenses: OpendTect Pro, Fluid Contact Finder.

Exercise objective:
Enhance the amplitude anomaly associated with a structure with Fluid Contact Finder (FCF).

Workflow:

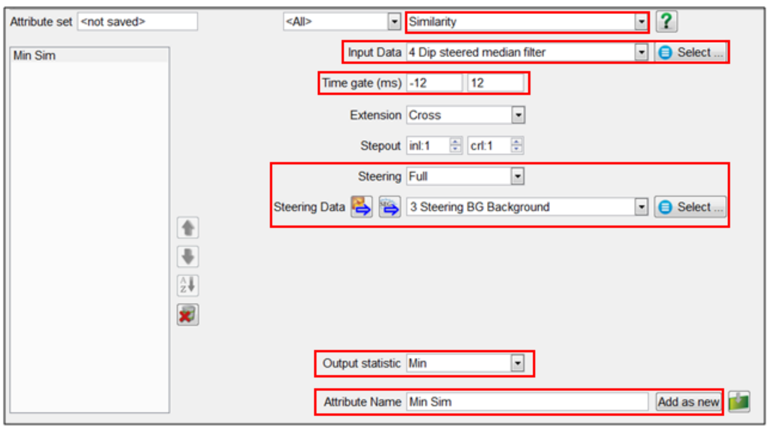
1. **Right-click** on 3D Horizon in the tree > Add …
2. **Select** *Demo 6 --> FS8* and **click** OK.





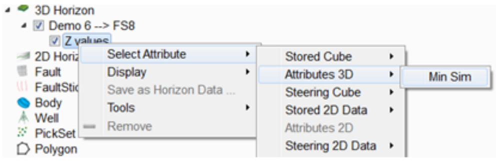
Workflow cont'd:

3. **Open** the attribute window .
4. **Choose** Similarity attribute from the drop-down list and **Select** *4 Dip steered median filter* data as input.
5. **Set** the time-gate to [-12, 12] ms.
6. **Select** Steering as Full and **use** *3 Steering BG Background*.
7. **Specify** Output statistics: Min.
8. **Name** the attribute *Min Sim* and **Add as new**.



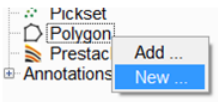
Workflow cont'd:

9. **Display** the attribute on *Demo 6 --> FS8* by **right-clicking** on Z values in the tree > Select Attribute > Attributes > Min Sim.

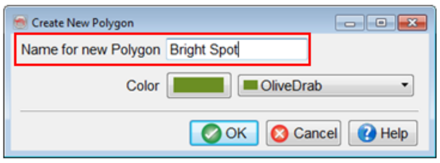


Workflow cont'd:

10. Create a new polygon by **right-clicking** on Polygon in the tree > New.



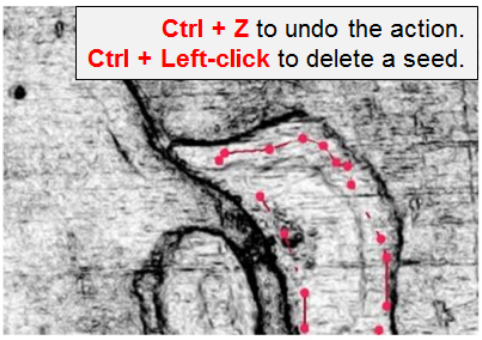
11. **Name** the new polygon: *Bright Spot*.

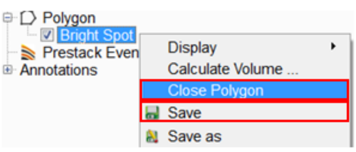


12. **Draw** the polygon using left-click, as shown in the image.

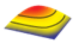
13. **Right-click** on the polygon in the tree (or in the scene) > **Close Polygon**.

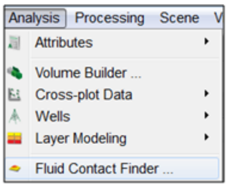
14. **Right-click** on the polygon in the tree > **Save**.





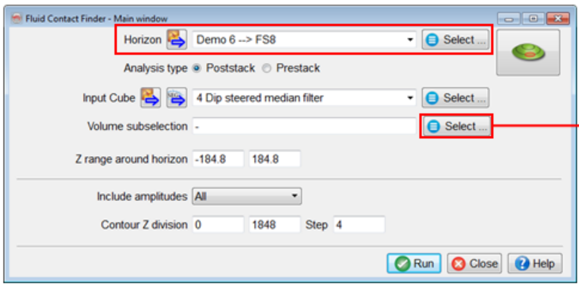
Workflow cont'd:

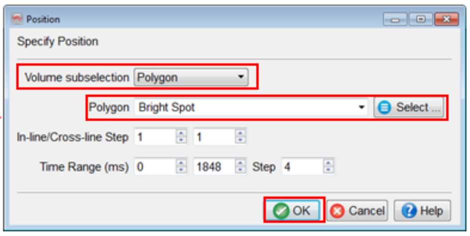
15. **Go** to Analysis > Fluid Contact Finder (or click on the  icon).



16. **Select** the *Demo 6 --> FS8* horizon, leave the default Input Cube *4 Dip steered median filter.*

17. **Click** on Select for Volume subselection and **choose** Bright Spot polygon created earlier.

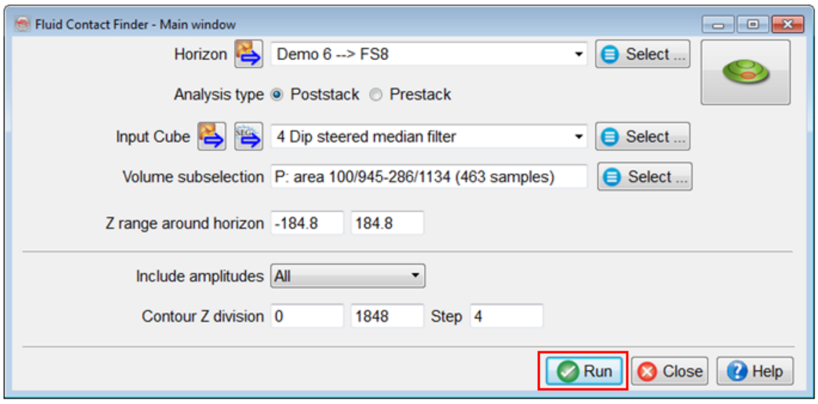




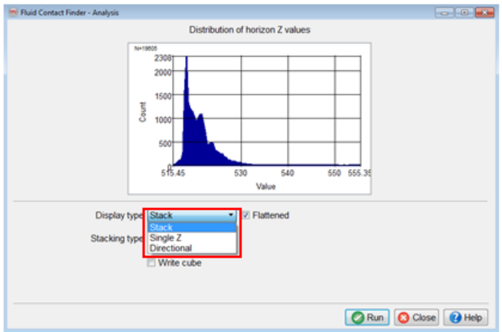
Workflow cont'd:

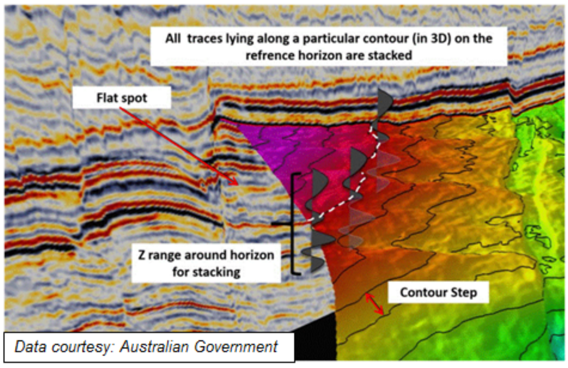
For the first test, contour Z division as the entire Z range of the survey. This can be restricted later. Also leave the Z range around horizon as default.

18. **Click** Run to start the extraction and clustering of the data



Display types available in FCF analysis window:
Stack: traces are stacked along depth/time contour bins and plotted as a 2D profile. The display can be flattened on a horizon. The stacked traces can be stored as a 3D volume if Flattened is checked.
Single Z: traces belonging to a single contour bin are displayed in a 2D viewer.
Directional: FCF-stacked amplitude at the horizon as a function of the distance to a selected position and the azimuth sector.



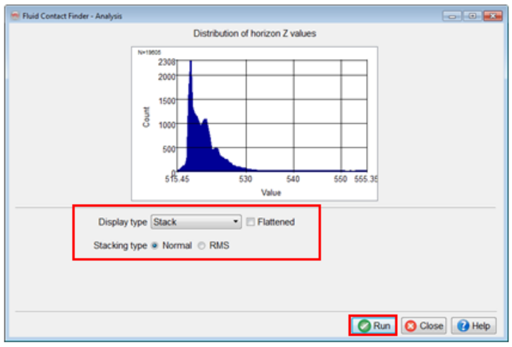


The image on the left (not from F3 Demo survey) illustrates the FCF stack concept.

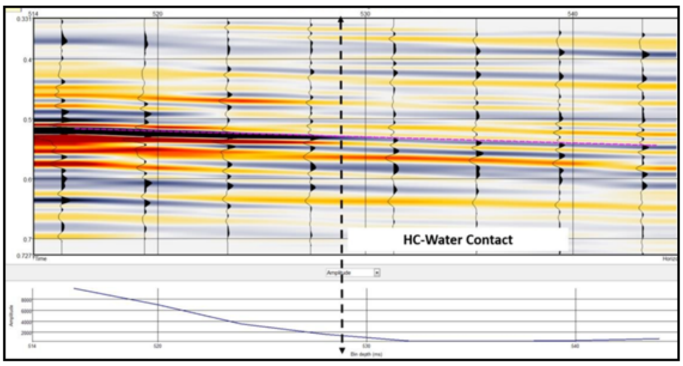
Workflow cont'd:

19. **Choose** Display type as Stack, **uncheck** Flattened and **click** Run.

This window will remain open so that several FCF analyses can be run.



20. The FCF stack shows stacked traces along common contour bins of *Demo 6 --> FS8* horizon. The possible fluid contact is highlighted: observe the drastic amplitude change at the flank of the structure.



2.3.6 Seismic Object Detection Using Neural Networks

What you should know about Neural Networks in OpendTect

Neural Networks in OpendTect are used for:

1. Visualizing seismic patterns along horizons and in 3D. This is a qualitative approach using an unsupervised Neural Network (aka clustering or segmentation).
2. Visualizing seismic objects such as chimneys, faults, salt domes, anomalies, etc. This is a two-class classification approach using a supervised Neural Network (aka object detection).
3. Predicting rock properties such as porosity, fluid content, etc. This is a quantitative approach using a supervised neural network.
4. Predicting lithology classes. This is a multi-class classification approach using a supervised neural network.

This chapter deals with visualizing patterns and objects. How Neural Networks can be used e.g. to predict porosity from inverted acoustic impedance and porosity well logs is described in the chapter on rock property predictions.

What you should know about supervised Networks in OpendTect

The supervised network is a fully-connected Multi-Layer Perceptron (MLP) with one hidden layer (i.e one layer between the input node and the output neurons). The learning algorithm used 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. In practice, supervised training, the user is teaching the network to distinguish between two or more pointsets.

What you should know about unsupervised Networks in OpendTect

The unsupervised Neural Network is the Unsupervised-Vector-Quantizer (UVQ). This Neural 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 center vectors on similarity. This has the advantage that in the application phase colours 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 center vectors yielding two possible outputs: Segment (or Class) and Match. Segment is the index of the winning cluster center. Match is a measure of confidence between 0 (no confidence) and 1 (input vector and winning cluster vector are identical).

The unsupervised segmentation approach reveals areas with similar seismic responses and is used extensively as an easy-to-use and quick interpretation tool. Clustering can be achieved using waveform and also using 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).

Waveform segmentation

Unsupervised segmentation 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, which is also called waveform segmentation because the input to the network is a waveform (= time-gate) extracted along the horizon. 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.

For waveform segmentation 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.

OpendTect supports two ways to create a horizon-based unsupervised segmentation: The *Standard Neural Network* method and the so-called "*Quick UVQ*" method.

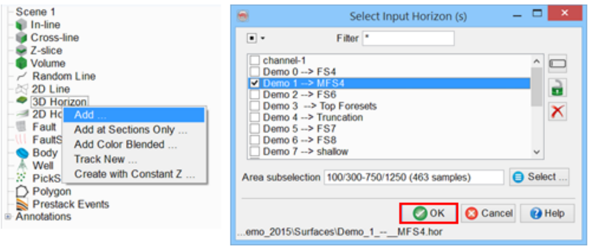
2.3.6a Waveform Segmentation - Quick UVQ

Required licenses: OpendTect Pro, Neural Networks.

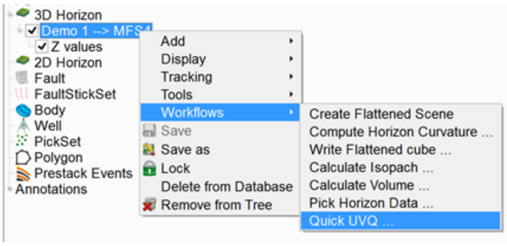
Exercise objective:
Visualize seismic pattern on a mapped horizon using Quick UVQ waveform segmentation.

Workflow:

1. **Right-click** on 3D Horizon in the tree > Load… > **Choose** *Demo1 → MFS4.*

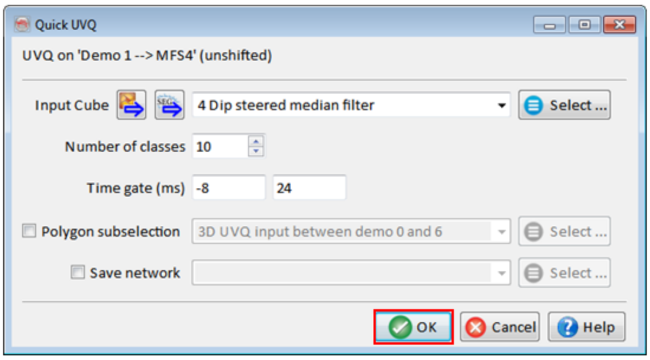


2. In the tree, **right-click** on *Demo1 → MFS4* > **Workflows > Quick UVQ**.



Workflow cont'd:

3. In the Input Cube field the default *4 Dip steered median filter* volume is already selected.
4. Number of classes describe how many clusters the waveforms will be divided into.
5. The time gate describes the investigation window.
6. Optionally, a polygon can be used for sub-selection. Also, the neural network can be saved to disk.
7. **Click OK** to train a neural network and produce results.

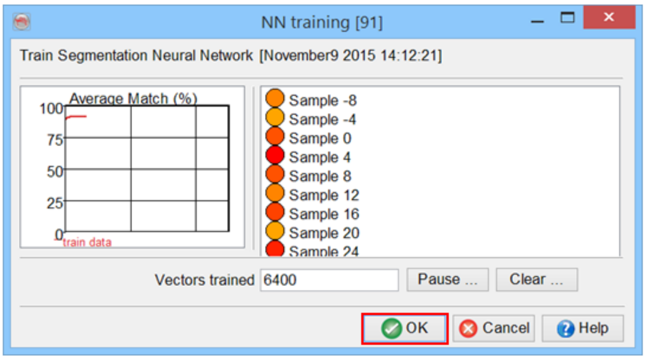


In practice, we always predict less number of classes (e.g. 5) to get a regional understanding of a depositional system. We then increase the number of classes to predict details.

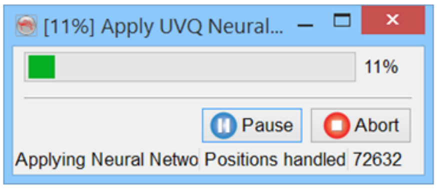
Time gate can be adjusted relative to a horizon. In this case, -8ms is used considering a horizon is not perfectly snapped to a peak/trough. The focus is mostly below the horizon by setting 24ms.

Workflow cont'd:

8. A NN training window will pop-up. If the training is above 90% and flat, then you can **press** OK button.



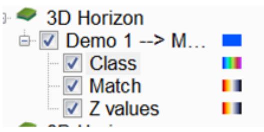
It will start applying the results on the input horizon.



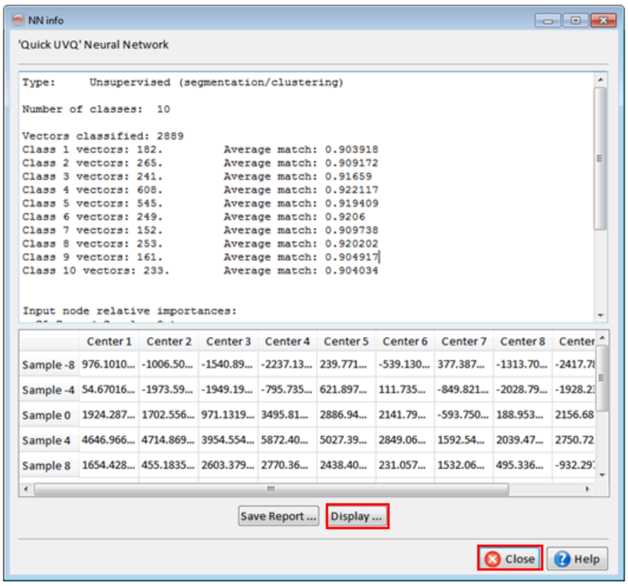
Workflow cont'd:

9. Once the NN processing is finished, you will see a NN Info window and two grids, (Class and Match) which are already displayed on the horizon.

Tip: If you are satisfied, you may want to save them as Horizon Data by right-clicking on each of them.

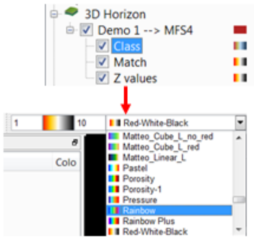


10. **Click** Display… to show class centers and **Close** the Info window.



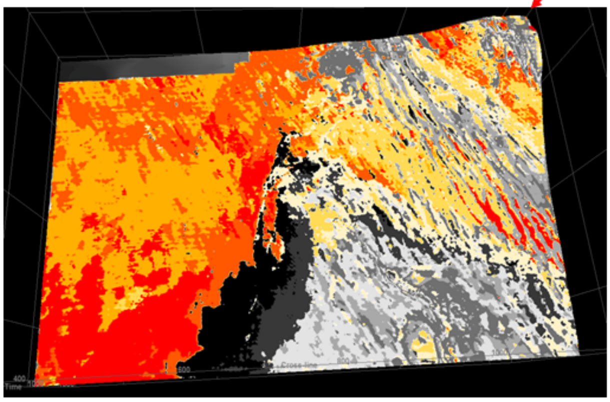
Workflow cont'd:

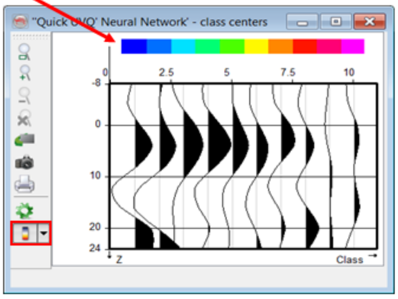
11. To match the colors, **click** on the Class grid, and choose Rainbow color bar.



12. Optionally, **click** on the color-bar icon in the class center if you want to change the color scheme there also.

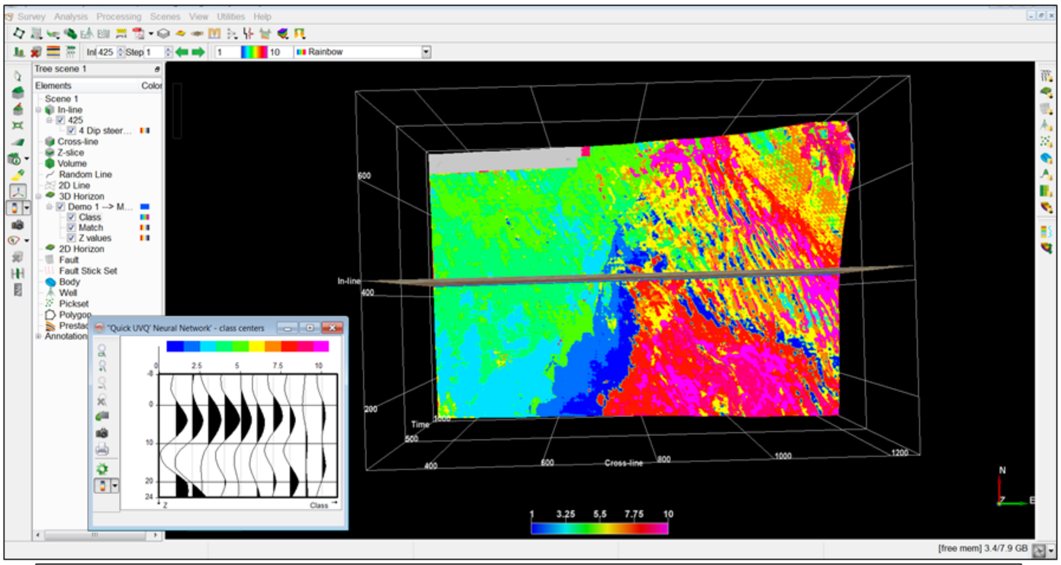
Colors are not matching....





Workflow cont'd:

13. Your results may look like this.



For segmented results such as UVQs, we prefer to use a segmented color bar. You can always change a color bar through manager (Survey > Manage > Colour tables).

2.3.6b Waveform Segmentation - Standard UVQ

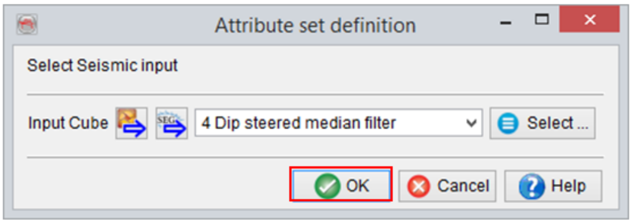
Required licenses: OpendTect Pro, Neural Networks.

Exercise objective:
Visualize seismic patterns on a mapped horizon using the standard unsupervised neural network method

Workflow:

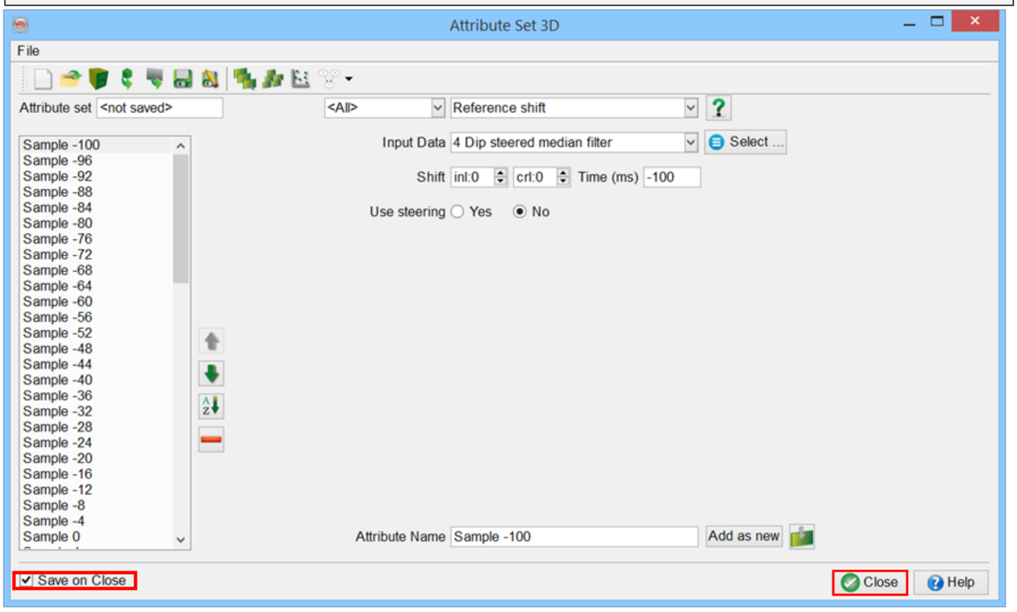
1. **Open** the Attribute set window and select the default attribute set named Workflow - Unsupervised Waveform Segmentation.

2. It will pop up a window asking to provide Input Seismics, the default volume is automatically selected. **Press** OK.



This default attribute set is designed to extract each samples within the time window [-100,+200]ms (with a step equal to the z step of the survey) regarding the application sample.

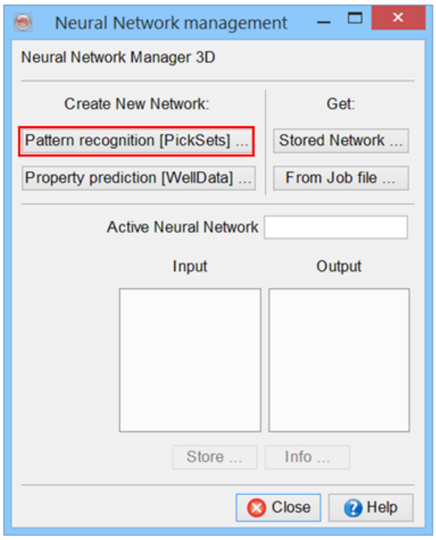
Uncheck Save on Close and close the Attribute Set 3D window.



Workflow cont'd:

3. **Start** the 3D Neural Network plugin by clicking the  icon.

4. **Select** the option Pattern recognition [PickSets].

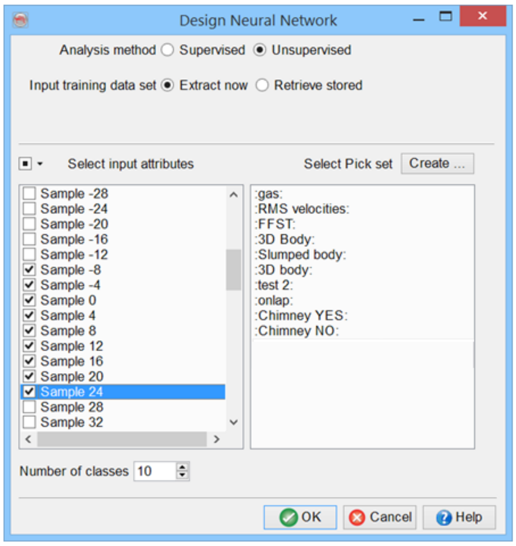


Workflow cont'd:

5. **Set** the analysis method to Unsupervised.

6. **Select** Samples within the window [-8,24]ms.

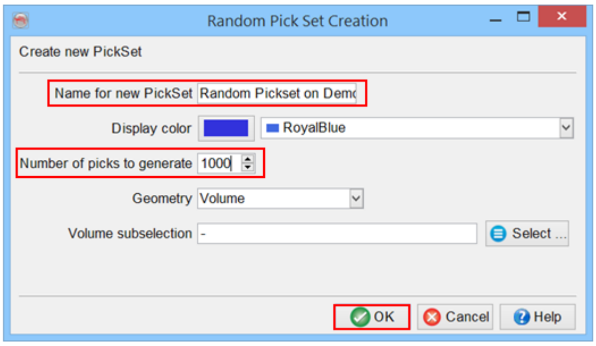
7. **Click** on Create button... to generate a random pickset.



Workflow cont'd:

8. **Create** a pickset containing 1000 picks along the horizon *Demo1 → MFS4*.

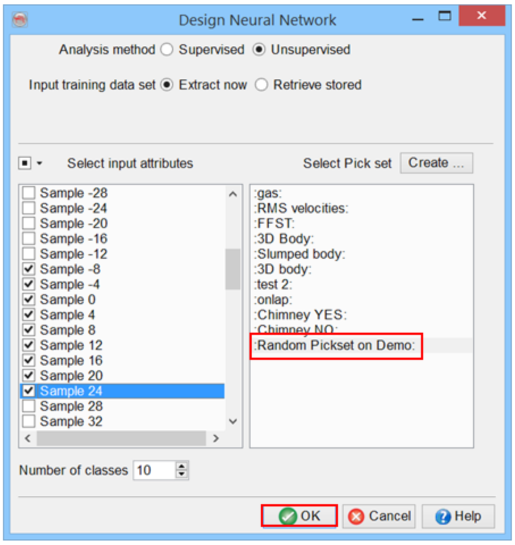
9. **Click** OK.



Workflow cont'd:

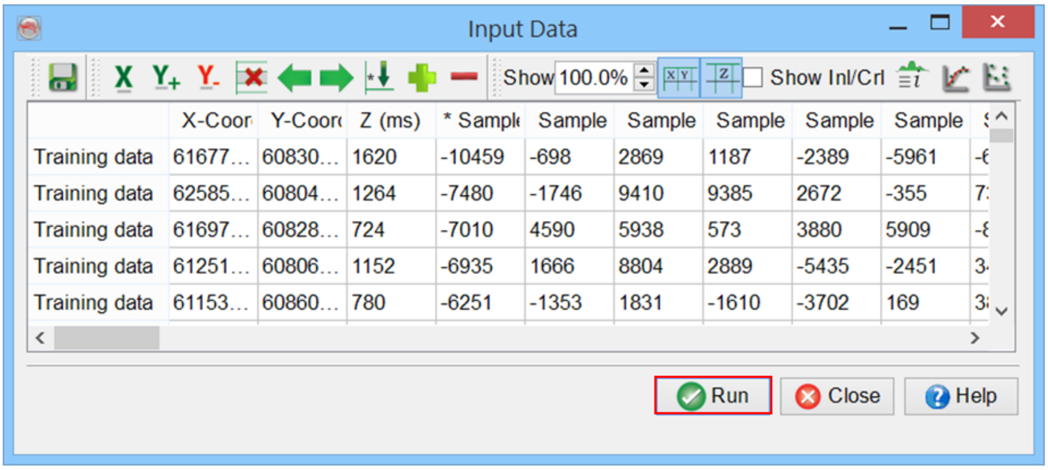
10. The pickset will appear in the list. Make sure that the correct set is selected.

11. **Click** OK.



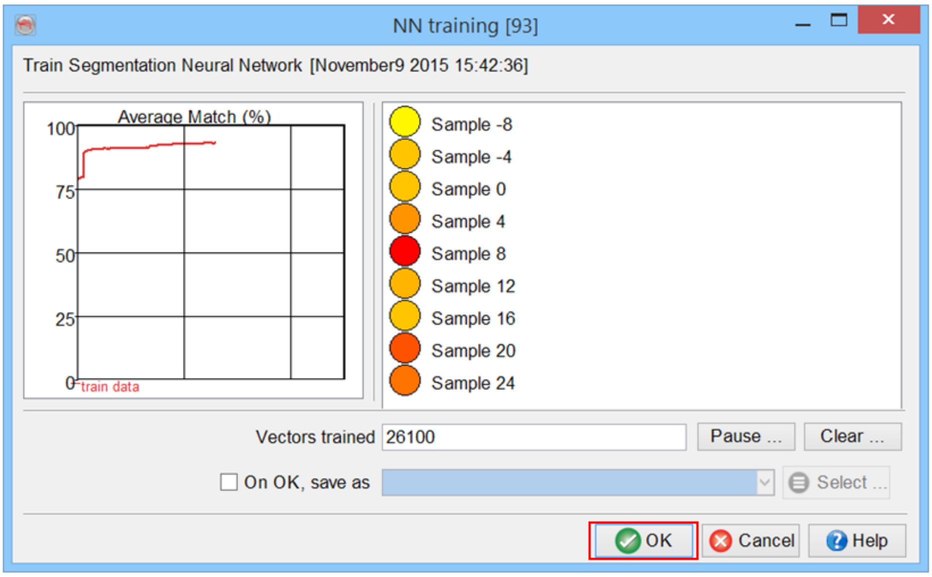
Workflow cont'd:

12. A spreadsheet with statistics will pop up. **Click** on Run.



Workflow cont'd:

13. This will start the neural network training. After the Average Match curve becomes flat, **click** on OK. Training with a 90% (match) is considered as a good prediction.

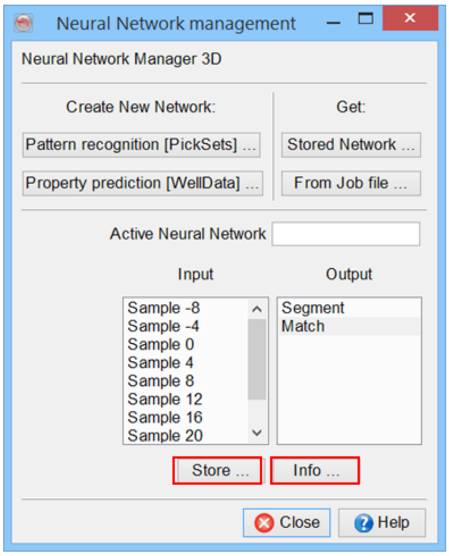


Workflow cont'd:

14. The trained neural network is now active, with appropriate input and output.

15. **Click** on Store .. to save the neural network to disk.

16. **Click** on Info…

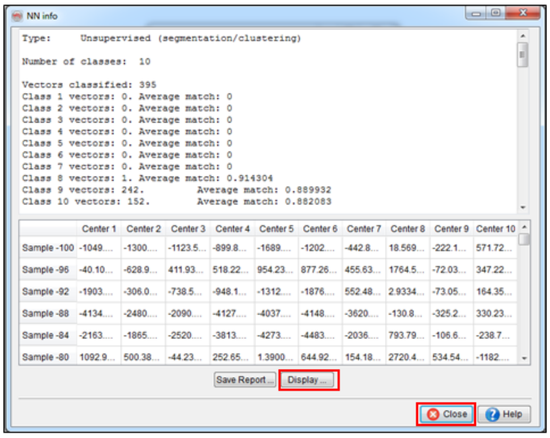


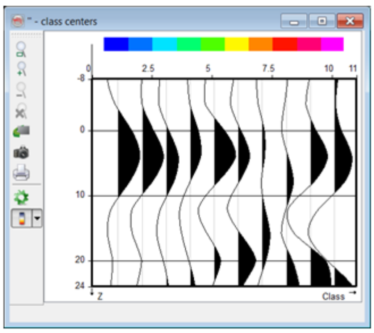
Workflow cont'd:

17. NN info window will pop up.

18. **Click** on Display to show Class Centers.

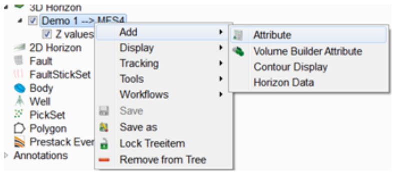
19. **Close** the NN info and the NN Management windows.



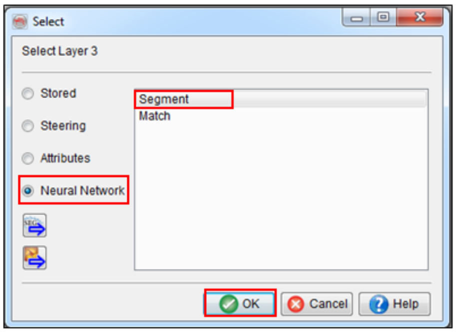


Workflow cont'd:

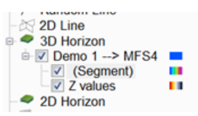
20. **Add** a 3D horizon *Demo1 → MFS4* in the tree. **Apply** the neural network to the horizon by **right-clicking** on the horizon name in the tree > Add > Attribute.

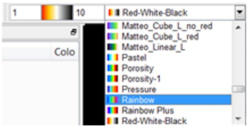


21. When prompted to select data, select *Segment* attribute from Neural Network tab.



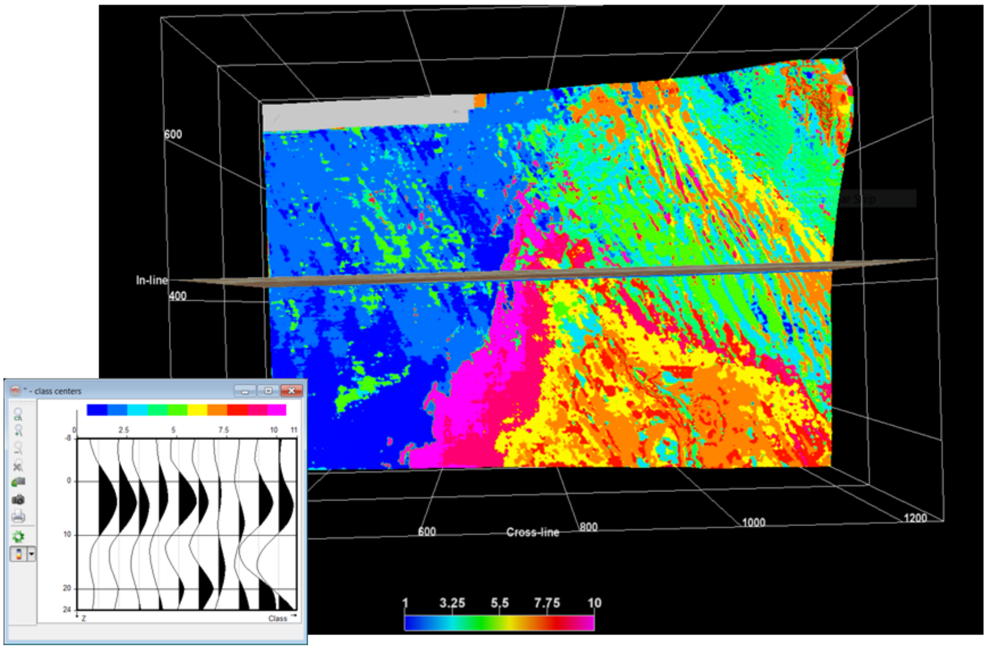
22. As Segment appears in the tree **change** the color bar to Rainbow.





Workflow cont'd:

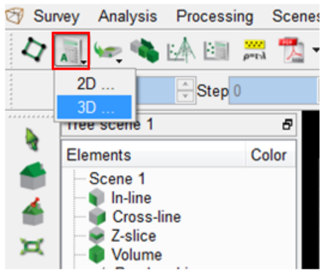
23. Your results may look like this.



2.3.6c ChimneyCube

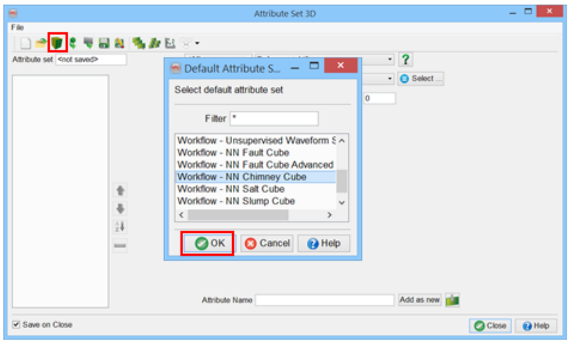
Required licenses: OpendTect Pro, Dip-steering, Neural Networks.

Exercise objective:
Create a ChimneyCube with the supervised Neural Network approach.



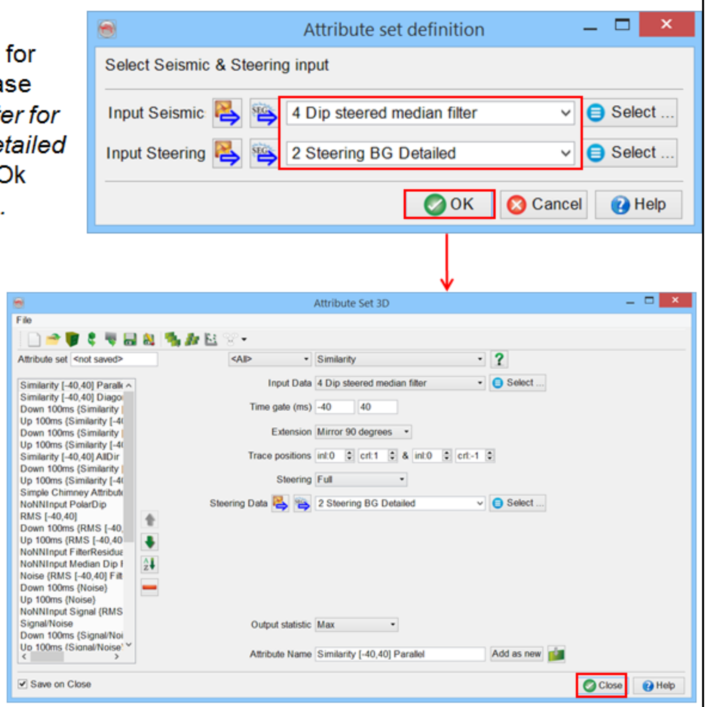
Workflow:

1. **Open** the attribute editor using the icon and open the default attribute set *NN ChimneyCube* via *the icon* and **click** on Ok.



Workflow cont'd:

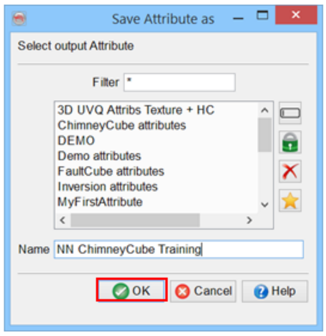
2. A pop up message will **prompt** for seismic and steering data. Please select *4 Dip steered median filter for seismics* and *2 Steering BG Detailed* for *steering Data* and **click** on Ok and **close** the Attribute window.



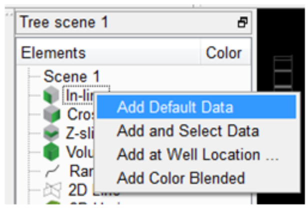
The attributes in this set should help differentiate *chimneys* and *background noise*. Visual inspection of the data shows chimneys present around inline 290 and 690. The chimneys appear as vertical noise trails

Workflow cont'd:

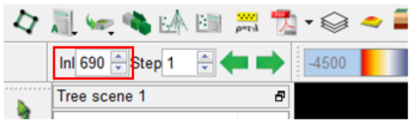
3. **Save** the Attribute set as *NN ChimneyCube Training* and **click** on Ok.



4. **Add** default data (i.e. *4 Dip steered median filter*) by **right-clicking** on inline.

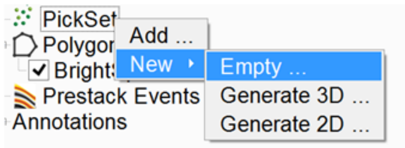


5. **Click** on the added inline number 425 and **change** it to 690 by entering it in the Inl box.

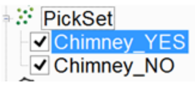


Workflow cont'd:

6. In order to **pick** chimneys and differentiate them from the background noise, two picksets are needed.



7. **Click** on Pickset in the tree > New Pickset > Empty. In the pop-up you will give a name to this as *Chimney_Yes.*



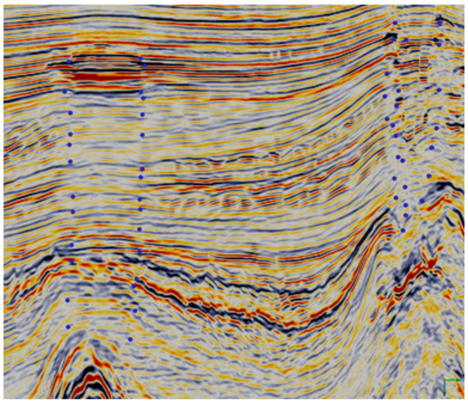
8. **Repeat** the Step 7 and create another pickset called *Chimney_NO.*

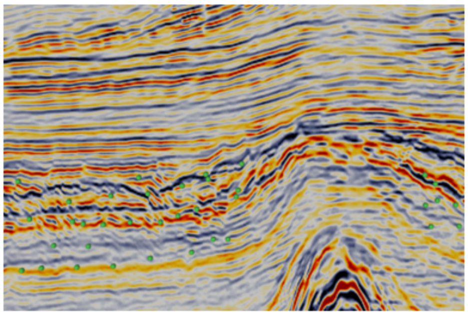
Workflow cont'd:

9. **Highlight** the *Chimney YES* pickset and **pick** locations in the scene that appear as chimneys.

10. **Repeat** the process for the *Chimney NO* pickset, **pick** locations where chimneys are not expected. **Save** both picksets by **right-clicking** on their names.

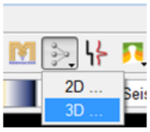
11. Scroll to another inline using the icons to make more picks. **Save** both picksets.



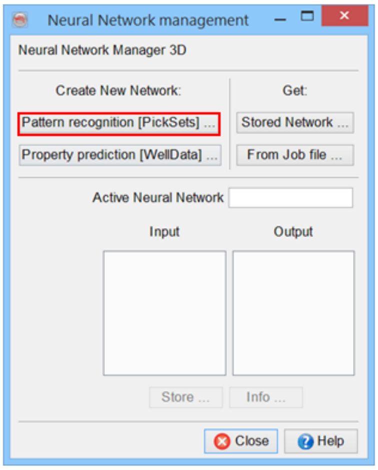


Workflow cont'd:

12. **Open** the 3D neural network by clicking on the icon.

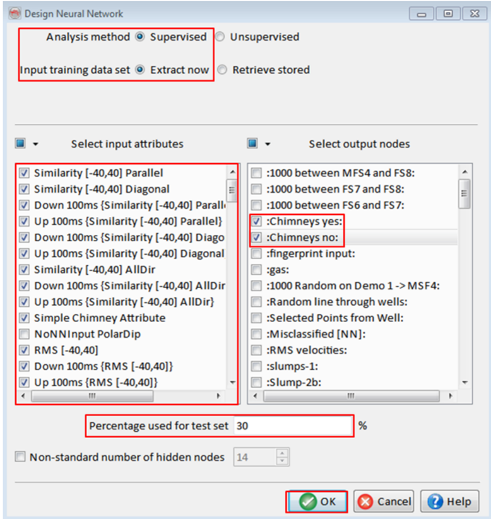


13. **Click** on Pattern recognition.



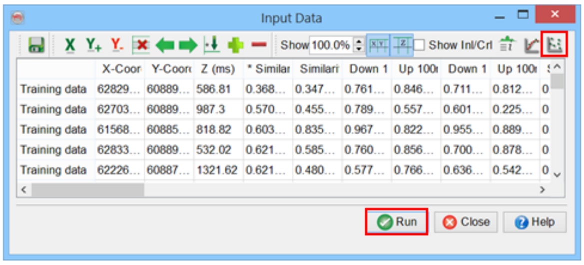
Workflow cont'd:

14. **Set** Analysis method to Supervised. **Deselect** attributes with prefix "*NoNN*" from the list. Select Chimney_Yes and Chimney_No picksets made by you. **Specify** 30% of the data for test set and **press** OK.

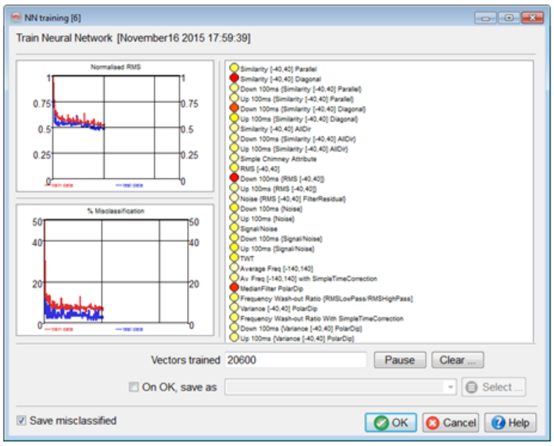


Workflow cont'd:

15. A spreadsheet with statistics will pop up, here you may edit and analyze the attributes by cross-plotting them against the *Chimney YES* and *NO* picksets. After investigating, **click** Run.



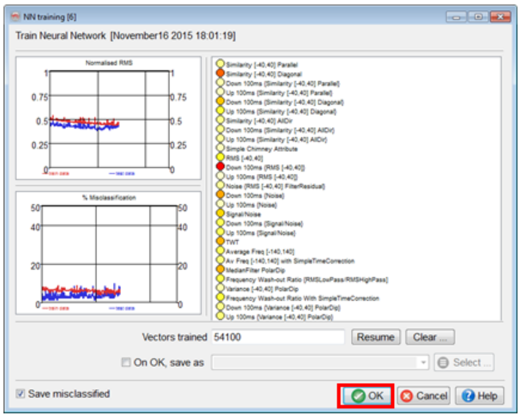
16. The neural network training will begin.

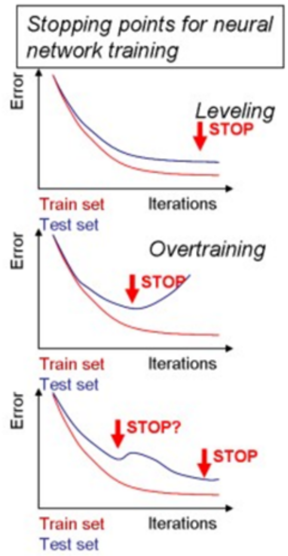


Workflow cont'd:

17. As the training of the neural network runs, the normalized RMS and % Misclassification curves will decrease. In order to avoid overtraining of the neural network, click OK as soon as the normalized RMS curve becomes flat.

18. If the training graphs become flat and are not changing, you may proceed and click OK button.



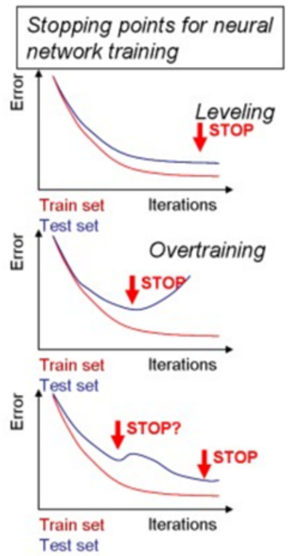


Workflow cont'd:

You can press clear to restart the training, for example if the neural network becomes over-trained

The colors of the input attributes change during the training. The colors reflect the weights attached to each input node and range from white via yellow to red. Red nodes have the most weights attached and are thus more important to the network for classifying the data.

Colors are very useful indicators on how to tune a network and discard attributes that may take up a lot of CPU time without contributing to the final result

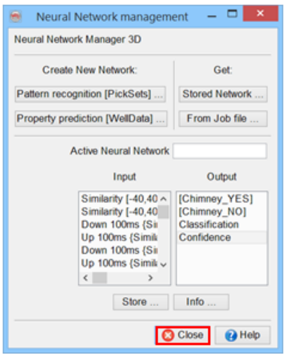


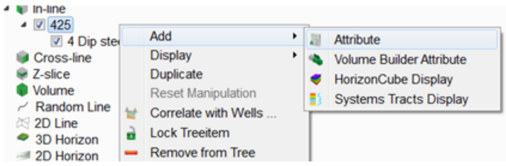
Workflow cont'd:

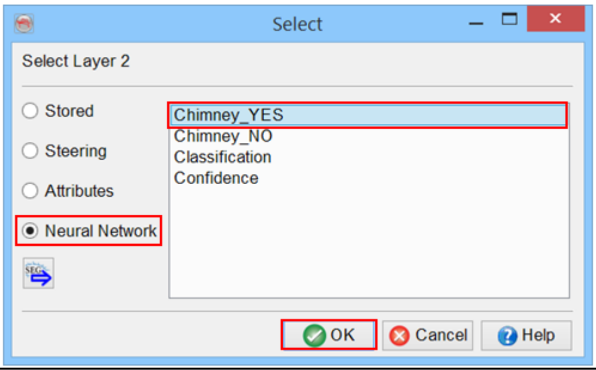
19. Optionally, **Store** the Neural Network (you will need to provide a new name).

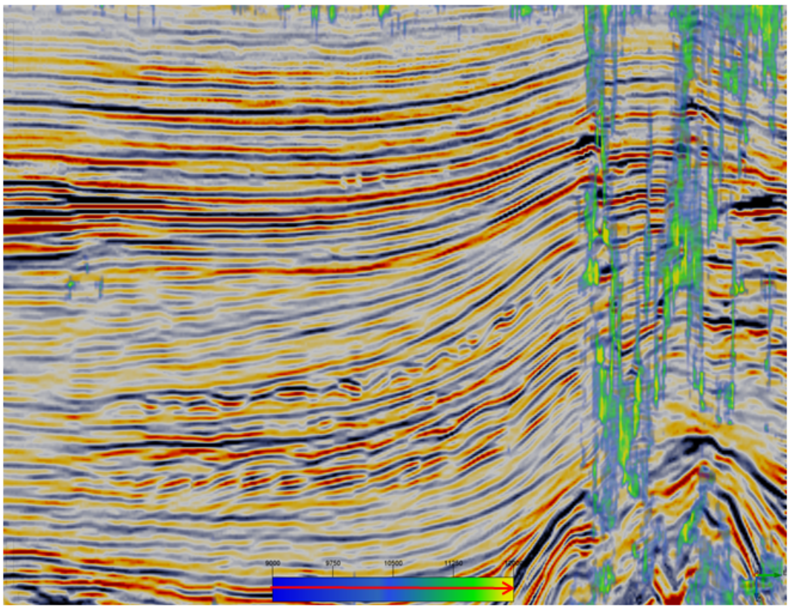
20. **Close** the Neural Network Management window.

21. **Test** the training results on your data. Add the neural network attribute named *Chimney YES* by **right-clicking** an inline (e.g. inline 690) in the tree.





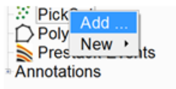


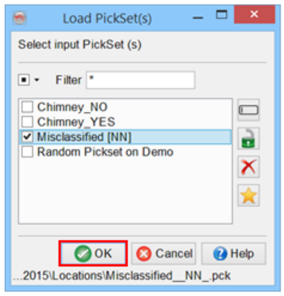


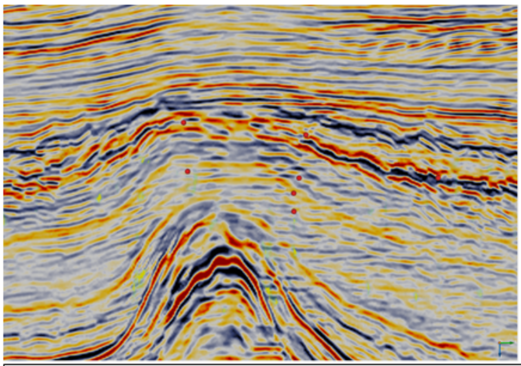
Example of chimney display on inline 690. The red arrow indicates increased likelihood of chimneys.

Workflow cont'd:

22. If you are not satisfied with the output, go back and **change** the location of your picks using the *Misclassified NN* pickset (generated automatically) by **right-clicking** *Pickset* in the tree







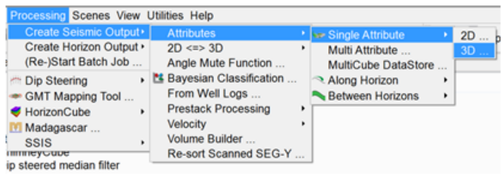
Misclassified NN pickset (in red) on inline 690

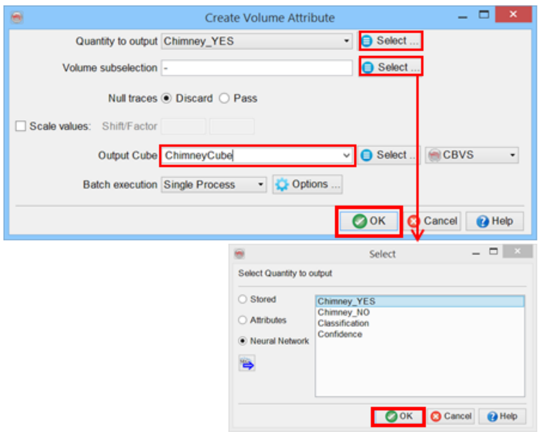
Workflow cont'd:

Create Output Volume

23. When satisfied with the results, the final step is to **output** the ChimneyCube volume as a seismic cube that is stored on disk via Processing > Create Seismic Output > Attributes > Single Attribute > 3D …

24. **Select** the *Chimney YES* attribute from the list, **give** the volume an appropriate name and **click** OK.





2.4 HorizonCube and Sequence Stratigraphy

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 modeling 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. Highly accurate low frequency models can be created by utilizing all the horizons of the HorizonCube, allowing a detailed initial model to be built.

In a similar fashion rock properties can be modeled. 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 plug-ins. To complete the workflow, the Neural Networks plug-in 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.

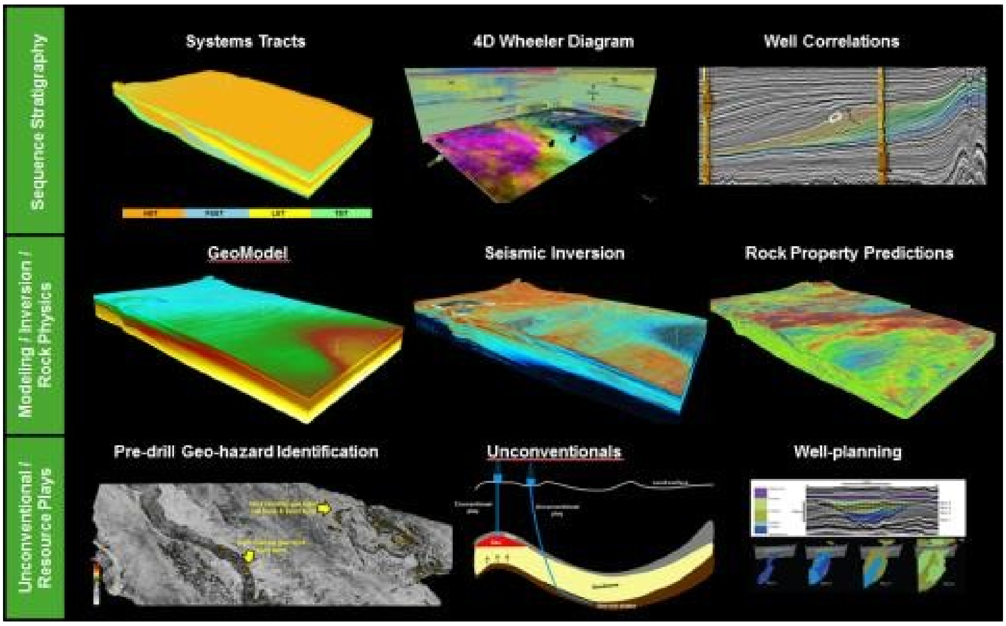
These advanced tools bring a high degree of precision to traditional seismic workflows, resulting in better seismic predictions and more accurate input into the reservoir management decision-making process.

Sequence Stratigraphy (SSIS plug-in)

The SSIS plug-in works on top of the HorizonCube plug-in. 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 plug-in)

The Well Correlation Panel plug-in 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

In this Chapter you will learn how to:

- Create data-driven and model-driven HorizonCubes.
- Truncate HorizonCubes.
- Extract horizons from a HorizonCube.
- Track single horizons from a Steering Cube.
- Correlate between wells.
- Wheeler transform data (= flattening).
- Interpret systems tracts.

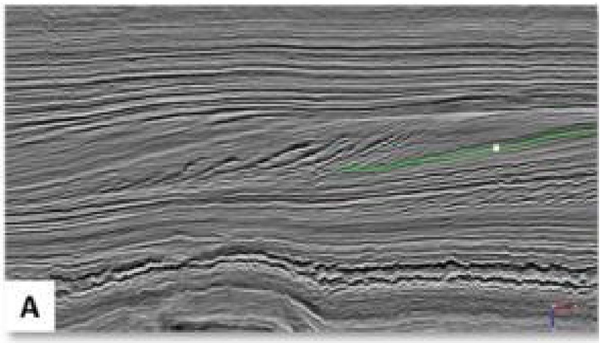
2.4.1 HorizonCube

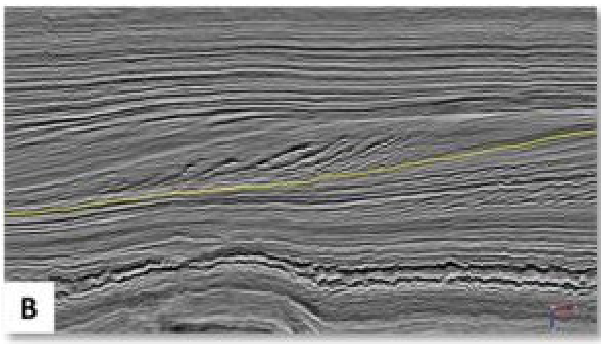
What you should know about HorizonCubes

- HorizonCubes consist of a dense set of (dip-steer) auto-tracked, or modeled horizons.
- HorizonCubes exists for both 3D and 2D seismic data sets.
- Horizons are first order approximations of geologic time lines.
- Horizons can never cross each other.
- There are two types of HorizonCubes: Continuous and Truncated.
- In continuous HorizonCubes all horizons exist everywhere; when horizons converge the density of the horizons increases. This tends to happen along unconformities and condensed sections.
- In truncated HorizonCubes horizons stop when they get too close together.
- Using HorizonCube density it is possible to convert continuous HorizonCubes to truncated HorizonCubes.
- Flattening on horizons in a HorizonCube is called a Wheeler transform.
- Depositional trends and systems tracts are easier to interpret in a Wheeler-transformed, truncated HorizonCube. Model building (interpolating well logs guided by horizons) is easier in a continuous HorizonCube.
- HorizonCube sliders are used in OpendTect to:
  - Analyze the depositional history.
  - Identify and extract horizons from the dense set of horizons.
  - Extract 3D bodies from iso-pach thicknesses or attribute responses.

Details

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).

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.

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.

The following exercises are showing an application in 3D. The workflows are very similar in 2D.

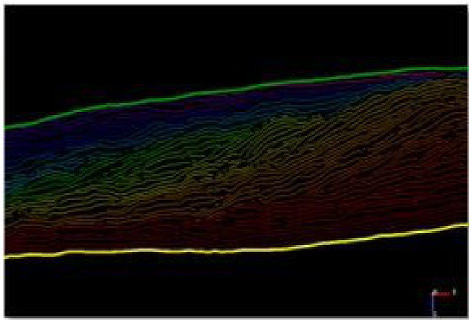
HorizonCube Types

Two types of HorizonCubes are created in OpendTect:

- **Continuous HorizonCube:** Contains events (or horizons) 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.

Two types of HorizonCube based on their geometrical configuration.



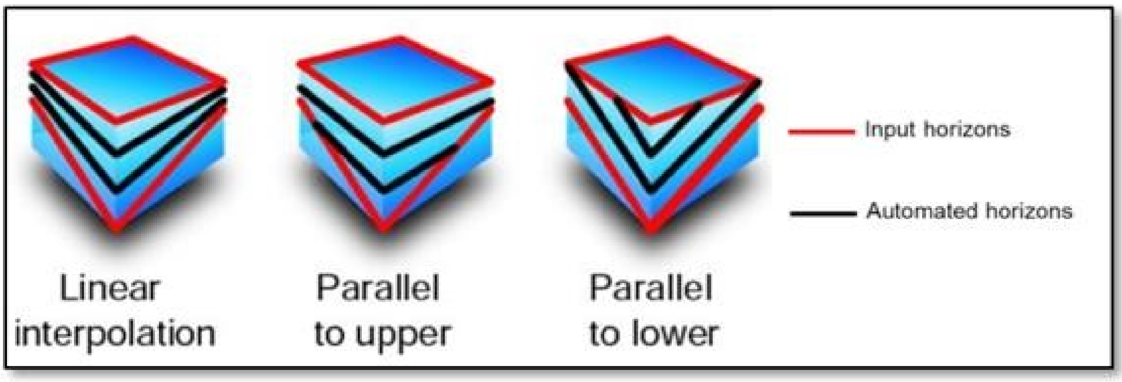
Continuous HorizonCube	*Truncated HorizonCube*
Applications:	Applications:
• Low Frequency Models • Geologic Modeling • Attribute Visualizations in 3D	• SSIS • Wheeler Transformation • Attribute Visualizations in 3D

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. There are two data-driven modes: tracking and multi-horizon inversion. In the tracking mode, a 3D auto-tracker tracks in a dip field. In the multi-horizon inversion, we follow the principle of unconformity tracker (2.3.1). In both cases the start (seed) position is fixed.

- **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.

HorizonCube Tools

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

- **Add more iterations:** To fill “gaps” in the HorizonCube.
- **Convert to SteeringCube:** Convert the HorizonCube into a dip-azimuth volume (SteeringCube).
- **Edit:** Use either error-based or linear-based methods to edit events in a HorizonCube.
- **Extract Horizons:** Extract horizons from the HorizonCube (stored as horizon data).
- **Get Continuous HorizonCube:** Converts a truncated HorizonCube into a continuous HorizonCube.
- **Grid HorizonCube:** Use various algorithms to fill unwanted holes in extracted horizons.
- **Merge HorizonCube:** Merges multiple HorizonCubes either vertically or laterally. The vertical merge is useful for bigger surveys. For instance, if you have three packages, you may run package 1 on machine 1, package 2 on machine 2, and so forth. Then you can merge the HorizonCubesvertically to get a single output. This will speed-up the processing time when compared to running a single HorizonCube with three packages.
- **Add or Recalculate 2D Line (2D HorizonCube):** Modify the HorizonCube by adding more 2D lines or add further horizons and faults.
- **Modify or Recalculate 3D Package (3D HorizonCube):** Modify a HorizonCube by adding more horizons/faults.
- **Truncate HorizonCube:** Operation to remove parts of the HorizonCube based on the event’s density (number of events within a defined time gate).

HorizonCube 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.

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 know 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 (2.3.1e Dip steered median filter). 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. (2.3.4 Seismic Spectral Blueing).
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 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.

Which SteeringCube algorithm is suitable for HorizonCube processing?

In our experience, the FFT (Fast Fourier Transformation) algorithm of dip estimation is preferred for horizon tracking or HorizonCube processing with a drawback of slowness. We recommend using the BG (phase-based) algorithm for data conditioning and attribute analysis. This implies for both 2D as well as 3D seismic cases.

What are the best parameters to start experimenting with various 3D SteeringCubes for HorizonCube?

Case 1: Assuming that the zone has a main frequency ranging between 25-40Hz.

To create the initial detailed SteeringCube, the following parameters are good to start with:

- Calculation [inl, xl, z] = [2,2,5]
- Filtering [inl, xl, z] = No filtering if the input data is already smoothed through dip- steered median filtering (DSFM).

You can then progressively filter this output and process the corresponding HorizonCubes e.g.: (*using as input the SteeringCube [inl, xl, z] = [2,2,5]*)

- Create several filtering results [1,1,3], [1,1,5], [1,1,7],… (if the data is not noisier).
- Or create several filtering results [2,2,3], [2,2,5], [2,2,7], … (if the data is noisier).

Case 2: Assuming that the zone has a lower main frequency e.g. 20Hz or below.

To create the initial detailed SteeringCube, the following parameters are good to start with:

- Calculation [inl, xl, z] = [2,2,7]
- Filtering [inl, xl, z] = No filtering if the input data is already smoothed through dip- steered median filtering (DSFM).

You can then progressively filter this output and process the corresponding HorizonCubes e.g.: (Input SteeringCube [inl, xl, z] = [2,2,7])

- Create several filtering results [1,1,3], [1,1,5], [1,1,7],… (if the data is not noisier).

- Or create several filtering results [2,2,3], [2,2,5], [2,2,7], … (if the data is noisier).

What are the best parameters to start experimenting with various 2D SteeringCubes for HorizonCube?

The settings for the 2D are much similar to 3D seismic datasets. The only difference is that the calculation and filtering step-outs are Traces and Z- samples. Therefore you can use the same suggestions as before.

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 between two or more framework horizons. So, if three framework horizons are provided, 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: pinch-outs, 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.

Framework horizons should be free of holes and should not cross. Optionally, they may stop at the faults. This is the Data Preparation done via the HorizonCube Control Center.

Does HorizonCube follow the framework horizons while tracking in a package?

The framework horizons are used to calculate the starting points for various iterations. However, the tracked horizons do not follow the framework horizons while tracking. It follows the dips within the frameworks. The tracker only makes convergence of the tracked events with the framework if the dips are making such a case.

Can both framework horizons have different geometries?

We do not recommend using such horizons. You may end up with unexpected results such as HorizonCube stopping at a bigger hole, no HorizonCube, or you may not be able to process a HorizonCube because the start position lies in a hole. We recommend using the horizons that have common spatial geometries/extension, grid spacing, no holes. OpendTect has several tools to perform such actions.

I have two horizons crossing each other. I want to use them a frameworks for HorizonCube. Can I solve the crossings in such horizons?

Yes! See the data-preparation tools available in the HorizonCube control center.

Fault Planes & Sticks

Fault Planes (3D) or faultsticksets (2D) are optional inputs that can be used when creating a HorizonCube. Faults serve as 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 “water-tight” with the faults. There is no limitation on number of faults or sticks. One can still process a HorizonCube for the intervals where the faults are absent.

The 3D HorizonCube Creator dialog will require Faults whereas the 2D HorizonCube Creator dialog will require FaultSticksets as an input.

2.4.1a Data-driven HorizonCube

Required licenses: OpendTect Pro, Dip-steering, HorizonCube.

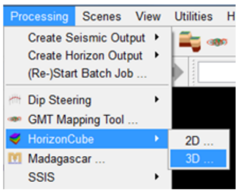
A – Tracking based data-driven HorizonCube

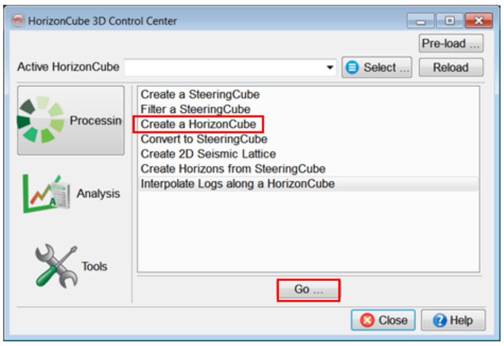
Exercise objective:

Create a continuous, data-driven HorizonCube in order to understand the depositional history of a prograding system using principles of seismic sequence stratigraphy.

Workflow:

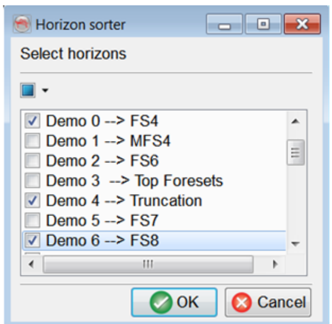
1. **Go to** Processing > HorizonCube > 3D...
2. **Select** the Create a HorionCube option and **click** the Go.. button in the HorizonCube 3D Control Center.





Workflow cont'd:

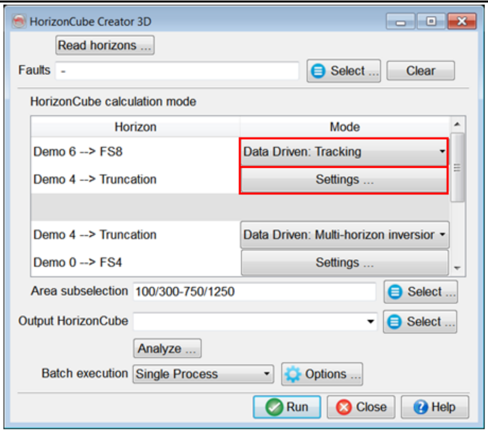
3. **Select** the horizons *Demo 0 → FS4*, *Demo 4 → Truncation* and *Demo 6 → FS8*. **Click** on OK.



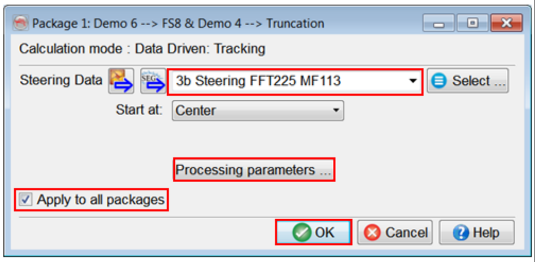
Workflow cont'd:

4. We will **create** a data driven HorizonCube in this exercise, i.e. the type that follows the SteeringCube. In Mode, **select** Data Driven: Tracking.

5. **Click** Settings… in the HorizonCube Creator 3D window.



6. **Set** the *Steering Data* to *3b FFT 225 MF113* and Start at to: Center. **Check** the Apply to all packages option and **click** OK.

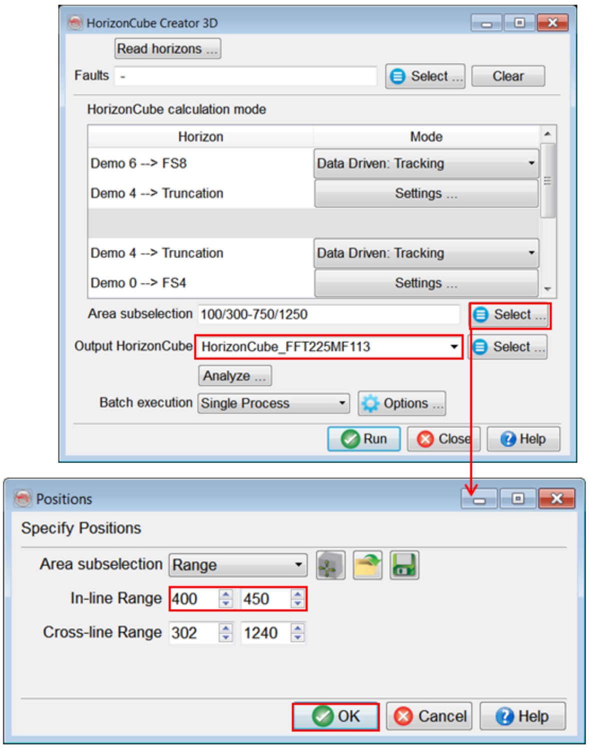


Processing parameters include settings such as spacing at start position, number of iterations etc.

Workflow cont'd:

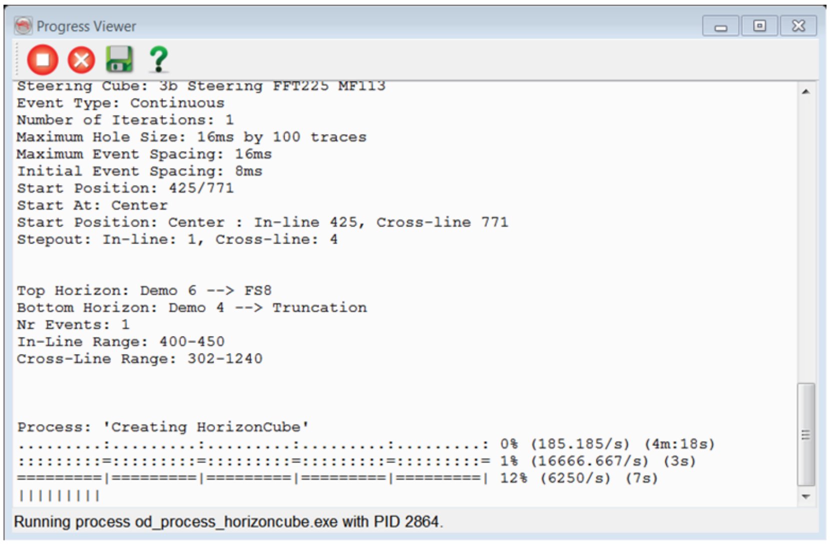
8. **Click** Select for Area subselection and **set** to inline range to 400 – 450. **Click** OK.

9. **Give** an appropriate name, e.g. *HorizonCube _FFT225MF113,* in the Output HorizonCube field and **click** Run.



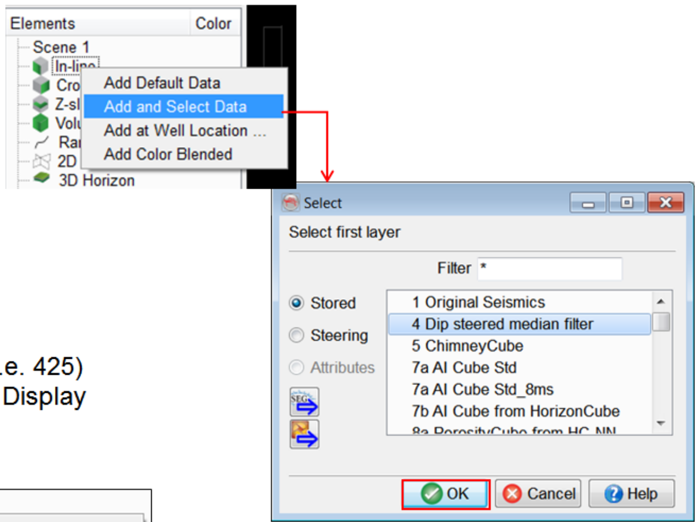
Workflow cont'd:

10. A Batch Processing window will pop up. Wait for the message **Finished Batch Processing** and close the window.

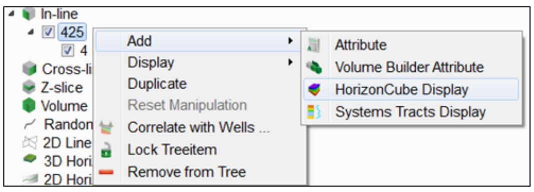


Workflow cont'd:

11. **Add** inline 425 in the scene and **select** the attribute *4 Dip steered median filter.*

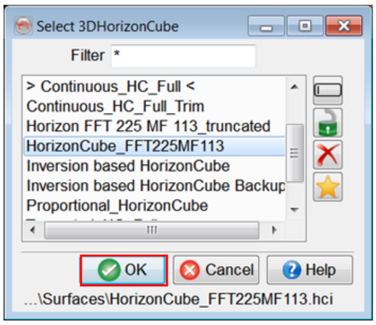


12. **Right-click** the inline number (i.e. 425) and **select** Add > HorizonCube Display

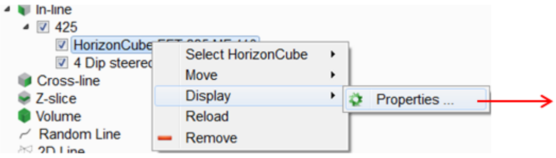


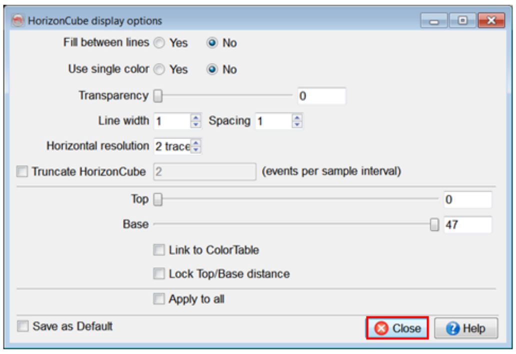
Workflow cont'd:

13. **Select** the *HorizonCube_FFT225MF113* that you just created.



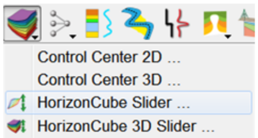
14. To explore HorizonCube display options **right-click** on the HorizonCube in the tree > Display > Properties. **Close** the window.





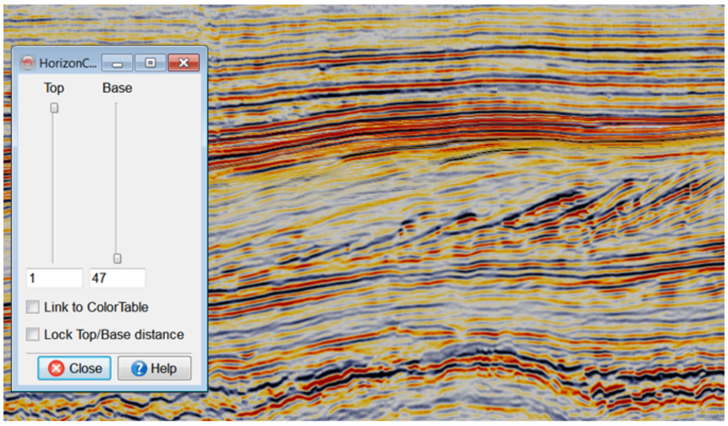
Workflow cont'd:

15. **Open** the HorizonCube slider by **clicking** the icon.



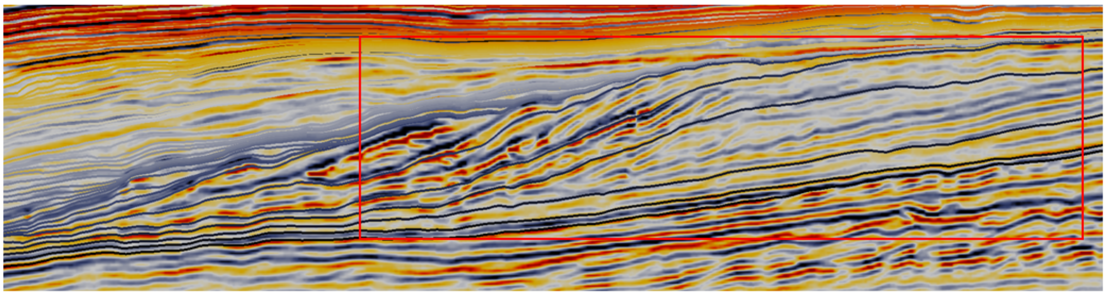
16. **Observe** and **QC** the results of your HorizonCube by using the Top and Base sliders.

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

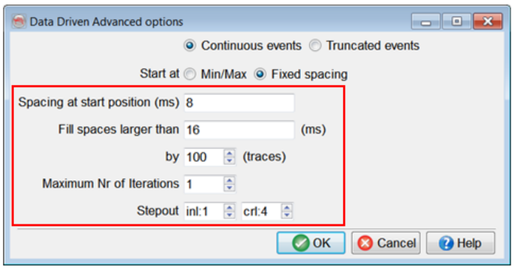


Workflow cont'd:

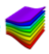
17. Observe how gaps are present in the prograding clinoforms. This is due to the HorizonCube being created with only one iteration. Iterations can be added later.



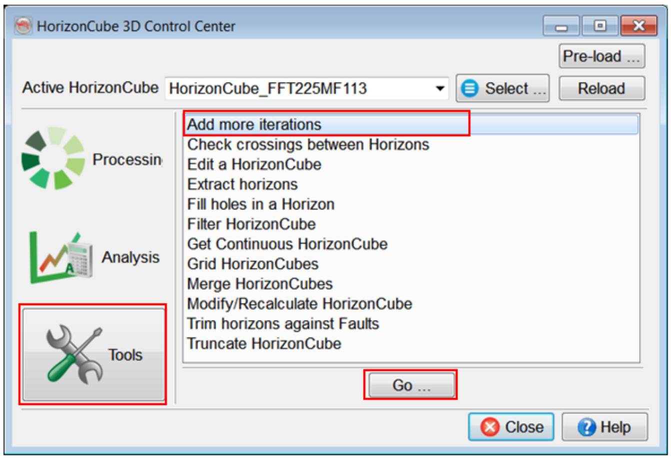
18. The gaps are filled by finding the gaps based on a given advanced setting. Advanced settings can be accessed by Processing >HorizonCube > 3D > Create > Settings > Processing parameters.



Workflow cont'd:

19. **Open** the HorizonCube 3D Control Center with the  icon.

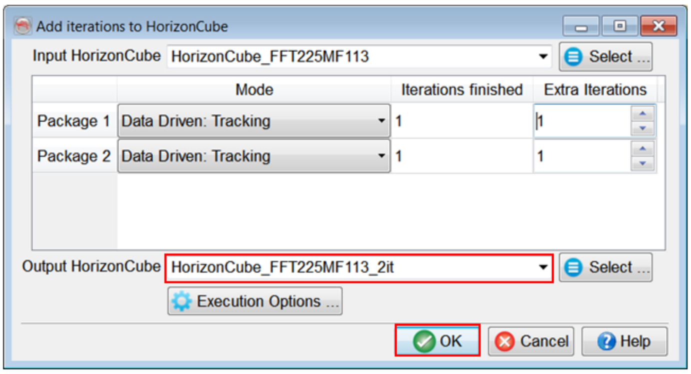
20. In the Tools menu, **select** Add More Iterations and **click** Go.



Workflow cont'd:

21. Leave the Extra Iterations option to 1, for each package.

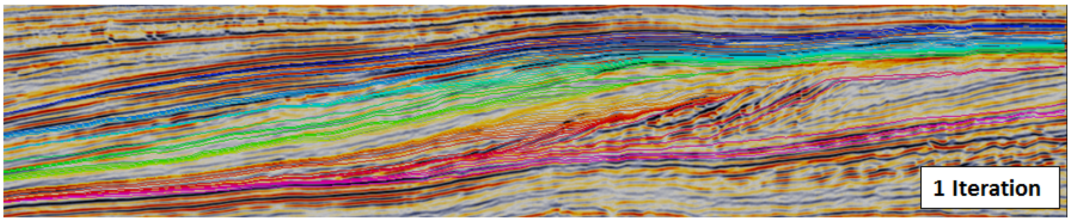
22. **Save** with a new name, e.g. *HorizonCube_FFT225 MF113_2it*, and **click** OK.

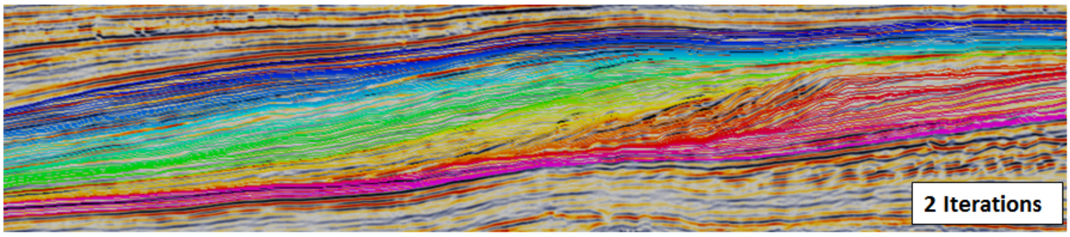


The first column Iterations finished shows how many iterations have already been processed. The tracked HorizonCube events from previous iterations will never change, only new events can be inserted between already existing ones

Workflow cont'd:

23. See the difference between output images of Iteration 1 and Iterations 2.

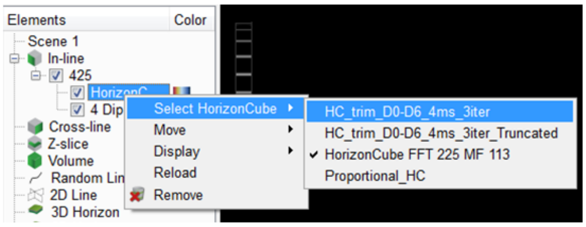




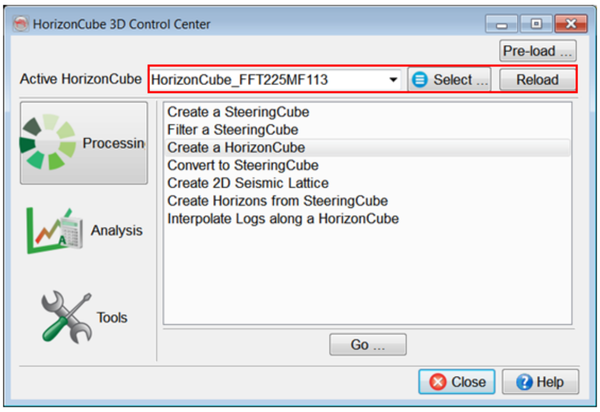
Note the gaps are filled by adding more data-driven horizon during the 2nd Iteration. Further gaps can be filled by adding one or more Iterations.

Workflow cont'd:

24. **Change** the active HorizonCube either by **right-clicking** the HorizonCube in the tree:



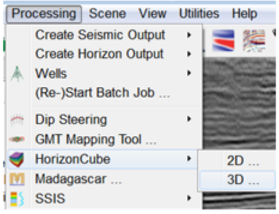
or by **selecting** it in the HorizonCube control center



Only one HorizonCube can be active at any time in OpendTect.

B – A Global Inversion based data-driven HorizonCube

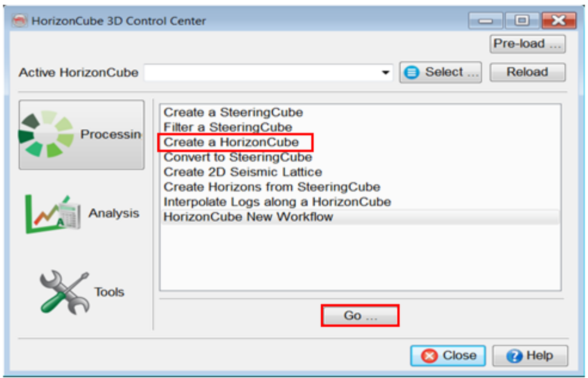
Exercise objective:
Create a continuous and data-driven HorizonCube based on inversion algorithm to understand the depositional history of a prograding system using principles of seismic sequence stratigraphy.



Workflow:

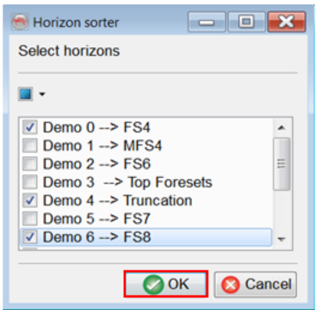
1. **Go to** Processing > HorizonCube > 3D...

2. **Select** the create a HorizonCube option and **click** the Go.. button in the HorizonCube 3D Control Center.

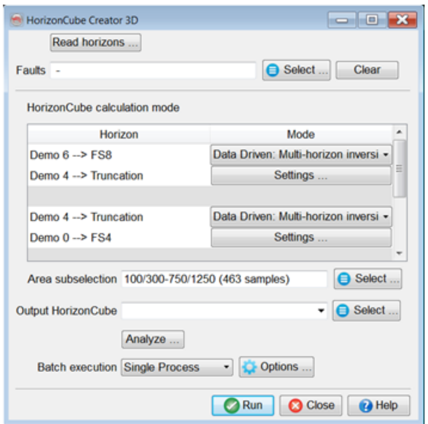


Workflow cont'd:

3. A data-driven HorizonCube is created in a package defined by top and bottom horizons. At least two horizons are required. **Select** the horizons *Demo 0 → FS4, Demo 4 → Truncation* and *Demo 6 → FS8*. **Click** on OK.



4. Optionally, Faults can be selected



In the HorizonCube creator, you choose an algorithm, settings etc.

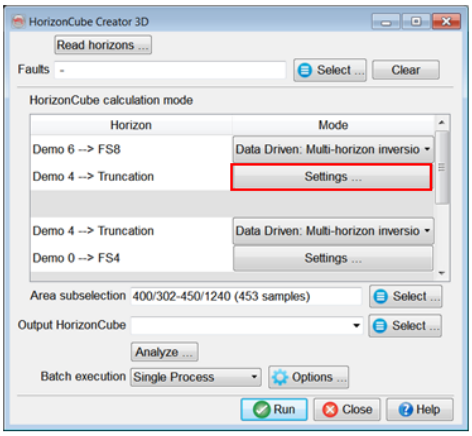
Workflow cont'd:

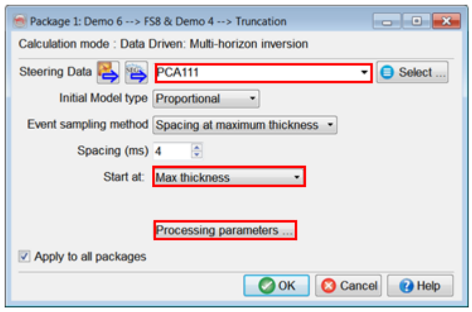
5. We will **create** a data driven HorizonCube using inversion based algorithm. *Data Driven: Multi-horizon inversion* is defined by default.

6. **Click** the Settings button for the upper most package.

7. **Set** the *Steering Data* to *PCA 111*.

8. **Click** on the *Processing Parameters*.

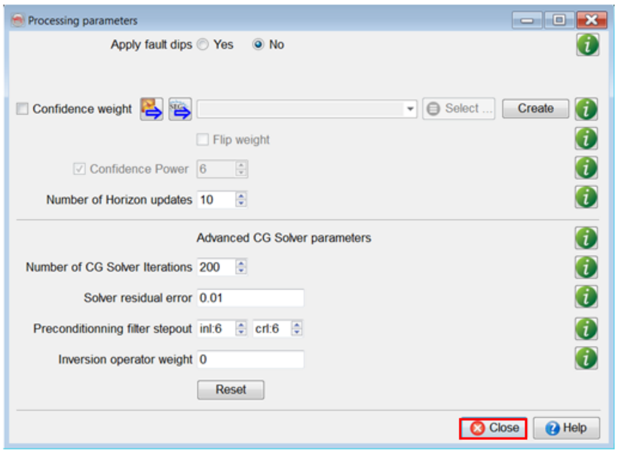




In each package, we will be using a same initial model (Proportional). Each proportional horizon will be updated using the defined processing parameters. **Apply to all packages** option will set the same settings to all packages.

Workflow cont'd:

- **Fault dips** will be calculated from interpreted fault planes and merged with reflection dips from the Steering Cube if toggle is Yes.
- **Confidence weight** assigns weights to the Steering Cube. Planarity is a good confidence measure that can be calculated here, or in the Faults & Fractures plugin.
- **Confidence power** increases the contrast between planar and non-planar features.
- **Number of horizon updates** are typically between10 or 20.
- **Number of CG solver iterations** are used to solve the gradient equations.
- **Pre-conditioning smoothing** reduces spikes in the output horizons.

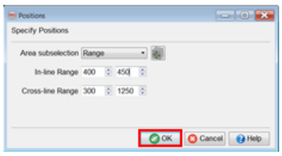


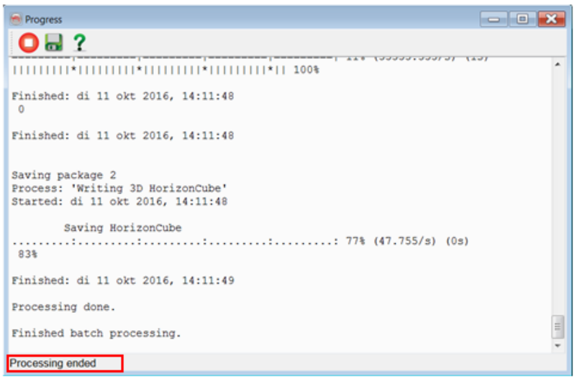
In this case stick to the defaults, hence press **Close** to continue.

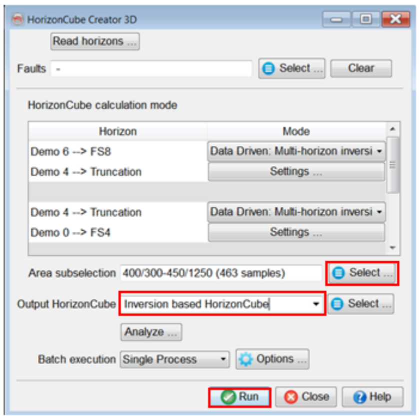
CG – Conjugate Gradient

Workflow cont'd:

9. We will **sub-select** the processing area to 400 – 450 in-lines.
10. Provide an output name: *Inversion based HorizonCube.*
11. Press **Run** to create this HorizonCube output.



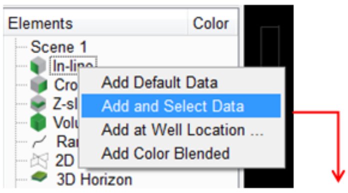


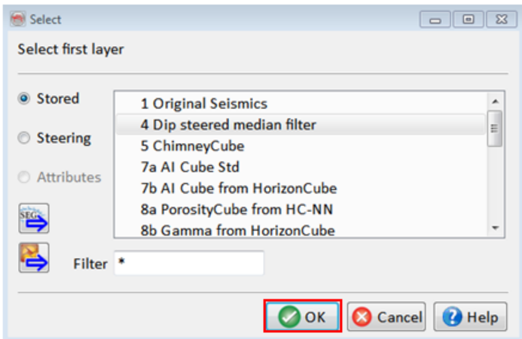


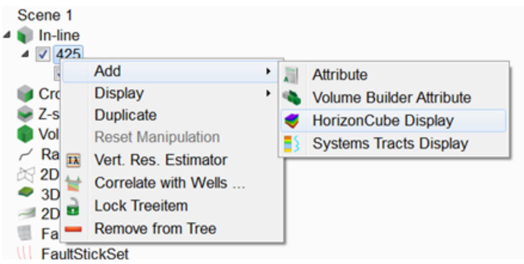
Workflow cont'd:

12. When processing is finished, **Add** inline 425 in the scene and **select** the attribute *4 Dip steered median filter and* **OK**.

13. **Right-click** the inline number and **select** Add > HorizonCube Display

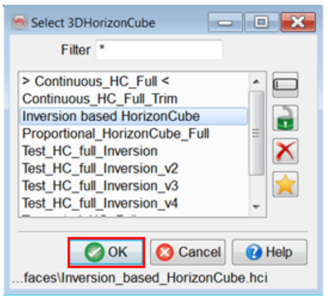




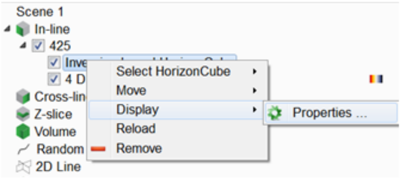


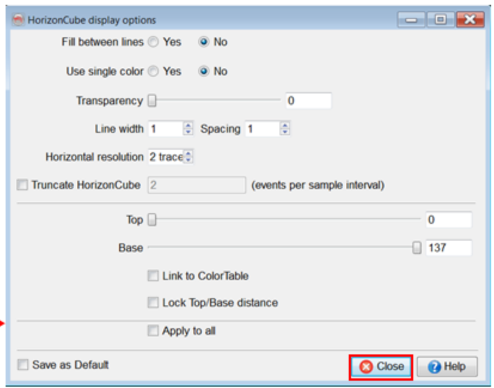
Workflow cont'd:

14. **Select** the *HorizonCube Inversion based HorizonCube* that is just created.

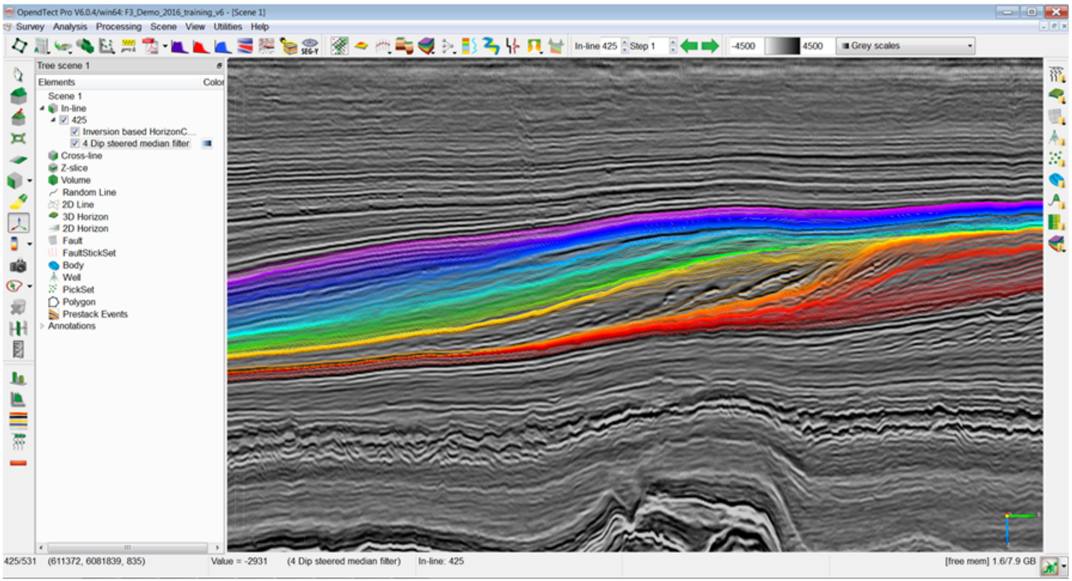


15. To explore HorizonCube display options **right-click** the HorizonCube in the tree > **Display > Properties**. **Close** the window.





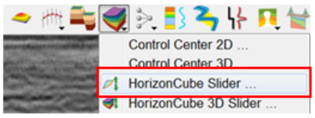
Workflow cont'd:



An example of this HorizonCube overlain on inline 425.

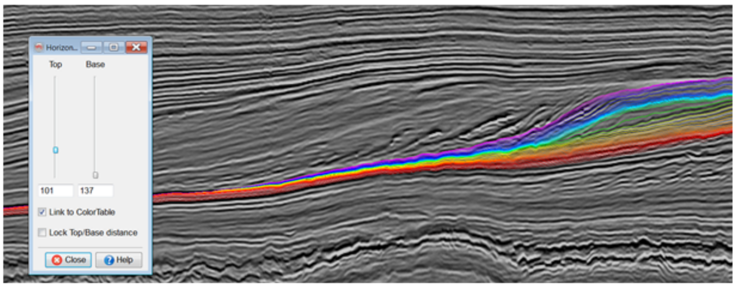
Workflow cont'd:

16. **Open** the HorizonCube slider.



17. **Observe** and **QC** the results of your HorizonCube by using the Top and Base sliders.

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

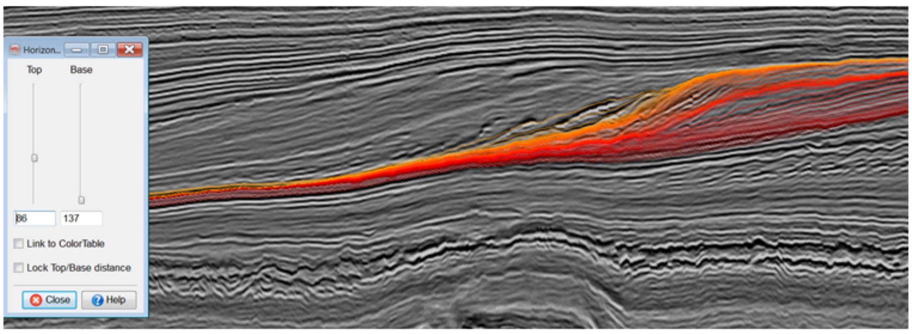


Workflow cont'd:

Optional Steps (Filling the gaps):

You may want to fill the holes by taking some events from a HorizonCube and re-computing the packages using the horizons. This workflow is presented in the following slides.

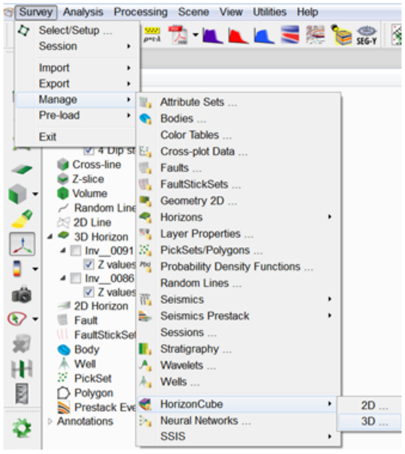
18. **Choose** the events defining a gap from this HorizonCube. Use **Top** slider to know which events are needed (e.g. events **86** & **91**).

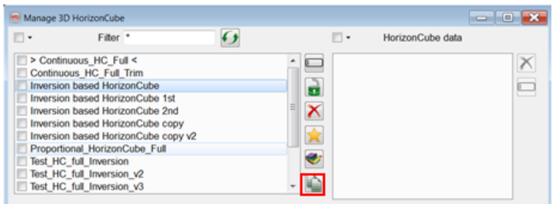


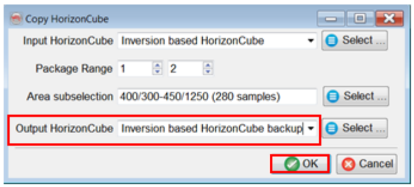
Workflow cont'd:

19. **Open** the HorizonCube manager.

20. **Copy** the *inversion based HorizonCube* with a new name since we will be changing this one and the other one will be our backup. Once done, close the HorizonCube manager.





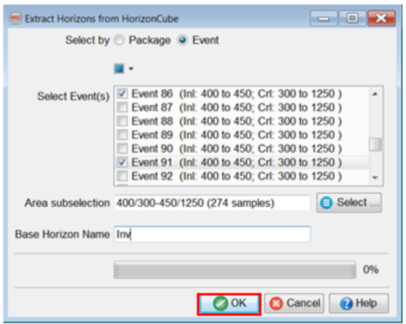


Workflow cont'd:

21. From the HorizonCube manager, **extract** events **86** & **91** from the selected HorizonCube. 

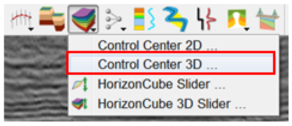
22. The base name will be set as a prefix with an automatically generated suffix (e.g. Inv_0086 will be a name of the output horizon). Press **OK**.

23. Once done, **close** the HorizonCube manager. At this moment, we are ready to modify an existing HorizonCube using these two horizons.

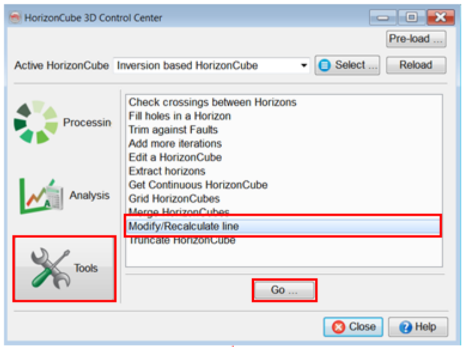


Workflow cont'd:

24. **Open** the HorizonCube control center.

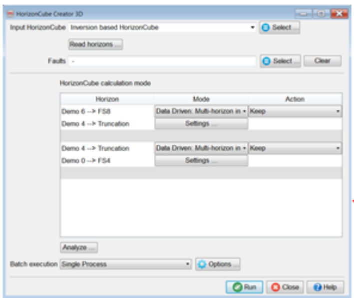


25. **Set** active HorizonCube to *Inversion based HorizonCube.*



26. Go to Tools and Select Modify/Recalculate …

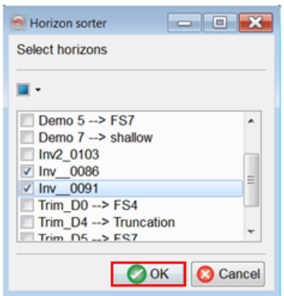
27. Press Go.

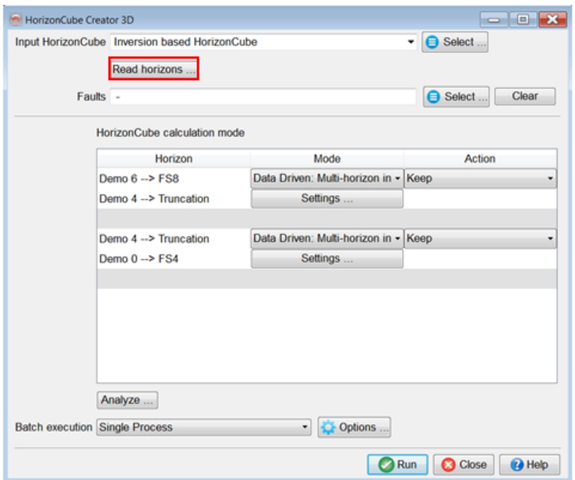


Workflow cont'd:

28. **Select** the HorizonCube: *Inversion based HorizonCube.*

29. Read horizons: (e.g.) Inv_0086 and Inv_0091





We will only select the horizons which we extracted in the previous steps.

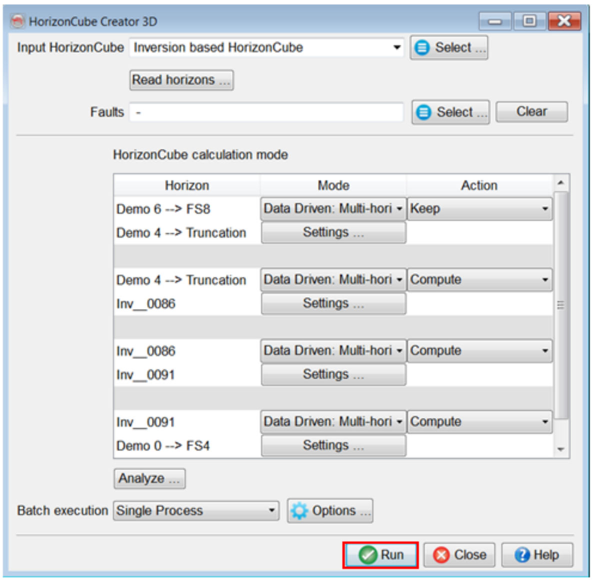
Workflow cont'd:

30. We will choose Action **keep** for the first package and **compute** for the rest of packages.

31. **Ensure** that the three packages for **compute** have the **same algorithm** i.e. Data Driven: Multi-horizon inversion.

32. **Run**

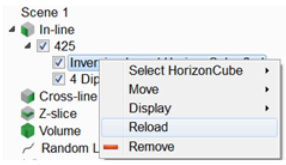
Optionally: You may choose a different algorithm and settings (such as start position) for each package. It depends on the nature and data quality in a package.

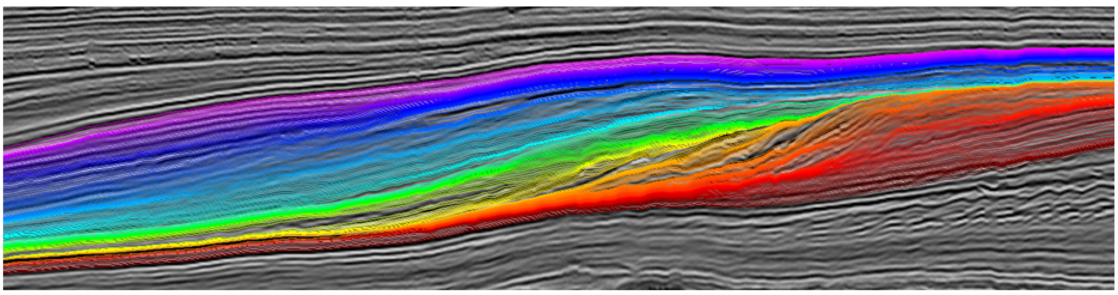


Workflow cont'd:

33. Once the processing is finished, **Reload** the HorizonCube: Inversion based HorizonCube.

34. The results may look like this after filling the gaps:





2.4.1b 3D Bodies From HorizonCube

Required licenses: OpendTect Pro, HorizonCube.

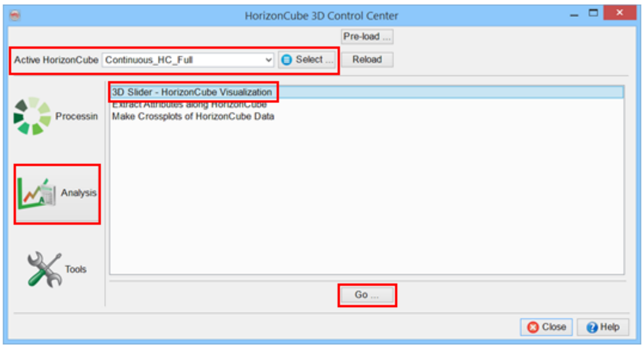
Exercise Objective:

Visualize a HorizonCube in 3D by using the 3D Slider - an add-on to perform analysis in 3D along iso-timelines.

In this exercise we will investigate a prograding system in 3D by making thickness maps and geo-bodies.

Workflow:

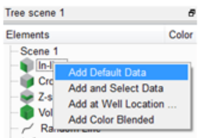
1. **Open** the *HorizonCube* 3D Control Center with the icon.
2. **Select** an active HorizonCube *Continuous_HC_Full*.
3. **Click** the Analysis button, **Select** the 3D slider and **press** Go.



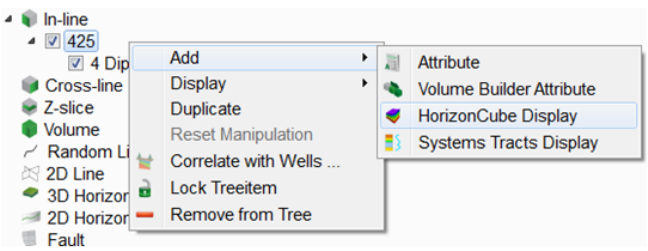
Keep the 3D slider window open. You may close the HorizonCube 3D control center window.

Workflow cont'd:

4. **Add** Default data for inline 425.

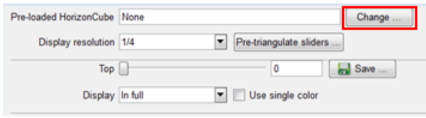


5. **Right-click** on the inline number > Add > HorizonCube Display.

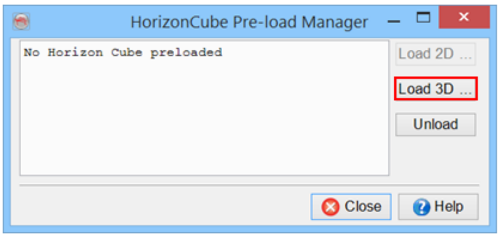


Workflow cont'd:

6. In the 3D slider window, **click on** Change to pre-load the HorizonCube *Continuous HC Full.*

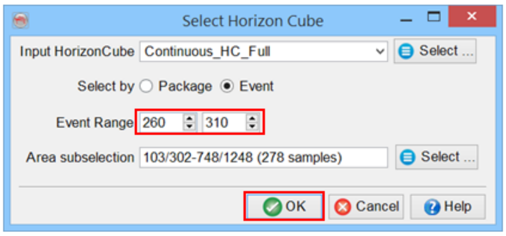


7. In the Pre-load Manager **press** Load 3D…



8. **Set** the Event range from 260 to 310.

9. **Press** OK and **close** the HorizonCube Pre-load Manager window.



Always preload with limited range when using small RAM (under 8GB).

Workflow cont'd:

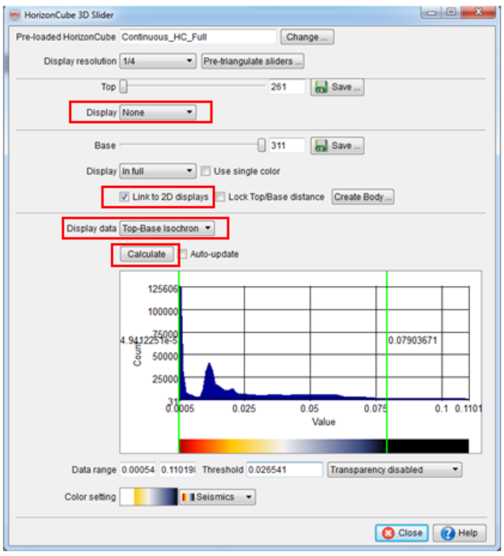
10. **Set** the Top horizon display: None and Base horizon display: In full.

11. **Check** Link to 2D displays option to see the HorizonCube events on the sections within the selected range.

12. **Set** Display data to Top-Base Isochron.

13. **Press** the Calculate button.

Note: The scene will be updated once you press the calculate button.

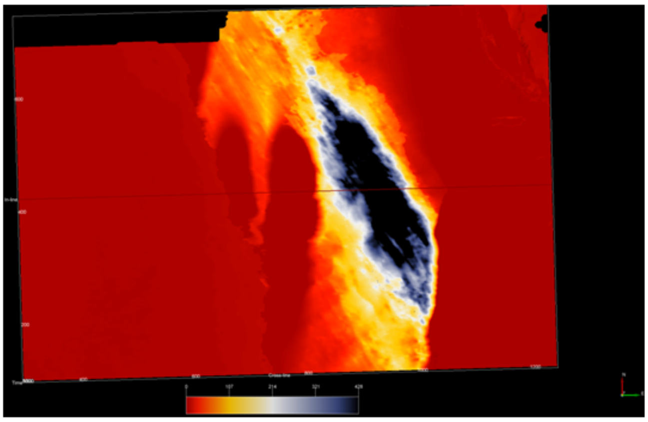


Workflow cont'd:

Making Thickness Maps

14. **Set** the top slider to 302 (press ENTER to update) and the Base slider to 310 (press ENTER to update) and **click** Calculate.

15. The result will appear automatically in the 3D scene on the base horizon after clicking Calculate.

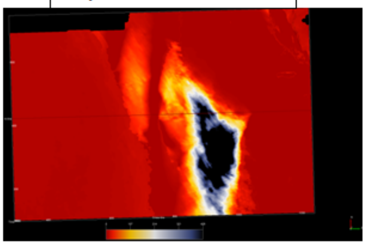


Example isochron map between events 302 and 310

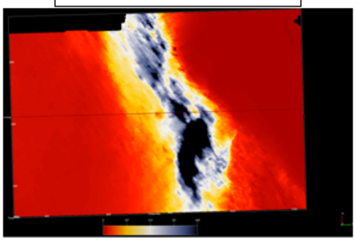
Workflow cont'd:

16. **Repeat** the exercise for the following horizon pairs and observe the shifts in the depositional center. **Press** Enter and **Calculate** every time after updating the numbers for the Top and Base sliders.

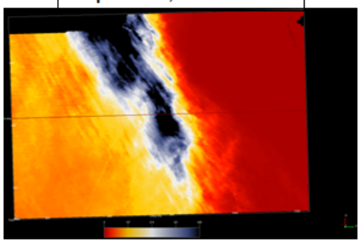
Top: 285, Base 302



Top: 275, Base 285



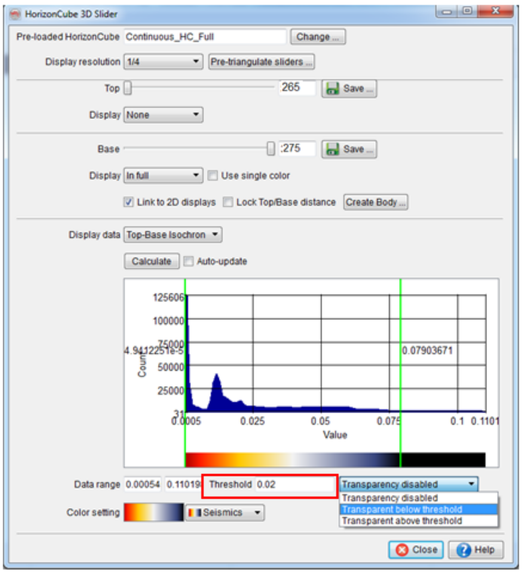
Top: 265, Base 275



Workflow cont'd:

Extracting Geobodies

17. For this exercise we will apply a transparency threshold for all thinner regions below the cut-off to preserve and outline of a thicker region.

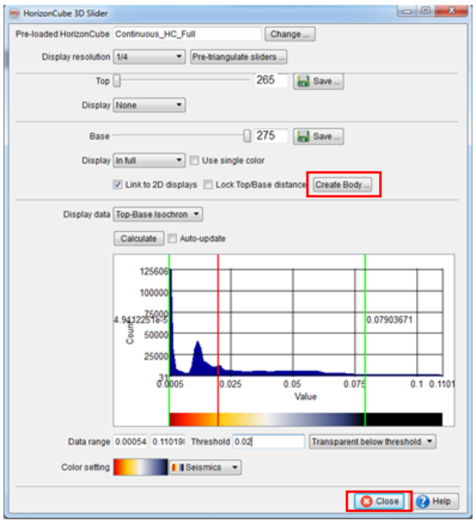


18. At the bottom of the 3D slider, **specify** Threshold = 0.02 (**Press** Enter) and **set** the transparency to Transparent below threshold. (In the histogram, a thin vertical red line will appear, which corresponds to transparency).

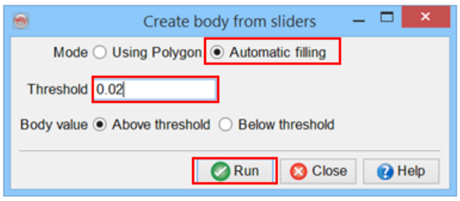
Workflow cont'd:

Extracting Geobodies

19. Press the Create Body button.



20. Set mode to Automatic filling, the threshold value will remain unchanged.



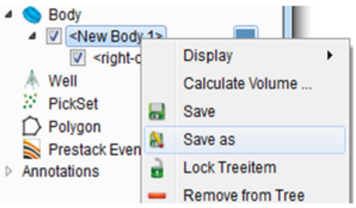
21. Set the Body value option to Above threshold. **Click** Run.

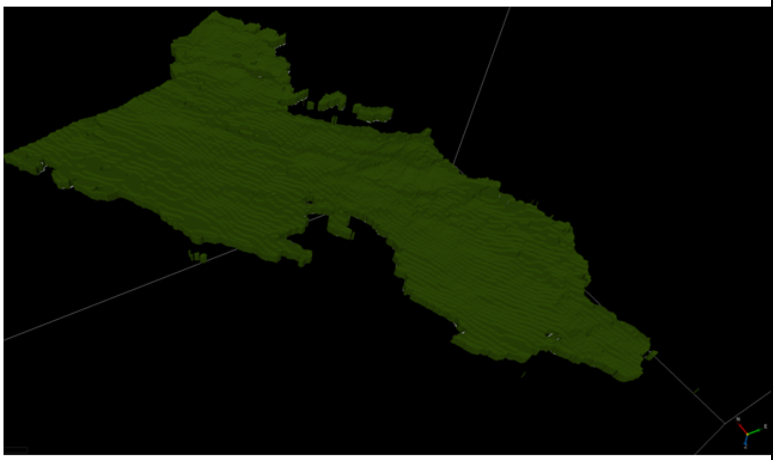
22. **Close** 3D Slider.

Workflow cont'd:

Extracting Geobodies

23. The body will appear in the scene. If you are satisfied with the geobody you may save it to disk by right-clicking on the <New Body > in the tree > Save as..





2.4.1c Truncate HorizonCube

Required licenses: OpendTect Pro, HorizonCube.

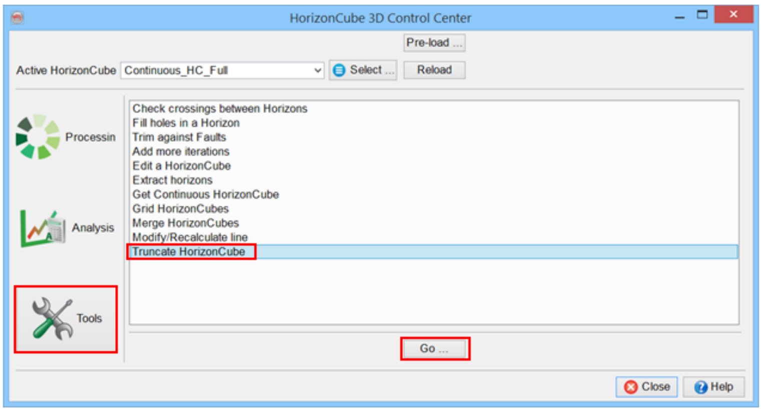
Exercise Objective:

Truncate a HorizonCube to prepare Wheeler diagrams and perform seismic sequence stratigraphic interpretation.

1. **Open** the HorizonCube 3D Control Center with the icon.

2. **Select** the Truncate HorizonCube option from the Tools menu and **click** Go…

There are two types of HorizonCubes: continuous and truncated



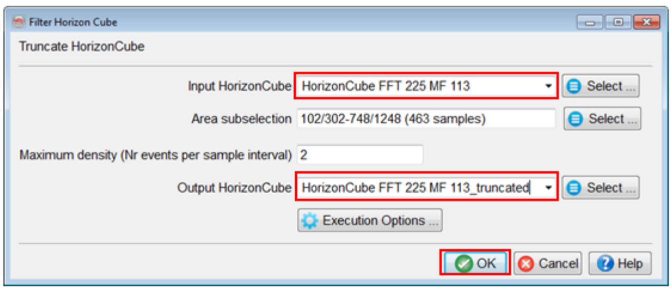
Workflow cont'd:

3. **Select** *HorizonCube FFT 225 MF 113* (created in previous exercise) as Input HorizonCube.

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

5. **Give** an appropriate name, e.g. *HorizonCube FFT 225 MF 113_truncated,* and **press** OK.

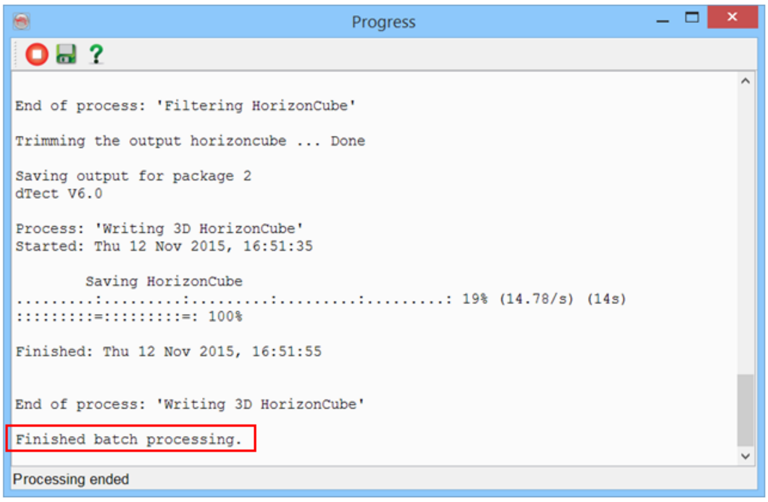
Tip: If the truncated HorizonCube includes too much irrelevant events (noise), go back and increase the *Maximum density*



Workflow cont'd:

6. Batch processing window will pop up.

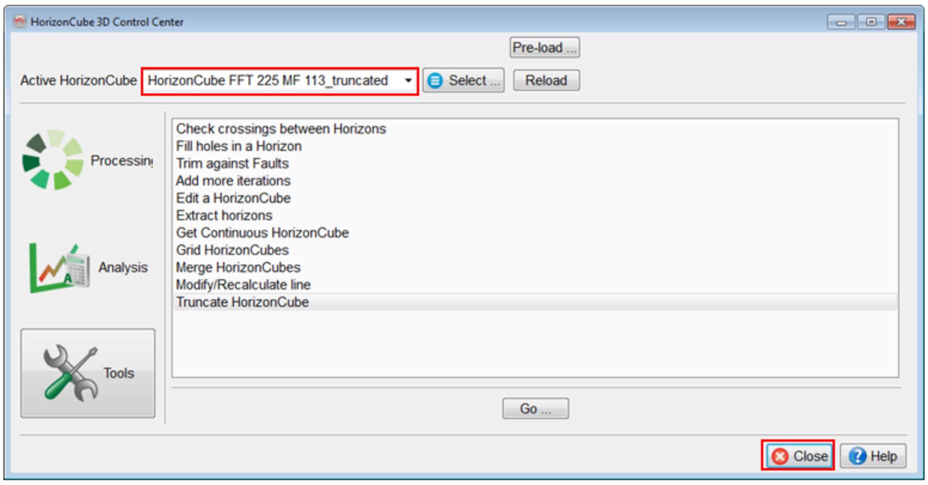
7. **Leave** the process running until you **read** the message: Finished batch processing.



Workflow cont'd:

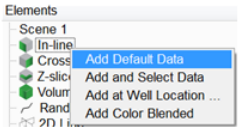
8. After processing, **switch** to the truncated HorizonCube via HorizonCube 3D Control Center by **selecting** *HorizonCube FFT 225 MF 113_truncated.*

9. **Close** HorizonCube 3D Control Center.

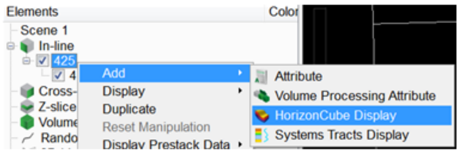


Workflow cont'd:

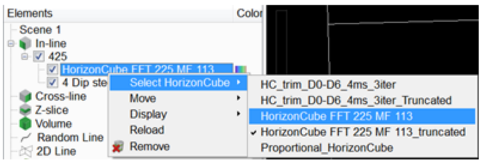
10. Right-click on In-line in the tree > Add Default Data.



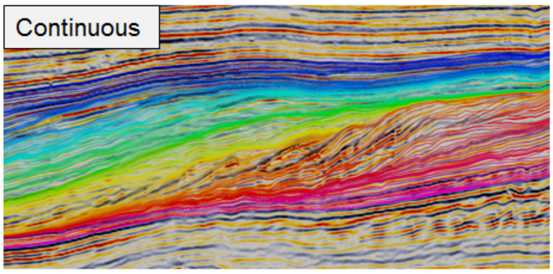
11. Right-click on the inline 425 > Add > HorizonCube Display, to display the truncated HorizonCube in the scene.

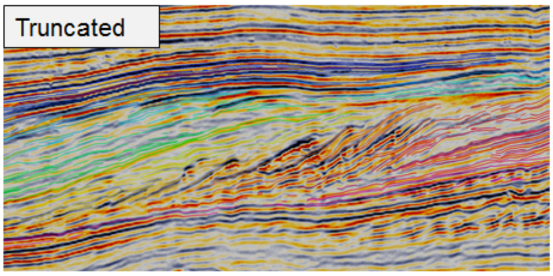


12. Switch back to the continuous HorizonCube by **right-clicking** on HorizonCube name > Select HorizonCube, to compare the two results.



The results should be similar to the ones shown below



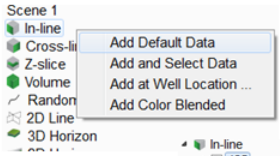


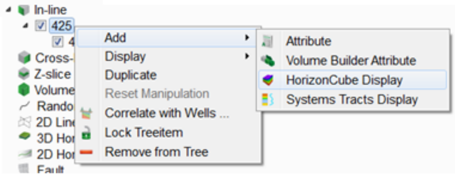
2.4.1d Horizons From HorizonCube

Required licenses: OpendTect Pro, HorizonCube.

Exercise Objective:

Extract multiple horizons from a HorizonCube.





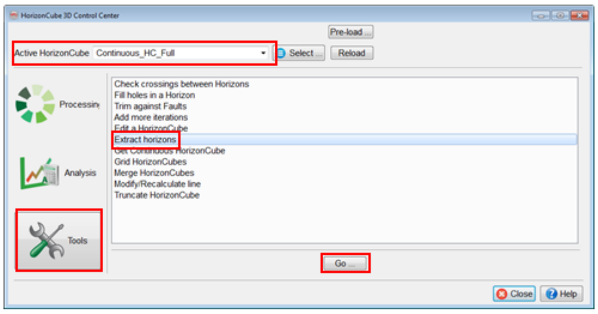
Workflow:

1. **Add** the default data by clicking *inline* in the tree. Next, **add** a HorizonCube overlay. Select the active HorizonCube *Continuous_HC_Full* if prompted.

2. **Open** the *HorizonCube* 3D Control Center with the  icon.

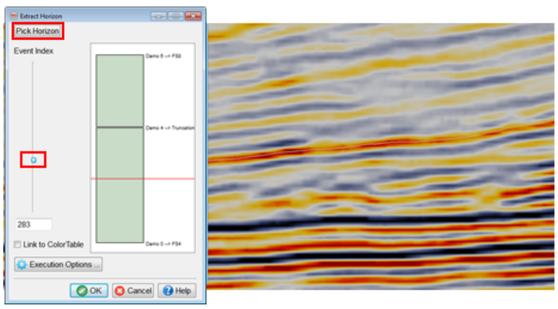
3. **Select** Extract Horizons under the *tools* menu and **click** *Go …*

The active HorizonCube is automatically displayed



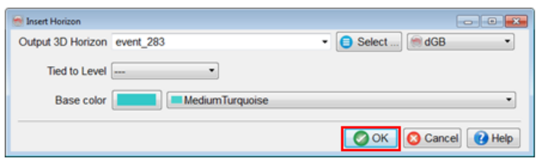
Workflow cont'd:

4. **Scroll** up and down using the slider, while **observing** the HorizonCube events in the scene.



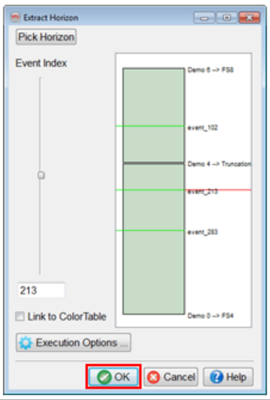
5. When you locate a horizon you wish to extract, **click** on Pick Horizon. A separate pop-up window will appear.

6. **Give** an appropriate output name and **click** *OK.*



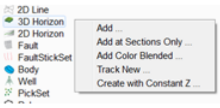
Workflow cont'd:

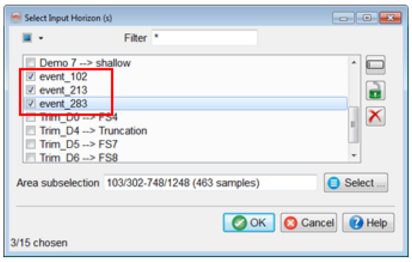
7. **Repeat** the exercise a few times for the events you wish to extract. Then **click** *OK.*



Picked horizons in the slider

8. A separate *batch processing* window will **open**. After the processing is done, the extracted horizons can be **loaded** via *horizons 3D > Load ..* in the tree.





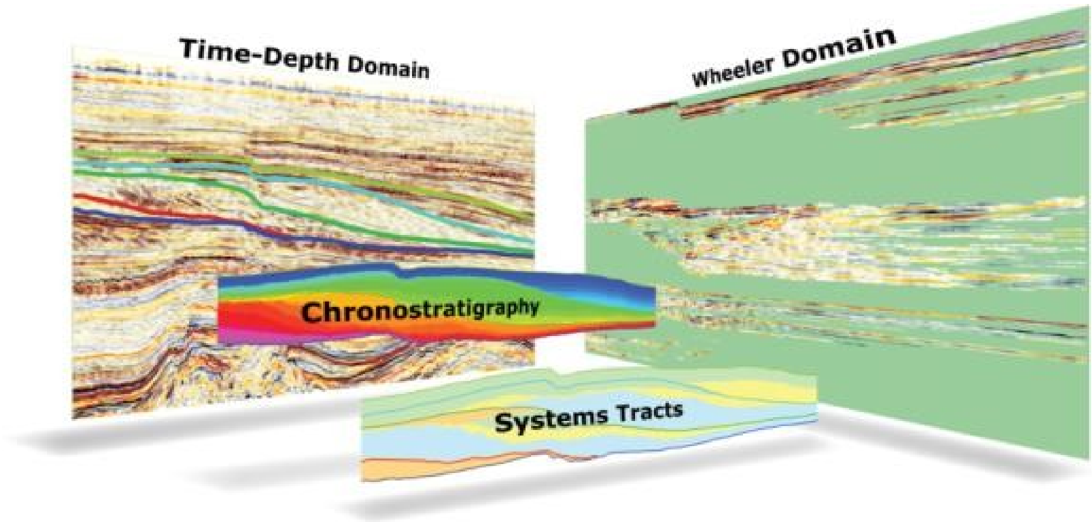
2.4.2 Sequence Stratigraphic Interpretation System (SSIS)

What you should know about SSIS

- SSIS is a commercial plugin by dGB that operates on a HorizonCube.
- SSIS supports Wheeler transformations and Systems Tracts Interpretation.

Details

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's SSIS plugin 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. 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) plug-in to OpendTect allows interpreters to automatically create a Wheeler transform in which they can study 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.

SSIS will only be of use if you have already calculated your HorizonCube. If you created a continuous HorizonCube, you will need to truncate this to see depositional variations in the Wheeler scene. Both creating a HorizonCube and truncating an existing one are covered in the previous section of this training manual.

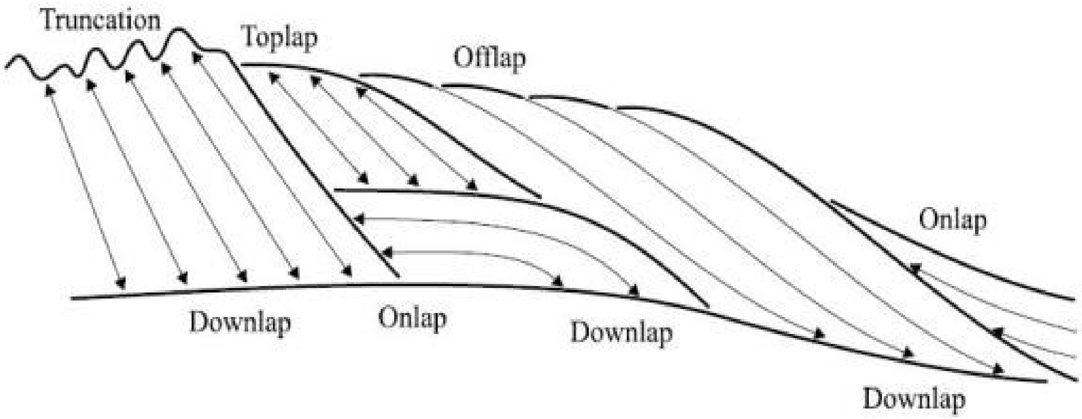
Lap-out patterns & stratal terminations

While it is not a requirement as part of the workflow to perform this step each time, but it is considered as a good practice. Annotating the stratal terminations in your data before making your interpretations can lead the observations towards proper interpretation.

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 of three basic tools: Arrows, images and scale bar. The arrows are intended to indicate lap-out patterns or stratal terminations, but can be used to highlight any feature. Seismic data can be animated with pictures to make communication easier and more direct with colleagues who are working on the same project. The scale bar allows you to very easily add scale information.

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

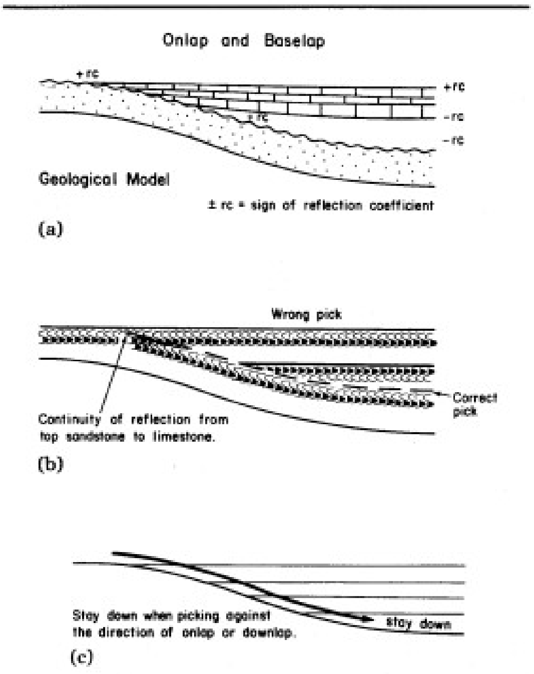


FIGURE 7.14 *Picking criterion—onlap and downlap.* (a) *Geological model: A sandstone of intermediate acoustic impedance is onlapped by shales of low acoustic impedance, and limestone of high acoustic impedance. The reflection coefficient signs are indicated on the diagram.* (b) *Seismic expression: 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.*

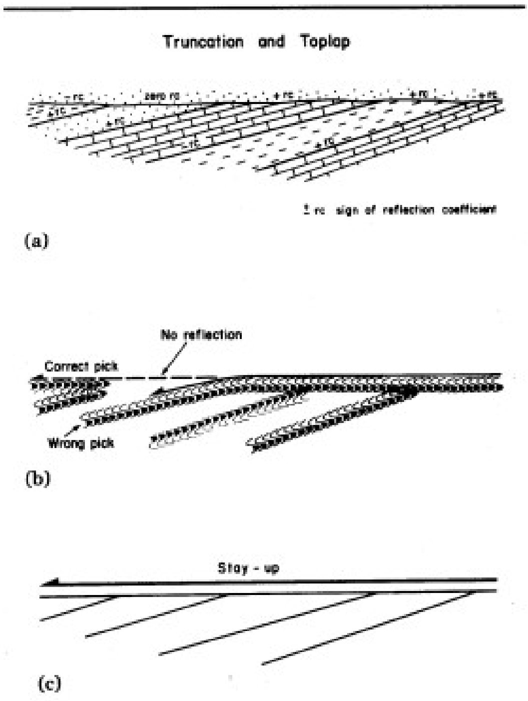


FIGURE 7.15 *Picking criterion—toplap and truncation.* (a) *Geological model: An interbedded sequence subcrops an unconformity overlain by a sand. Signs of the reflection coefficient are indicated. There is no acoustic-impedance contrast between the sands.* (b) *Seismic expression: The unconformity has 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

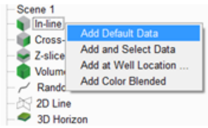
2.4.2a Stratal Terminations

Required licenses: OpendTect Pro, SSIS.

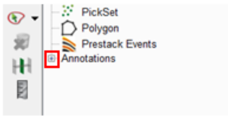
Exercise objective:
Annotate stratal terminations and lap-out patterns using standard **Arrows**.

Workflow:

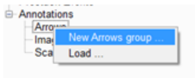
1. **Add** inline 425 using default data.



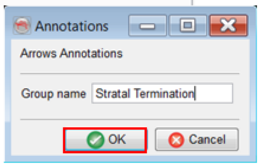
2. **Expand** the Annotations item.



3. **Click** on Arrows and **select** New Arrows Group…



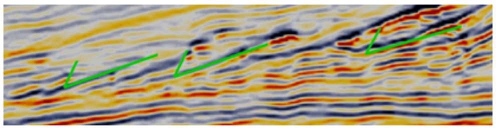
4. Name the arrow group to *Stratal Termination* and press **OK** to add this to the tree.



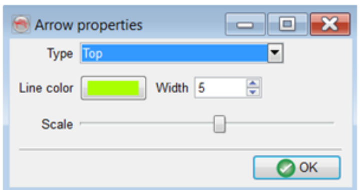
OpendTect annotation (arrows, images, and scale) are handy tools to highlight and describe features of interest. In seismic sequence stratigraphic interpretation arrows are used traditionally to map lapout patterns and truncations.

Workflow cont'd:

5. *Stratal Termination* element should be active in the tree (a click on the name activates the item). Switch to the right mode .



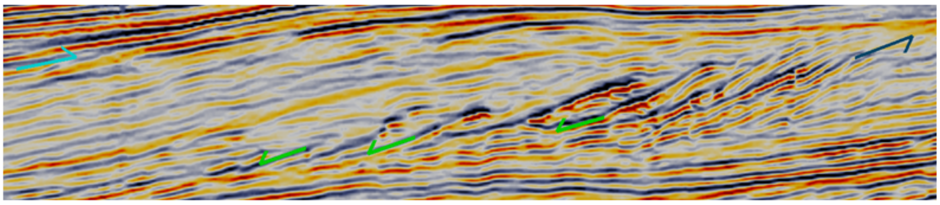
6. Now you **pick** on the seismic inline at positions where you want to insert an arrow. First click adds an arrow head. Rotate and click one more time to pin it.



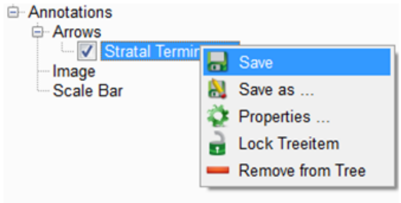
- Ctrl + Click on the arrow to delete it.
- Change the type, color, width and size of the arrow via right-click on *Tree > Annotations > Arrows > Stratal Terminations > Properties...*

Workflow cont'd:

7. Continue the interpretation on this line.



8. **Right-click** on *Stratal Termination* and **Save**.



Optionally make different arrow groups:

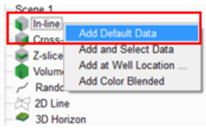
- Downlaps.
- Onlaps.
- Truncations.

2.4.2b Stacking Patterns

Required licenses: OpendTect.

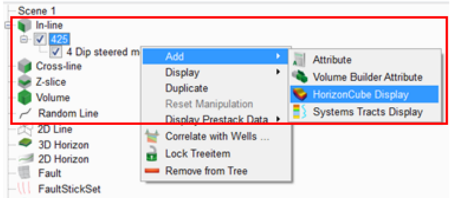
Exercise objective:

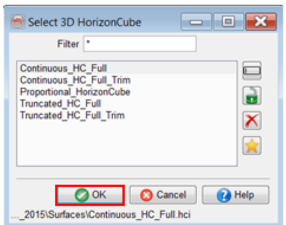
Evaluate stratal stacking patterns using the HorizonCube slider.



Workflow:

1. **Add inline** with default data (if the line exists, skip this step).
2. **Add** HorizonCube overlay on inline 425.
3. If no HorizonCube is selected, it will ask you to select a HorizonCube. You will choose *Continuous_HC_Full*.



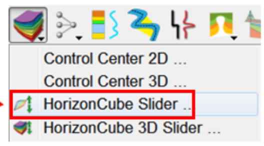


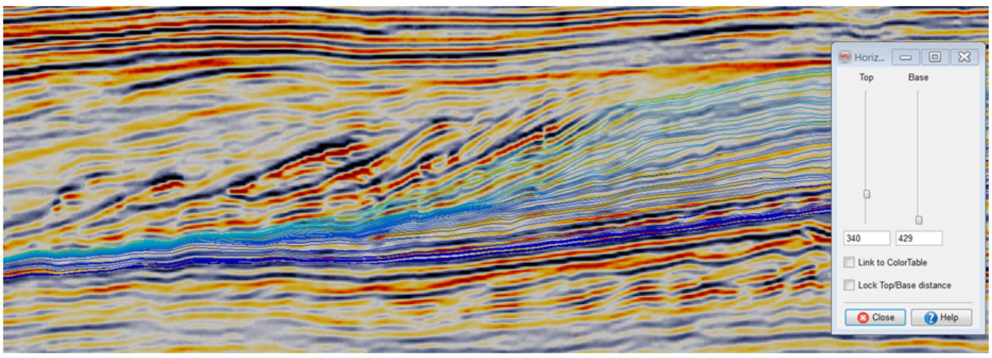
Common stacking patterns are:

- Aggradation
- Progradation
- Retrogradation
- and combination of these.

Workflow cont'd:

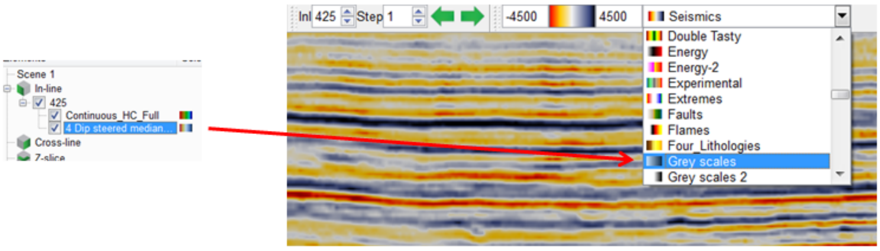
4. **Launch** the HorizonCube slider.
5. **Play with the sliders** by moving the Top Slider & observe changes in the scene.





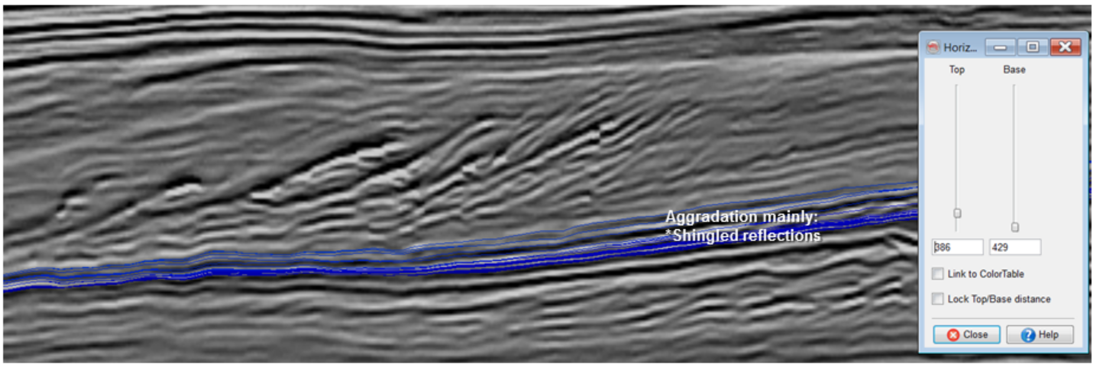
Workflow cont'd:

6. For better color contrast, you may want to **change the color scale** of the background image to *Greyscale*. See the steps below:



Workflow cont'd:

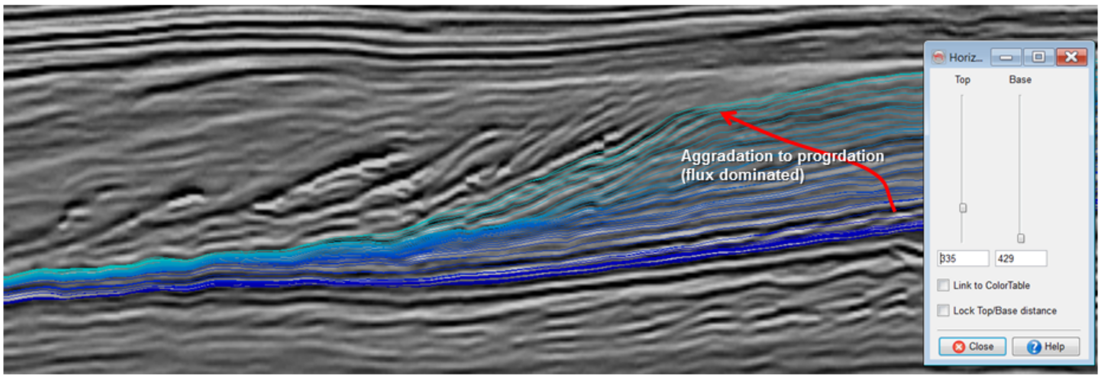
7. (a) An example illustration of making observations:



* You have also learnt about this zone while doing spectral decomposition (RGB Blending) & waveform segmentation.

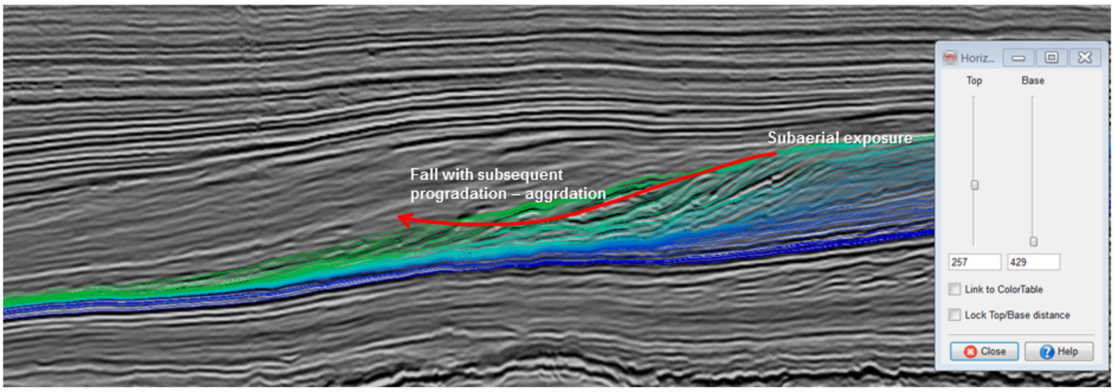
Workflow cont'd:

7. (b) An example illustration of making observations:



Workflow cont'd:

7. (c) An example illustration of making observations:



Note: The scene is a bit zoomed out.

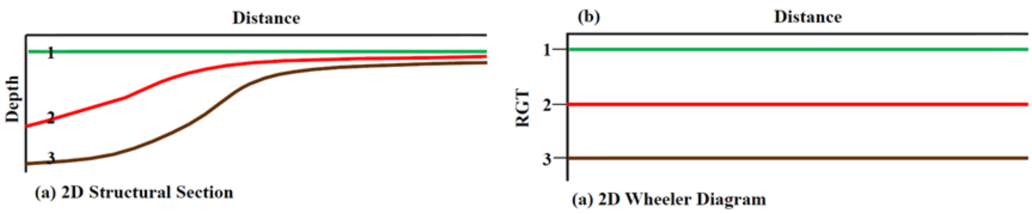
2.4.2c Wheeler Scene

Required licenses: OpendTect Pro, SSIS.

Exercise objective:

Wheeler transform (flatten) seismic data and co-render the flattened seismic with the flattened horizons of a truncated HorizonCube.

Basic concept of Wheeler diagrams (Flat horizons)

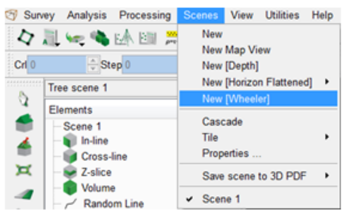


Structural domain horizons / surfaces are representative of relative geologic time (from P.R. Vail)

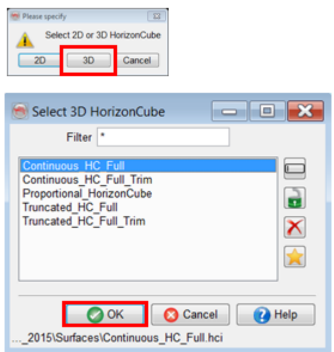
RGT – Relative Geologic Time

Workflow cont'd:

1. **Add** Scenes > New [Wheeler].

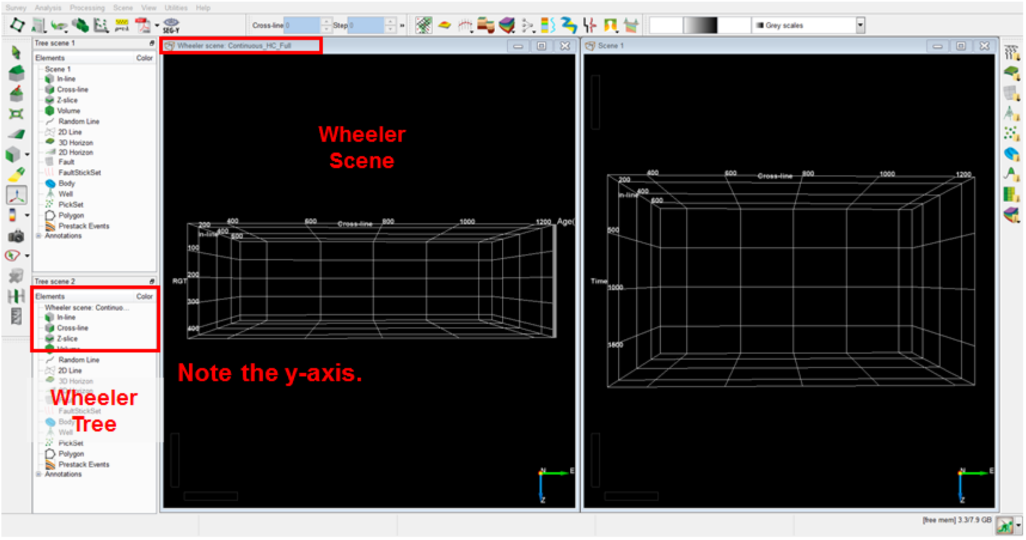


2. If no HorizonCube is active, it will ask to select a HorizonCube, **Select** *Continuous_HC_Full*. Otherwise, it will use the active HorizonCube to create a new Wheeler scene.



Workflow cont'd:

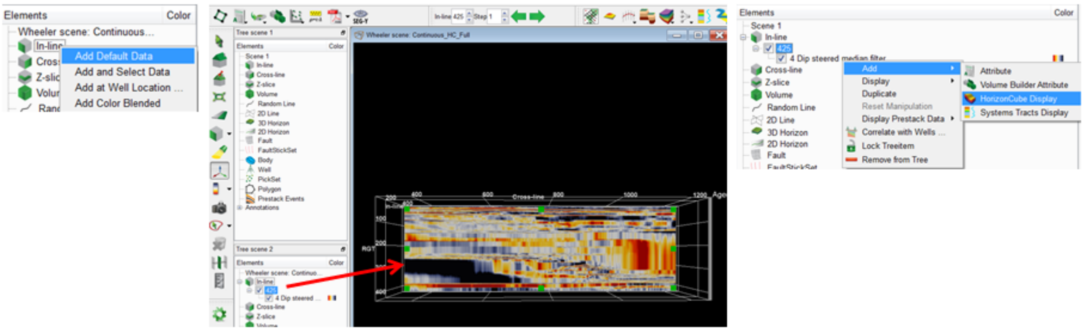
It will launch a new empty scene with a special **Tree Scene 2** attached to it.



Workflow cont'd:

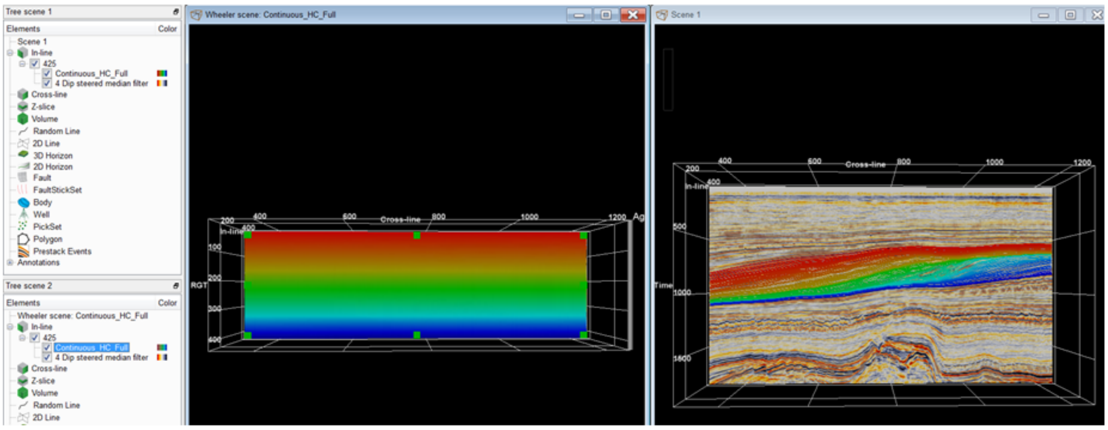
3. **Add a default data** in both the normal and Wheeler scenes.

4. **Add a HorizonCube** on inline 425.



Workflow cont'd:

Your display may look like as shown below. Note that viewing a continuous HorizonCube in Wheeler scene is not interesting. You may want to truncate it to remove all convergence patterns (next slide).

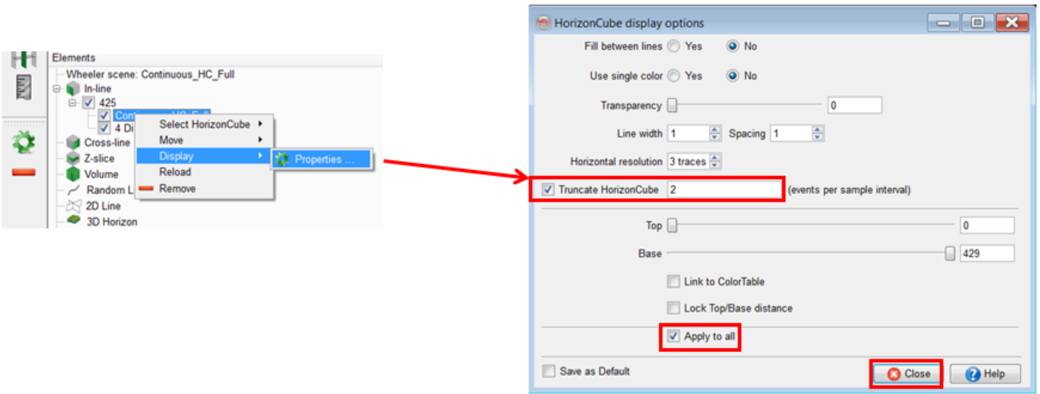


Workflow cont'd:

5. **Make** a truncated HorizonCube display (on-the-fly) using HorizonCube display properties dialog.

6. **Check Truncate HorizonCube**, click next to 2 and press **Enter** from the keyboard.

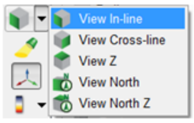
7. **Apply to all** to apply the same HorizonCube settings to all displays. When you will close the dialog, it will apply the same settings to all other scenes.



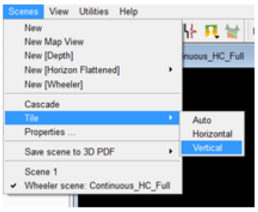
Workflow cont'd:

Adjust the display:

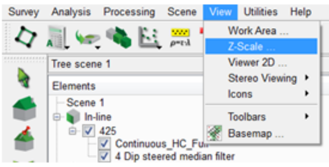
8. **Make** an inline view.

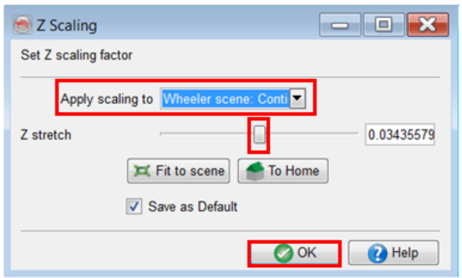


9. **Tile** the scenes.



10. **Change the z-scale** of the Wheeler to adjust the display according to your view.





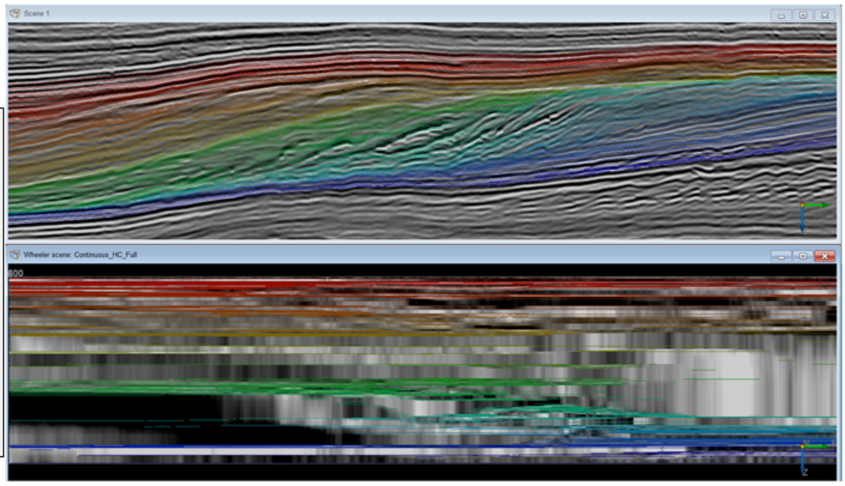
Workflow cont'd:

11. **Change** the perspective  view to the orthographic  view.

12. **Adjust** the scene by co-visualizing both views. You may also need to zoom in.

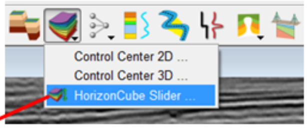
Tip: Avoid rotating a scene. Just use:

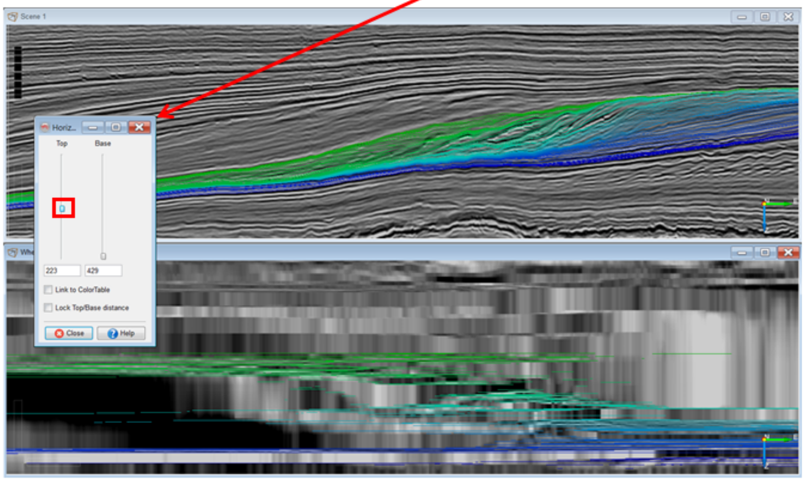
- pan (mouse wheel pressed or Ctrl+left mouse button pressed)
- zoom (spin mouse wheel or Ctrl+Shift+Left mouse button pressed).



Workflow cont'd:

13. **Use** the **HorizonCube slider** to slide the events up and down. Now you are ready to perform sequence stratigraphic interpretation.





2.4.2d Systems Tracts

Required licenses: OpendTect Pro, SSIS.

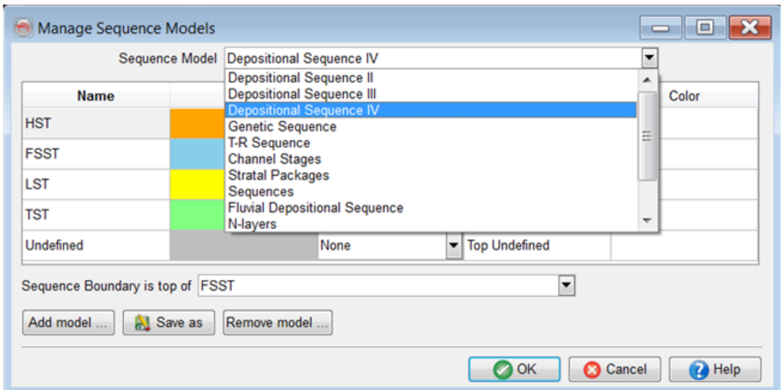
Exercise objective:
Perform systems tracts interpretation with the SSIS plugin.

This exercise assumes that you are familiar with sequence stratigraphy and the followings:

- Transgression & transgressive systems tract (TST)
- Normal Regression & highstand or lowstand systems tract (HST/LST)
- Forced Regression & falling stage systems tract (FSST)

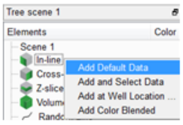
Sequence Stratigraphic Models in OpendTect:

Each model has its own *name, color code, base-level phase, Top surface name, top surface color.*

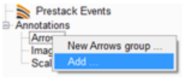


You can also make your own model if you press the **Add model** button.

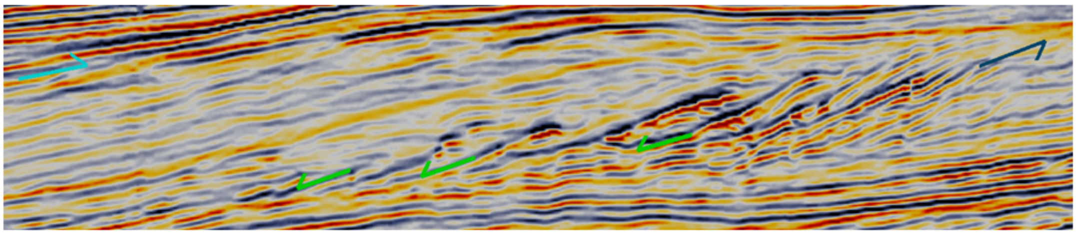
Worklow:

1. **Add inline 425** (if it does not exist). 

2. (**Optional**) In Exercise 2.4.2a, you made some **annotations (arrows) on inline 425**. You may want to display them in the scene to begin with SSIS interpretation.

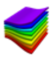


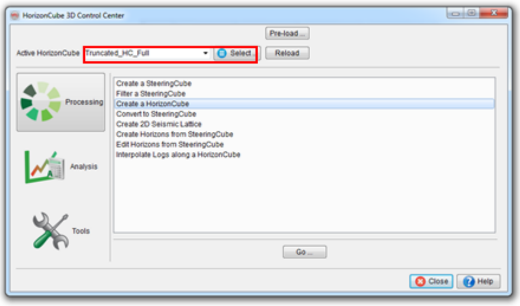
Following this, select the ones that you saved earlier on.



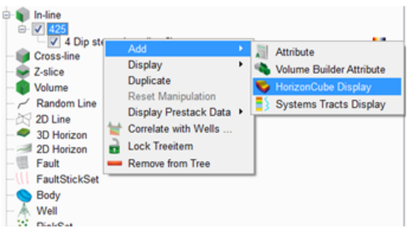
Workflow cont'd:

Tip: If you intend to study depositional shifts, we recommend selection of a truncated HorizonCube (which is already pre-processed).

3. **Activate** a truncated HorizonCube (Truncated_HC_Full).
   - Launch the 3D HorizonCube control center. 
   - Select the active HorizonCube.



4. **Add the HorizonCube** display on inline 425.

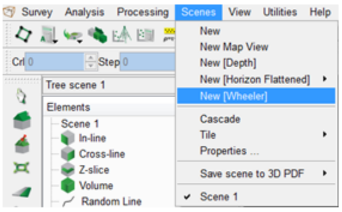


Workflow cont'd:

There are two ways of preforming SSIS interpretation:

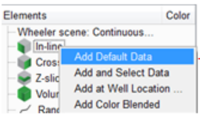
- Stacking patterns in a normal (structural) scene.
- Or co-visualizing both the normal and Wheeler scenes.
- In this exercise, we will co-visualize both scenes.

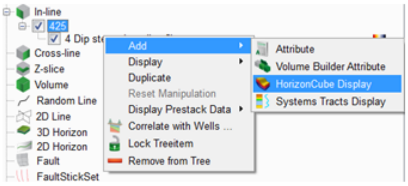
5. If you do not have any Wheeler scene display, **Add a Wheeler Scene*** (Scene > New Wheeler ..) .



6. **Add inline 425** with default data for the Wheeler tree/scene.

7. **Add HorizonCube** display.

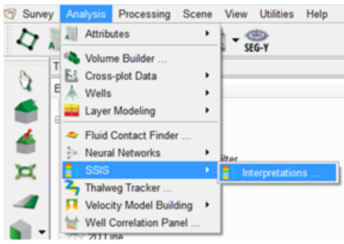




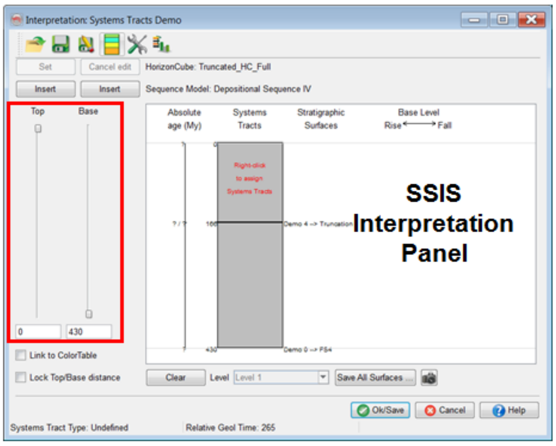
* See Exercise 2.4.2c

Workflow cont'd:

8. **Open** the SSIS interpretation window by clicking on this icon. An interpretation window will open, with the familiar HorizonCube sliders on the left side; interpretation column, base level curve, and timeline in the white pane on the right.



HorizonCube Slider

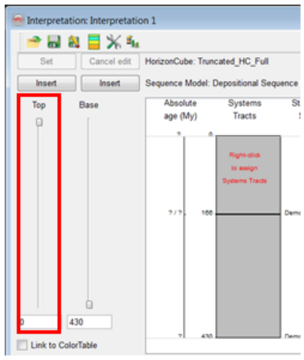


SSIS Interpretation Panel

Workflow cont'd:

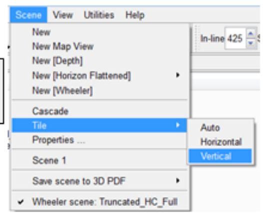
9. **Open** the Sequence Models selection window by pressing: 
    - View the options of the sequence models available. For this exercise, the default model (Depositional Sequence IV) will be used.
    - Close this window when you have finished viewing the options.

10. To begin your interpretation, you will use the HorizonCube sliders:
    - Slide the **top slider** all the way to the bottom while co-visualizing the Wheeler and normal scenes.
    - Slowly drag the **top slider** up until you find a breaking point that would indicate a different system tract.

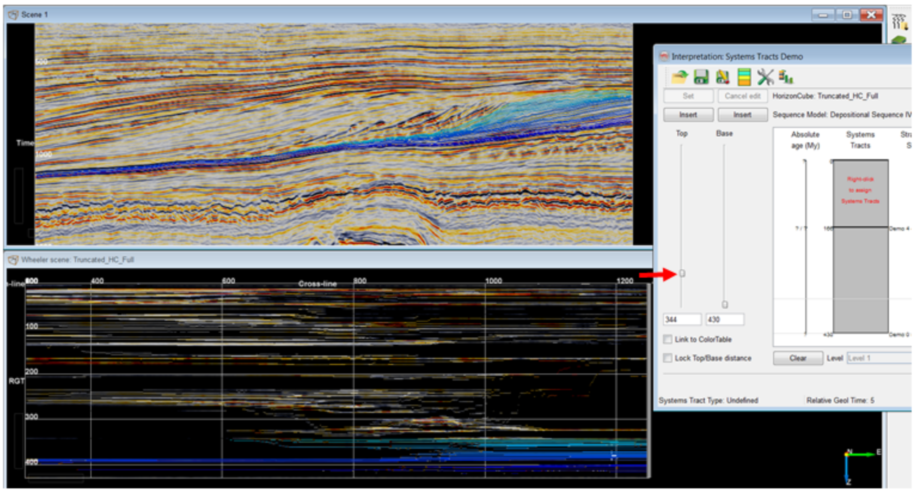


Workflow cont'd:

Tip: You may want to tile the scenes vertically.

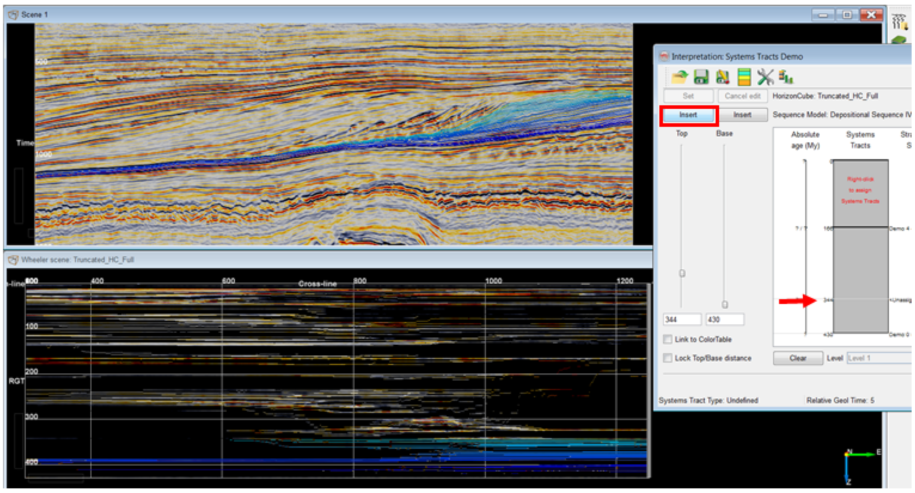


11. Position the **top slider** where you intend to insert a boundary.



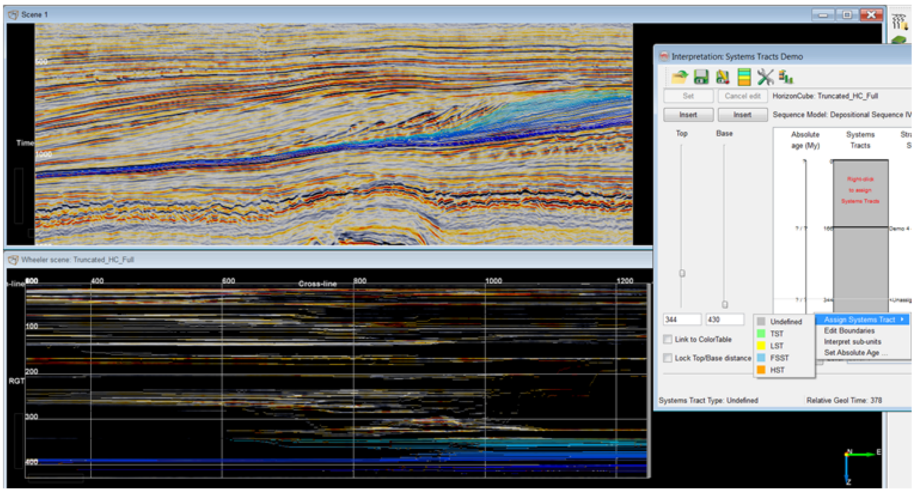
Workflow cont'd:

12. **Press** the **insert** button which lies just above the top slider. This will insert a boundary in the stratigraphic column.



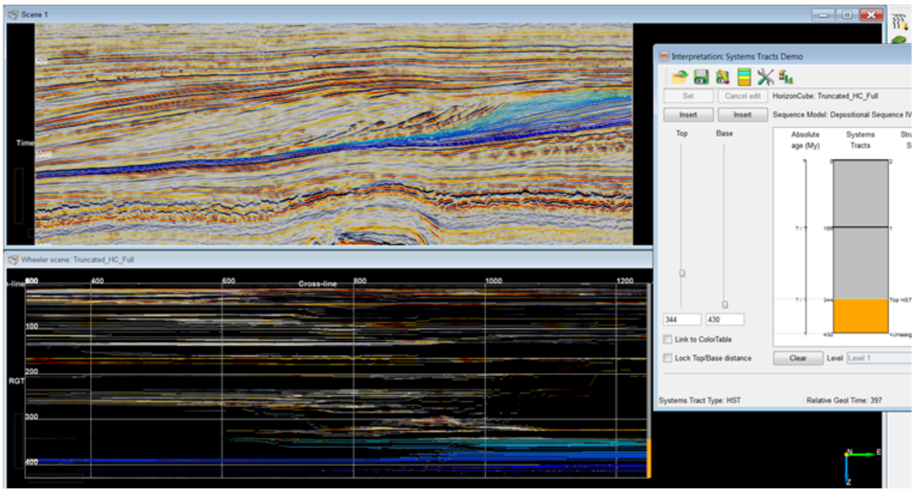
Workflow cont'd:

13. **Right-click** in the middle of the package that you added and assign the systems tract.



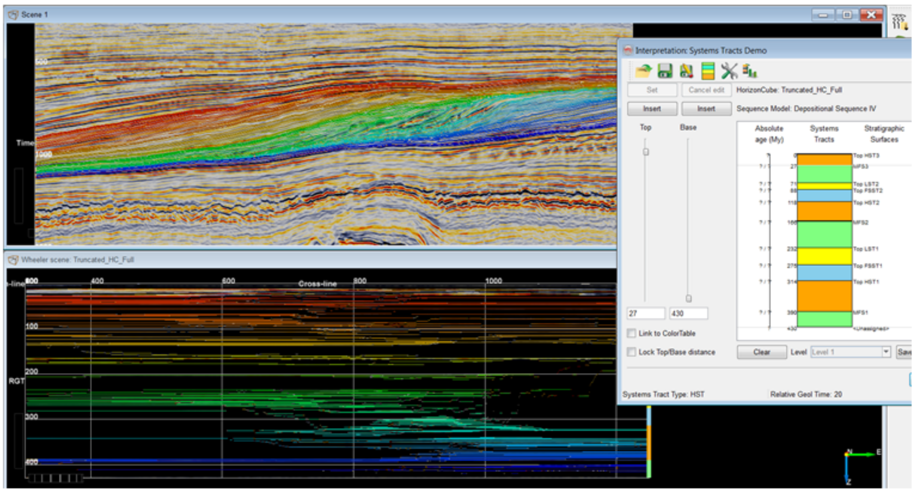
Workflow cont'd:

14. The selected systems tract will be assigned.



Workflow cont'd:

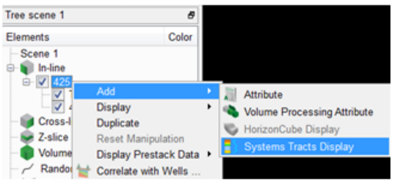
15. By repeating these steps, the entire stratigraphic column can be interpreted and systems tracts are assigned.

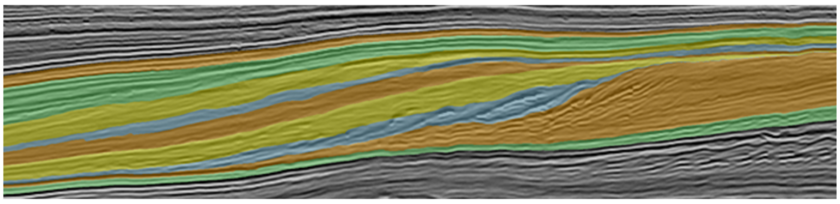


Workflow cont'd:

16. You may want to **overlay** the inline with the interpreted **Systems tract** in both scenes.

17. Once done, you may want to **Save** this interpretation.





You can save more than one interpretation per HorizonCube.

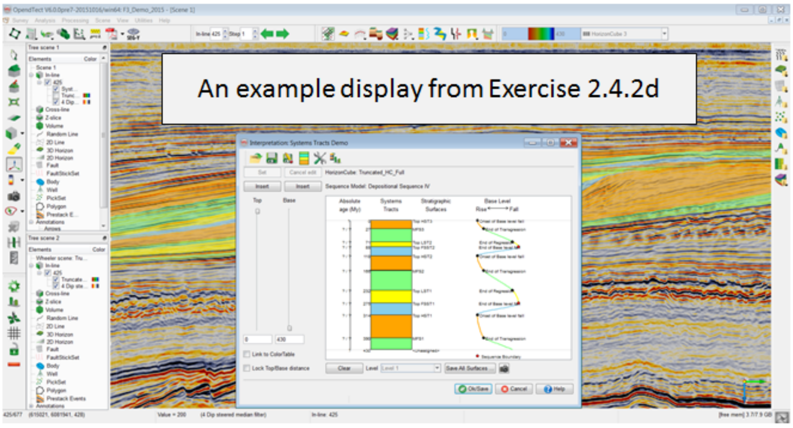
2.4.2e Statistical (Thickness) Curves

Required licenses: OpendTect Pro, SSIS.

Exercise objective:
Extract statistical (thickness) curves to express data-driven nature of base-level variations.

This exercise requires an existing SSIS interpretation and an active* HorizonCube.

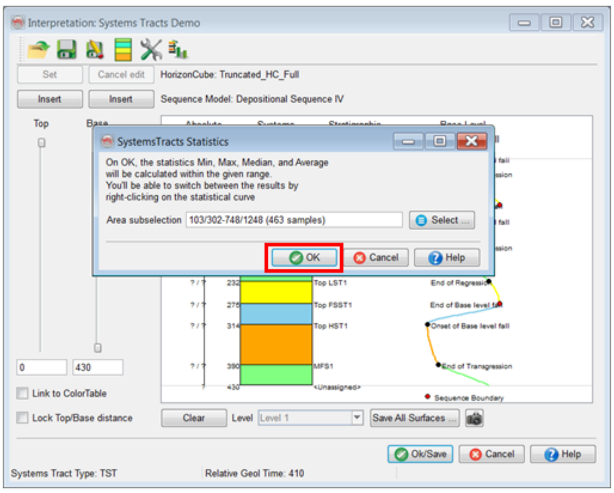
In Exercise 2.4.2d, you made some **SSIS interpretation**. You may want to use them as a reference interpretation to extract statistical curves.



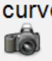
* Processing > HorizonCube > 3D >....

Workflow:

1. In the SSIS window, **launch** the statistical curve extraction dialog: 

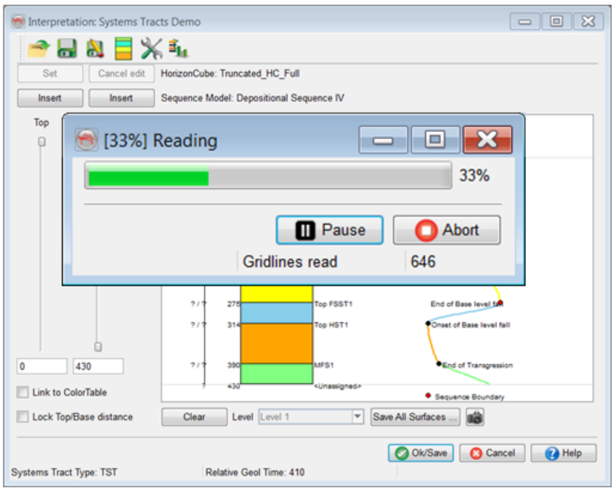


Tips on area sub-selection:

1. Try to plot the thickness variations at a given depocenter vs. coastal regions per systems tract
2. Compare the two curves by taking snapshots. 

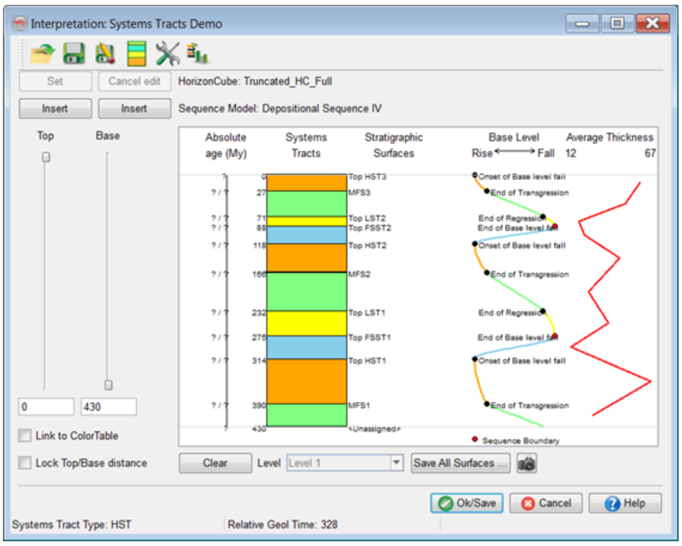
Workflow cont'd:

2. If you proceed further, it will start extracting data within the sub-selected area and perform statistics.



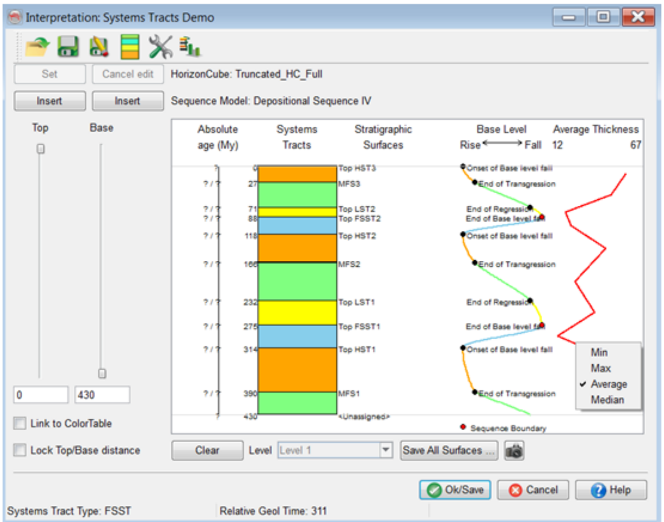
Workflow cont'd:

3. Once the processing is finished, an Average Thickness curve will appear in **red**.



Workflow cont'd:

4. You may want to change the statistics and plot a different curve. To do that, just **right-click on the curve** and choose other stats.



2.4.2f Stratigraphic Surfaces

Required licenses: OpendTect Pro, SSIS.

Exercise objective:
Extract systems tract boundaries as seismic horizons of OpendTect.

There are several ways available to extract stratigraphic surfaces (or horizons) from a HorizonCube.

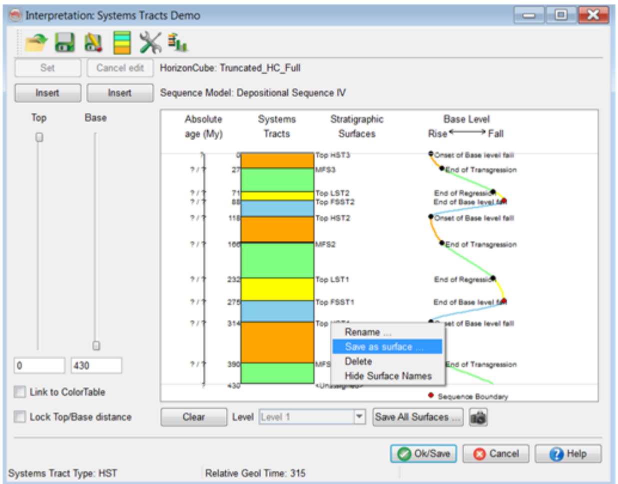
In this exercise, you will learn three ways:

1. In SSIS window: **one horizon** at a time.
2. In SSIS window: **multiple** horizons.
3. In HorizonCube manager: **extract events**.

Workflow:

Method 1:

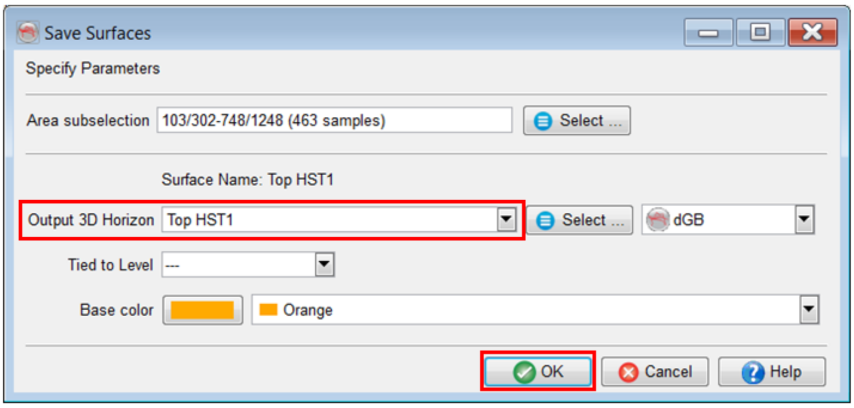
1. In the SSIS window, **right-click** on the surface name and choose **Save as surface**.



Workflow cont'd:

Method 1:

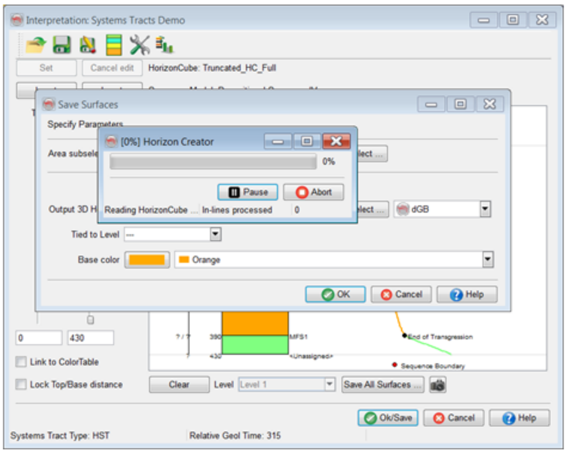
2. In save surfaces dialog, **specify a Horizon** name and **press** OK.



Workflow cont'd:

Method 1:

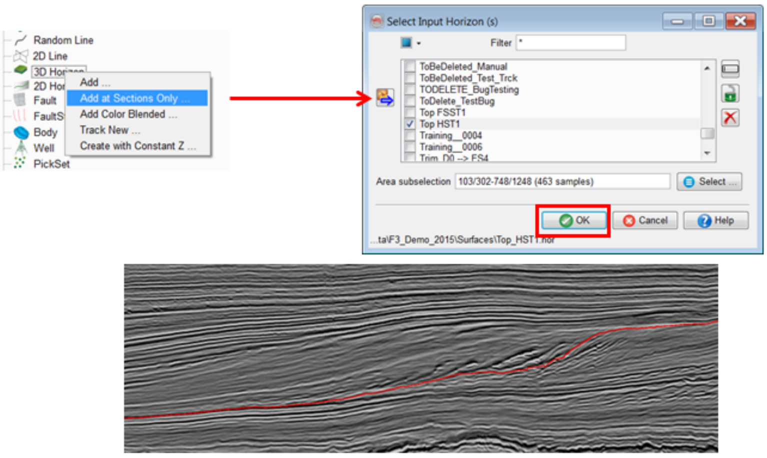
3. It will start extracting a horizon from the HorizonCube. In case, the HorizonCube is truncated, it will start interpolating the horizon.



Workflow cont'd:

Method 1:

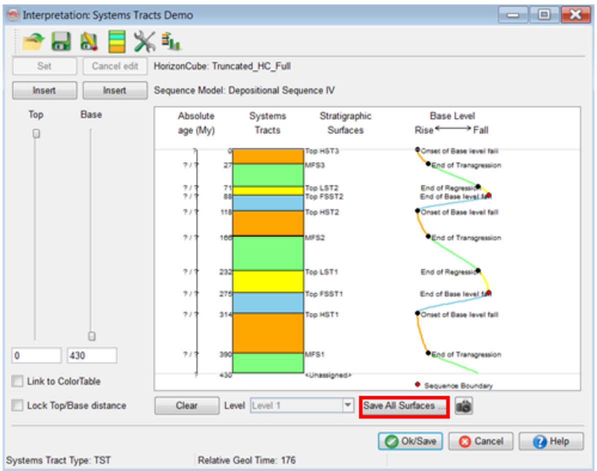
4. The extracted horizon is copied as a general OpendTect horizon to the project database. Hence, you can **display the horizon** in the scene to QC it.



Workflow cont'd:

Method 2:

1. If you want to **save all surfaces**, then proceed with this part.

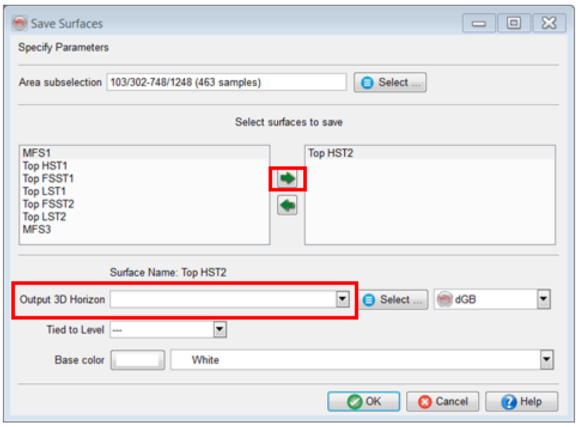


Workflow cont'd:

Method 2:

2. On the left panel, you see the surfaces names that you have interpreted. You will have to add them to the right.

3. For each surface that is added, you will specify the **Output Horizon** name.



Tip: You can copy the input name for output horizon, e.g. MFS2 (using mouse drag over the label and CTRL+C).

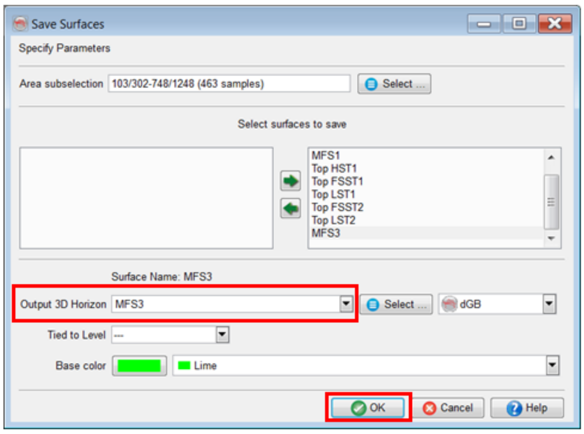
Workflow cont'd:

Method 2:

4. Following this procedure, you can add multiple horizons in the list.

5. Once done, proceed by pressing the **OK** button.

6. It will output all of them as general OpendTect horizons and you can QC the outputs by displaying them in the scene as shown in **pt. 4 (Method 1)**.

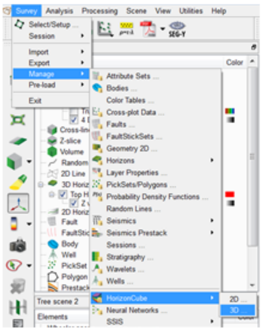


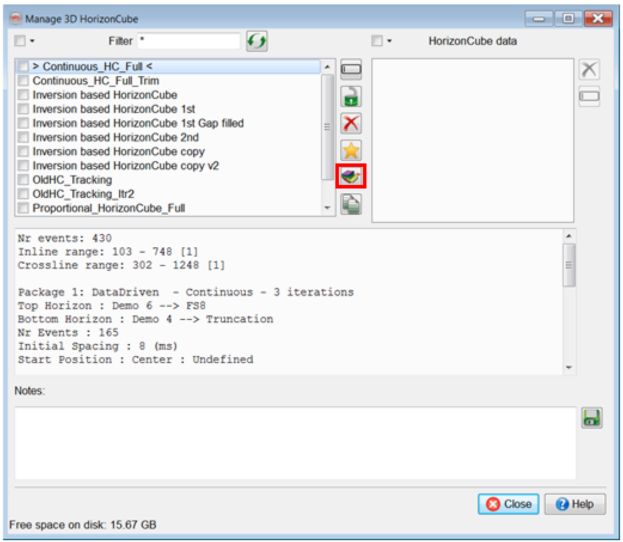
Workflow cont'd:

Method 3:

Directly extract horizons from a HorizonCube using **HorizonCube manager.**

1. Survey > Manage > HorizonCube > 3D
2. **Select** *Continous_HC_Full* & **press** copy to horizons icon.

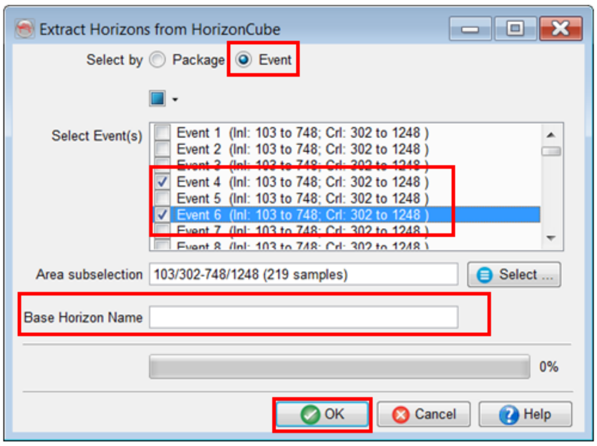




Workflow cont'd:

Method 3:

3. In the pop-up window you may choose one horizon or multiple horizons (say **Event 4** and **Event 6** only) to be converted to general OpendTect horizons. The **Base Horizon Name** is the prefix for the output horizon name. On **OK**, it will start extracting the horizons.
4. Once done, close this window.



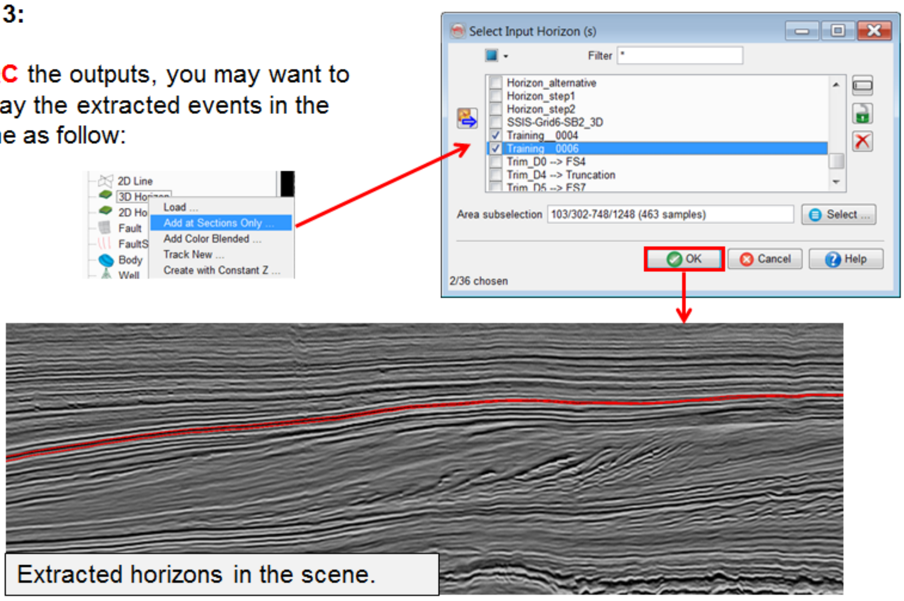
Uncheck-all: Ctrl+Z or uncheck the list through the small check box available at the top of the list.

Group selection: Mouse drag over the check boxes in the list.

Workflow cont'd:

Method 3:

5. To **QC** the outputs, you may want to display the extracted events in the scene as follow:



Extracted horizons in the scene.

2.4.2g Stratigraphic Attributes

Required licenses: OpendTect Pro, HorizonCube.

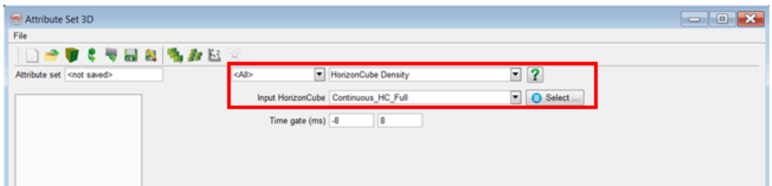
Exercise objective:

Define and understand the HorizonCube/SSIS attributes.

Workflow:

1. Launch the **3D attribute** set window. 

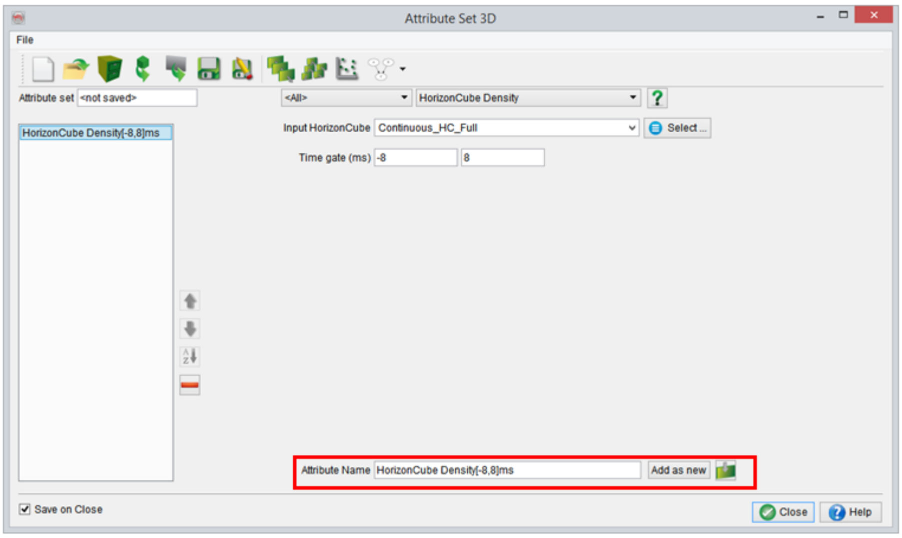
2. **Select** a HorizonCube density attribute.



We suggest using a Continuous HorizonCube as an input for this attribute because it requires horizons within a specified time gate. The truncated HorizonCube removes such events and hence this attribute is not suitable for such inputs.

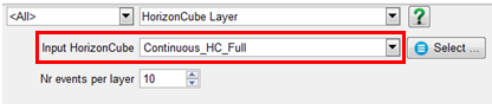
Workflow cont'd:

3. **Specify** the attribute name and **add it as new**.

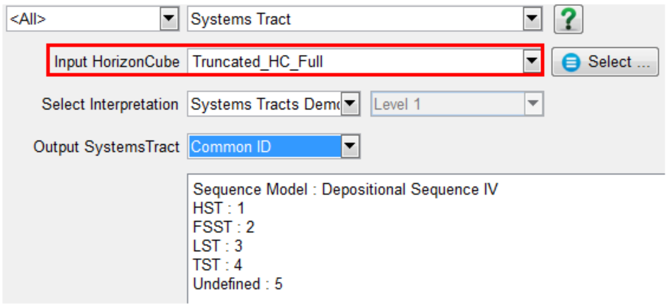


Workflow cont'd:

4. Following the previous steps (2-3), **define*** a few more attributes e.g. HorizonCube layers and Systems tract (Common ID, Unique ID, and Isochron) attributes.



Note the input HorizonCube for this attribute is the truncated one because the interpretation is made on that input.

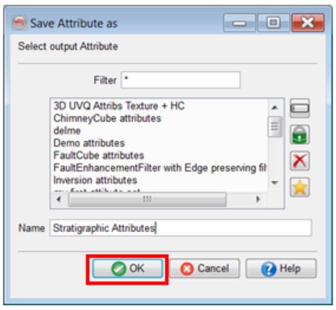


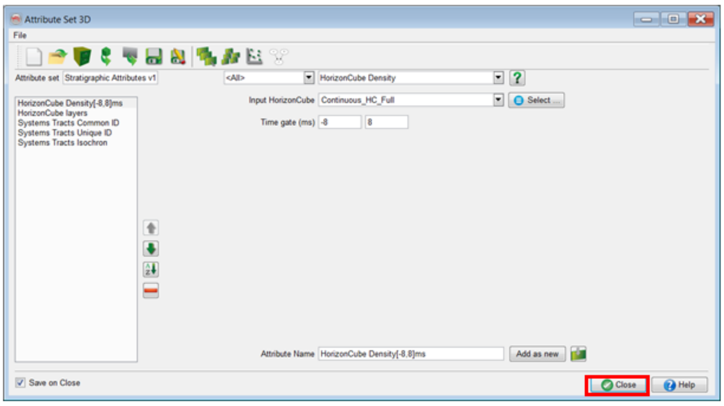
* Per defined attribute, you will have to specify its name and press the button add as new.

Workflow cont'd:

5. Once you have defined these five attributes, **save** the attribute set as e.g. *Stratigraphic Attributes*. If the name already exists, then overwrite.

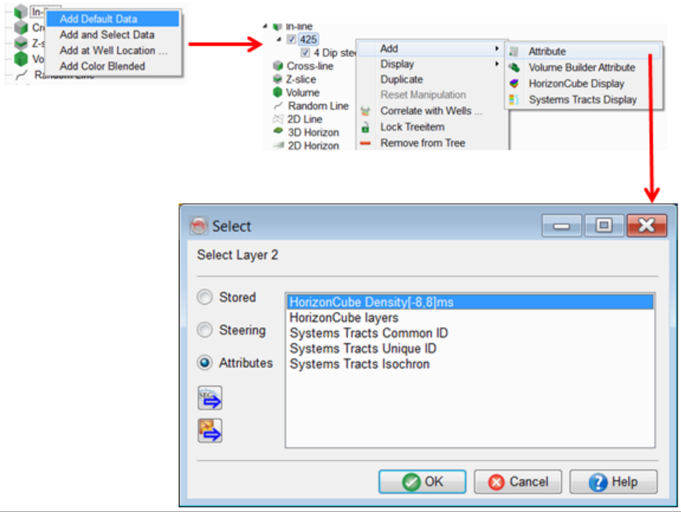
6. **Close** the attribute set window.





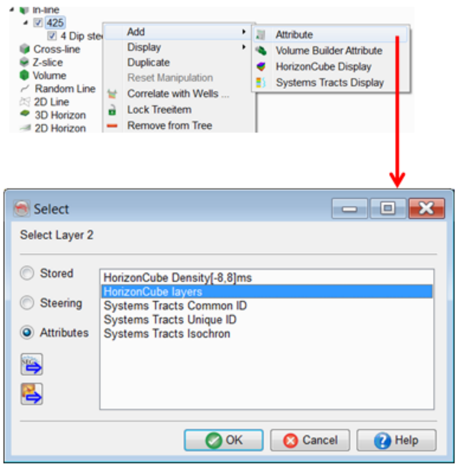
Workflow cont'd:

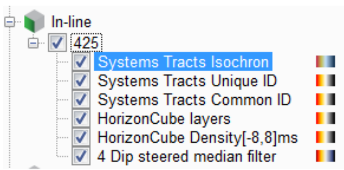
7. Next you may want to **display these attribute** on an inline before processing.



Workflow cont'd:

8. Following the same steps, **overlay the remaining** attributes on the same inline.

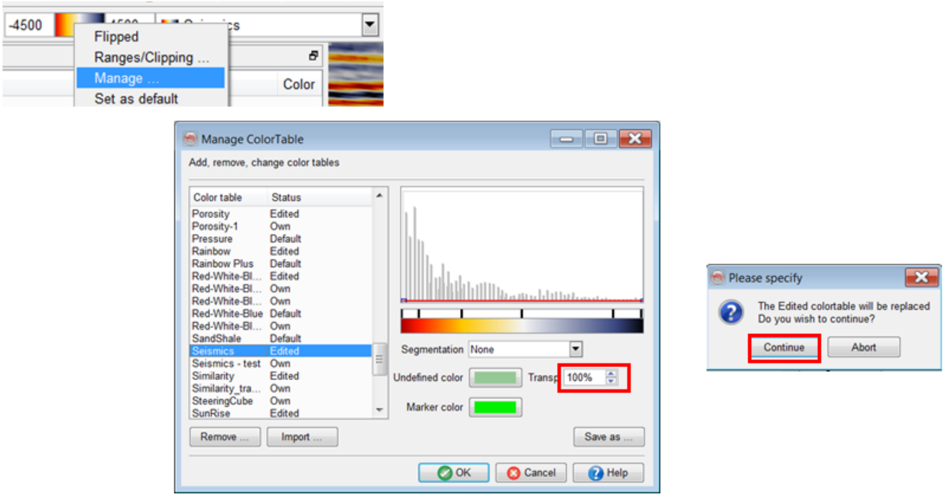




Your inline view may look like this after overlaying six attributes on each other.

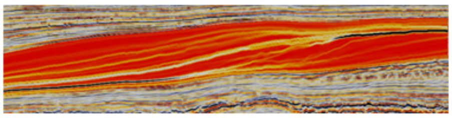
Workflow cont'd:

9. Your attributes may have a green/yellow coloured (default undefined values) areas which could be set to transparent by following these steps.

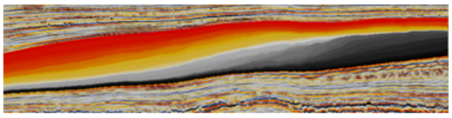


Your results may look like this:

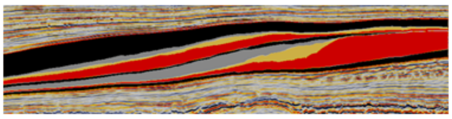
HorizonCube Density:
Black regions in this case represents gaps in deposition e.g. unconformities and condensed sections.



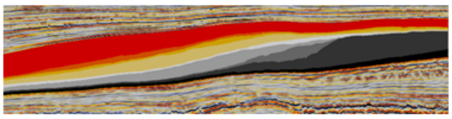
HorizonCube Layers:
This is like an input model containing layer definition per 10th event. A good input for geological/reservoir modeling.



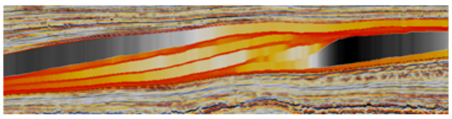
Systems Tracts Comon ID:
A repetition of same colour in this case represents the same systems tract, which has a common ID in this volume. Again, this volume can be use for modelling or prediction purposes.



Systems Tracts Unique ID:
All systems tracts have their own unique IDs in this volume.



Systems Tracts Isochron:
This is a thickness volume per systems tract. A good product to explain the base-level variations based on your data. Or adding another dimension to the Wheeler diagrams when this attribute is used as an overlay in the Wheeler scenes (e.g. 4D Wheeler diagrams).



2.4.2h Stratal Slicing

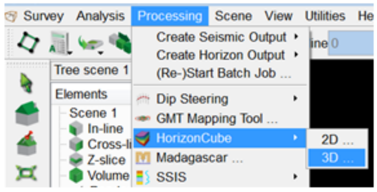
Required licenses: OpendTect Pro, SSIS.

Exercise objective:

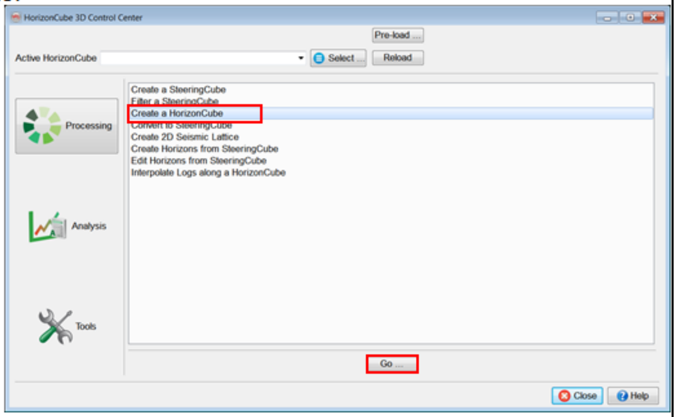
Analyze 3D seismic data by slicing through all available data.

Workflow:

1. **Go to** Processing > HorizonCube > 3D.



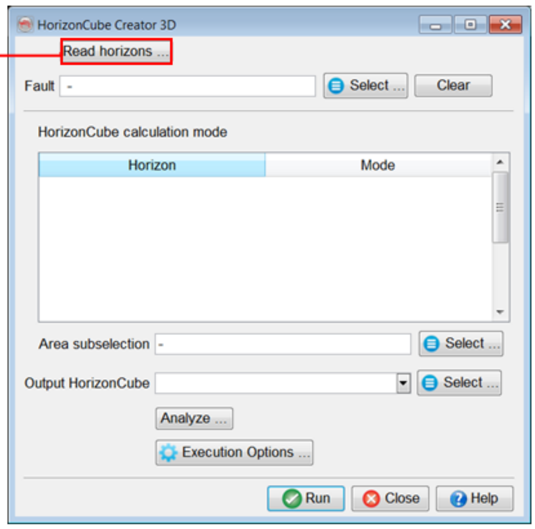
2. In the HorizonCube 3D Control Center **select** on Create a HorizonCube from the list and **click** Go…

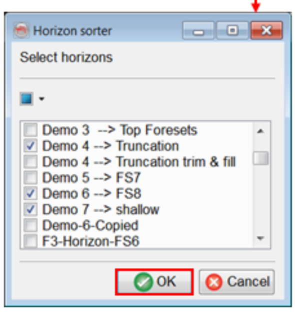


Workflow cont'd:

3. In HorizonCube Creator, **click on** Read horizons…

4. **Check** three horizons *Demo 4*, *Demo 6*, *Demo 7* and **click** OK.

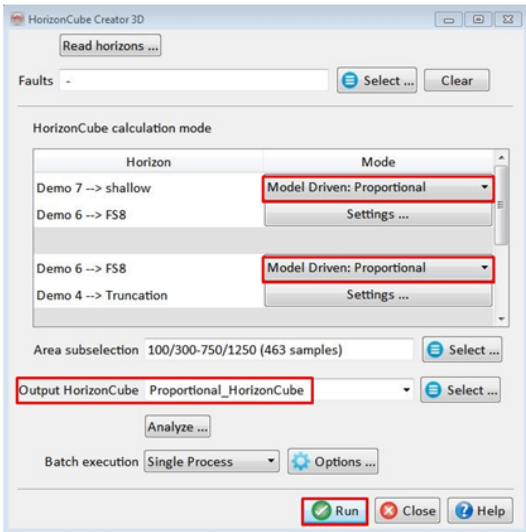




Workflow cont'd:

5. The table will be filled automatically with two packages. Select Model Driven: Proportional for the both the packages. **Type in** an output name to the HorizonCube *Proportional_HorizonCube* and **press** Run to start the batch processing.

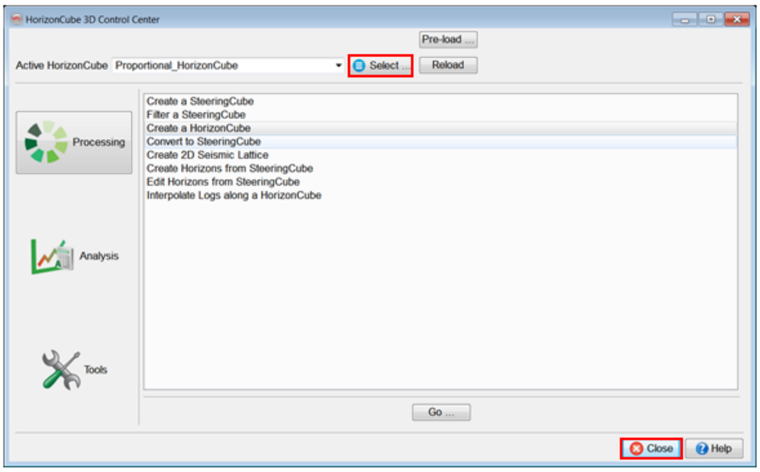
Settings for the proportional HorizonCube are based on event sampling (spacing at maximum thickness and fixed number of events).



Workflow cont'd:

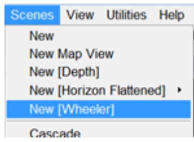
6. When processing is finished, **set** an active HorizonCube: **click** on Select button in HorizonCube 3D Control Center and **pick** *Proportional_HorizonCube*.

7. **Press** Close.

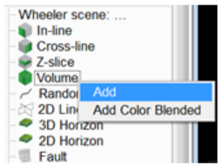


Workflow cont'd:

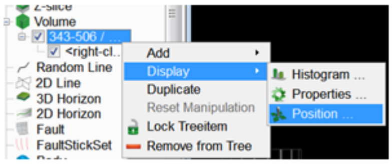
8. **Make** a Wheeler scene: Scene > New [Wheeler].



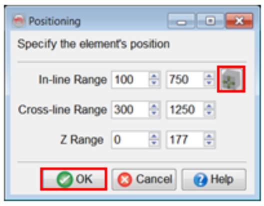
9. **Load** an empty volume in Wheeler scene: **Right-click** on Volume in the Wheeler scene tree > Add.



10. **Right-click** on the volume > Display > Position…

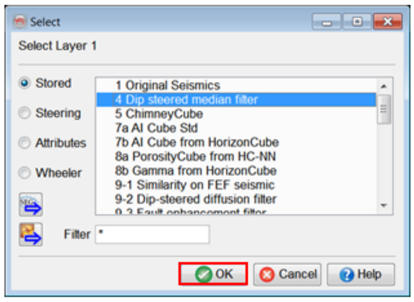


11. **Set** ranges to the full survey : **click** on the icon and **press** OK.

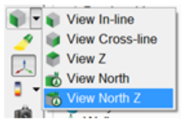


Workflow cont'd:

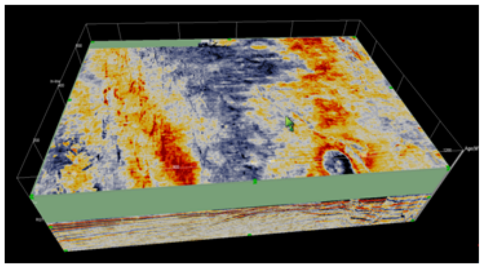
12. **Select** *4 Dip steered median filter* from the list of attributes and **press** OK.



13. **Click** View Z or View North Z to rotate the volume.



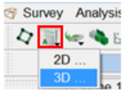
14. In mouse position mode , **click** on section and **pull down** to slice through. **Slice** the volume upward and downward.



In similar way you may slice in inline and crossline directions

Workflow cont'd:

Optionally a Wheeler Cube can be created as follows:

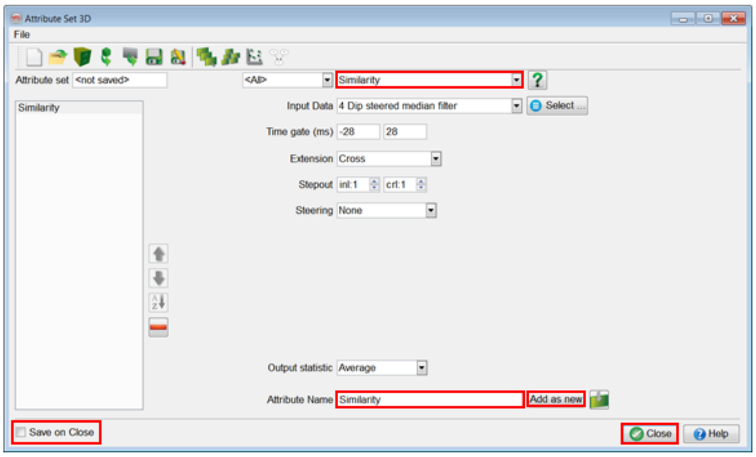


15. Click on icon > 3D to launch Attribute Set window.

16. Select Similarity attribute from the attribute list.

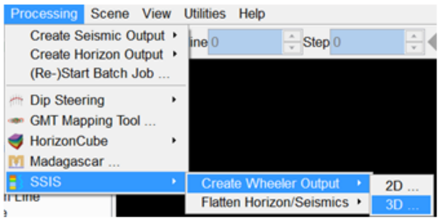
17. Type in a name, e.g. *Similarity*, and press Add as new.

18. Uncheck Save on Close and **close** the window.

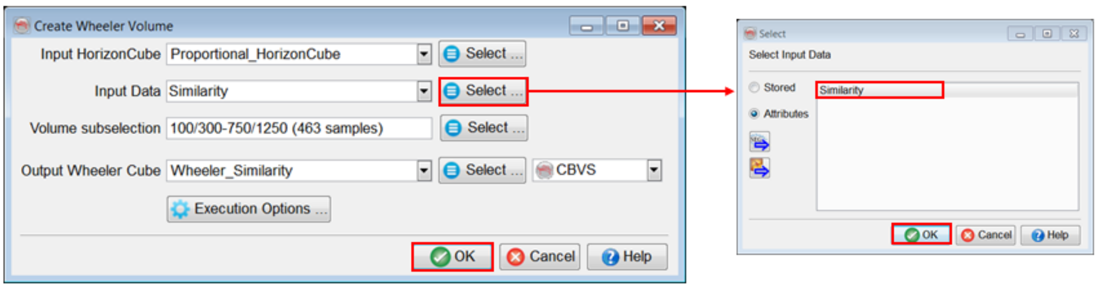


Workflow cont'd:

19. Create wheeler volume: **go to** Processing > SSIS > Create Wheeler Output > 3D.

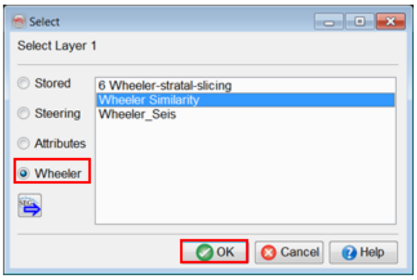


20. Fill the required fields as shown below and **press** OK to start processing.

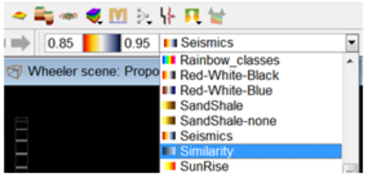


Workflow cont'd:

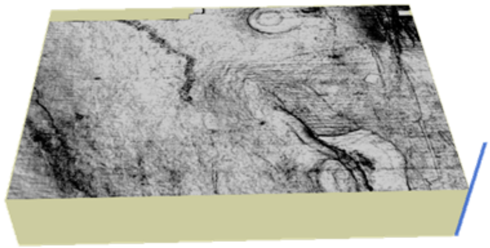
21. **Display** the *Wheeler Similarity* cube in a volume by selecting the attribute from the Wheeler tab:



22. **Click** on *Wheeler_Similarity* attribute in the tree to make it active and **change** the color bar to *Similarity*.



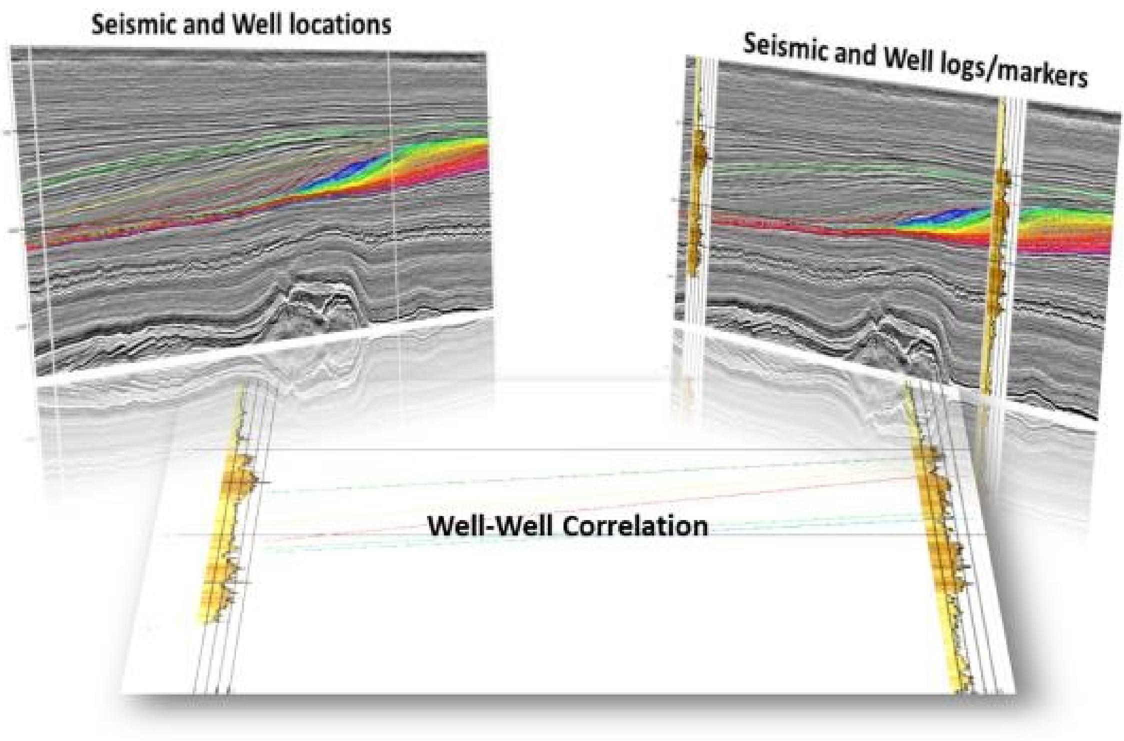
23. **Slice** the volume upward and downward for the z-axis to see geomorphologies.



2.4.3 Well Correlation Panel

What you should know about Well Correlation Panel

- The Well Correlation Panel is a commercial plugin by dGB.
- It is used to pick and QC well log markers.
- It can be used to create conventional well correlation panels without seismic backdrop.
- Typically, however, a random line is created through the wells and the seismic is used as a backdrop to guide the interpretation.
- A HorizonCube, either 3D, or a dedicated 2D version created along the random track, can optionally be added to help correlate markers from well to well.



Details

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 the 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 points 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.

2.4.3a Well Correlation Panel

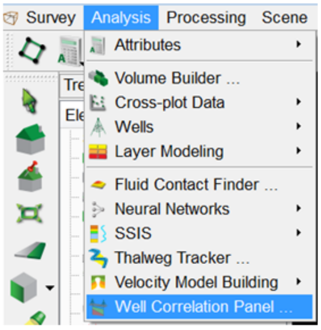
Required licenses: OpendTect Pro, Well Correlation Panel, HorizonCube.

Exercise objective:

Create a well correlation panel and QC the well markers using the seismic data and a HorizonCube to guide you.

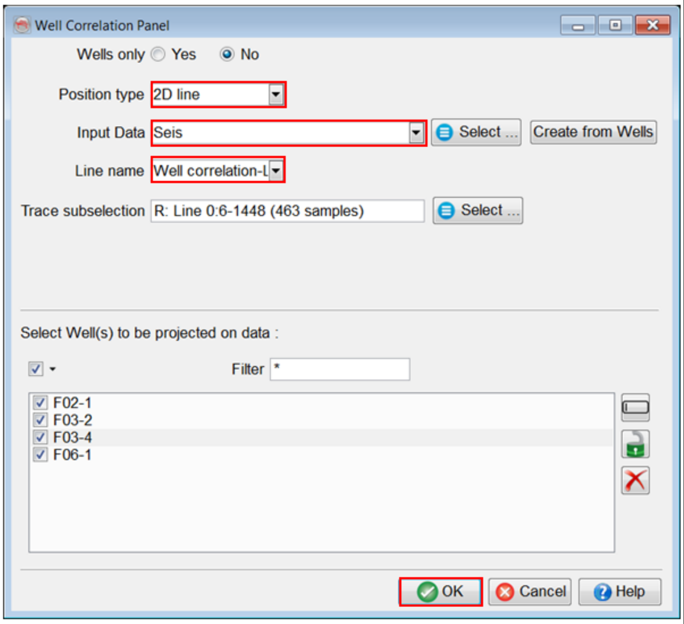
Workflow:

1. **Launch** the Well Correlation Panel (WCP) window: Analysis > Well Correlation Panel, or via the  icon.



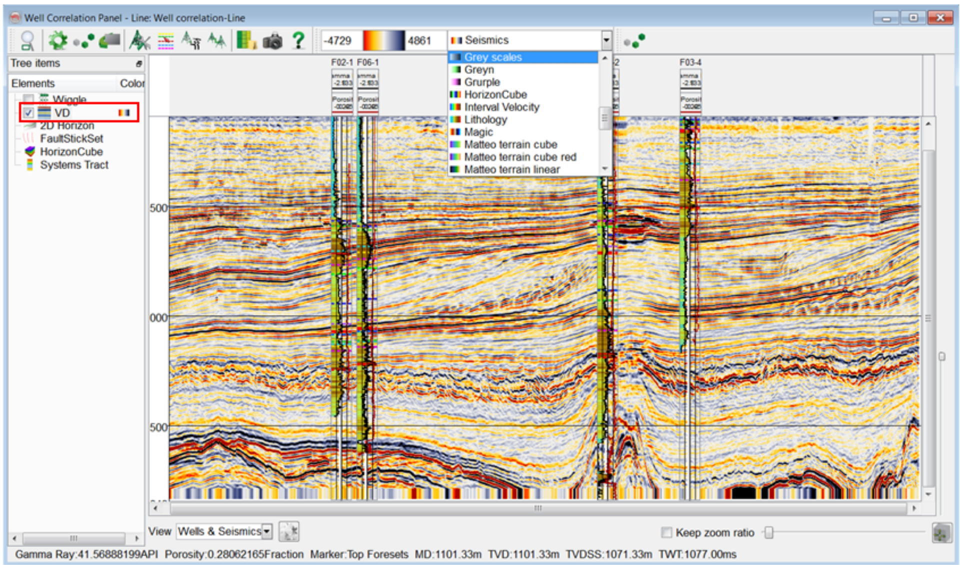
Workflow cont'd:

2. **Select** data type: 2D line.
3. For Input data, **select** *Seis* and **select** the line name *Well Correlation-Line*.
4. At the bottom of the window, **select** all four wells available in the list.
5. **Press** OK.



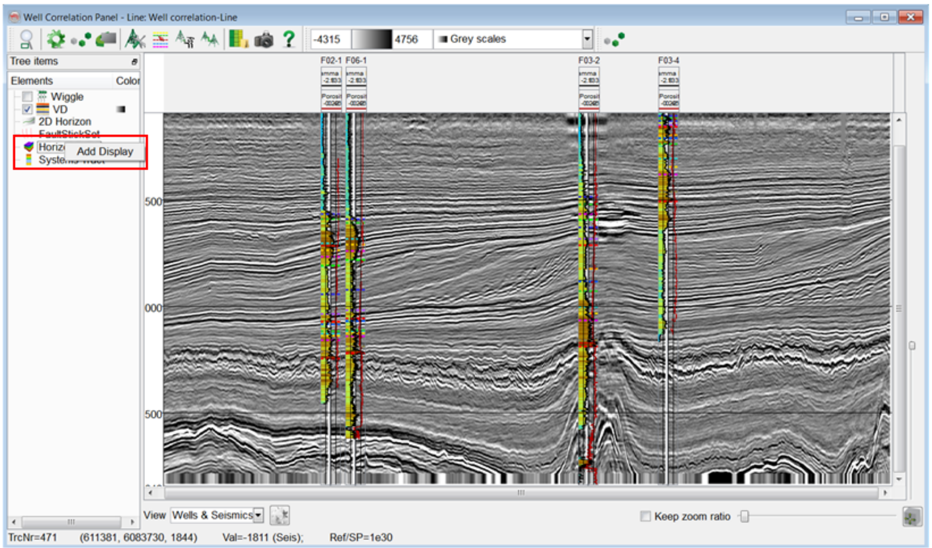
Workflow cont'd:

6. **Change** the seismic color spectrum to Grey scale: **click** on VD and from the top bar **spin** the color to Grey scale.



Workflow cont'd:

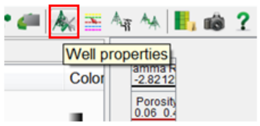
7. **Overlay** the seismic data with the HorizonCube: **right-click** on HorizonCube in the tree and **select** Add Display.
   Choose the 2D HorizonCube *"HorizonCube SC-FFT-trunc Random line between wells"*.

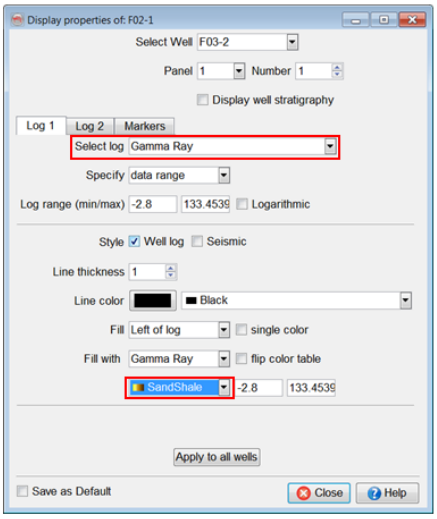


Workflow cont'd:

8. Now **display** a Gamma Ray (GR) log on all wells: **click** on the well properties icon  from the WCP window.

9. In the Log 1 tab, you may **select** Gamma Ray log with a SandShale color bar.



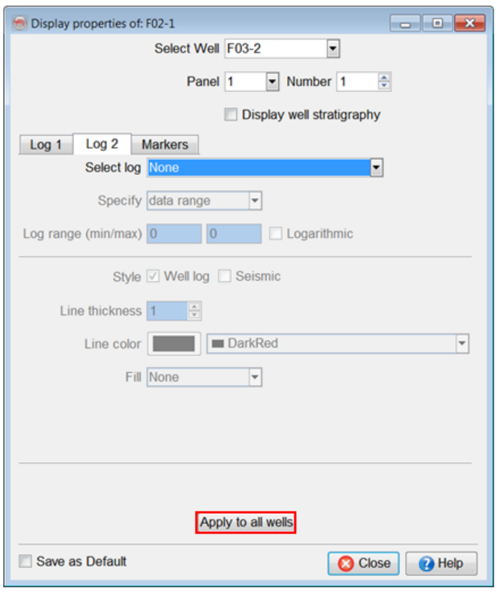


Workflow cont'd:

10. In the Log 2 tab, leave the log selection to None.

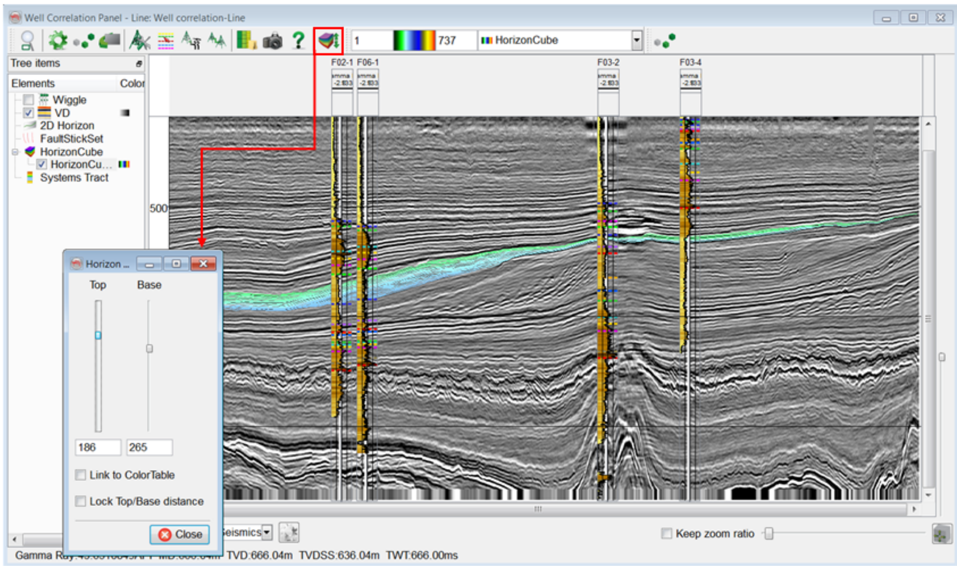
11. Press Apply to all wells to display the Gamma Ray log on all wells displayed in the panel.

12. Close this window.



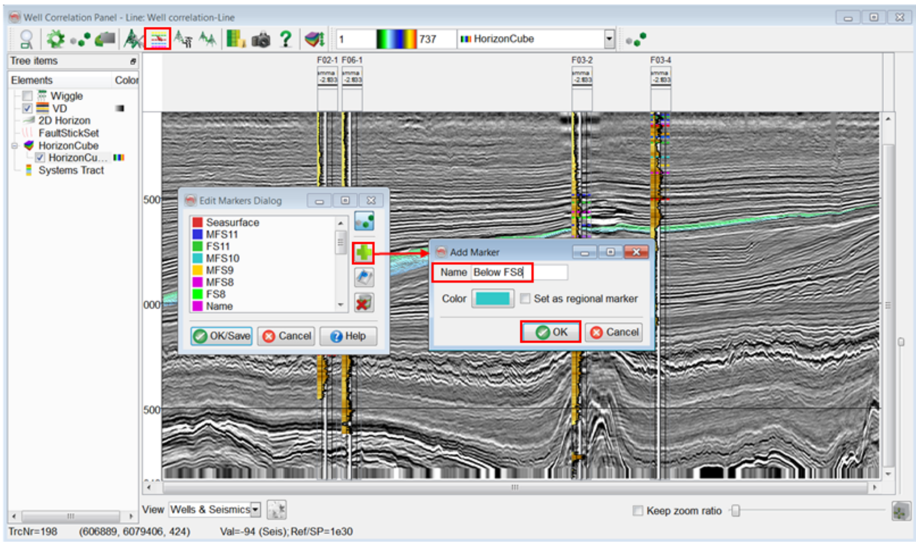
Workflow cont'd:

13. Now **start** interpreting the depositional trends and possible systems tracts boundaries by **moving** the HorizonCube slider up and down.



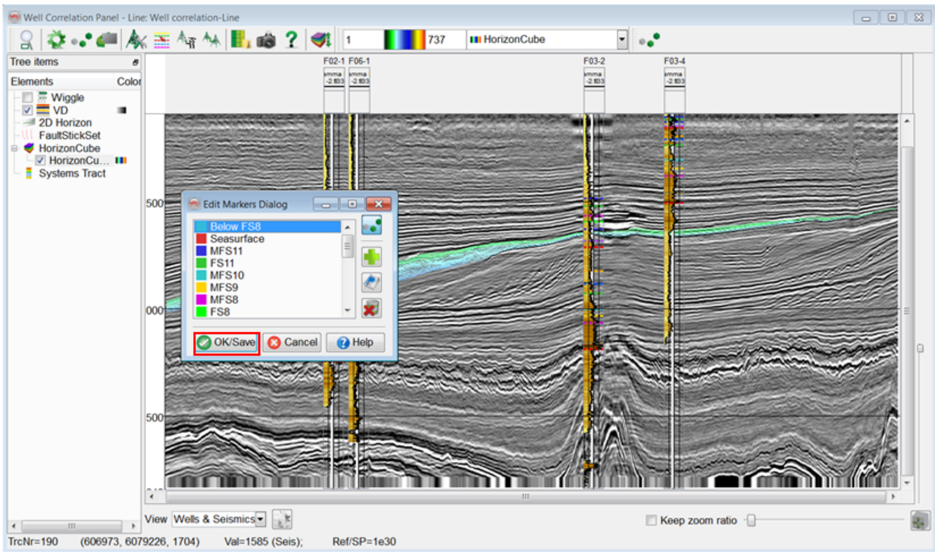
Workflow cont'd:

14. To edit the markers: **click** on the icon.
15. **Add** a new defined boundary as a marker by clicking on .
    In the pop-up dialog, **give** a new name and color to the new marker and **click** Ok.



Workflow cont'd:

16. Once the marker is added in the list, it will become an active marker: **click** in the well area to add a marker. To **delete** a marker, use CTRL + mouse click on the marker.
17. When done with the marker interpretation, **press** Ok/Save button in the markers dialog.



2.5 Seismic Predictions

This chapter deals with Quantitative Interpretation possibilities in OpendTect using commercial plug-ins developed by dGB, ARK CLS & EarthWorks. These plug-ins cover a wide range of seismic inversion and forward modeling methods.

In this chapter you will learn how to:

- Perform relative (band-limited) acoustic impedance inversion with Seismic Coloured Inversion (SCI) plug-in.
- Perform model-driven absolute acoustic impedance inversion with Deterministic Inversion (DI) plug-in.
- Perform stochastic inversion with Multi-Point Stochastic Inversion (MPSI) plug-in.
- Predict porosity from inverted acoustic impedance and porosity well logs using Neural Networks plug-in.

The inversion plug-ins (SCI, DI, MPSI) can be used to invert to (Extended) Elastic Impedance volumes using the same work flows described in this Chapter. For more extensive training in inversion, please contact dGB at info@dgbes.com.

Training of SynthRock, dGB's plug-in for simulation of pseudo-wells and HitCube inversion (matching stochastic pseudo-well synthetics against measured seismic responses) is not included in this manual. A separate training manual exists. For more information, please contact dGB at info@dgbes.com.

2.5.1 Relative Impedance Inversion (SCI)

What you should know about Seismic Coloured Inversion (SCI)

- SCI is a plug-in by ARK CLS.
- It enables rapid band-limited inversion to Acoustic or (Extended) Elastic Impedance.
- The SCI operator matches the seismic amplitude spectrum to the well log spectrum.
- Default trends can be used in the absence of well logs.
- The workflow is very similar to Seismic Spectral Blueing (see section 2.3.4).

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:

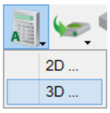
1. Seismic: Amplitude-Frequency plot
2. Smoothing of seismic mean
3. Well: Amplitude-Frequency plot
4. Global trend of well plot
5. Design operator
6. Apply Operator
7. Quality Check

2.5.1a Coloured Inversion

Required licenses: OpendTect Pro, Seismic Coloured Inversion.

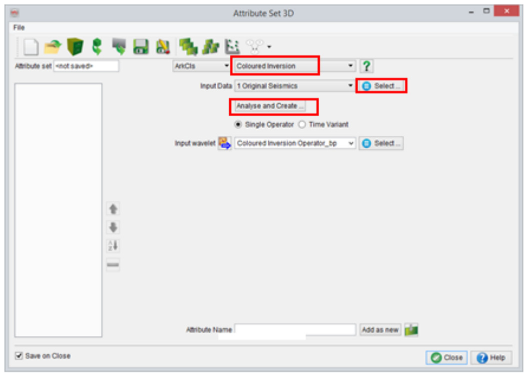
Exercise objective:

Invert the seismic data to relative acoustic impedance using SCI plugin.



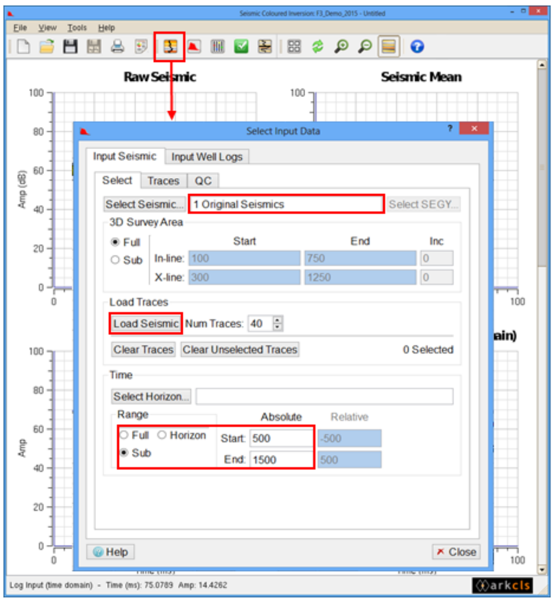
Workflow:

1. **Launch** the *Attribute Set 3D* window.
2. **Choose** *Colored Inversion* from the Attribute list.
3. For Input Data **click** Select and **choose** *1 Original Seismics.*
4. **Toggle** the *Single Operator* option to create a global SCI operator.
5. **Click** on **Analyze and Create ...** to launch the SCI main window.



Workflow cont'd:

In order to design an operator with the SCI application, it is first necessary to select and analyze the seismic and well data spectra. This is achieved by loading some seismic trace data and well log impedance data (in time).



6. **Click** on  to pop up the *Select Input Data* window.
7. **Check** if *1 Original Seismics* is selected.
8. **Click** Load Seismic to load the default *40* traces.
9. For *Time Range* **toggle** *Sub* and **enter** 500 and 1500 ms as range *Start* and *End* respectively.

Workflow cont'd:

10. Switch to *Input Well Logs* tab.

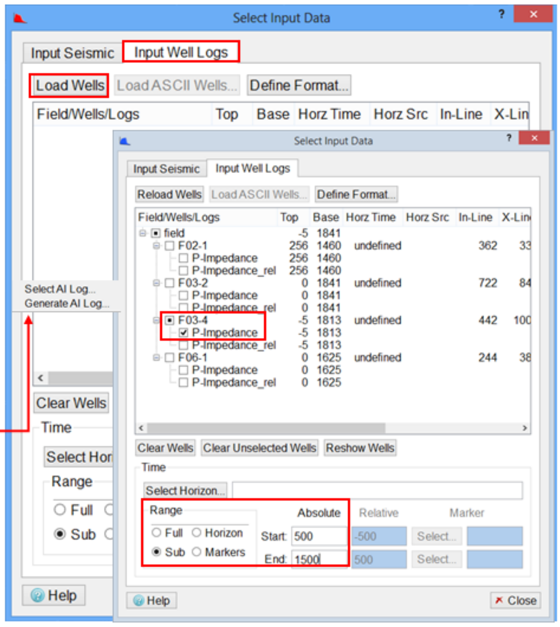
11. Click *Load wells.*

12. Select the well F3-04 and **choose** *P-Impedance* log.

13. For *Time Range* **toggle** *Sub* and **enter** 500 and 1500 ms as range *Start* and *End* respectively.

14. Close the *Select Input Data* window.

You can add, generate new log from select input data window. Right click on any of the wells, then you can chose to add or create a new AI logs.

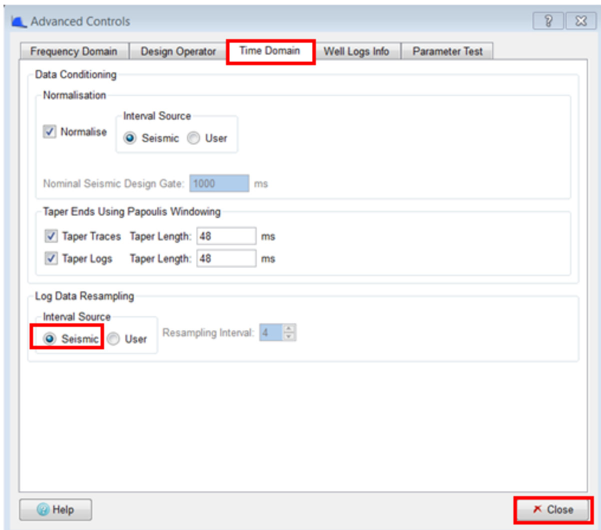


Workflow cont'd:

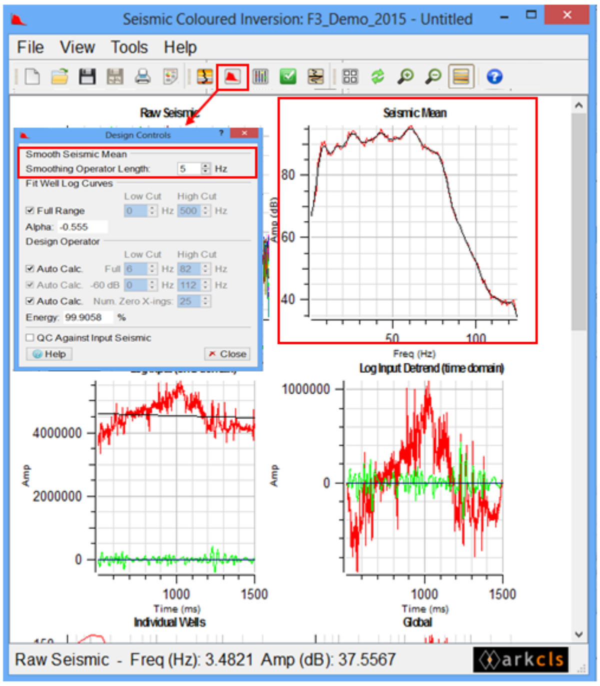
15. Click on the advanced controls icon to choose the seismic sampling rate for the well log data resampling.

16. Go to Time Domain tab.

17. Log Data Resampling should be **set** to Interval Source: Seismic. Once set, close this dialog.



Workflow cont'd:



18. **Click** on [icon] to pop up the Design Controls Dialog.

19. **Smooth** the amplitude-frequency plot of seismic data by **setting** an appropriate Smoothing Operator Length (*keep an eye on the Seismic Mean curve)*.

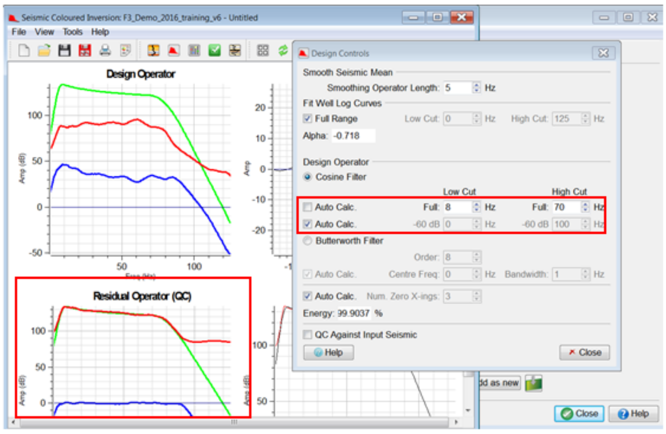
Workflow cont'd:

As a rule of thumb, any Operator (time domain) larger than 200 is too high. You can adjust the operator by changing the number of zero crossings.

20. **Tweak** other parameters (low cut, high cut) of the design operator such that it overlaps the seismic bandwidth (*check in the Seismic Mean curve*) and the residual (*Blue curve in QC*) is nearly zero.

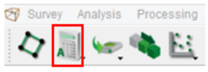
21. **Save** the Operator [icon] and optionally you can save the session [icon] .

22. **Close** the SCI main window.



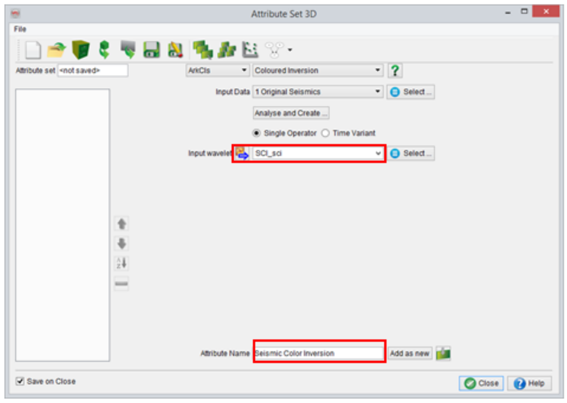
Workflow cont'd:

23. You will return to the attribute set window.



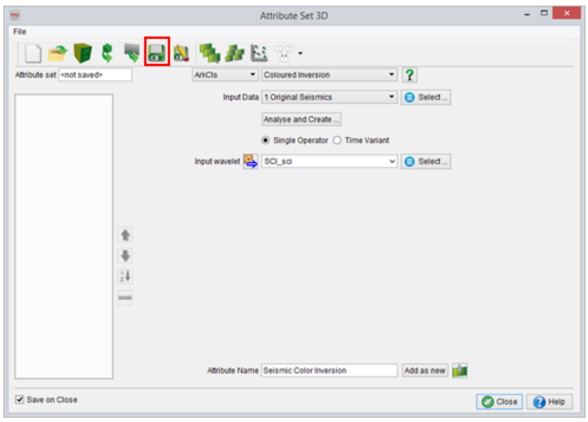
24. The input wavelet will already be selected for you.

25. **Give** a name to the new attribute and **Add as a new**.



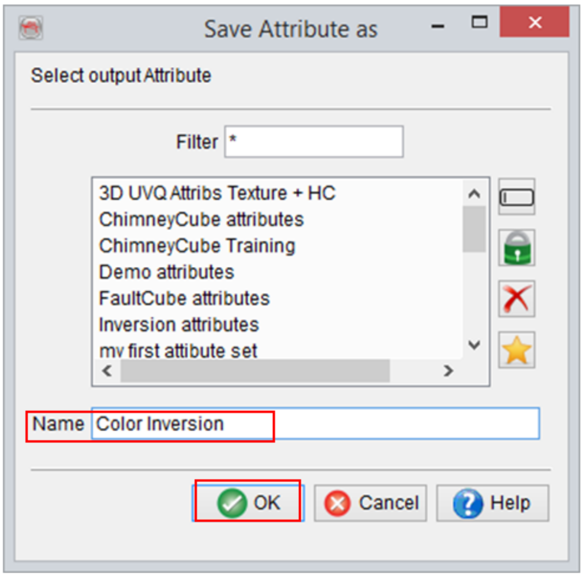
Workflow cont'd:

26. **Save** the attribute set by clicking  icon.



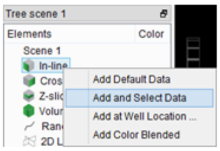
Workflow cont'd:

27. A new window will pop up, **Name** your attribute set and **press** OK.

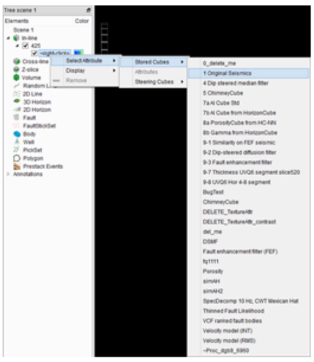


Workflow cont'd:

28. **Add** an inline in the tree (Inline > Add).



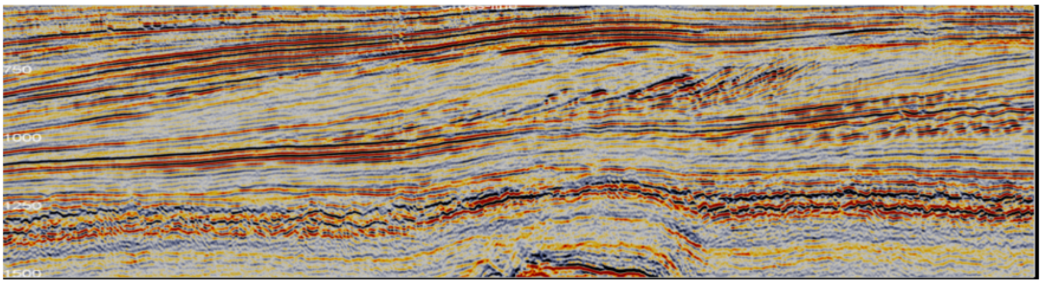
29. **Right-click** on the empty attribute for inline 425 and **follow** Select Attribute > Stored Cubes > 1 Original Seismics.



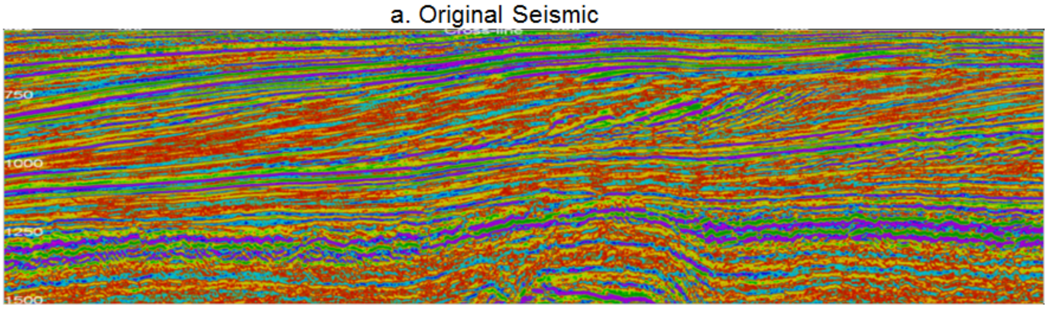
30. **Right-click** again on inline 425 and **select** the color inversion attribute that you have just created (Select Attributes > Attributes > Seismic Color Inversion).

Workflow cont'd:

31. Now you can see the results, and compare it with original data



a. Original Seismic



b. Colored Inversion of the Seismic

2.5.2 Absolute Impedance Inversion (DI & MPSI)

What you should know about DI and MPSI

The Deterministic Inversion (DI) plug-in 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 (variograms) 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 (Multi-Point Stochastic Inversion) module starts after the deterministic inversion. Many realizations of the impedance inversion are computed starting from the mean impedance volume (from DI) 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.

Variogram Analysis

What you should know about variograms

Variogram modeling is free (open source) in OpendTect. It is included in the commercial part of this training manual because variogram parameters are necessary inputs for deterministic and stochastic inversion described hereafter.

A variogram describes the spatial continuity of a variable. The inversion model in the upcoming exercises 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 semi-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.

2.5.2a Extracting Horizontal Variograms

Required licenses: OpendTect Pro, Deterministic Inversion.

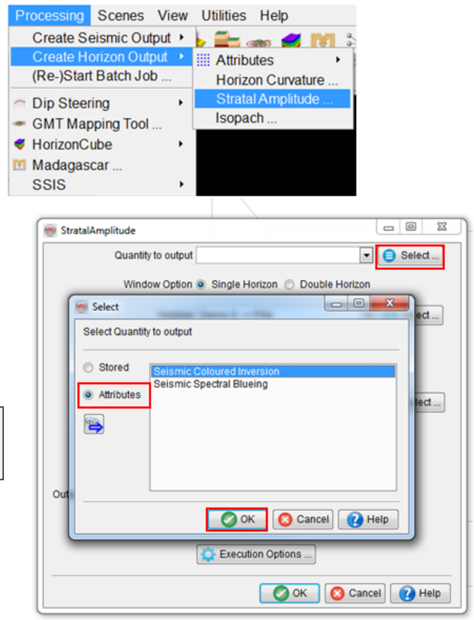
Exercise objective:

Extract horizontal variogram parameters from color inverted grids.

1. **Extract** an attribute map using Stratal Amplitude. **Go** to Processing > Create Horizon Output > Stratal Amplitude.
2. In the pop up window, **select** the quantity to output.
3. In the Attributes section, **select** *Seismic Colored Inversion*.

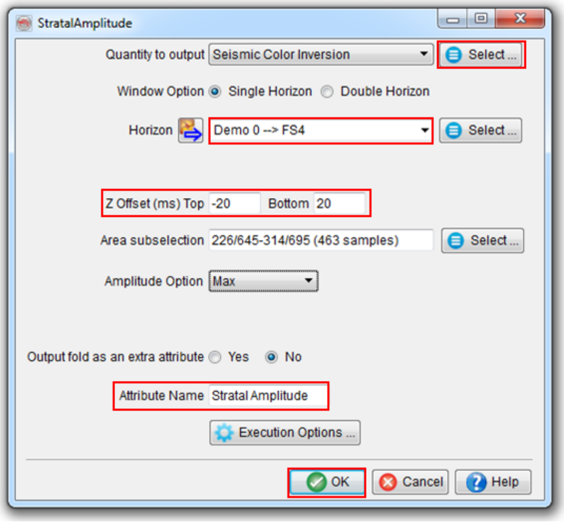
   See exercise 2.5.1 on how to define the Coloured Inversion attribute.

4. **Hit** OK.



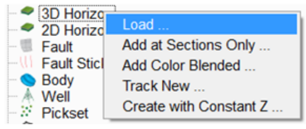
Workflow cont'd:

5. **Keep** the window option as default, i.e Single Horizon.
6. **Select** the target horizon: *Demo 0 --> FS4* Horizon.
7. **Set** offset top: -20, bottom: 20 ms.
8. **Select** the amplitude option to output: Max.
9. **Name** the attribute.
10. Start the process: **click** on OK.

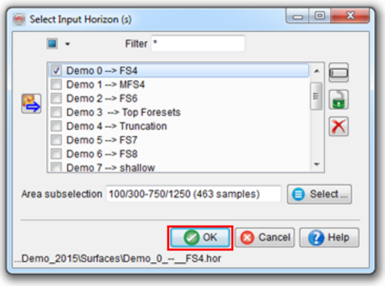


Workflow cont'd:

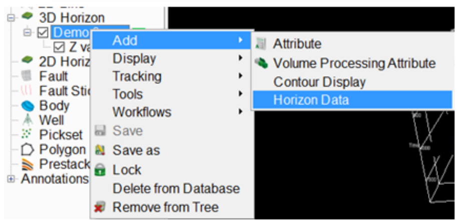
11. In the tree, **Right-click** on 3D Horizon and select **Load**.



12. Select the horizon *Demo 0 --> FS4* and **Hit** Ok.



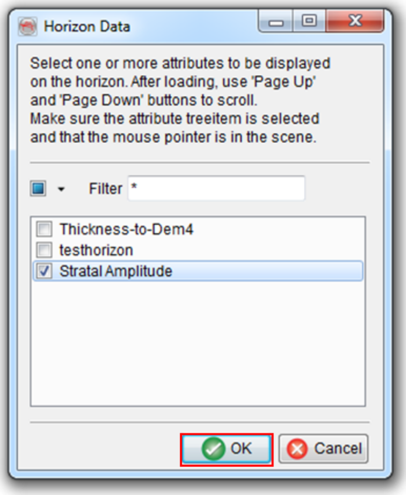
13. Add attribute at horizon location: **Right-click** on *Demo 0 --> FS4* > Add > Horizon Data.



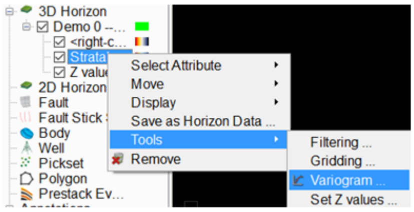
Workflow cont'd:

14. Select the *Stratal Amplitude* attribute you just created.

15. Hit OK.



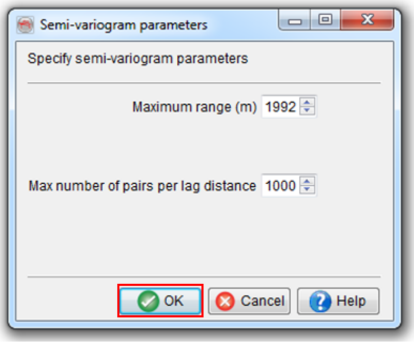
Workflow cont'd:



16. **Right-click** on *Stratal Amplitude* in the tree.

17. **Follow**: Tools > Variogram.

> With this option, you access the horizontal variogram. It allows you to analyze lateral variability of your data around the horizon. This information is in particular used when building the background model for broadband seismic inversion.



18. **Hit** OK.

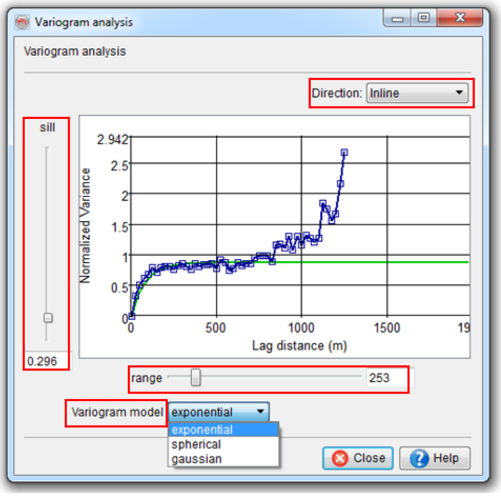
Workflow cont'd:

> In this window, the objective is to fit a variogram model (Green) by setting it's sill and range that best fit your data (Blue curve). Try to achieve a good fit at least for smaller lag distances. Mind the impact of number of pairs per lag on the smoothness of the data extracted curve.

19. The analysis can be done in different directions; Inline, Diagonal, or Crossline (i.e. the analysis is anisotropic) : **change** the direction and **observe** the impact on the variogram.

20. **Modify** sill and range, using the sliders, to fit a variogram model to the data.

21. **Choose** out of the three available variogram models; Exponential, Spherical and Gaussian.



> Variogram parameters are used for example when building the initial model for MPSI inversion.

2.5.2b Extracting Vertical Variograms

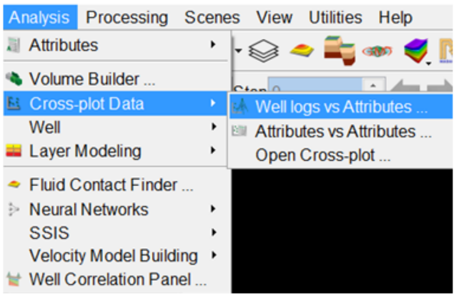
Required licenses: OpendTect.

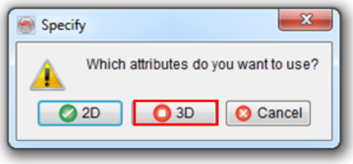
Exercise objective:

Extract vertical variogram parameters from impedance well logs.

Workflow:

1. To extract P-Impedance logs from various wells: **Go to** Analysis > Cross plot Data > Well logs vs. Attributes.





Workflow cont'd:

2. **Select** all wells that will be used for data extraction.

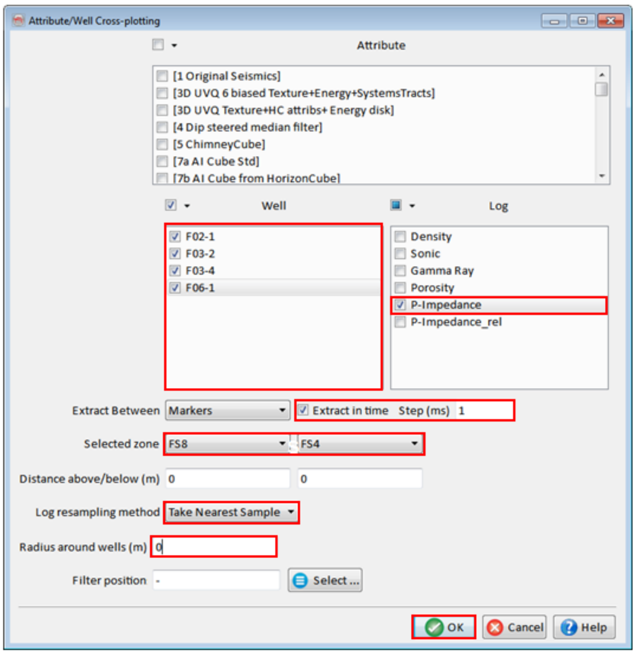
3. **Select** Impedance logs associated with the wells.

4. **Toggle** Extract in time and **set** step: 1 ms.

5. **Extract** between Markers: *FS8* and *FS4*.

6. **Select** log resampling method as Take Nearest Sample.

7. **Set** the radius around wells to 0 and **press** OK.



Workflow cont'd:

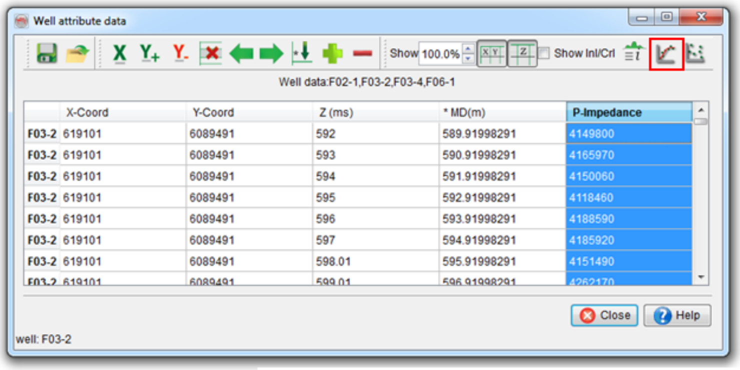
8. Cross plot table window pops up.

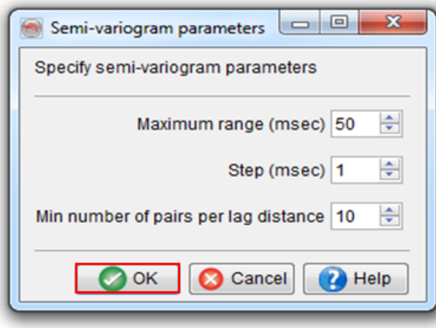
9. Select P-Impedance Column.

10. Click on this icon to start the variogram analysis.

11. Variogram parameters window pops up.

12. Click OK.





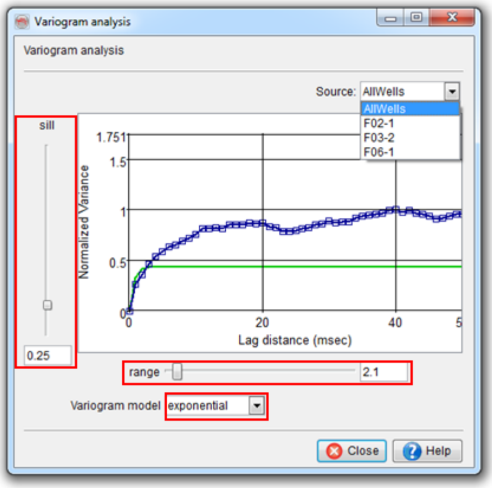
The vertical variogram parameters used here are comparable to the horizontal variogram analysis of Exercise 2.5.2a. The main difference is in the number of available data points. Variogram analysis requires a minimum number of pairs per lag distance and therefore sufficient data must be input in order to obtain a representative variogram.

Workflow cont'd:

13. The variogram analysis can be done for either all the wells (recommended) or for one particular well.

14. Modify sill and range, using the sliders, to fit a variogram model (Green) to the data (Blue).

15. Choose out of the three available variogram models; Exponential, Spherical and Gaussian.



It's recommended to use the same model for this vertical variogram analysis, as used previously for horizontal variogram analysis (Exercise 2.5.2a).

2.5.3 Porosity Prediction using Neural Networks

What you should know about Neural Networks for Rock Property Prediction

- This is a supervised approach using a Multi-Layer-Perceptron neural network.
- The network will find the optimal (non-linear) mapping between seismic attributes (usually impedance logs) and target well log attributes (porosity, gamma-ray, Vshale, Sw …).
- The network is trained on data points extracted along the well tracks.
- Part of the extracted points are used as test set to determine the optimal point to stop training and avoid over fitting.
- The trained network is applied to (inverted) seismic data.
- The input data (inverted seismic) needs to be scaled to match the scaling of the input data set that was used in training (logs).

Details

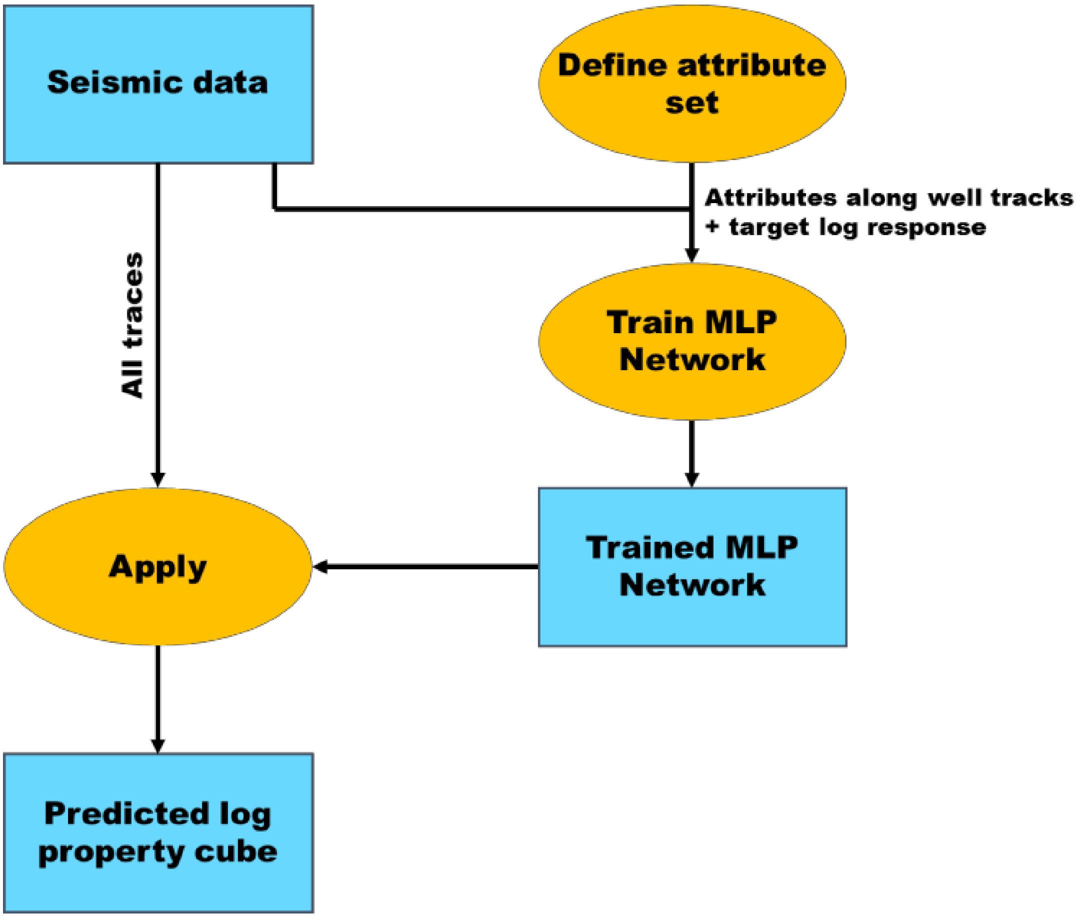
In the exercise that follows, we will convert seismic information to porosity using a neural network inversion workflow.

As in the chimney cube exercise (see Chapter Seismic Object Detection using Neural Networks), 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.

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.

2.5.3a Neural Network Prediction

Required licenses: OpendTect Pro, Neural Networks.

Exercise objective:

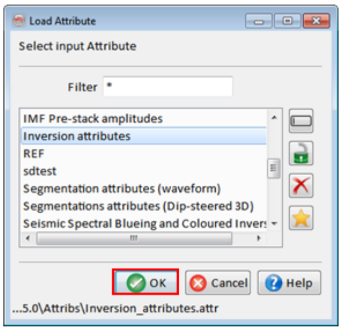
To convert seismic information to porosity using a neural network inversion workflow.

Well data Preparation

1. **Well**(s) need to be available in the survey. If they are not available: **import** wells (track, logs, markers, optionally time-depth curve or checkshot).
2. **Tie** well to the seismic (see exercise 1.5.1).

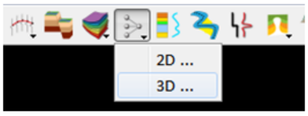
Workflow:

1. **Open** attribute set window.
2. **Click** on file> *Open set* , or click on .
3. **Select** the saved set '*Inversion attributes*' and **Hit** Ok.

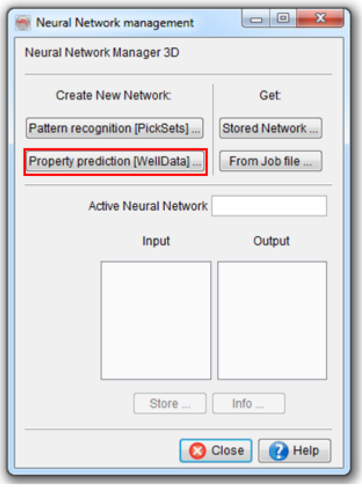


Workflow cont'd:

4. **Open** the neural network plugin with the icon > 3D or **go to** Analysis > Neural Networks > 3D.



5. **Select** Property prediction [*Well Data*] from the Neural Network manager.



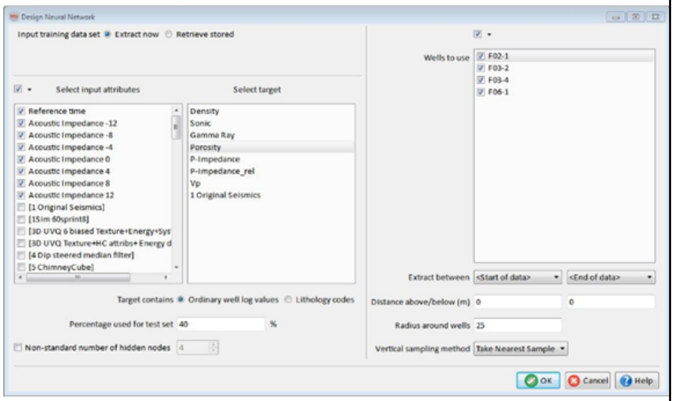
Workflow cont'd:

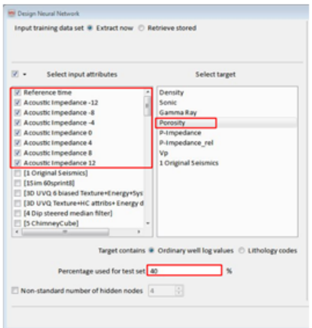
6. Data selection window pops up.

7. **Select** the input attributes as on the picture.

8. **Select** the target quantity among the available well logs: Porosity.

9. **Set** the percentage of data to be used as test set: 40%



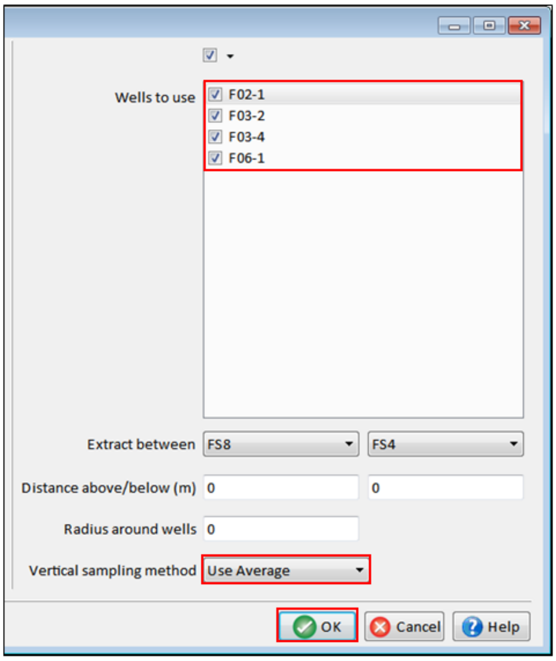


Workflow cont'd:

10. **Select** all the wells.

11. **Limit** the extraction window as shown on the picture.

12. **Select** Average Vertical sampling method and **Press** OK.



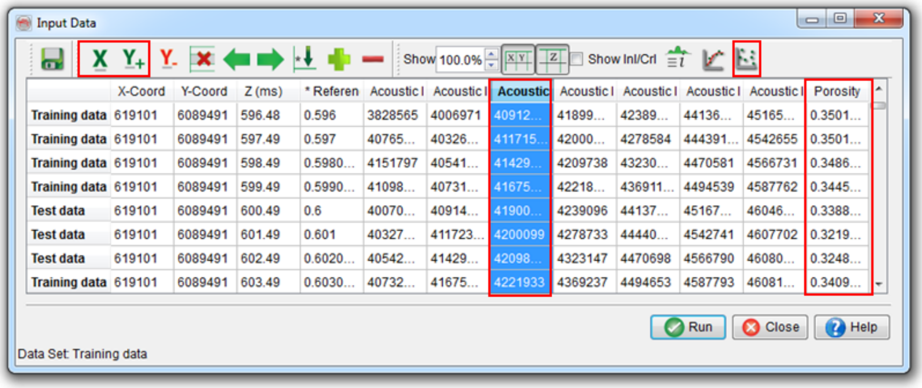
Workflow cont'd:

An optional step is to QC the extracted data set (tested and training) by plotting Acoustic Impedance (Y) versus Porosity (X)

13. **Highlight** Porosity column and press **X** .

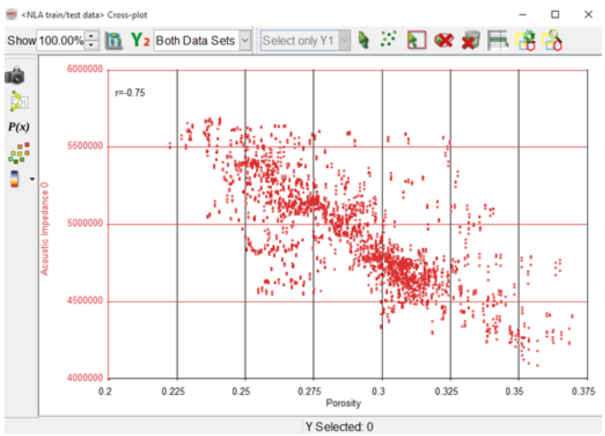
14. **Highlight** AI 0 column, and press **Y+**.

15. **Click** on .



Workflow cont'd:

16. Cross plot window pops up.



17. **Click on** ➡ in previous window to move Y column and see how other attribute plot against Porosity.

18. **Close** cross Plot window.

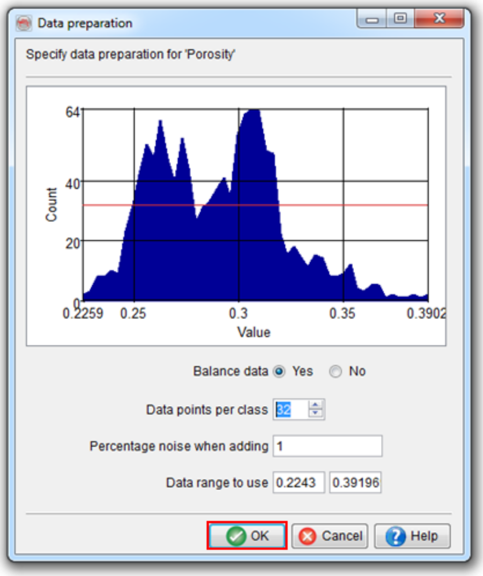
19. **Press** Run in Previous Window.

Workflow cont'd:

20. The balancing data window pops up.

In this step, you have the option to balance your data. If the data is not properly sampled, balancing is a recommended pre-processing step.

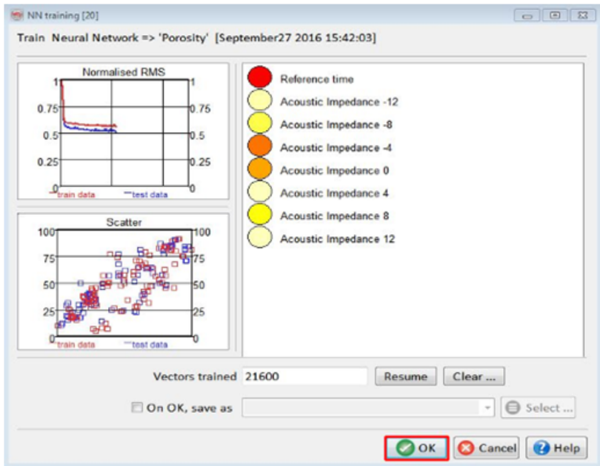
21. To continue, **Press** OK.



Workflow cont'd:

22. The Training data window pops up.

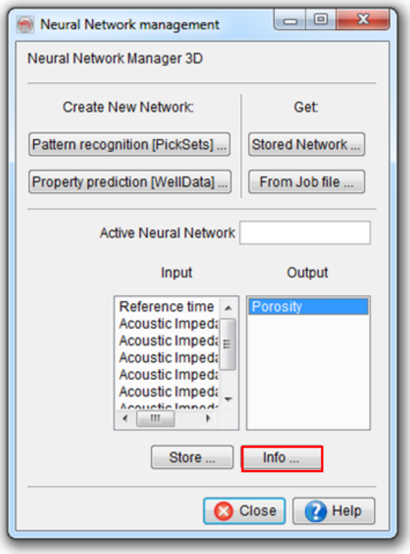
23. To continue, **Press** OK.



Workflow cont'd:

24. Back in the Neural Network, Output property is highlighted.

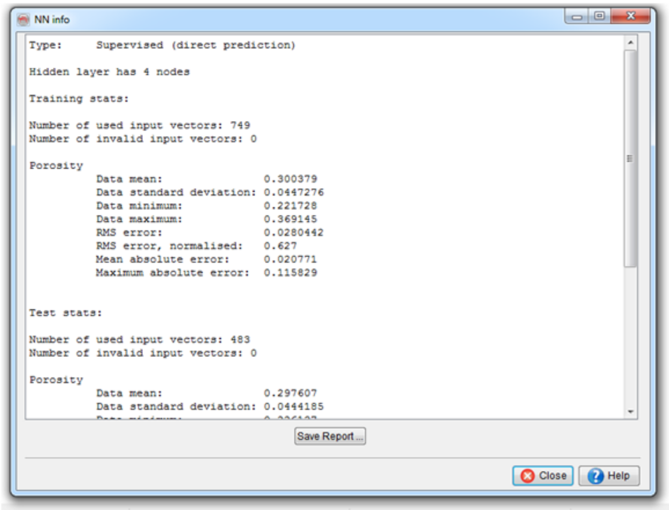
25. Click on *Info* to see summary Of Neural Network characterisation.



Workflow cont'd:

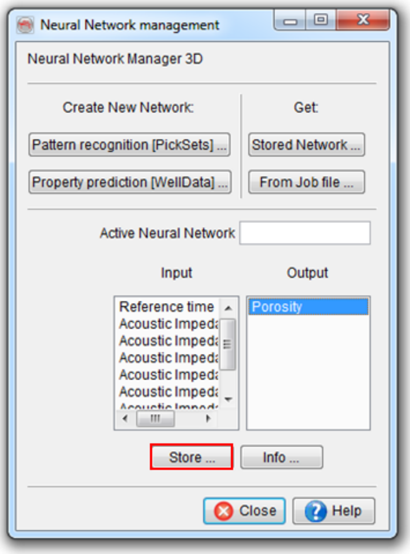
26. Neural Network info (report) pops up.

27. Click on Save Report (optional).



Workflow cont'd:

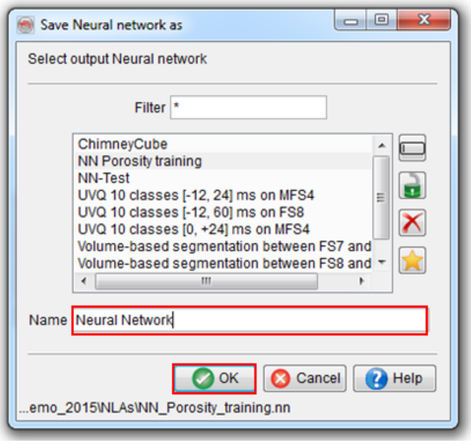
28. Store the Neural Network.



Workflow cont'd:

29. Give a name to the Neural Network output.

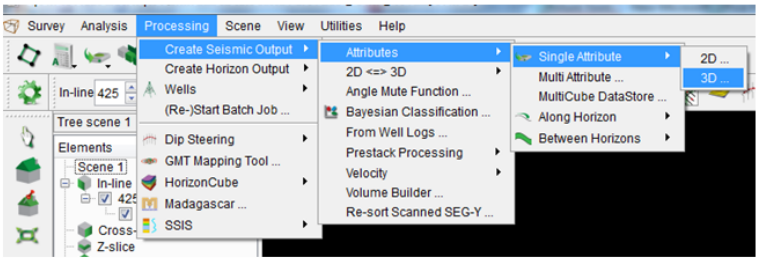
30. Press OK.



Workflow cont'd:

31. Create Porosity Cube.

32. Create seismic output using:



Workflow cont'd:

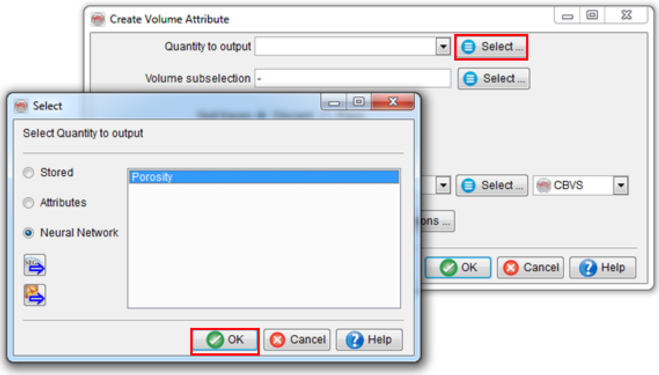
33. Select quantity to output

34. New window pops up.

35. Toggle Neural Network.

36. Select Porosity.

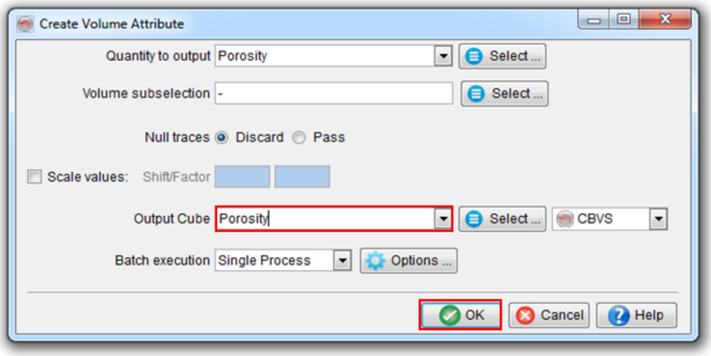
37. Press OK.



Workflow cont'd:

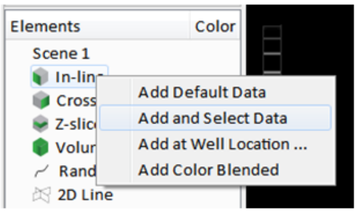
38. **Give** a name to the output Cube.

39. **Press** Ok.

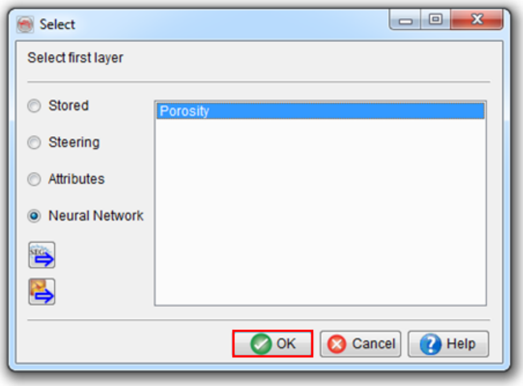


Workflow cont'd:

40. To apply the output on an inline to perform QC by giving **Right click** on Inline > Add and Select data.

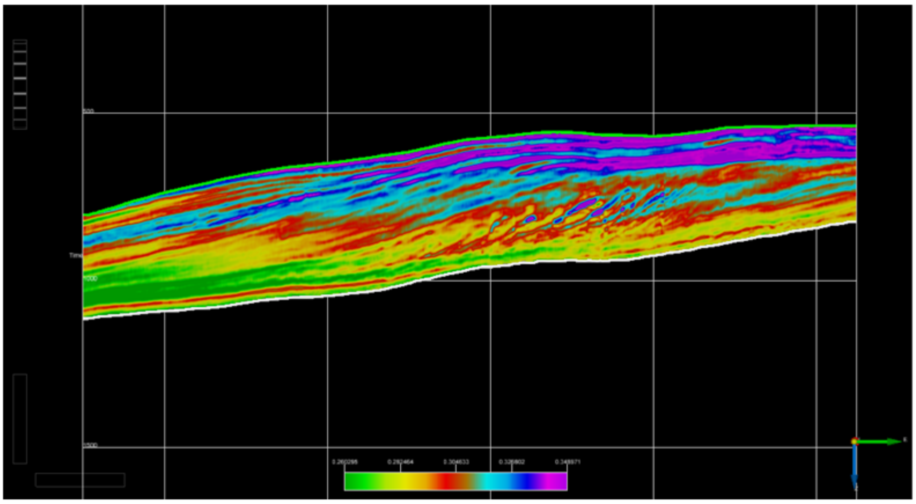


41. In the selection window, under the Neural network category, **select** Porosity and **Press** Ok.



Workflow cont'd:

42. The Porosity prediction result display on *Inline 425* should look like the image below.



2.6 Machine Learning

This chapter deals with the Machine Learning (ML) capabilities within OpendTect Pro using the commercial ML plug-in developed by dGB.

In this chapter you will learn how to use the ML plugin to:

- Perform Log-to-Log Prediction for Density.
- Perform Log-to-Log Prediction for Porosity.
- Perform Lithology Classification using Well Log data.
- Predict Seismic Bodies using Supervised 3D Models.
- Predict Fault Locations using the Unet 3D Fault Predictor.
- Predict Rock Properties using a combination of Seismic Data & Well Logs.
- Predict Seismic Features using a Seismic Image-to-Image Workflow.
- Fill blank traces in Seismic Data using a Seismic Image Regression Workflow.

More information on these topics an be found online in the Machine Learning Chapter of OpendTect Pro & dGB Plugins Documentation - 6.6.

We also have an extensive playlist of Machine Learning videos on our YouTube Channel.

For more information, please contact dGB at info@dgbes.com.

2.6.1 Well workflows

TheWell Log Prediction workflows in this section are Supervised Machine Learning workflows and require only well logs as inputs.

The target logs are used for generating/predicting missing logs.

Log Prediction produces continuous logs.

2.6.1a Log-Log Density

Required licenses: OpendTect Pro & Machine Learning

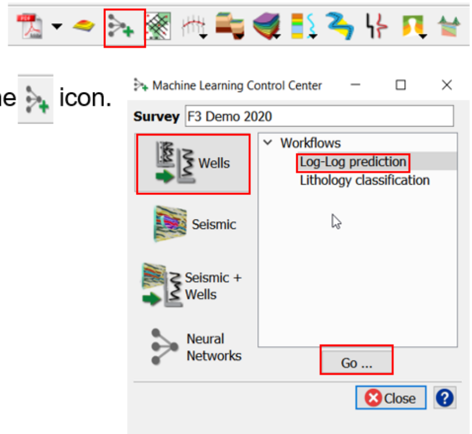
Exercise objective:

To predict missing logs using the log-log prediction tool, which is part of the machine learning plugin. In this case, we want to predict the Density log.

Well data Preparation

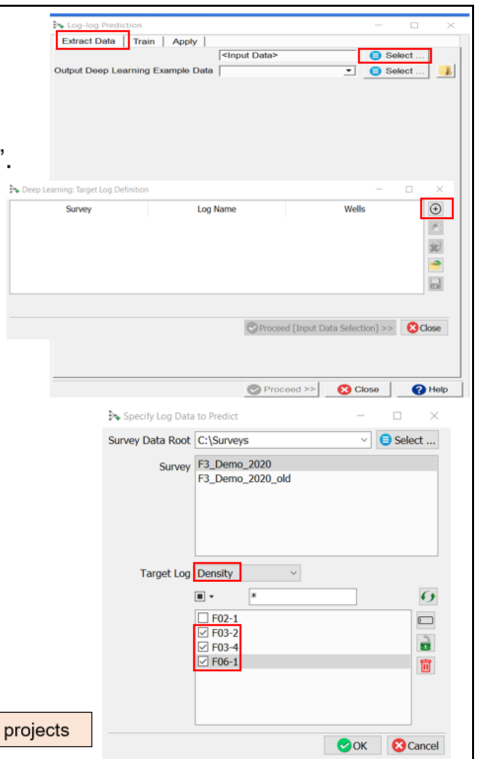
Well(s) need to be available in the survey. If they are not: **import** wells (track, logs, markers, optionally time-depth curve or checkshot).

Workflow:



1. **Open** the Machine Learning Control Center with the icon.
2. **Click** on Wells.
3. **Select** Log-Log prediction, and **Hit** Go.

Workflow cont'd:



4. **Press** Select - Input Data in the "Log-log prediction" window. **Select** icon in the "Target Log Definition".
5. In the *"Specify Log Data to predict" window,* **Select** *Survey*, Target Log (e.g. Density), and the Wells that will be used for the data extraction.*

The well F02-1 is not selected, and will be used as a blind well.

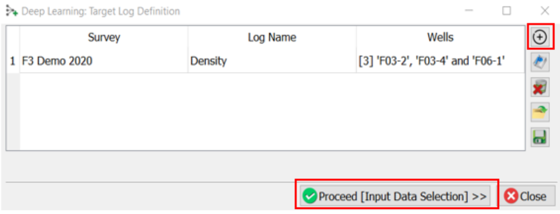
6. **Press** OK.

* The option to select data from other surveys is available only in commercial projects

Workflow cont'd:

7. "Deep Learning: Target Log definition" window pops up.

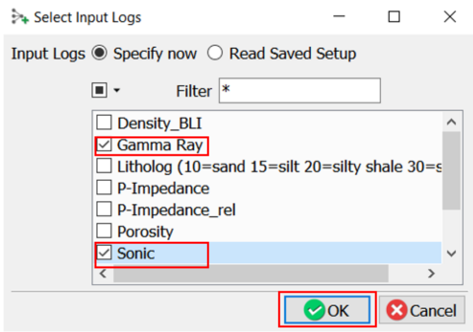
A new data from different survey* can be added by clicking on (+) icon.



8. Press Proceed [Input Data Selection].

9. In the ''Select Input Logs" window, **Select** logs that will be used to predict 'Density' log (e.g. *Sonic, Gamma Ray).*

10. Press OK.



* The option to select data from other surveys is available only in commercial projects

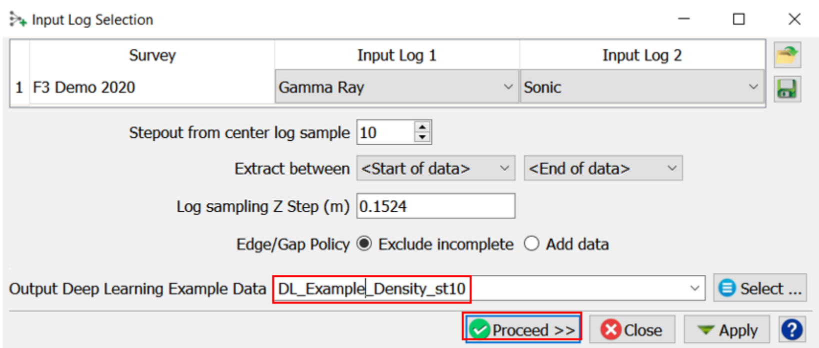
Workflow cont'd:

11. *''Input Log Selection"* window pops up.

Input Logs can be modified in here. Keep the default parameters as indicated in this window.

12. Type a new name for the *Output Deep Learning Example Data (e.g. DL_Example_Density_st10).*

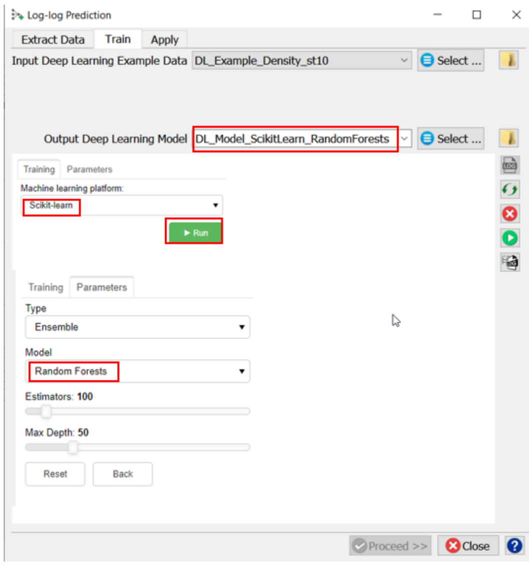
13. Press Proceed.



Workflow cont'd:

14. The *Train* tab get activated. Train the extracted examples data using suitable learning algorithm. Keep the defaults parameters, "Scikit-learn" platform and "Random Forest" Model.

Different machine learning platforms and parameters can be tested.



15. **Specify** a new *Output model* name (e.g. DL_Model_ScikitLearn_RandomForests).

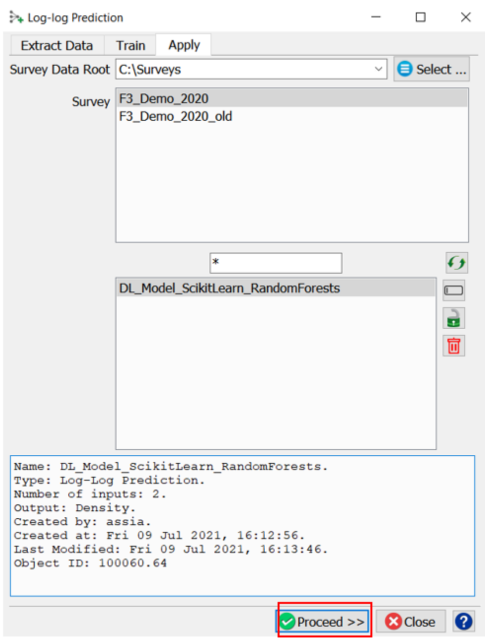
16. **Press** Run.

Workflow cont'd:

17. **Press** "Apply" tab
Check all the selected default parameters are Ok.

*The Survey and Training model can be modified in here.

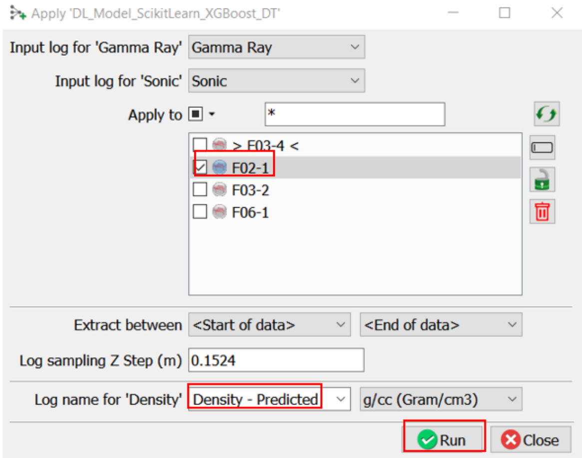
18. **Press** Proceed.



* The option to select data from other surveys and training model is available only in commercial projects

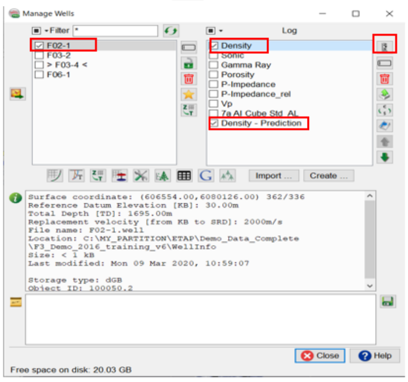
Workflow cont'd:

19. "Apply training model" window pops up.
20. Apply the trained model to a blind well. **Select** F02-1.
21. **Type** a new name for the predicted log (e.g. Density_Predicted).
22. Keep default parameters and **Press** Run to continue.

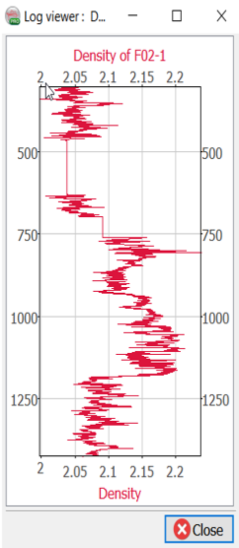


Workflow cont'd:

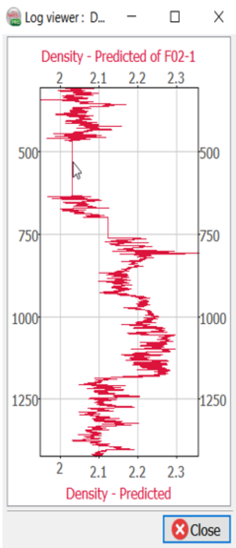
23. QC results by displaying the predicted log adjacent to the recorded log
24. **Click** on the Well Manager icon .
25. **Select** the well "F02-1" and the logs "Density" and "Density-Predicted".
26. **Click** on view logs icon .



Density

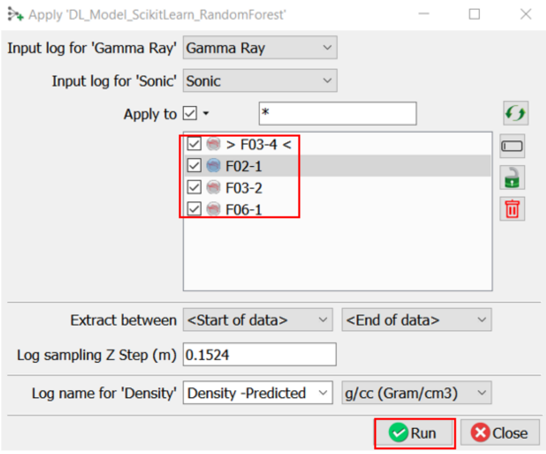


Density-Predicted



Workflow cont'd:

If result is satisfactory, go back to the ''Apply training'' window, and apply the trained model to all the wells where you want to predict density log.



27. **Select** all wells.

28. **Type** a new name (e.g. Density_ Predicted). Keep default parameters and **Press** Run to continue.

2.6.1b Log-Log Porosity

Required licenses: OpendTect Pro & Machine Learning

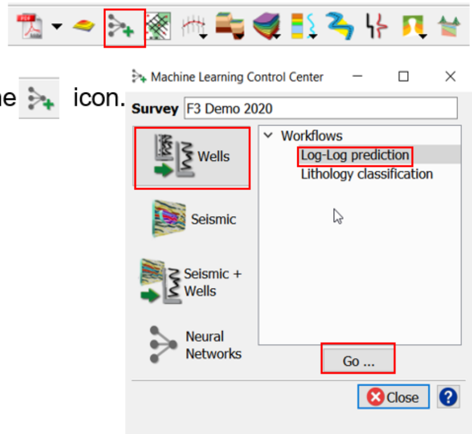
Exercise objective:

To predict missing logs using the log-log prediction tool, which is part of the machine learning plugin. In this case we want to predict the Porosity log.

Well data Preparation
Well(s) need to be available in the survey. If they are not available: **import** wells (track, logs, markers, optionally time-depth curve or checkshot).

Workflow:

1. **Open** the Machine Learning Control Center with the icon.
2. **Click** on Wells.
3. **Select** Log-Log prediction and **Hit** Go.

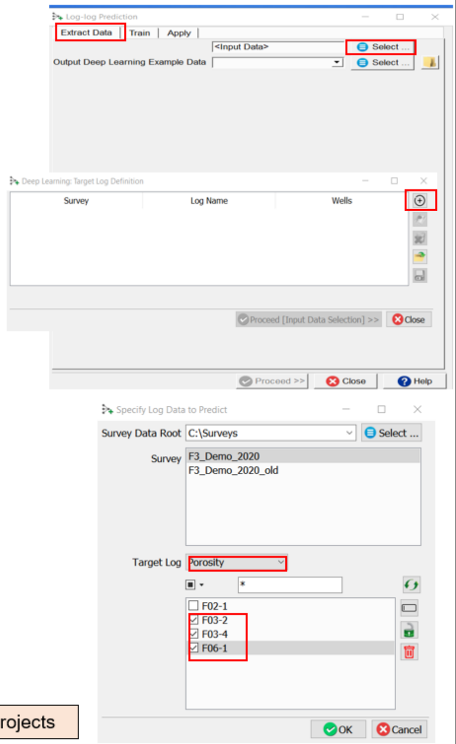


Workflow cont'd:

4. "Log-log prediction" window pops up.
5. Press **Select** - Input Data in the "Log-log prediction" window. **Select** icon in the "Target Log Definition".
6. *"Log Data to predict" window pops up.*
7. In the *"Specify Log Data to predict" window*, **Select** *Survey**, *Target Log (e.g. Porosity)*, and the *Wells that will be used for the data extraction.*

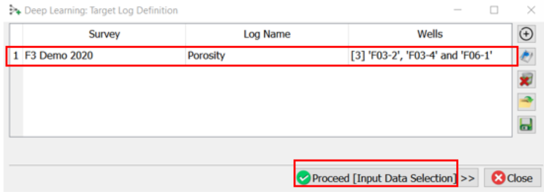
Well F02-1 is not selected, and will be used as a blind well.

8. **Press** OK.



* The option to select data from other surveys is available only in commercial projects

Workflow cont'd:



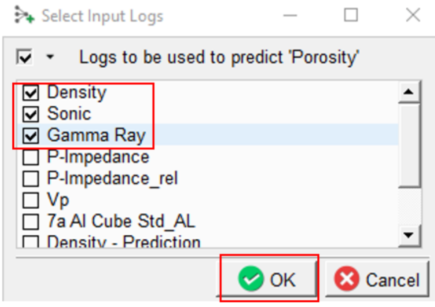
9. "*Deep Learning Target Log definition*" window pops up.

10. **Keep** the default parameters and **Press** Proceed [Input Data Selection].

11. *Select Input Logs* window pops up.

12. **Select** the Density, *Sonic* and *Gamma Ray* logs that will be used to predict the 'Porosity' log.

13. **Press** OK.



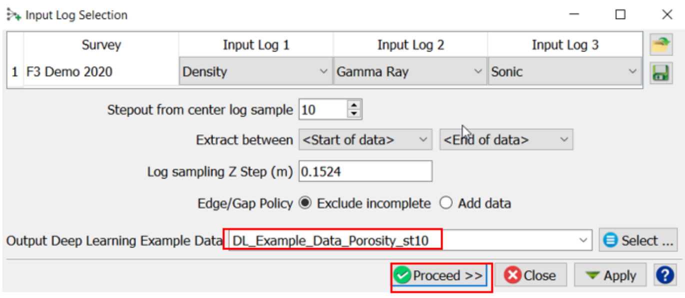
Workflow cont'd:

14. *Input Log Selection* window pops up.

Input Logs can be modified. Keep the default parameters as indicated in this window.

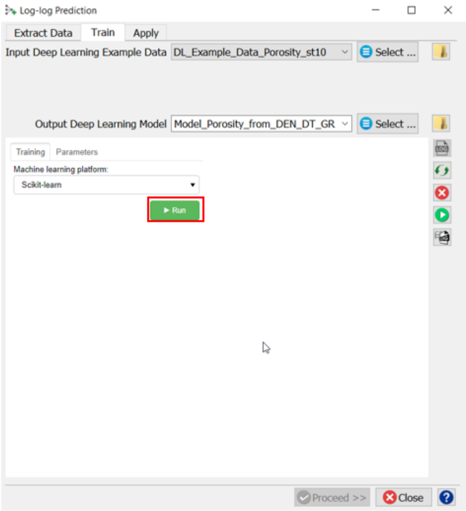
15. **Type** a new name for the *Output Deep Learning Example Data (e.g. DL_Example_Data_Porosity_st10).*

16. **Press** Proceed.



Workflow cont'd:

17. The *Train* tab opens. Select the Machine learning platform: Scikit-learn (Random Forests).

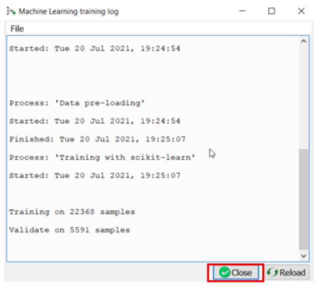


Different machine learning platforms and parameters can be tested.

18. **Keep** the defaults parameters. **Enter** new *Output model* name (e.g. Model_Porosity_from_DEN_DT_GR).

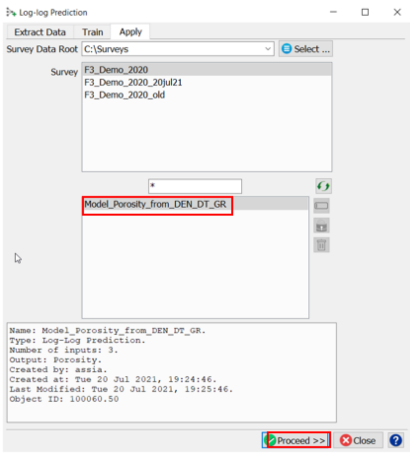
19. **Press** Run.

Workflow cont'd:



20. The 'ML training log' window pops up. When the process finish, **Click** Close.

21. In the 'Apply tab' of the Log-log Prediction window, verify all defaults selected data are correct.



The Survey and the Training Model can be modified in this window.

22. **Press** Proceed.

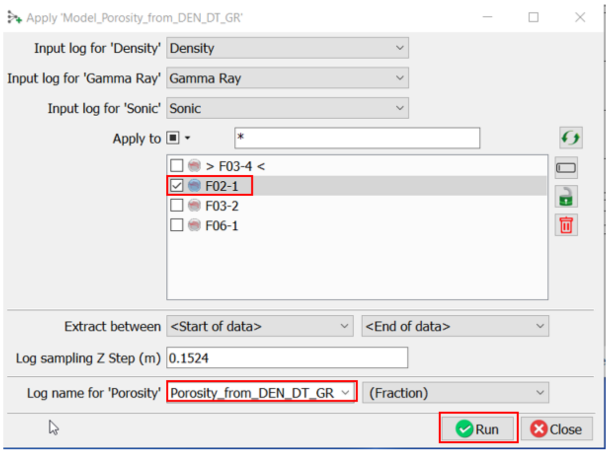
Workflow cont'd:

23. The 'Apply' created training model window pops up.

24. **Apply** the trained model to a blind well (not used in the training process). **Select** F02-1.

25. **Keep** default parameters and **Press** Run to continue.

26. When the computation finishes, **Press** Close.



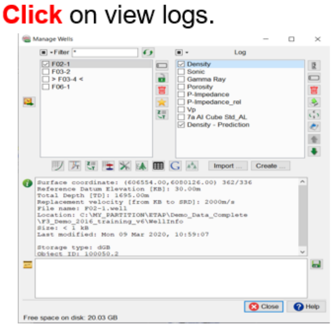
Workflow cont'd:

QC results by displaying the predicted log adjacent to the recorded log.

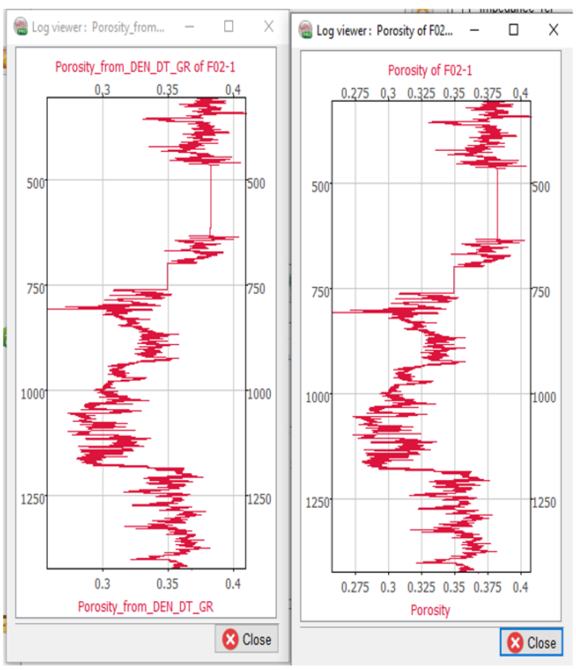
27. **Click** on the Well Manager icon.

28. **Select** the well F02-1, and the logs Porosity and predicted porosity: Porosity-from_DEN_DT_GR.

29. **Click** on view logs.



Porosity Predicted-Porosity



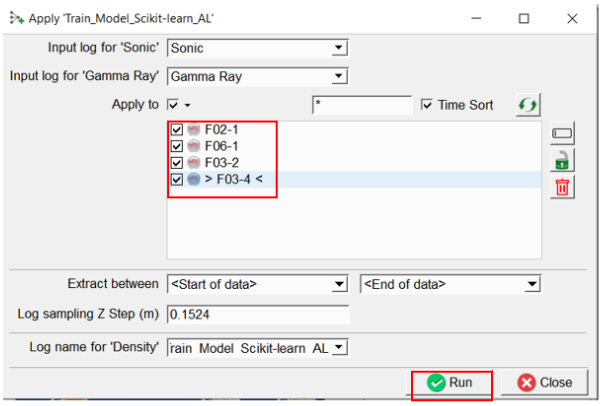
Workflow cont'd:

If result is satisfactory, go back to the previous Step "Apply Training Model".

30. **Select** all wells where you want to predict porosity.

31. **Keep** default parameters and **Press** Run to continue.

32. **QC** the predicted well porosity logs as in the previous step.



2.6.2 Lithology Classification

Required licenses: OpendTect Pro & Machine Learning

Exercise objective:

To predict lithology logs using the ''*Lithology classification* tool'', which is part of the machine learning plugin.

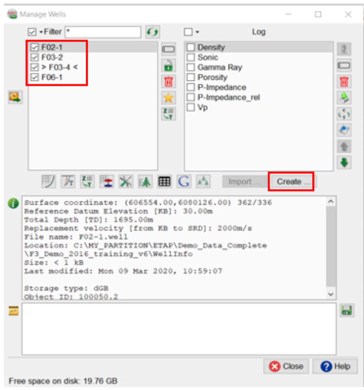
Well data Preparation
Well(s) need to be available in the survey. If not, **import** wells (track, logs, markers, optionally time-depth curve or checkshot).

Workflow:

For the purpose of this exercise, we will create a fake lithology log using Mathematics (as no lithology log exists in the survey)

1. **Open** the Well Manager .

2. ***Select** All Wells in the* 'Well Manager'', *and* **Hit** *Create.*



Workflow cont'd:

3. *In the "Calculate a New Well Log" window,* **Specify** the parameters as indicated *below to create a fake litho-log:*

   a. **Select**: MathFunctions.

   b. **Type** the Formula: *GR < 40 ? 1 : 2*

   c. **Hit** Set.

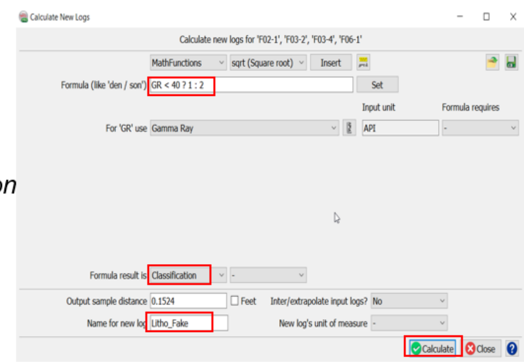
   d. **Select** Gamma Ray log.

   e. **Select** for the *Formula Results, Classification*

   f. **Type** Name for new log: Litho_Fake.

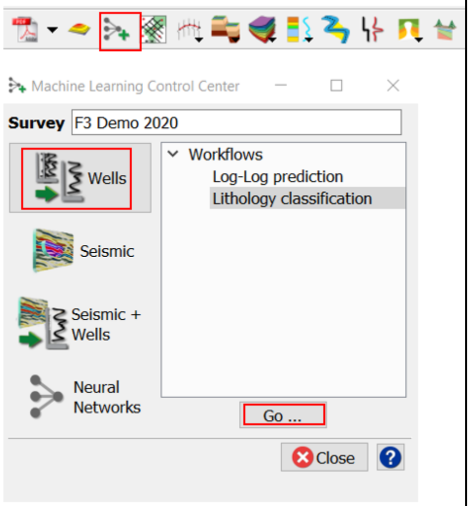
   g. **Select** Output Unit of Measures: None.

4. **Press** Calculate.



Workflow cont'd:

5. **Open** the Machine Learning Control Center with the icon.
6. **Click** on Wells.
7. **Select** *Lithology classification.*
8. **Hit** Go.



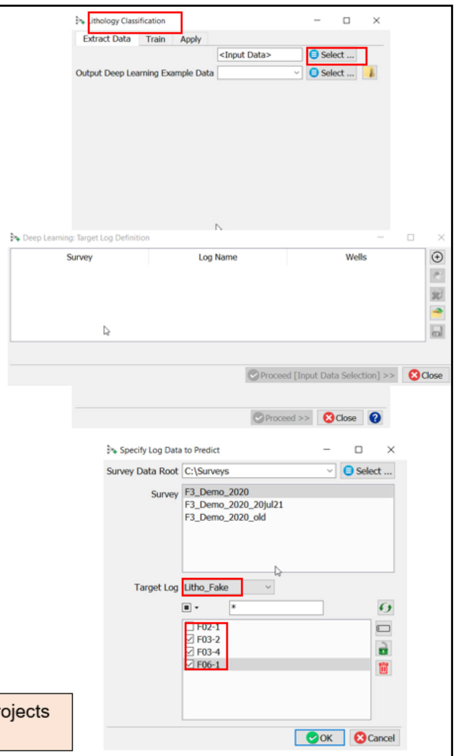
Workflow cont'd:

9. "Lithology Classification" window pops up. **Press** Select - Input Data. **Select** icon in the "Target Log Definition".

10. *"Log Data to predict" window pops up.* **Select**: *Survey*, Target Log,* and *Wells* as indicated in the window.
In this case the "Litho_Fake" log will be predicted.

> The well F02-1 is not selected, and will be used as a blind well.

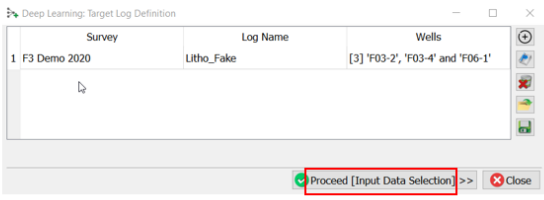
11. **Press** OK.



* The option to select data from other surveys is available only in commercial projects (not in the free demo project)

Workflow cont'd:

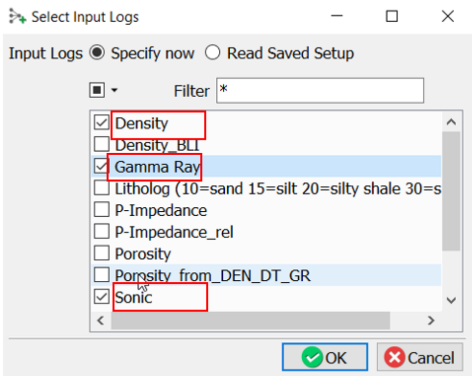
11. **"***Deep Learning: Target Log definition"* window pops up.



12. **Press** Proceed [Input Data Selection].

13. In the *"Select Input Logs"* window, **Select** the Density, *Sonic* and *Gamma Ray* logs.

14. **Press** OK.



Workflow cont'd:

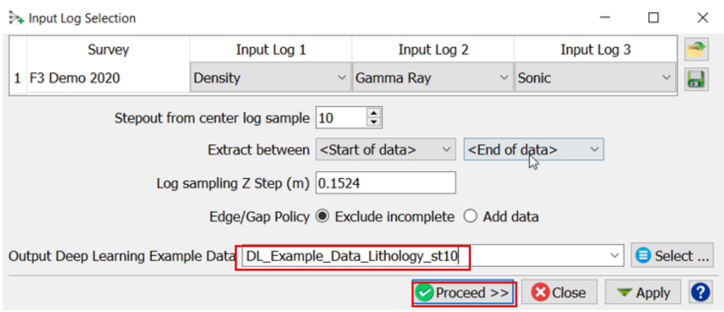
15. *"Input Log Selection"* window pops up.

Input Logs can be modified here. Keep the default parameters as indicated in the window.

16. **Specify** a new name for the *"Output Deep Learning Example Data" (e.g. DL_Example_Data_Lithology_st10).*

17. **Press** Proceed.

.



Workflow cont'd:

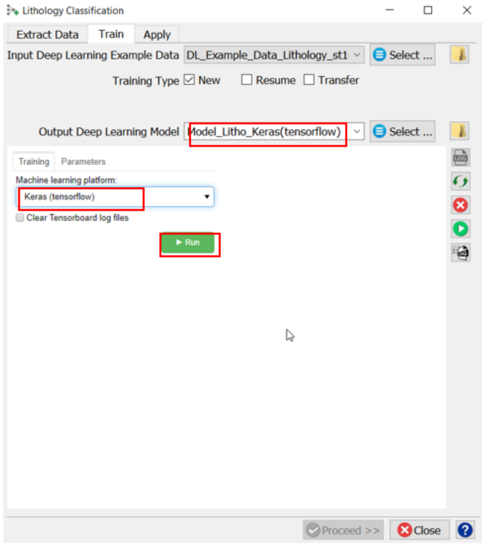
18. **Select** Training Type New.

19. *"Train" tab* becomes active. Train the extracted examples using the default learning algorithm (e.g. Keras (tensorflow).

Different machine learning platforms and parameters can be tested.

20. **Keep** the defaults parameters. **Specify** a new *Output mode*l name (Model_Litho_Keras(tensorflow).

21. **Press** Run.

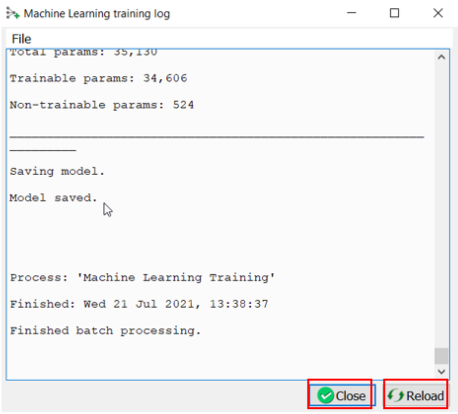


Workflow cont'd:

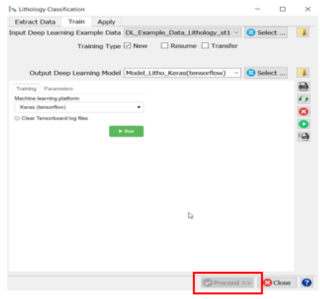
22. The Machine Learning training log file pops up. Otherwise **Click** on  icon.

23. **Hit** Reload to refresh the window.

24. When the processing is done, **Close** the training log file.



Workflow cont'd:

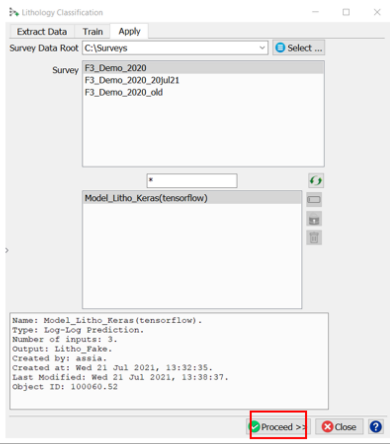


25. **Hit** Proceed in the 'Lithology Classification-Train' Window.

26. "Apply" tab get activated, **Verify** the Survey and Model are correct. Otherwise, modify accordingly.

> *The Survey, Training model can be modified here.

27. **Press** Proceed.



> * The option to select data from other surveys is available only in commercial projects (not in the free demo projects)

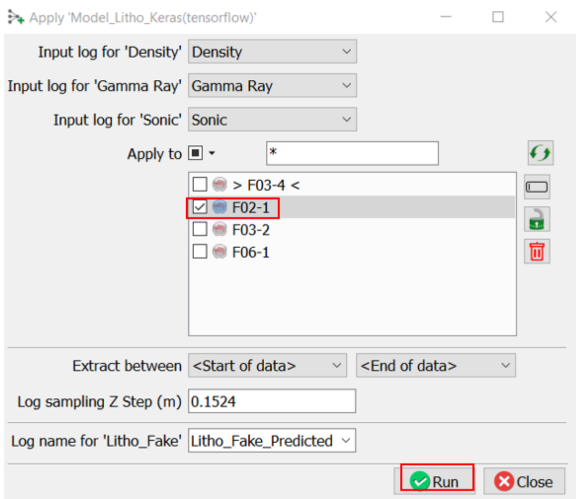
Workflow cont'd:

28. "*Apply* created training model" window pops up.

29. **Apply** the trained model to a blind well (not used in the training process). **Select** F02-1.

30. **Keep** default parameters. **Type** a new Log name for the predicted lithology log "Litho_Fake_Predicted".

31. **Press** Run to continue.



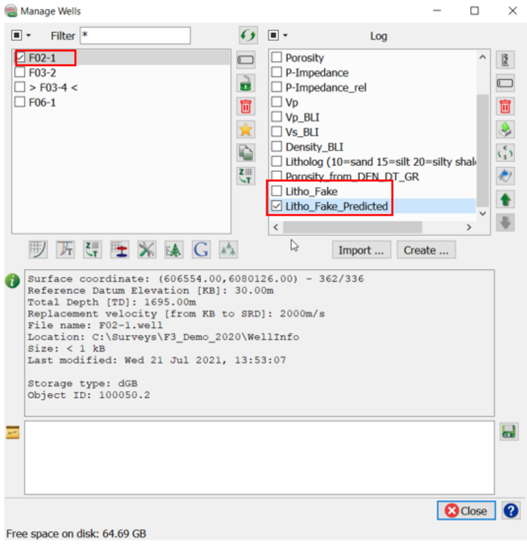
Workflow cont'd:

QC results by displaying the predicted log adjacent to the recorded log

32. **Click** on the Well Manager icon.

33. **Select** the blind well F02-1, Litho_Fake and Litho_Fake_Predicted logs.

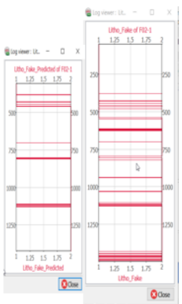
34. **Click** on view logs.

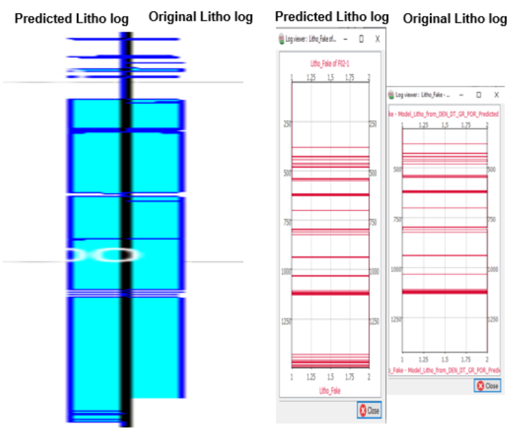


Workflow cont'd:

35. **Compare** the original vs predicted litho-log.

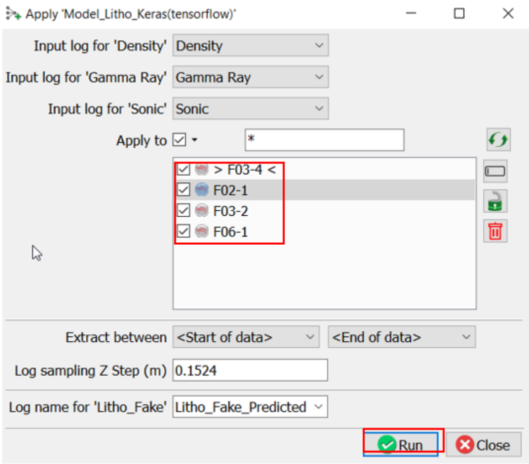
Note: The missing parts at the top and base of the predicted log are due to missing values in the input logs.





Workflow cont'd:

If result is satisfactory, go back to the previous step and Apply the trained model to all Wells



36. **Select** All Wells. Keep default parameters as indicated in the window.

37. **Press** Run to continue.

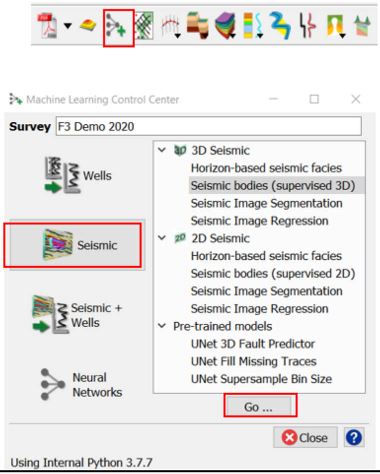
2.6.3 Seismic Bodies - Supervised 3D

Required licenses: OpendTect Pro & Machine Learning

Exercise objective:

To predict seismic geo-bodies using the "*Seismic bodies (supervised 3D)"* tool which is part of the machine learning plugin. In this exercise, we want to predict Chimney location.

Seismic data Preparation
Seismic need to be available in the survey. If not, **import** seismic, and interpret key seismic bodies locations (e.g. Chimney yes, Chimney no), or use existing trained model.

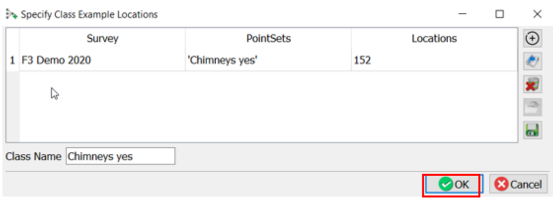


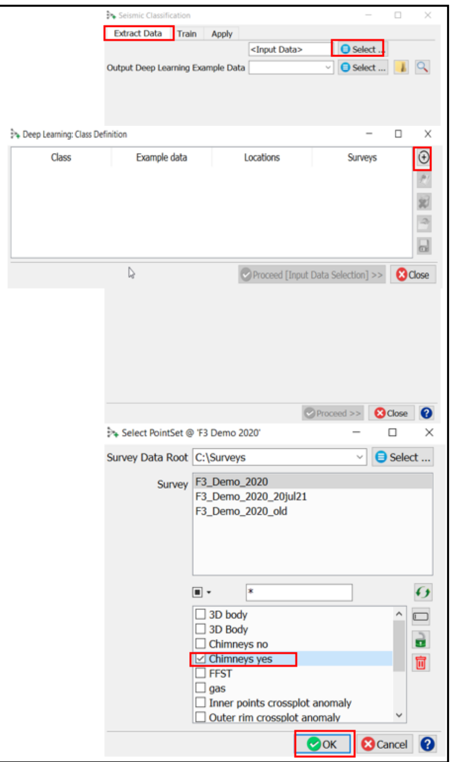
Workflow:

1. **Open** the Machine Learning Control Center with the icon.
2. **Click** on Seismic.
3. **Select** Seismic bodies (supervised 3D), and **Hit** Go.

Workflow cont'd:

4. *"Seismic Classification"* window pops up. **Select** *Input Data* in the "*Extract Data" tab.*
5. In the "Class Definition" window. **Select** icon in to "Add Class Definition".
6. In the "Select PointSet" *window,* **Select** the *Survey and* the 1st *Class Example Locations (e.g. Chimney yes).*
7. **Press** OK in the *"Specify Class Example Locations"* window.



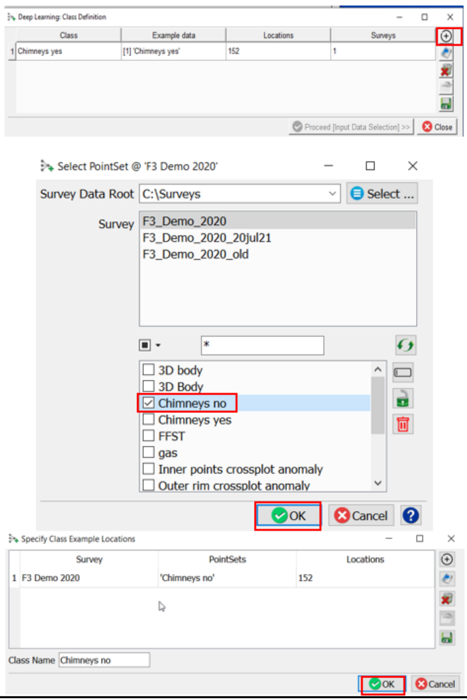


Workflow cont'd:

8. In the "Deep Learning: *Class Definition" Window,* **Hit** icon ⊕ to add more PointSet.

9. In the "Specify PointSet" *window,* **Select** the *Survey and* the 2nd *class example locations (e.g. Chimney no).*

10. **Press** OK in the *"Specify Class Example Locations"* window.

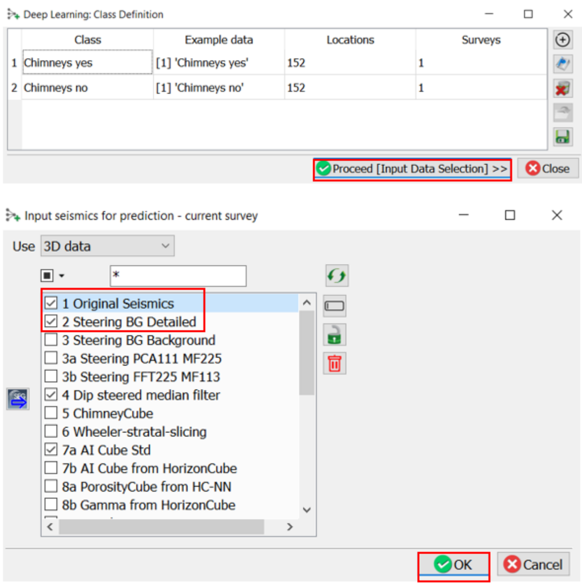


Workflow cont'd:

11. In the ***"Deep Learning: Class Definition"*** window, **Verify** that the default selected data are correct. **Press** Proceed [Input Data Selection].

12. In the *"Input Seismic for prediction"* window, **Select** the appropriate 3D *seismic cubes, and seismic attributes.*

13. **Press** OK.



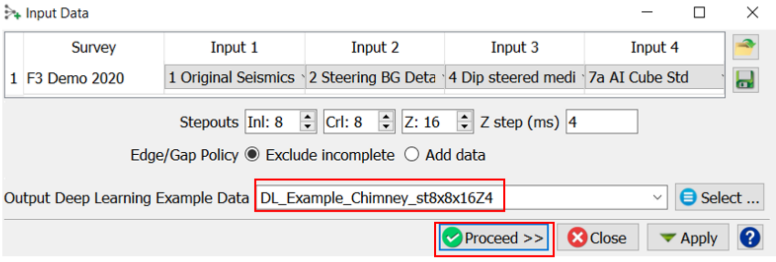
Workflow cont'd:

14. *"Input Data"* window pops up.

Input cubes can be modified. Keep the default parameters as indicated in this window.

15. **Specify** a new name for the *Output Deep Learning Example Data (e.g. DL_Example_Chimney_st8x8x16Z4).*

16. **Press** Proceed.



Workflow cont'd:

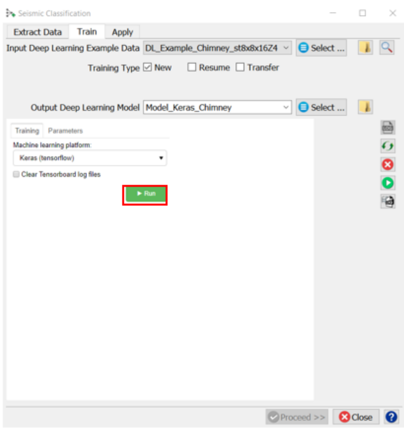
17. *Train* tab opens-up. Select one of the learning algorithm (e.g. Keras-tensorflow) to train the extracted examples data.

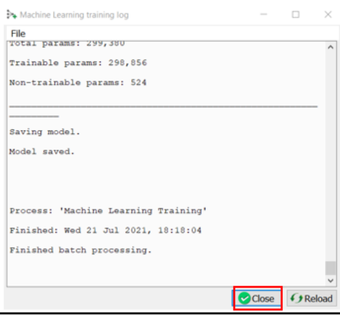
Different machine learning platforms and parameters can be tested. Keep the defaults parameters.

18. **Specify** a new *Output model* name (e.g Model_Keras_Chimney).

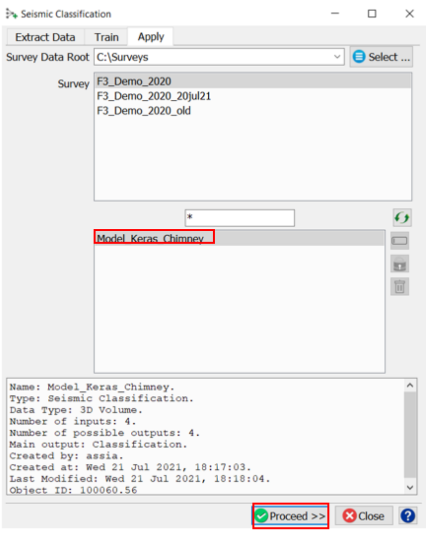
19. **Press** Run.

20. Once the computation is done, **Close** the ML log window.





Workflow cont'd:



21. **Select** the "Apply" tab. Check all selected data Ok.

*The Survey, Training model can be modified here if necessary.

22. **Press** Proceed.

* The option to select data from other surveys is available only in commercial projects

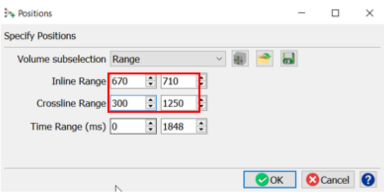
Workflow cont'd:

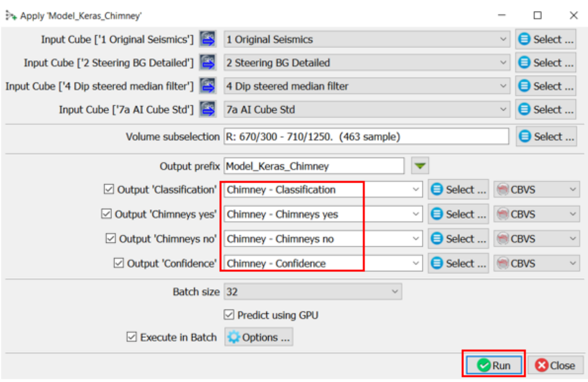
23. In the *"Apply created training model"* window, **Verify,** all the default selected input 3D cubes are correct.

   a. To optimize computation time, **Modify** "Volume sub-selection" and set it to an area of interest, where Chimneys have been interpreted (e.g. Inline range: 670-710, Crossline range: 300-1250).

   b. **Specify** a new name for the 3D output cubes: Classification, Chimney yes, Chimney no, and Confidence.

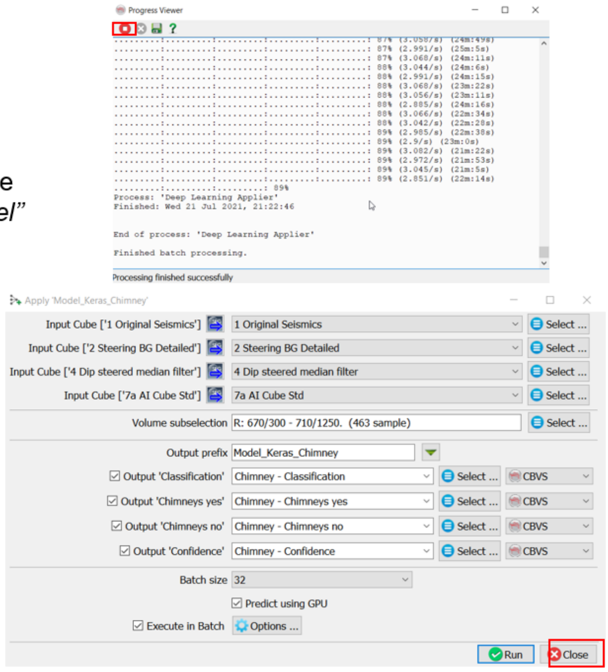
24. **Press** Run to continue.





Workflow cont'd:

25. When the processing is done, **Close** the "*Progress Viewer"* and the "*Apply Model"* windows.



Workflow cont'd:

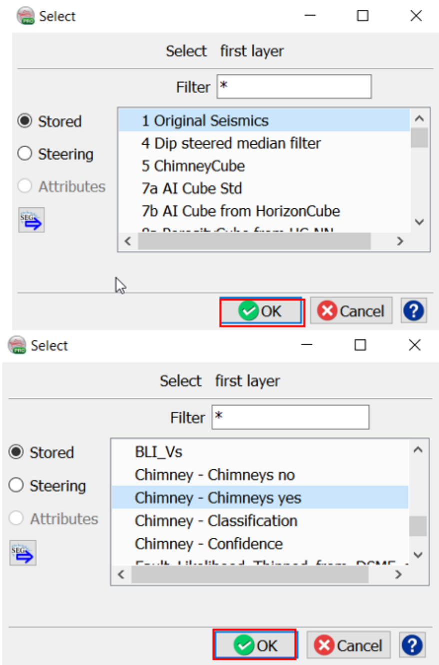
QC results: display the predicted Chimney Yes probability 3D cube

26. **Right Click** on the: Scene > Inline > Add and select Data.

27. **Select** the predicted 3D Chimney location probability (e.g. Chimney_yes), and overlay the seismic (e.g. 1 Original Seismic).

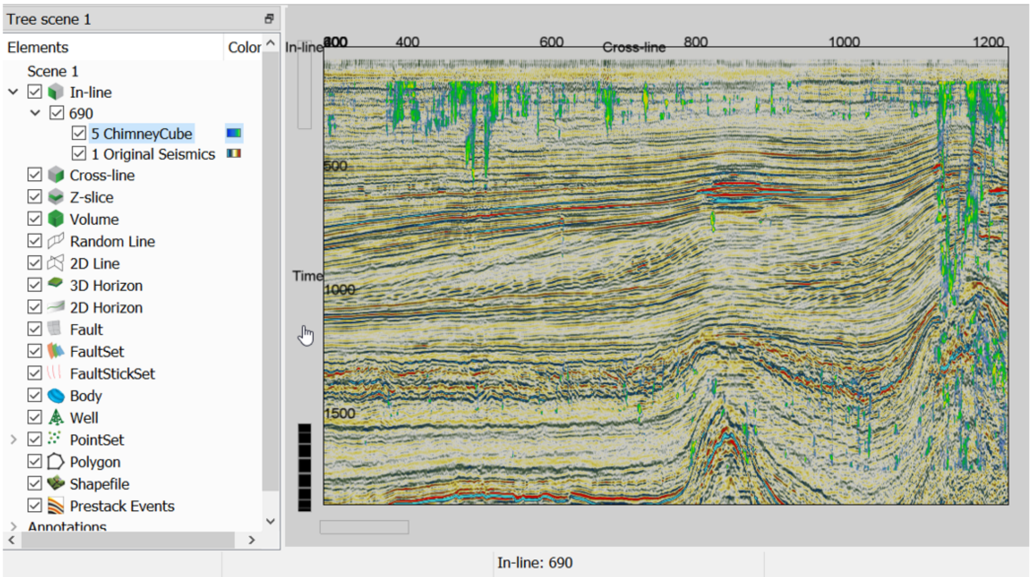
Modify the Inline number to be within the input range.

28. **Right-click** on the Inline number, and **Type** in the Inline field: In-line 690 .



Workflow cont'd:

QC results: display the predicted Chimney and overlay the original seismic on in-line 690.



2.6.4 Seismic Unet 3D Fault Predictor

Required licenses: OpendTect Pro & Machine Learning

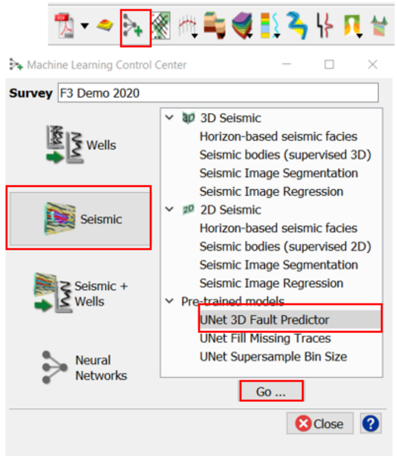
Exercise objective:

To predict fault's location using the *"Seismic – Pre-trained models - Unet 3D Fault Predictor"* tool which is part of the machine learning plugin. In this exercise, we want to predict faults location.

Seismic data Preparation
Seismic need to be available in the survey. If not, **import** seismic, and interpret some "key fault" locations or use an existing trained model.

Workflow:

1. **Open** the Machine Learning Control Center with the icon.
2. **Click** on Seismic.
3. **Select** the *"Pre-trained models – Unet 3D Fault Predictor"* and **Hit** Go.

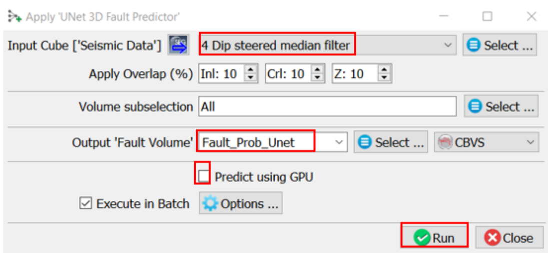


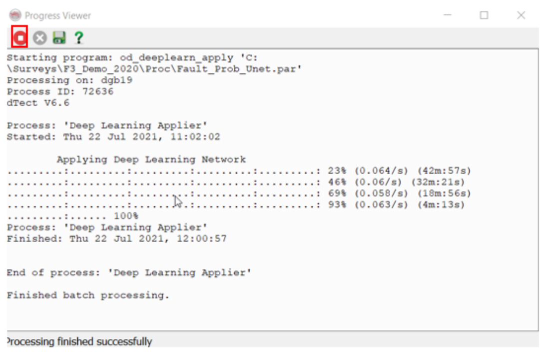
Workflow cont'd:

4. *"Apply Unet 3D Fault Predictor"* window pops up.
5. **Select** *Input Cube (e.g. 4 Dip steered median filter). Use a volume subselection to optimize the processing time.*
6. ***Specify*** *a new name for the "Output Fault Volume to Cube" (e.g. Fault_Prob_Unet).*

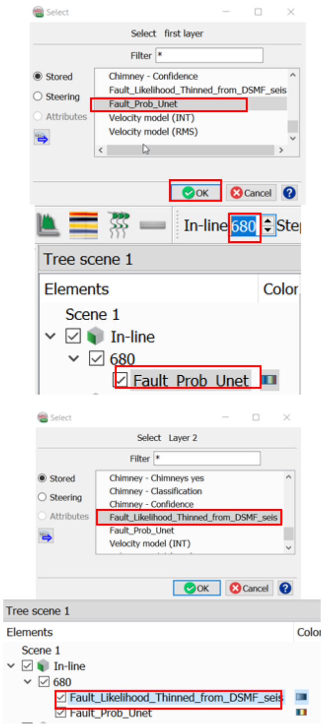
Try running the prediction without the GPU, if it fails, as a result of lack of memory.

7. **Hit** Run.
8. When the processing finish, **Press** button to close the Progress Viewer window.





Workflow cont'd:



QC the output fault probability results on the In-line 680.

9. ***Right Mouse click*** *on In-line > Add and select Data > Store.* ***Select*** *the created Fault Probability cube (e.g. Fault_Prob_Unet_In680), and* **Hit** OK.

10. ***Type*** *in the Inline field: 680, and* **Hit** Enter.

The same way, add to the display, the existing Thinned likelihood probability display.

11. **Right-Click** *on Inline 680 > Add > Attribute >Stored.* ***Select*** *the existing thinned fault likelihood (e.g. Fault_Likelihood_Thinned_from_DSMF_seis), and* **Hit** OK.

Workflow cont'd:

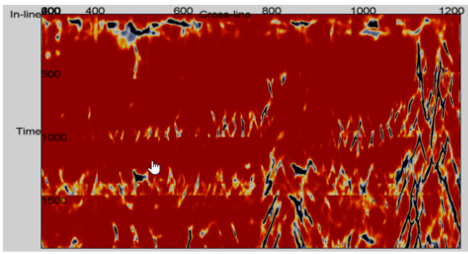
12. **Display** the predicted fault probability, and **Compare** with the thinned fault likelihood.

Note:

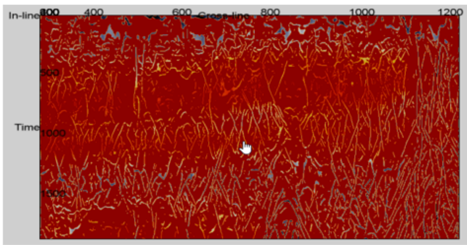
The thinned fault likelihood, contains more small faults and noise. Whereas the predicted fault probability, contains more faults information and less noise.

The predicted fault probability is un-thinned. To be able to make a fair comparison with the thinned fault likelihood, a thinning needs to be applied to the predicted fault probability

Predicted fault probability (un-thinned)

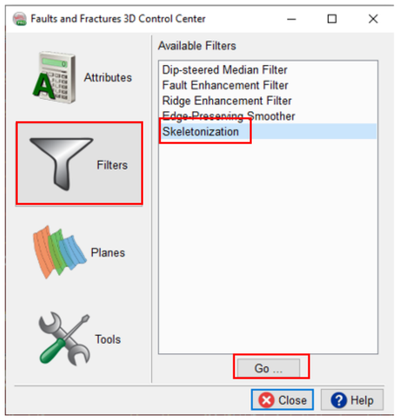


Thinned fault likelihood



Workflow cont'd:

The next step, is to apply a thinning to the predicted fault probability.

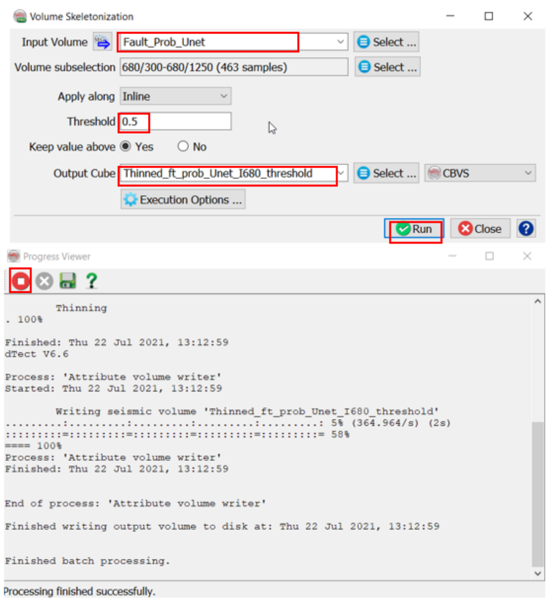


13. **Select**: faults and fractures > 3D icon 

14. The Faults and Fractures 3D Control Center window pops up. **Select** Filters > Skeletonization.

15. **Press** Go.

Workflow cont'd:



16. The Volume Skeletonization window pops up.

17. **Set** the parameters as specified in the window:
    a. Volume subselection: Inline range = 680
    b. Threshold: 0.5
    c. **Type** a new name for the "Output Cube" e.g. Thinned_ft_prob_Unet_I680_threshold"

18. **Hit** Run.

19. The Progress Viewer window pops up. Once the computation is done, **Hit** Close icon  .

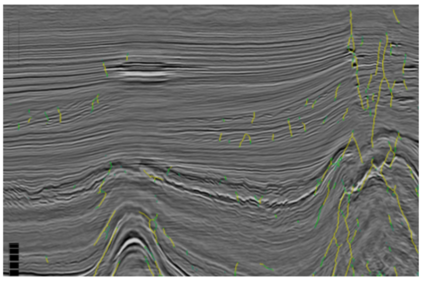
Workflow cont'd:

20. **Display**: the new thinned predicted fault probability. **Right mouse click** on the Inline 680 > Add > Attributes. **Select** the new thinned predicted fault probability (e.g. Thinned_ft_prob_Unet_I680_threshold). Please make note the name should not contains characters like '.'

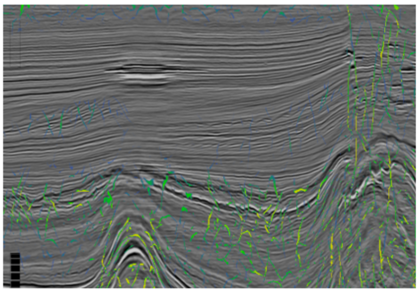
21. **Compare** with the existing thinned fault likelihood.

Notice that the thinned fault likelihood, contains more small faults and noise, whereas the thinned predicted fault probability, output more faults information and less noise.

Thinned predicted fault probability



Thinned fault likelihood



2.6.5 3D Seismic and Wells RockProperty Prediction

Required licenses: OpendTect Pro & Machine Learning

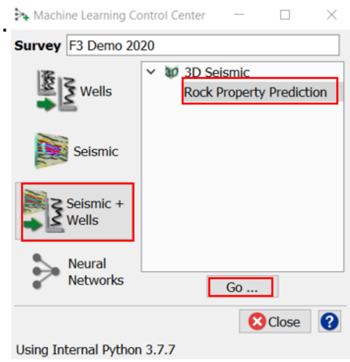
Exercise objective:

To predict rock property using the *3D Seismic + Wells, Rock Property Prediction* tool which is part of the Machine Learning plugin. In this exercise, we want to predict a Porosity cube.

Well data Preparation
Seismic (and/or attributes) and **Well**(s) need to be available in the survey. If not, **import** seismic and wells (track, logs, markers, time-depth curve or checkshot).

Workflow:

1. **Open** the Machine Learning Control Center with the icon .
2. **Click** on Seismic + Wells > 3D Seismic
3. **Select** Rock Property Prediction, and **Hit** Go.



Workflow cont'd:

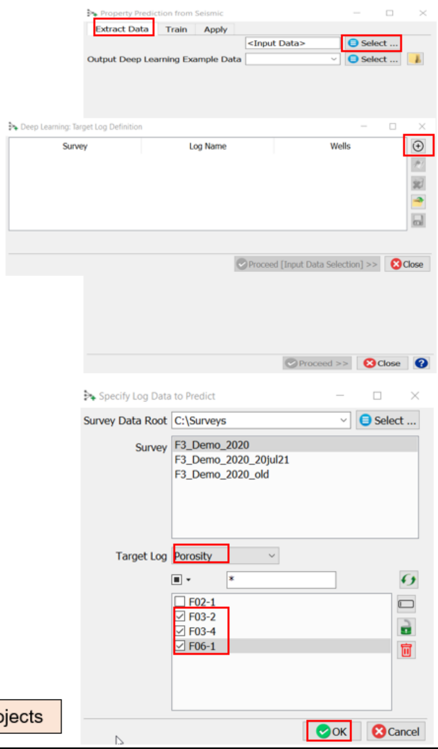
4. "Prediction from seismic" window pops up. **Press** Select - Input Data.

5. **Select** icon in the "Target Log Definition". The "*Specify Log Data to predict" window pops up.*

6. **Select**: *Survey*, Target Log (e.g. Porosity),* and *Wells that will be used for the data extraction,* as indicated in the window.

The well F02-1 is not selected, and will be used as a blind well.

7. **Press** OK.

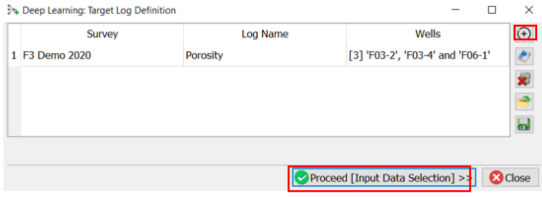


* The option to select data from other surveys is available only in commercial projects

Workflow cont'd:

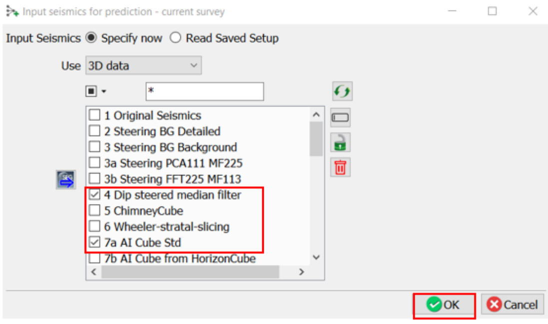
8. Deep Learning: Target Log definition window pops-up.

*A new data selection from different survey can be added by clicking on ⊕



9. In the ''Input seismic for prediction'' window, **Select** a suitable 3D data to use as input for the training e.g. RMS attribute, Q Factor attribute, Instantaneous phase attribute, Dominant frequency attribute, Seismic volume etc.

10. **Press** OK.



* The option to select data from other surveys is available only in commercial projects

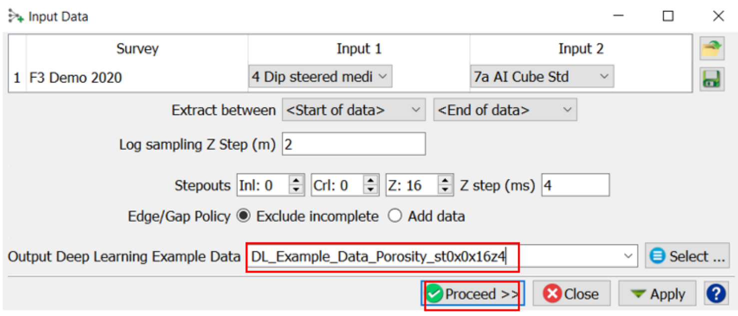
Workflow cont'd:

11. *"The Input Data"* window pops up.

Input data can be modified using the drop down selection. Keep the default parameters as indicated in this window.

12. **Specify** a new name for the *Output Deep Learning Example Data (e.g. DL_Example_Data_Porosity_st0x0x16z4).*

13. **Press** Proceed.



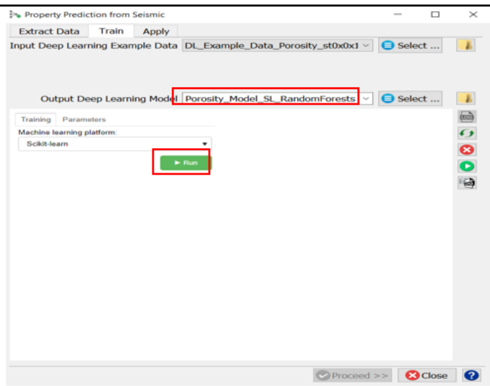
Workflow cont'd:

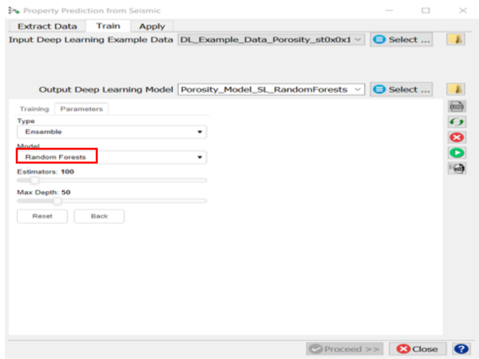
14. The *Train* tab gets activated. Train the extracted examples data using the default learning algorithm Scikit-learn (Ensemble: Random Forests).

> Different machine learning platforms and parameters can be tested.
> Keep the default parameters for this exercise.

15. **Specify** a new *Output model* name e.g. Porosity_Model_SL_RandomForests.

16. **Press** Run.

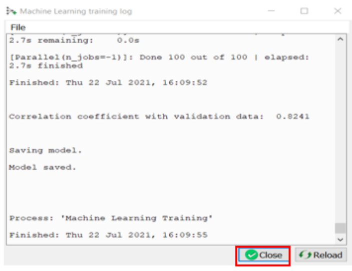


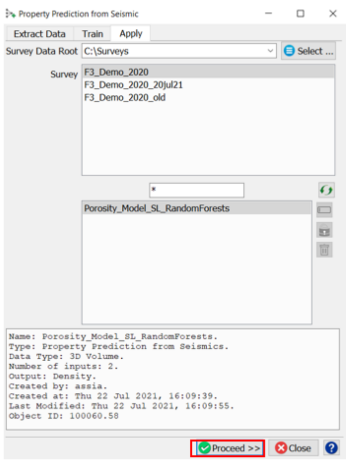


Workflow cont'd:

17. **Hit** Close in the ''Machine Learning training log'' window, when the processing finishes.

18. The Apply tab get activated. The Survey, Training model can be modified here. Keep the default selection as indicated in the window. **Press** Proceed.





Workflow cont'd:

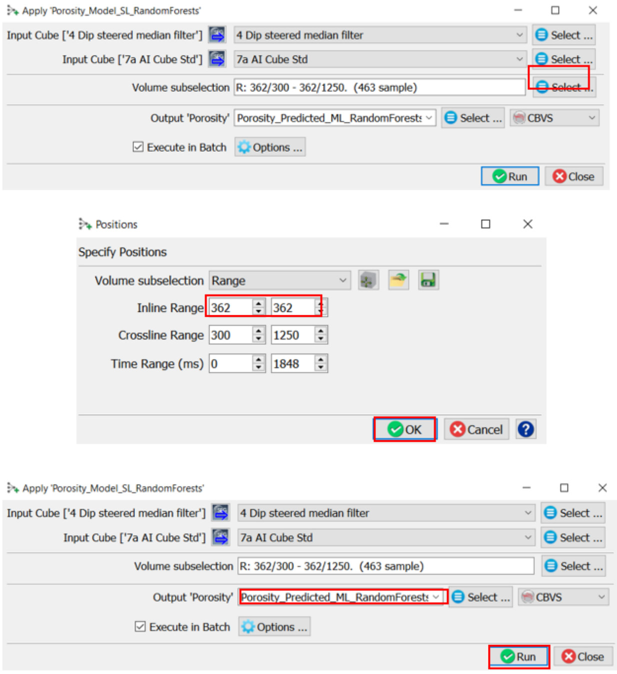
19. The ''Apply created training model'' window pops up. Apply first the trained model on 1 Inline.

20. In the volume sub-selection, **Select** Inline range 362. Choose an Inline crossing a well with porosity log e.g. F02-1.

21. **Hit** OK.

22. In the ''Apply the trained model'', Keep default parameters, **Specify** a new name for the output porosity to cube (e.g. Porosity_Predicted_ML _RandomForests).

23. **Press** Run to continue.



Workflow cont'd:

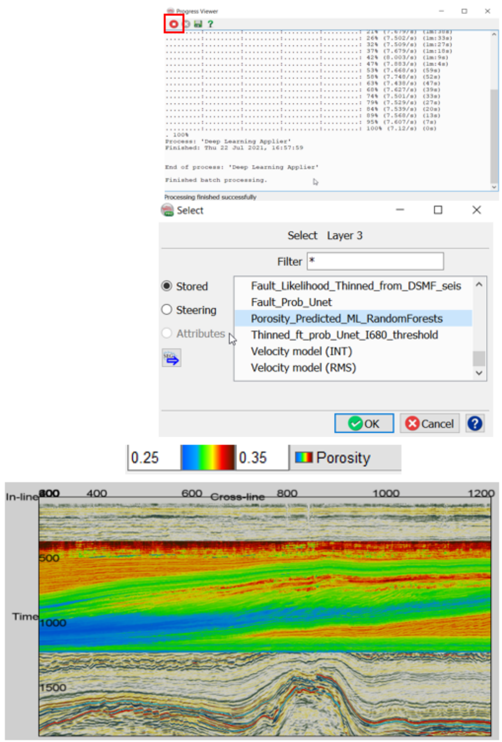
When the computation finishes, close the Progress viewer window.

QC results by displaying the predicted Porosity on the test Inline (e.g. 362) and overlay the crossing well F02-1, with the porosity log.

24. **Right Mouse Click** on the Inline folder > Add Default Data e.g. Deep Steered Median Filter. Type: 362 in the In-line field Change the In-line no to 362 In-line 362 .

25. **Right Mouse Click** on the In-line 362 > Add > Attributes. **Select** under Stored the new predicted porosity (e.g. Porosity_Predicted_ML_RandomForests), and **Hit** OK.

26. **Modify** the Porosity colour limit to (0.25-0.35)

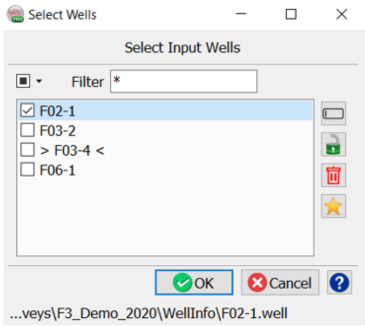


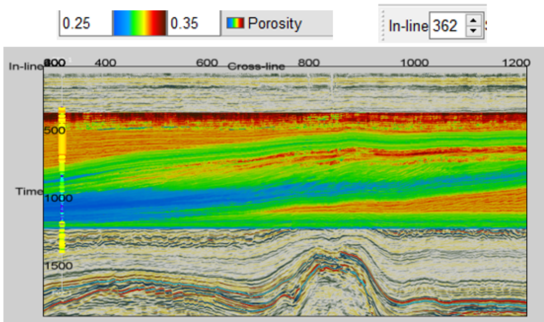
Workflow cont'd:

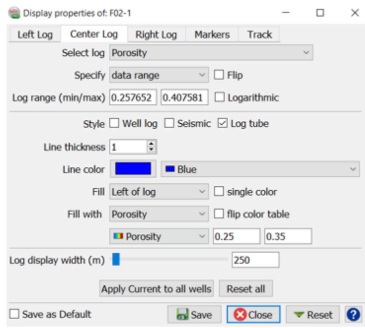
27. **Right Mouse Click** on the well folder> Add, **Select** the well F02-1, **Hit** Ok.

28. **Right Mouse Click** on the Well F02-1 > Display > Properties, **Select** Porosity log, **Change** the color bar to Porosity. **Modify** the Porosity color range similar to the predicted porosity cube range (0.25 - 0.35).

29. **Apply** to All Wells, and Hit Close.





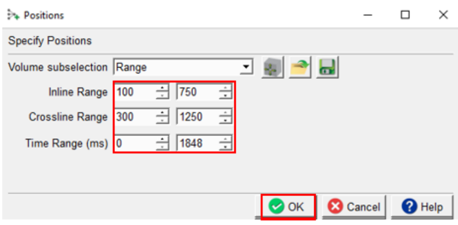


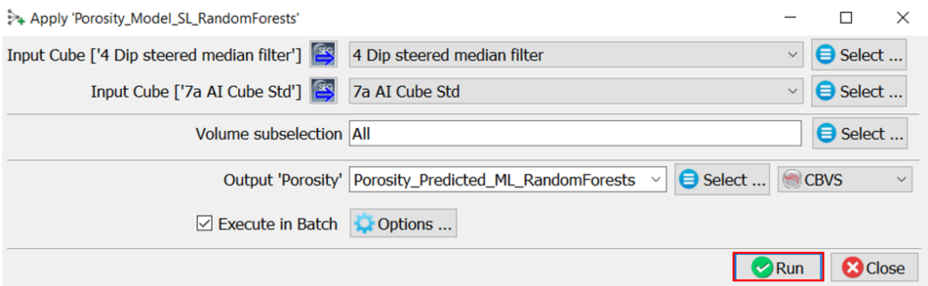
Workflow cont'd:

If result is satisfactory, go back to the previous Step and **Apply** the trained model to the entire survey.

30. **Go back** to the Apply tab > Volume sub-selection > In-line range and reset of the entire range.

31. **Keep** all other default parameters and **Press** Run to continue.





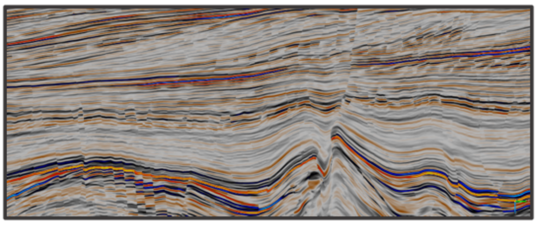
2.6.6 Seismic Image to Image - Fault Prediction

Required licenses: OpendTect Pro & Machine Learning

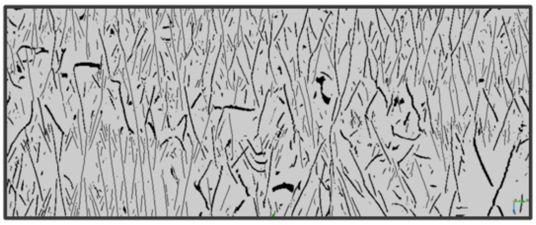
Exercise objective:

To predict seismic features using the *Seismic Image to Image* workflow in the machine learning plugin. In this exercise, we will predict fault locations from seismic data.

Warning 1: To predict real faults use the pre-trained U-Net fault predictor
In this exercise we train a U-Net to predict faults from pre-processed seismic input. The input is Edge-Preserved Smoothed (EPS) seismic data. The target is a mask volume with ones (faults) and zeros (no-faults) that was created from Thinned Fault Likelihood (TFL) computed from the EPS volume. **Note** that from a geoscience perspective this is not a meaningful exercise because we do not need a machine learning model to predict a desired outcome that can be computed directly with an algorithm. The main purpose of this exercise is to learn how to run image-to-image workflows.



Input EPS* seismic

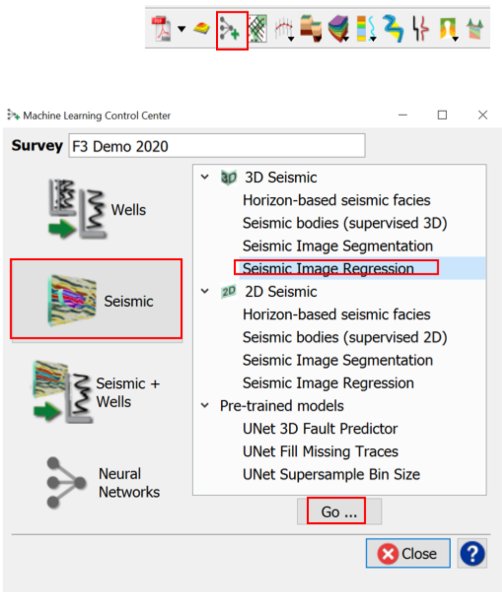


Target mask (0,1) of TFL* from EPS

EPS and TFL-mask are **NOT delivered with F3. To replicate this workflow first create EPS and TFL (from EPS) in the Faults & Fractures plugin. Next create a mask from TFL with the mathematics attribute using this formula: TFL > 0.01 ? 1 : 0*

Exercise objective:

Warning 2: heavy GPU requirements
In this exercise we create 1008 cubelets of 128x128x128 samples. These cubelets are extracted from half the input - and target volumes. The trained U-Net is applied to the full volume. Application is very fast (minutes) but training takes several hours on a GPU. The graphics card we used is a Nvidia GeForce RTX 2080 Ti with 11 GB DDR6 memory. In principle the exercise can also be run on a CPU but then training may take several days.



Workflow:

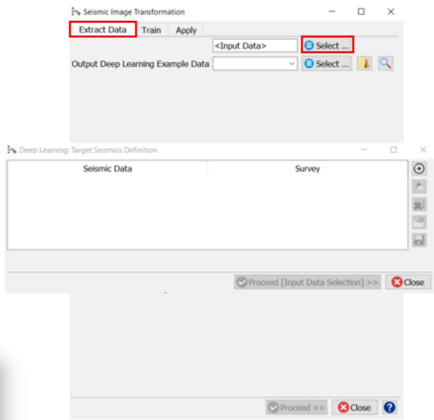
1. **Open** the *Machine Learning Control Center* with the icon.
2. **Click** on *Seismic*.
3. **Select** *Seismic Image to Image*, and **Hit** *Go*.

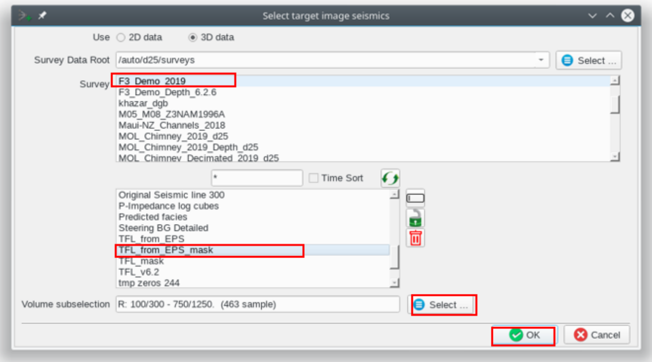
Workflow cont'd:

4. *Seismic Image Transformation* window pops up.

5. **Select** *Target Data* in the *Extract Data* tab. ***Click*** *on the target data specification.*

6. In the *Select target image seismic* window, **Select** the *Survey* and the target cube *TFL_from_EPS_mask*



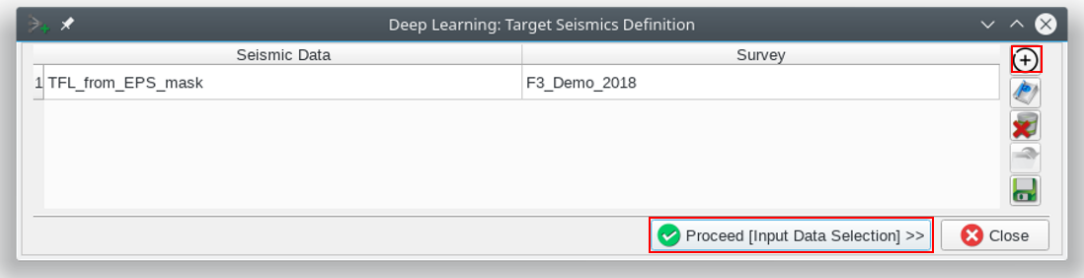


Workflow cont'd:

7. The *Deep Learning: Target Seismics Definition* window pops up.

8. **Press** *Proceed [Input Data Selection]*

*Additional seismic attributes can be added using the icon . Keep the defaults data.

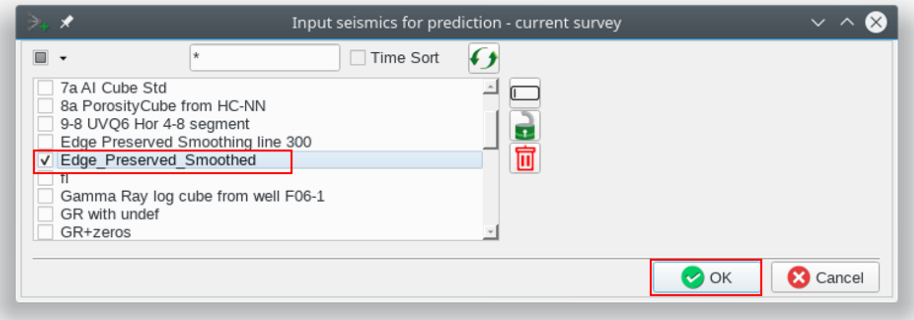


* The option to select data from other surveys is available only in commercial projects

Workflow cont'd:

9. **Select** *Edge Preserved Smoothed as* input seismic to be used for the prediction

10. **Press** OK

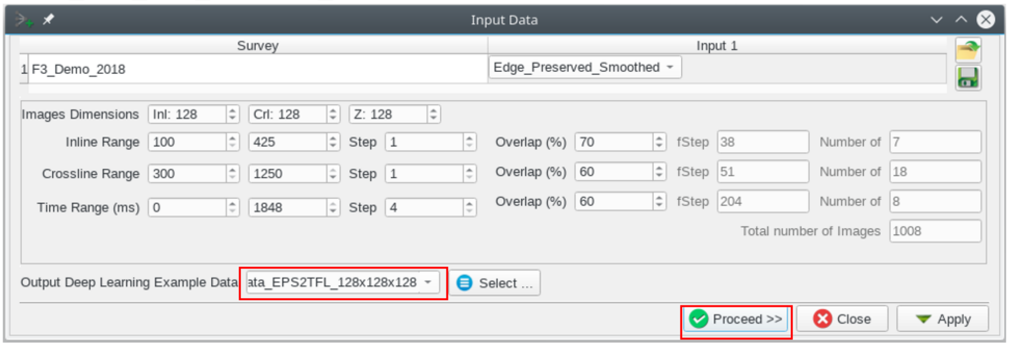


Workflow cont'd:

11. In the *Input Data* window **set** the *Image dimensions* of the cubelets to 128 x 128 x 128 samples. Note: to extract 2D images set one of the dimensions to 0.

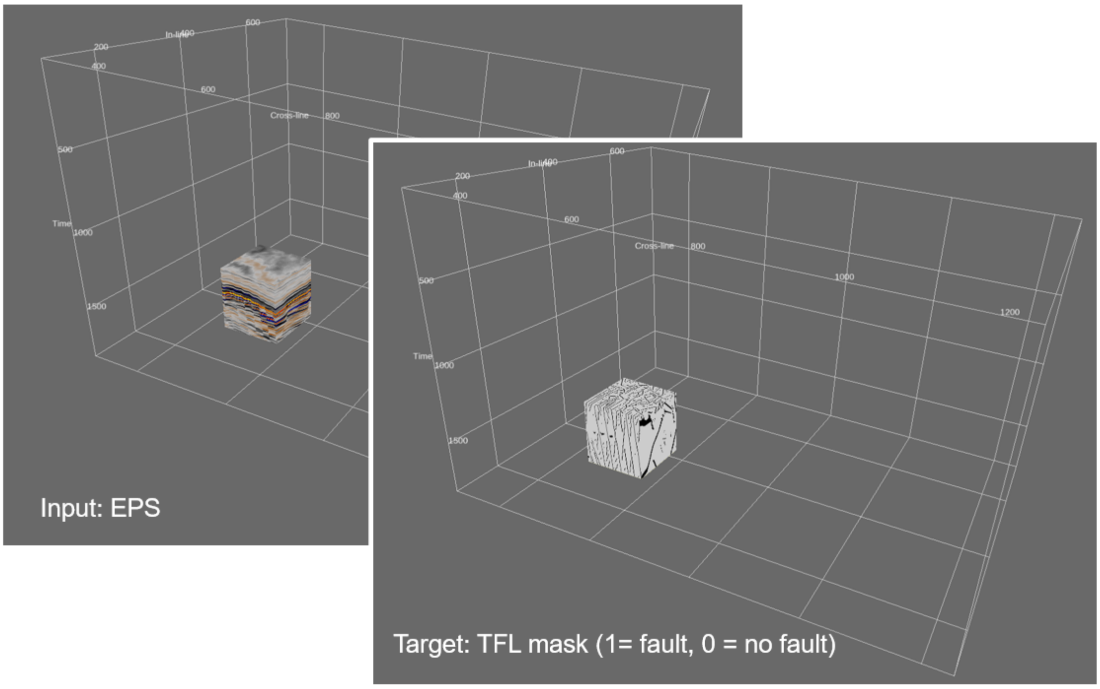
12. **Specify** the *Inline, Crossline, Time Ranges* and the corresponding *Overlap** percentages to such that we extract approx. 1000 cubelets from one half of the input and target volumes (see image for specifications).

13. **Specify** a name for the *Output Deep Learning Example Data* (e.g. ML_train_data_EPS2TFL_128x128x128) and **press** Proceed.



**Overlap: if the number of examples that can be extracted from a given range and overlap does not fit exactly, the last example is extracted from the boundary backwards.*

Example cubelets. Dimensions are: 128 x 128 x 128 samples



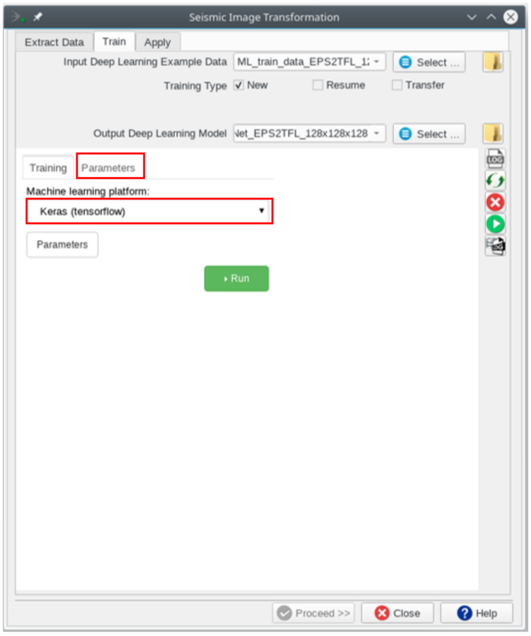
Workflow cont'd:

14. Specify the *Output Deep Learning Model* name (e.g. ML_U-Net_EPS2TFL_128x128x128)

15. In the *Train* tab, **Select** Keras (tensorflow) as *Machine learning platform*

16. **Select** the *Parameters* tab

> The machine learning plugin supports two platforms: Keras (tensorflow) for deep learning (convolutional neural networks) and Scikit Learn for all sorts of other machine learning models (e.g. Random Forests). Supported models and training parameters are specified in the Parameters tab.



Workflow cont'd:

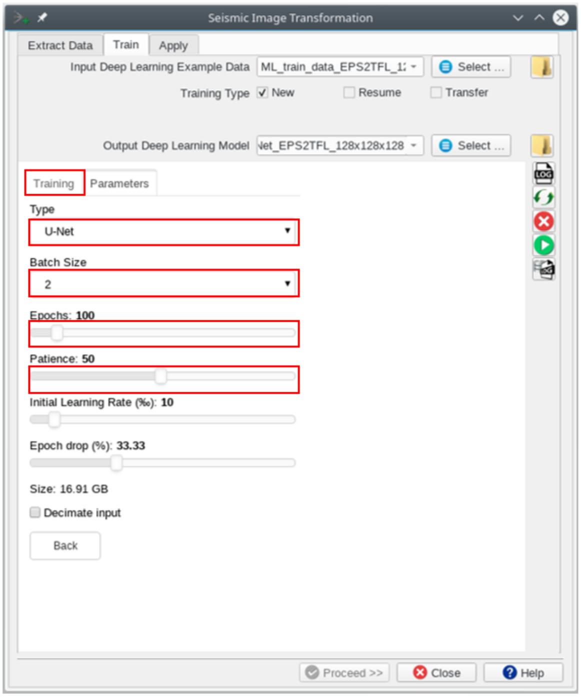
17. In the *Parameters* tab **Select** *Type* U-Net

18. **Set** *Batch Size* to 2. A U-Net needs a lot of GPU memory in the training phase. If memory is exceeded, training stops with an error message. You can then try to rerun with a smaller batch size. Try with the largest possible batch size as training performance increases with batch size.

19. **Set** the number of *Epochs* to 100 (this is the number of training cycles through all examples that are offered in batches of Batch Size).

20. **Set** *Patience* to 50. This parameter avoids early stopping when the error does not decrease after this number of Epochs.

21. **Go back** to the *Training* tab.

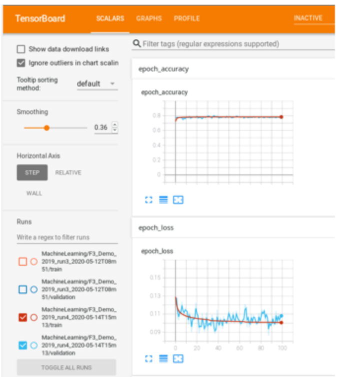


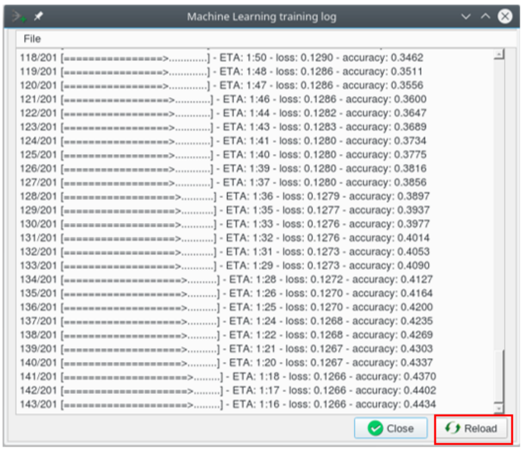
Workflow cont'd:

22. In the *Training* tab **Press** *Run*

23. The Machine Learning training log window pops up. This window can also be started by pressing the LOG icon. **Press** *Reload* to refresh.

24. *TensorBoard*, a program to examine models and track training performance is started automatically in a browser.

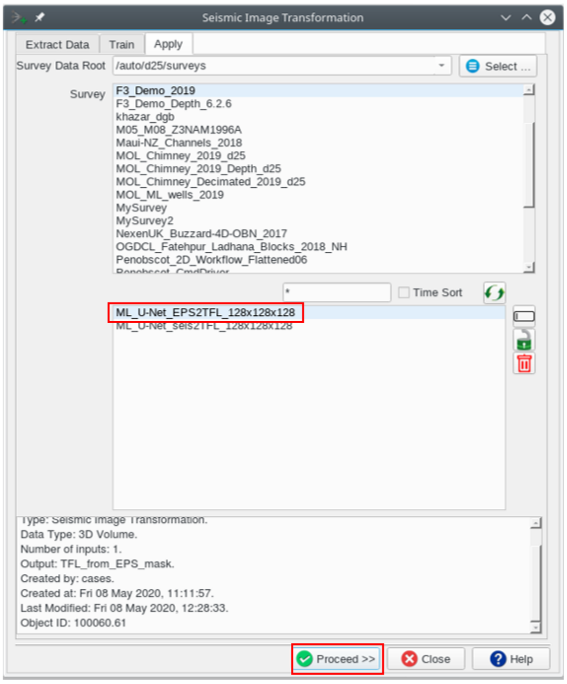




Workflow cont'd:

25. When training is finished, **Select** the *Apply* tab

26. Select the trained model ML_U-Net_EPS2TFL_128x128x128 and **Press** Proceed.

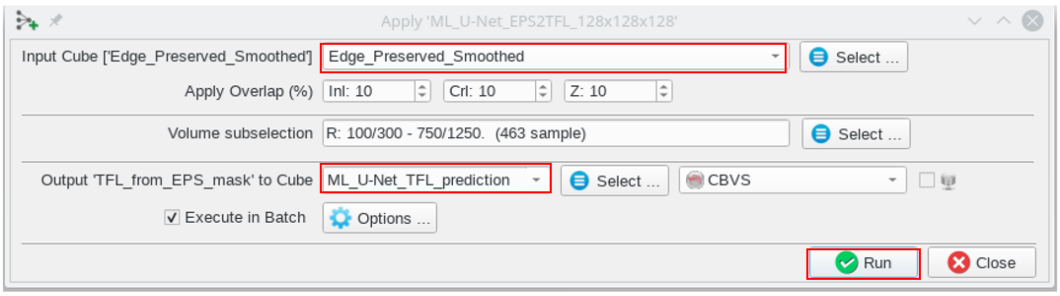


Workflow cont'd:

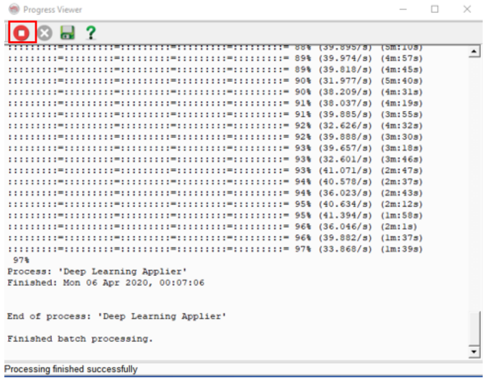
27. In the *Apply* window **Select** the *Input Cube* Edge_Preserved_Smoothed.

28. Specify the *Output Cube* name that will be created by the trained model, e.g. ML_U-Net_TFL_prediction.

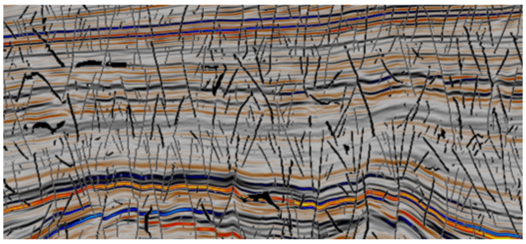
29. Press Run to start processing.



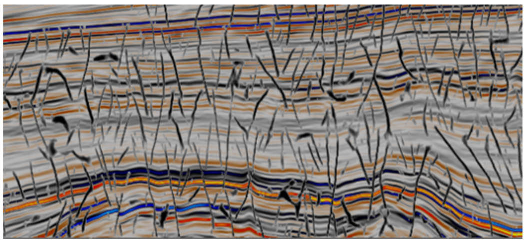
Workflow cont'd:



30. A *Progress Viewer* window pops up. Applying the trained U-Net is very fast. The resulting fault prediction can be viewed e.g. as overlay on the EPS of inline 425.



Inline 500 EPS + TFL mask



Inline 500 EPS + U-Net Prediction

2.6.7 Seismic Image Regression (Unet) - Fill Seismic Traces

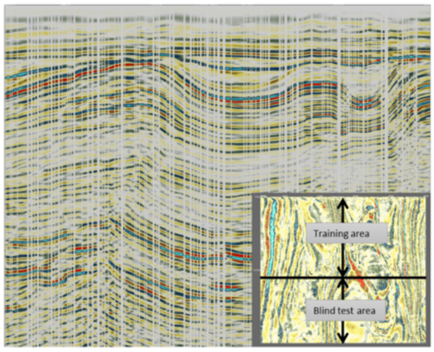
Required licenses: OpendTect Pro & Machine Learning

Exercise objective:

To fill blank seismic traces using the 'Seismic Image Regression' workflow which is part of the machine learning plugin. The model will have to learn how to recreate an image from example images containing blank traces. Therefore, we need an input data set in which we have deliberately blanked some of the traces.

For the purpose of this exercise:

- We use OpendTect's attribute engine to randomly blank +/- 33% of all traces
- We select examples from one side of the volume for training the U-Net
- We apply the trained U-Net to the full volume, so that we can validate the interpolation results in the blind test zone



Note: In this exercise we train a 2D Unet but you can equally well train a 3D Unet. The differences between 2D and 3D Unets are as follows:
1. A 2D model trains much faster (hours vs days)
2. 2D models can be trained on workstations with less GPU / CPU capacity
3. Interpolation results are comparable although 2D interpolation may introduce some striping (like a footprint)
4. Application of a trained 3D model is much faster than a trained 2D model (minutes vs hours)

Randomly blank traces workflow:

To train our 2D Unet regression model we create a data set with 33% randomly blanked traces. From this cube we extract examples for training in a restricted area. The trained model is applied to the entire volume, whereby the area from which no examples are extracted acts as blind test area. The real value is of course when we apply the trained model to an area with real missing traces (which we don't have in this case). Random blanking (replacing the values with hard zeros) is done in OpendTect's Attribute engine and can be done in different ways. In this case, we will create an attribute set to perform the following tasks:

1. Math attribute with formula: "randg(1)". This generates random values with a Gaussian distribution and 1 standard deviation;
2. Apply this attribute to a horizon and save as horizon data;
3. Horizon attribute that retrieves the random values from the saved horizon data. A Horizon attribute replaces a value at an inline, crossline position with the value extracted from the given horizon;
4. Math attribute with formula: "abs(value)> 1 ? 0: seis". We assign the retrieved horizon data to the variable "value" and the seismic data to "seis". This attribute assigns values larger than the absolute value of 1 standard deviation to zero while all other values are given the value of the seismic data.
5. Additional attributes in the set are used to compare/QC results before and after prediction.

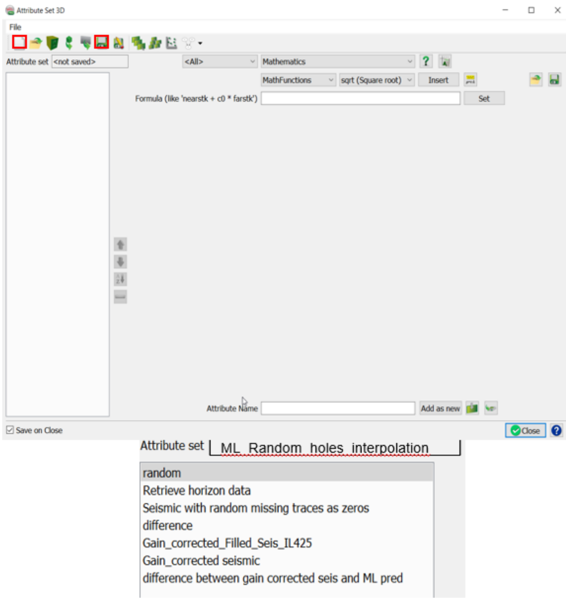
Randomly blank traces workflow:

Create a new 3D attribute set to randomly blank traces as explained in the following steps.

1. Select the 3D Attributes engine icon.

2. Create a new 3D attribute set
These attributes that will be explained in the next steps.

3. Save as attribute set with the name ‘ML_Random_holes_interpolation’.

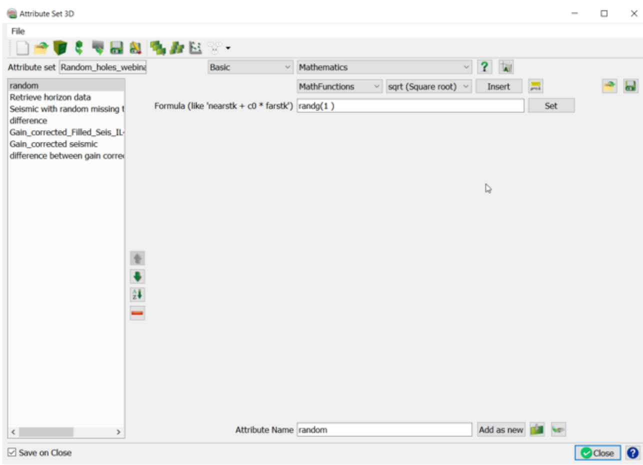


Randomly blank traces workflow:

4. Create 1st attribute with name ‘random’ as indicated in the attribute set window and **Hit** ‘Add as new’.

5. **Set** Math attribute with formula: “randg(1)”.
This generates random values with a Gaussian distribution and 1 standard deviation;

Apply this attribute to an horizon and save as horizon data as indicated in the next step.



Randomly blank traces workflow:

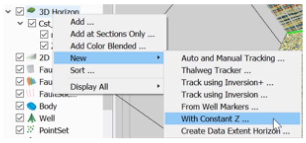
Create a seismic horizon at Z = 1 s. Then apply the random attribute to this horizon and save this as horizon data. This horizon data will be used in the attribute that does the actual blanking.

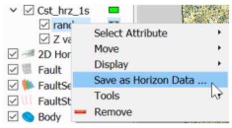
6. Create a constant seismic horizon at Z = 1s.

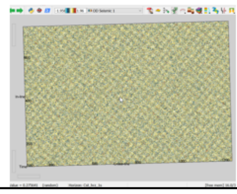
7. Right mouse click on the 3D Horizon < New < With constant Z.

8. Enter Z value (ms)= 1000. Type an Output 3D Horizon name e.g. Hrz_1s. **Hit** Create.

9. Display the horizon – attribute ‘random’. **Save as** Horizon data.







Randomly blank traces workflow:

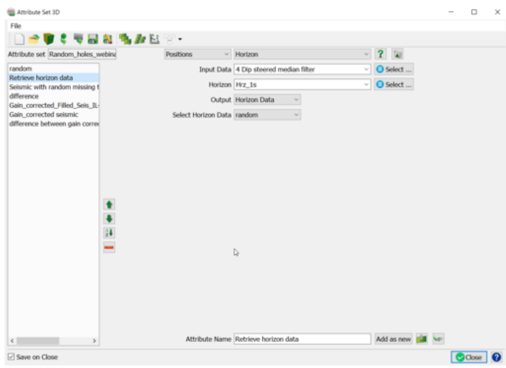
Create an horizon attribute that retrieves the random values from the saved horizon data. The horizon attribute replaces a value at an inline, crossline position with the value extracted from the given horizon.

10. **Create** 2nd attribute ‘’Retrieve horizon data’’ as indicated in the attribute set window and **Hit** ‘Add as new’.

11. Select the Input Data that will be blanked ‘4 Dip steered Median filter’.

12. Select the constant horizon ‘’Hrz_1s’’ created in the previous step.

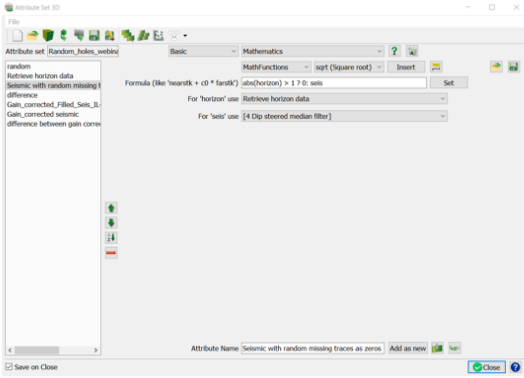
13. **Select** Output ‘’Horizon Data’’ and Horizon Data ‘’random’’.



Randomly blank traces workflow:

Create an attribute that will randomly blank traces as zeros in the input seismic.

14. Create 3rd attribute 'Seismic with random missing traces as zeros' as indicated in the attribute set window and **Hit** 'Add as new'.

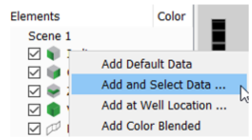


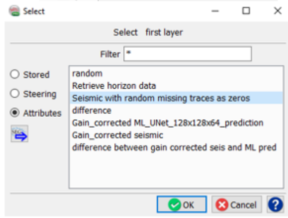
15. Set a Math attribute with formula: "abs(value)> 1 ? 0: seis". This assign the retrieved horizon data to the variable "value" and the seismic data to "seis". This attribute assigns values larger than the absolute value of 1 standard deviation to zero while all other values are given the value of the seismic data.

16. Select the previously created attribute 'Retrieve Horizon Data' in the 'For Horizon to use'.

17. Select the seismic you wish to blank in the 'seis' (e.g. 4_Dip steered median filter).

Blank traces workflow cont'd:

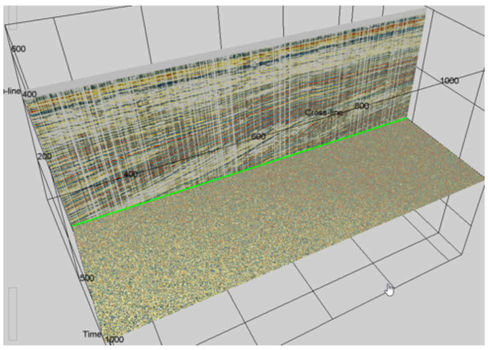




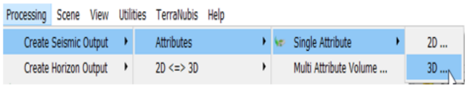
18. Display the new seismic attribute with blanked traces. **Right mouse click** on the In-line. **Select** "Add and Select Data"

19. **Select** the attribute "Seismic with random missing traces as zeros" and **Hit** Ok.

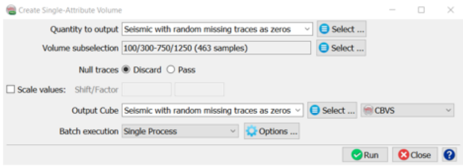
Notice that random traces have been blanked.



Blank traces workflow cont'd :

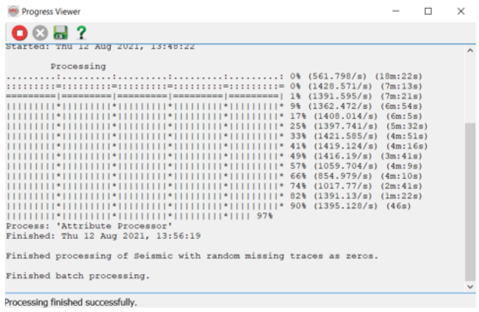


20. **Select**, ''Create a Seismic Output'' from the attribute – Seismic with random missing traces as zeros.



21. In the ''Create Single Attribute Volume'' window, keep the default parameters. **Type** an Output name (e.g. Seismic with random missing traces as zeros) and **Run**.

22. **Close** the progress window when the processing finish



23. **Display**/QC the created seismic

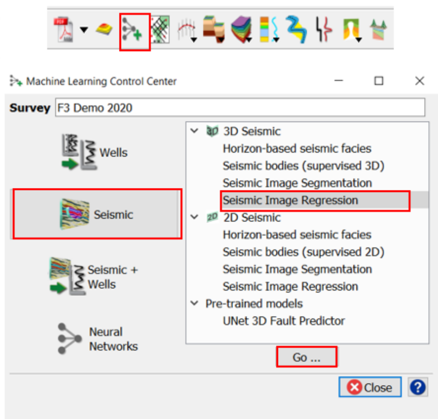
This seismic will be used as input for the next step, ML Seismic Image Regression prediction.

Exercise objective:

To fill blank seismic traces using the 'Seismic Image Regression'' tool which is part of the machine learning plugin. The model will have to learn how to recreate an image from example images containing blank traces.

Workflow:

1. **Open** the Machine Learning Control Center with the  icon.
2. **Click** on Seismic.
3. **Select** the 'Seismic Image Regression' and **Hit** Go.



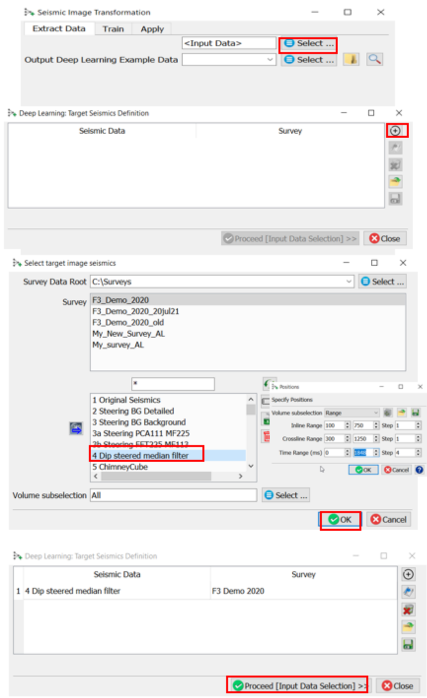
Workflow cont'd:

4. In the *'Extract Data' tab*, **Press** the Select button. The "Deep Learning Target Seismic Definition" window pops up.

5. Press the **+ icon** and **Select** the target seismic volume (e.g.4 Dip steered median filter). *And* ***OK.***

***Note:** it is possible to create a Training Set from examples extracted from multiple surveys. To do this, press the + icon again and select the target volume to add to the table below.

6. Press Proceed [Input Data Selection]. The "Input seismic for prediction" window pops up



* The option to select data from other surveys is available only in commercial projects

Workflow cont'd:

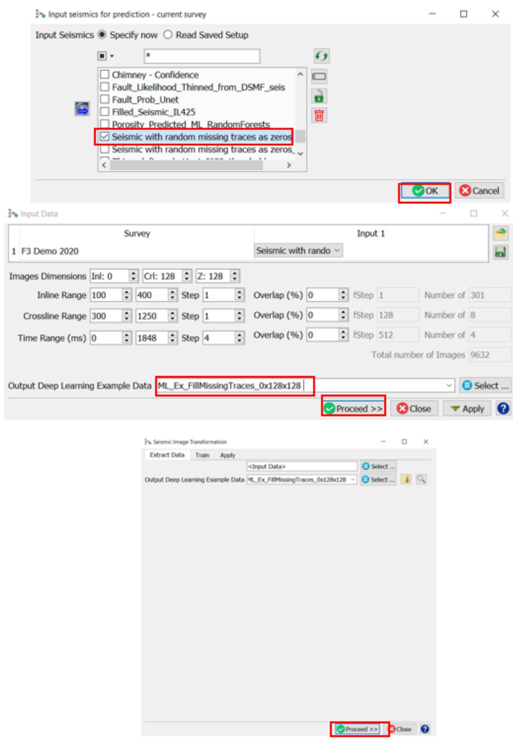
7. **Select** the input seismic data (i.e. the seismic with the missing traces as zeros) and **Press OK**.

8. In the "Input Data" window **set** the dimensions of the input features. To minimize processing time for this exercise, **Set** the Images dimension to: 0x128x128, overlap: 0x0x0 and Inline range: (100 – 400).

Note: If the current HW has large amount of GPU and CPU/computing power, the recommended Image Dimensions are 128x128x128.

9. Specify the name of the Output Deep Learning Example Data (e.g. ML_Ex_FillMissingTraces_0x128x128) and **Press Proceed** to start the extraction process.

10. When this process is finished **Press Proceed** in the "Seismic Image Transformation" window to continue to the Training tab.



Workflow cont'd:

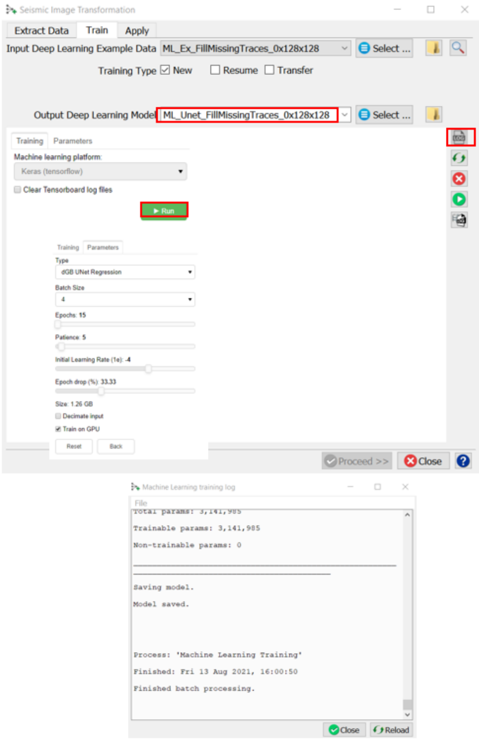
11. After the training data is selected the available models are shown. For seismic image workflows we use **Keras (TensorFlow)**.

12. **Check** the **Parameters** tab to see which models are supported and which parameters can be changed.

13. Specify *a name for the "Output Deep Learning Model" (e.g. ML_Unet_FillMissingTraces_0x128x128).*

14. Hit Run.

15. **Open** the processing log file to follow the progress. When the log file shows "Finished batch processing", the Proceed button turns green. You can press **Proceed** or **Open** the **Apply** tab.



Workflow cont'd:

16. Once the Training is done, the trained model can be applied. **Select** the trained model and **Press Proceed.**

17. The **Apply** window **pops up**. Here you can optionally apply to a **Volume subselection**. **Type** an Output name (e.g. Seismic*_ML_Unet_FillMissingTraces_0x128x128)*

*Note: You can run on GPU or CPU using the **Predict using GPU** toggle. Running the application on a GPU is many times faster than running it on a CPU*.

18. **Press Run** to create the desired output.

19. **Close** the 'Progress Viewer' window when the processing is finished.

Workflow cont'd:

Compare the original seismic data with the Unet predicted filled seismic results. The line is extracted from the blind test area.

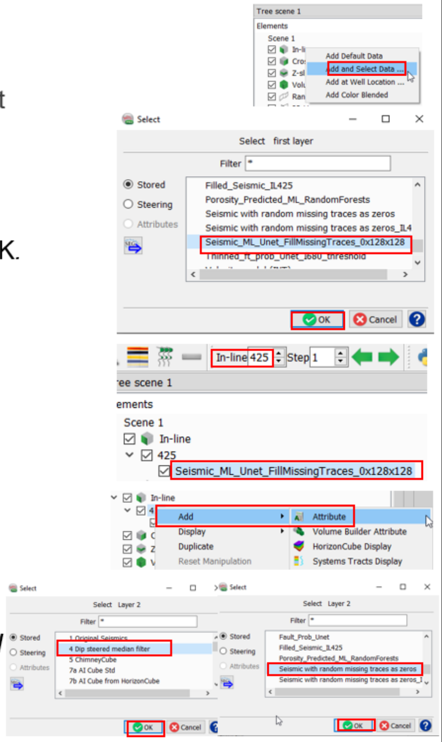
20. ***Right Mouse Click*** *on In-line > Add and select Data > Store.* ***Select*** *the created Filled Seismic (e.g. ML_Unet_FillMissingTraces_0x128x128), and* **Hit** OK.

21. ***Type*** *in the Inline field: 425, and* **Hit** Enter.

The same way, add to the display, the original seismic and seismic with missing traces .

22. **Right-Click** *on Inline 425 > Add > Attribute >Stored.* ***Select*** *the original seismic (e.g. 4 Dip steered median filter), and* **Hit** OK.

23. **Right-Click** *on Inline 425 > Add > Attribute >Stored.* ***Select*** *the seismic with missing traces (e.g.* Seismic with random missing traces as zeros*), and* **Hit** OK.

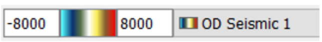


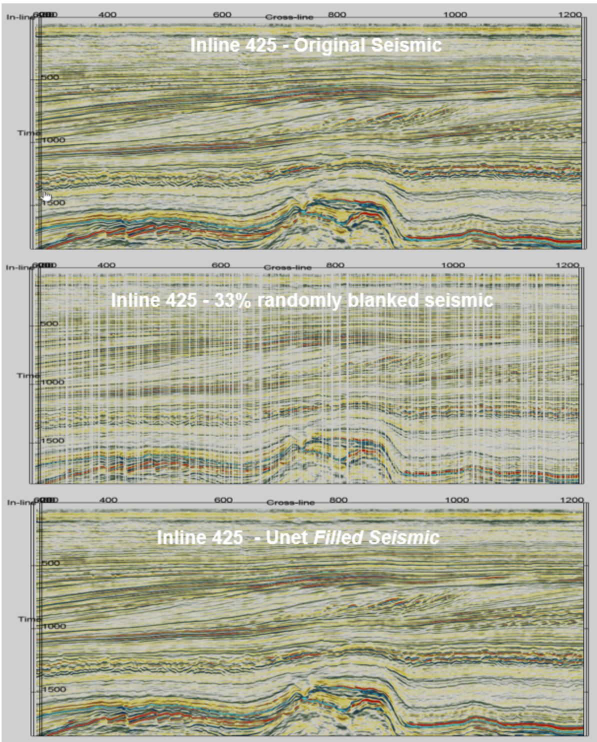
Workflow cont'd:

24. **Compare** visually in the blind test area the:

- *Original seismic (4 Dip steered median filter)*
- *Randomly blanked traces seismic (*Seismic with random missing traces as zeros*)*
- *Unet filled seismic (ML_Unet_FillMissingTraces_0x128x128)*

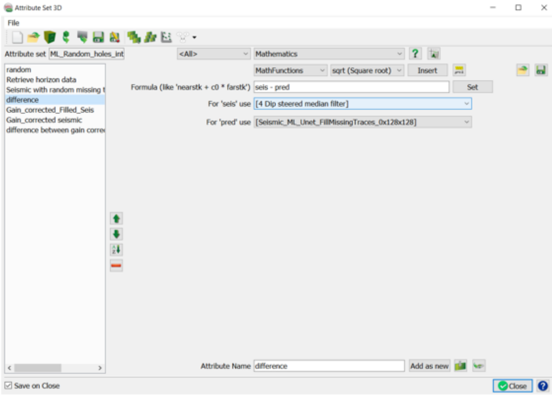
25. For more accurate comparison, ***Set*** *similar colour range for the 3 seismic cubes. Highlight the seismic cube, Set the colour bar range to (-8000, 8000).*





Workflow cont'd:

For a better quantitative comparison, create a new attribute 'difference' that computes the difference between the predicted and the original seismic.



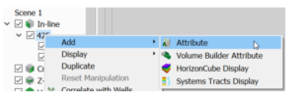
26. Select the 3D attribute icon . **Open** the attribute set . **Select** the attribute set ''ML_Random_holes_interpolation''

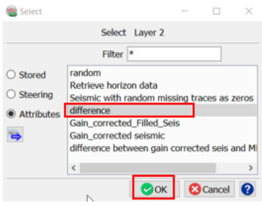
27. **Create** a 4th attribute ''difference'' as indicated in the attribute set window and **Hit** 'Add as new'.

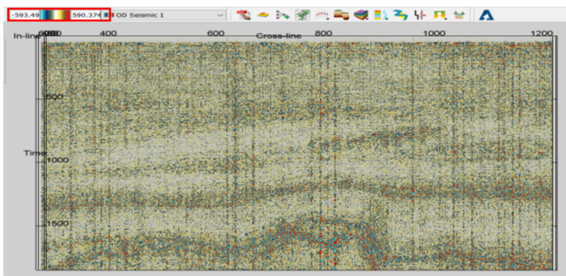
28. Select the Original seismic (e.g. *4 Dip steered median filter) for 'Seis', and the predicted seismic (e.g. ML_Unet_FillMissingTraces_0x128x128) for 'pred'*

Workflow cont'd:

Display/QC the attribute ''difference''. Difference = Original seismic (*4 Dip steered median filter)* – Predicted seismic (*ML_Unet_FillMissingTraces_0x128x128)*

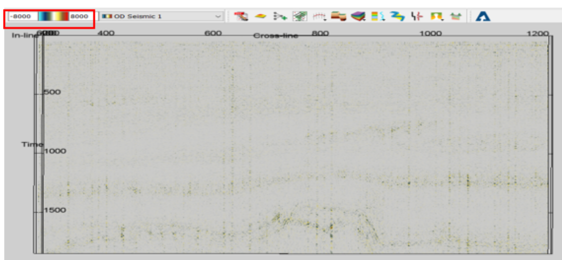






29. Right-Click *on Inline 425 > Add > Attribute.* ***Select*** *the attribute 'difference'', and* **Hit** OK.

Notice the small values of the difference, range (-593, 590).



30. For more accurate comparison, **Modify** the color range to similar range as the original and predicted seismic [-8000,8000]

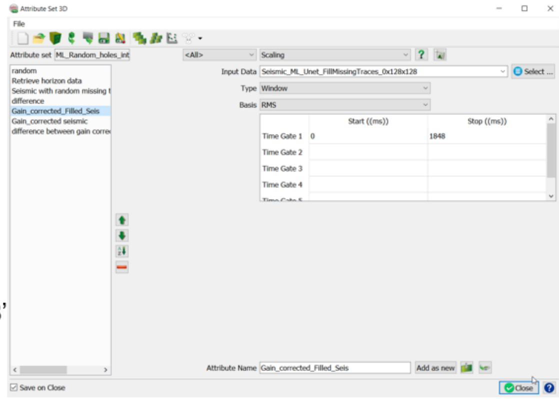
Workflow cont'd (Optional):

For more accurate comparison, apply an RMS gain scaled correction to the original and predicted seismic, than compute the difference.
Create a new Gain correction attributes to be applied on the original and predicted seismic.

31. Select the 3D attribute icon . **Open** the attribute set . **Select** the attribute set ''ML_Random_holes_interpolation"

32. Create a 5th attribute ''Gain_corrected_Filled_Seis" as indicated in the attribute set window and **Hit** 'Add as new'

33. Select the Input Data ''Seismic_ML_Unet_FillMissingTraces_0x128x128'



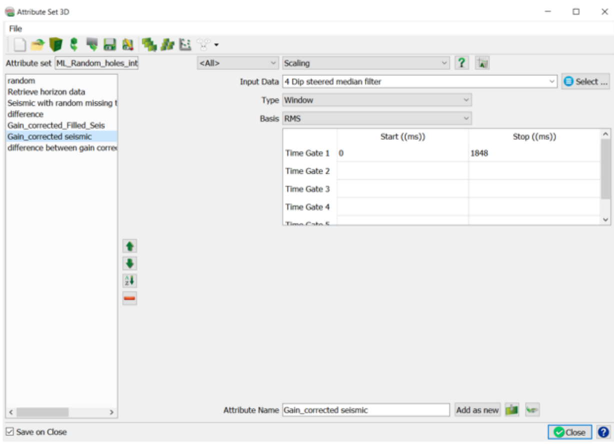
Workflow cont'd (Optional):

For more accurate comparison, apply an RMS gain scaled correction to the original and predicted seismic, than compute the difference.
Create a new Gain correction attributes to be applied on the original and predicted seismic.

34. Select the 3D attribute icon . **Open** the attribute set . **Select** the attribute set ''ML_Random_holes_interpolation"

35. **Create** a 6th attribute ''Gain_corrected seismic" as indicated in the attribute set window and **Hit** 'Add as new'

36. Select the Input Data 'Gain_corrected seismic"



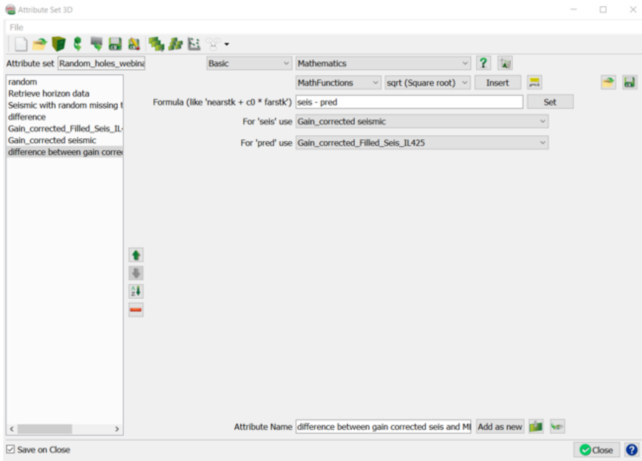
Workflow cont'd (Optional):

Create a new attribute that will compute the difference between the RMS gain corrected original seismic and ML predicted seismic

37. Select the 3D attribute icon . **Open** the attribute set . **Select** the attribute set ''ML_Random_holes_interpolation''

38. Create a 7th attribute ''difference between gain corrected seis and ML pred'' as indicated in the attribute set window and **Hit** 'Add as new'.

39. **Select** the ''Gain_corrected seismic'' as input for 'seis' and the ''Gain_corrected_Filled_Seis'' as input for 'pred'

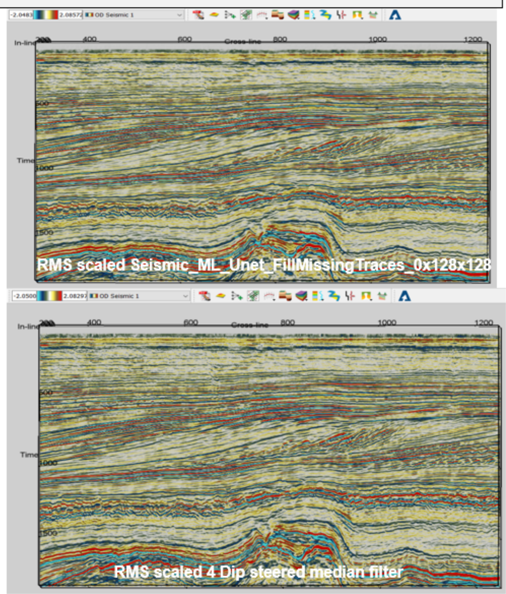


Workflow cont'd (Optional):

Display the attribute ''Gain_corrected_Filled_Seis'' (RMS scaled Seismic_ML_Unet_FillMissingTraces_0x128x128) and the ''Gain_corrected seismic''(RMS scaled 4 Dip steered median filter).

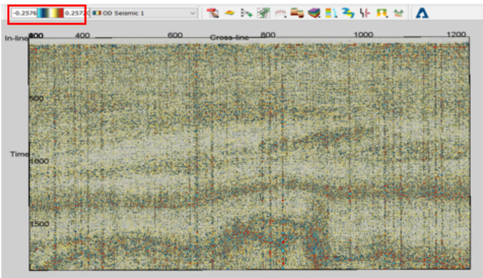
40. Right-Click *on Inline 425 > Add > Attribute.* ***Select*** *the attribute* ''Gain_corrected_Filled_Seis'', *and* **Hit** OK.

41. Right-Click *on Inline 425 > Add > Attribute.* ***Select*** *the attribute* 'Gain_corrected seismic'', *and* **Hit** OK.



Workflow cont'd (Optional):

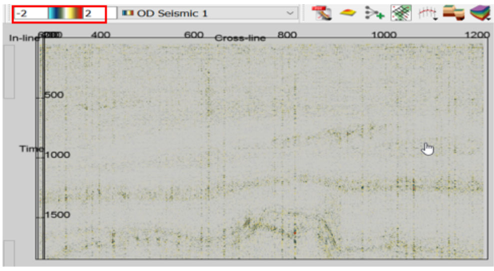
Compare quantitatively in the blind test area the RMS gain corrected difference between the *original seismic and the predicted seismic.*



42. **Display** the ''difference between gain corrected seis and ML pred'' seismic attribute. **Right mouse click** on the In-line 425. **Select** ''Add and Select Data''.

43. **Select** the attribute ''difference between gain corrected seis and ML pred'' and **Hit** Ok.

Notice the very low values of the ''difference between gain corrected seis and ML pred''. The range [-0.257, 0.257].



44. For more accurate comparison, display the difference attribute with similar colour range as the gain corrected original and predicted seismic. ***Highlight*** *the seismic cube, Set the colour bar range to [-2, 2].*

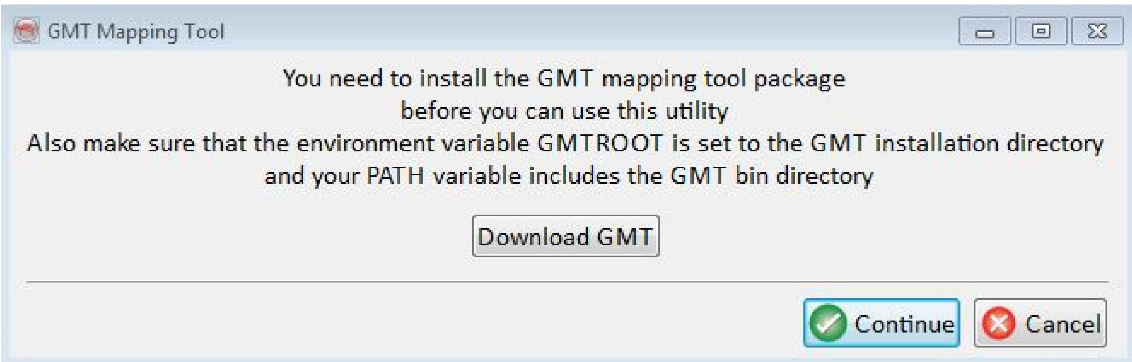
Appendix - GMT Software

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.

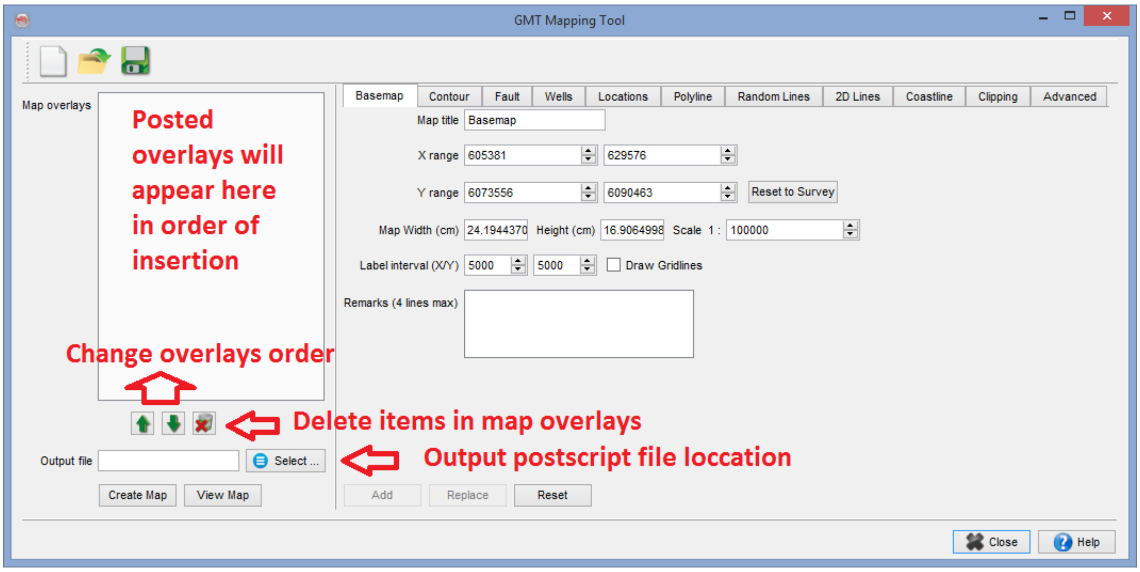
In this appendix, we will shortly explain the GMT plug-in and we will create different maps in OpendTect:

To launch GMT tools, go to Processing menu > GMT Mapping Tool. 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 website.



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 can be set from *Computer* > *System Properties* > *Advanced System Settings*.

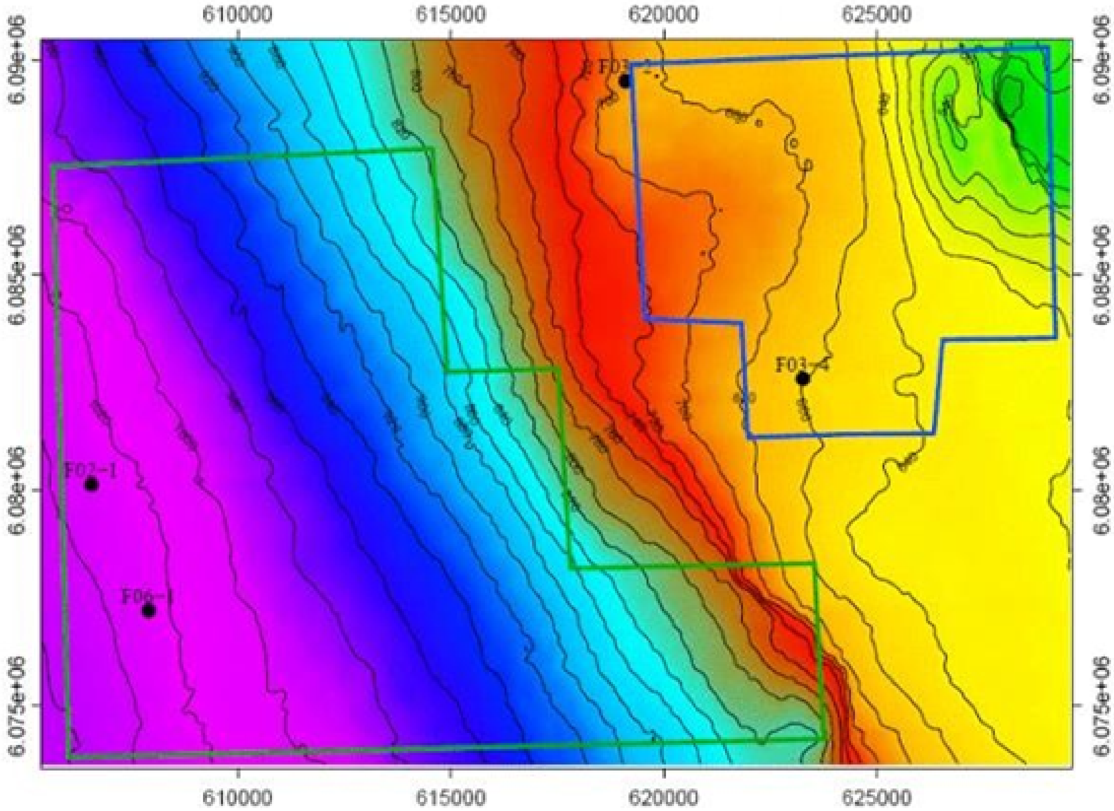
After successful installation of GMT package, the GMT user interface will be started:



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