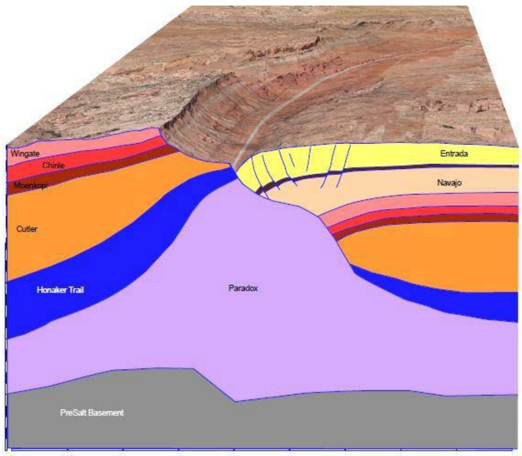
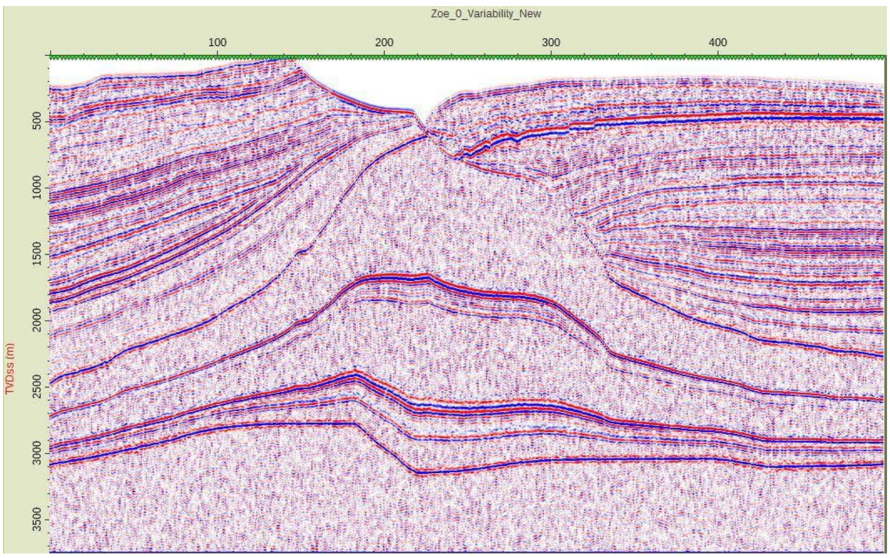
Synthetic Seismic Modelling of Geological Outcrops





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Introduction

Seismic imaging is the key method for imaging the structure of the subsurface. Data are generated by sending acoustic energy (sound waves) into the Earth and recording the reflections which are returned from the various layers. Seismic imaging is used extensively in the petroleum industry and also in mining, civil engineering and hydro-geology. The majority of geology students will ultimately end up in jobs that make extensive use of seismic data.

Geology students are trained to study seismic data using datasets that have been donated from various industrial sources. They also spend a significant proportion of their time studying rocks in the field, but the connection between the two is generally quite poor. Seismic data lack the detail and resolution of seeing rocks at the surface, but the outcrops that are normally studied are typically far smaller than the volume or area covered by a seismic section which maybe several tens km long and extend to km into the Earth's crust. Consequently students become good at looking and seismic data and good at understanding rocks in the field, but often lack the ability to mentally combine the two. The gap can be filled though the use of forward seismic modelling that nowadays allow us to simulate seismic acquisition and seismic imaging across geological outcrops .The practice and use of this methodology will impacts their transition to the employment market.

The aims of this project were twofold:

1. To take existing software code which is used to generate synthetic seismic data from vector images (correl draw or similar) and generate a suite of synthetic seismic lines for outcrops visited on various fieldtrips. This included a series of outcrops that are visitred during the ntergrated Petreoleum Geoscicence MSc field trip to Utah.. The synthetic seismic was be generated using a variety of acquisition design, different source frequencies, illumination methods and overburden thicknesses to highlight the range of seismic images that might be generated by the strata if they were in the subsurface.

2. To develop a workflow and web based front end for the software which will allow the rapid upload of geological data (e.g Import of external horizon and elastic property data in simple ASCII or standard SEG-Y formats) into the forward seismic modelling to generate synthetic seismic data, so that the same output can quickly and easily be generated for any outcrop in the current or future fieldtrip portfolio

Outcomes include:

1. A library of synthetic seismic images which are now used for field teaching
2. Workflows for building synthetic seismic lines
3. Workflow for efficient and rapid importing of external horizon and elsastic property

Background

A workflow was developed for the creation of the synthethic seismics. This workflow is presented below. The key parameters that affect the final results are:

·**Geological complexity**: The geological settings of the section is going to influence the time that we are going to spend creating the seismic and the number of virtual wells that we will need to create to generate the reflectivy series.

·**Frequency**: We have been working with frequencies from 25-30 Hz, which are the most common in real seismic acquisition. Frequency and investigation depth are extremely correlatable. High frequencies allow us to get more detailed resolution but constrained to really shallow depths, on the other hand, low frequencies allow us to go deeper but with less detail.

·**Thickness**: As we explained in the last point, the thickness of our section (depth) is going to influence the final result. Because we are working with 25 Hz frequencies we are going to reach the best results with thick sections (>300 meters thick)

Workflow for generating seismic

Outcome: Generate synthetic seismic sections from a virtual outcrop or a field photo. Using a combination of field photos and well data possible to generate a synthetic seismic section in RokDoc 2D.

Steps:

1. Digitise field photo in Corel or Inkscape etc. This will be the backdrop you import into RocDoc for making the synthetic.
2. Open RocDoc and start a new session in RocDoc-2D.
3. Set your parameters based on your backdrop or your well data.
4. Digitise the image in RocDoc by creating events. Events that are closed are individual bodies.
5. Assign wireline properties to your bodies, density and velocity are the most important as these will be used for generating the seismic response.
6. Generate a wavelet (Ricker most common).
7. Generate a synthetic specifying which frequency to use, higher frequency's will result in better imaging.
8. Input a well with real velocity and density data analogous or from the area this will generate a better synthetic.

Digitise field photo

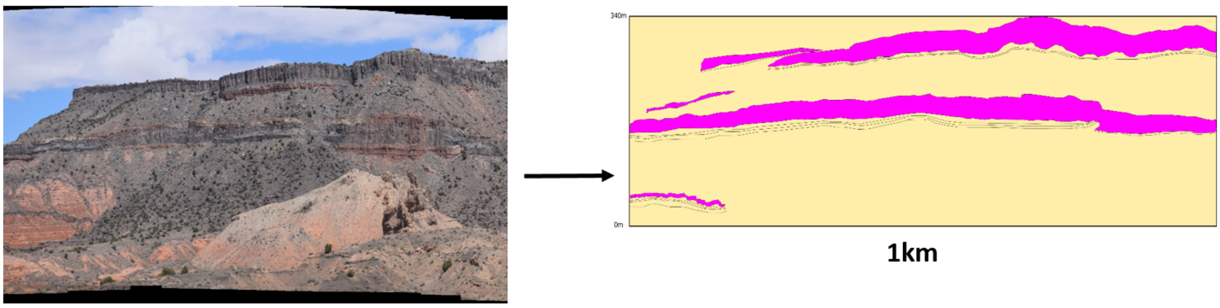
This can be made as complex or as simple as you want it to be. Field photos with multiple thin beds will take longer and ultimately take longer to digitise in RocDoc-2D. RocDoc-2D also struggles to digitise vertical features unless you have a greater number of Traces and line spacing (see No.2).

1.1. Digitise field photo in a illustrator software.

1.2. Need to know the height of your section and the length.

1.3. Export the image as a .jpeg.

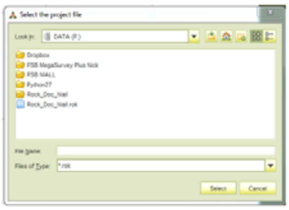
Example: Igneous sills in the Entrada Sandstone, San Rafael, Utah:



This is a simple example but it can be much more complex. See Jose examples.

Start RocDoc

Open up RocDoc and start a new project and give your project a name (fig.1).



Click on RocDoc-2D tab and start a new session. A box will open which will ask for the input parameters for the image you digitised and want to make a synthetic out of (fig.2):

Parameters for the new session should be based on your image, i.e. a 340m and 1km wide.

The greater the number of traces the easier it is to digitise your image in RocDoc.

You can also enter available well data you have here but this workflow will enter well data at a later stage.

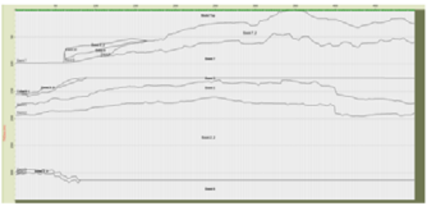
Click ok and ok on the next two dialogue boxes. These parameters can stay as default. Your RocDoc-2D window will now open.

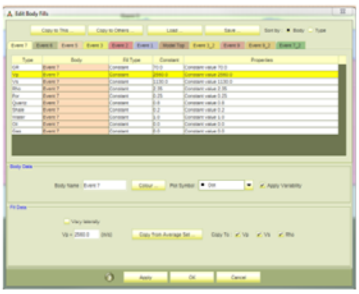
Create bodies and assign them values

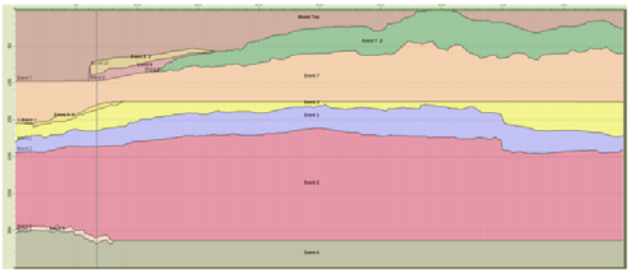
Once you have digitised all your features in the backdrop it will look something like this:

You can now make bodies using the bodies tab: Right click *bodies* then make *bodies.*

You can then add edit the body fill by using *edit body fill*. The seismic response is generated from the Acoustic Impedance which is generated from density and sonic. Edit your Vp and Rho values for each body.







Create bodies and assign them values

Once you have digitised all your features in the backdrop it will look something like this:

You can now make bodies using the bodies tab: Right click *bodies* then make *bodies.*

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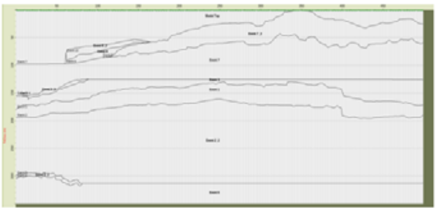
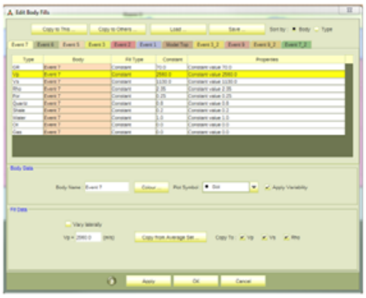
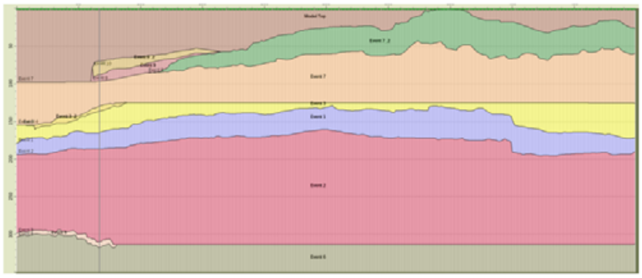
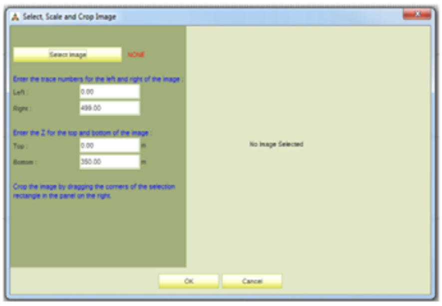


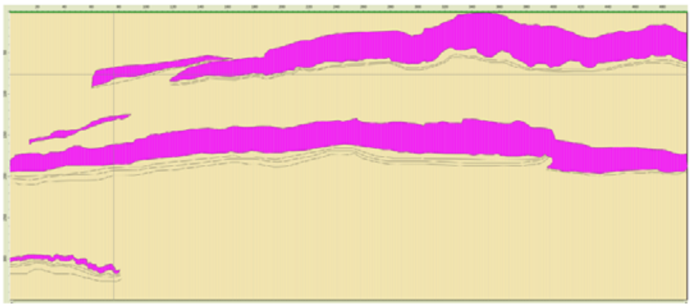




Upload your back drop & Digitise it

Right click on *Backdrop-Add backdrop* the following box will then open and you can then select the image you previously digitised from your field photo. The parameters you previously entered should match your image





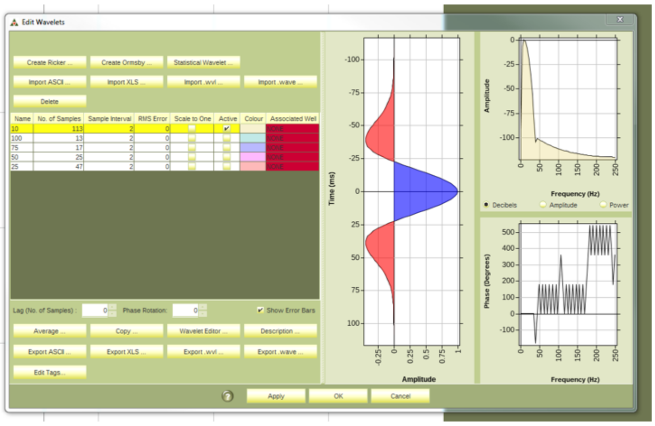
You can now digitise the features in your backdrop by right clicking on *events-add event*. You can then digitise the features, you can only add one point per trace in an event which is why it is better to have more traces. Vertical features are difficult to digitise.

Create synthetic

Synthetic is generated by first creating a wavelet: got to main RocDoc window-*project data-wavelets.*

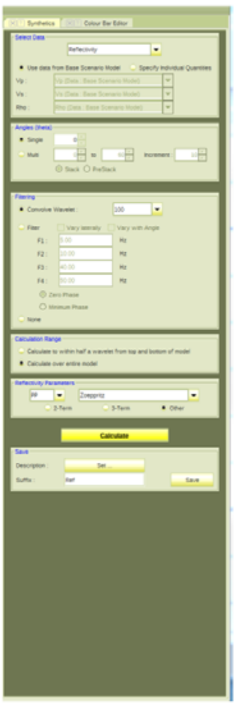
This opens a new window, click on: *create Ricker-then ok the next few windows.*

This will be used to generate your synthetic.



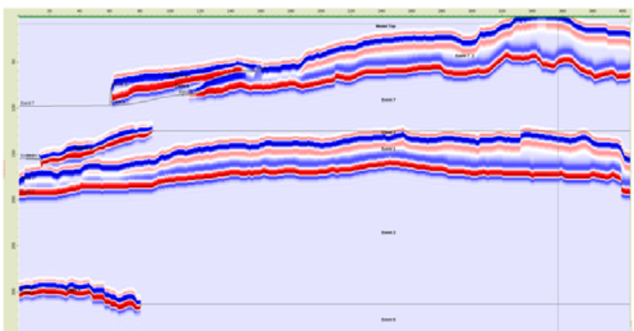
Create synthetic

Right click on reflectivities: *Create synthetics* this will open the synthetics window where you choose the following inputs and use the ricker wavelets you generated earlier.



You can then display your seismic line by ticking the synthetic created under reflectivities:

In this example only the igneous sills values have been altered so there is no reflectivity recorded for the events between the sills. If you later the Vp and Rho values for them this will change the output.



If you have well data for the region or for nearby you can input this well data into your 2D model to generate a more realistic synthetic.

This can be done by adding the well into the project at the start or by planning a well that fits your model then uploading real values to that well.

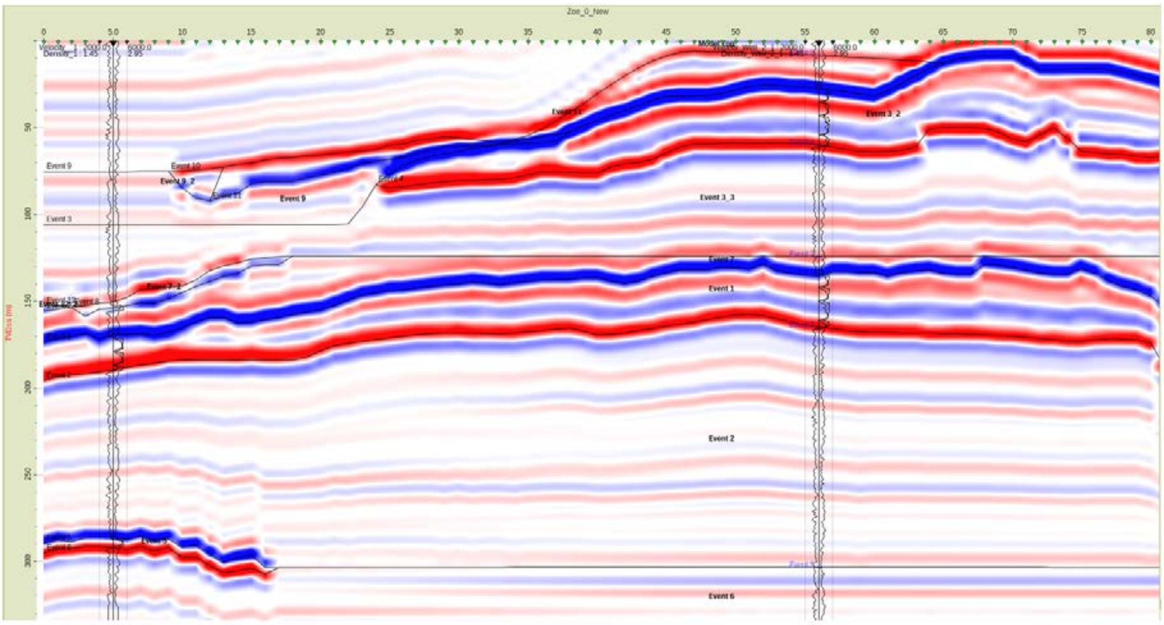
Go to utilities tab: *plan well- start planning* then click on your 2D model where you want the well to go. This well will now appear in your main RocDoc window and you can now upload the real sonic and density data to this well:

Well management-create log from file (the velocity and density data should be in a .txt file and the 1st column will be depth and the second column the values). You assign the velocity and density values you have to the well you planned previously.

You can repeat this process several times and from here you can then create your synthetic but the synthetic response for the bodies will be generated using the well data. The edit bodies fill tabs will say interpolation instead of constant.

Create synthetic

Finished synthetic using well data for inputs. Still a simplistic model.



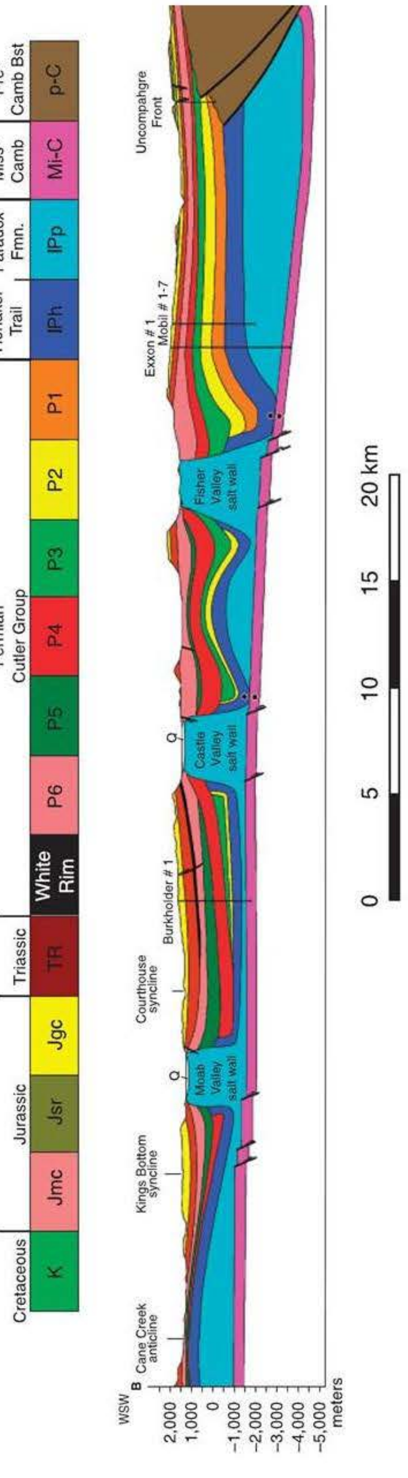
Results

For each of the studied sections the original image that we used to create the seismic is presented followed by the resulting synthetic seismic. These are presented in association with the settings that were used during the synthetic seismic generation and the rock properties that were used as an input for the different formations.

To create the synthetic seismics continues logs for density and wave propagation velocity (Vp) were used. Small sections of well logs were digitised for every formation and then put together. This is termed a virtual well (A user created well using real values, and adapting it to the geological structure of our section)

The rock properties tables refer to average values, extracted from different well logs located around Utah (*in situ* values) or from other analogues located around the Norwegian Sea.

·Regional section through the Moab and Castle Valley Salt Walls.



Parameters used:

·Wavelet: Ricker wavelet (Zero phase)

·Time acquisition: 2ms

·Frequency: 25 Hz

·Incidence angle of the seismics waves: 0 degrees

·Propagation of the seismic waves: Zoeppritz equations

·Rock Properties:

Formations	Facies/Lithology	Vp (m/s)	Rho (g/cc)
Entrada Fm.	Aeolian Dunes	3586.8	2.209
Navajo Fm.	Aeolian Dunes	3720.23	2.25
Wingate Fm.	Aeolian Dunes	3731.34	2.29
Chinle Fm.	Fluvial Channels and Eolian Dunes	4728.58	2.528
Moenkopi Fm.	Fluvial Channels and Eolian Dunes	4739.33	2.57
Cutler Fm.	Fluvial Channels, Floodplain, Eolian	5681.81	2.596
Hoonaker Trail Fm.	Marine Limestones and Sandstones	5952.38	2.65
Paradox Fm.	Evaporites	4587.15	2.243
Pre-Salt Fms.	Unknown	6097.56	2.759

Comments:

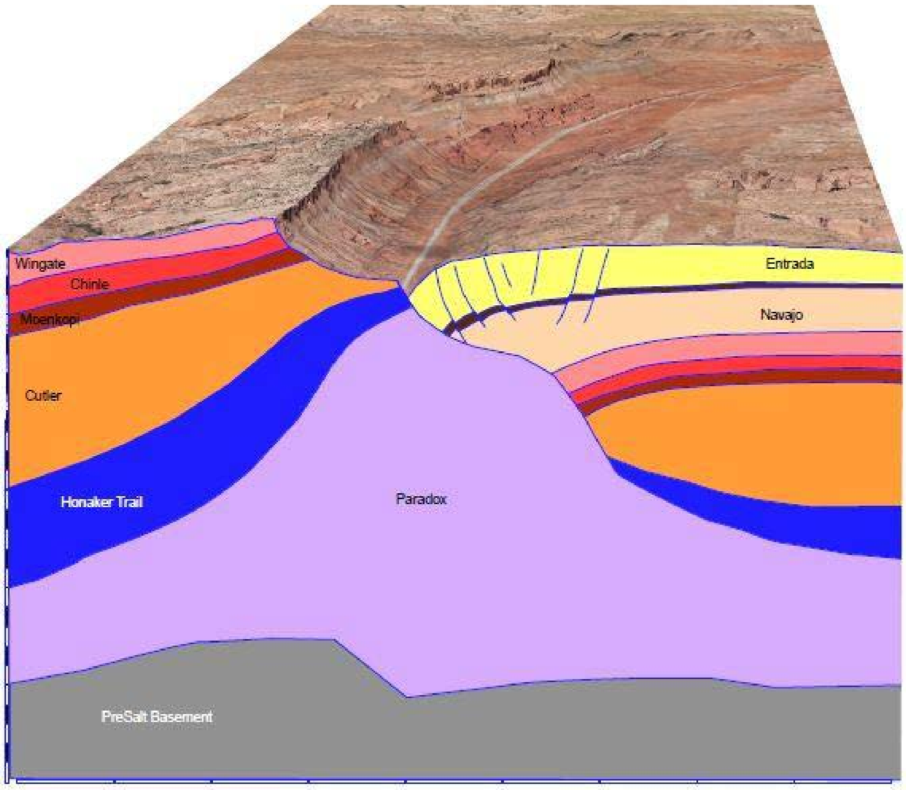
The scale of this seismic is 60 km wide and 7 km thick across the whole Paradox Basin.

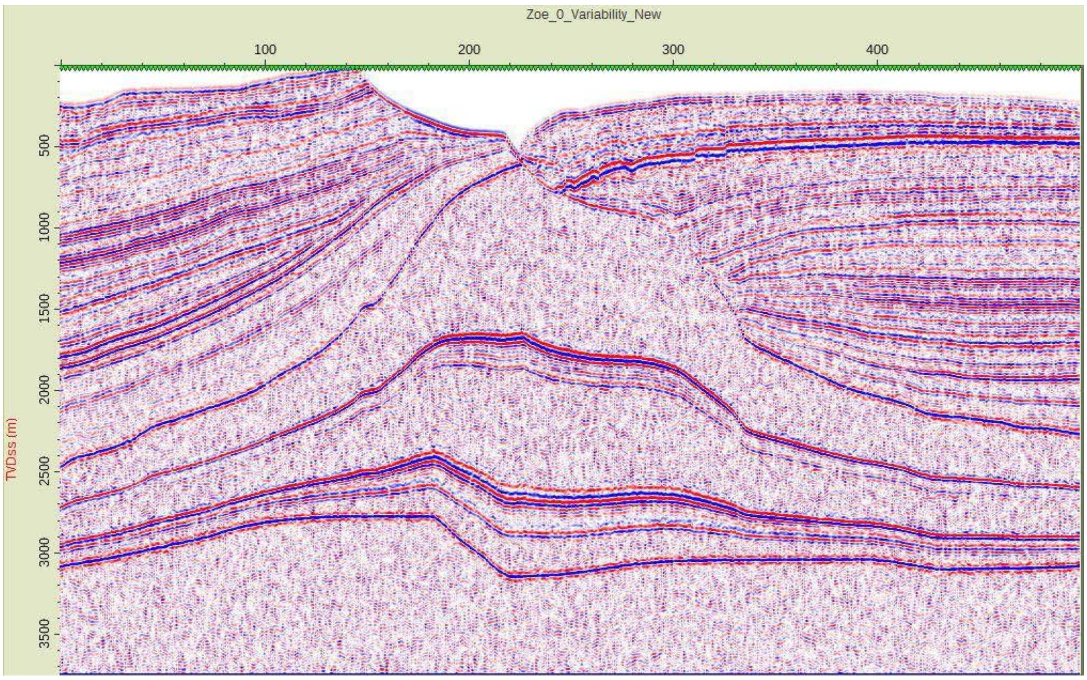
To generate this seismic we used well log values from Utah, so the seismic response that you are seeing is the real one for this formations. To create a more realistic result we add a small quantity of noise.

To create the reflectivity series, we designed 9 virtual wells using the values from Utah well logs

This is the biggest section that we created and it’s the perfect example to get a closer look to the potential of the synthetic seismics generation.

Moab Fault at the Arches Visitors Centre





Parameters used:

·Wavelet: Ricker wavelet (Zero phase)

·Time acquisition: 2ms

·Frequency: 25 Hz

·Incidence angle of the seismics waves: 0 degrees

·Propagation of the seismic waves: Zoeppritz equations

·Rock Properties:

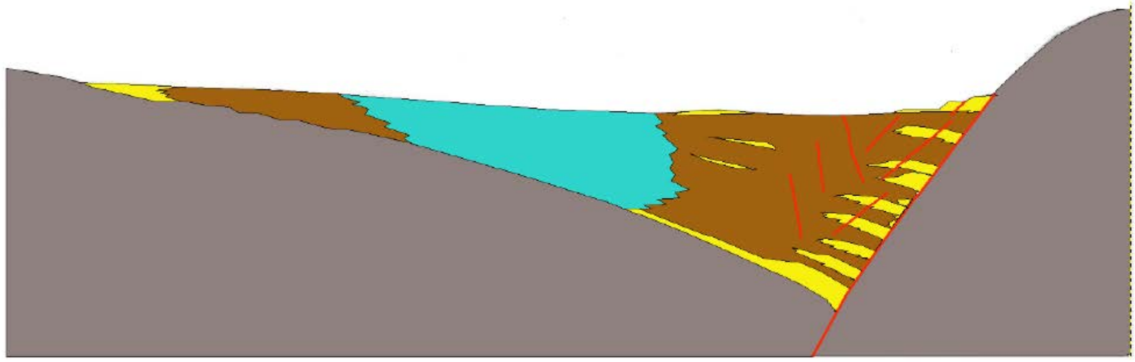
Formations	Facies/Lithology	Vp (m/s)	Rho (g/cc)
Entrada Fm.	Aeolian Dunes	3586.8	2.209
Navajo Fm.	Aeolian Dunes	3720.23	2.25
Wingate Fm.	Aeolian Dunes	3731.34	2.29
Chinle Fm.	Fluvial Channels and Eolian Dunes	4728.58	2.528
Moenkopi Fm.	Fluvial Channels and Eolian Dunes	4739.33	2.57
Cutler Fm.	Fluvial Channels, Floodplain, Eolian	5681.81	2.596
Hoonaker Trail Fm.	Marine Limestones and Sandstones	5952.38	2.65
Paradox Fm.	Evaporites	4587.15	2.243
Pre-Salt Fms.	Unknown	6097.56	2.759

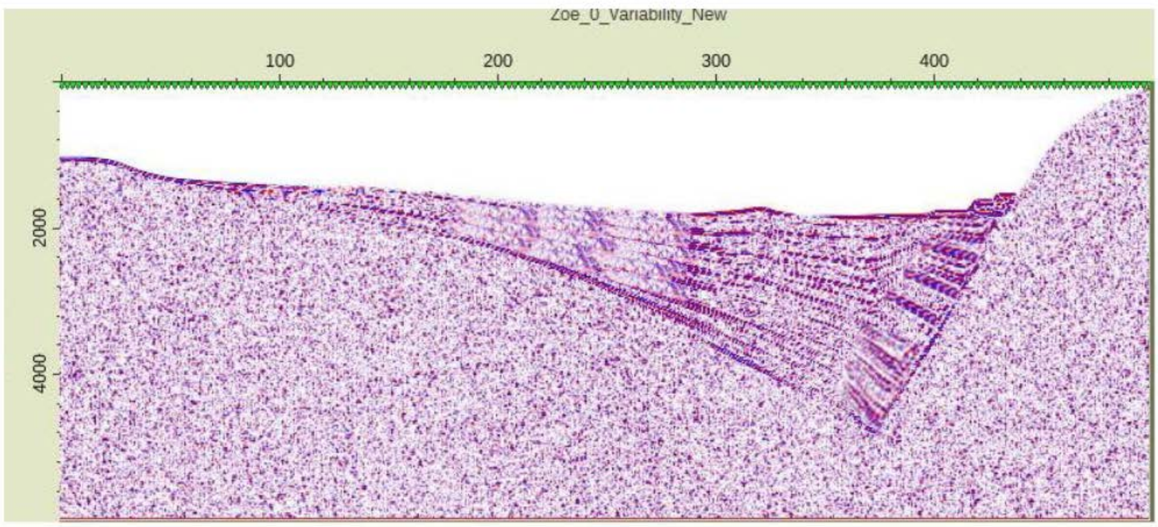
Comments:

To generate this seismic we used well log values from Utah, so the seismic response that you are seeing is the real one for this formations. To create a more realistic result we add a small quantity of noise.

To create the reflectivity series, we designed 2 virtual wells using the values from Utah well logs, one on the hanging wall and the other one on the footwall.

Wasatch Fault.





Parameters used:

·Wavelet: Ricker wavelet (Zero phase)

·Time acquisition: 2ms

·Frequency: 25 Hz

·Incidence angle of the seismics waves: 0 degrees

·Propagation of the seismic waves: Zoeppritz equations

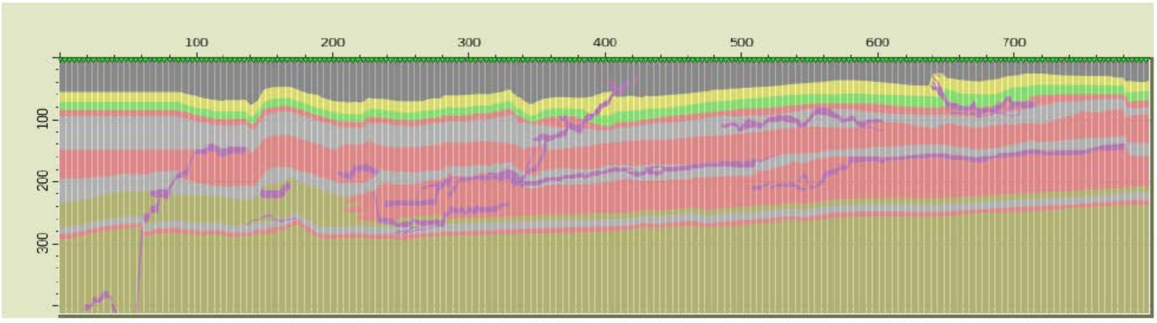
·Rock Properties:

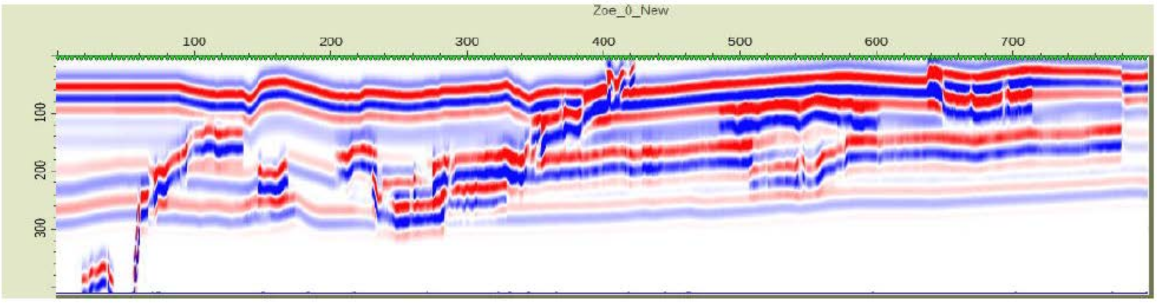
Formations	Facies/Lithology	Vp (m/s)	Rho (g/cc)
Lunde Fm.	Mudstones	2788.9	2.249
	Fluvial Channels belts	3144.65	2.328
Paradox Fm.	Evaporites	4587.15	2.243

Comments:

The values for density and velocity have been acquired from well logs located on the Norwegian sea which are analogues for this formations. We add a bit of noise to get a more realistic result.

·Faroe-Shetland Complex (Greenland).





Parameters used:

·Wavelet: Ricker wavelet (Zero phase)

·Time acquisition: 2ms

·Frequency: 25 Hz

·Incidence angle of the seismics waves: 0 degrees

·Propagation of the seismic waves: Zoeppritz equations

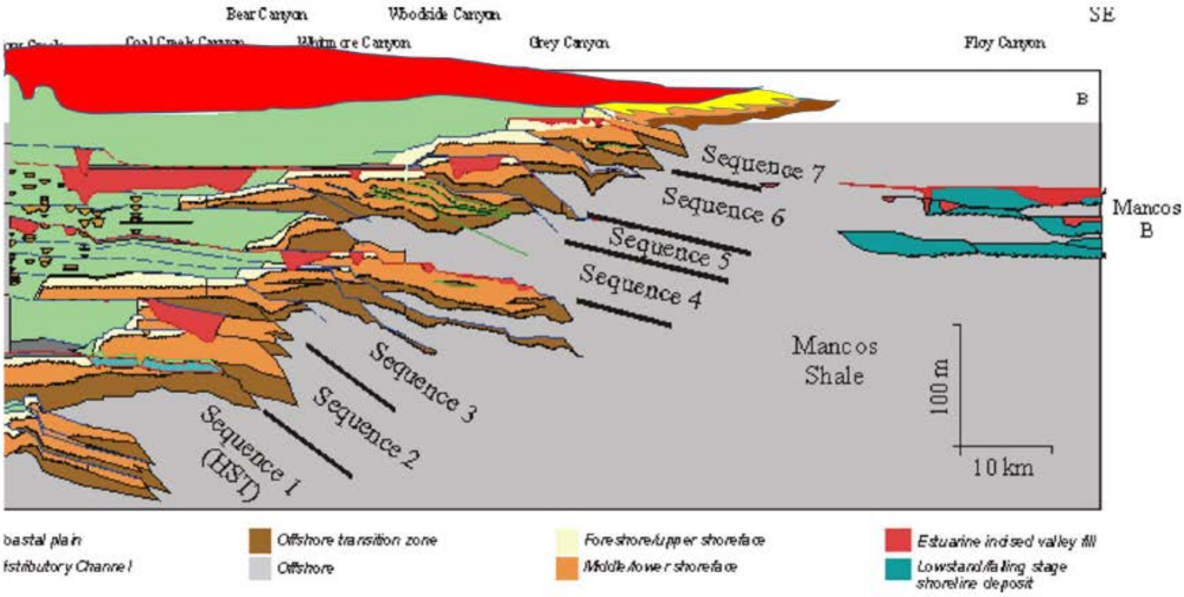
·Rock Properties:

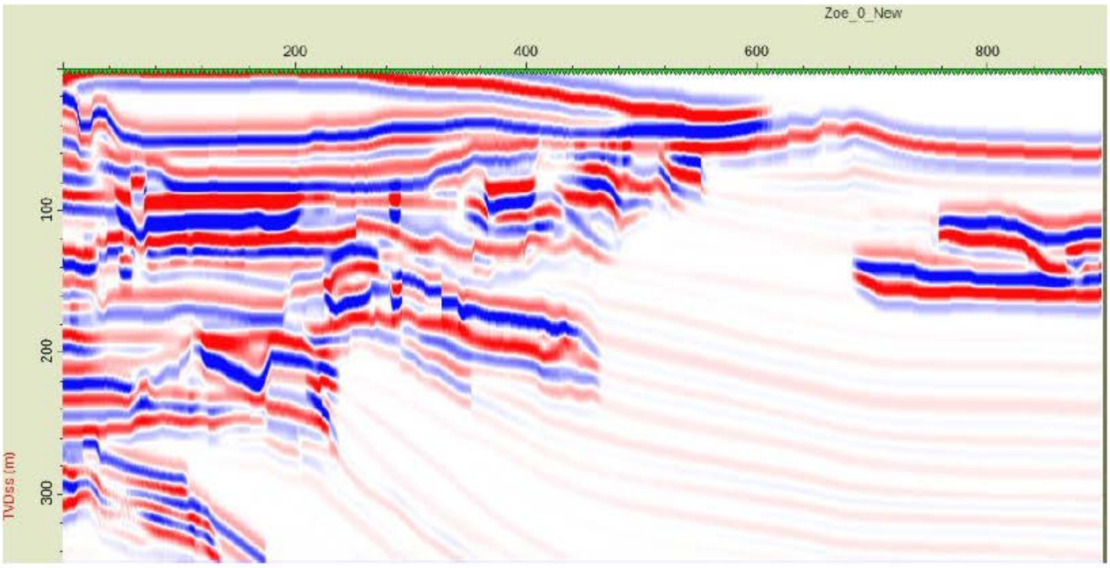
Formations	Facies/Lithology	Vp (m/s)	Rho (g/cc)
Ror Fm.	Mudstones	3389	2.459
Tilje Fm.	Homogeneous Sandstones	3484.32	2.48
	Sandstones (<80%)	3257	2.415
	Poorly Cemented Sandstones	2915	2.109
	Hetherolitic Sandstones	3105.59	2.311
Draupne Fm.	Organich Rich Mudstones	2375.29	2.07
Basalts	Dolerite Sills	6291	3.03

Comments:

The values for density and velocity have been acquired from well logs located on the Norwegian sea which are analogues for this formations. In this case we didn't add noise to the seismic.

·Book Cliffs.





Parameters used:

·Wavelet: Ricker wavelet (Zero phase)

·Time acquisition: 2ms

·Frequency: 25 Hz

·Incidence angle of the seismics waves: 0 degrees

·Propagation of the seismic waves: Zoeppritz equations

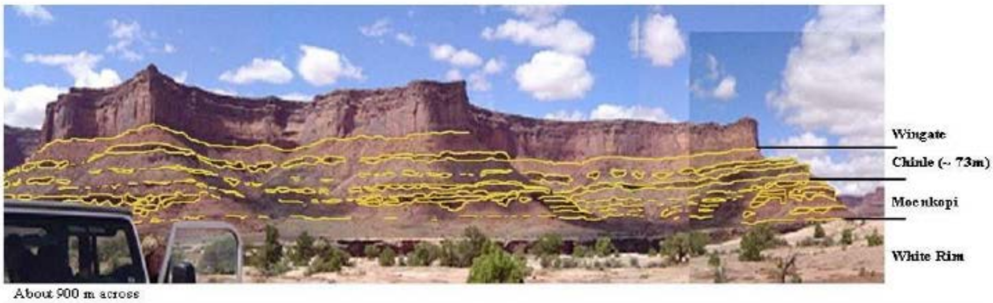
·Rock Properties:

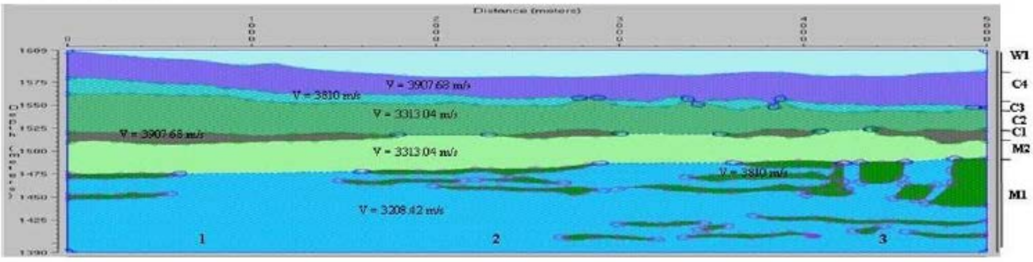
Formations	Facies/Lithology	Vp (m/s)	Rho (g/cc)
Ness Fm.	Coastal Plain	2816.9	2.293
	Coal	2392.34	2.091
Etive Fm.	Upper Shoreface	2785.51	2.101
Rannoch Fm.	Lower Shoreface	2849	2.208
	Transition zone	3105.59	2.353
Dunlin Grp.	Offshore Mudstones	3257.32	2.45

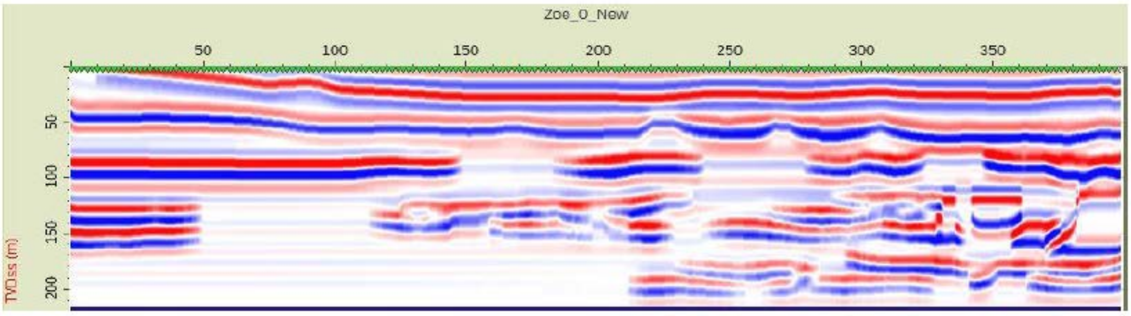
Comments:

The values for density and velocity have been acquired from well logs located on the Norwegian sea which are analogues for this formations. In this case we didn't add noise to the seismic.

·Chinle Formation.







Parameters used:

·Wavelet: Ricker wavelet (Zero phase)

·Time acquisition: 2ms

·Frequency: 25 Hz

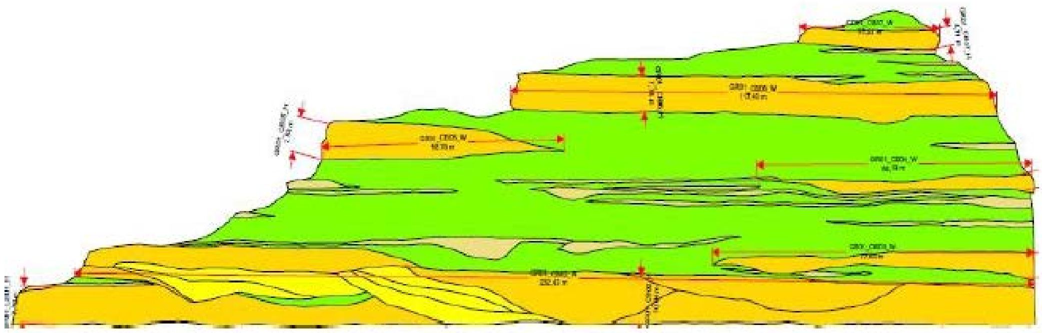
·Incidence angle of the seismics waves: 0 degrees

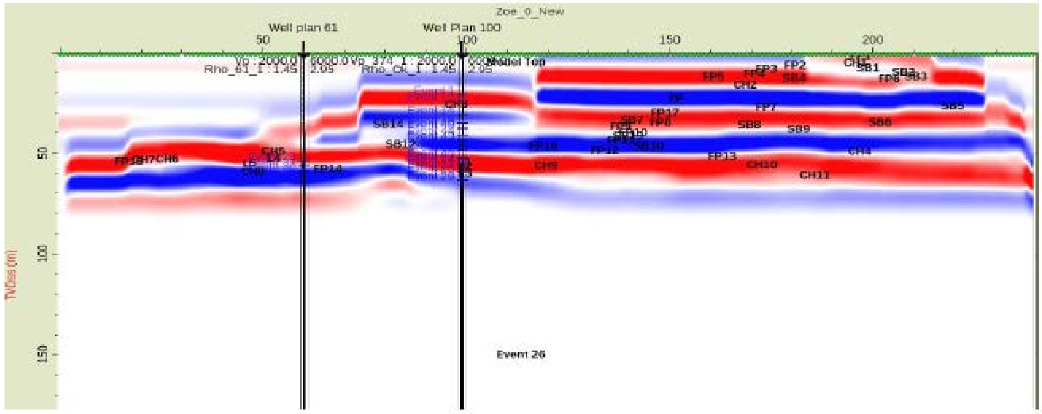
·Propagation of the seismic waves: Zoeppritz equations

·Rock Properties:

Formations	Facies/Lithology	Vp (m/s)	Rho (g/cc)
Wingate Fm.	W	3907.68	2.29
Chinle Fm.	C4	3810	2.528
	C3	3313.04	
	C2	3907.68	
	C1	3313.04	
Moenkopi Fm.	M2	3810	2.57
	M1	3208.42	

·Green River Formation.





Parameters used:

·Wavelet: Ricker wavelet (Zero phase)

·Time acquisition: 2ms

·Frequency: 25 Hz

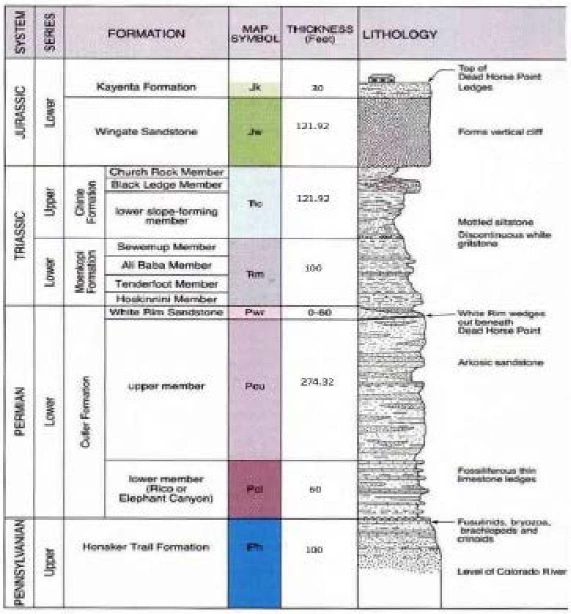
·Incidence angle of the seismics waves: 0 degrees

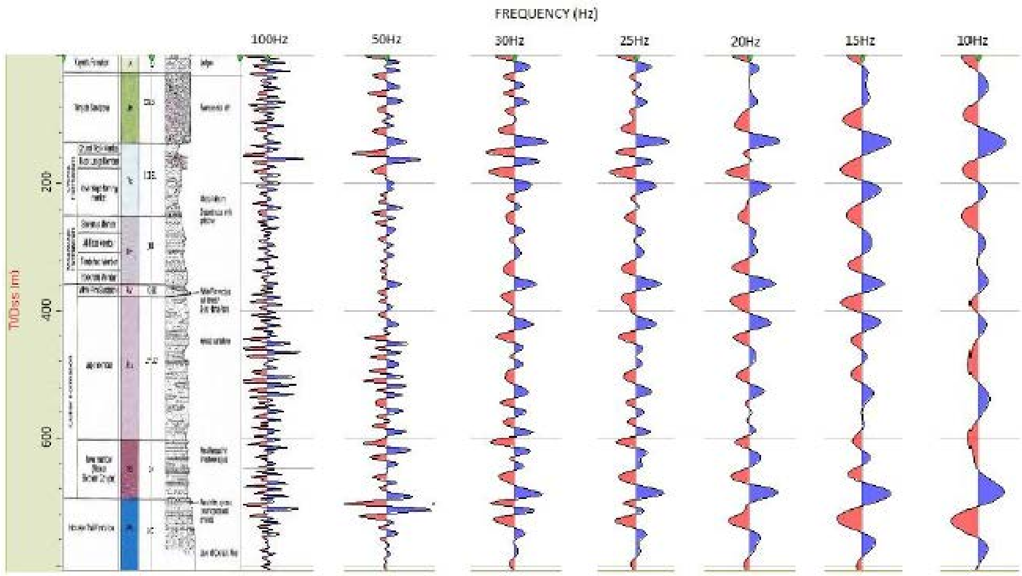
·Propagation of the seismic waves: Zoeppritz equations

·Rock Properties:

Formations	Facies/Lithology	Vp (m/s)	Rho (g/cc)
Lunde Fm.	Sheet Floods and Crevasse	3021.14	2.339
	Floodplain	2788.9	2.249
	Lateral migration fluvial	3538.13	2.398
	Fluvial Channels belts	3144.65	2.328

·Dead Horse Point.





Parameters used:

·Wavelet: Ricker wavelet (Zero phase)

·Time acquisition: 2ms

·Frequency: 10 Hz – 100 Hz

·Incidence angle of the seismics waves: 0 degrees

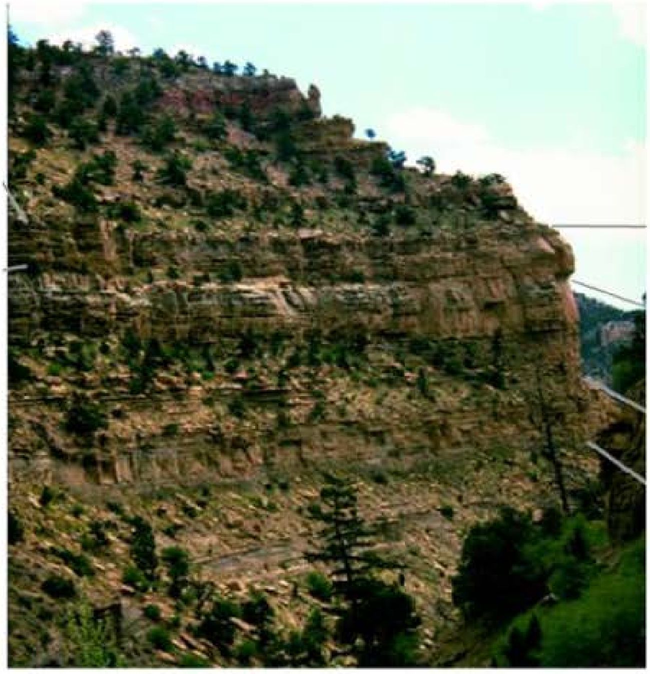
·Propagation of the seismic waves: Zoeppritz equations

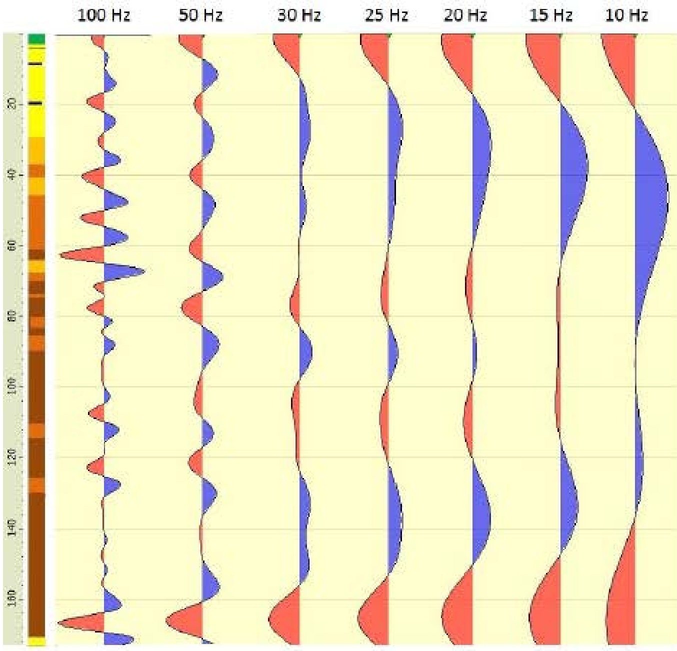
·Rock Properties:

Formations	Facies/Lithology	Vp (m/s)	Rho (g/cc)
Wingate Fm.	Aeolian Dunes	3731.34	2.29
Chinle Fm.	Fluvial Channels and Eolian Dunes	4728.58	2.528
Moenkopi Fm.	Fluvial Channels and Eolian Dunes	4739.33	2.57
Cutler Fm.	Fluvial Channels, Floodplain, Eolian	5681.81	2.596
Hoonaker Trail Fm.	Marine Limestones and Sandstones	5952.38	2.65

Comments: This image represents the result of convolute a single trace at different frequencies across the whole geological section to show how the vertical resolution of our seismic changes. High frequencies give us better resolution than low frequencies.

·Gentile Wash.





Parameters used:

·Wavelet: Ricker wavelet (Zero phase)

·Time acquisition: 2ms

·Frequency: 25 Hz

·Incidence angle of the seismics waves: 0 degrees

·Propagation of the seismic waves: Zoeppritz equations

·Rock Properties:

Formations	Facies/Lithology	Vp (m/s)	Rho (g/cc)
Ness Fm.	Coastal Plain	2816.9	2.293
	Coal	2392.34	2.091
Etive Fm.	Upper Shoreface	2785.51	2.101
Rannoch Fm.	Lower Shoreface	2849	2.208
	Transition zone	3105.59	2.353
Dunlin Grp.	Offshore Mudstones	3257.32	2.45

Comments:

This image represents the result of convolute a single trace at different frequencies across the whole geological section to show how the vertical resolution of our seismic changes. High frequencies give us better resolution than low frequencies.