USE OF QUANTITATIVE SEISMIC ANALYSIS TO DEFINE RESERVOIR ARCHITECTURE AND VOLUMES

AN EXAMPLE FROM THE JOHAN SVERDRUP FIELD

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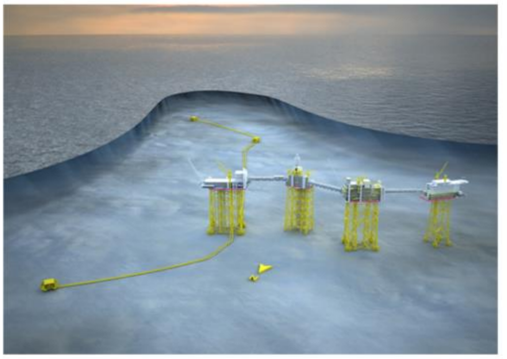

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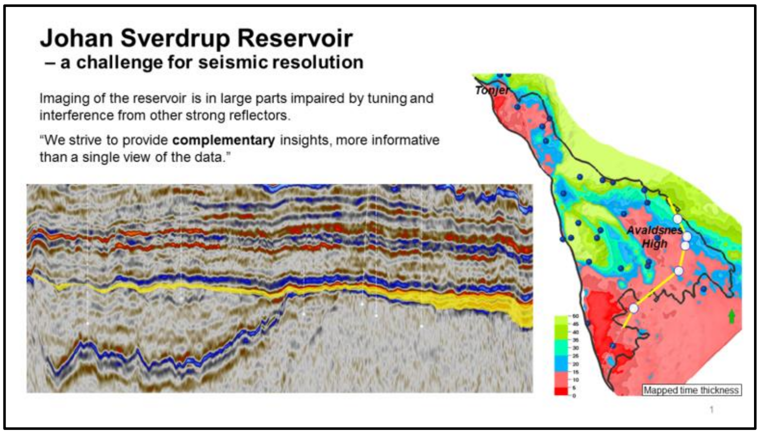


Text...

- The giant Johan Sverdrup Field was discovered in 2010, and improvement in seismic imaging played an important role in it's discovery.

- Only one year before the discovery, PGS acquired on behalf of Lundin a new 3D seismic survey with Geostreamer technology that provided broadband data and allowed a step change in imaging of the subsurface.

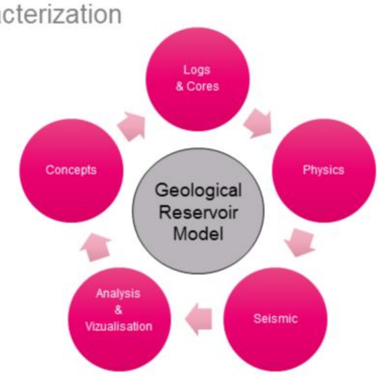
- The usual seismic challenge – how to improve resolution, however, still remained. A quite extensive area shows a thin reservoir below tuning thickness in the southern area of the field.

- In this presentation we will have a closer look at the reservoir, both in the seismic time and frequency domain. In addition we demonstrate techniques that lead to a better understanding of the thin layer architecture.

Outline

Seismic resolution – first order challenge in reservoir characterization

- Introduction
- Basic principles
- Options for visualizing thin bedded resolution
- Examples - Visualizing internal layering
- Verification
- Conclusions



Text...

- After this short introduction I will first review some basic principles and options for visualizing thin bedded resolution
- …and in the second part go through some practical examples of visualizing internal layering from work in the Johan Sverdrup field…
- …before finally concluding by a short summary.

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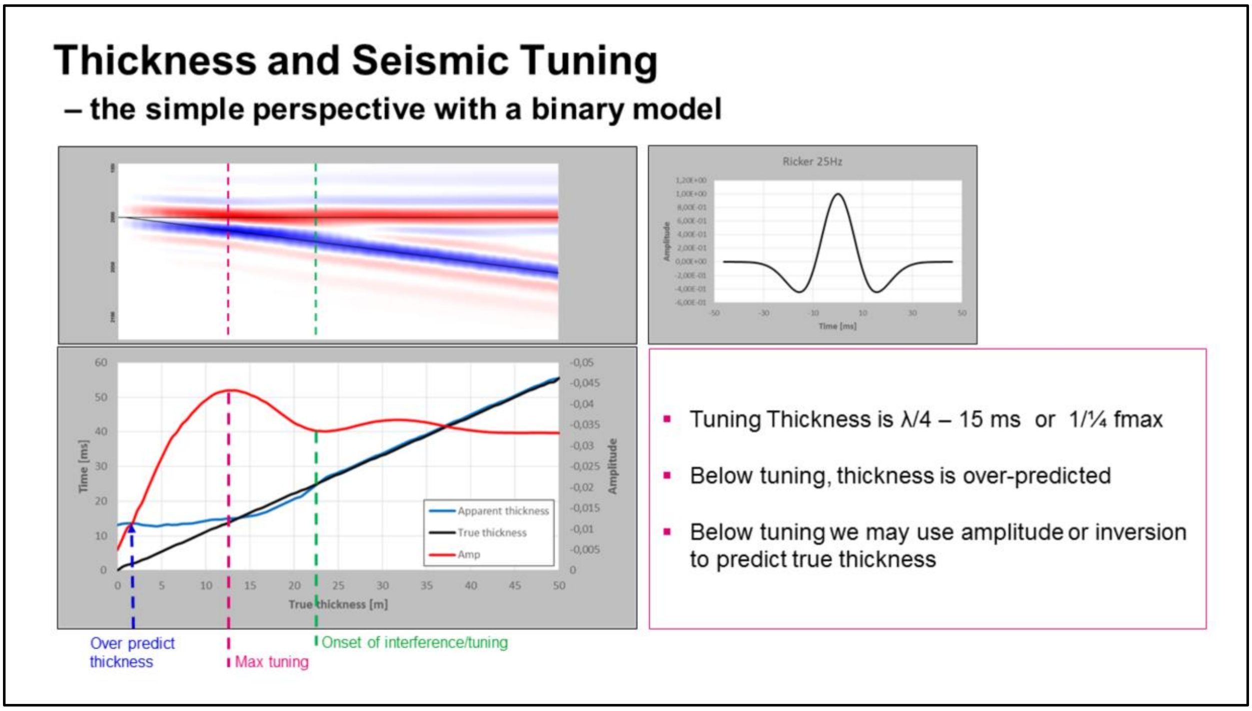
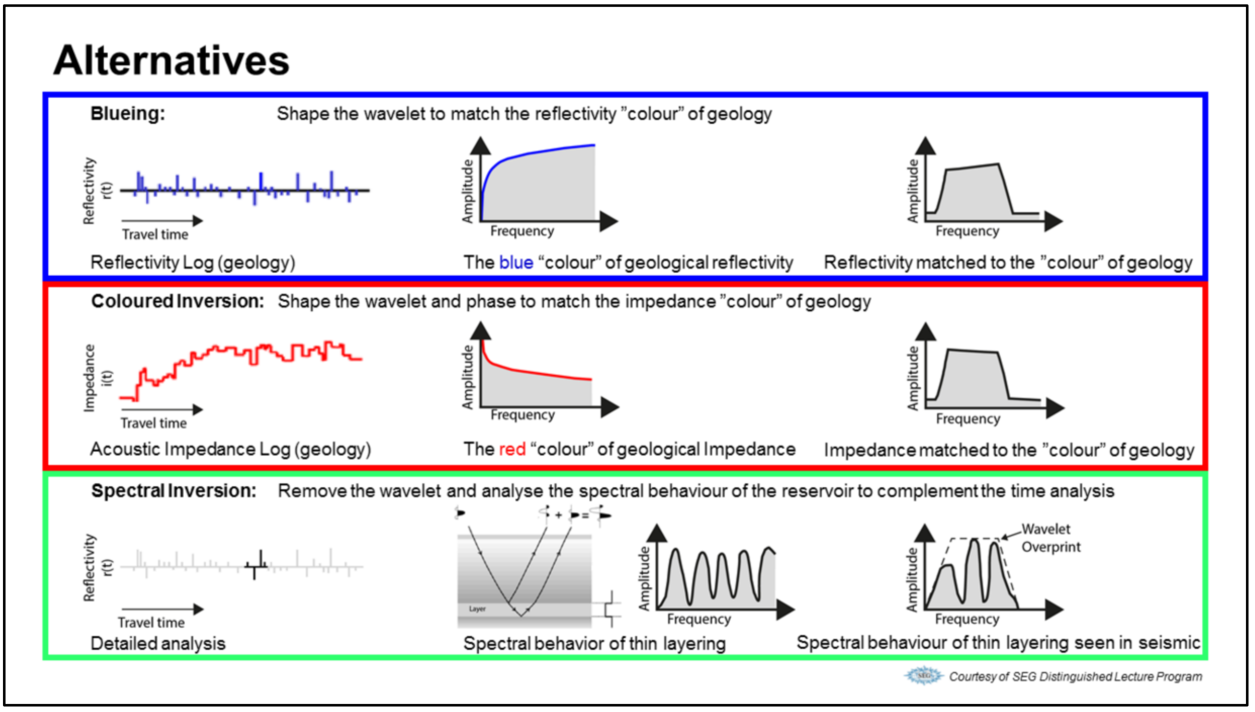


Text...

- Let me start with a simple wedge model to define tuning to illustrate a few aspects which are important for thin layering.
- When the wedge thins its reflections undergo interference and produce a single event of increasing amplitude, which is strongest at the tuning thickness. This is when the thickness is about one quarter of the dominant wavelength. In the case of Sverdrup reservoir, when the layer thickness is about 15 msec.
- At a spacing greater than that, the event begins to be resolvable as two separate events of which we can map the thickness.
- Below the tuning thickness we will also have a trough that follow a peak, but if we interpret these as the top and base of the reservoir, we will overestimate the true thickness. Eventually, we will loose the signal due to noise, but in case we have a strong event we may easily over-predict thickness.
- Knowing the tuning thickness for the data we are working on is therefore very important.
- Well, there are several ways to recover thicknesses lower than the tuning thickness. For our work we used an approach that is based on an inversion of amplitude spectra and I will show you a few examples of this today
- Next slide…



Text... (shorter)

- In seismic processing switching between time and frequency domain is common, as we see different aspects in the different domains. When looking at a derived reflectivity log we notice that reflectivity is richer in high frequency (i.e. blue) whereas an impedance log is richer in lower frequencies (i.e. red).

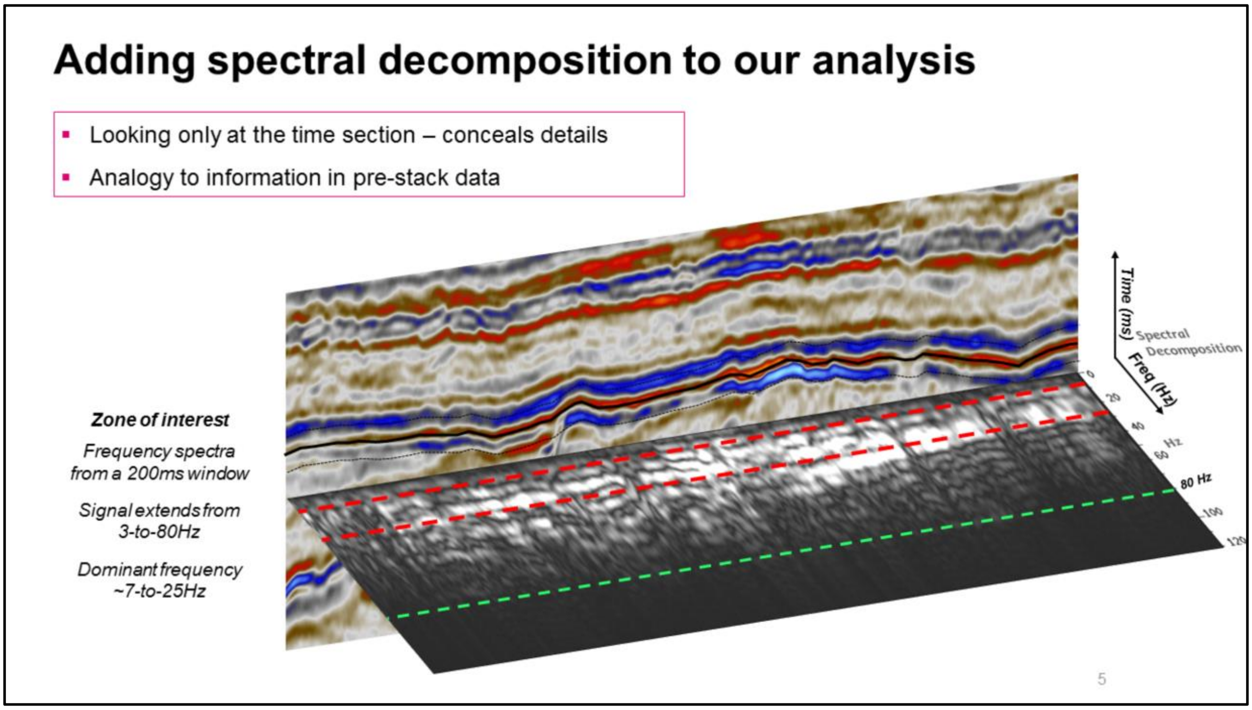
- As the purpose of seismic is to image geology, it is therefore useful to represent the seismic with the color of the geology.
    - In Blueing we aim to mimic the color of true reflectivity
    - In colored inversion we aim to mimic the red color of true acoustic impedance

- So from the original seismic we construct two new volumes, one is the blued reflectivity, the other is Coloured Inversion, which provides a layer or impedance representation.

- Another way to exploit the information in the frequency domain is to look at inference patterns. These patterns reveal geologic tuning and the wavelet overprint.
- We can remove the wavelet overprint and unravel the tuning, and then predict the layering from the interference patterns.

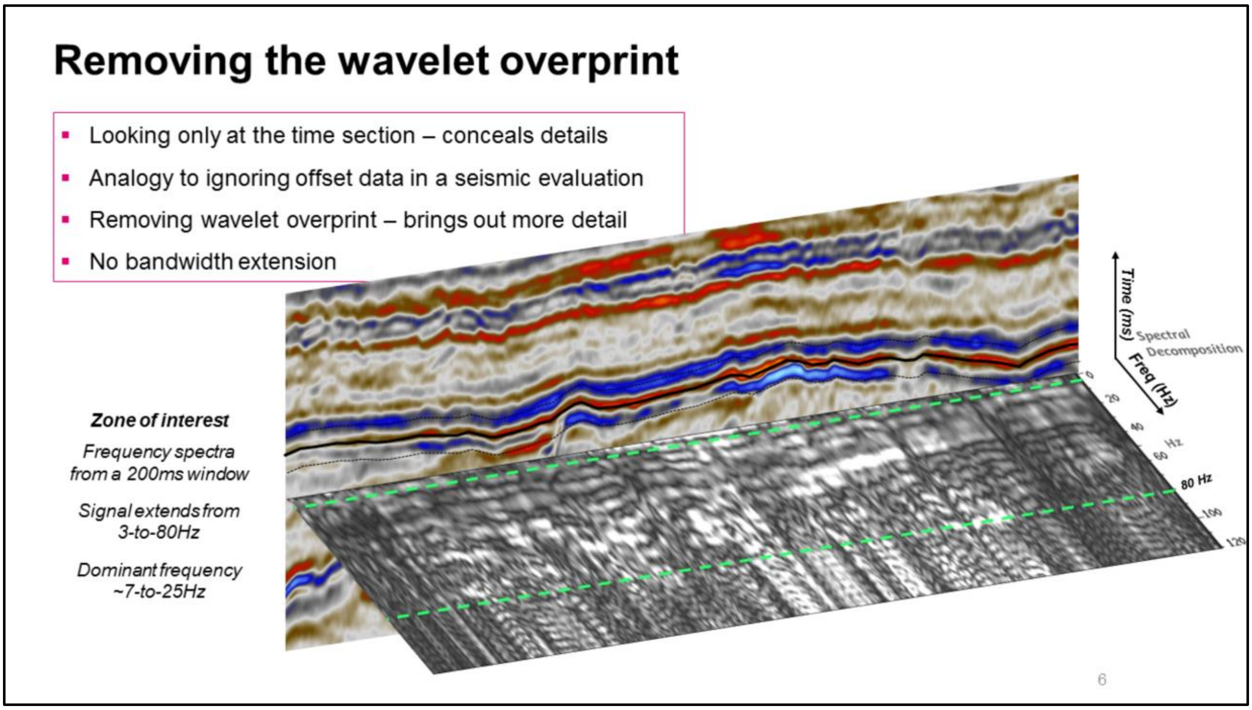
- This approach is called spectral inversion which we will come back to.

- Next …



Text…

- When examining the frequency content in a short window around the layer of interest we see that in the zone of interest, signal exists in the frequency range from about 3-to-80Hz.
- In the input data, the dominant frequency of the wavelet is ~15-to-25Hz, which means that the frequencies between 25Hz and 80Hz are under-utilized.
- The good news is that we can remove the wavelet overprint to make full use of the available signal.
- Next



Text...

- By removing the wavelet overprint, we see the available signal even better. The ringing that we see beyond 80Hz tells us that it is mostly dominated by noise. We can modify "our" seismic wavelet to reveal more of the useful bandwidth between 25-80 Hz by "Blueing" and in equivalent way to reveal more of the useful bandwidth below 7 Hz by applying "Coloured inversion".

- Unfortunately, we may not make use of it all, when bringing the signal back to the time section. Somewhere between 50-60 Hz we need to start weighting down the frequencies, otherwise we may introduce artifacts. One of these is: stronger side-lobes, which may or may not be an issues, contingent on the actual setting we are working in.

- An alternative to Blueing and Coloured inversion is to apply a 3-to-80Hz spectral inversion. So the question is: By using the entire signal bandwidth, can we obtain more details in our assessment ?

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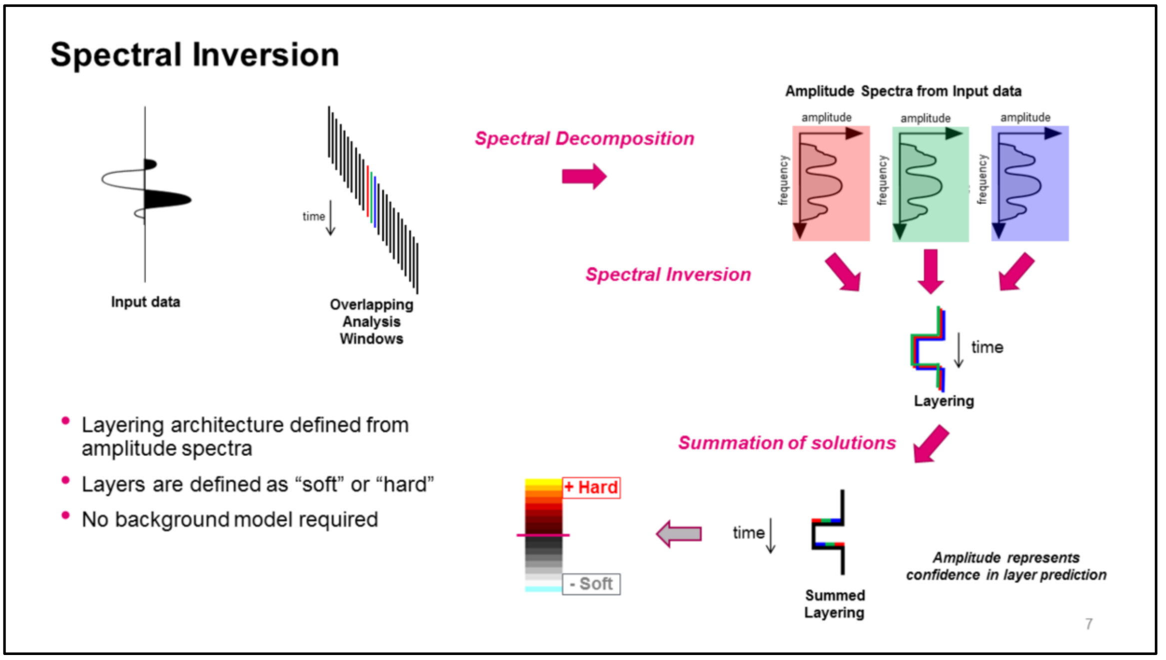
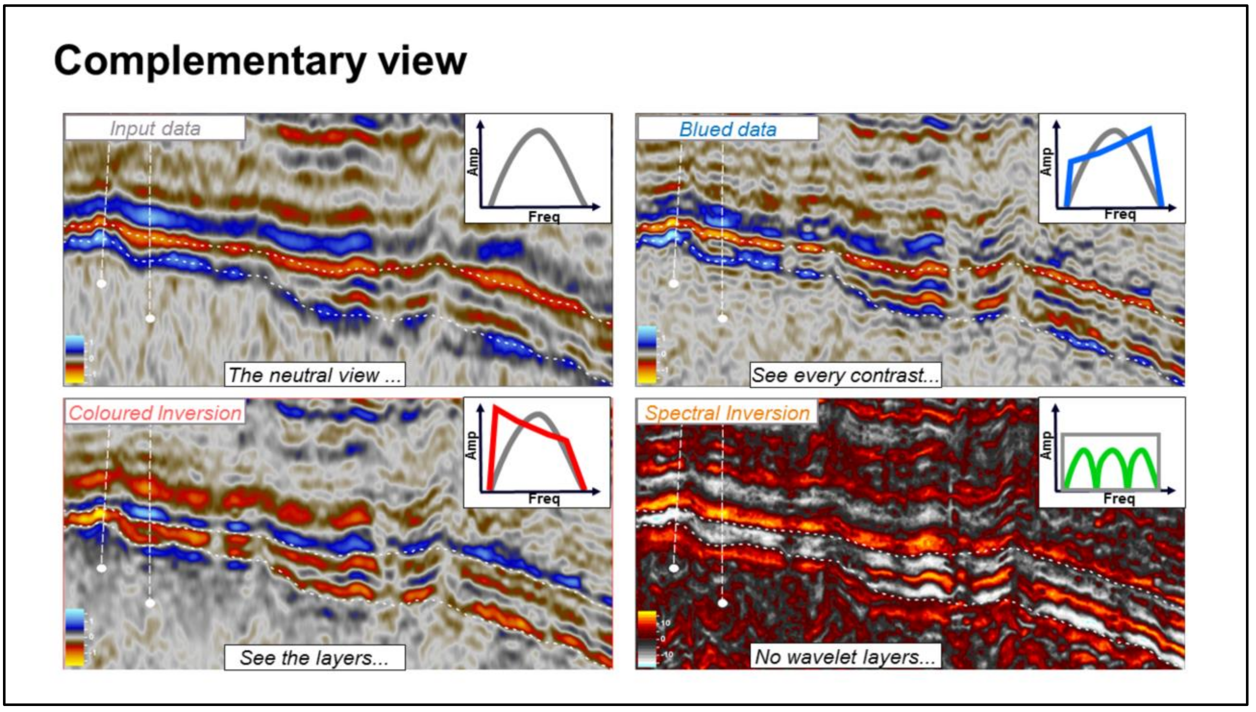


Text...

- With spectral inversion the goal is to define layering from the available bandwidth of signal - in our case 3-to-80Hz).
- To sample the spectral interference, we use many overlapping analysis windows of each is transformed from time to frequency. The three spectra you see in red, green and blue e.g. are obtained from such three overlapping time windows.
- This process removes the wavelet overprint, such that the limits of resolution are no longer tied to the wavelet shape and dominant frequency. In theory, a layer as thin as a few meter may be predicted.
- We solve for soft and hard layer patterns that spectrally match each input time window. Subsequent analysis windows will overlap, providing us with overlapping solutions. See for example the layering solutions for the red, green and blue spectra.
- By summing the overlapping solutions, we obtain a confidence measure at each depth.
- The spectral inversion output is then color-coded according to this confidence.
- You may find any color code to represent this, for the following just note that we code the output from the spectral inversion as shown here: increasing from black to red and yellow for hard layer confidence and increasing from black to white and blue for soft layer confidence.

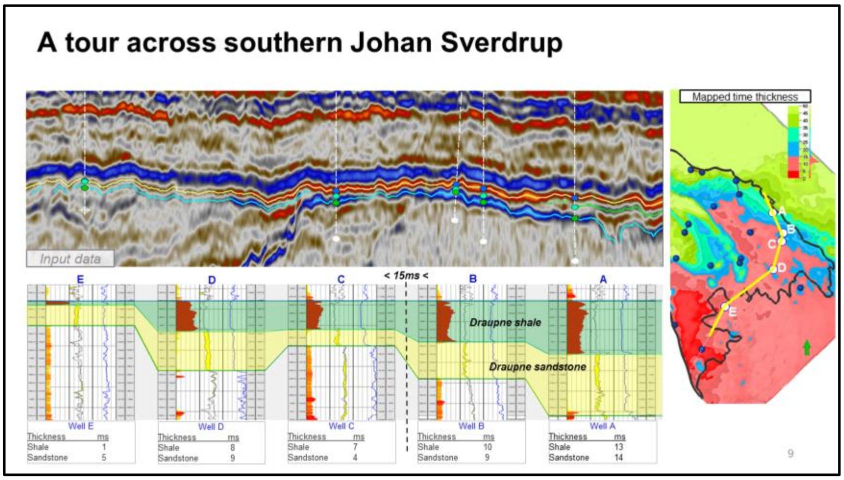
Next...



(Animation is not correct yet!)

Text...

- This slide summarizes what is available to us at this stage.
- In the upper left image we have the data as handed over from processing.
- Upper right is a blued version. We clearly reveal a lot of more detail.
- Lower left is the Colored inversion. Its another aspect that presents the layers rather than layer boundaries as the reflectivity does.
- The lower right corner shows the results from the spectral inversion. It provides also layering, but now not tied to the wavelet shape anymore. And as just pointed out, with red-yellow colors for hard and greyish-white for soft layers. And, I repeat, the color intensity is a measure of how well a layer is predicted
- We are now provided with more datasets of different bias than just the single one we had before, and thus so better equipped for meeting challenges in the seismic interpretation.
- Next …



Text...

- But let me now lead you through a few examples and have a closer look what we can achieve with this equipment when we are faced with the problem of a gradually thinning reservoir as we find it in parts of the southern Johan Sverdrup field.

- Here we find a thin reservoir container, mostly below 15 millisecond, which is about the temporal thickness or limit of what our input data are able to resolve.

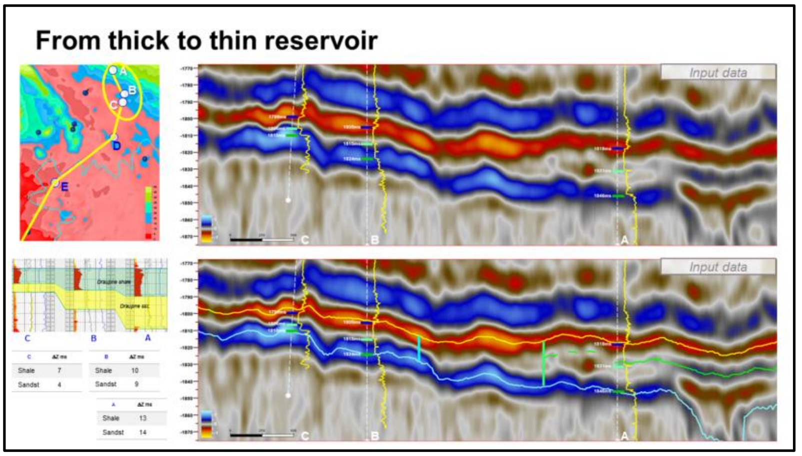
- Our input is good quality pre-stack depth migrated data from Statoil, and the section we follow is intersecting five wells from well A to E.

- Top and base of the reservoir container are marked by yellow and light blue lines. They enclose the Jurassic Viking Group which here consists of the non-reservoir Draupne shale and underlying proper reservoir, the Draupne sandstone.

- Along the section the thickness of the reservoir container gets continuously thinner, from well A where it is still thick enough to become above tuning thickness to well E where it is at its thinnest.

- For a better understanding of what I am going to show, I should also mention that the rocks above and below are in general of higher acoustic impedance, i.e. they are harder than the Draupne shale and sandstone.

Next...



From thick to thin reservoir: Input data

Text...

- Let us start near well A and step up on the Avaldsnes High where we find well B and close to it the sidetrack C.
- The upper seismic section shows the input data and the wells intersected by the section.
- On the bottom the seismic is the same as above, but now with the auto-tracked interpretations of the top and the base of the container that will be repeated on the following slides.
- On all wells are also three tops annotated: from above to below the top of the shale, under the top of the sandstone, and below the base of the sandstone.
- With this input seismic we can resolve two units around Well A which becomes difficult to follow beyond the green vertical bar.

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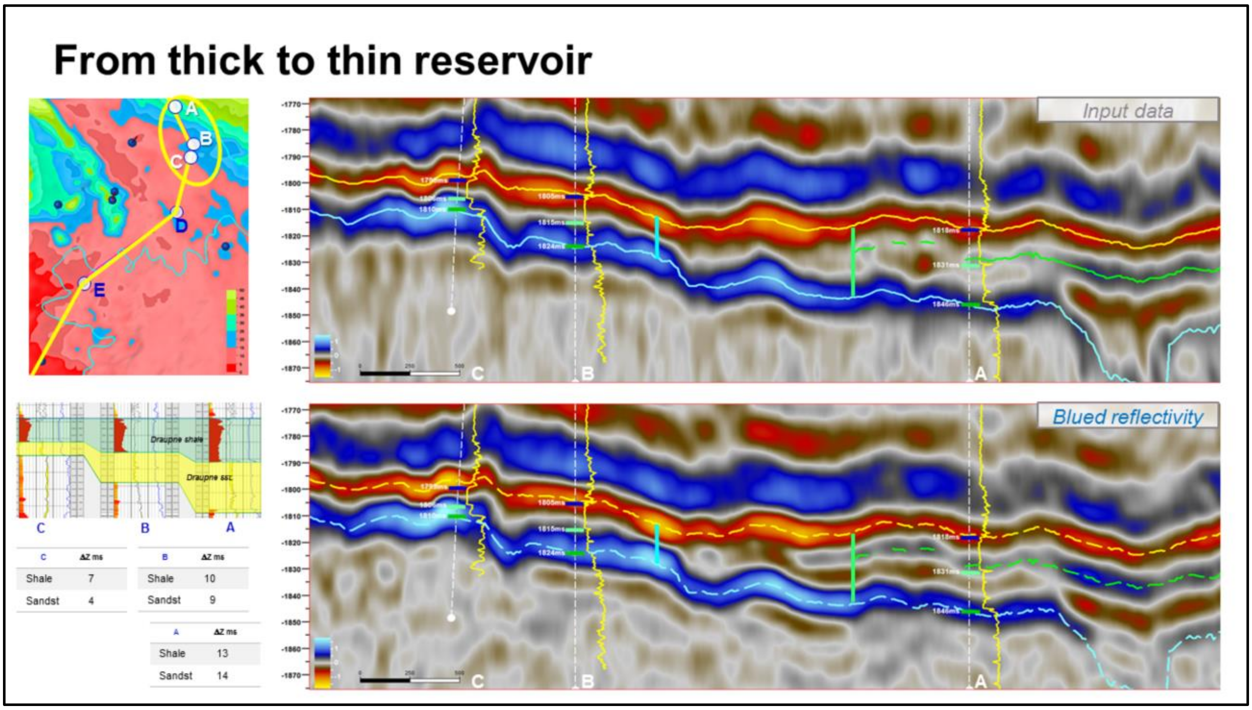


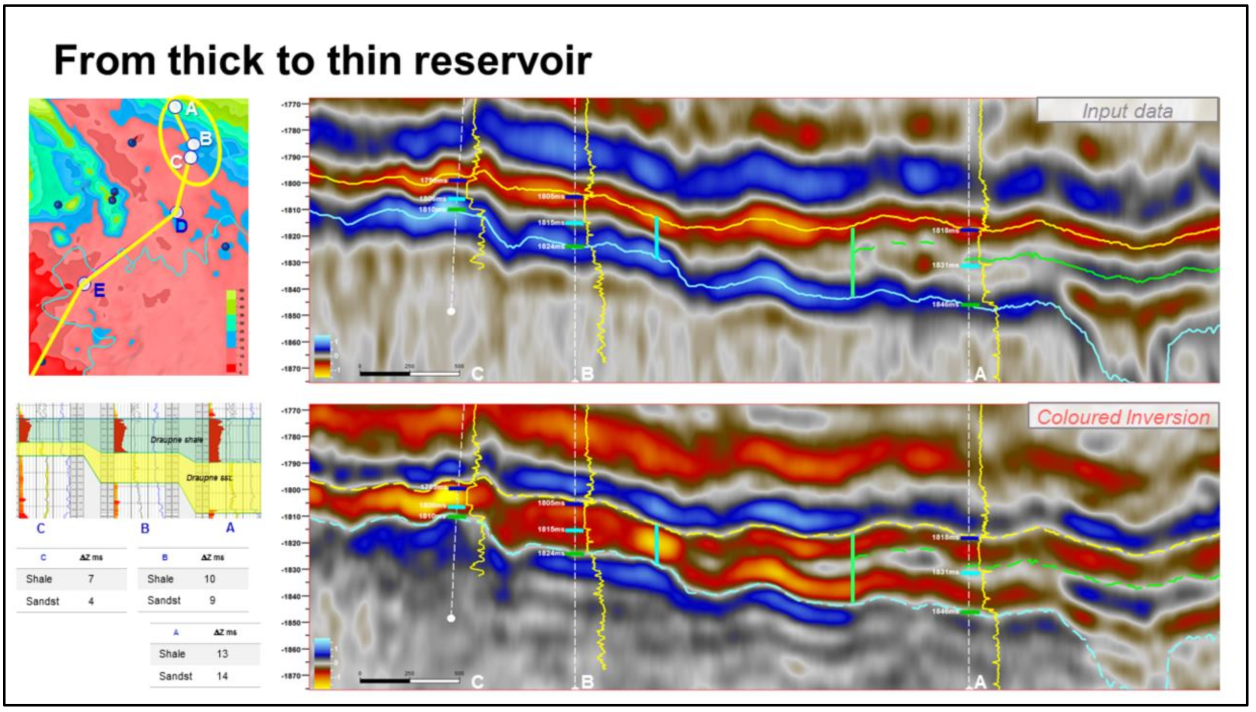
From thick to thin reservoir: Blueing versus input data

Text...

- On the bottom section we replace now the input data with the blued seismic still with the same horizons posted on top.

- The advantage of incorporating the blued seismic is clearly seen. One now can push an interpretation of the top reservoir mid-way between the green bar and Well B.

Next...

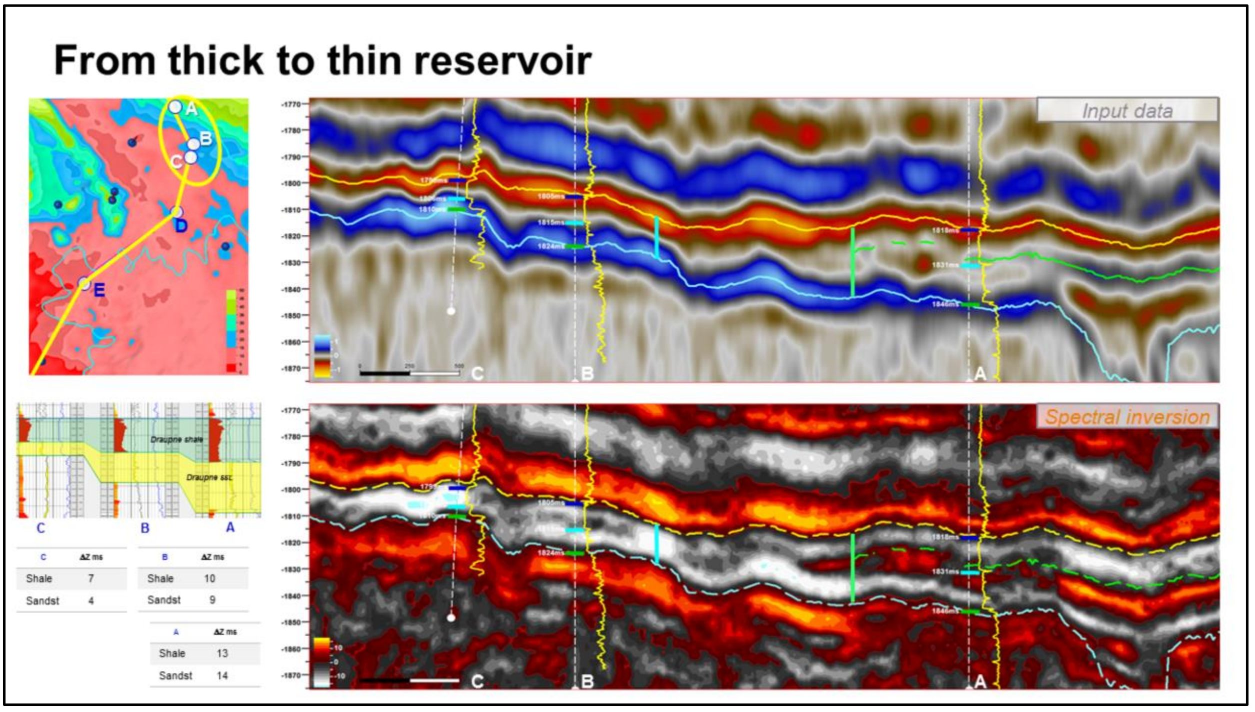


From thick to thin reservoir: Colored inversion versus input data

Text...

- Now the bottom section display the colored inversion with the same horizons posted on top.
- The colored inversion data is less prone to developing side-lobes, although this version has less gentle high end slope, the image now confirms what was observed in the blued seismic volume.
- We can clearly resolve the upper shale from the sand almost all the way to the blue bar. But beyond this point, the seismic data only reveals one layer for us.

Next…

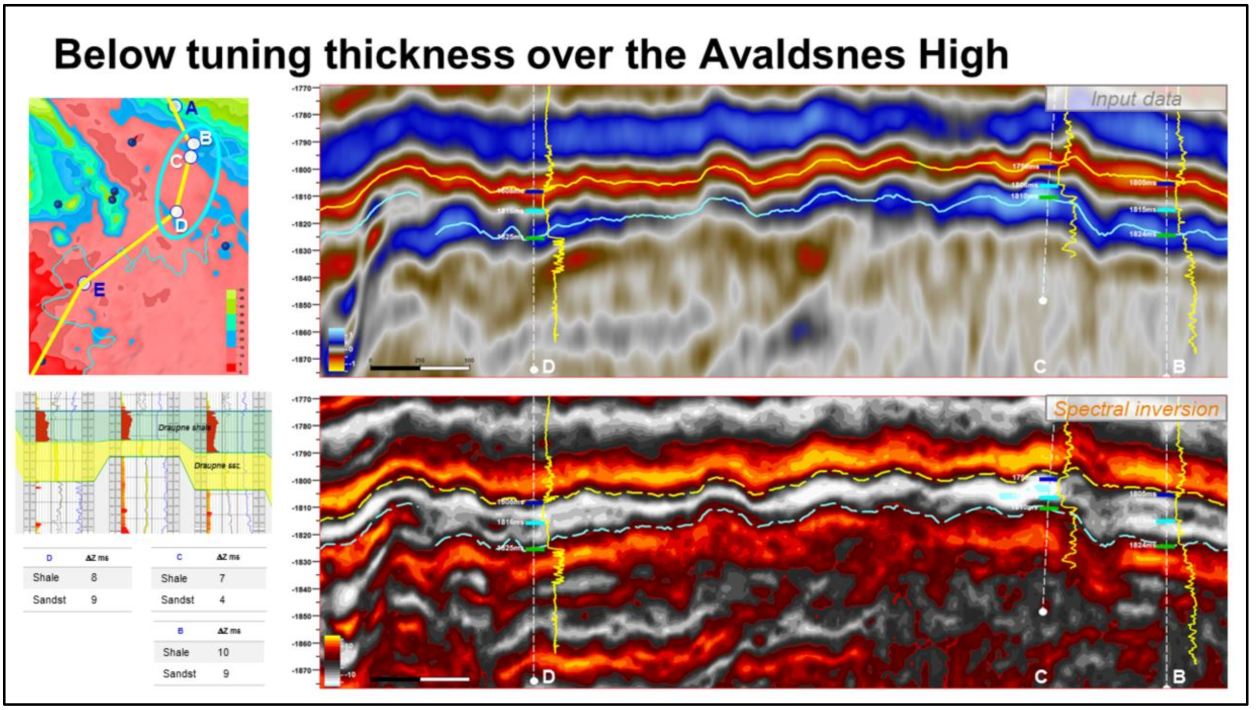


From thick to thin reservoir: Spectral inversion versus input data

Text...

- Finally we investigate the spectral inversion data.
- The spectral inversion confirms what we have seen both from the Blueing and the Coloured inversion data. It is to some extent comparable from Well A to the blue vertical bar.
- But beyond the blue vertical bar, we observe on the spectral inversion that both layers are present beyond Well B and almost into Well C on the left side of the section.
- And this observation is indeed confirmed in the wells.

Next...



Text…

- Let me now move further along our section up on the Avaldsnes High.
- First we view the input data:
- Here we still can map the top and base of the container quite well, but not differentiate anymore between the sand and the shale as on the former section.

- On the west side of the High we have now well D: It shows nearly the same as in Well B – almost the same sand/shale thickness ratio.

- From the input data alone, we cannot make this observation, we only see the top and base of the container - anything between is hidden for us. We are around the tuning thickness such that the input data cannot resolve such a detailed layering.

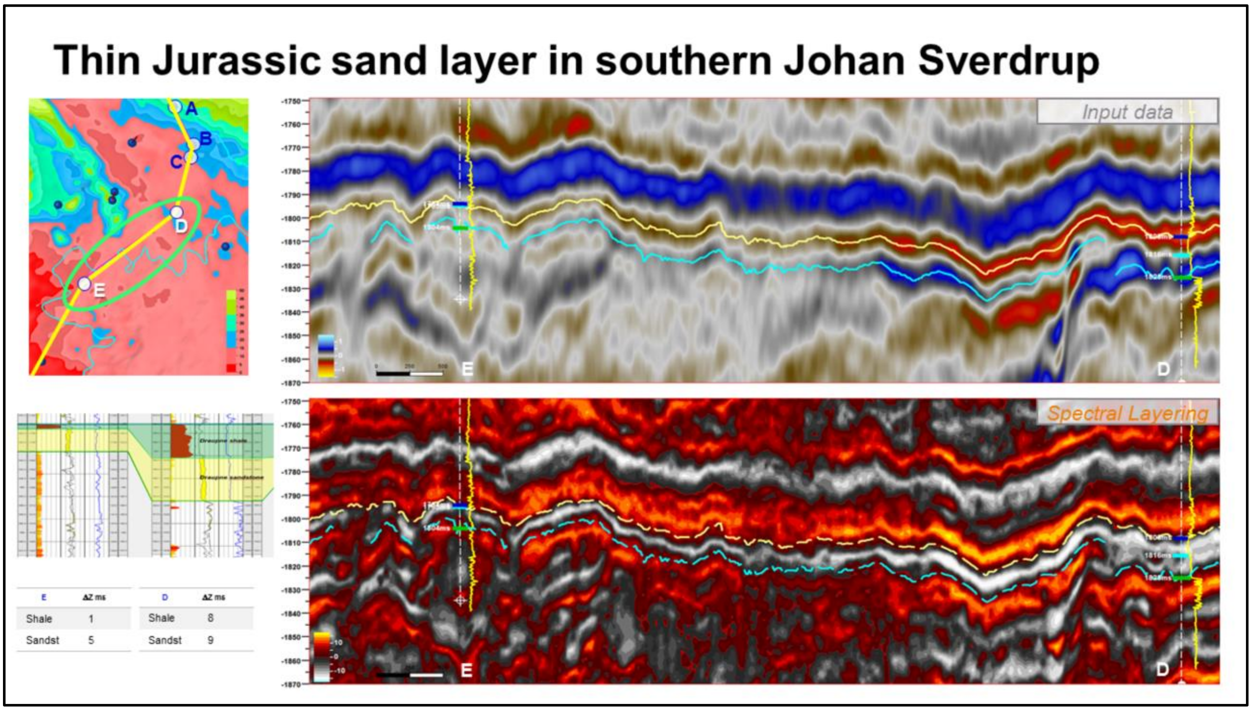
- Now we look at the Spectral inversion and check whether we can gain more information from there..

- And again, as before, there is a clear separation into two layers between the top and the base of the container in and around well D: The separation into two layers is the same as we already observed in well B and C.

- On the high itself, between wells C and D the two layers seem to merge into one and this separation is not seen anymore.
- But now we make another interesting observation. One is that the merged layer is better defined, but it also reveals significant thickness variations. This is clearly in contrast to interpretation of the input data which is more or less constant over the Avaldsnes High.
- It seems that the true thickness of the layer can be much better estimated from the Spectral inversion than from the input data.

- I will now leave this scene and go to the next section which leads to well E

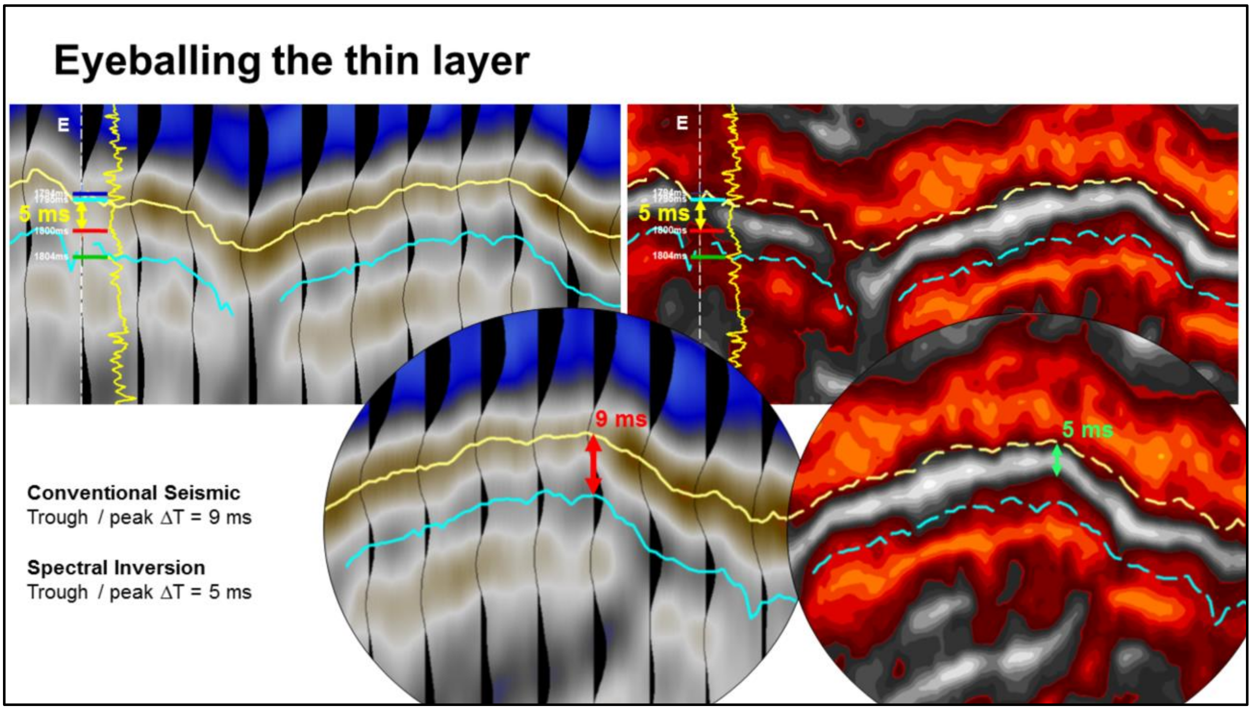
Next…



Text...

- In this part the scene is somewhat different from what we saw before:
- Again, first the input data where the top and base are reasonable well defined and can be mapped, although we observe a gradually loss of energy of the reflectors further away.
- The reason for this is that the reservoir is getting thinner and less well resolved.
- From what we have learned so far, we know that the thickness for the interval we are mapping on the input data can only be the apparent thickness as we are below tuning thickness.
- But let us check how this looks for the spectral layering on the section below: The sandstone layer is well visible as a white-to-grey band between the interpreted horizons.
- What is of interest, is that the sandstone band, although varying in thickness, in general is clearly thinner. - Which does not surprise us anymore as we know that we couldn't pick the true thickness below tuning from conventional seismic.
- But it gets also obvious that the sandstone, which in this case is softer than the surrounding strata, is nicely identified through the inversion and its true thickness now can be estimated much better.
- But let me check all of this in well E and around.

Next...



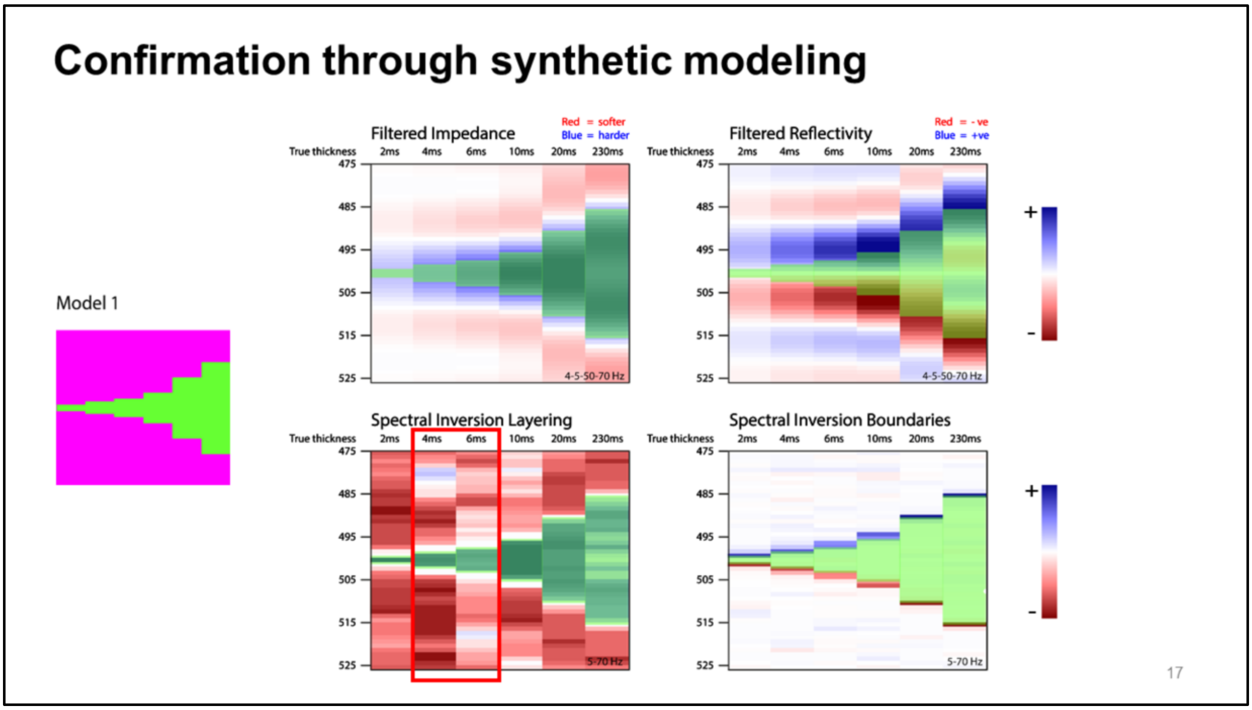
Text…

In well E the sandstone is only 5 ms thick as shown in the acoustic impedance log. However, the input data cannot resolve this.

On the contrary the spectral inversion data are able to resolve such a low thickness.

If we look at close-up of the neighboring…
Click…
… High, we can measure the over-prediction on the input data versus that what the true thickness seems to be when checking the spectral inversion data.
9 versus 5ms is quite significant difference in context thin bed mapping… (Pause)

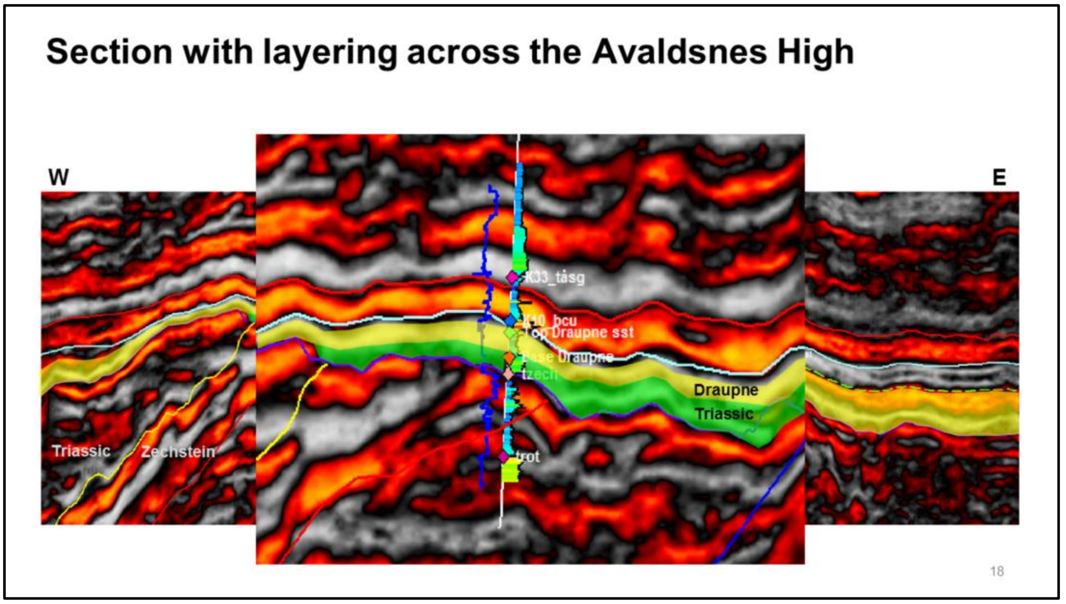
Click…



(Synthetic modeling – to substantiate the results of the inversion)

Here we show the synthetic modeling which verifies the that the spectral inversion is able to resolve layers as thin as 4-6 ms as shown before.

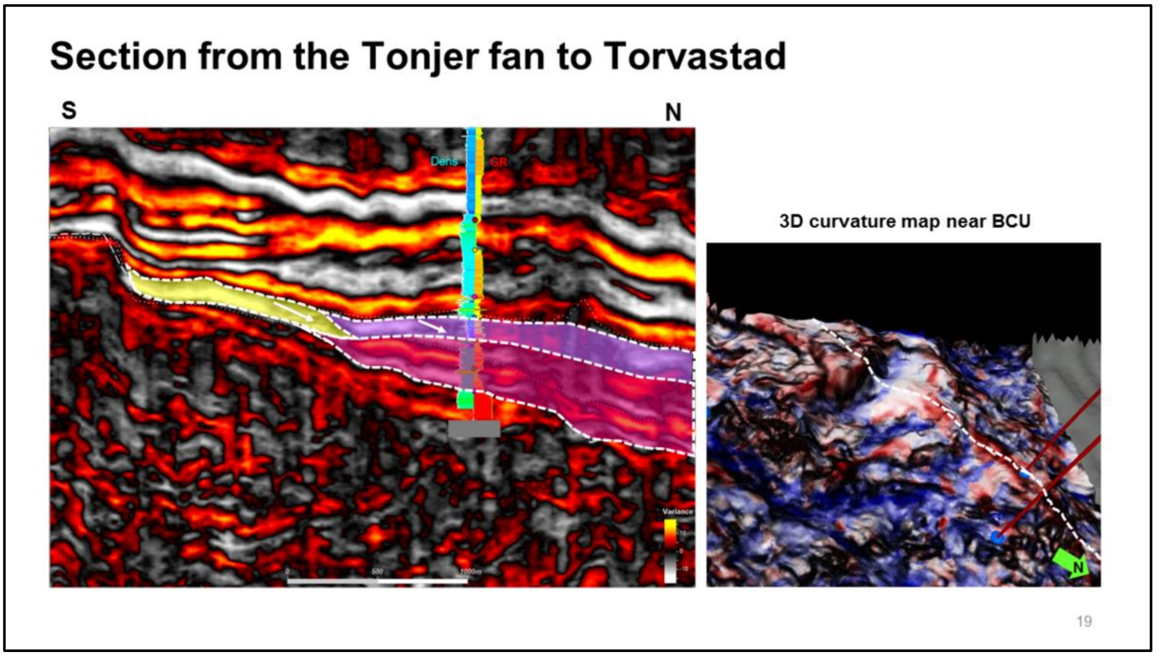
Next...



Text...

- This example is a section from the spectral inversion displaying the thickness variations across the Avaldsnes High:
- In the west there is a strong local thinning of the Viking Group above sub-cropping Zechstein. It is then thickening towards east where two layers are resolved.
- The thickening increases further until the shale and the sand start separating. In addition internal layering within the Draupne shale is visible.
- Click...
- Here a close-up that better shows a nice differentiation of a two-fold layering which cannot be separated on normal seismic. All observations are confirmed by the well-tie.

Next...



Text...

- This is from the Tonjer area, which is in direct contact with the Utsira High Basement High. On these data is not much internal reflectivity to see.

Click...

- When now viewing the Spectral Inversion we see improved resolution. Next to the Basement fault, a clear soft layer occurs, in combination with down-lap signature to the right. It indicates a narrow pro-grading fan delta, which is contrasting the more distal layers in the Torvastad well.

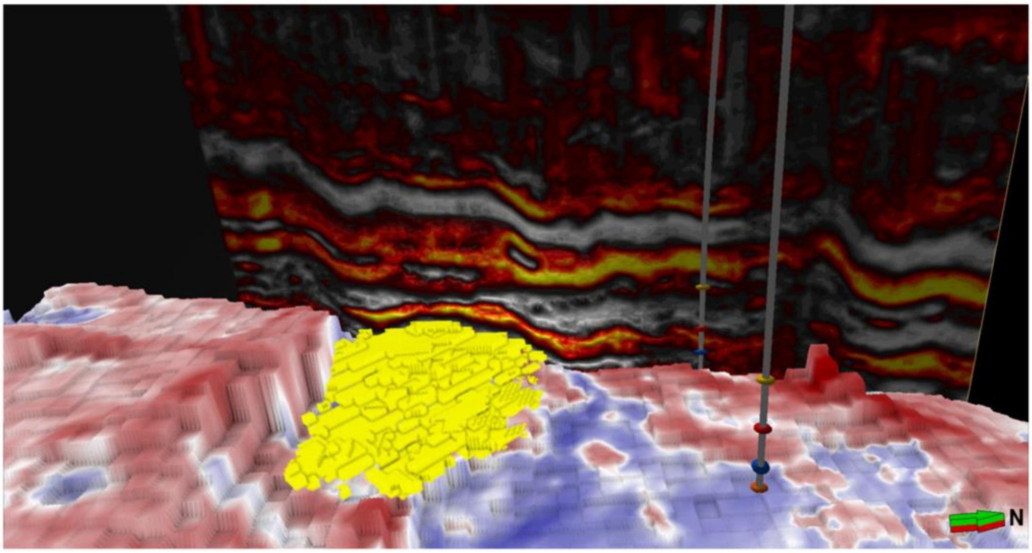
Click...or flip between the layers...

- The overlay shows an interpretation of the sequences with the prediction of sand in yellow. The sequences are defined by apparent pro-grades and down-laps which the better resolution reveals.

- Also note the lobe-shapes on the curvature map near top reservoir...this really resembles geometries expected to be seen on a sedimentary fan!

Next...

Tonjer fan extracted as geobody
– a way to estimate volumes



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Text...

- Finally, we have in 3D the same line intersecting the base reservoir...
- Click...
- now shown as a curvature surface...
- (Automatic shift after 5 seconds...)
- This is an example how thickness could be predicted by geobody extraction.

Next...

Summing-up

- Exploit the available bandwidth
- View the data with “different colors”
- Analyze the data in different domains
- Spectral Inversion demonstrates resolution beyond the tuning thickness and resolves thin layers and geomorphology
- The resolution can be more than 40% higher than from conventional processed seismic data

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Text...

In this presentation we demonstrated the use of spectral analysis to exploit the available bandwidth.
We used the "natural" colors – or frequency distribution of the geology to maximize the resolution in the impedance and the reflectivity domain.

By switching between time and frequency domain gives us a better basis for maximizing the resolution of our seismic data.

Spectral inversion has been used to investigate thicknesses below tuning, and helps us quantifying thin layers. Combined with geomorphology we have a better chance for quantifying our seismic data within a geological context.

Using Spectral inversion to investigate the seismic within the useable bandwidth we have been able to improve the resolution by more than 40 %, compare to a conventional analysis of our seismic data.

Acknowledgements

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The interpretations, views and opinions expressed in this paper are those of the authors, and are not shared by the other unit partners.

The authors would also like to thank Det norske, Petoro and OpenGeoSolutions for permission to give this presentation.

DETNORSKE petoro openGEOsolutions

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Final Slide

The authors would like to thanks the Johan Sverdrup Unit partners for the permission to show data.

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