BELVEDERE MAORPET
A COMPANY INCORPORATED UNDER THE LAWS OF THE STATE OF DELAWARE

INCREASING THE SEISMIC RESOLUTION

PSEUDO SONIC & PSEUDO GAMMA RAY SEISMIC SECTIONS

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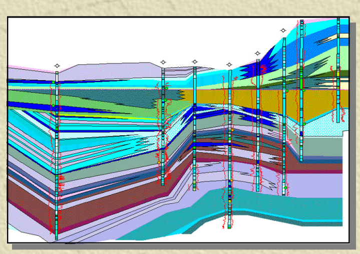

Conventional “Geological Cross Sections” are limited, when going into small details. The reason is the “sampling rate”. The popular rule tells that you have to take at least two samples from every wave, when you try to digitize a curve.

The well-log curves have rather high frequency content in the depth direction, but the sampling rate is also high, so there are no sampling rate problems within the log curve itself.

The trouble starts, when you try to move horizontally, between two wells. The distance is so large, that there must be several “waving” in the well-log value, until you arrive from one well to the other.

A fortunate case is, when you can “flatten” on a known, characteristic event. This case you don’t expect too much change along the “flattened” event, which means, sampling at the singular well locations are usually enough. Unfortunately you can not flatten on all existing layers, and anyway, you do expect some changes between the wells.

There are always some very small elements everywhere, what you should be able to use for the magical “flattening”. The solution is to use the seismic wave, as interpolator operator. The seismic wave „knows” these locations, it „knows” what was going on when it visited the deep layers in the earth. Just let it work for you.

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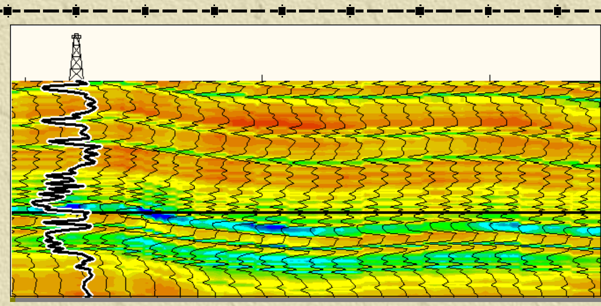

Well-log extrapolation is a simple tool to extend horizontally the well-log values into the neighborhood of a well. Well-log extrapolation uses the seismic time (or depth) sections as interpolator operator.

Well-log extrapolation can be based on one single well. This case the validity of the result is limited to the close surrounding of the well location (approx. 2 to 5 kilometers), depending on the quality of the intersecting seismic section. It can also be based on two, or more wells. This case the computation goes into a “learning” process first, which will significantly increase the reliability of the results. Well log extrapolation works extremely well on 3D data, where the “mistie” problem of the 2D line intersections does not create unwanted phase shifts and other artifacts.

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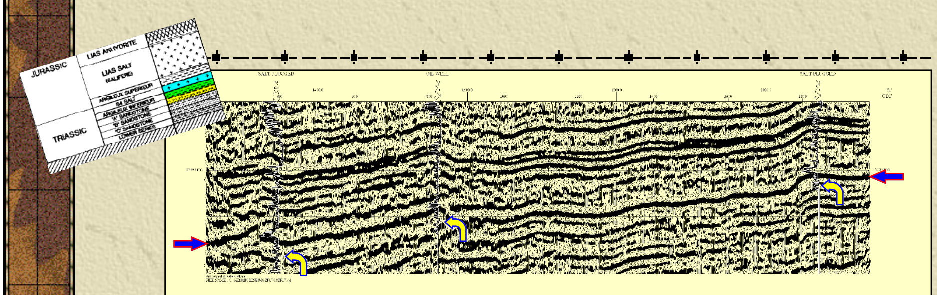

Here is an example to show the effectiveness of the log extrapolation. The presented seismic time section crosses three wells. The middle one is a productive oil well. It is producing from a Triassic sand reservoir. The locals call it „A” sand. The other two wells are dry holes, where the „A” sand is salt plugged.

The top of the sandstone is an eroded, unconformity surface. This surface was covered first by shale, then, at the end of the Triassic by salt. The Jurassic starts with a thick shale sequence. The blue arrows point to the top of the Triassic salt.

Even looking with very sharp eye to the seismic section; no one could say honestly what are the differences between the three holes and where could be the limit of the discovered oil body.

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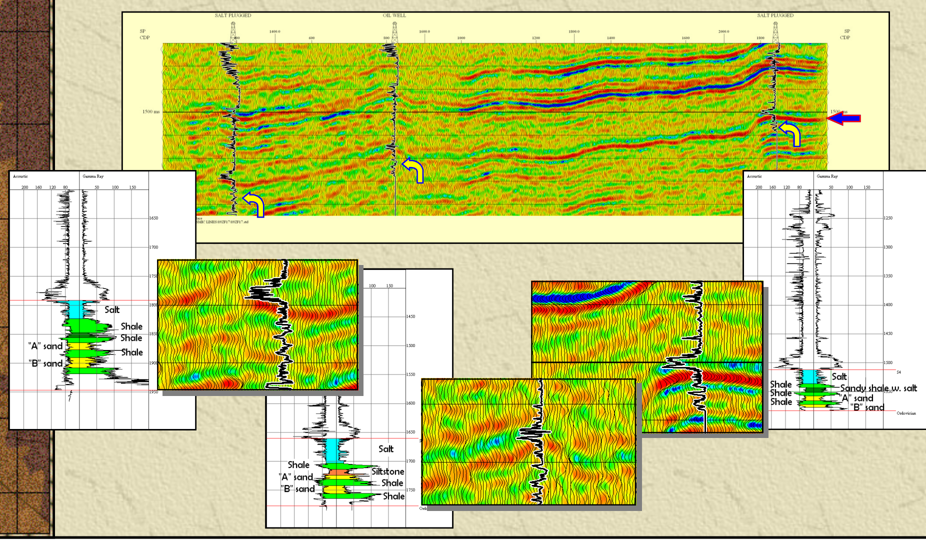

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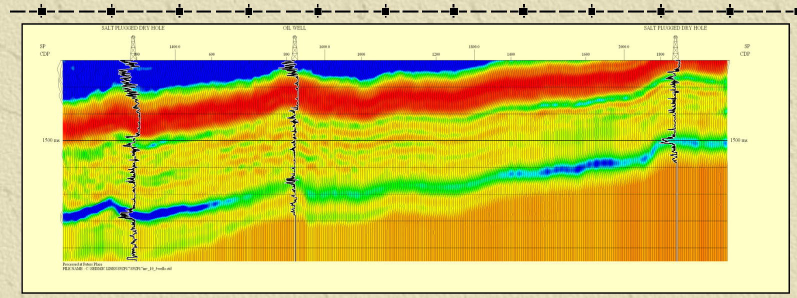

Acoustic impedance section

Inverting to acoustic impedance section does not bring any improvement in the understanding of our probelms, but we will need this step for the acoustic log extrapolation.

The seismic section itself is a reflectivity function, while the acoustic log is a velocity (or more exactly a transit time) function. The inversion of the reflectivity; the acoustic impedance section is the one, which is a closer relative to the acoustic log. This is why we have to use the acoustic impedance section as the interpolator operator.

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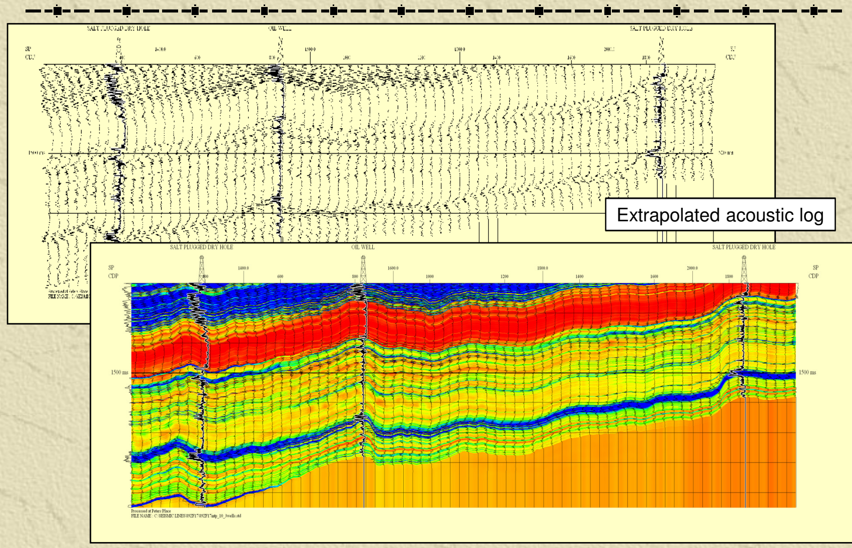

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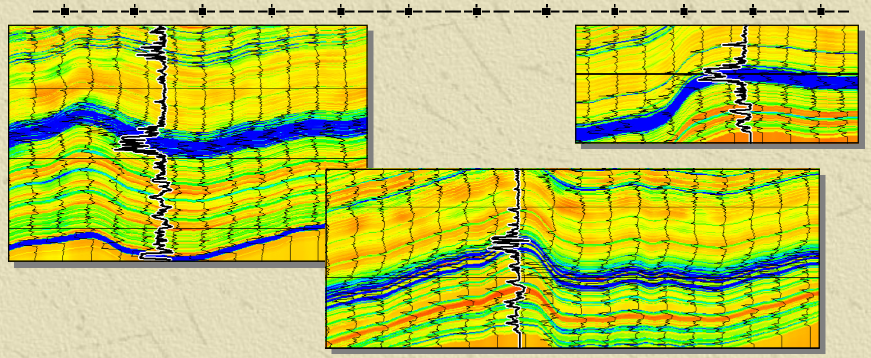

Cutouts of the extrapolated acoustic log section. Please notice; the resolution is nearly as high as the resolution of the original acoustic log itself.

There is a minor degradation in resolution only because during the depth to time conversion of the log we had to apply a light high cut filter to avoid harming the sampling rate law.

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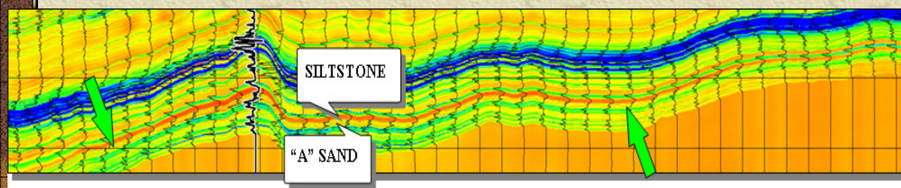

It is easy to follow the siltstone body and to recognize the “A” sand, just below it. The clear character of the siltstone-sandstone duplex seen in the central oil well fades out after a distance (green arrows). These limits might be the limits of the salt-free “A” sand.

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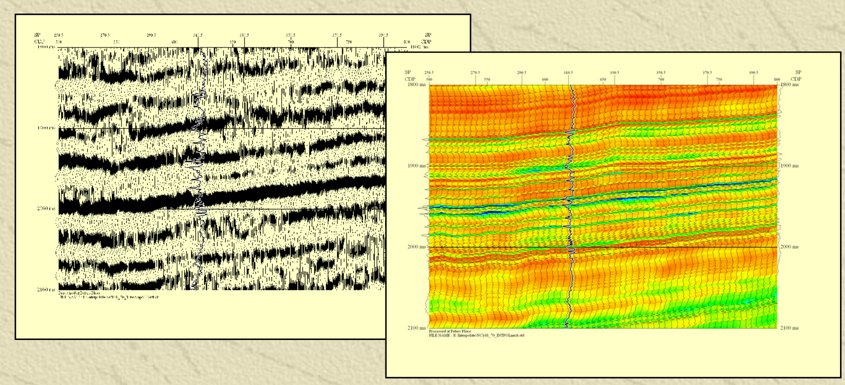

Second example; to illustrate the resolution improvements.

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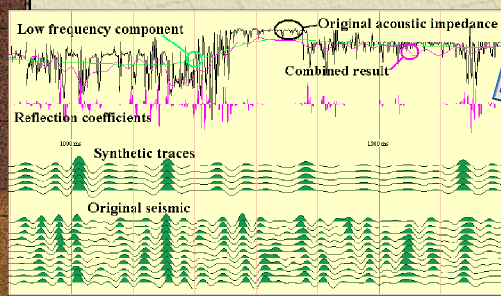

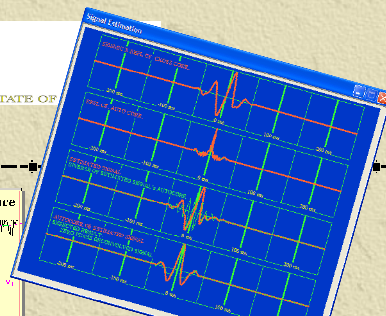

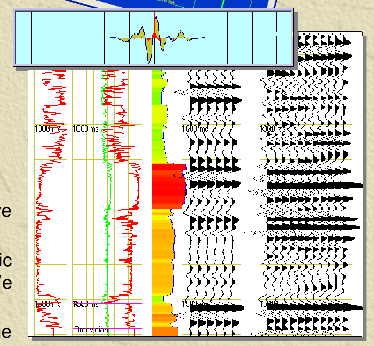

Steps of the acoustic inversion:

1. We compute acoustic impedances from the „P" wave transit time log.
2. We subtract the „seismic wave" from the nearby seismic traces using a deterministic optimization technique. We design the „inverse" filter.
3. We „inverse" filter the seismic section and compute the acoustic impedance section from the inverted „reflection coefficients".

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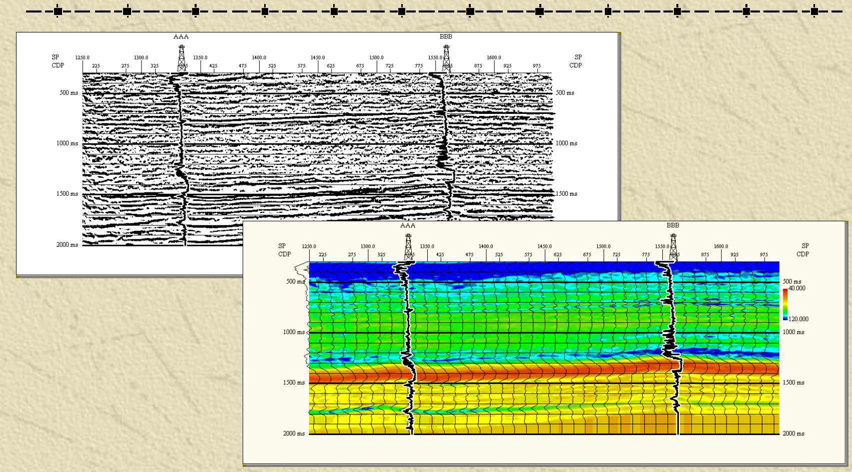

One more example of the acoustic inversion, based on two acoustic logs

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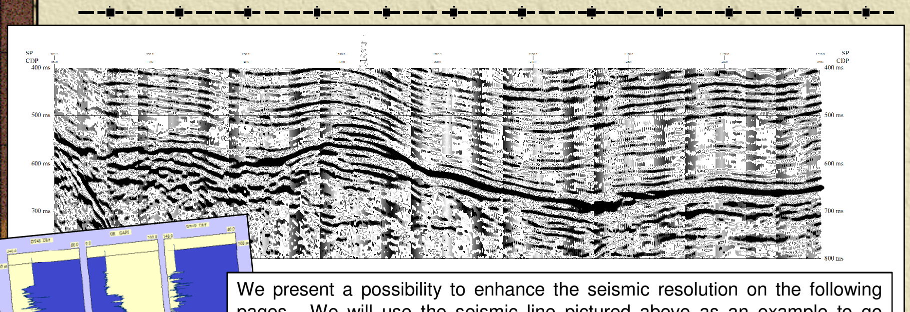

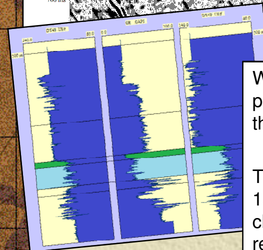

We present a possibility to enhance the seismic resolution on the following pages . We will use the seismic line pictured above as an example to go through the step-by-step process.

This 2D seismic line crosses a well, drilled in 2001. The well was producing 158 Million m^3 gas in the period from 2002 to 2010, when the production was closed down. The presented seismic line was acquired before the drilling. The reservoir is carbonate. The lower part of the carbonate body (light blue) is very tight, with max. 2-3% porosity, while the upper zone (green) is porous, having 16-25% porosity. This upper zone contains the gas, which was considered as biogenic origin. Depth is 652-685 meter (perf: 652-662m from KB).

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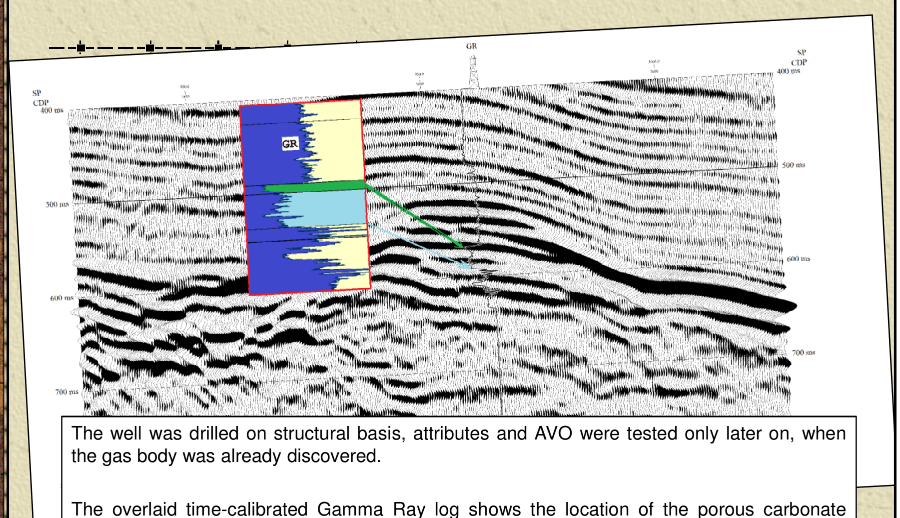

The well was drilled on structural basis, attributes and AVO were tested only later on, when the gas body was already discovered.

The overlaid time-calibrated Gamma Ray log shows the location of the porous carbonate reservoir on the time section.

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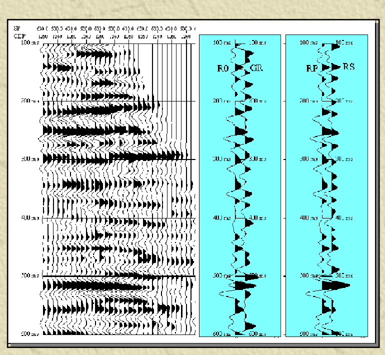

Our first move will be the AVO analysis. Instead of going the usual way, which is to produce intercept (R0) and gradient (GR) time sections, we will follow a different route. This solution was proposed by a group of authors in 1994, entered into the industry under the name as Fatti's equation.

The main difference to the other solutions is, that this version computes directly the P and S wave reflectivity (RP and RS).

RP is identical to the R0 intercept section. RS is the S wave reflectivity, but it will be timed exactly as the P wave, there will be no arrival time differences. We might say, it is similar to a synthetic model trace, computed from the S wave sonic log and time transformed by the P wave velocity.

The advantage to use the RS, instead of the mysterious gradient section is, that the RS reflectivity section has a meaning itself; it is just a simple time section. We can use it the same way, as we use any other seismic time section that we are familiar with.

There is also a computational advantage: in case the R0 is zero, other methods will result zero by any multiplication by the R0, independent from the value of the GR. Here this singularity does not generate any troubles.

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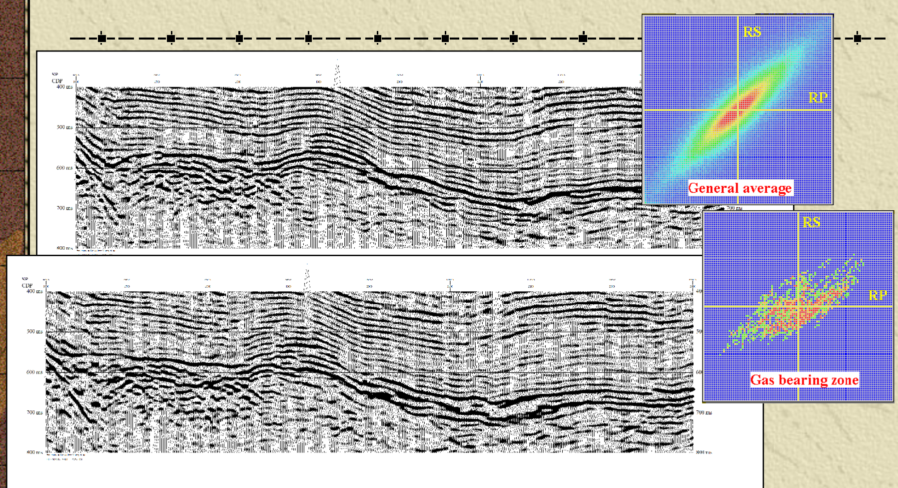

RP (top) and RS (bottom) sections. The RS-RP cross plots show the discrepancies in the gas bearing zone. This is, what we call as „robust" AVO. It works even in carbonate reservoirs.

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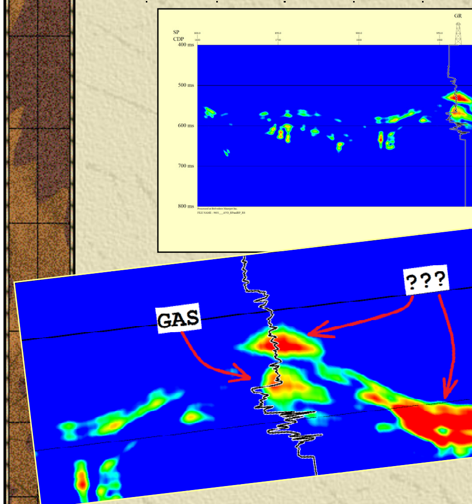

Result of RS versus RP cross-plot.

The AVO anomaly, related to the gas bearing zone is clearly recognizable. But, there are some other anomalies present as well, which are not related to the presence of the gas.

Just as an interesting story; the operating oil company got excited about the possibilities and made an AVO analysis on the conventional way too. The results were very similar to these ones and they drilled the big anomaly to the right of the existing well. Even the porous part of the carbonate body was absent . . .

Resolution is still poor. This is not exactly, what we want.

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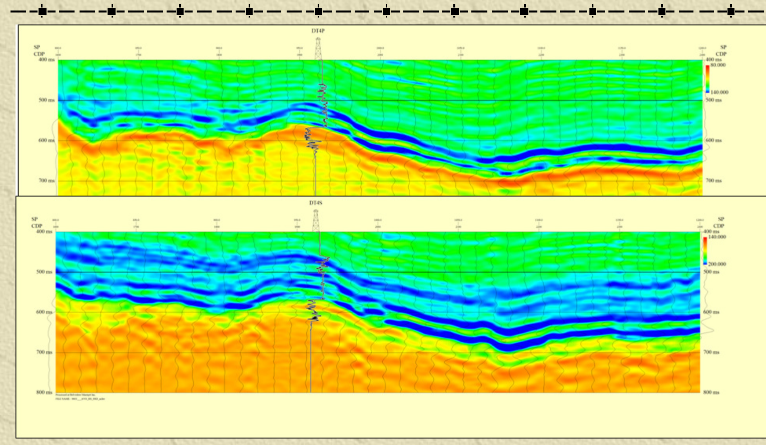

Acoustic inversion of the RP (top) and RS (bottom) sections. We used the P and S wave sonic logs, respectively for the inversion.

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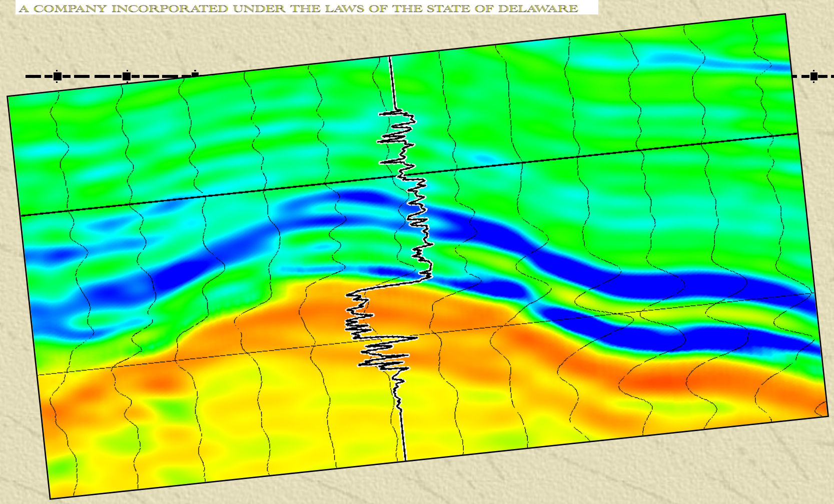

Detailed image of the P wave inversion. The log already fits nicely to the section. We will use these sections to extrapolate both the P and S wave sonic logs.

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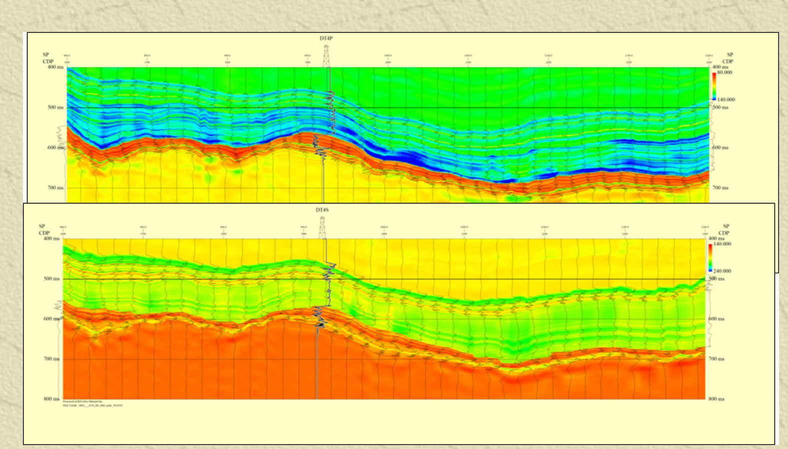

Extrapolated P and S wave logs

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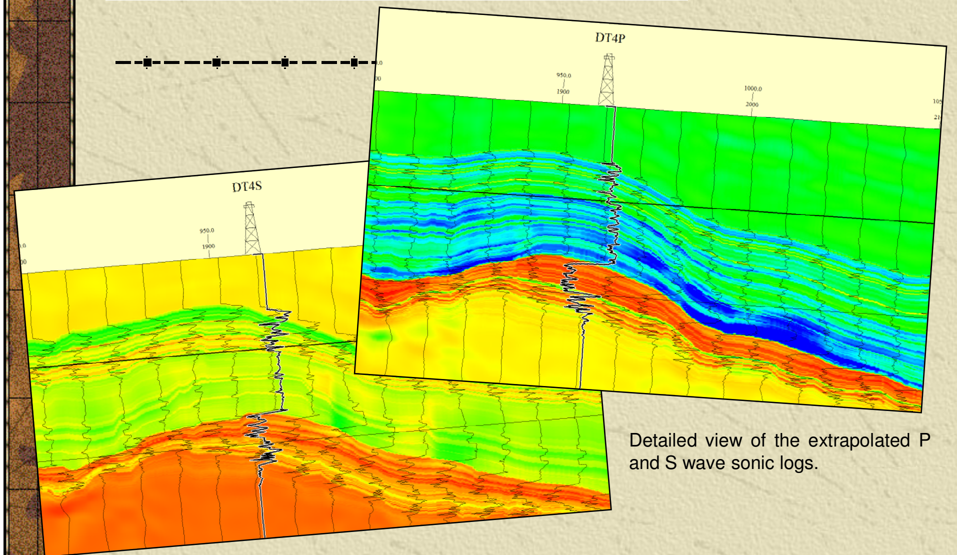

Detailed view of the extrapolated P and S wave sonic logs.

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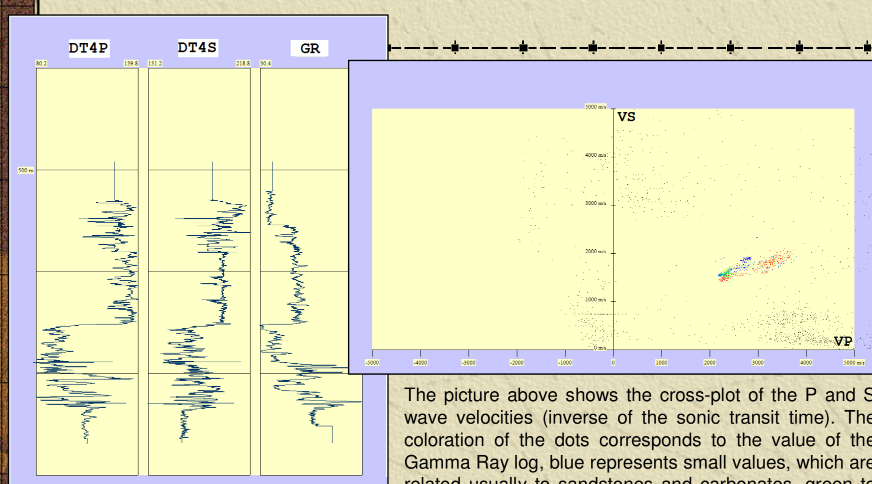

The picture above shows the cross-plot of the P and S wave velocities (inverse of the sonic transit time). The coloration of the dots corresponds to the value of the Gamma Ray log, blue represents small values, which are related usually to sandstones and carbonates, green to yellow are the medium values and the red ones are the largest values, they represent usually the shale sediments.

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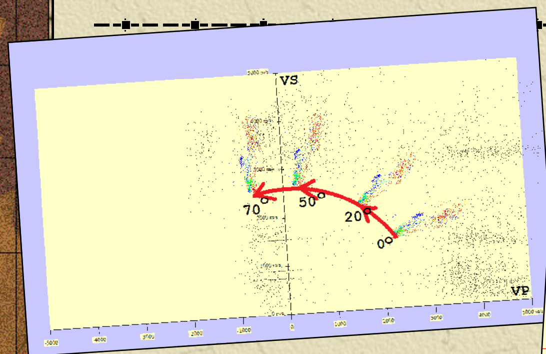

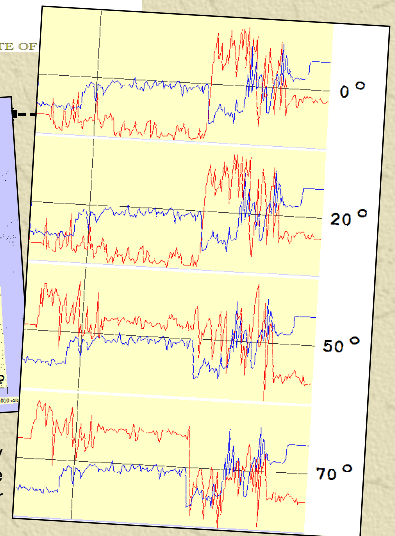

Our problem is: we want to extrapolate the gamma ray log as well. But the seismic section itself is not a relative of that log, so it would not be suitable as interpolator operator. We want to create a pseudo gamma ray seismic section, what might function as the interpolator operator for the gamma ray log.

The trick is: we start rotating the VS-VP plot and compare the rotated VP against the original gamma ray log. We will find a rotation angle, when the two fits nicely together (picture to the right). As we apply the same rotation to our RP-RS seismic section, we obtain a pseudo gamma ray log section.

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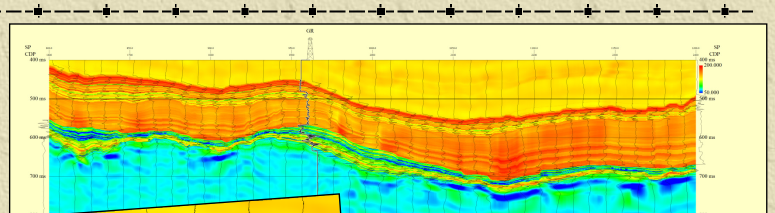

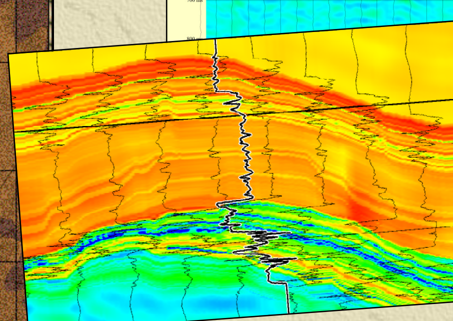

Some authors call this seismic section as “lithlogical impedance” section.

Now we have a time section, which is some kind of a relative of the Gamma Ray log, so we can expect that we might be able to use it as interpolator operator to extrapolate the Gamma Ray log.

Interesting to see, that the obtained seismic traces are really similar to the Gamma Ray log, although we did not use any information from that log to obtain them.

We used (and rotated) only the RP and RS acoustic impedances, what we got from the AVO analysis

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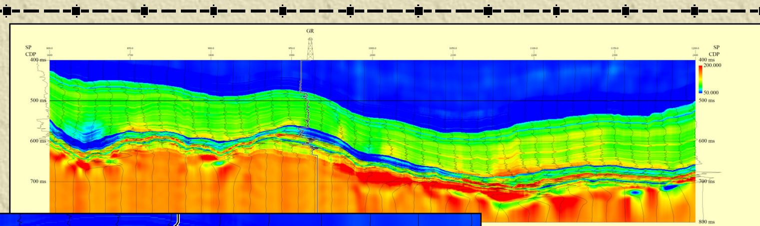

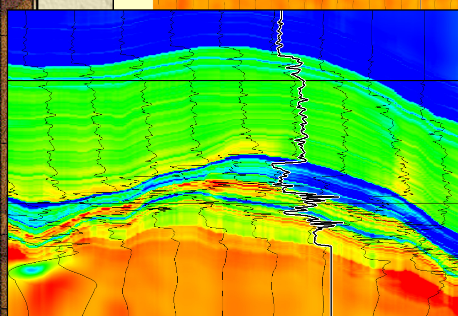

Extrapolated gamma ray seismic section.

On the detailed picture to the left one can see that the resolution is as high as the resolution of the time converted Gamma Ray log. One can even start to examine the reservoir body.

Please notice, we arrived to the point, what a reservoir analyst might dream of. We have P and S wave sonic log sections and also the Gamma Ray section. One can study even the sequence boundaries, at any point of the seismic section.

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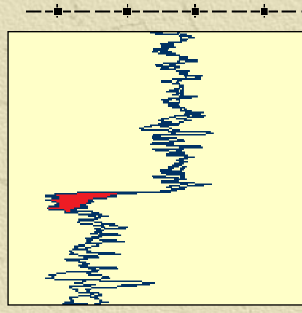

We have one last point to complete this project.

We have the P and S wave sonic log time sections and a pseudo Gamma Ray time section.

Let's consider what should we expect, when we go down from the sealing shale into the carbonate layer? Both the sonic and the Gamma Ray values should dramatically jump. (Carbonates show much higher wave propagation velocities than the shale and shale has much higher gamma ray reading than carbonates)

But, what will happen, when the carbonate layer is extremely porous and contains gas?

The answer is: the sonic will not immediately follow the drop of the Gamma Ray, because the wave propagation velocity in the carbonate body will be decreased by the presence of gas. The difference of the two gives an easy way to detect the gas lens.

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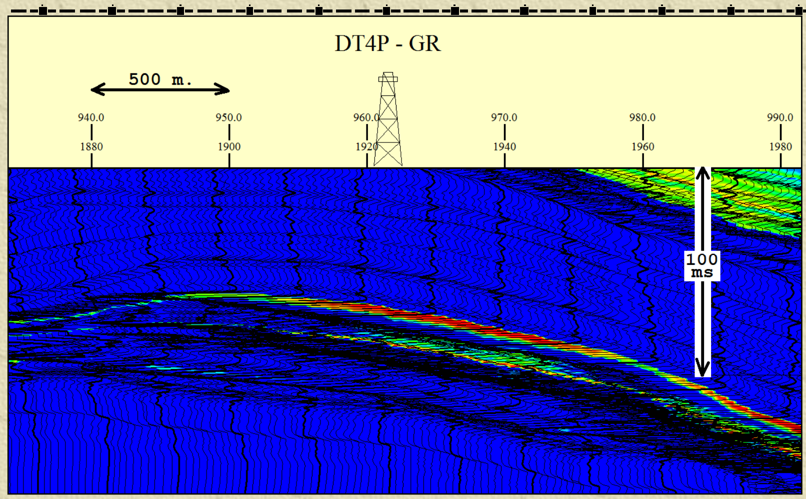

… and this is the final result, where we wanted to go …

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Data needed to obtain these results:

Seismic: At least one migrated final seismic (time) section intersecting a well
AVO processed data (R0-GR, or RP-RS), or NMO corrected unstacked data
Well-logs: Sonic „P" wave transit time log
Sonic „S" wave transit time log
Gamma ray log
VSP or Check-shot: depth vs. two way time (or velocity) function

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