The Santos cluster block 3D survey: learning's from the largest 3D survey in the world.

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Abstract

The Santos cluster block 3D seismic survey project comprises the acquisition and processing of the largest 3D survey in the world to date (20109 full fold km2!!). The combined forces of seismic vendor Veritas DGC and participation of 6 Oil Companies made this gargantuan project possible. Significant learning's in deepwater seismic acquisition and processing have been gathered over the time span of this project, which started mid 2001 with the acquisition and just finished processing in March 2003. The most significant learning's are reported in this article.

Introduction

The cluster block survey covers 4 large concession areas in a relatively outboard position in the Santos basin offshore Brasil. (See Figure 1 for a map and survey outline). Underwriting Oil companies are Petrobras (Operator), BG Group, ChevronTexaco, Petrogal, RepsolYPF, Shell and -through its non-exclusive nature- the seismic acquisition and processing vendor VeritasDGC. To make the survey a reality, significant planning was required, and most Companies have attended all planning meetings that have taken place prior to, and during the project. To satisfy the interests of all Companies did not prove to be difficult, contrary to initial expectations. Instead, all Companies realized that the only way to make this project a reality, flexibility and proactive participation would be of prime importance. An important factor, both from a business and technical point, is the fact that a single company (Petrobras) operates the entire cluster. As a result, significant contributions were made through the sharing of ideas and learning that each company had build in deepwater around the world. Additionally innovative processing techniques have been used on this project, despite the obvious danger that due to its very large size, repeat processing in case of a failure of a certain processing step, was hardly a possibility.

The geology in the area covered by the survey varies significantly with at least two major play domain types recognized within the survey boundaries. Common features across nearly the entire area comprise steep salt domes and steep narrow mini-basins, combined with salt induced thrust zones. Large lateral velocity contrasts require detailed velocity picking and QC to ensure temporal and lateral resolution is preserved. Furthermore the presence of a high velocity contrast, characterized by an endemic reflection that is often mistaken for the top of the salt bodies, gives rise to significant ray path distortions, which cannot be properly accounted for by time migration algorithms. In many cases this has resulted in poor imaging at depth. A solution to this problem is also presented.

Acquisition

The requirement for multiple vessels to record this survey was obvious from the start, however, downtime due to interference had to be kept to a minimum. Two vessels were selected for this work (S/V Viking I and II) and the survey split into 4 parts (see Figure 2 for the layout). The first vessel started recording in the area marked "A center", whilst the second vessel started in the area marked "B north 1". Both portions were finished roughly at the same time, after which the vessels moved to the remaining two areas labeled "B North 2" and "D south". The requirement established in several tests, and from experience in the area and in other deepwater settings is that the vessels stay apart for some 70 km measured at 45-degree angle. This will reduce interference to within acceptable limits. Since the sail line direction is obviously the same over the survey (east / west in this case) and given the large lateral dimensions of the survey area the vessels could maintain this separation for most of the time. On occasions the vessels approached each other within the 70 km limit, but even a separation of 50 km for a short period could be tolerated without any negative effects on the stack.

As part of the acquisition design, 150 m line spacing was chosen. This would allow the deployment of 6 streamers per vessel (6000 m length), with less anticipated down time and a slightly larger footprint compared to 8 streamers at 100 m spacing. Estimates showed that with this configuration the survey could be completed with 2 vessels in one year. The actual duration came out at 13 months, an acceptable overrun of just one month. This was mainly caused by abnormal weather patterns causing somewhat higher than anticipated downtime, and the later arrival of the second vessel.

It was realized at the start that the 150 m line spacing would be too large to properly migrate the steep salt flanks. Interpolation of the survey from 25 x 37.5 m bins to 25 x 18.75 m bin size using an FX algorithm proved to be sufficient to overcome the problem. To handle the significantly increased trace count it was decided to drop the number of offset planes on input to the migration. Testing showed that interpolation to a finer binsize far outweighs the effects of the reduction in the number of offset planes on the final result and even reducing this number by a factor 4 did not significantly impact the data, but significantly reduced the turnaround time.

Processing

The detrimental effect of "cold-water" static's particularly on deepwater seismic data quality is well known. Those statics are caused by temperature and salinity variations, causing changes in the velocity of sound waves through the water column. Since the cluster block survey took just over a year to acquire, all seasons were represented, and significant static variations were obvious. Several solutions have been presented on other projects, but the solution implemented on this survey, although not entirely new, is a particular elegant one.

First the zero offset static is determined from a regional model, which in turn is derived from 2D data. The 2D data crosses multiple 3D sequences at a near 45-degree angle (see Figure 1) and comparisons with the 3D clearly showed the variations in the seabed arrival on adjacent 3D sequences. With cross correlation techniques the zero offset static could be determined, but manual intervention was needed to Q.C. the static on each sequence. The application of the zero offset static resulted in a noticeable improvement, however, it was recognized that on the longer offsets significant amounts of delays are still present, due to the slanted ray paths through the large water column (Figure 3 explains). Additional compensation was needed through an offset and time dependant correction –actually a dynamic correction- to properly align the traces on the far offsets. Figure 4, Figure 5 and Figure 6 show some far offset traces, with respectively no statics, zero offset statics and the dynamic correction applied. The solution including the dynamic part on the far offsets is particularly good, however, it should be noted that the actual solution is ray path dependant, and therefore this approximation is not strictly valid for dipping reflectors and/or complex velocity distributions. The amount of additional correction for dipping events was modeled during the processing and found to be significantly less than the actual correction itself i.e. this error could simply be ignored.

Deepwater multiples are a particular problem in the Santos basin. This is illustrated in Figure 7. Migration “swings” the multiple energy around, resulting in severe degradation of the primaries also at levels above the first order seabed multiple.

From experience in the deepwater part of the Santos basin the application of several demultiple techniques, stacked on top of each other is a requirement. SRME followed by Radon demultiple and –on occasion- followed by multiple diffraction attenuation techniques may be needed. It should be noted that very often the data coming from a recording vessel is processed through Radon demultiple. Due to limitations on the computer resources on board of the vessels, often the SRME step is omitted. Since SRME cannot be applied post Radon, it is often problematic to get the recommended sequence on new data. VeritasDGC applied an equivalent process to SRME, on the data already processed through Radon. This implementation (“COWED” = common offset wave equation demultiple) is a migration technique, which also requires the data prior to the application of Radon demultiple. The field data was processed to a sufficient stage where the filters could be derived, which where then applied on the data with Radon demultiple. The COWED step was followed by further treatment through multiple diffraction attenuation. Good results were obtained as can be seen by comparing Figure 7 and Figure 8. It should be noted that the multiple diffraction attenuation technique was available, but was refined for this project and is now available with Veritas as a program with the acronym “RMA”.

One could argue that the demultiple techniques work well, but little primary energy is observed to substantiate the success of these techniques. Figure 9 shows a stack, and clearly a small half graben shows in the area indicated by a circle, which was not clearly visible without or with limited application of the various demultiple techniques.

Full Kirchhoff curved ray PSTM on 20109 sq. km of 3D seismic data is a significant undertaking. Trade-offs had to be made and a large amount of resources had to be mustered around the world to get this job done. To prevent aliasing of the steepest dips it was decided migrate the data using a ray tracing increment of every trace (instead of the default 3 traces). As a result a significant portion of the processing capacity on the Linux cluster in Houston (4000 nodes at the time) and nearly all of the capacity with Veritas in Singapore (2000 nodes) was occupied 24 hrs/day for a couple of months.

The inclusion of a depth migration step (‘Hybrid‘ Kirchhoff migration) boosted the quality in the deeper portion of the data significantly, but made the requirements on computer resources even more demanding.

This Hybrid Kirchhoff migration, as described further below, was only tested and successfully applied on 2D data in the Santos basin. Through suggestions of the consortium and proactive foresight by the contractor this procedure was ultimately implemented for 3D data, which is an industry “first”. Excellent results were obtained with this method throughout the entire cluster block survey.

Hybrid Kirchhoff migration was used to accommodate the large lateral velocity contrast observed over the endemic reflector described in the introduction to this article. The velocity model prior to the PSDM step is shown in Figure 10. Above the endemic reflector the sediment velocities as picked on PSTM gathers are used. Below this reflector the velocity field is flooded with a constant velocity, representative of the salt and the sediments immediately above and below the salt. After the PSDM step the data is converted back to the time domain and residual velocities are picked using an automated approach. No model updating is performed. The data with PS**T**M is shown in Figure 11. The data after the PS**D**M (Hybrid migration) step is shown in Figure 12. One can observe a very significant improvement, leading to the application of this technique on the entire survey with success.

Lastly we would like to report on another novel approach relating to the migration. This concerns the pre-migration conditioning of the traces. With most processing packages the input traces are migrated using the actual trace coordinates. The output is located in the center of the output bin, such that the traces can be stacked properly. On the cluster block survey the traces were interpolated back to their theoretical bin-centers prior to the migration. This yielded a relatively large improvement to the data quality, which may be explained by the reduction of local aliassing effects where traces on input fall at the extremities of adjacent bins. Figure 13 shows the result of a migration without the bin-centering step. Figure 14 shows the same migration but with the traces moved to their centers prior to the migration step. Note the significant improvement in continuity, due to the suppression of slanted noise.

Conclusions

1.) Excellent interaction between the Seismic Vendor, the Operator and all Partners was a recognized requirement at the start and was ultimately key to the success of this project.

2.) It is well known that deepwater statics can cause severe degradation of the data quality. Splitting the static solution into a true static correction (zero offset) and an offset and time dependant part (a dynamic correction) is recommended in the Santos basin.

3.) In the deepwater Santos basin, strong water bottom multiples are a significant problem, which can be treated through a combination of SRME, Radon demultiple and Multiple diffraction attenuation techniques. On modern surveys often the data comes from a vessels with Radon already applied, i.e. too far into the sequence to apply SRME. Veritas has a workaround (“COWED”) which worked well on this survey.

4.) The improvements with Kirchhoff PSTM over other more conventional approaches is well known. Significant improvements could be gained as a result of bincentering – moving the traces to the accurate bincenters prior to migration.

5.) The usage of a PS**D**M algorithm (Hybrid migration), without any model updating, proved to be superior to full PS**T**M on the Santos clusterblock survey. The presence of an endemic reflector (close to top salt) marking a sharp velocity contrast with significant structure, made the usage of Hybrid migration necessary.

Acknowledgments

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Special thanks to the following people for their key role in making this survey a success: Eduardo Faria, Mariela Martins, Rogerio Fontana and Rosangela Maciel from Petrobras, Antonio Luis Tisi from Shell, Helmut Hsao from ChevronTexaco, Cosme Peruzzolo, Andy Phipps, Doug Mainous and Wei Han Yang from Veritas.

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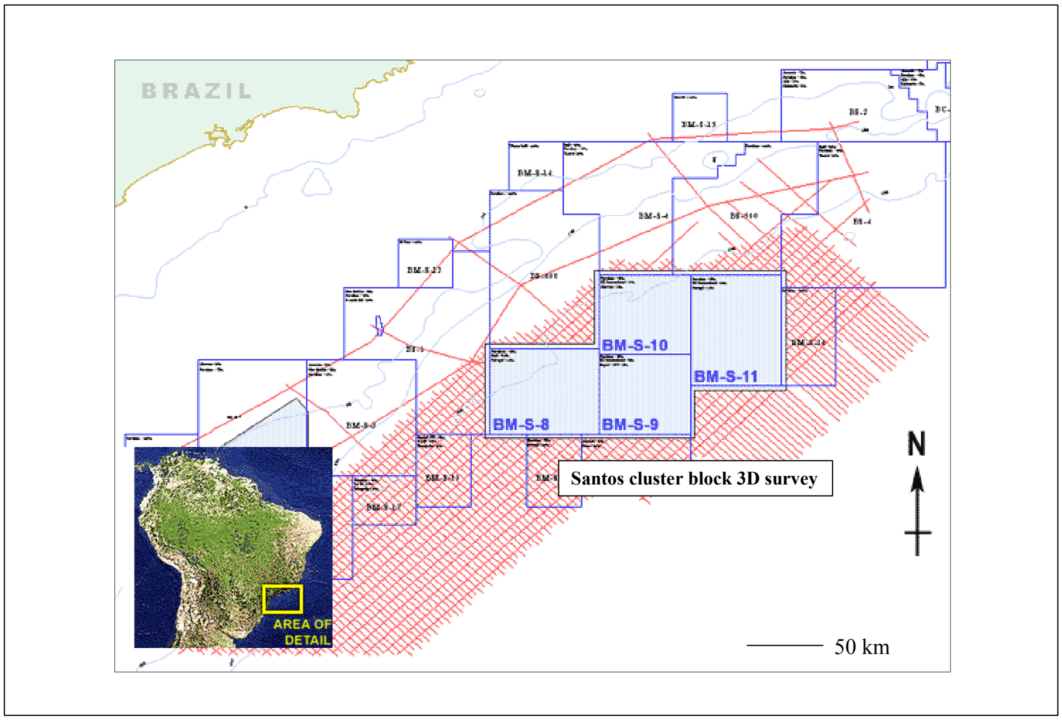

Figure 1: Santos cluster block 3D survey location map.

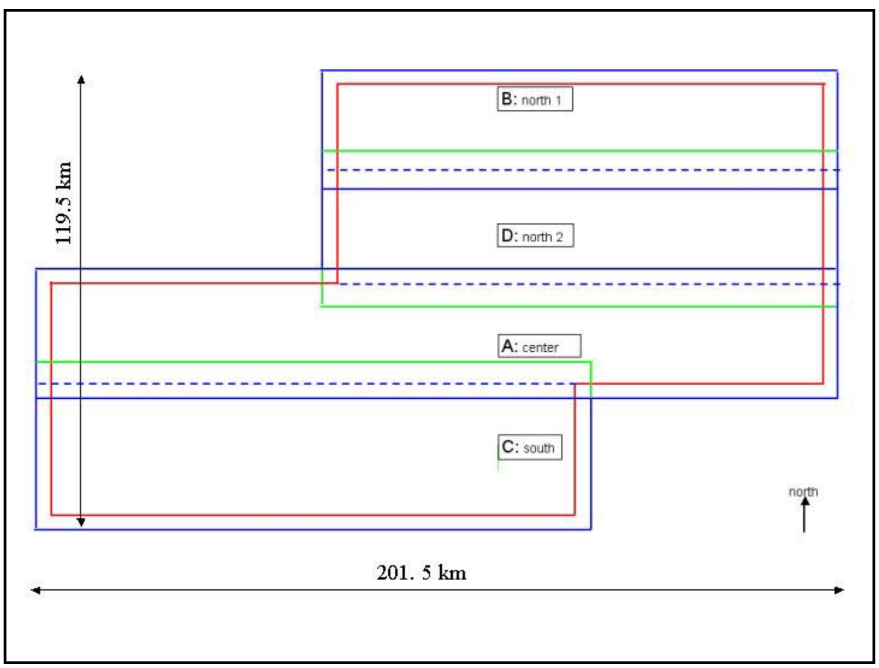

Figure 2: Santos cluster block 3D survey layout. The red line indicates the outer perimeter of the licence areas. The blue lines indicate full fold coverage. The green lines indicate overlap areas for processing purposes.

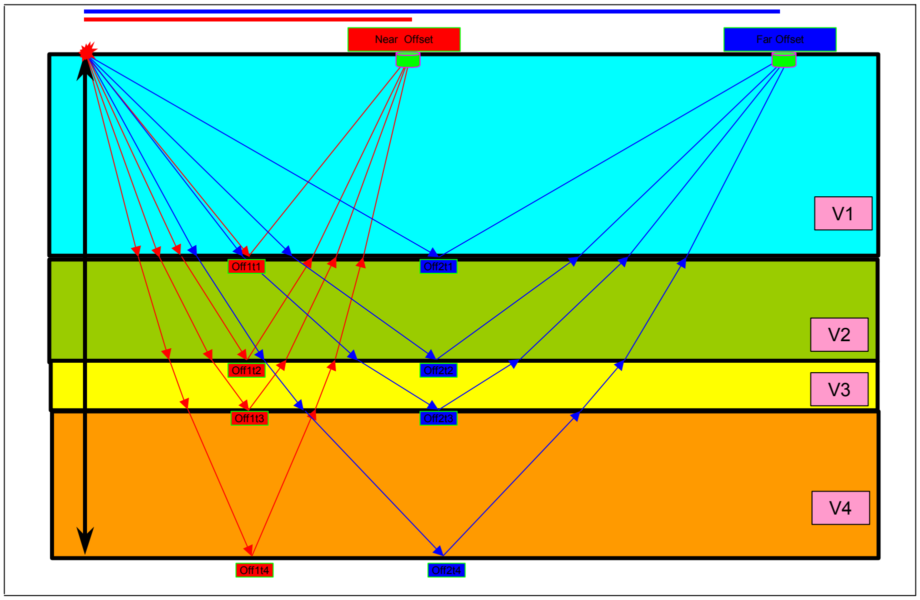

Figure 3: After comparing the red (near offset) and blue (far offset) ray paths for this simple model one can see that the water column static correction varies with time and offset. Only the zero offset does not have a time variant component.

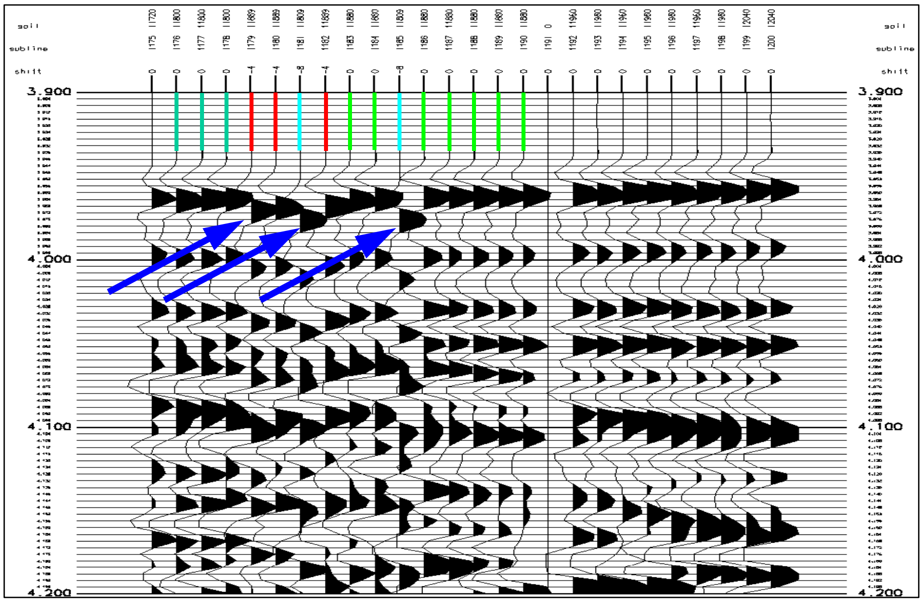

Figure 4: Offset 4370. No static corrections applied. Color-coding at top by acquisition sequence.

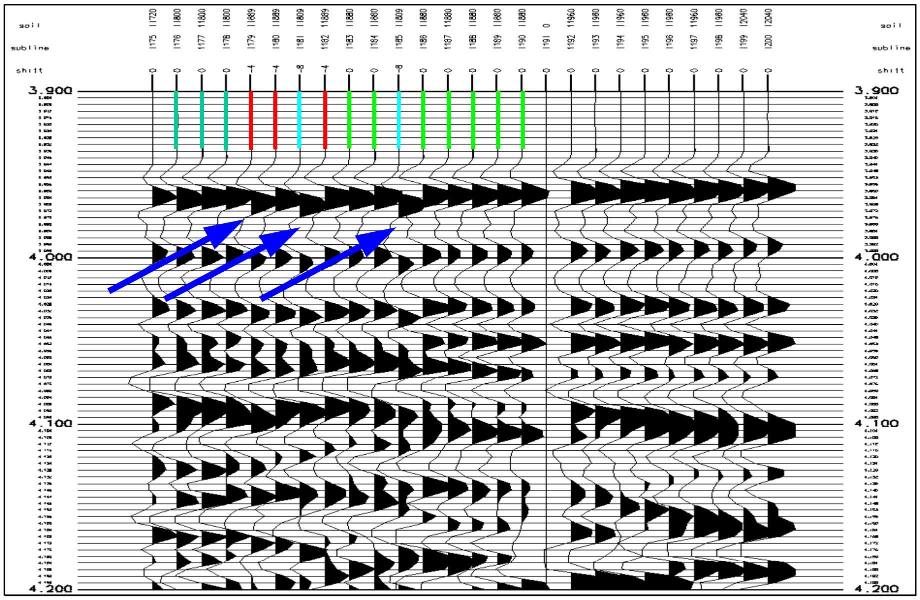

Figure 5: Offset 4370. Static corrections from zero offset have been applied, improving the continuity of the reflections compared to the data displayed in Figure 4.

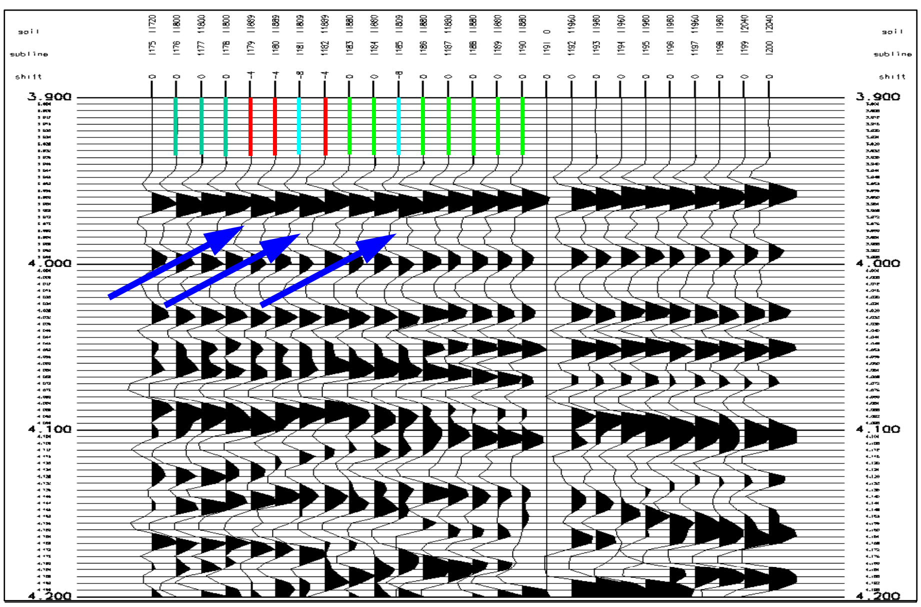

Figure 6: Further improvements were obtained on the data shown in Figure 5 by using an offset and time dependant correction to compensate for water column velocity variations.

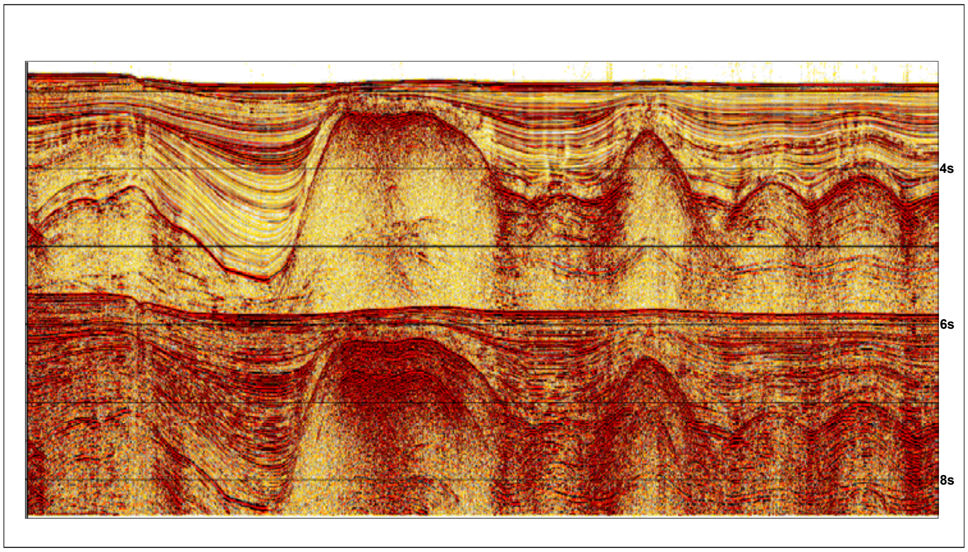

Figure 7: Near offset data, before the application of demultiple techniques. The very strong first order seabed multiple contaminates the deeper portion of this section.

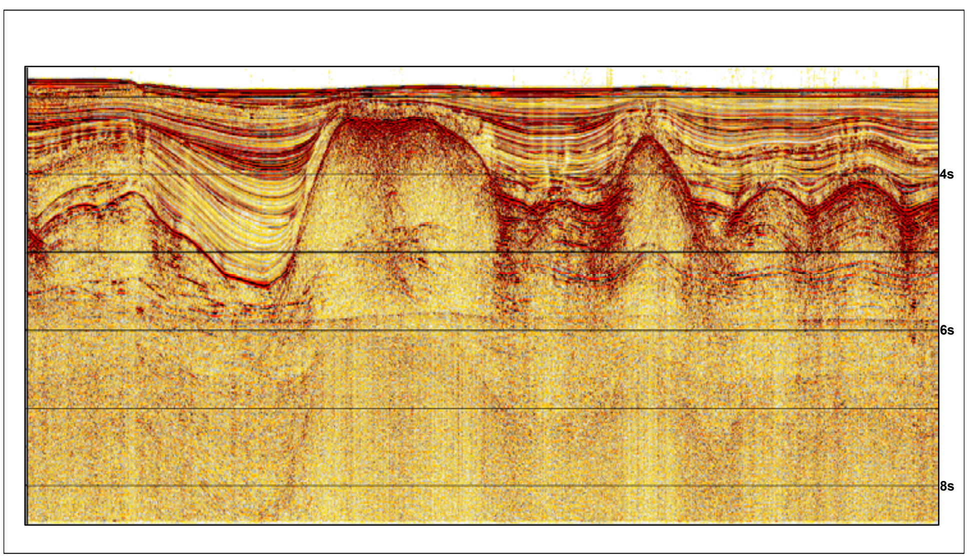

Figure 8: Data of Figure 7 with the application of Radon demultiple, Common offset wave equation demultiple and a multiple diffraction attenuation step. Very significant improvements are obvious, however, only limited amounts of primary data are present in the deeper zone were most of the multiple energy was removed.

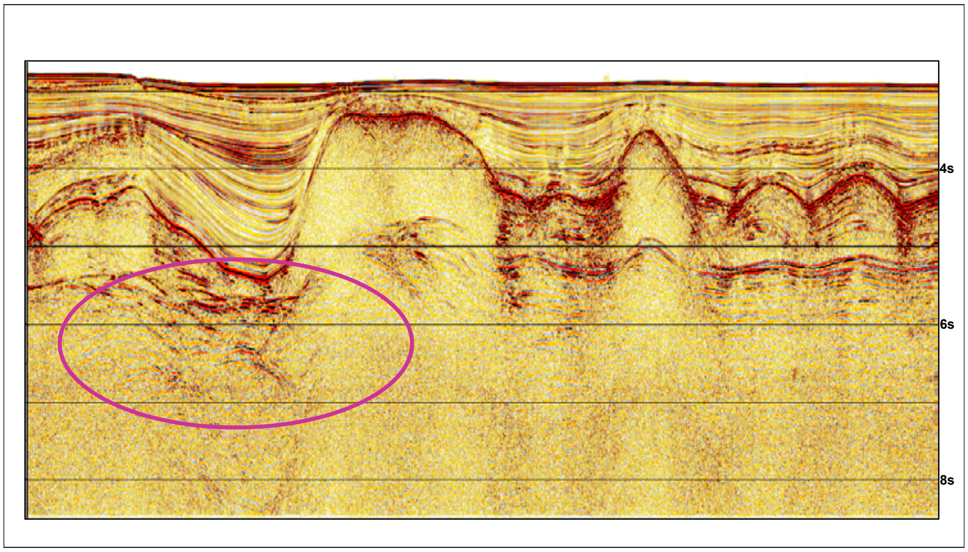

Figure 9: Stacked data, using data as shown in Figure 8 as input. Note the half-graben, below the salt, which is now clearly imaged.

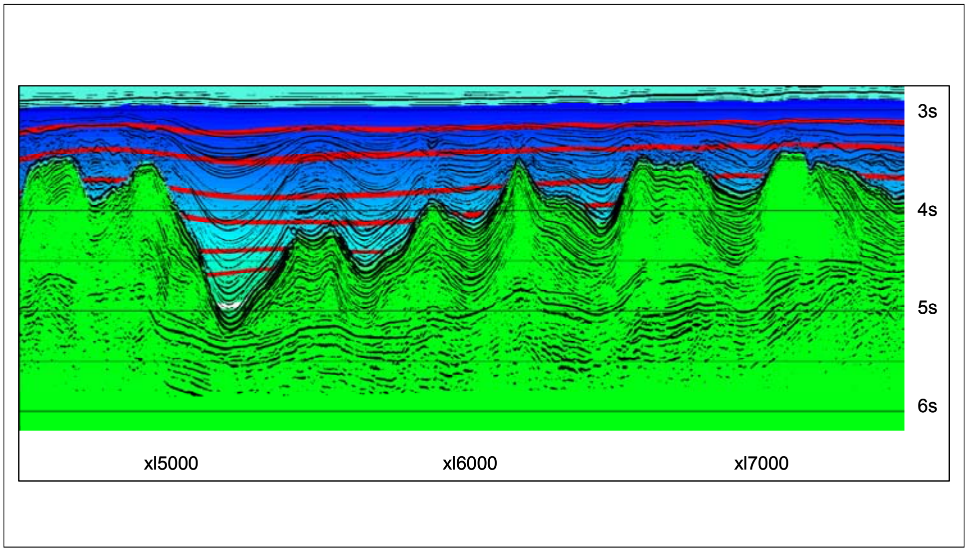

Figure 10: Velocity model overlay on seismic backdrop. The data was migrated using PSDM and this velocity model. Residual velocity corrections were applied prior to stacking the data.

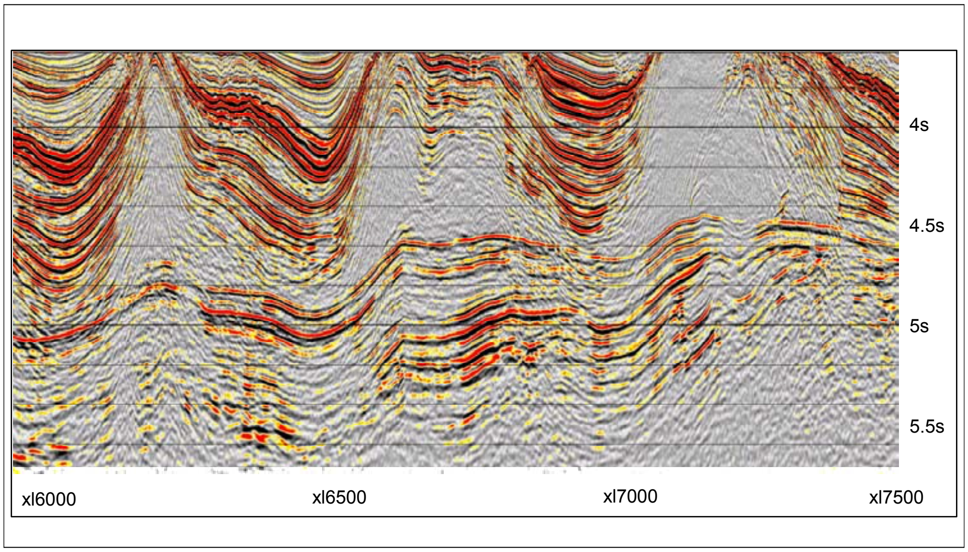

Figure 11: PSTM using stacking velocities as derived on the sediments.

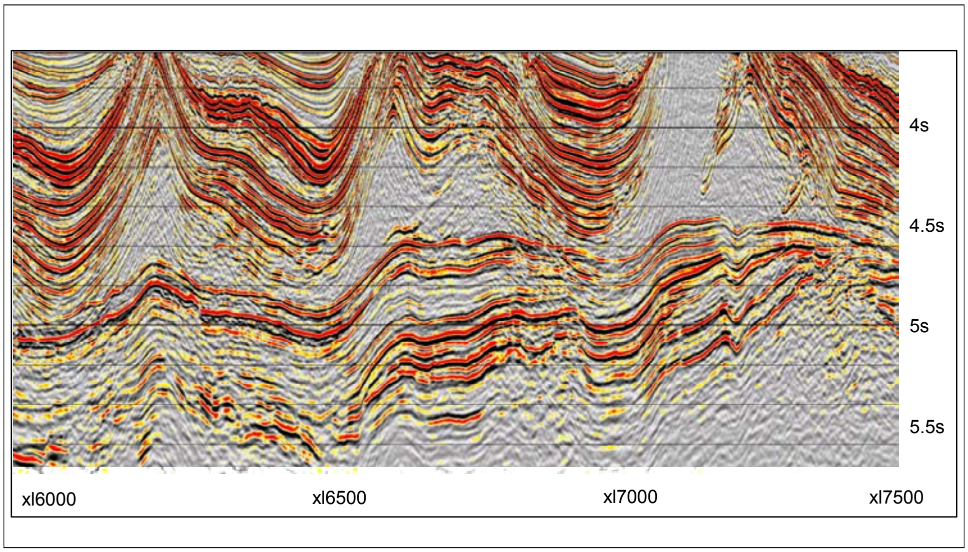

Figure 12: Hybrid migration using the velocity model as shown in Figure 11. Significant improvements are obvious throughout the section. Particularly noteworthy are the considerable improvement in the continuity of the pre-salt reflections.

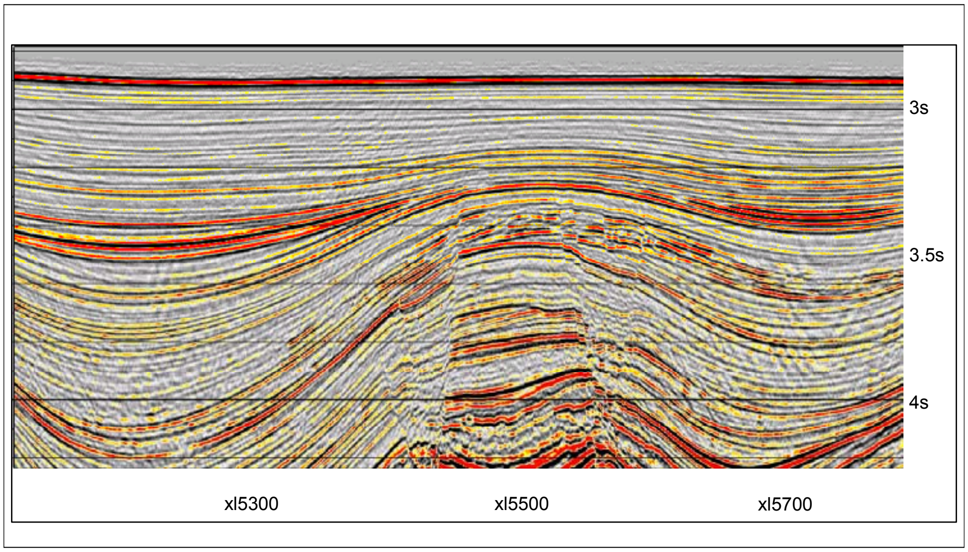

Figure 13: Stack of PSTM data, migrated using the actual trace coordinates.

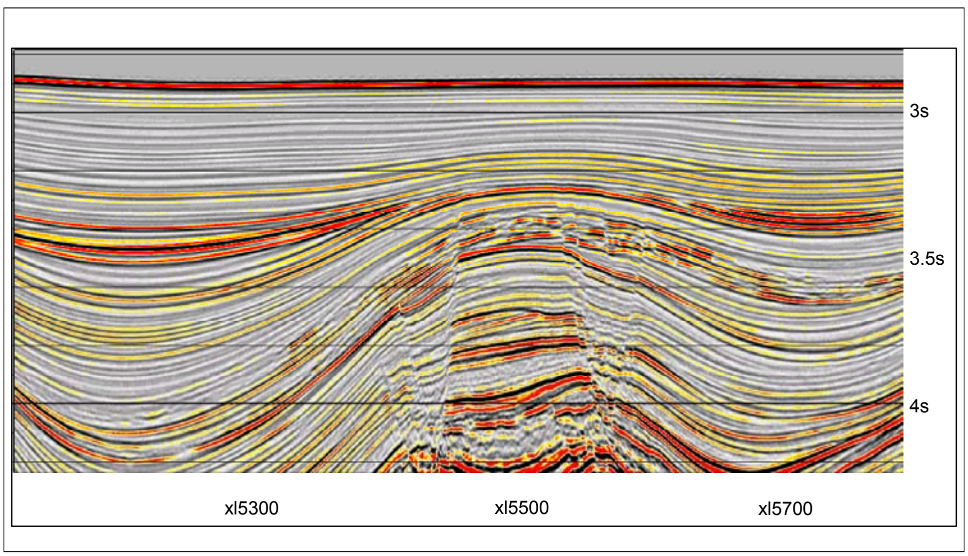

Figure 14: Stack as shown in Figure 13, but with bin centering applied prior to migration.