Petroleum Res. J. Vol. 20 (2007); P. 35–44, 11 Figs.

Anisotropic Prestack Depth Migration In C97 And NC98,Libya

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هجرة عمق ناجم عن تراص مسبق متباين بعقديْ الامتياز C97 وNC-98، ليبيا

س. هاينتش وعبد الله سالم بن عبد الله

التصوير الزلزالي المحسن تحت نطاقات الصدوع المركبة، حيث تزداد استمرارية الانعكاسات وتتحسن حديّة التركيز على الصدوع وبأقل ضوضاء ممكنة، يمكن الحصول عليه، بهجرة العمق الناجمة عن تراص مسبق متباين الخواص. فهو يحسن نوعية الصور بالتقليل من الضوضاء وباستمرارية أكبر للانعكاسات وتحديد أفضل للصدوع. وللنتائج المتحصل عليها تأثير فعال في حفر آبار جديدة وقد تعمل هذه التقنية على تحسين صور أماكن أخرى مرتقبة في ليبيا تقع تحت نطاقات الصدوع المركبة، ولضمان نجاح هذه التقنية فإن المطلوب من الجيولوجيين والجيوفيزيائيين العاملين في شركات النفط، أن يولّوا اهتمامات أكثر وتفاعلات أكبر من تلك التي يمارسونها في تقنيات المعالجة الزلزالية العادية.

Abstract: *Improved seismic imaging below a complex fault zone, more continuity of reflections, better focusing of faults and less noise are achieved by anisotropic Prestack depth migration (PreSDM). It improves the image quality by reducing noise, more continuity of reflections and better fault definition. The obtained results had a major impact on drilling of new wells. The technology of PreSDM may improve imaging of other Libyan prospects that are located below complex fault zones. To achieve success, this technology requires significantly more attention and involvement from oil company's geophysicists and area geologists than standard seismic processing techniques.*

INTRODUCTION

Study Area

An anisotropic Prestack depth migration (PreSDM) project was operated in 2001 – 2004 by Wintershall – Libya with Waha Oil Company being project partner. It covers an area of 1242 Km² mainly in Concessions C97 (Wintershall-Libya operator) and NC-98 (Waha Oil Co. operator) in the eastern Sirt Basin of Libya with small extensions into C100, C102 and NC-59 (Fig.1). In addition to producing oil fields, the area contains several potential exploration prospects. It was one of the first applications of depth imaging in Libya and is one of the largest onshore depth imaging projects world-wide. However, to keep project sizes reasonable the project was split into three phases, assuring consistency between all phases (Fig. 1).

The area of study is generally of low structural relief, but has complex faulting resulting in strong lateral changes in velocity. These lateral changes degraded the seismic image in the original standard time processing.

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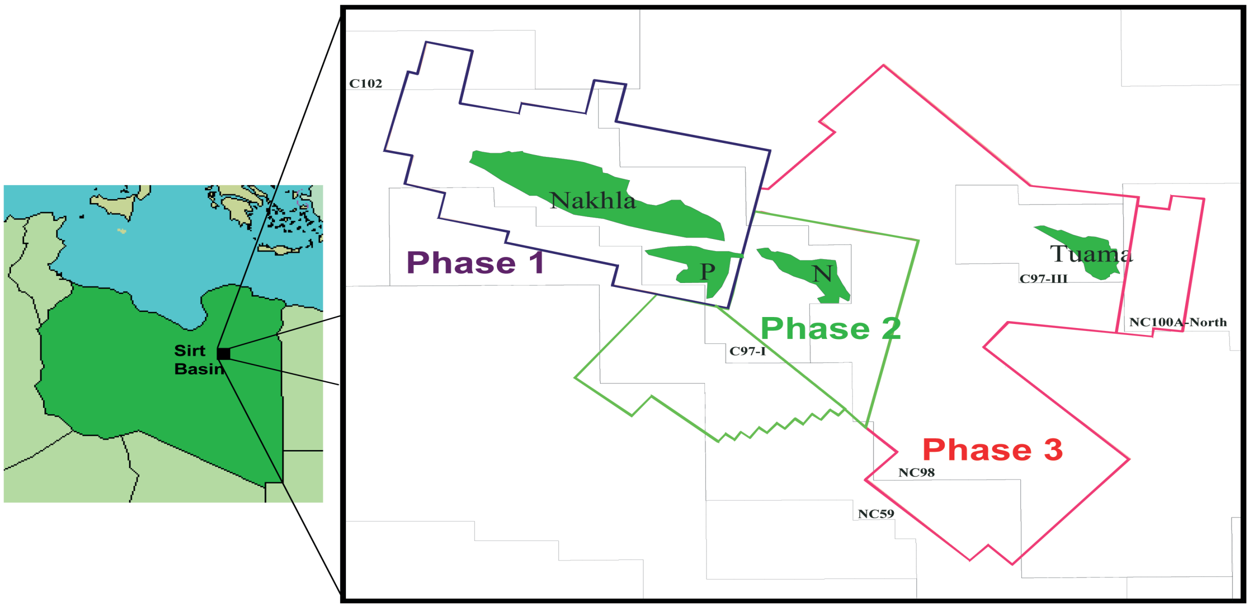


Fig. 1. Project outline. Concessions C97 and NC98 are located in the eastern part of the Sirt Basin.

Objective

The main objective of the project was to improve the image quality below the complex fault zone. Figure 2 shows an overlay of PreSDM seismic and the corresponding section of the obtained velocity / depth model. A system of long and very steep faults cause the large lateral velocity variations. As a consequence, nonhyperbolic moveout is present and therefore standard time processing does not manage to focus the image properly below the fault zone.

Another objective was to obtain a seismic image in “true” depth (*i.e.* that ties existing well marker depths within the seismic bandwidth) therefore vertical transverse isotropy (Thomson’s delta and epsilon parameters) was introduced to the velocity model as a first order approximation of anisotropy.

PROJECT STEPS

Data Preparation

When matching seismic with well data as an objective, it is very important to assure the integrity of all data. With about 40 wells located within the project area, a consistent log re-processing including the calculation of time–depth curves based on VSP constrained sonic logs, synthetics in time and depth and consistent picking of well marker depths prior to the project proved extremely valuable. Interpretation of existing time seismic provided the eight horizon maps for the initial model.

Time Pre-processing

Time pre-processing is an important major step prior to depth imaging. In this project, seismic data from eight seismic surveys (acquired between 1991 and 2002 with different parameters) were used which required very careful analysis for matching phase, time and amplitudes. In recent years, techniques for de-noising and demultiple have advanced. The reduction in the noise level of the PreSDM result, compared to the original Poststack time migration result (Fig. 3), is to some degree due to these advancements.

Multiples pose a big problem in many data sets in the region. These are intra-bed multiples that have the same moveout as primaries, and therefore velocity based demultiple techniques failed. Model based techniques were also not successful due to difficulties in defining a proper model. In subsets of the project, Tau-P deconvolution was applied to partly attenuate these intra-bed multiples; In other areas, multiples could not be attenuated without harming the top reservoir primary and therefore remain a challenge for the seismic interpretation.

Velocity Model Building

The geology in the Sirt Basin requires the use of a layered velocity model. Eight layers were parameterized; Each with their own laterally varying V0 and spatially invariant depth gradient and Thomson’s anisotropy parameters (delta, epsilon). For the initial model, VSP calibrated sonic logs were

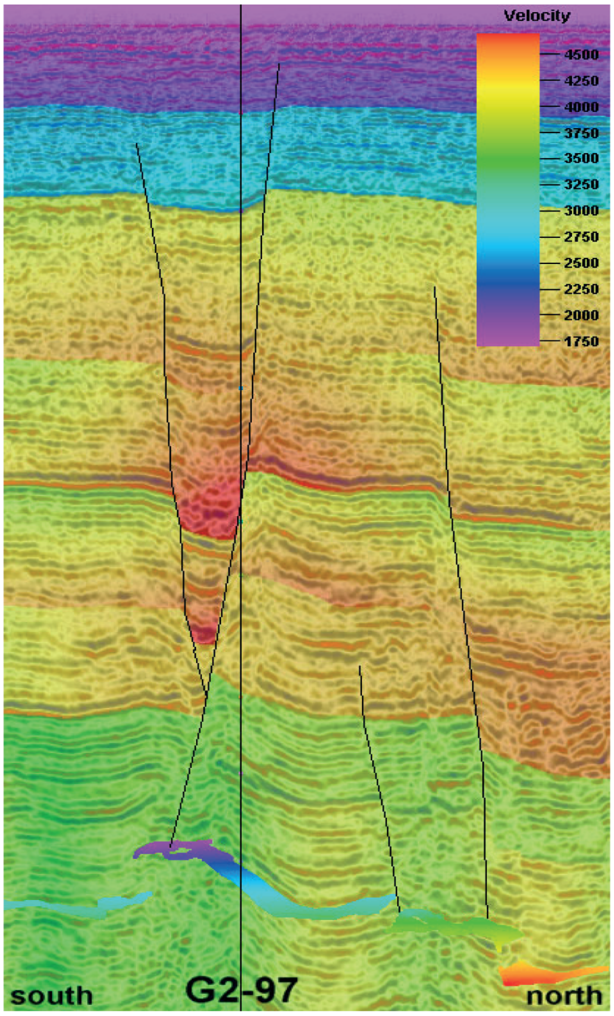


Fig. 2. Overlay of Prestack depth migrated seismic and the corresponding section of the obtained velocity / depth model. A system of long and very steep faults cause the large lateral velocity variations as indicated by the grey background. These lateral velocity changes are the main reason why Prestack depth migration improves the quality of seismic results.

analyzed to determine constant depth gradients for each layer and these were not changed during the model updating. Interpretations of the time seismic and stacking velocities were used in Dix inversion to build the initial model.

In each iteration of velocity model updating, first velocity residuals were picked on the result of a coarse PreSDM (performed with the previous model) then tomographic updates were performed until flatness of image gathers were achieved. When the average well misfit was significant, an anisotropic tomographic update was then performed. Then a structural update migration (usually inlines and crosslines every 500m) was interpreted, and the next iteration could start. Usually four iterations with, two horizons each were performed. Interpretations were performed in the depth domain because vertical depth-time conversions would have introduced significant artifacts around the faults.

Final PreSDM and Post-processing

After completion of the velocity model building process, a full volume PreSDM was applied followed by post migration processing that included residual moveout, stack, and standard Poststack processing steps like deconvolution, filters and scaling.

PROJECT MANAGEMENT

For a successful project, this technology requires significantly more attention and involvement from oil company's geophysicists and area geologists than standard seismic processing techniques. In standard projects, first the seismic processing is performed and only after its completion the result is interpreted. In case of PreSDM, processing and interpretation are coupled. After a first iteration of processing, the interpreter picks the most shallow horizons that are fed back into the next iteration of processing. Only after several iterations of processing and interpretation, a final processing result is obtained that is then subject to final interpretation. Each iteration requires sufficient attention from the oil company's geophysicists and area geologists.

In this project seismic processing was done by WesternGeco in Gatwick and the supervision, coordination and interpretation were performed by Wintershall-Libya in Tripoli and Monarch Technical Services in London, with support from Waha Oil Company. Optimal (fast Internet based) communication and supervision to achieve efficient decision making and team work were key for this successful study.

RESULTS AND DISCUSSION

Figures 3, 4 and 5 compare original Poststack time migration, Prestack time migration and PreSDM (scaled to time for comparison purposes) on a line in the west of the project area. Prestack Kirchhoff time migration (Fig. 4) was tested in an early phase of the project, but although there is some image improvement, compared to the original Poststack time migration (Fig. 3), it is not a convincing improvement. It is the Prestack Kirchhoff depth migration result (Fig. 5) that shows significant improvement in image quality compared to Poststack and Prestack time migration: less noise, more continuous reflections, better focused

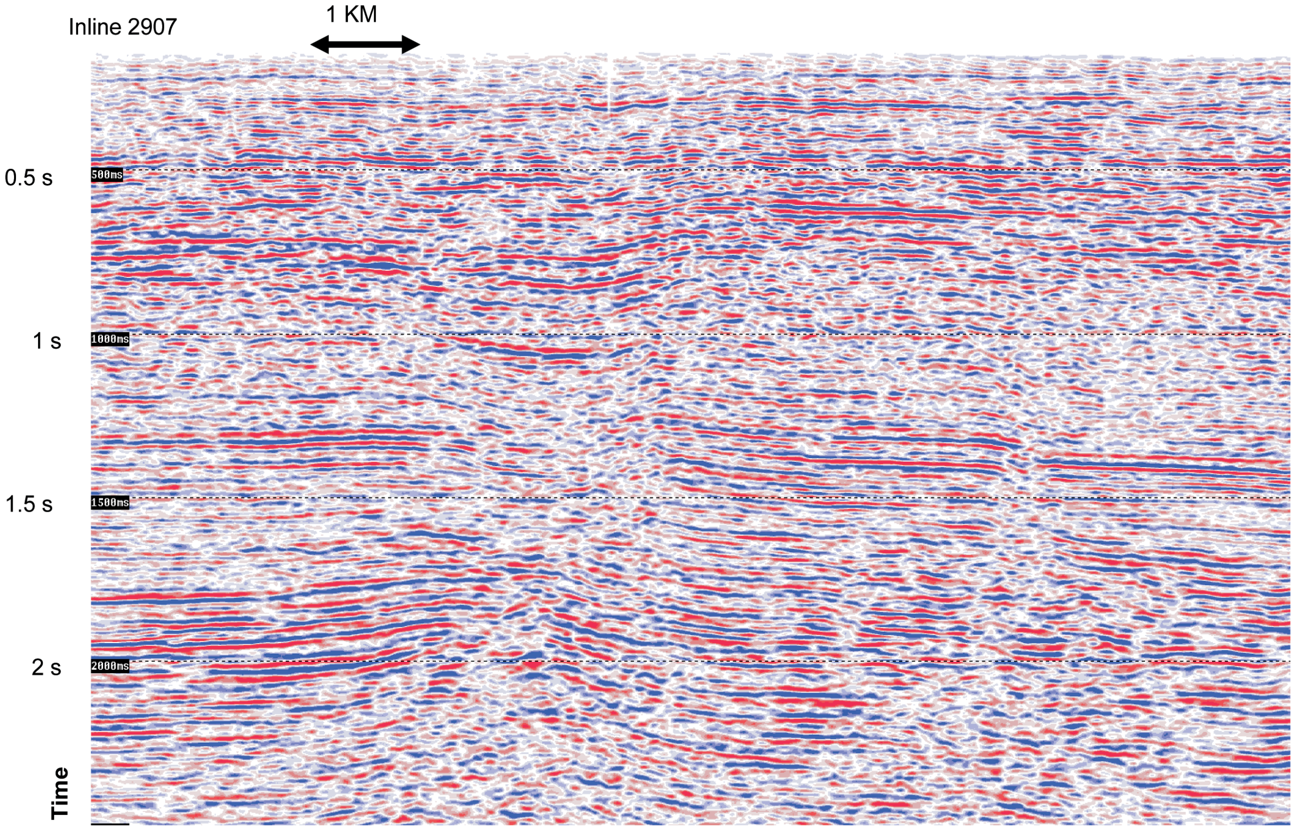


Fig. 3. Standard Poststack time processing result for one inline in the west of the project (for comparison with Figures 4 and 5).

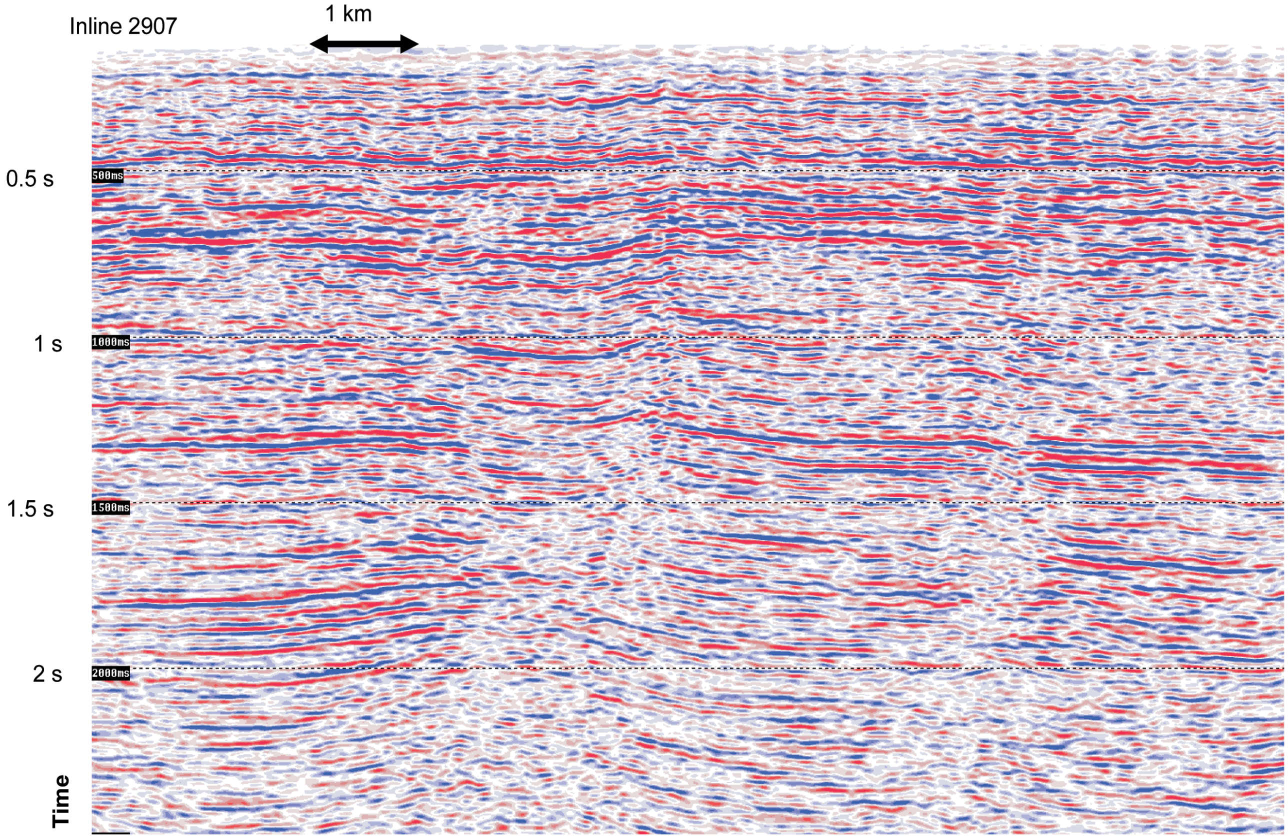


Fig. 4. Prestack Kirchhoff time migration result for the same inline as Figure 3. This test shows some (but not convincing) image improvements compared to Poststack time migration.

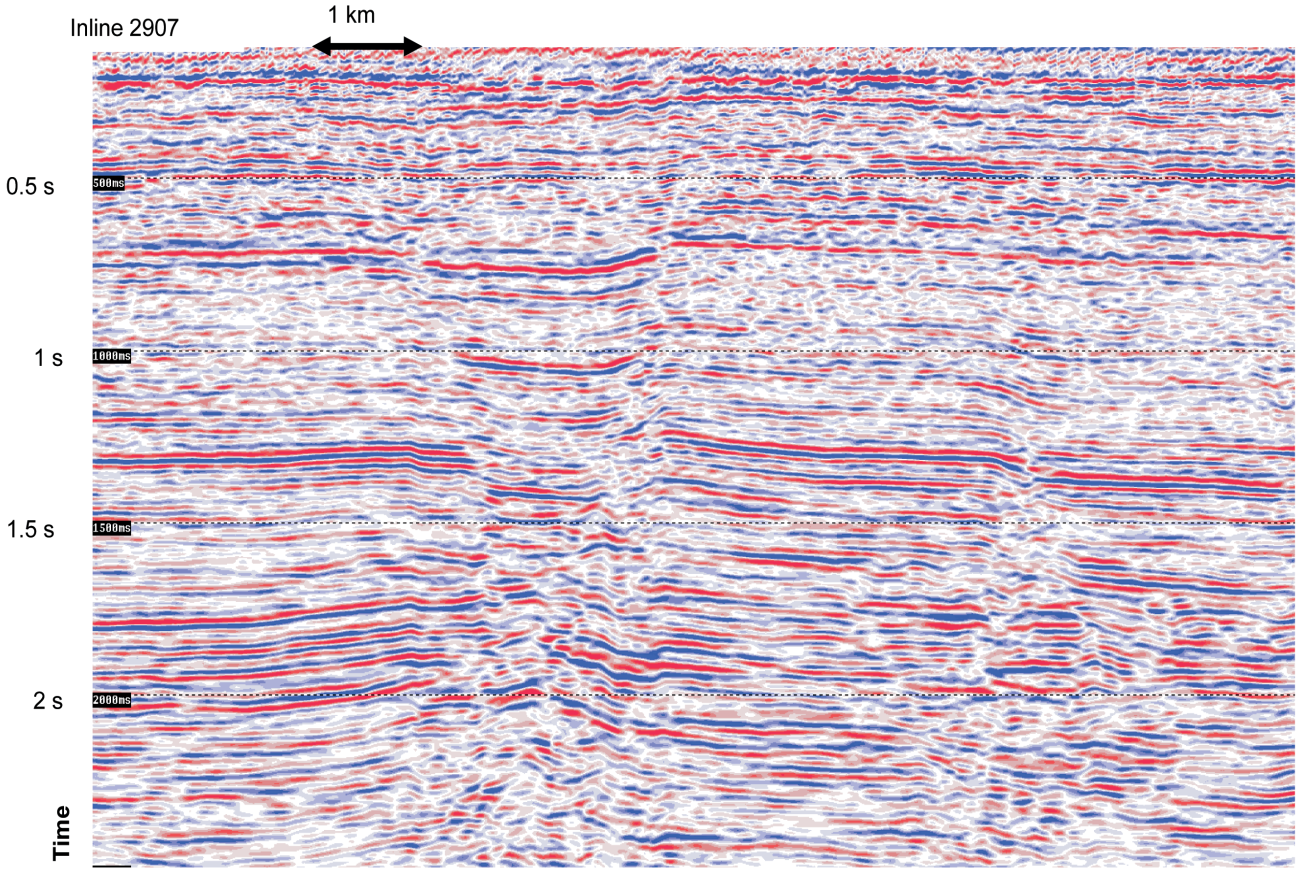


Fig. 5. Prestack Kirchhoff depth migration result (scaled to time for comparison purposes) for the same inline as Figures 3 and 4.

faults and more continuity in the reservoir zone below the faults.

The improved fault definition is even more clear in the comparisons of Figures 6 and 7; the noise reduction and improved reflector continuity is most impressive on Figure 7 where faults that were not visible before on the time migration result become visible. These comparisons are from the centre of the project area.

The Poststack time migration result on the left of Figure 8 shows an apparent time dip that differs significantly from the depth dip (right part of Fig. 8). In Figure 9, the Poststack time migration result shows a false time structure, in depth the reflectors are dipping continuously and don't show a structure. The Prestack depth migration resolves velocity artifacts that are inherent to time seismic as apparent time dip and false structures.

The project had a major impact on one particular well (Fig. 10) originally planned as vertical well to reach a target that appears to be safe on the time seismic, the depth seismic imaged it on the downthrown side of a fault. The well was side tracked by 600m to the up thrown block and hit the target reflector within a few metres of prediction.

The main objective (improved image quality compared to Poststack and Prestack time migration) was achieved and the second objective (to obtain a seismic image in "true" depth that ties *existing* well marker depths within a tolerance of 30 metres) was also achieved. However, one of the wells based on the interpretation of this project came in 112 metres too deep which is far outside the tolerance of the applied technology.

The VSP velocities (left part of Figure 11) showed very high values averaging at 5700m/s within the layer bounded by the horizons Top Megraf and Top Sirte. After further analysis, it was concluded that these anomalous velocities correspond to a steep fault where fluids moved up causing dolomitization of the limestone close to the fault (simplified sketch in the right part of Figure 11). Due to the steepness of the fault, a thick vertical dolomitized section was created. Close to this well, the width of the anomaly (perpendicular to the fault) is in the order of a few hundreds of metres which explains why seismic velocity analysis (every 500 m) was unable to see it. Even high resolution velocity analysis (every 100m) proved unable to see this anomaly due to limited data quality close to the well. The reason why this problem

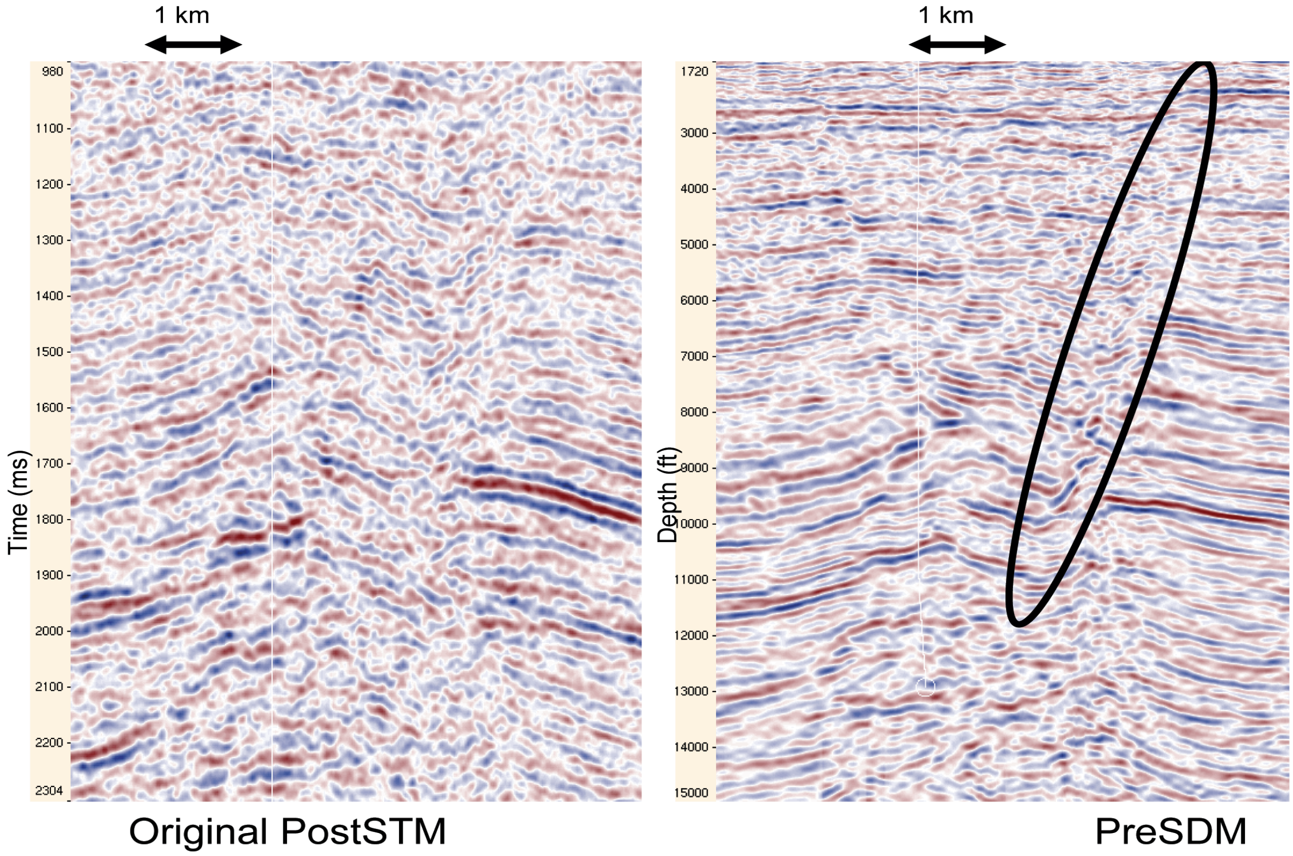


Fig. 6. Prestack Kirchhoff depth migration (right) shows better focussed faults, more continuous reflections, less noise and more continuity in the reservoir zone below the faults compared to original Poststack time migration (left).

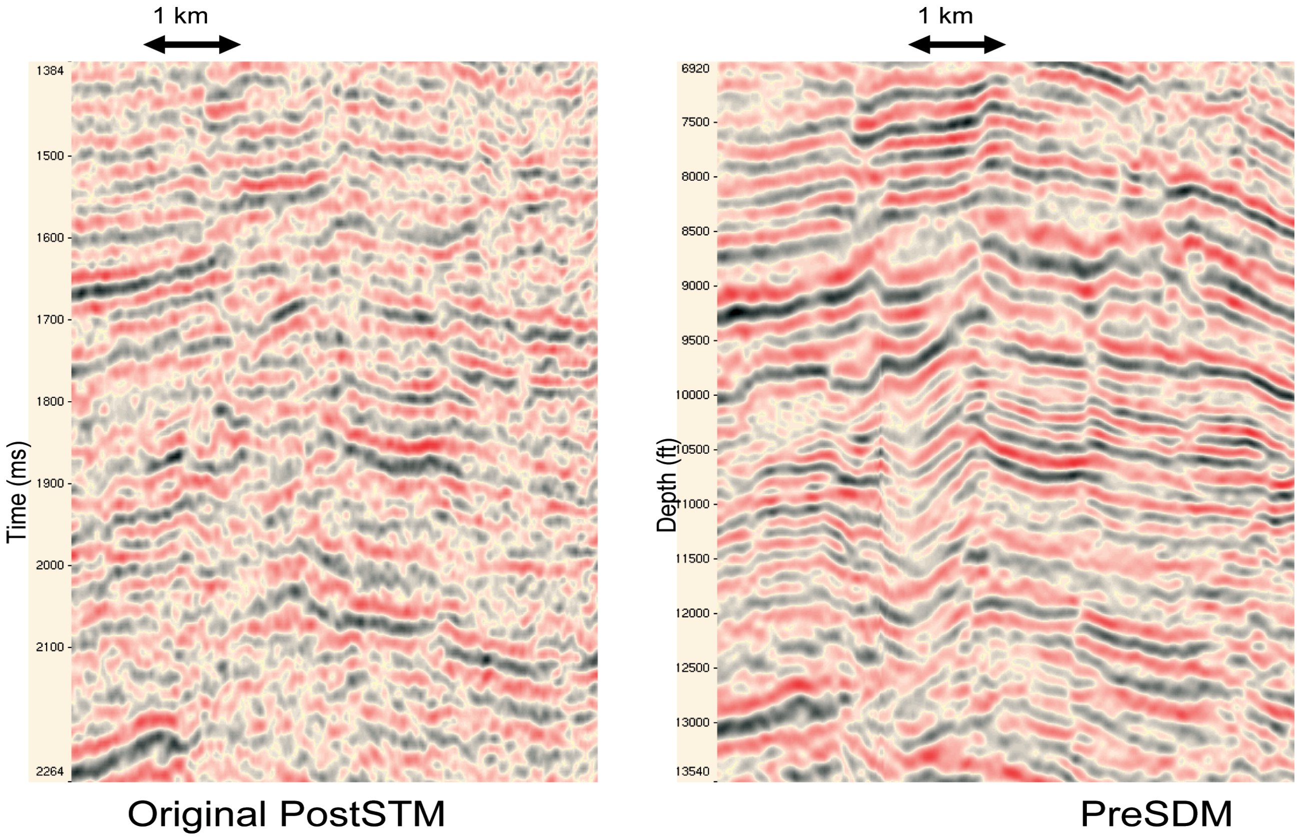


Fig. 7. Prestack Kirchhoff depth migration (right) shows less noise, more continuous reflections and better focussed faults compared to original Poststack time migration (left).

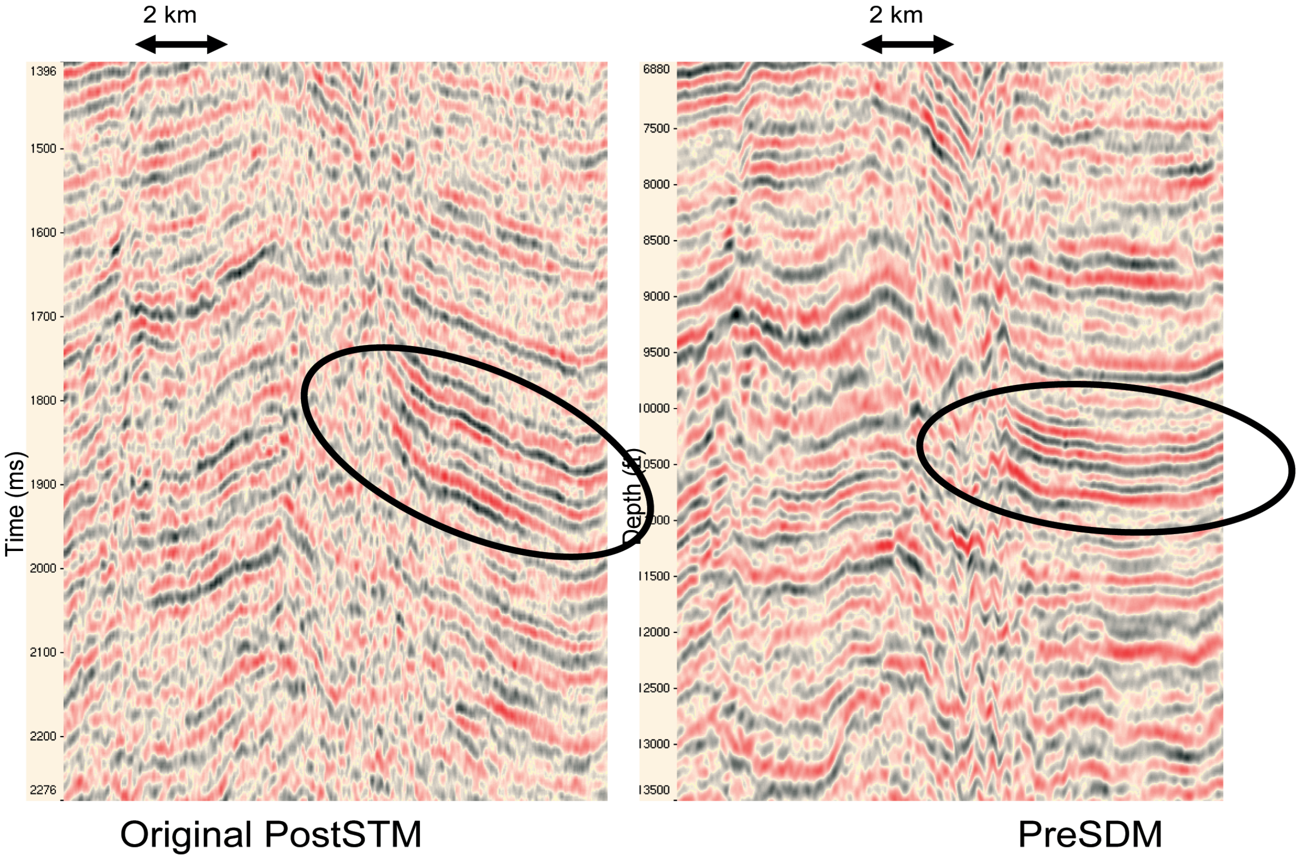


Fig. 8. Prestack Kirchhoff depth migration (right) shows events with a very small dip compared to the apparent time dip visible after Poststack time migration (left).

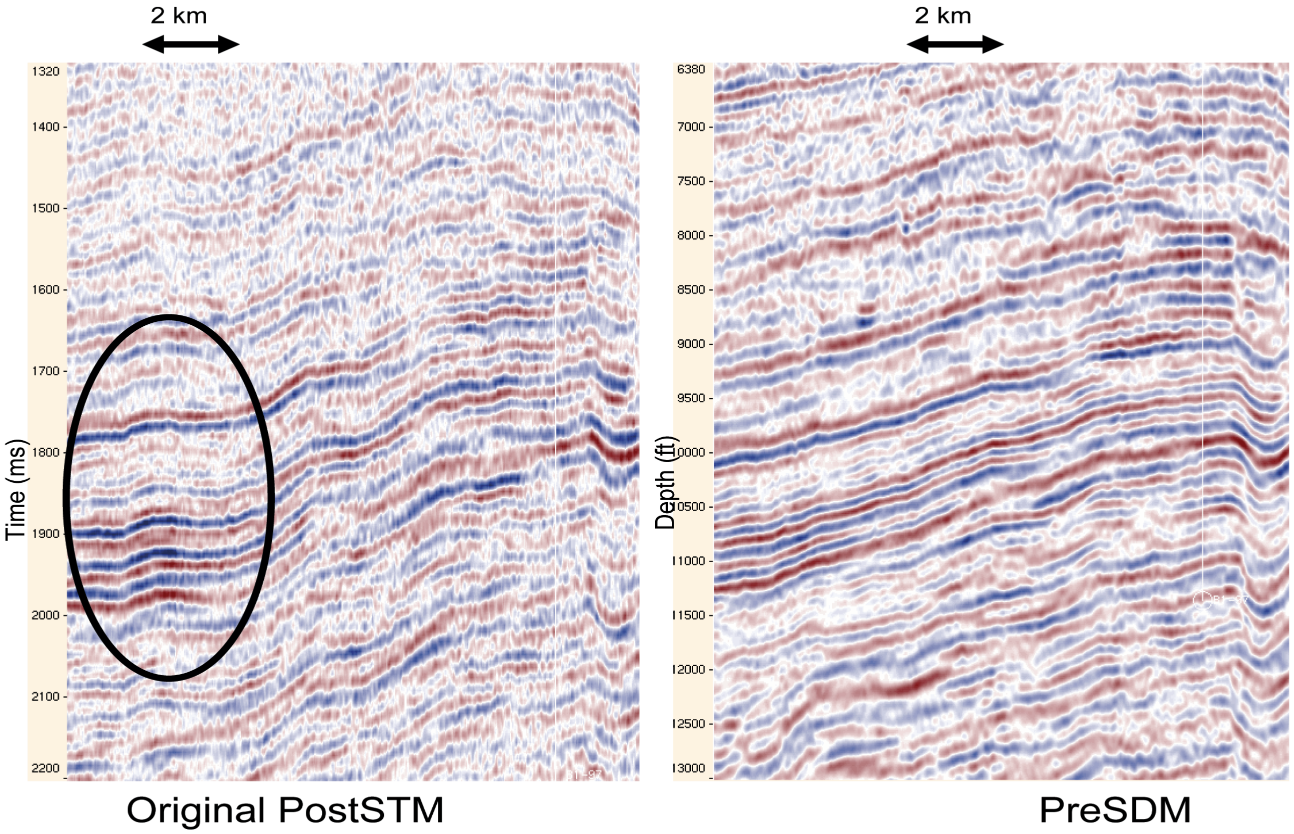
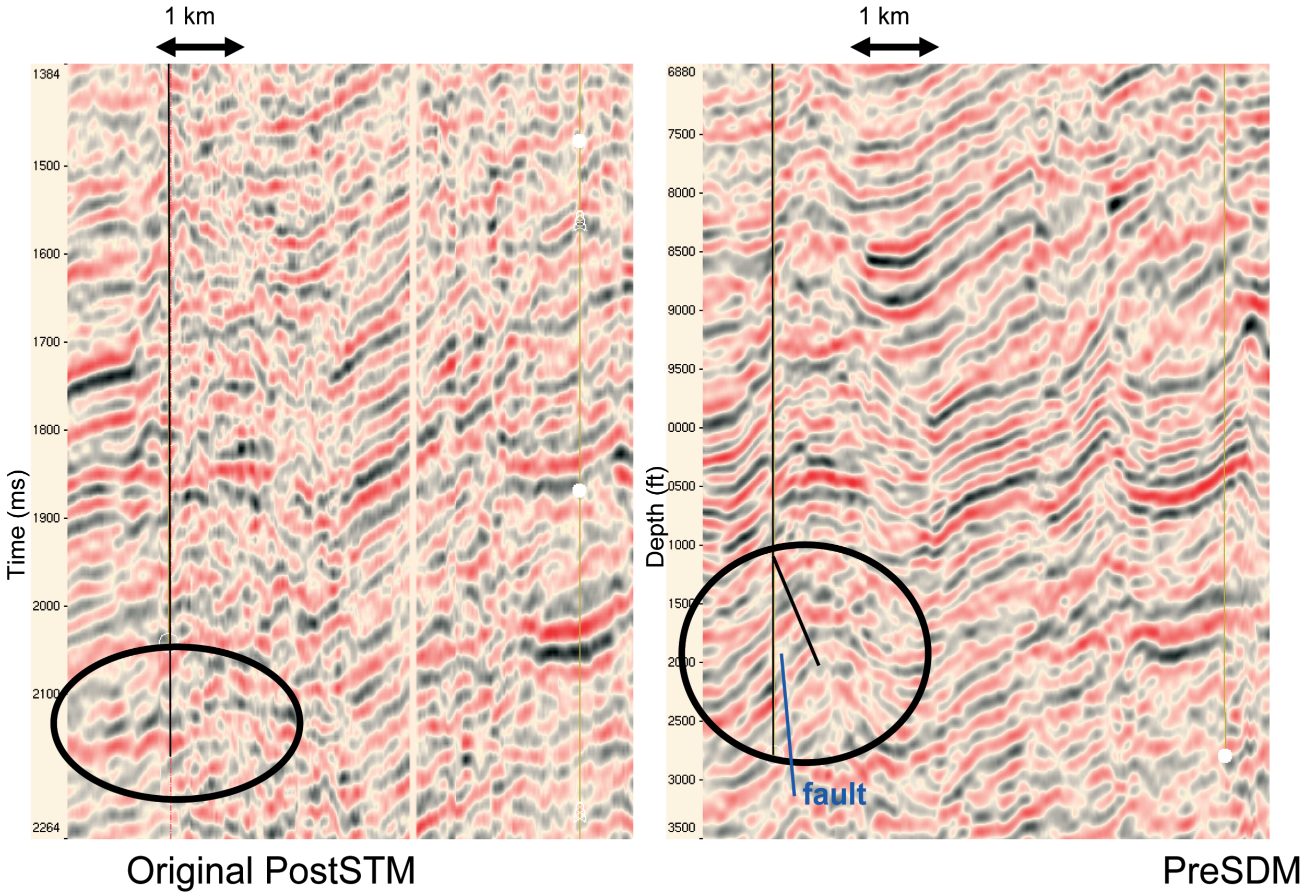


Fig. 9. A false structure visible on the original Poststack time migration (left) disappears after Prestack depth migration (right). This was a velocity artifact.



Original PostSTM

PreSDM

Fig. 10. Major impact on one particular well..

was only encountered after Prestack depth migration is that the Poststack time migrated seismic in the area of this well was so badly distorted that no well had been placed before.

In later phases of the project, special attention was given to identify this anomaly. In the central part of the project, the width has increased to more than five kilometres so that standard velocity analysis was able to see it. In later project phases, much special attention was spent estimating the high resolution character of the velocity model.

Preliminary results from this project have been presented by Hanitzsch *et al.* (2003).

CONCLUSIONS

PreSDM provided a significantly improved image quality compared to Poststack and Prestack time migration: less noise, more continuous reflections, better focused faults and more continuity in the reservoir zone below the faults. Also, artifacts, like apparent dips and false structures on old time seismic data, were removed or corrected after Prestack depth migration.

PreSDM had a major impact on interpretation. In particular, a better integrated fault interpretation was obtained due to the better focus of the overburden. For planning of new wells, it became evident that time seismic images should not be relied on. So far, about a dozen new (exploration and development) wells have been drilled based on the results of this Prestack depth migration project, and in all (but one) cases the target reflector was hit within 60m.

In the study area, dolomitization occurs along steeply dipping faults that can cause very high velocities. If not accounted for in the velocity model, such anomalies can cause depth prediction misfits of more than one hundred metres. Such an anomalous zone can have several hundreds of metres vertical thickness above top Sirte, be very long parallel to faults but only a few hundreds of metres wide perpendicular to fault. Therefore, it is hardly possible to recognize these anomalies with standard velocity analysis and its estimation with high resolution methods can be very challenging depending on data quality. It is sometimes possible to estimate such anomalies from image distortions; they cause deeper down when not taken into account, at least when the background velocities have already been estimated

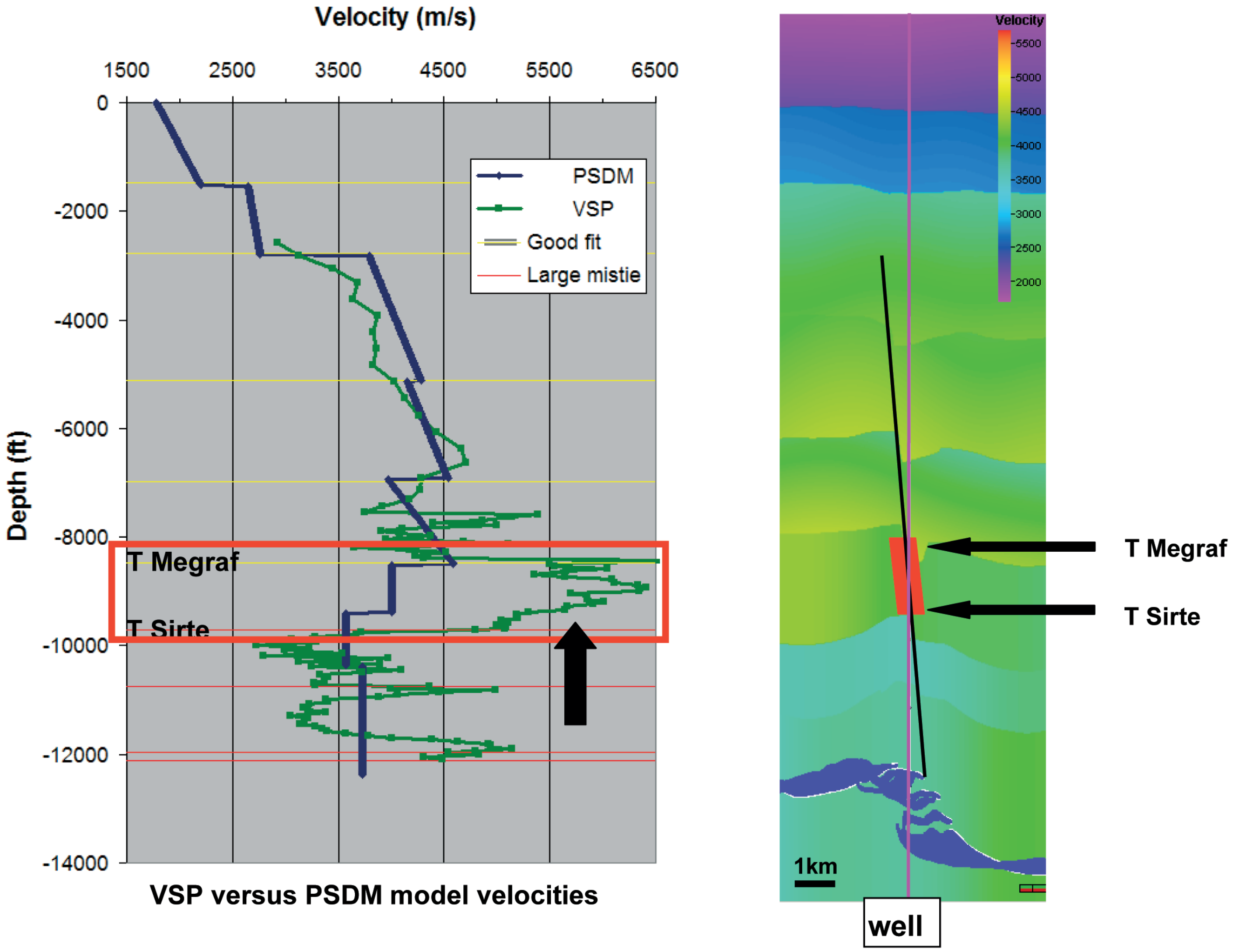


Fig. 11 (left). Measured VSP versus PreSDM model velocities at a particular well location. This well came in 112m deeper than prediction due to the high velocities above Top Sirte. (right). As discussed in the text, these high velocities are due to dolomitization along a major steeply dipping fault.

and data quality is sufficient. This may require several extra iterations during velocity model building. In any case such zones of dolomitization increase the depth prediction uncertainty.

To achieve success, PreSDM requires significantly more attention and involvement from oil company's geophysicists and area geologists than standard seismic processing techniques.

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