The Effect of Acquisition Direction on preSDM imaging

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The Effect of Acquisition Direction on preSDM Imaging

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Introduction
A production 3D preSDM project from the southern North Sea using several vintages of input data was run using a velocity-depth model common to the whole area, with good final results. The expected progressive improvement from postSTM to postSDM to preSDM was demonstrated for the target horizons.

As a separate study to the production project, we undertook to investigate the effect of acquisition direction on final image quality. To achieve this, we selected two vintages of data which were shot orthogonally to one another, but which otherwise had the same acquisition parameters. These data had sufficient overlap to permit full imaging in the area under investigation.

Ray trace studies were performed to assess the effects of target illumination from the dip-shot and the strike-shot surveys. Using the actual recorded navigation positions from the two surveys, 3D two-point finite offset ray tracing was performed using a common model.

Our preconceptions that dip-shooting would be better suited for pre-stack imaging were generally supported. In addition, for the vast majority of the overlap zone, the images produced from both surveys were very similar. The same interpretation would have been made on the basis of the independent orthogonal surveys: which is reassuring. However, in some specific instances, this was not the case, as the effect of cable feather on the subsurface coverage was significant for the dip-shot data. Infill seismic shooting was designed with surface fold in mind, but did not take into account the subsurface fold at target level.

In an attempt to assess the possible presence of fracture induced azimuthal anisotropy in the overburden, which may have manifested itself as velocity differences between the surveys, 3D preSDM CRP velocity analysis was performed independently for the data vintages in the area of overlap.

Background
The direction of shooting for a 3D marine survey has an impact on our ability to determine velocities, stack, and image the seismic data acquired. Decisions as to the shooting direction are more often governed by practical (or financial) considerations than by geophysical ones. With this as the backdrop, it is left for processing geophysicists to deliver quality products despite acquisition ‘limitations’.

It has been asserted (Bernitsas, et al, 1997) that strike shooting for complex or cylindrical structures leads to multi-valued ray paths which can give rise to images which are grossly misleading. For preSDM imaging this could perhaps be avoided by imaging with multi-valued travel times, thus taking into account energy which has propagated for all possible (P-wave) ray paths. The problem is compounded if we consider mode conversions. An alternative (but uneconomical) solution to the multi-path problem was presented by deBazelaire et al (1999), where they shot a survey 4 times, each survey being rotated by 45° with respect to the other. Thus some part of each of the four acquisitions was able to image the complex structure under investigation. A similar comparison was also made by Manin et al (1992), comparing conventional processing results for surveys shot orthogonally, and also by O’Connell, et al (1993), in Shell’s GOM Bullwinkle experiment. These three acquisition experiment papers all dealt with post-stack time imaging. For the pre-stack case, Etgen & Regone (1998), considered the effect of acquisition direction for synthetic data. For the most part, the conclusions of previous authors could be summarised as being that:

- strike shooting is best for post-stack processing, (including pre-stack time migration that ultimately is used for a post stack migration) as it avoids complex ray bending which corrupts stacks. However, if the cross-line spacing is too coarse, then the image can be degraded by migration artefacts,
- dip shooting is best for pre-stack depth imaging below a complex overburden.

From the perspective purely of resolution (i.e. ignoring ray-path issues) we could draw a different conclusion: if the spatial sampling was uniform and equivalent for both the strike and dip surveys, and the velocity model was correct, the two acquisition approaches should yield equivalent images (G.J.O. Vermeer, pers.comm.).

However, for the real data cases considered here, issues concerning resolution will be secondary.

In the study conducted here, where we are in a position to compare both strike and dip shooting, we have used first arrival travel times (the structure not being sufficiently complex to give rise to concerns over head-wave generation) to drive the Kirchhoff pre-stack migration.

At the outset of the orthogonal survey study, our objective was to assess if we might have differences in imaging the target Rotleigendes sands due to azimuthal velocity variations in the overlying Zechstein evaporite sequence. However, given the small differences found between the velocities independently analysed in the orthogonal surveys, we were left with the problem of why the images were so different for some areas but not for others.

In an attempt to address this issue, we undertook further work to assess subsurface coverage issues and their impact on image quality.

Methods
Velocity model update was performed using CRP-scanning, the CRP’s being computed from perturbed suites of travel times (Audebert & Diet, 1996, Jones, et al. 1998).

The model contained ten layers, incorporating a chalk-filled graben structure in the overburden, with vertical compaction gradients as necessary.

Three vintages of data were used for the production run, but for the detailed study described here, only two vintages were considered. This was because these two data volumes were acquired consecutively using the same seismic vessel, and with the same instrument and acquisition parameters: the only difference was the shooting direction (which in this case was orthogonal) (Figure 1).

For surveys 1 and 2, which used the same vessel, acquisition was performed using two sources and three streamers, with a 2100m cable, with an in-line spacing of 12.5m and a cross-line spacing of 18.75m. 36-fold data were input to the migration, 18-fold CRP data output.

The reason for the orthogonality was that the graben structure turns through approximately 90 degrees to the south of the area: hence both the northern and southern surveys were designed so as to be shot 'dip' to the predominant structural direction.

In addition to the CRP-scan velocity analysis used to update the preSDM velocity field, we have also used a continuous velocity analysis approach (Doicin et al, 1995; Jones, et al, 1999) to investigate the azimuthal anisotropy issue (discussed later).

Image Quality for the two surveys

An overview of the production project results can be found in an article by Henry et al, 1998. Figure 2 shows a representative 3D preSDM section (line L-L' indicated on figure 1). The chalk-filled graben structure is easily seen, as is the strong evaporite event at 2.5km depth.

Progressive improvement from postSTM to postSDM to preSDM was observed, with significant structural clarification in the faulting of the Zechstein evaporite sequence above the target sands (Figure 3).

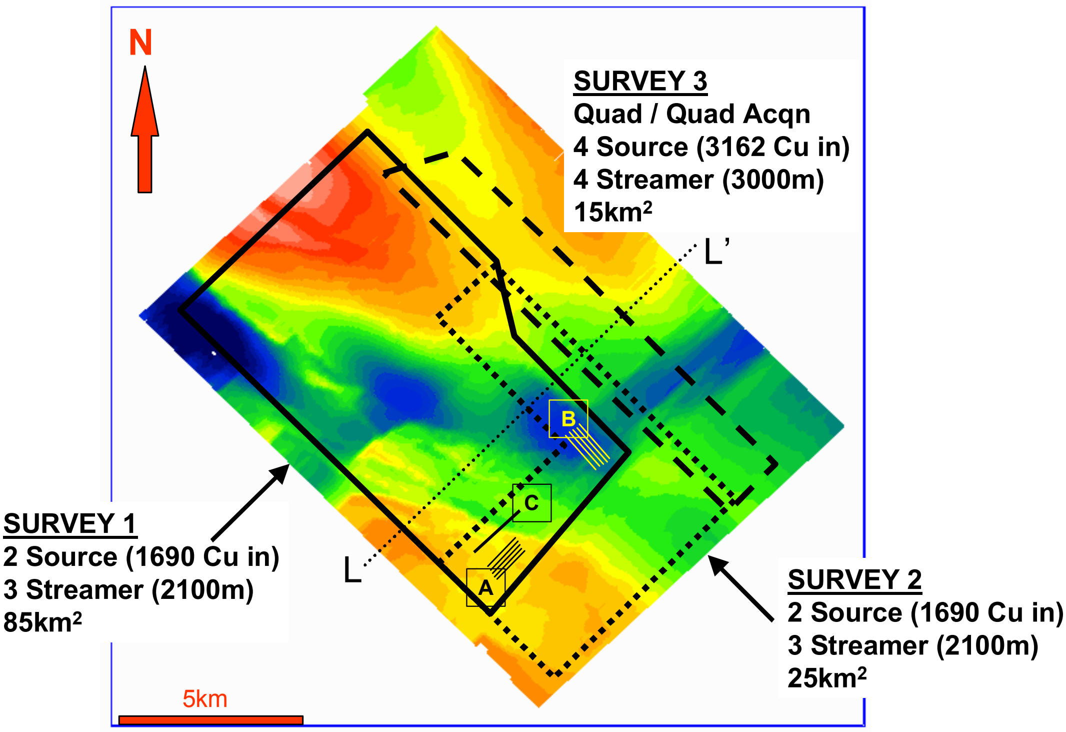
Various lines and cross lines were compared from the obtained images. Terminology can be confusing here as for one survey the dip direction is the inline whereas for the second survey the dip is crossline. These assignations reverse when the graben turns through about 90 degrees to the south of the area.

It is worth noting that the velocity estimates in the overlap zones were very similar. Thus for these data, we concluded that we were able to estimate the velocity field equally well for data shot in either the strike or the dip directions.

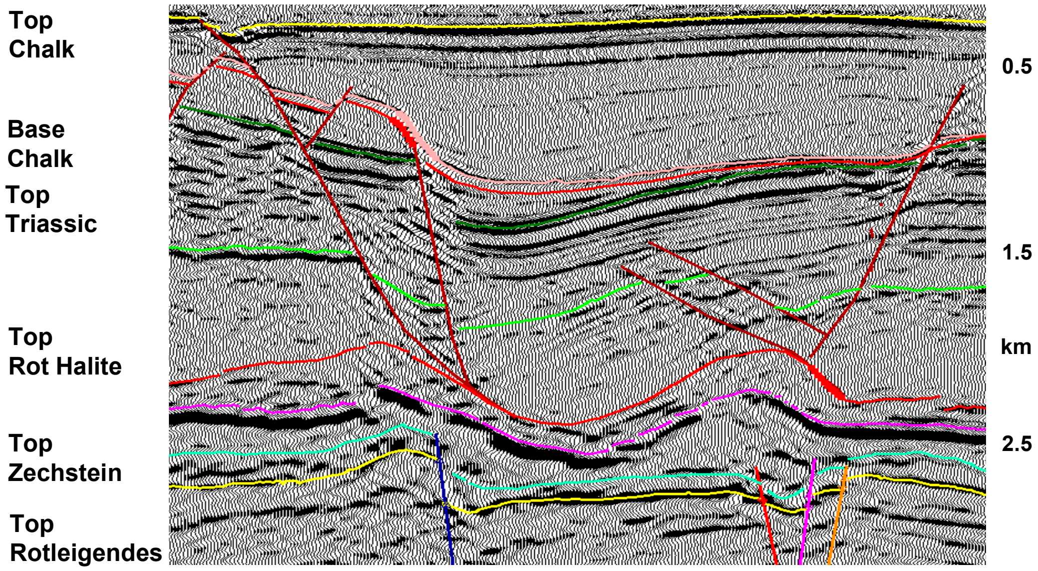
For the majority of the dip-shot data, the structural imaging was superior (for example, at locations A and B in Figure 1). At location A, survey 1 is dip to the structure, whereas at location B, (where the graben has turned) it is survey 2 that is dip. Figure 4 shows comparisons of several adjacent images from surveys 1 and 2 at location A, and Figure 5 shows the comparison for location B. The main contributing factor to the superiority of dip images is their denser spatial sampling.

However, at location C (Figure 1), where survey 1 is also dip, the lines shown in Figure 6 a & b indicated that it is the result of the strike imaging (Figure 6b = survey2 = strike direction) which are in this case superior in terms of resolution and structural simplicity. The dip image (Figure 6a = survey 1 = dip direction) appears to be inferior. The corresponding image gathers from the centre of these images (Figures 6 c & d) indicate significant differences in the character of the wave-forms, especially with regard to their behaviour with offset. Differences in residual multiple content are also evident, as also are very small residual moveout difference between the images.

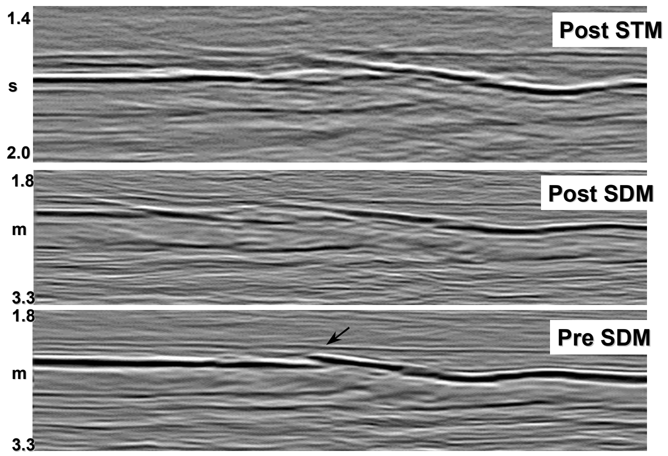
1. Basemap & Top Triassic Structure Map



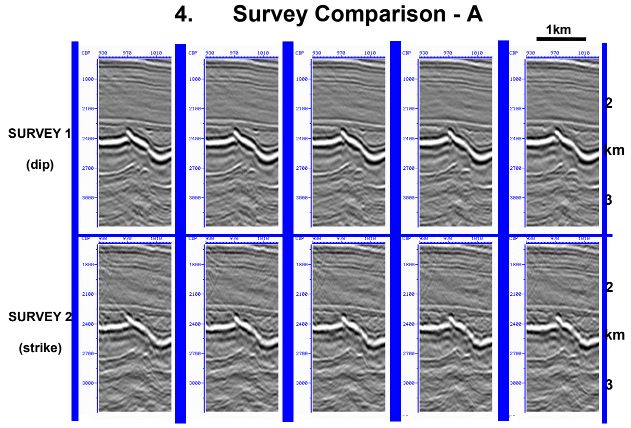
2. Inline 420 Final 3D PreSDM



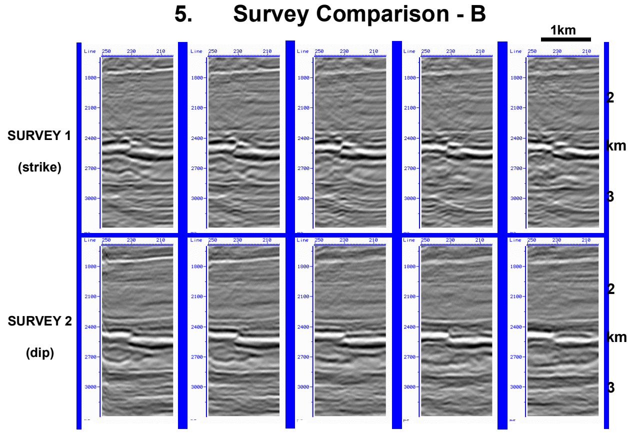
3. Comparison of post and pre stack images



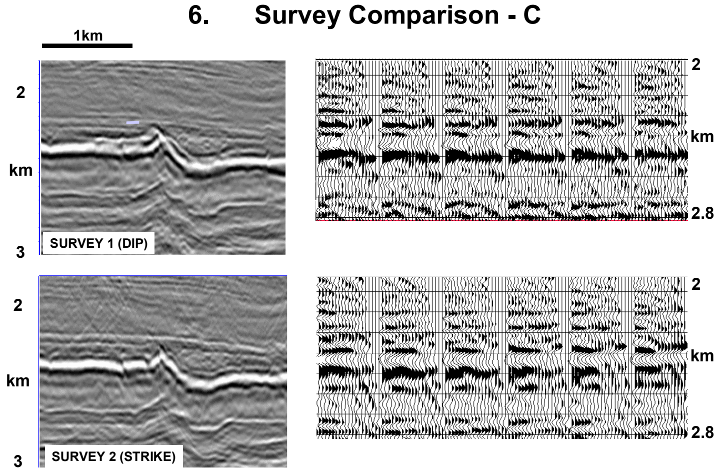
4. Survey Comparison - A



5. Survey Comparison - B



6. Survey Comparison - C



It should be remembered that for this 'production' phase of the project, the same 'common' velocity model was used to migrate all three data vintages. Hence the possibility could exist that the velocity model may not be correctly tuned for a given data set, or could be an unacceptable compromise for all data sets in the areas of overlap. As seen from the gathers, this problem does not appear to arise, as they are all acceptably flat.

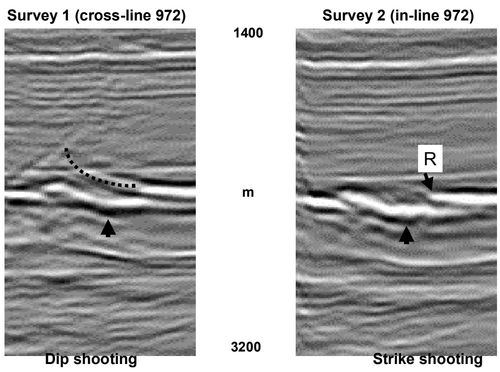
To eliminate the possibility of velocity differences being the cause for the differences in imaging, each data volume was migrated several times with perturbed renditions of the velocity model. None of these perturbation-scan images resulted in a similar image from survey 1 and survey 2, and the strike images (survey 2) were consistently superior at location C.

The conclusion of these latter observations was that the 'common' velocity model, used for the production migration of all surveys, was suitable for the various data volumes. In other words there was no strong evidence to suggest that a different velocity field should be used for the independent data volumes (in the areas of overlap). Thus, in general terms there was little azimuthal variation in the velocity field

However, there were very slight azimuthal differences in the interval velocity of the layer above the target (which may be related to fracturing), but not enough to explain the differences in the images. These differences are discussed later.

Investigation of the character of the anomalous events at location C, indicates that the apparent repetition of the Zechstein evaporite sequence results from cross-line impulse response noise contamination. In figure 7, we see a comparison of images orthogonal to line C, for surveys 1 and 2. In these images we see several small segments of evaporite rafts. Whereas for survey 2, the raft segment (labelled R in 7b) terminates cleanly, we note an impulse response artefact for the corresponding image from survey 1.

7. 3D pre SDM Sections Orthogonal to C

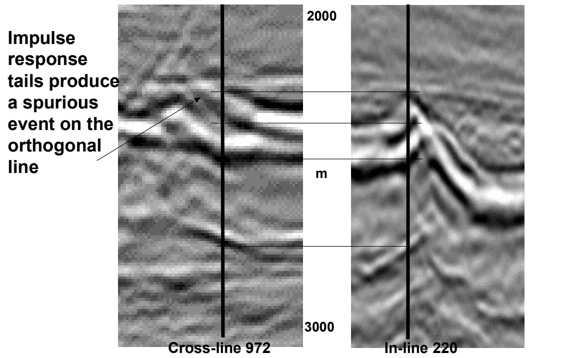


Displaying an intersecting (in-line, cross-line) pair for survey 1 (Figure 8) clearly shows the origin of the spurious 'repeated' evaporite segment. In comparison, a similar display for survey 2 (Figure 9) shows no such problems.

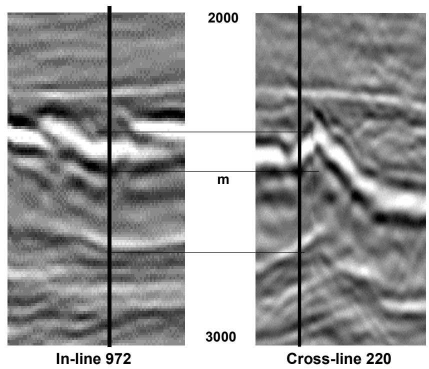
Given that the migration code has performed well for the majority of the survey, we questioned the causes of these artefacts. It is evident that we are not getting the requisite 'destructive interference' in certain parts of the survey 1 images. This raised the question of whether we have sufficient contribution to the migration at these locations.

To assess the issue of image contribution, we performed 3D finite offset 2-point ray tracing through the common model for both acquisitions to assess differences in target illumination. (This assessment assumes that it is sufficiently diagnostic to rely on first arrival ray-theoretical indications given by the qualitative analysis of this procedure).

8. Survey 1 (dip-shooting): in-line vs cross-line at C



9. Survey 2 (strike-shooting): in-line vs cross-line at C



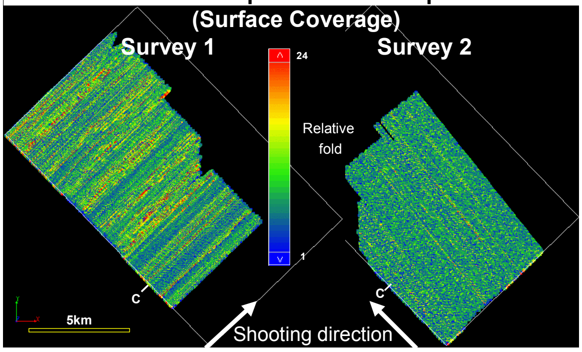
Firstly, we confirmed that the acquisition specifications concerning surface nominal coverage had been fulfilled. Figure 10 compares the surface fold of coverage for the two surveys. Both are within specification, although survey 1 required infill data. Figure 11 shows some of the streamer position plots in the vicinity of line C. We note that survey 1 was shot orthogonal to the current direction, and so suffers from significant cable feathering. Conversely, survey 2, acquired parallel to the predominant current, shows little cable feathering.

The subsurface fold maps (for the top Zechstein) for the two surveys are shown in Figure 12. It can be seen that survey 1 (which was dip to the structure at location C) suffers from large variations in fold due to cable feathering. The ray tracing performed here also included the navigation locations of all contributions from the infill-shooting program.

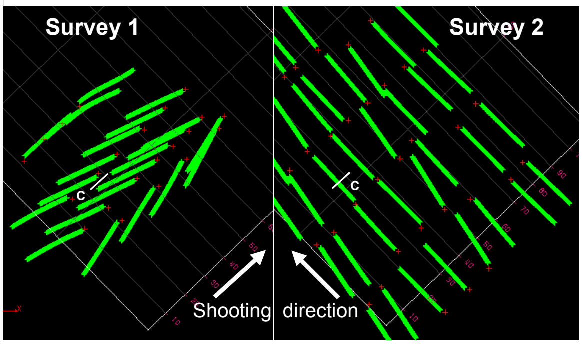
In other words, we can conclude that in this instance, the infill designed to produce uniform surface coverage gave rise to an inadequate subsurface coverage. Quantitatively, the fold of coverage along line C for survey 2 is approximately twice that of survey 1 (this is seen more clearly in the enlargement of the subsurface fold maps, shown for coverage in the vicinity of line C, in figure 13). For location A the differences in subsurface fold are not so great, and at location A it is the dip images (resulting from survey 1) which appear superior.

It is this large variation in the amount of energy arriving at the subsurface locations along line C that gives rise to the differences between the images.

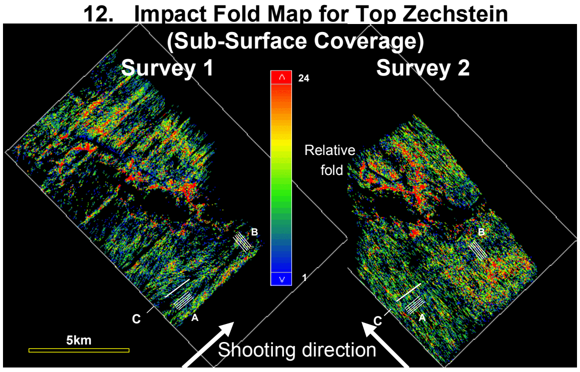
10. Acquisition Fold Map (Surface Coverage)



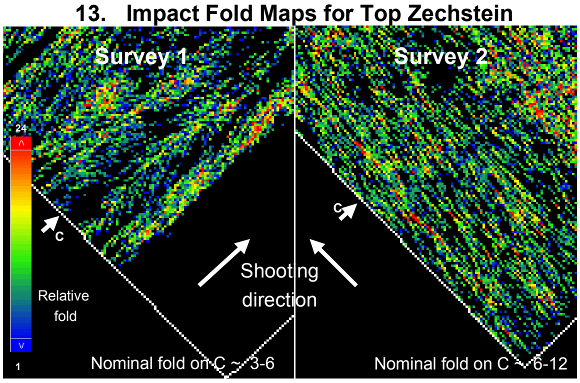
11. Cable Feathering



12. Impact Fold Map for Top Zechstein (Sub-Surface Coverage)



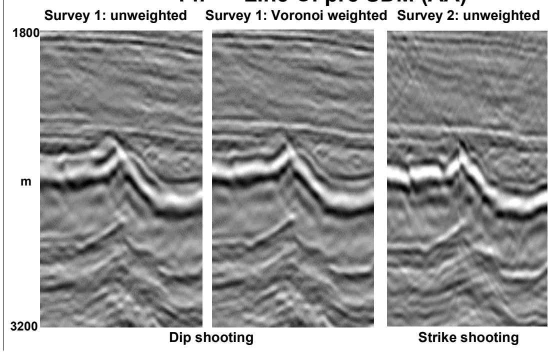
13. Impact Fold Maps for Top Zechstein



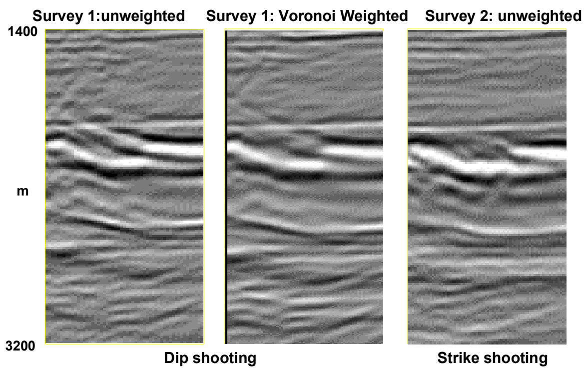
In the results shown here, we have not tried to compensate for these unacceptable variations in image contributions. However, it is possible with various weighting schemes, to alleviate these effects somewhat. Figure 14 shows a comparison at location C for survey 1 (unweighted) versus survey 1 (weighted) versus survey 2 (unweighted). The migration-weighting scheme employed in the central image was the Voronoi scheme, where the input traces are given weights in proportion to the area of a polygon that separates them from neigbouring traces.

A similar comparison for images orthogonal to location C is shown in Figures 15.

14. Line C: pre SDM (AA)



15. 3D pre SDM Sections Orthogonal to C



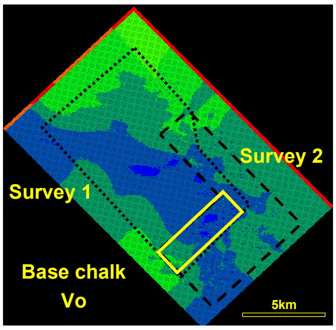
Azimuthal velocity differences between the two surveys

As a final part to this study, we looked in more detail at the slight azimuthal variation in the velocity field for some layers. The extent of the overlap zone investigated is shown in Figure 16. Here we see a map of the base chalk V(0) grid (where $v(x,y,z)=v(x,y,0)+k(x,y)z$) indicating the area under study.

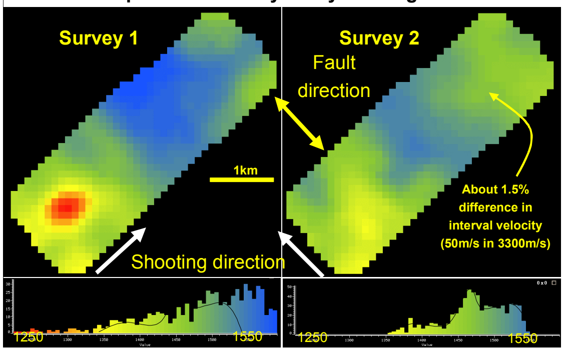
Firstly, we reconstructed the velocity model in the overlap zone independently for surveys 1 and 2. This meant repeating the CRP-scan picking separately for the two surveys. This is in contrast to the 'production' migration, where velocity updates were averaged in the overlap zone to produce a single model.

Results of the independently derived velocity fields are shown in Figure 17. Overall, the differences are slight, the maximum differences being about 1.5% (or 50m/s in the chalk velocity of 3300m/s). However, the CRP picking was only performed on a 500m by 500m grid, so this is perhaps not highly resolved enough to see differences.

16. Independent Velocity Analysis

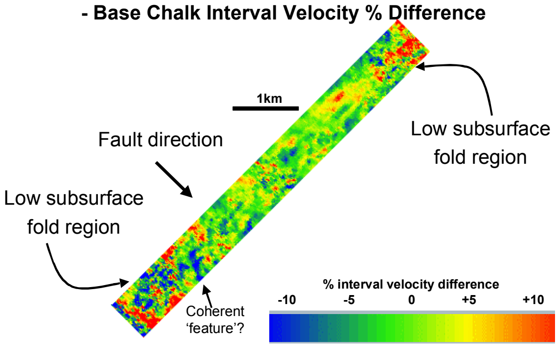


17. Independent Velocity Analysis: V0 grid for chalk



In an attempt to get better velocity resolution, we took a slightly different approach. Taking the CRP gathers from the two surveys, after final migration with a common velocity model, we 'backed-out' the migration velocity field, by applying inverse NMO to the otherwise flat CRP gathers. A dense velocity analysis technique (Adler, 1999; Jones et al, 1999) was then used to yield independent velocity estimates on an 18.75m by 12.5m grid. The percentage differences in velocity for the base chalk event are shown in Figure 18. Although the independent model building took place over a swath of width about 2km, the output of fully migrated overlapping data was restricted to a swath width of about 500m, hence the narrow percentage difference map.

18. High Density Velocity Analysis (on all CRP gathers) - Base Chalk Interval Velocity % Difference



We see that other than at the ends of the swath where the aperture may be questionable, the differences are small (~1%). Other than some acquisition related striping, the only coherent feature is perhaps the event with a percentage difference of about 8% indicated in the lower part of the map. Overall, we conclude that these results are inconclusive.

Conclusions

For two data volumes acquired orthogonally over the same area, imaging of the overburden was very similar for both acquisitions, with no significant differences in velocity for the most part.

However for the Zechstein evaporites and the underlying target Rotleigendes sands, we observed differences in image quality between the images produced from the two surveys in some parts of the study area. Ray-trace modelling of the sub-surface illumination indicates considerable differences in subsurface fold (target illumination) between the different acquisitions.

It was concluded that these differences in target illumination were responsible for the differences in image quality. However, certain migration weighting schemes are able to alleviate these problems to some extent.

A detailed investigation of azimuthal variation in velocity yielded ambiguous results. Although differences in interval velocities of about 1.5% existed in the chalk, no reliable predominant azimuthal dependence was found from analysing the percentage differences in velocity fields.

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