Comments to "Processing the Hod 3D multicomponent OBS survey, comparing parallel and orthogonal acquisition geometries" by Kommedal et al., 2002, TLE, 795-801.

It is not occurring all too often that oil companies or contractors acquire 3D seismic data across the same area using two or more different acquisition geometries. And if it happens, it does not always occur that the results are shared with the geophysical community at large. Therefore, BP Norway is to be commended for sharing the results of the interesting Hod 3D survey with us in which parallel and orthogonal acquisition geometries are compared.

The acquisition of both parallel and orthogonal geometry gave the authors "an opportunity to compare the seismic images produced from these shooting geometries to see if there is factual support for the rumors that parallel shooting results in better converted PS-wave images than orthogonal shooting". And indeed, the authors show that the results for orthogonal geometry are inferior to that of parallel geometry. However, they suggest that this is not due to geometry differences but to the use of conventional DMO, stack, and migration, rather than proper prestack depth migration.

The rumors alluded to in the previous paragraph may be related to some geophysicists having read the abstract of my paper "Converted waves: properties and 3D survey design" presented at the 1999 SEG Conference, which states "parallel geometry tends to be better geometry for PS acquisition than orthogonal or any other crossed-array geometry". That paper argues that there are good theoretical reasons to predict that parallel geometry is better for PS than orthogonal and it is great to see this confirmed now by results using real data. I would like to take this opportunity to illustrate some theoretical insights on C-wave acquisition using the Hod geometries as examples. Yet, I would like to start with some comments on the P-wave results and make some suggestions for improvement.

Parallel geometry, P-waves. Figure 4 of Kommedal et al. shows amplitude striping in two horizon amplitude maps for the P-wave data. Such stripings can be caused by irregular fold, irregular offset distributions and/or irregular illumination. It is the task of the survey designer to minimize each of these contributions to striping, whereas the seismic processor has to reduce any remaining effects to acceptable levels. Figure 1a describes a cross-section in the crossline direction through the template of the parallel geometry. (The authors provided a puzzle to the reader wanting to reconstruct this template. 50 m between shots along each shot line track and a shot line length of 10500 m requires 210 shots per shot track. With a total of 8841 shots per template this leads to 42.1 shot tracks, which does not fit. However, with 210 and 211 shots on alternating shot tracks a round number of 42 shot tracks results. With 75 m between shot tracks, there are 6 such tracks between each pair of receiver cables, hence 18 tracks between the outer cables and 2 x 12 tracks = 2 x 2 cable intervals outside the cables, leading to Figure 1.) The width of this template is 7 x 450 m = 3150 m. Hence the coverage per cable equals 3150/2 = 1575 m. The crossline roll of the template equals 4 x 450 m = 1800 m. Hence the average crossline fold is 4 x 1575 / 1800 = 3.5. This irregular crossline fold is one of the causes of striping. It might have been reduced by using a template width of 8 x 450 m = 3600 m. In that case the coverage by each cable would have been equal to the template's crossline roll of 1800 m.

A regular crossline fold of 4 cannot be obtained after the fact. However, fold can be regularized by removing all traces with a crossline offset larger than 900 m. In that case each cable records a symmetric coverage of 900 m and the average crossline fold is 4 x 900 / 1800 = 2. This should reduce the striping in the data without affecting the S/N ratio too much: the data quality is excellent.

Orthogonal geometry, P-waves. The parameters given in Table 1 of Kommedal et al. are even more of a puzzle when trying to reconstruct the template or patch of the orthogonal geometry than it was for the parallel geometry. With a line length of 7350 m, there should be 7350 / 25 = 294 shots per shot line. This leads to 6682 / 294 = 22.73 shot lines. I guess that the outer shot lines have been shortened, but to what extent is impossible to reconstruct. Anyway, the most important parameters for this geometry are clear. A template with 22 shot lines is drawn in Figure 2.

The inline fold in this geometry builds up gradually from 0 along the edges to 10 in the center of the configuration. The crossline fold is irregular because the run in / out of 3000 m is not a multiple of 450 m, the receiver line interval. 2700 m or 3150 m would have been adequate as run in / out. In processing the traces with crossline offset larger than 2700 m should be removed for regular fold. This applies to the crossline offsets of all four cables. If the offsets larger than 2700 m are not removed from the data set, the asymmetry of the cross-spreads would lead to additional spatial discontinuities in the crossline direction. After removal of all redundant traces, the crossline fold of this geometry would reduce to 2700 / 450 = 6, with total fold being 60 in the center and tapering off to the edges. Taking these steps in processing would probably reduce the acquisition footprint and any remaining footprint will be due to variations in offset distribution and in illumination.

Regularizing fold in P-wave acquisition automatically leads to more regular illumination and imaging, because illumination fold and image fold tend to be close to fold-of-coverage. In horizontal geology illumination fold and image fold are even equal to fold-of-coverage. This does not apply to C-wave acquisition, because illumination fold is always different than fold-of-coverage. Regularizing the images can only be achieved by expensive prestack depth migration techniques. Yet, the irregularities are larger in data acquired with orthogonal geometry than in parallel geometry, as I will now discuss.

Parallel geometry, C-waves. The conversion point from P-wave to S-wave tends to lie much closer to the receiver than to the source. With the receiver cables in the middle of the swath, the illumination range of a horizontal reflector is less wide than the midpoint coverage as illustrated in Figures 1b and c. Note that at the illustrated depth of 2000 m, a small gap in illumination develops between adjacent swaths for Vp/Vs = 3. For larger Vp/Vs ratios and/or smaller depths these illumination gaps become larger, leading to incomplete images and striping. At other places crossline illumination is inevitably irregular. On the other hand, there are no spatial discontinuities in the inline direction. In this direction illumination is regular. An interesting consequence of this illumination behavior is that conventional prestack migration algorithms will produce migration smiles in the crossline direction, whereas the migration results in the inline direction will not show any serious migration smiles.

Orthogonal geometry, C-waves. Illumination with C-waves generated in orthogonal geometry is quite different than discussed above for parallel geometry. Now the total data set consists of a large number of partially overlapping cross-spreads with each cross-spread having its own limited-size illumination area on each reflector. The illumination areas on a horizontal reflector at z = 2000 m for one cross-spread are shown in Figure 3, one for Vp/Vs = 2 and one for Vp/Vs = 3. These illumination areas differ considerably from the midpoint area, unlike the situation for P-wave illumination. The data inside each illumination area are well-behaved and are suitable for prestack migration. However, the edges of each illumination area are as many causes of edge effects, i.e., migration smiles. As a consequence, conventional prestack migration algorithms will produce migration smiles not only in the crossline direction, but also in the inline direction. These migration smiles will severely affect the S/N of the imaged data, both in inline direction and in crossline direction.

Comparison parallel versus orthogonal, C-waves. The differences in illumination properties between the two geometries is the main reason to expect better image quality for parallel geometry than for orthogonal geometry. On top of that, there are also differences in resolution that will further increase the difference.

See for a discussion Chapter 6 in Vermeer (2002). Yet, it should be possible to mitigate the problems with orthogonal geometry by tapering the edges of all cross-spreads, i.e., by making the edges softer. This should be done for each cross-spread individually, and it must be time-variant as well. Therefore, the spatial taper should be made part of the mute operation. Tapering of the crossline edges in parallel geometry might also be attempted, but in this geometry the number of points available for tapering is limited (only 42 in the Hod survey), and tapering across illumination gaps as in Figure 1c will further reduce effective illumination.

Vector fidelity. Another reason for quality differences between orthogonal and parallel geometry may be the lack of vector fidelity between the horizontal geophones inside a bottom cable. The vector infidelity is clearly demonstrated in the comparison between azimuth sectors of the orthogonal geometry in Figure 8b and c in Kommedal et al. The section created predominantly by the crossline geophones (Figure 8c) is considerably worse than the section created by the inline geophones. In orthogonal geometry, vector fidelity is essential for good quality results, whereas in parallel geometry the crossline geophone plays a much more modest role than the inline geophone, hence reliance on vector fidelity is less. The issue of vector fidelity has been solved to a large extent by the introduction of self-contained node systems in which a 3-component geophone plus hydrophone is planted separately in the sea bed by a subsea robot. The expense of this system necessitates the use of areal geometry (sparse distribution of nodes and dense distribution of shots). This geometry also suffers from inherent spatial discontinuities (the edges of the illumination areas of the 3D receiver gathers), but here as well these might be softened by tapering.

Conclusions. This reaction to Kommedal et al. suggests that there is theoretical support for the "rumors that parallel shooting results in better converted PS-wave images than orthogonal shooting". Prestack migration is not going to remedy this problem, which is essentially a geometry problem. The asymmetry between inline and crossline direction in orthogonal geometry makes this geometry less attractive for 4-component sea-bottom acquisition. Better alternatives are parallel geometry (in case azimuth-dependent effects are not of interest) or areal geometry (for analysis of azimuth-dependent effects). This paper presents some suggestions to improve the results of the processing of the P-wave as well as of the C-wave data. It would be interesting to learn about the results of such processing.

Suggested reading. On migration of P-wave data: "From acquisition footprints to true amplitude" by Gesbert (Geophysics, 2002, 830). Geometry comparison for C-waves: "Converted waves: properties and 3D survey design" by Vermeer (SEG 1999 Expanded Abstracts). An expanded version of this abstract has appeared as Chapter 6 in "3-D seismic survey design" by Vermeer (SEG, 2002). This book also discusses properties of parallel, orthogonal, and areal geometries for P-wave acquisition.

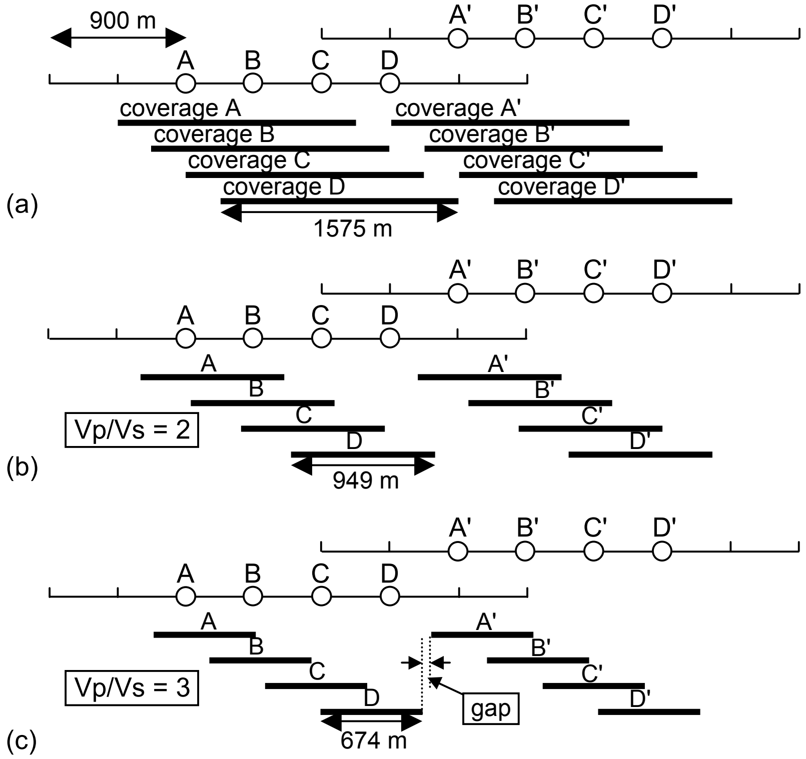

Fig. 1. Coverage and illumination of P- and C-waves for swath used in Hod 3D survey. Shown is cross-section through swath in crossline direction. The 4 cables are designated with A, B, C, and D. The range of shotlines is indicated by a thin horizontal line with 450 m tick marks. Two swaths are shown. The shotlines extend 900 m on either side of the group of cables. (a) Crossline fold-of-coverage. Note that crossline fold jumps between 3 and 4. Crossline fold would be continuous by extending the swath 225 m in both directions. Coverage equates to P-wave illumination for horizontal reflector. (b) C-wave illumination of horizontal reflector at 2000 m depth for Vp/Vs = 2. (c) as (b) for Vp/Vs = 3. Now there is a small illumination gap between consecutive swaths.

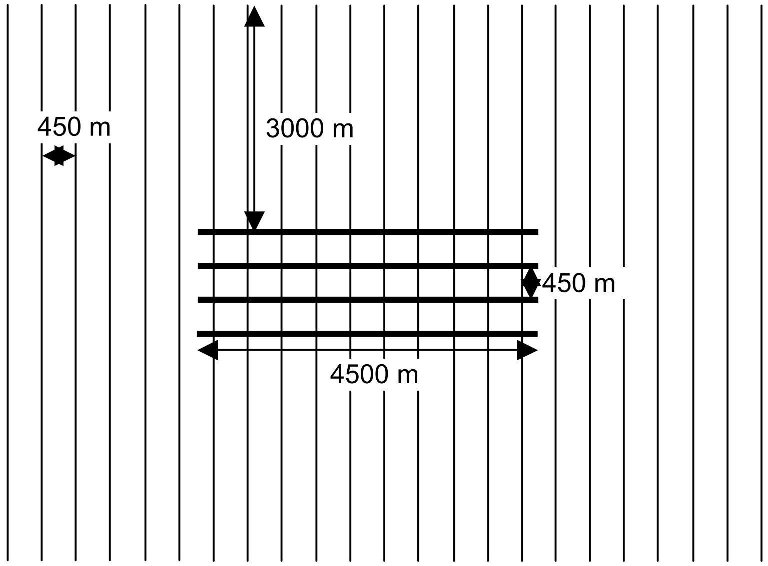

Fig. 2. Approximate template used for acquisition of orthogonal geometry.

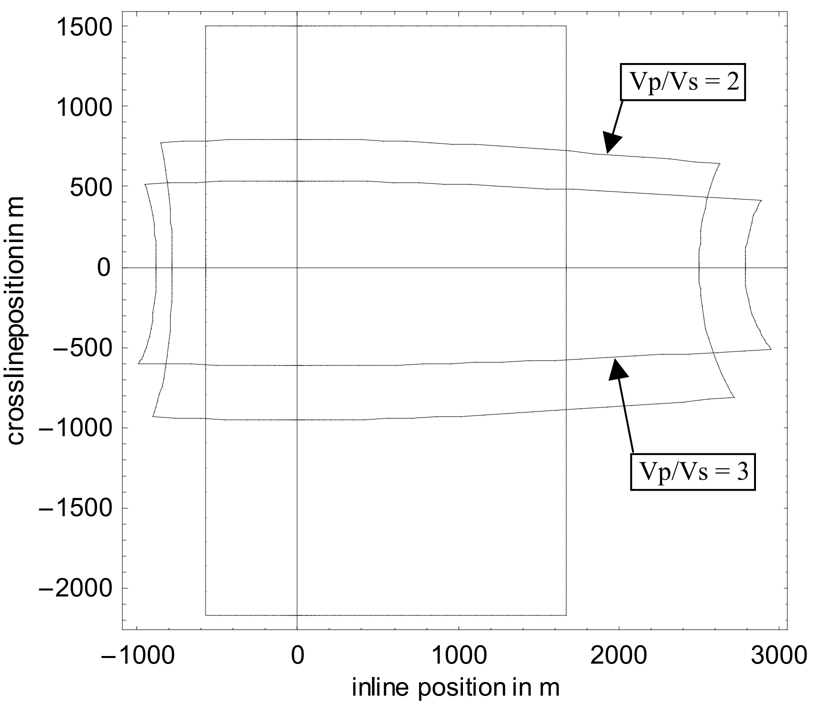

Fig. 3. Illumination of horizontal reflector by C-waves of single cross-spread from Hod survey. The cross-spread corresponds to the ninth shotline from the left and to the top receiver line of the template in Figure 2. The rectangular area represents the midpoint area of the cross-spread. The edges of this midpoint area are defined by shots at (0, 3000) and at (0, -4350) and by receivers at (-1150, 0), and at (3350, 0). These same shots and receivers determine the edges of the illumination area on a horizontal reflector at z = 2000 m, depicted for Vp/Vs = 2 and Vp/Vs = 3.