The Design and Application of Converted-wave Offset Vector Tiles

Richard Bale, Tobin Marchand, Keith Wilkinson and Jeff Deere, Key Seismic Solutions Ltd., Calgary, Canada.*

Summary

We describe a modification of the design criteria normally adopted for Offset Vector Tiles, so that they can be used more effectively with converted-wave data. Our modification is based on the asymptotic conversion point correction and is a function of the Vp/Vs ratio.

There are a number of potential applications of this approach in converted-wave processing. Here, we demonstrate the improvement that results in converted-wave prestack time migration of single offset vector tiles using this PS Offset Vector Tile design.

Introduction

The concept of representing offset and azimuth information by inline and crossline offsets was introduced independently by Vermeer (2002) as “Offset Vector Tiles” (OVTs), and by Cary (1999) as “Common Offset Vectors” (COVs). The main benefit of using OVTs over conventional offset binning and azimuth sectoring is that, by a proper choice of sampling of the inline and crossline offset coordinates, each OVT constitutes a “minimal” single fold dataset covering the survey area: i.e. a tiling of the plane. We will use the OVT nomenclature in this abstract, as it emphasizes this tiling property. For common midpoint (CMP) geometry, the appropriate OVT sampling choice is simply twice the receiver line interval in one direction and twice the shot line interval in the other. This leads naturally to a tiling of the inline/crossline plane with rectangular CMP patches. The resulting minimal datasets can be migrated to form one image for each OVT, while preserving offset and azimuth, and hence providing suitable migrated data for azimuthal analysis.

However, for PS data the coverage is represented not by CMP locations, but by “Common Conversion Point” (CCP) locations. The true CCP locations are a function of offset, depth and the Vp/Vs ratio, with further complications for anisotropy. A simple approximation which is used for much preliminary PS processing is to neglect the depth dependence and use the “Asymptotic Conversion Point” or ACP locations. The asymmetry of the ACP domain results in a compression of the coverage towards the receiver line, and an expansion away from the shot line.

If the same criterion is used for OVT construction as for the P-wave case, then the corresponding ACP coverage is no longer single fold, and does not properly tile the plane. There are two separate problems, which we refer to as micro-scale and macro-scale binning effects. The micro-scale effect is that the ACP locations do not fall on the same bin centres defined by CMP geometry. This can lead to a well-known periodicity of the total ACP fold (Eaton and Lawton, 1992). The macro-scale effect is that the ACP tiles are a different shape to the CMP tiles, and do not uniformly cover the survey area: instead we have gaps in the shot line direction and overlaps in the receiver line direction (Vermeer, 2002). The result is that conventionally designed OVTs are not sufficient for a prestack migration of PS data to generate complete, well sampled, prestack images, in the same way as can be done for PP data. It is the macro-scale effect which we address in this paper.

Theory of PS OVTs

A simple correction for this problem involves a modification of the OVT definitions based on the Vp/Vs ratio, to restore the desired tiling property of the OVTs.

Letting the Vp/Vs ratio be denoted by γ, and the source-receiver offset vector by $\mathbf{r}$, then the asymptotic conversion point vector is given by (Fromm et al, 1985):

$$\mathbf{r}_{acp} = \frac{\gamma}{1+\gamma}\mathbf{r} \qquad (1)$$

If we assume that the shot lines are oriented parallel to the x-axis and the receiver lines parallel to the y-axis, then the offset X and Y grid intervals, denoted C_x and C_y, required for OVTs to accommodate binning via equation (1) are:

$$C_x = (1+\gamma)\,\Delta R\,, \qquad (2a)$$

and

$$C_y = \left(\frac{1+\gamma}{\gamma}\right)\Delta S\,, \qquad (2b)$$

where ΔS and ΔR are the shot and receiver line intervals respectively. If we set $\gamma = 1$, we recover the conventional CMP criterion of twice line spacing.

Since first publishing equation (2) (Bale et al., 2013), we have learned that Gaiser (pers. comm.) has also described the same correction in his multicomponent course notes.

In figure 1, we compare the OVT tiling patterns for a given X-offset and Y-offset range. As stated previously, the X- and Y-offset increment required for uniform CMP coverage is twice the receiver- and shot-line increments. For the example in figure 1a we examine the CMP coverage for a OVT that corresponds to an X-offset range from $2\Delta R$ to $4\Delta R$, and a Y-offset range from $2\Delta S$ to $4\Delta S$.

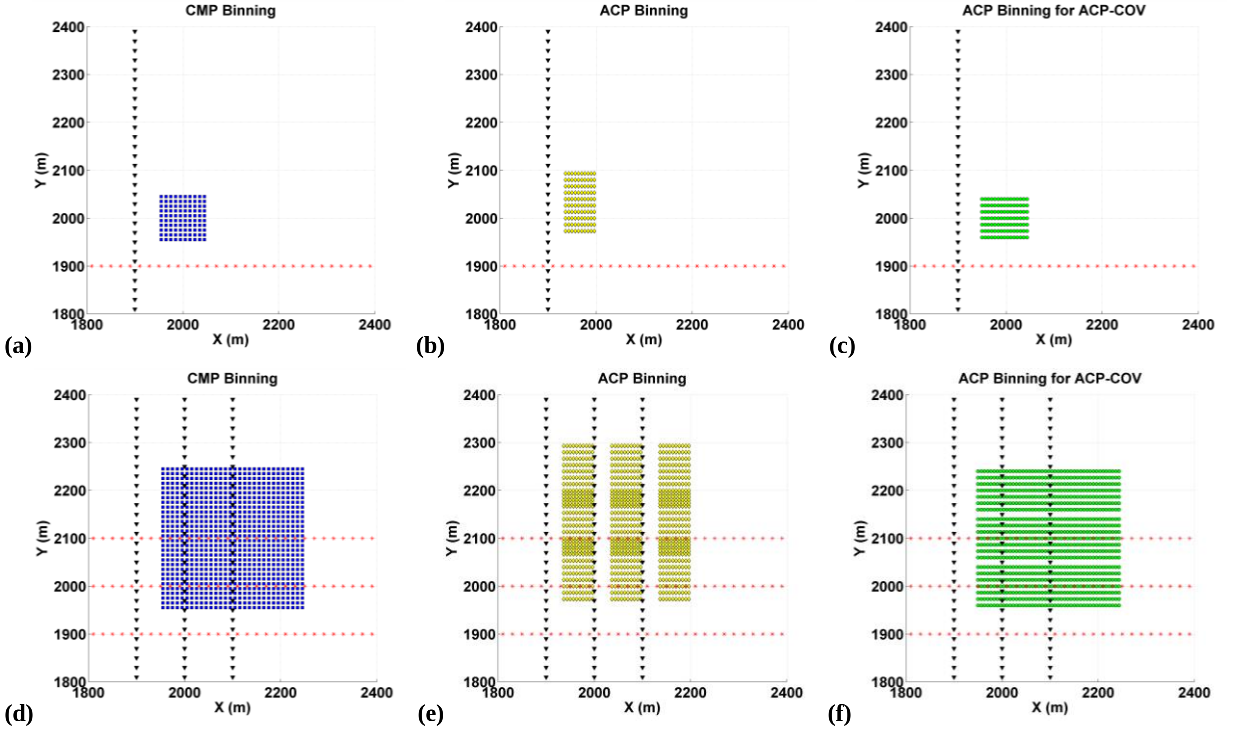

Figure 1: Comparison of OVT coverage for a single OVT: (a) and (d) CMPs using the standard OVT definition; (b) and (e) ACPs using the standard OVT definition; (c) and (f) ACPs using the PS-adapted OVT definition. In (a), (b) and (c) a single tile from the OVT, resulting from one cross-spread, is shown. In (d), (e) and (f), the 9 tiles resulting from three shot lines and three receiver lines are shown. The Vp/Vs ratio is 2 for the ACP cases.

Figure 1a shows an “elementary tile” for this OVT with CMP coverage for a single shot line running in the X direction (red stars), and a single receiver line running in the Y direction (black triangles). Figure 1d shows the CMP coverage for the 9 tiles which result from 3 shot lines and 3 receiver lines. For this conventional OVT with CMP geometry, the tiles exactly cover the area with uniform single fold and no gaps or overlap, as is well known.

Figure 1b shows the elementary tile for ACP coverage using the standard OVT definition, whereas figure 1c shows the elementary tile for ACP coverage using our modified sampling criterion of equation 2 for the PS OVT definition. Figures 1e and 1f show the resulting 9-tile coverage patterns with the 3 shot lines and 3 receiver lines. For the conventional OVT, but using ACP geometry (1e) there are gaps and overlaps in the tiles. For the OVT definition adapted to the ACP geometry (1f) we have eliminated gaps and overlaps between tiles, thus addressing the macro-scale effect, though binning irregularities (the micro-scale effect) remain.

Examples

As for PP data, the goal of using the OVT domain for PS data is to produce a single fold subset of the data which covers the entire survey and allows for properly formed images with a (nominally) common offset vector.

In a previous paper (Bale et al, 2013) we describe an application of the PS OVTs for binning analysis by making use of reciprocal OVTs to detect lateral displacements of structure in the data. As shown by Audebert et al (1999) in a 2-D context, these shifts are indicative of errors in the γ used for the binning correction, and may be used to infer an updated γ value. The generation of PS OVTs allows this same approach to be extended to a true 3-D binning γ analysis.

Here we focus instead on the benefit to prestack migration of properly formed PS OVTs.

The data example used here is the Turgeon-Farrell 3D Merge, which was acquired in North East British Columbia, by Olympic Seismic Ltd., in 2012. It consists of a merge of 2 surveys both acquired using the OYO GSR cable-less recording system. The total merged survey area is 710 square km. The shot and receiver intervals are 50m, while both the shot-line and receiver-line spacing is 400m.

Figure 2 shows fold of coverage for single OVTs over part of the survey. The OVTs in figure 2(a) and (b) are both constructed using the conventional definition based on twice shot and receiver line spacing. They show CMP coverage and ACP coverage respectively. While the CMP coverage is close to ideal, except where there were line deviations, this is not the case for ACP coverage: there are gaps and overlaps, as anticipated from the analysis in the previous section. The OVT shown in figure 2(c) is based on the PS OVT definition described in equation 2, using γ=2. A comparison with figure 2(b) confirms that the PS OVT is a much better approximation to a single fold coverage subset of the data. Subsequent analysis of binning γ led to a revised value of 1.6, and this in turn led to a revised PS OVT. This is the PS OVT design used in the migration examples below.

To assess the impact of OVT design on imaging, we ran converted-wave prestack time migration on single OVTs designed using both the conventional OVT offset criterion and the PS criterion of equation 2. The X- and Y-offset grids are displayed in figure 3, for the conventional OVT design in (a) and for the PS OVT design with γ=1.6 in (b). For the conventional OVT design, (a), each cell corresponds to X- and Y-offset ranges of 800m. For the PS OVT design, (b), each cell corresponds to an X-offset range of 650m and a Y-offset range of 1040m. The blue line segments in each box represent the nominal offset and azimuth of the OVT. Zero offset lies at the centre of the grid.

Since the two design criteria lead to different X- and Y-offset grids, we cannot exactly match the OVTs for comparison. However, two approximately equivalent OVTs were selected for comparison, by choosing similar nominal offsets and azimuths, as described in the caption of figure 3. Figure 4 shows a comparison of a crossline, migrated with: (a) the conventional OVT definition of figure 3(a); and (b) the PS OVT definition of figure 3(b). The image in figure 4(a) illustrates the impact of the non-uniform fold, especially the gaps, on prestack migration. We observe clear migration swings associated with incomplete cancellation caused by these gaps. In comparison, the migration result in figure 4(b) which has the PS OVT input shows a more continuous image with reduced migration artifacts.

It should be noted that, as for PP migration using conventional OVTs, the uniform fold of coverage doesn't eliminate all migration effects. Each OVT has only approximately constant X- and Y-offsets, with the actual offsets changing discontinuously at the boundaries of each tile. The size of the discontinuities is the same as the X- and Y-offset intervals between different OVTs (section 2.5.5 of Vermeer, 2002). These offset jumps can lead to some residual migration effects, but these are much less significant than those caused by using the conventional OVT design for PS data where it is inappropriate.

Conclusions

The original motivation for adopting OVTs in conventional (P-wave) processing was to produce single fold subsets of the complete data which could be used to construct independent images, while preserving offset and azimuth. Using the same design for converted waves does not lead to single fold subsets, and generates gaps in coverage. We have shown that a modification to the design criterion, based on ACP geometry instead of CMP geometry, can resolve this problem. The resulting PS OVTs produce more coherent converted-wave images after migration than use of the conventional OVT design. We demonstrate this using real data from North East British Columbia.

Acknowledgments

We thank Key Seismic Solutions for permission to publish this work. We thank Olympic Seismic Ltd. for permission to publish the Turgeon-Farrell data examples. We acknowledge the multicomponent processing group at Key Seismic, and in particular Peter Vail, for processing the data.

References

Audebert, F., Granger, P., and Herrenschmidt, A., 1999, CCP-scan technique (1): True common conversion point sorting and converted wave velocity analysis solved by PP and PS Pre-Stack Depth Migration: SEG Technical Program Expanded Abstracts, 1186-1189.

Bale, R., T. Marchand, K. Wilkinson, and J. Deere, 2013, The Design and Application of Converted-wave COVs: CSEG/CSPG/CWLS GeoConvention.

Cary, P., 1999, Common-offset-vector gathers: An alternative to cross-spreads for wide-azimuth 3-D surveys: SEG Technical Program Expanded Abstracts, 1496-1499.

Eaton, D. W. S., and Lawton, D.C., 1992, P-SV stacking charts and binning periodicity: Geophysics, **57**, 745–748.

Fromm, G., Krey, T., and Wiest, B., 1985, Static and dynamic corrections, in Dohr, G., Ed., Seismic shear waves: Handbook of geophysical exploration, Geophys. Press, Vol. 15a, 191-225.

Vermeer, G. J. O., 2002, 3-D Seismic Survey Design: Geophysical References Series, SEG.

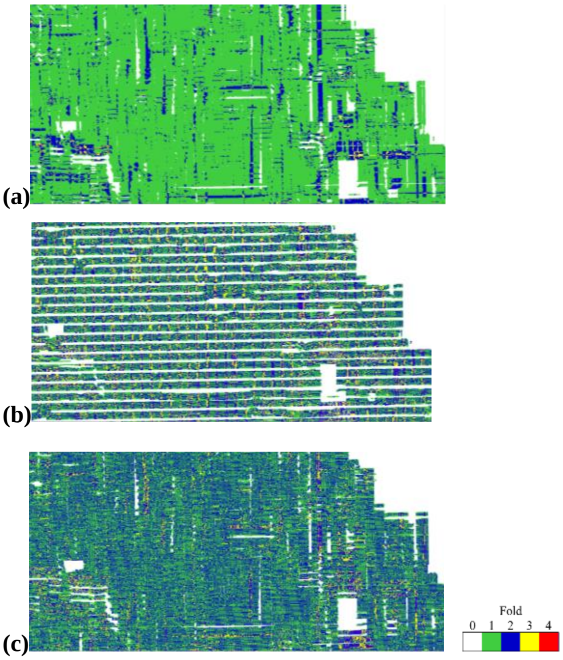

Figure 2: Fold maps for Turgeon-Farrell: (a) CMP fold using conventional OVT sampling; (b) ACP fold (γ=2) using conventional OVT sampling; and (c) ACP fold using PS OVT sampling defined by equation 2. White areas indicate gaps in coverage.

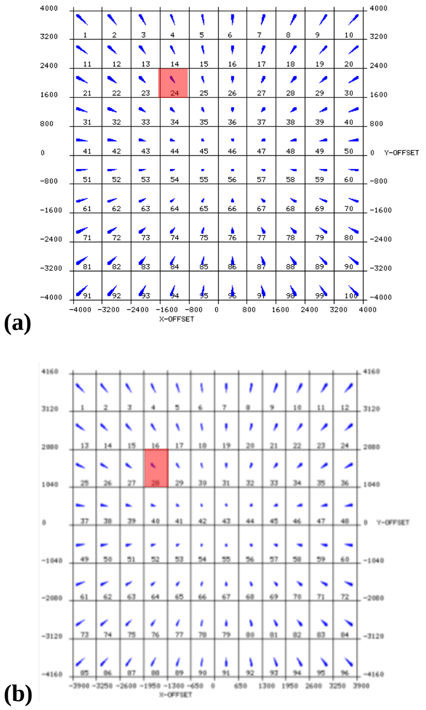

Figure 3: X- and Y-offset grids: (a) using conventional OVT design; and (b) using PS OVT design with γ=1.6. The shaded boxes indicate the OVTs selected for the migration comparison of figure 4: (a) offset: 2332m, azimuth: 328.1° at centre of OVT; and (b) offset: 2252m, azimuth: 312.9° at centre of PS-OVT.

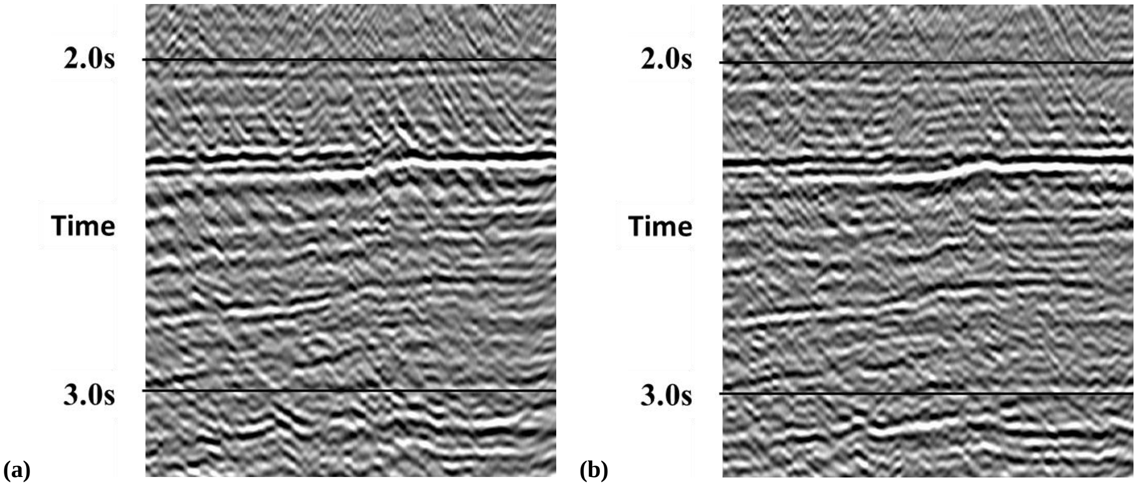

Figure 4: Portion of a crossline from prestack time migration of single OVT volumes: (a) using conventional OVT design of figure 3a; (b) using PS OVT design of figure 3b.