Processing with offset-vector-slot gathers

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Summary

Conventional prestack processing suffers from the absence of proper common-offset gathers in the crossed-array geometries. This requires a new approach to prestack processing, which recognizes the particular requirements of those geometries. This paper provides a strategy for prestack processing based on the construction of pseudo-minimal data sets (pMDSs), i.e., data sets, which are as nearly as possible MDSs, yet extend across the whole survey area. The strategy assumes 3-D symmetric sampling of the input data. The most suitable pMDS in orthogonal geometry is a collection of offset-vector slots (OVS gathers). Each OVS contains data with a limited in-line offset range and a limited cross-line offset range.

Introduction

Conventional processing of 3-D data is basically an extension of 2-D processing. For parallel acquisition geometry, which looks like repeated acquisition of 2-D lines, this approach is satisfactory. However, an orthogonal geometry has entirely different properties and needs a different approach to prestack processing. As a first step in that direction, Vermeer (1998a) proposed the use of cross-spread-oriented prestack processing to exploit the spatial continuity in the cross-spread acquired with symmetric sampling.

Cross-spreads belong to a class of single-fold data sets called minimal data sets (MDSs) (Padhi and Holley, 1997). An MDS is suitable for imaging that part of the subsurface volume which it has illuminated. Because of the limited extent of the cross-spread, only a limited part of the subsurface can be imaged, and the images are incomplete around the edges of the cross-spread. As an alternative, one could try to construct *pseudo*-minimal data sets (pMDSs), which extend across the whole survey area and deviate as little as possible from a true MDS. The construction of pMDSs was discussed in Vermeer (1998b). In that paper, the pMDSs were applied for the creation of common image gathers (CIGs).

In the present paper, I introduce a much wider assortment of pMDSs, which can be constructed from regularly sampled orthogonal geometries. Each prestack processing step can benefit from a reasoned selection of pMDS on which to operate; one process benefiting from quite a different choice than another. This paper is compressed from Vermeer (2000).

Construction of pMDSs

Even though cross-spreads have limited extent, it is possible to create single-fold coverage across the whole survey area by a tiling of adjacent (non-overlapping) cross-spreads. In such a single-fold gather, the data is piecewise continuous, with pretty large discontinuities between the adjacent cross-spreads. Therefore, it would be desirable to find a single-fold coverage using data with smaller discontinuities. As the discontinuities of the cross-spreads are a given, the only way to reduce their effect is by spreading the discontinuities thinly over the survey area. This can be done by selecting a tiling of offset-vector slots (OVSs), each slot having the size of the unit cell (area between two adjacent receiver lines and two adjacent source lines). Each OVS contains data with a limited in-line offset range and a limited cross-line offset range (Figure 1). In such a tiling or OVS gather, the same OVS is taken from all cross-spreads of the geometry. In these single-fold OVS gathers the frequency of spatial discontinuities is much higher than in adjacent cross-spread tilings. Their magnitude, however, is much smaller.

Cary (1999) also introduced the OVS gather as a basic building block of wide-azimuth surveys. He called them common-offset vector (COV) gathers, which would be a bit too optimistic as offset still does vary across each tile of the gather. Yet, I like the expression "offset vector", and therefore, I introduced here the expression offset-vector slot, which was called offset/azimuth slot in Vermeer (1998b). COV gather is a more appropriate name for the subset of the ideal parallel geometry.

Up till now, the cross-spread has been subdivided into OVSs, which taken together fill the whole cross-spread. However, a single-fold OVS gather can also be constructed using a generating OVS, which still has the size of a unit cell, but which can be located anywhere inside the cross-spread. This will increase the flexibility of selecting suitable OVS gathers considerably. A generating OVS may also consist of $n \times m$ unit-cell sized areas together. Taking the same area of each cross-spread in this way leads to $n \times m$ fold OVS gathers. Higher fold in an OVS gather may be useful for high-fold data, or for noisy data.

For any single-fold tiling of the survey area the tiles should have dimensions $SLI \times RLI$ or multiples thereof (*SLI*: source line interval; *RLI*: receiver line interval). However, in some cases it may be desirable to construct the tiles from smaller OVSs. For instance, along the *x*-axis, a pair of rectangles may be used (Figure 2). This implies the use of an OVS with the area of half a unit cell and its mirror image. Finally, for situations where azimuth does not play a role, unit-cell sized tiles may be constructed from four small OVSs (Figure 2).

Application to prestack processing

In the following, ideas are put forward for the most suitable input gathers for noise removal, muting, first-break picking, residual statics picking, velocity analysis, AvO and AvAzimuth, velocity model updating, and prestack migration.

Noise removal. The ground roll energy tends to be partially aliased, because of its slow velocity. The non-aliased part of the ground roll (and even a bit more) can be removed by prestack velocity filtering. The obvious input gather for this process is the cross-spread, so that noise can be removed either by cascaded application of shot and receiver domain *fk* filtering, or by a 3-D velocity filter.

Muting. The unit cell of a regular orthogonal geometry represents the 2-D periodicity of the acquisition geometry. Usually, the acquisition imprint shows this same periodicity. Consider Figure 2. The eight quarter-unit-cell sized OVSs indicated with the checkered squares and the striped squares have the same absolute offset distribution. The same mute time can be assigned to all traces inside these squares. If this procedure is carried out for all OVSs with the same absolute offset distribution, the effective fold-of-coverage will be constant for constant time. This should reduce the acquisition imprint of the geometry.

Hill et al. (1999) show a clear correlation between time slice amplitude and the fold of data contributing to the time slice. They used synthetic data acquired with zigzag geometry. The muting proposed here for orthogonal geometry could also be adapted to other regular acquisition geometries. If applied to their data, the acquisition footprint would be removed almost entirely.

First-break and residual statics picking. In OVS gathers, offset and azimuth have limited variation, allowing picking of traces that are quite similar. Therefore, picking in OVS gathers might be a good starting point. In case there are serious picking problems, it may be beneficial to combine OVS gathers of mirror OVSs in the opposite quadrant, as these have about the same azimuths.

An alternative to picking in gathers of (*SLI*, *RLI*)-sized OVSs is picking on a per cross-spread basis. The advantage of this alternative is that the area with spatial continuity in a cross-spread is much larger than in an OVS gather. The more flexible approach is to combine picking in the OVS gathers with picking in the cross-spreads. Especially in combination with the nearest-neighbor approach to picking (Vermeer, 2000), this should give the best results.

Velocity analysis and DMO. Conventional velocity determination after DMO splits the input data into small offset ranges, each offset range is DMO'ed separately, followed by gathering of the results per bin and semblance analysis. In a parallel geometry or in a narrow orthogonal geometry, this procedure should work satisfactorily. However, in a wide geometry, common offset-range gathers have very irregular fold, and are not likely to produce well-resolved DMO images. A common offset-range gather is shown in Figure 3. It illustrates the irregular fold, and shows the many edges in such a gather.

Although Vermeer et al. (1995), Collins (1997) and Padhi and Holley (1997) showed that cross-spreads are suitable for DMO, it is still necessary to split the data over offset ranges for velocity determination. The smallest offset slots, which still give complete single-fold coverage, can be found along the acquisition lines as indicated in Figure 2 with the gray rectangles. For an in-line fold of 6, there are 6 different OVS gathers with disjoint offset ranges. If the geometry would also be 6-fold in the cross-line direction, another 5 OVS gathers can be made from OVSs along the source line. For a maximum in-line offset and a maximum cross-line offset of 3000 m, the range of offsets in any OVS gather would still be at least 500 m. Hence, the uncertainty about the offset at the image point is still quite large. This may require a velocity scanning procedure rather than a semblance technique.

AvO and Amplitude versus azimuth. The determination of AvO parameters from an orthogonal geometry is a challenging task. The main problem is that proper common offset gathers are not available for analysis. It is also difficult to give a general recipe for AvO analysis, because there are so many different types of problems. Whatever the AvO problem is, I expect that solutions will have to be sought in a judicious use of OVS gathers. Depending on the problem, these gathers would be either NMO-DMO'ed or prestack migrated, followed by stacking.

The next step would be to pick the horizon on the stacked data volume, followed by making horizon slices according to these picked times in the contributing OVS gathers. The OVS gathers can be stacked pairwise with their mirror OVS gather in the opposite quadrant. The horizon amplitudes can now be analyzed in $M/2$ overlapping unit-cell-sized slots as indicated in Figure 4 (M: total fold).

For analysis of azimuth-dependent effects, the same procedure can be applied as proposed for AvO. Again, unit-cell sized areas of the survey have to be taken together, but split over the M different OVSs. Pie slices taken from the collection of data represent data with the same azimuth range (Figure 4). Now amplitude behavior has to be analyzed on a per pie slice basis.

Velocity-model updating. The process of velocity-model updating can be subdivided into two major steps: (1) the creation of images using subsets of the total data set, followed by (2) an analysis procedure to find an improved velocity model.

For a successful velocity model-updating procedure, the images produced in step 1 should be clean and should not suffer from artifacts. Moreover, many velocity-model updating procedures are based on the measurement of deviations in the CIGs as a function of offset. Figure 3 suggests that clean images cannot be made with absolute-offset gathers. This poses considerable extra challenges for the velocity-model updating procedure. Using a tiling of adjacent cross-spreads would produce clean images in most places but strong artifacts in other places. A better alternative might be to use OVS gathers.

Whether cross-spreads or OVS gathers are used for imaging, the problem remains that the offset of the imaging trace is not known without further action. This is caused by the variation in offset that occurs across a cross-spread and still occurs across the OVS gather. A way to finding the offset in the image point is to apply an idea proposed in Harris et al. (1998). In their MITAS procedure they determine an area around the image point that is included in the imaging process, whereas the data outside this area is discarded. However, knowing the position of the image trace also means that its offset can be retrieved and be used for further analysis in the velocity-model updating procedure.

True amplitude prestack migration of regular and irregular data. A shot/receiver pair illuminates a dip angle in an output point. All shot/receiver pairs together determine the range of dips that can be illuminated by the input data. Albertin et al. (1999) propose to equalize the distribution of dip angles across the unit sphere in the output point by weighting according to the local density. They show that this is equivalent to applying Beylkin's determinant.

Rousseau et al. (2000) carry Albertin's idea a bit further and suggest to apply it to the MDSs of the acquisition geometry. However, the low fold of an MDS may easily lead to gaps in the range of dips being illuminated. Weighting of the traces around such gaps has two effects: (1) if the gap occurs in the flat part of the bowl-shaped reflection events (after flattening of the diffraction traveltime surface), then weighting ensures a better amplitude of the image, but (2) if the gap occurs in the steep part of the bowl-shaped reflections, weighting of the traces increases aliasing artifacts.

A pairwise grouping of OVS gathers would reduce the risk of illumination gaps (Figure 5). For best results, Harris et al.'s (1998) method could be used to establish the image point and to apply aperture limitation around that point, followed by Albertin weighting.

Conclusions

Prestack processing of data acquired with orthogonal geometry or any other crossed-array technique is much more complicated than processing of data acquired with parallel geometry. In parallel geometry use can be made of common-offset gathers as MDSs, which extend across the whole survey area. In orthogonal geometry only pseudo-minimal data sets are available and these should be exploited for optimal prestack processing. The pMDSs can be constructed by taking offset-vector slots from corresponding positions in all cross-spreads of the geometry. Spatial discontinuities, which are inherent in the orthogonal geometry, are thinly distributed across the survey area by these OVS gathers. Most processing ideas in this paper have not been put to the test yet. Before that can be done, some software development is necessary, although some ideas can be implemented with only minor modifications to existing software.

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Processing with OVS gathers

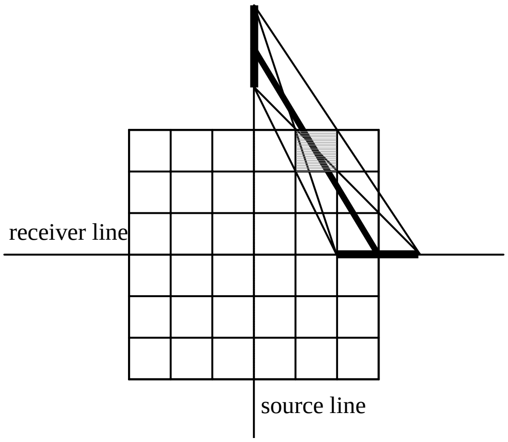

FIG. 1. Offset-vector slot in cross-spread of 36-fold geometry. Heavy lines along source line and receiver line indicate range of shots and receivers contributing to OVS. Heavy line through middle of OVS indicates average offset and average shot/receiver azimuth.

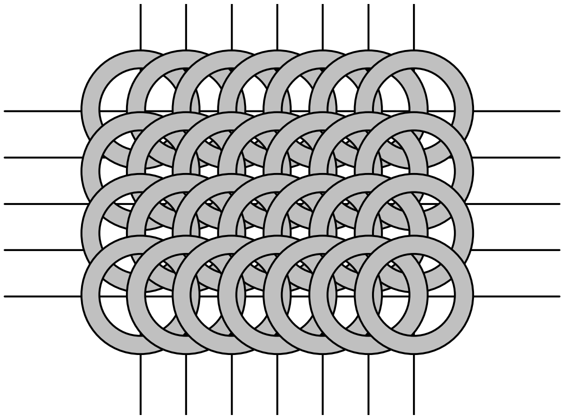

FIG. 3. Offset-range gather in orthogonal geometry. Each ring represents traces in midpoint domain with a narrow range of absolute offsets.

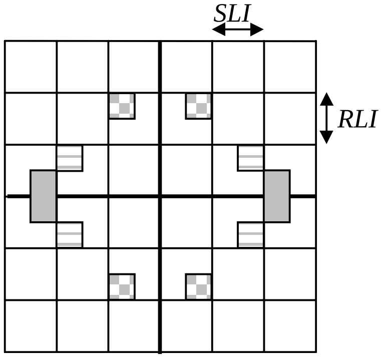

FIG. 2. Special case OVSs. Together, the two rectangular OVSs (dimension ½ *SLI* x *RLI*) can be used to construct an OVS gather with small spatial discontinuity between the OVSs. Together, the four checkered squares (dimension ½ *SLI* x ½ *RLI*) may be used to construct an OVS gather in case azimuth does not play a significant role. All eight small squares may be assigned the same mute time to achieve constant fold.

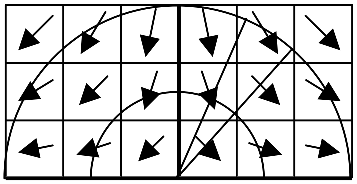

FIG. 4. Basic unit for AvO and amplitude versus azimuth analysis. All OVSs corresponding to the same unit-cell sized part of the survey area are displayed next to each other for further analysis. OVSs with opposite azimuth have been stacked together. Amplitudes for the same offset can be averaged along rings with a constant absolute offset range. Repeating this for all relevant positions in the survey area allows to analyze the spatial variation of the AvO effect. Azimuth-dependent effects can be analyzed using pie-slice shaped areas, which contain data with the same azimuth range. Arrows indicate dominant azimuth.

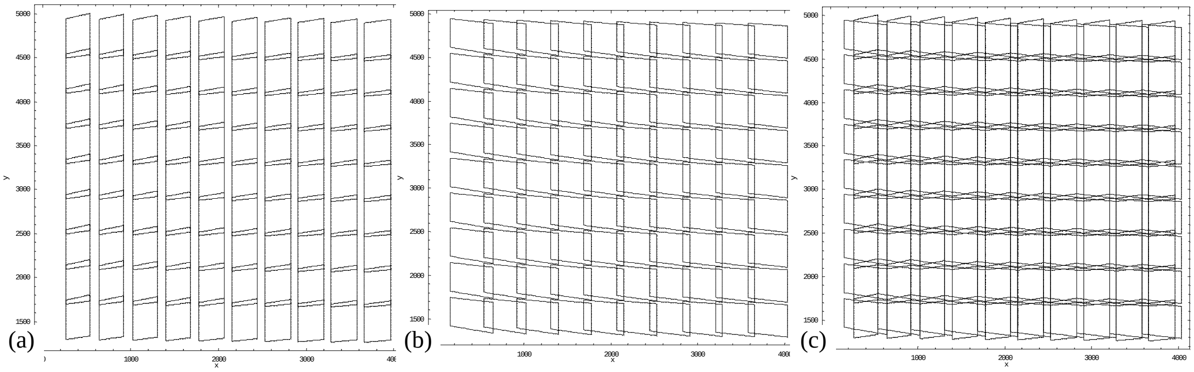

FIG. 5. Illumination of 15° dipping reflector by OVS gather. (a) OVS of upper right corner in cross-spread. (b) OVS of lower left corner. (c) Superposition of the other two. Although not exactly, the gaps in (a) tend to be overlaps in (b), and the overlaps in (a) are gaps in (b). The superposition gives a nearly regular illumination.