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CREATING IMAGE GATHERS IN THE ABSENCE OF COMMON-OFFSET GATHERS

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Introduction

Data acquired with the parallel geometry can be described as a collection of common-offset gathers. Prestack migration of such data can be conveniently considered as the repeated application of the migration process to all common-offset gathers. Therefore, it is possible to create image gathers for which each trace is the migration result of a single offset. Errors in the velocity model exist if the events show upward or downward curvature as a function of offset in the image gathers (Deregowski, 1990). In contrast, data acquired with the orthogonal geometry in land or OBC surveys do not allow the construction of common-offset gathers. Instead, the data of an orthogonal geometry 3D survey can be described as a collection of cross-spreads. Each cross-spread has illuminated its own little part of the subsurface that can be imaged by migration. However, the resulting image gathers do not bear a direct relationship with offset, making it considerably more difficult to diagnose and correct for velocity errors.

The purpose of this paper is to point out the problems that have to be faced with migration velocity analysis of data acquired with geometries other than the parallel geometry, to suggest solutions for those problems, and to encourage researchers to take up this challenge and find tractable solutions.

The paper starts with the introduction of cross-spreads, other minimal data sets, illumination fold and image fold. Then pseudo-minimal data sets are introduced as single-fold data sets, which cover the whole survey area. Finally, the pseudo-minimal data sets serve as input to the vector-weighted diffraction stack migration proposed by Tygel et al. (1993).

Padhi and Holley (1997) also consider many issues discussed in this paper. Their paper introduced the concept of minimal data sets, and also discussed approximate minimal data sets, which I call pseudo-minimal data sets.

Cross-spreads and other minimal data sets

A cross-spread is the collection of all traces that have a shotline and a receiver line in common. The total data set of an orthogonal geometry contains as many cross-spreads as there are intersections between shot and receiver lines. Each cross-spread is a single-fold 3D data set. Total fold in any point is made up by as many overlapping midpoint areas of cross-spreads. To create a survey with constant total fold, it is necessary that tilings can be made of cross-spreads with adjacent midpoint areas: where one cross-spread stops, the next one takes over.

The cross-spread is but one example of a *minimal data set*. Minimal data sets are single-fold 3D data sets suitable for imaging that part of the subsurface, which they have illuminated (Padhi and Holley, 1997). Other minimal data sets are the 3D common-shot gather, the 3D common-receiver gather, and the 3D common-offset gather with constant azimuth (COCA gather).

Illumination fold and image fold

The 3D zero-offset data set is the simplest minimal data set. It extends across the whole survey area, and illumination of the subsurface can be easily analysed using normal-incidence raypaths leaving from the interfaces. If such raypaths do not reach the surface, the corresponding part of the subsurface has not been illuminated by the zero-offset data set. If the raypaths do reach the surface, the corresponding part of the subsurface has been illuminated and can be imaged. Hence, each part of the subsurface is illuminated at most once by the zero-offset data set, and in each output point at most one image can be constructed using the data set.

This reasoning can be extended to COCA gathers, which also extend across the whole survey area. Again, parts of the subsurface will be illuminated, and can be imaged. If there are M different overlapping COCA gathers, each area of the subsurface has been illuminated at most M times, i.e., the *illumination fold* is at most M, and similarly, *image fold* is at most M.

The situation becomes more complicated for other minimal data sets, which do not extend across the whole survey area, such as cross-spreads and 3D common-receiver gathers. Each cross-spread has illuminated a limited part of the subsurface only. That part can be imaged, although incomplete images result for points close to the edges of the illumination areas. It is possible to create single-fold coverage across the whole survey area by making a single-fold tiling of cross-spreads with adjacent midpoint areas. However, the corresponding illumination areas and image areas will not be adjacent, except for horizontal events. Figure 1 shows that adjacent cross-spreads may produce partially overlapping illumination areas as well as holes in the illumination.

Despite the larger complexities of minimal data sets of limited extent, it may still be assumed that the average illumination fold is about equal to the fold-of-coverage (= the number of overlapping midpoint areas of the minimal data sets) (see also Vermeer, 1998). The average image fold will be smaller due to the edge effects.

Imaging with minimal data sets

In migration, the data contributing to an output point are collected by computing the diffraction traveltime for each trace contributing to the output point. In a cross-spread, the collection of diffraction traveltimes forms a diffraction traveltime surface. The image point is located where this surface is tangential to the reflection traveltime surface of the cross-spread. The image point forms the point of stationary phase in the Kirchhoff migration integral. The reflection times are converted to a depth surface in the output point. The depth values that do not differ more than the length (in depth units) of the wavelet from the depth in the image point contribute to the signal in the output point. Traces outside this *zone of influence* (Brühl et al., 1996, Vermeer, 1998) should cancel each other. Figure 2 illustrates this process for the cross-spread, but — with different figures — this description applies just as well to other minimal data sets. For *true-amplitude* migration each of the minimal data sets requires its own geometry correction factors to be computed from Beylkin's Jacobian (Schleicher et al., 1993, Vermeer, 1995).

Pseudo-minimal data sets

There will be at best as many valid images as the illumination fold, which is about equal to fold-of-coverage M. Therefore, it would be nice to have single-fold data sets, which cover the whole survey area, but do not deviate too much from minimal data sets. There should be M such *pseudo-minimal data sets*, each capable of providing a correct image in most output points. Then, in most output points, M images are available for diagnostics of the velocity model. I discuss two possible strategies for the construction of pseudo-minimal data sets for the orthogonal geometry.

Each cross-spread is a perfect minimal data set. However, it has limited extent, and to make things even worse, the extent varies as function of traveltime. One way of creating pseudo-minimal data sets extending over the whole survey area is to make single-fold tilings from adjacent cross-spreads. Fold determines the number of tilings that can be made for a survey.

To illustrate the use of such pseudo-minimal data sets, let us consider a constant-velocity medium with a single dipping reflector illuminated by four adjacent cross-spreads. Figure 3a shows the traveltime surface across the four cross-spreads. This surface is smooth inside each cross-spread, but shows kinks in the contours across the cross-spread boundaries. Figure 3b shows a migration panel for an output point (indicated by a "+" in Figure 3b) that corresponds more or less with the point on the reflector that has been illuminated by the "four-corners point" of the geometry. The zone of influence extends across the cross-spread boundaries, and shows considerable discontinuities across those boundaries. This is caused by the large jump in azimuth between adjacent cross-spreads. The large jump causes that adjacent traces, but in different cross-spreads, illuminate different parts of the subsurface. However, note that the cross-spreads along the diagonals have the same shot/ receiver azimuths (modulo π) in the corners that touch, hence for these pairs of cross-spreads the variation is still smooth.

From these observations we may conclude that each tiling should find very reliable images and zones of influence for the small offsets, but that the large offsets cannot be all that precise. How big this problem is, has to be found out in practice.

The nominal fold of a geometry only applies to the deep data where the mute function would hit for larger offsets than recorded. Only for those data the tiling can be made from adjacent (nominal) cross-spreads. Shallower, the effective fold is lower, and the tiling has to take that into account, leading to fewer tilings. This phenomenon is typical for the orthogonal geometry where for a given level all offsets contributing to that level are represented in the minimal data set. To ensure well-imaged image gathers, it is essential to take this variation in coverage into account, even though it complicates matters.

An alternative to tiling with cross-spreads is tiling with offset/ azimuth slots. To this end each cross-spread is split over as many offset/ azimuth slots as the fold. Each offset/ azimuth slot has the size of a *unit cell* (= area enclosed by two adjacent shotlines and two adjacent receiver lines). The number of times the unit cell fits on the cross-spread in the crossline direction equals the crossline fold, in the inline direction it equals the inline fold. In this way a tiling across the 3D survey consists of adjacent offset/ azimuth slots of the same kind, for instance, all top-right corners of all cross-spreads form one such tiling. The advantage of this pseudo-minimal data set is that it shows no big jumps in shot/ receiver azimuth as in the cross-spread tiling. A disadvantage is that there are many more edges across which the migration depth surfaces will show kinks. The smaller the shot- and receiver line intervals the smaller the tiles and the smaller the discontinuities across the tiles.

Figure 4 illustrates imaging with an offset/ azimuth tiling. Figure 4a shows the traveltime surface and Figure 4b the migration panel. From this we may get the feeling that offset/ azimuth slotting is more robust than cross-spread slotting. An additional advantage of offset/ azimuth slotting may be that it is easier to handle the shallow data (just drop the slots that do not contribute to a certain level).

Vector-weighted diffraction stack

Velocity-model updating schemes are often based on the use of offset-dependent depth or time differences in the image gathers for each output point. In the orthogonal geometry, the image gathers produced by the pseudo-minimal data sets do not correspond to single offsets, making it difficult to apply those updating schemes. Yet, it can be done, using the vector-weighted diffraction stack as proposed by Tygel et al. (1993). The aim of migration with the vector-weighted diffraction stack technique is to find for each reflector in each output point the corresponding trace in the (pseudo-) minimal data set that has illuminated that point. In the subsets the midpoint (x, y)-coordinates are the only spatial variables that vary smoothly, hence these are the weights to be applied. It is also possible to find the time of the event in the imaging trace by inclusion of traveltime in the vector of weights.

From the (x, y)-coordinates of the imaging trace its offset can be reconstructed. This can be done for all image traces in the same output point, so that the images may be sorted according to offset, and conventional velocity-model updating techniques may be applied. Although this technique was already published in 1993, no practical examples of its application have been shown as yet (as far as known to me). A major problem is the sensitivity of this technique for noise. Therefore, only the strongest events are candidates for this analysis.

Conclusions

Velocity-model updating techniques can benefit from a careful choice of the input for the image gathers. Pseudo-minimal data sets, which are single-fold data sets that approximate minimal data sets as closely as possible, have been proposed. The vector-weighted diffraction stack is suggested as a method to find the offset of the imaging trace, to be used for velocity updating.

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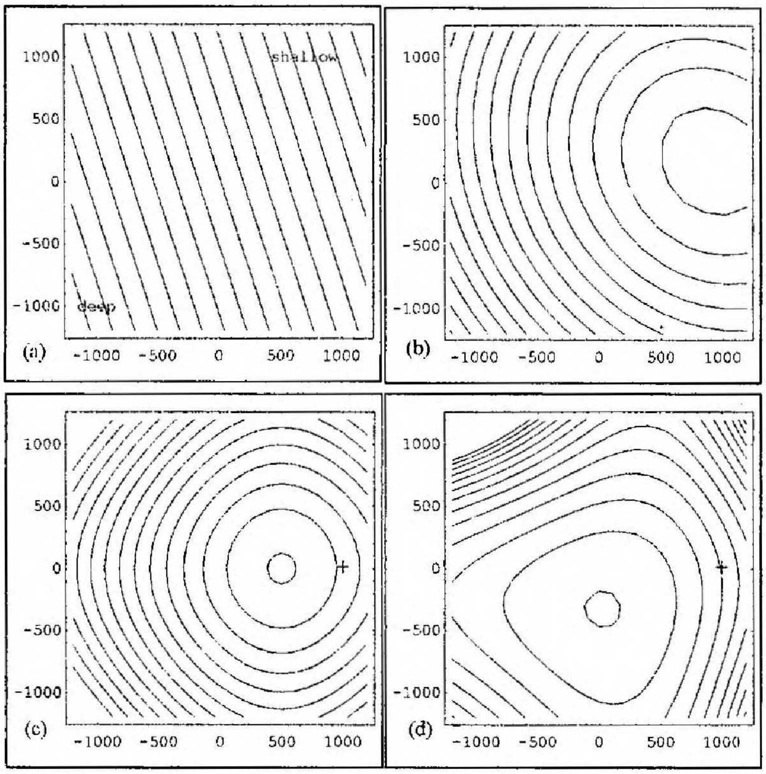

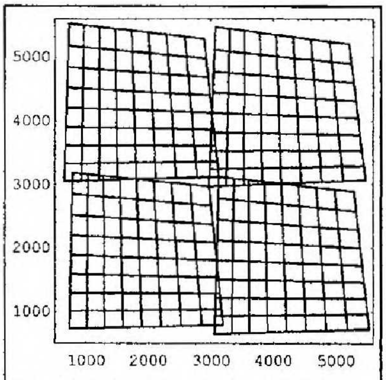

Fig. 1 Illumination of reflector with 15• dip by four adjacent cross-spreads.

Fig. 2 Contour plots of dipping event for midpoint area of cross-spread. (a) reflector depth, (b) reflection traveltimes, (c) diffraction traveltimes for point on reflector at +, (d) migration panel: reflection traveltimes converted to depth for output point at +. Image point is at the apex of this surface.

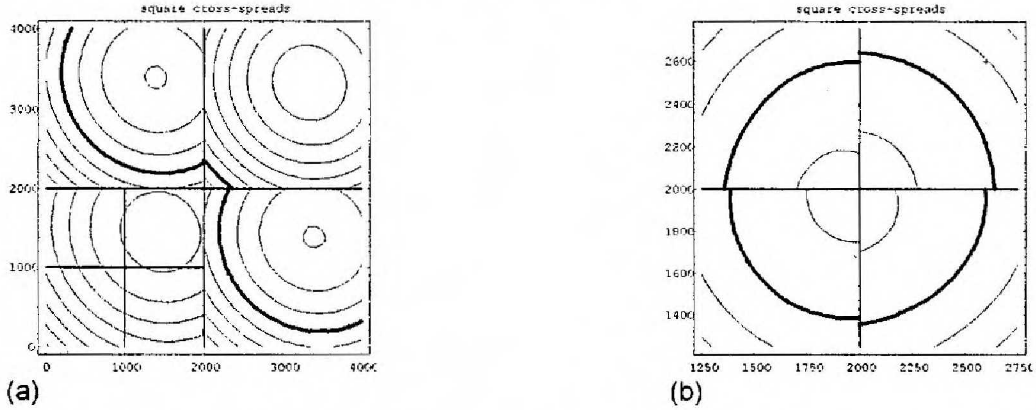

Fig. 3 Single-fold imaging with tiling of cross-spreads. (a) traveltime surface across four adjacent cross-spreads, contour interval 100 ms, (b) migration panel for single output point.

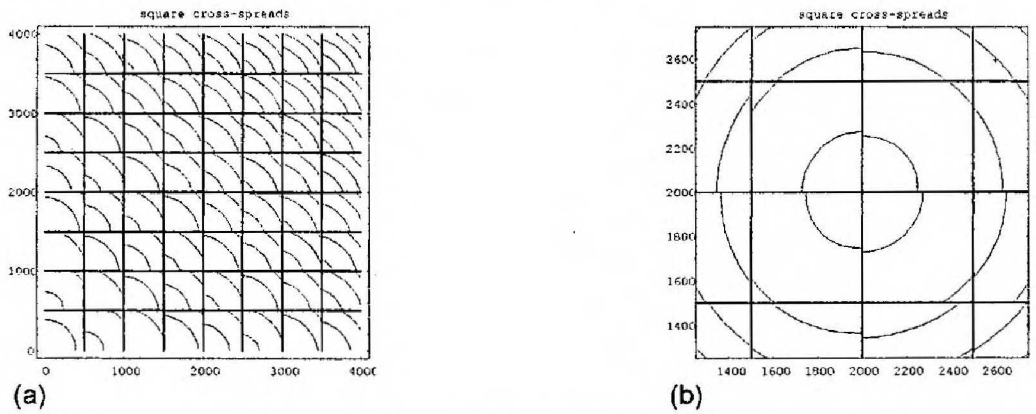

Fig. 4 Single-fold imaging with offset/ azimuth slots. Shown are top-right slots with size 1/16th of a cross-spread. Same subsurface as in Figure 3. (a) Traveltime surface across 4 x 16 slots, contour interval 50 ms, (b) migration panel centred on image point for one output point. Note the larger number of smaller discontinuities as compared to Figure 3b.