

GC Azimuth and Offset in Design of Successful 3-D Survey*

By
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Introduction

Even though the first 3-D seismic survey was acquired almost 40 years ago, it has been in only the last 15 years that 3-D has evolved from an R&D project for major oil companies to a "commodity" tool that is almost ubiquitous. Accompanying that evolution has been an improvement in the hardware and software necessary to design, acquire, process and interpret the resulting 3-D data as efficiently as possible.

Despite the broad acceptance of 3-D seismic, no clear standard for survey design has emerged. Nor should one be expected. The best survey is always a function of the geology that needs to be imaged. As long as the subsurface of the earth is not "standardized," there can be no "standard design." Furthermore, most users are not just interested in the best data quality possible; they want the best overall survey. The difference between the two is that the best survey must also consider economic and surface issues.

Ultimately, a successful 3-D survey is one that gathers "good enough" data -- good enough, that is, to meet the economic demands of our industry. However, in any endeavor that lacks standardization, there are bound to be a few eight tracks and BetaMaxes. Therefore, it is worthwhile to take a look at some of the more common misconceptions that can impact the success of a 3-D survey.

Wide Azimuth 3-D Equals 'True' 3-D?

There is no short and simple answer to the question of optimum source-to-detector azimuth. Intuitively, a wide-azimuth survey that collects long offset data from all directions might seem to be better -- but this is not always the case. In fact, most early 3-D seismic surveys were narrow azimuth, although it was probably a matter of necessity as much as intentional design. In basins with moderate-to-deep objectives, the number of

channels in the recording system restricted the contractors' ability economically to acquire wide-azimuth seismic data.

However, most of these early surveys were "good enough" to be considered successful, or if they were not, it probably was not the lack of azimuth that caused them to fail. For deep geologic objectives, equipment limitations can still exist. Achieving long offsets in the cross-line direction requires either very widely spaced receiver lines or a lot of lines in the active recording patch.

Before choosing a wide-azimuth design, a question that must be asked is how will these different azimuths be used? If pre-stack, azimuthally dependent analysis of the data is planned (see, for example, Search and Discovery Article #40098 (2003), "3-D Seismic Data in Imaging Fracture Properties for Reservoir Development," by Bob Parney and Paul LaPointe), then wide-azimuth data is absolutely necessary. If not, designing a survey to record long offsets in all directions can easily create more problems than it solves.

Three Different Wide-Azimuth Designs

To help understand the implications of wide-azimuth shooting, comparison is made of offset-distribution plots from a standard narrow-azimuth geometry (Figure 1, Design A) to three different wide-azimuth designs (B, C, and D). However, before doing that, a careful look at each of the four different acquisition strategies should be made.

For all four surveys we will assume a maximum usable offset of 10-11,000 feet. Other key design parameters are listed in Tables 1 and 2. In particular, notice the "Maximum Cross-Line Offset" values listed in Table 2. As shown in Figure 2, wide-azimuth design B has greater cross-line offset than narrow-azimuth design A (Figure 1), despite having the same number of receiver lines, channels, and fold. It does this by using a receiver line spacing that is more than twice the spacing used for design A.

Design C (Figure 3), on the other hand, has the same receiver line spacing as A (the narrow design), but uses 24 lines in its patch geometry to achieve the added width. However, to keep the fold (and cost) about the same as that of the narrow design, source line spacing for C has more than doubled.

Finally, there is design D -- the "best" of the wide designs. It uses the same source and receiver line spacing as the narrow plan. The major design difference is in its recording patch -- 24 lines of 96 channels versus only 10 lines for A. As a result, the fold produced by design D will be more than twice that of the other surveys. There is one other difference between these two designs: relative cost. Design D will cost more to acquire, because significantly more recording equipment will be needed.

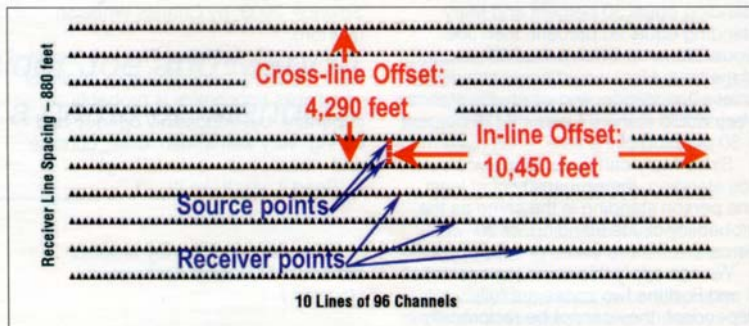


Figure 1. Narrow-Azimuth Design A. The recording patch is 10 lines of 96 channels with individual channels spaced 220 feet apart. The receiver lines are 880 feet apart. Overall, the resulting rectangular geometry is 20,900 feet long in the in-line direction and 7920 feet wide in the cross-line direction.

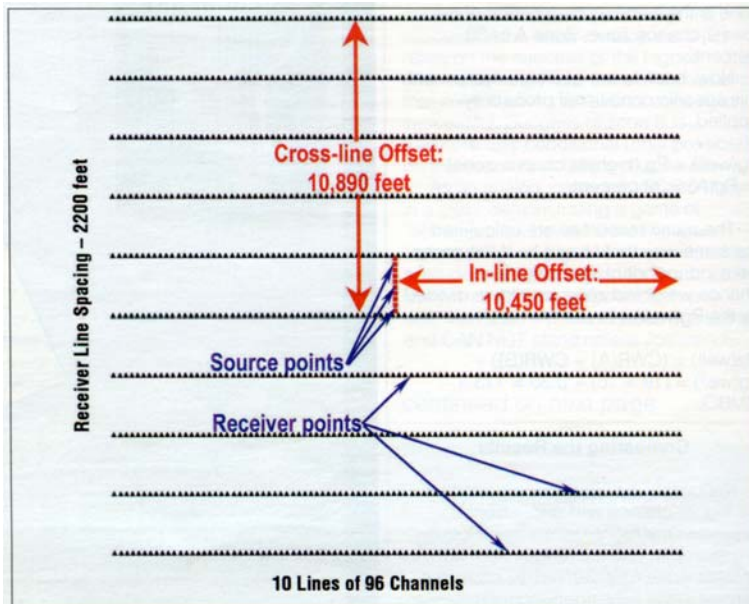


Figure 2. Wide-Azimuth Design B. The recording patch is 10 lines of 96 channels with individual channels spaced 220 feet apart. The receiver lines are 2200 feet apart. Overall, the resulting square patch is 20,900 feet long in the in-line direction and 19,800 feet wide in the cross-line direction.

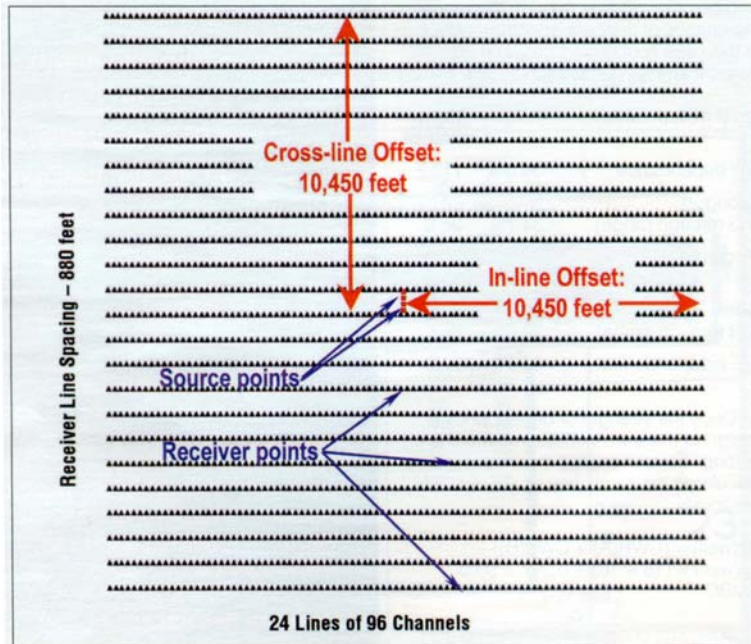


Figure 3. Wide-Azimuth Designs C and D. The recording patch is 24 lines of 96 channels with individual channels spaced 220 feet apart. The receiver lines are 880 feet apart. Overall, the resulting square patch is 20,900 feet long in the in-line direction and 20,240 feet wide in the cross-line direction.

Design	Recording Patch	Receiver Line Spacing	Source Line Spacing	Nominal Fold
A	10 lines of 96 receivers	880 feet	1,760 feet	30
B	10 lines of 96 receivers	2,200 feet	1,760 feet	30
C	24 lines of 96 receivers	880 feet	3,960 feet	32
D	24 lines of 96 receivers	880 feet	1,760 feet	72

Table 1. Design parameters.

Design	Maximum In-line Offset	Maximum Cross-line Offset	Relative Cost
A	10,450 feet	4,290 feet	\$\$
B	10,450 feet	10,890 feet	\$\$
C	10,450 feet	10,450 feet	\$\$
D	10,450 feet	10,450 feet	\$\$\$

Table 2. Design attributes.

The Importance of Offset Distribution

For any particular 3-D survey design, a wide range of attribute plots can be easily produced and examined. However, for any given fold, the attribute that will have the most impact on data quality is offset distribution. The potential problems created by poor (irregular) offset distribution are numerous, and in some cases the damage is irreparable by even the cleverest data processor.

These problems might include (but limited to) the following processing related issues:

- DMO (Dip Move Out) artifacts.
- Poorly resolved surface-consistent statics solutions.
- Poorly resolved refraction statics solutions.
- Inferior, or highly variable stack attenuation of coherent noise.
- Degraded AVO analyses.
- Increased appearance of an acquisition footprint.
- Increased difficulty estimating correct processing velocities.

Certainly, not all surveys with poor offset distribution will be ruined by problems such as these, but it is better to address them during the design phase than after the data are acquired. We shall examine offset distribution plots and offset-limited fold plots from several different wide-azimuth designs. We shall also compare these plots to similar plots from a typical narrow-azimuth design. This comparison will reveal some of the adverse effects that can result from wide-azimuth shooting.

Design Comparison

Offset Distribution

Given the importance of source-to-detector offset distribution for each individual cell, for any given fold and bin size, offset distribution is the single most important design attribute, especially when it comes to processing and interpreting the final data volume.

One of the best ways to display this offset information is with a trace offset scatter plot -- also known as a "necklace plot," which displays source-to-detector offset distances (along the vertical axis) for every pre-stack trace that belongs within a particular cell. Adjacent cells are indicated along the horizontal axis, so that entire cell-lines can be examined at one time. Gaps in offset-domain coverage appear as voids in a pattern of overlapping "necklaces." The larger the void is, the greater the likelihood of noticeable artifacts in the processed data.

Figures 4A and 4B are necklace plots that correspond to designs A and B (Figures 1 and 2). Recall that design A is the narrow-azimuth survey, where the cross-line maximum offset is only about 40 percent of the in-line maximum. Design B, on the other hand, has in-line and cross-line maximum offsets that are approximately equal to each other.

Note that even though designs A and B produce the same fold, the offset distribution for the wide design (Figure 1B) is markedly poorer. The same observation also holds true for Wide Azimuth Design C (Figure 4C). In both cases, near and mid-range offsets have been sacrificed in order to achieve large cross-line offsets. As a result, the data volume produced by either design B or design C is likely to be inferior to the volume produced from A -- the narrow design.

Of the three wide-azimuth designs modeled, only design D has better offset distribution (Figure 4D) than design A. However, the D design also has more than two and a half times the fold of A, and that extra fold does not come free. The cost of acquiring design D will be substantially higher than any of the other three designs.

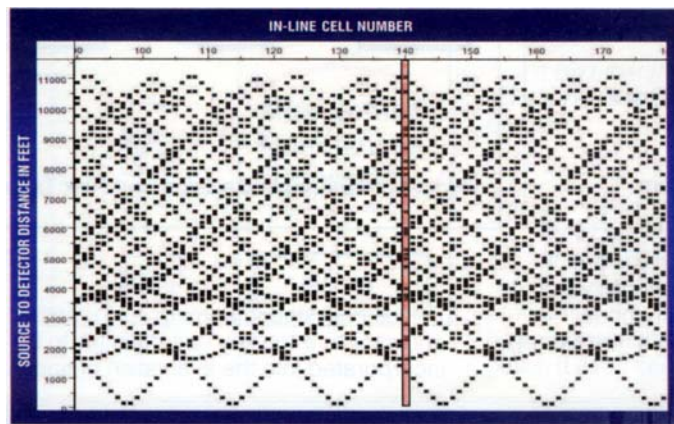


Figure 4A. "Necklace" plot for Narrow-Azimuth Design A. For these displays the Y (vertical) axis indicates source-to-detector offset distance in feet for each pre-stack trace within a cell. The X (horizontal) axis shows subsurface cell location. In-line cell number 140 has been highlighted to show all trace offset distances for a single cell. The offset distribution for this design is fairly uniform with 30 individual offset traces between 0 and 11,000 feet at cell number 140, for example. This should produce better results during data processing.

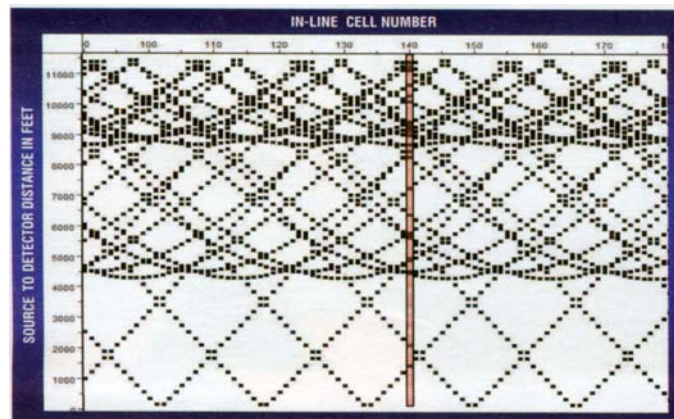


Figure 4B. "Necklace" plot for Wide-Azimuth Design B. This design will produce large gaps in offset domain sampling of the data, where from 0 to 4000 feet there are only two offset traces.

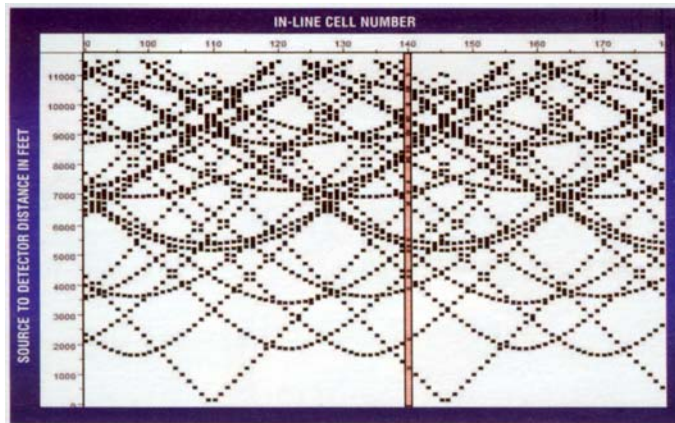


Figure 4C. "Necklace" plot for Wide-Azimuth Design C. As with design B, this design will result in very irregular sampling of source-to-detector offset distances, where from 0 to 4000 feet there are only three offset traces.

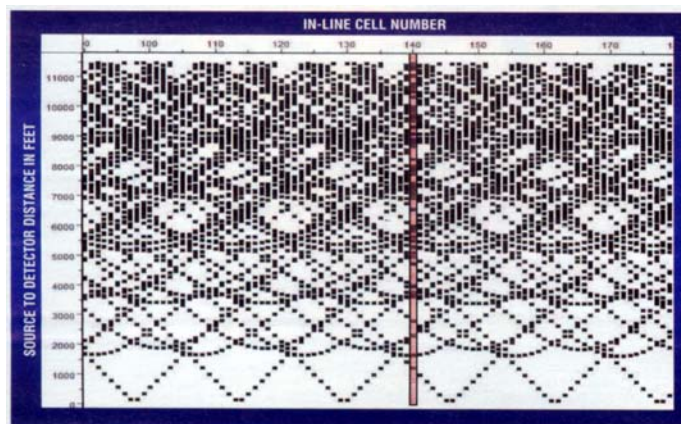


Figure 4D. "Necklace" plot for Wide-Azimuth Design D. Design D has better offset sampling than the other three designs, but it is also much higher fold. It has 72 individual offset traces between 0 and 11,000 feet.

Shallow Fold

In addition to having poor offset distribution, the ability of designs B and C to image shallow events is degraded. We can see this degradation by examining fold plots that have been offset-limited to source-to-detector distances of 5000 feet or less (Figures 5A, 5B, 5C, and 5D). Limiting the offsets to 5000 feet or less is representative of the offset mute that is applied to shallow data by the data processors.

For this example, we will consider geologic depths of about 4000 to 6000 feet to be "shallow." Although the nominal fold for Wide-Azimuth Designs B and C is about the same as Narrow-Azimuth Design A, the offset-restricted fold is quite different. Figure 5A

shows that offset-restricted fold for design A ranges from 10 to 14, whereas the wide designs B and C (Figures 5B and 5C) only have four to eight traces per cell. This means the ability to map a shallow, secondary objective accurately, or to use a shallow marker horizon for isochron mapping, probably will be compromised by using either design B or C. Only design D achieves wide-azimuth data and effective imaging of shallow events (Figure 5D). Unfortunately, as we have noted before, design D will cost more to acquire than any of the other three design options.

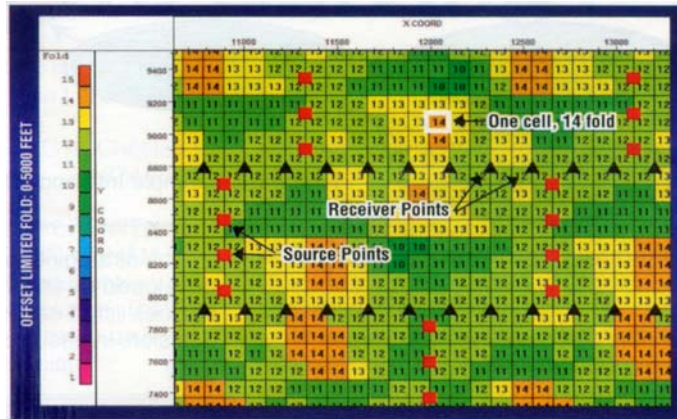


Figure 5A. Offset-limited fold plot for Narrow-Azimuth Design A. Figures 5A, 5B, 5C, and 5D show a magnified portion of the fold plot that results when source-to-detector offsets are limited to 0 to 5000 feet. Individual cells or subsurface bins are delineated as squares. Trace count in any given cell is indicated by both the color and number within each square. Offset-limited fold for this design is much higher than designs B or C, and ranges from 10 to 14.

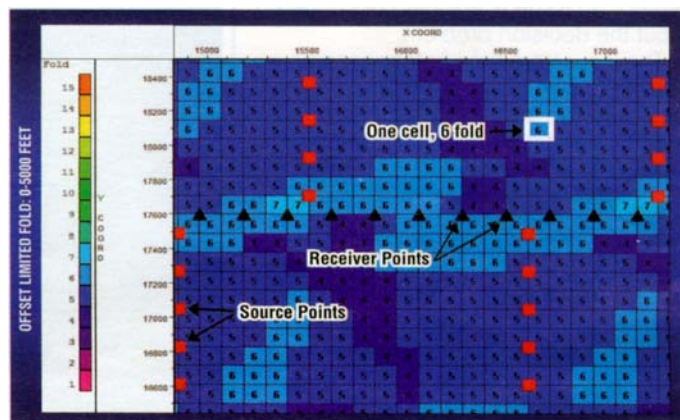


Figure 5B. Offset-limited fold plot for Wide-Azimuth Design B. Offset limited fold for design B is from 4 to 7 fold.

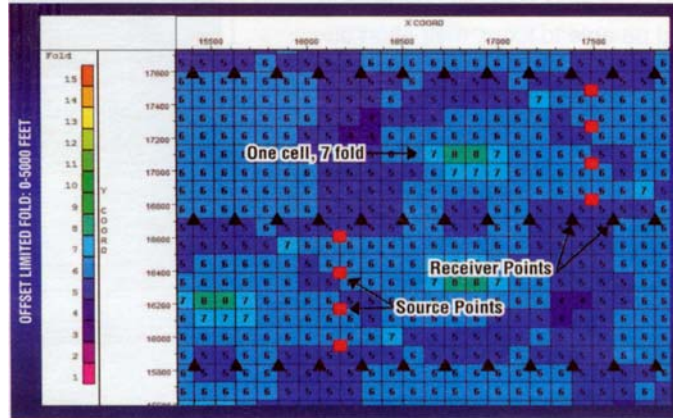


Figure 5C. Offset-limited fold plot for Wide-Azimuth Design C. Offset restricted fold for design C fold is similar to design B. It ranges from 4 to 8 fold.

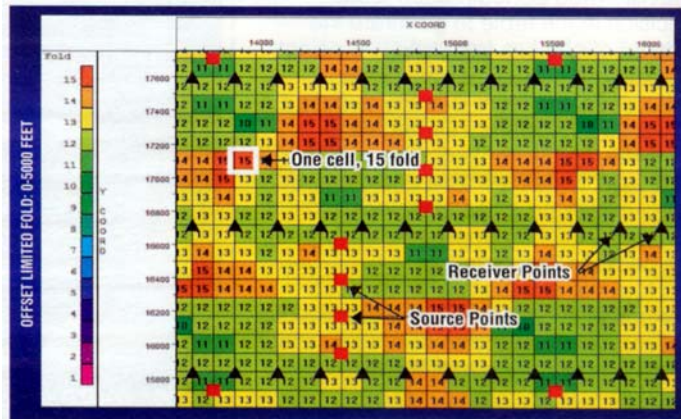


Figure 5D. Offset-limited fold plot for Wide-Azimuth Design D. The offset limited fold for design D (10 to 15) is only slightly higher than Narrow-Azimuth Design A despite having nominal fold that is more than twice as high. Most of the extra fold consists of longer offsets in the cross-line direction.

Conclusions

The specific point of this article is not to suggest that designs B, C or D are necessarily better -- or worse -- than design A. Rather, it is to call attention to the fact that those extra azimuths are going to cost you in one way or another. Either the price of your seismic survey will go up, or the offset distribution and shallow imaging will deteriorate, or both. Therefore, you must carefully weigh the pluses against the minuses in the final seismic subsurface image. What are you getting? What are you losing? What will it cost?

Overall, the best overall 3-D seismic survey is not necessarily the one with the best quality data; nor does it have to be the one with long offset data from all azimuths. The best survey really depends on balancing a combination of factors -- in particular, subsurface geology and economic objectives. For some projects, wide-azimuth data is a necessity; for others, it can be more of a liability than an asset. The critical issue is to

record seismic data that are "good enough" to image the geology and still meet the economic requirements of the user. This is accomplished by recognizing the important role of survey design in the planning process.

Acknowledgments

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