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Imaging Properties of Modern 3-D Seismic Acquisition Systems

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ABSTRACT

The patterns of source and receiver locations, i.e., the acquisition geometry, used in a seismic survey affect the resulting data in a variety of ways. Herein is a study of the relationships between the acquisition geometry and the resulting subsurface illumination patterns by comparing basic land and Ocean Bottom Cable geometries with modern marine geometries. From the imaging point of view, there are certain advantages to some of the land-type acquisition geometries. By examining a new set of acquisition attributes based on imaging properties, such differences in image quality can be predicted and perhaps corrected in the survey design stage.

Keywords: acquisition, imaging, quality assurance, survey design

INTRODUCTION

Significant cost reductions in data acquisition have resulted in widespread use of 3-D seismic data. Improved technology, economies of scale, and innovative 3-D survey designs have all contributed to cost reductions. Perhaps the most important of these innovations has been the efficient use of sources and cables in land, marine, and transition zone acquisition for increased productivity.

Indeed, the number of common midpoint (CMP) lines acquired per shot line generally is just the product of the number of source lines and the number of cables or receiver lines. Thus, for reasons of productivity, the seismic industry strives for more receiver lines and/or source lines within the basic acquisition layout, which in turn generally implies wider configurations.

While the advantages of wide geometries are sometimes clear from an economic standpoint, the geophysical properties of the resulting seismic data are not always well-understood. Wide acquisition geometries are not inherently either good or bad — the answer depends on the particular aspect of the data in question. This study concentrates on the subsurface illumination and imaging quality of a 3-D survey design. Imaging quality generally depends on many factors, not the least of which is the actual subsurface geology. However, in practice certain geometries, for example wide marine geometries, can have very irregular subsurface illumination patterns and serious sampling deficiencies in the form of dip- and azimuth-dependent shadow zones (Beasley, 1993; Vermeer, 1994). This paper examines several acquisition geometries, including marine, land, and transition zone in light of their subsurface illumination properties. This comparative study shows that for typical 3-D geometries, wide-tow marine geometries suffer from significant shadow zones, while much wider land and transition zone geometries generally do not.

METHOD

Subsurface geology plays a critical role in the imaging quality of the seismic data. However, as geology is variable and not often known in detail, generic methods of evaluating possible acquisition geometries are necessary. Traditionally, quantities such as midpoint fold, offset, and azimuth distribution have been used as comparative measures of 3-D acquisition geometries. However, evaluating such surface-related quantities is inadequate because reflection points and midpoints coincide only for flat reflectors. One approach is first to choose a particular Earth model and then determine the subsurface reflection points associated with each source and receiver pair by ray-tracing or some other means. The resulting reflection points can then be analysed to determine if reflectors have been properly sampled. This method generally is not practical for models with 3-D complexity due to the effort involved in analysing all possible reflector geometries. Alternatively, the 3-D DMO operator can be inverted to efficiently analyse the illumination characteristics of the acquisition geometry for all possible reflector geometries (Beasley, 1993). This method was used in this study.

MARINE EXAMPLE

The acquisition geometry consisted of 10 cables, each 3000 m in length. Receiver line-spacing is 100 m to yield a width of 900 m. Two sources straddle the sixth receiver line to give 20 CMP lines per boat pass. This geometry is similar to one recently reported in *Offshore* that was achieved using three vessels (George, 1994). The constant-velocity subsurface model consisted of a flat reflector and four dipping events: +45° and -45° inline, +45° and -45° crossline. Ray tracing was used to generate synthetic data from this model, and the data were processed through 3-D DMO and stack. Even though CMP fold is constant, irregularities in spatial sampling were indicated by amplitude variations in the crossline direction. Moreover, significant shadow zones were observed when the vessel was shooting up-dip.

Equalised DMO (Beasley and Klotz, 1992) can generally correct for the amplitude and phase distortions, but the missing data in the shadow zones may not be completely restored. Figure 1 shows a diagnostic plot of the subsurface illumination for this geometry, based on inverting the DMO operator, that predicts the poor sampling.

LAND AND TRANSITION ZONE EXAMPLE

Unlike streamer geometries in which the sources and receivers move together, land and transition zone and Ocean Bottom Cable (OBC) geometries offer flexibility in the placement of sources and receivers. Here, a typical cross-spread shooting geometry consisting of two parallel cables separated by 600 m is studied and a cross- and split-spread shooting configuration in which the shots extend 2600 m to either side of the spread is employed.

OBC Inline Illumination %, -

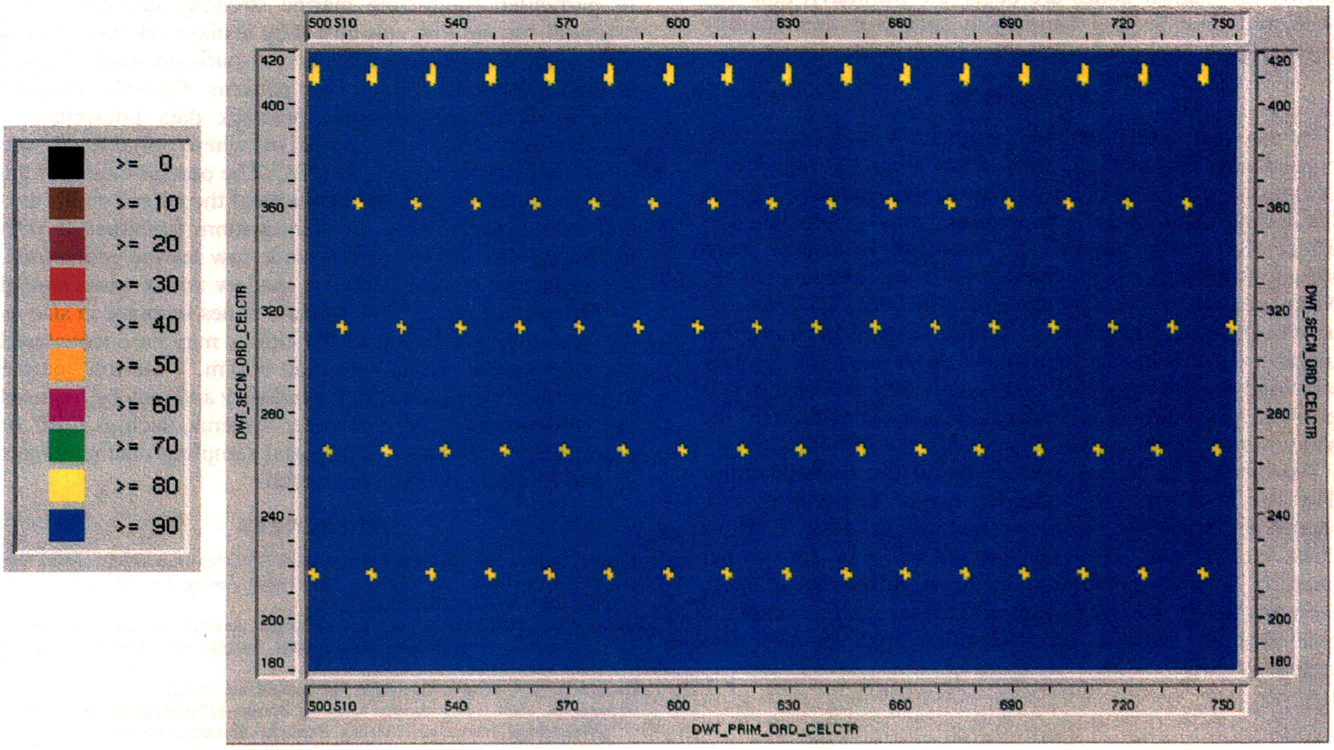

Figure 1. Percentage of illumination for inline negative dips for a wide-tow streamer configuration. The low percentage values between swaths indicate severe shadow zones.

Wide-tow Illumination %, -

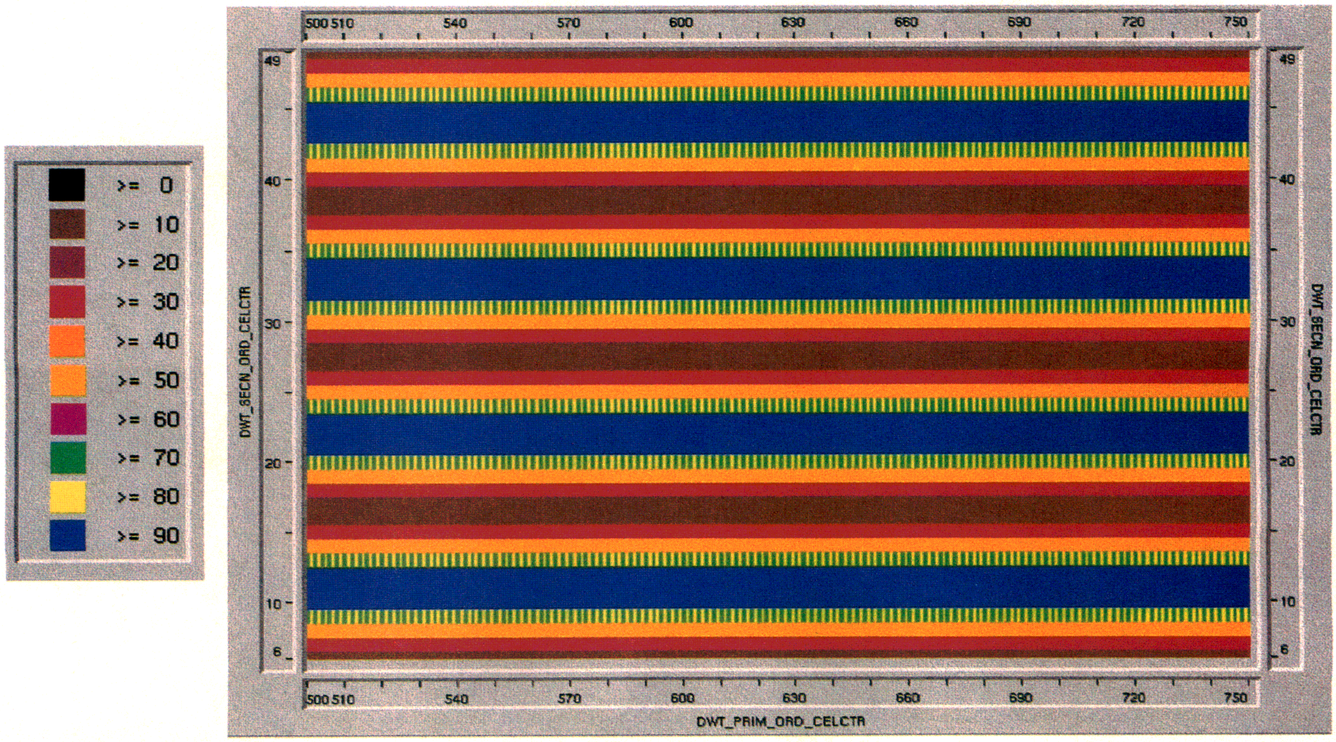

Figure 2. Percentage of illumination for inline negative dips for a cross-spread OBC geometry. The OBC geometry has consistently high percentage illumination and does not exhibit the shadow zones seen in Figure 1.

Figure 2 shows the subsurface illumination for this geometry to compare with Figure 1. Although the OBC geometry is actually wider than in the marine geometry above, no shadow zones are observed. Similarly, land and transition zone designs that employ such crossline shooting geometries do not generally suffer from shadow zones.

DISCUSSION

In the real world of data acquisition and processing, particularly for marine data, there may be significant deviations from the planned acquisition geometry. Cable feathering, obstructions, and environmental objectives may affect the actual source and receiver locations. Such situations have not been considered in the above analysis. Moreover, these methods are based on DMO analysis and are thus limited. Nevertheless, further analysis indicates that the above conclusions on shadow zones hold for velocity varying with depth and for systematic cable feathering. It is possible that random cable feathering could ameliorate the shadow zone problem, but this is not a reliable solution.

Another aspect to consider is size of the shadow zones. The size is offset- and depth-dependent, diminishing with increasing depth, but increasing with larger offset. Thus, as deep targets may rely on long-offset data for proper imaging, even deep targets can be significantly affected. As a practical matter, the amplitude stripes seen on synthetic examples are similar to those often seen in real data examples.

CONCLUSIONS

Efficient use of multiple receiver and shot lines in reflection seismic surveys is essential for economic reasons. In particular, multicable marine streamer geometries are essential for the low unit cost they achieve. However, very wide cable distributions may have significant shadow zones in their subsurface illumination patterns. Possible solutions include overlapping swaths; prestack data interpolation; limiting the width of the spread; or, where possible, the use of different systems, such as OBC. The precise extent of the shadow zones depends on the width of the spread and is dip- and azimuth-dependent, becoming more pronounced with increasing dip. For the case of wide-tow marine geometries, 45° reflectors show significant shadow zones when spread widths exceed 500 m. The shadow zones increase in size as dip increases and so some difficulties may be encountered even for spread widths less than 500 m. Wide-tow marine acquisition is ubiquitous in the industry and may be required due to depth limitations of other systems, such as OBC or other factors. However, the spatial sampling characteristics should be analysed and considered.

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