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Seismic Imaging Challenges in the North of India

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Summary

In order to be able to optimize the imaging in areas of very complex geology, it is now well understood by the seismic industry that we need to acquire data with fine spatial sampling, high trace density and a wide azimuth recording geometry. Unfortunately, the sampling requirements of some of the improved pre-stack depth migrations are not well understood and surveys are frequently acquired with inadequate sampling for the preferred migration algorithms.

The surface topography over many of these complex geological areas, such as in the North East of India, is frequently very difficult terrain on which to record data, with steep hills and sometimes dense vegetation. This paper will discuss the sampling requirements of the newer imaging algorithms and some potential ways that data acquisition can be accomplished to meet these needs.

Keywords*: complex geology, rough topography, imaging, migration, data acquisition*

Introduction

In the early days of 3D data acquisition, survey geometries used on land were often narrow azimuth swath geometries. When recording in mountainous areas where there was a significant regional stress direction, the long axis of the swath was typically selected to be in direction of this stress, since finer spatial sampling could be more economically achieved by reducing the interval between the receivers in this direction than by reducing the source point interval. In the crossline direction (i.e. perpendicular to the receiver lines) it was commonly assumed that this was the "strike" direction and that the spatial sampling could be coarser. This meant that in many surveys the source point spacing was wider and therefore the drilling and explosives costs could be reduced. However, as many interpreters know, in most complex geological areas there is rarely a simple "dip" and "strike" direction.

Figures 1 and 2 show pre-stack time migrated images (PSTM) from a survey in an Arctic area with relatively complex geology. The survey is situated in the foothills of a major mountain range and the oil company had decided on a bin size of 33.5m in the "dip" direction and 50m in the "strike: direction. The dip was believed to be perpendicular to the mountain front and strike parallel. The final survey was acquired with a wide-azimuth geometry and finer spatial sampling (16.75m bin size in each direction) and it can be easily seen that there are not predominant dip and strike directions. These data were processed using all of the recorded field data but simulating the oil company's original acquisition parameters.

Figures 3 and 4 are at the same locations at Figures 1 and 2 but now processed using the higher density and finer spatial sampling of the actual recordings. The trace density of these data is six times greater than that shown in Figures 1 and 2 except with lower source and receiver effort for each trace. Some of the benefits of the improved sampling are indicated by the red circles.

Many data examples have been shown recently that demonstrate that wide-azimuth recording provides much better illumination of the subsurface than narrow azimuths. However, in order to be able to process the wide-azimuth data correctly we must ensure that we have adequate offset sampling within all azimuth ranges. Early discussions about the relative merits of wide versus narrow azimuth

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geometries were generally based on similar fold or trace densities and because of this, wide-azimuth acquisition typically had very poor offset sampling. As recording system capabilities have increased in recent years we can now acquire much higher trace densities and therefore improved offset and azimuth sampling.

Sampling requirements for modern processing algorithms

Seismic data processing and imaging alternatives have expanded greatly over the last few years. Some of the newer alternatives have been driven by success in exploration for unconventional resources (fracture orientation, stress field determination), and some have been driven by imaging advances (wave-equation and reverse-time migration). All of them place a burden on seismic acquisition that is far beyond the demands of conventional land data acquisition in mountainous or Foothills areas. They require the seismic processing of complete wavefields which, in turn, requires more sources and receivers per unit area.

Conventional Foothills processing produces a pre-stack time migrated image as its final step before structural interpretation. The migration is applied to sparsely acquired data with static corrections applied. Velocity is uncertain, the depth and lateral position of the target are uncertain, and migrated amplitudes are guaranteed to be unreliable for determining subsurface azimuthal properties such as fracture orientation. Depth migration of sparse data, even after spatial interpolation, reduces uncertainty in velocity and target location, but still provides unreliable azimuthal amplitude information. The sampling requirements of migration (even Kirchhoff migration) dictate much finer spacings for sources and receivers than is conventional. Finer sampling, and associated processing of complete wavefields, allow for better near-surface analysis and corrections, better structural imaging, and amplitudes for analyzing subsurface azimuthal properties. For example, the industry has traditionally tried to record data with very regular grids of sources and receivers. As the trace density is increased the requirement of very regular source and receiver grids and uniformity of fold can usually be relaxed. Many of the interpolation algorithms that have been developed recently actually work better with irregularly sampled grids than with uniform sampling.

When designing 3D surveys in difficult geology one of the first steps is to ensure that the spatial sampling is adequate to ensure that the highest signal frequencies on the steepest dips are not aliased. This is typically calculated for the CMP bin size. The problem with this is that this is not correct for all migrations. If we wish to perform a pre-stack depth migration with reverse time migration in the shot domain, the spatial sampling that will typically control the aliasing will be the receiver line interval. In most land surveys this is quite large and will result in a very low aliasing frequency.

High density, wide azimuth acquisition geometries are now well accepted in the Middle East. Extremely dense source grids are acquired with a greatly reduced source effort at each shot location. The reduced source effort often results in significantly lower signal to noise ratio on the individual records, yet the processed images are greatly improved. Obviously the tight source grids cannot easily be acquired in Foothills areas, but it may be possible to acquire much denser grids than conventional with the use of lower source effort and the use of different source types in different parts of the survey.

Possible methods to improve land data acquisition in mountainous areas

There are a number of opportunities available for improving our data quality in difficult mountainous environments. Modern recording systems can acquire many tens of thousands of data channels without any problems. In most cases the number of geophones per recording station can be reduced to maintain a similar "geophone density" per kilometre of receiver line. The next step is to record wide azimuth data with as many receiver lines as possible. Reducing the receiver line interval will help address the issue of aliasing for pre-stack depth migration mentioned above. A full wide azimuth geometry with the same maximum offset inline and crossline will address the fact that in complex geology we will have dips in all directions. It should also improve our ability to determine the velocity/depth model for pre-stack depth migration.

Do not constrain the source and receiver lines to be perfectly uniform or linear. This will make possible the use of all available access and minimize environmental damage. It can also help reduce the cost. Finally, this will improve the results of modern interpolation algorithms so that we can improve the wavefield sampling before wavefield migration.

For sources the situation is more difficult. As discussed previously in the Middle East we have observed significant improvements in data quality with the use of very dense source grids using vibrators. In areas with dense vegetation this will not be possible. Also, in most mountainous areas the source is typically explosives and these do not lend themselves to a simple reduction of source strength since the cost of drilling remains very similar for varying charge sizes unless the hole depth is significantly reduced. However, we can improve the source density by using a variety of different sources in different parts of the survey. Many surveys are acquired today with multiple source types and the differences in the signal and noise levels are managed very well. Even differences in the source spectrum can be almost invisible in the final imaging.

Conclusions

For modern processing algorithms we need to improve the spatial sampling of our field data. Although difficult, there are ways that this can be achieved without inordinate increases in data acquisition costs. Environmental issues can also be minimized by the use of available access in many regions without adverse effects on the data quality. In fact, in some cases this may actually provide improvements in the final interpretation data volume.

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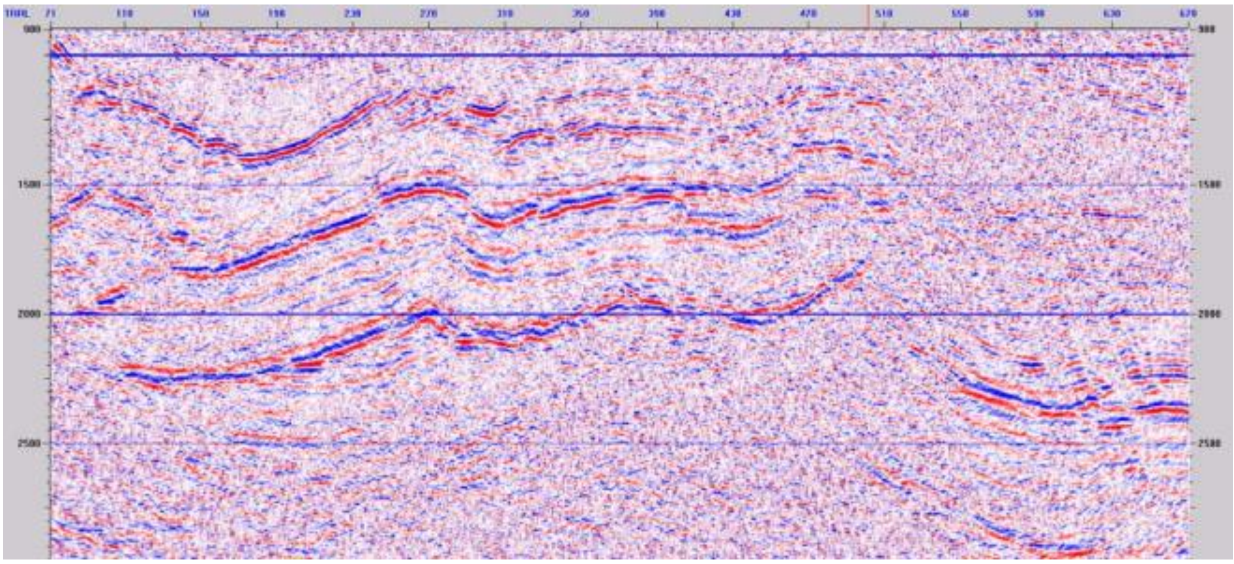

Figure 1 Pre-stack time migrated line extracted from the data volume in what had been presumed to be the “dip” direction. Processed using the bin size and array dimensions of the original survey design.

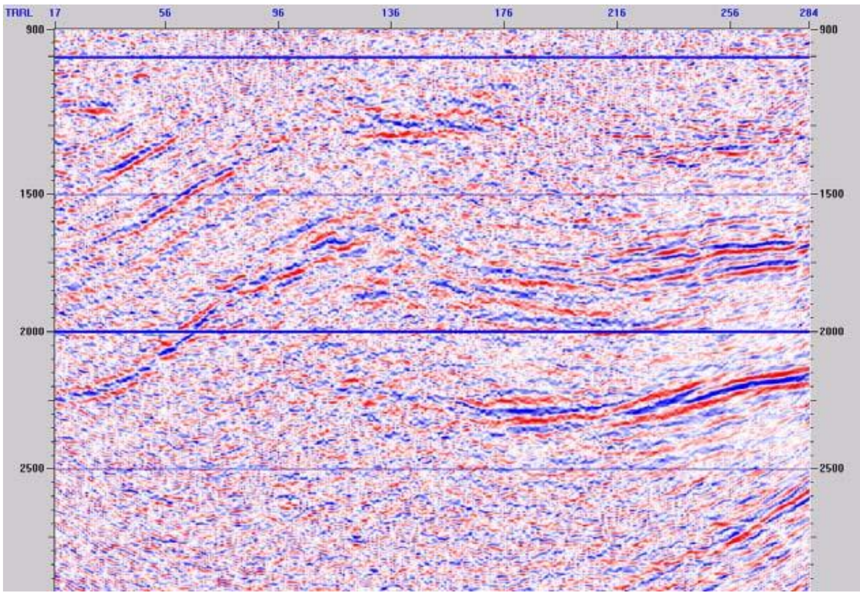

Figure 2 Pre-stack time migrated line extracted from the data volume in what had been presumed to be the "strike" direction. It is clear that there are similar or steeper dips in the direction parallel with the regional geologic stress.

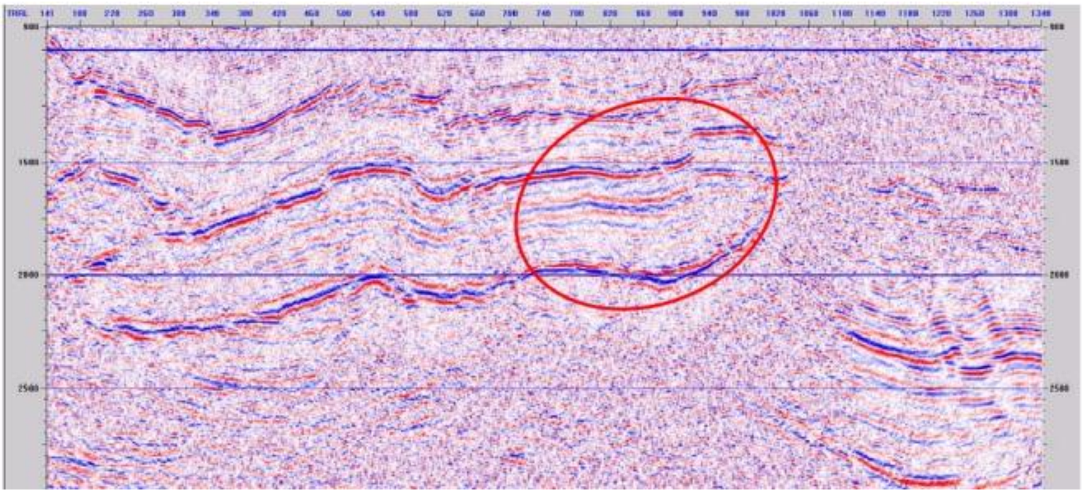

Figure 3 PSTM line at the same location as Figure 1 but with higher density and finer spatial sampling. Some of the improvements in the imaging are highlighted within the red circles.

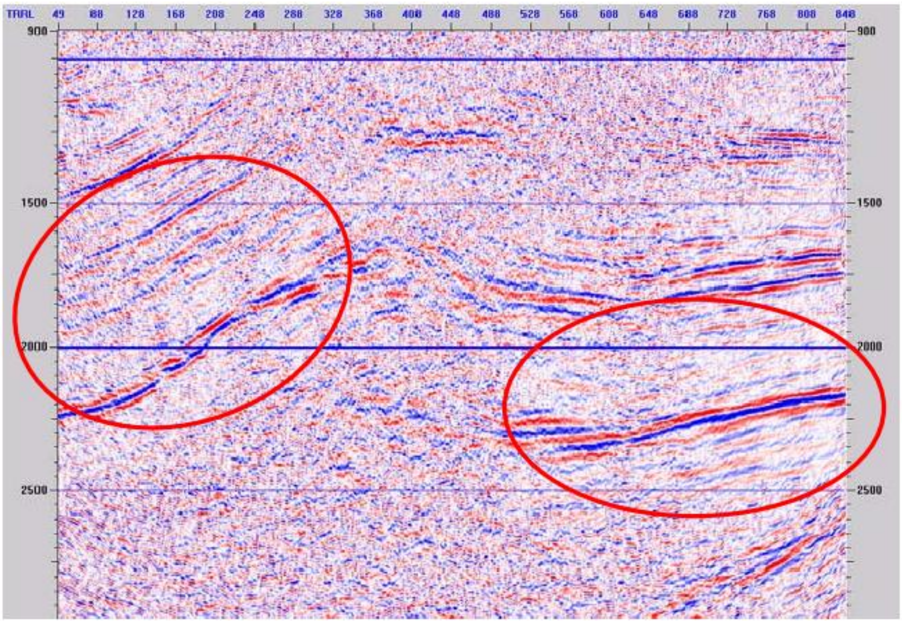

Figure 4 For comparison with Figure 2, same subsurface location but higher trace density and finer spatial sampling.