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Enhanced 3D Imaging from 2D Seismic Data and its Application to Surveys in the North Sea

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SUMMARY

We have developed an enhanced methodology to create a 3D seismic migration volume from a set of 2D seismic lines. The key challenge is to interpolate coarsely spaced 2D seismic lines into a dense 3D seismic volume before performing a post-stack migration. Building a geologic time model which essentially consists of a set of geological time horizons and using them to guide the interpolation is a practical approach to address the coarse sampling issue. Successful application of enhanced methodology to a data example from the North Sea demonstrates its effectiveness.

Introduction

In some of the newly explored areas around the world, 3D seismic surveys may not be available. Assessment of the exploration potential and in some cases, even a critical well-drilling decision is dependent upon the availability of existing 2D seismic data. Due to the 3D nature of geologic structures, 2D migrated images may not be accurate due to off-plane 3D effects. To make seismic interpretation easier and help facilitate sound business decision making, producing a 3D seismic image is desirable. Interest has grown in recent years for 3D seismic products derived from 2D survey data. Since the 1980's and the pioneering work of Lin and Holloway (1988), there has been periodic interest in the generation of dense 3D images from 2D images of suitable quality for interpretive purposes. Given the incredible increase in compute power available today, it is possible to expand upon this foundation utilizing improved algorithms that were simply unaffordable in previous times.

We have developed an enhanced methodology to create a 3D seismic migration volume from a set of 2D seismic lines. In this paper, we will describe the methodology with examples from some recent applications. A key challenge in performing this type of interpolation is that the available 2D sampling is extremely coarse (typically 2 km to 3 km gaps) and is limited by the line separation. We will present a practical solution to address the trace interpolation issues. We also demonstrate the effectiveness of this methodology by showing a case history of its application.

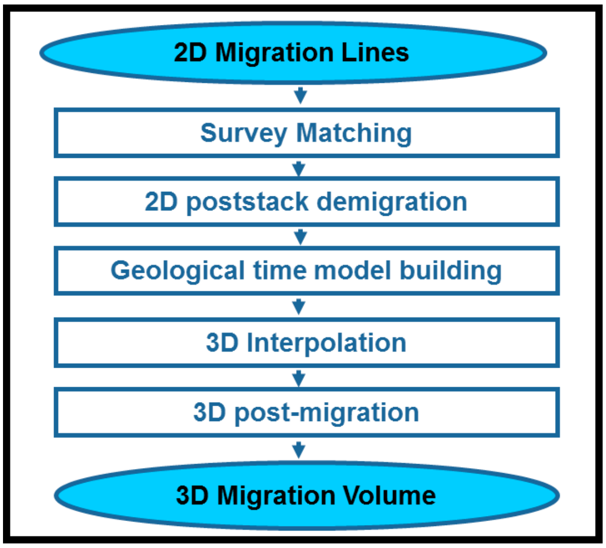

Figure 1. Work flow diagram for 2D Cube technology.

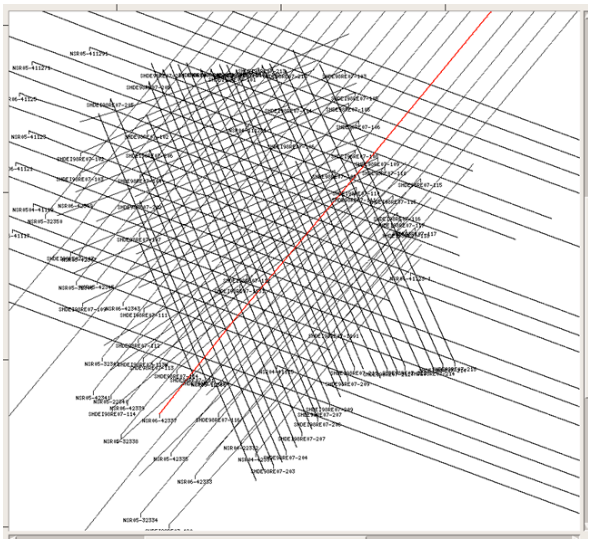

Figure 2. Survey maps for the input 2D acquisition

Method

Typically the input data for this methodology are taken from a set of overlapping 2D seismic surveys in the same area. The suggested starting point for this work flow is a set of 2D migration images and their associated velocity models. As indicated by the data flow diagram in Figure 1, we need to perform the following key steps: 1) Survey matching; 2) 2D post-stack demigration; 3) Geological time model building; 4) 3D interpolation of the demigrated 2D seismic data; 5) 3D post-stack migration of the interpolated seismic data volume. In the following text, we will describe some of the details for each of these five steps.

A key challenge for this methodology is to perform the trace interpolation across distances on the order of kilometers, far beyond distances that can be handled by standard interpolation techniques. Given this challenge, it is desirable to utilize multiple over-lapping 2D surveys which provide smaller effective spacing between lines and improved azimuthal coverage (Figure 2). Data from different vintages must be matched as closely as possible in terms of amplitudes, shifts, and spectral character. This matching process is the first step.

The second step is to perform 2D demigration on all available lines. Demigration is performed to generate data closely resembling 2D stacks at zero-offset, which would be expected to tie at intersections and largely have the effects of velocity inconsistencies removed (Wang et al., 2005). Any small residual discrepancies at line intersections are corrected in a manner minimizing structural changes.

The third step is to build a 3D geological time model consisting of a dense set of horizons, each assigned a hypothetical geologic time (Parks 2009). These are used to guide interpolation across the large distances involved. To obtain the horizons, we densely measure the apparent time dips from all 2D demigrated seismic lines and use them to construct a dense set of 2D model horizons. The surfaces must be accurate enough to track the seismic layering over line kilometre scale distances with minimal drift. The use of measured dips alone has been found to lead to inadequate event tracking in many cases. Incorporating the seismic data more directly into the process has been found to be a key in enhancing model accuracy. The resultant 2D geological model acts as a framework for extending the dense 2D horizons outward to fill the 3D space in a consistent manner along estimated true dips.

After the 3D geological model is formed, we are ready for the fourth step, interpolation of the 2D seismic to a 3D cube. Conceptually, for each output point (x,y,t), we use the geological model to determine which geologic time horizon passes through it. We then map contributing 2D seismic amplitudes to the output sample location. In practice the contribution from each input trace to the output trace is computed sequentially to form a gather of candidate image trace contributions to the output location. The gather is processed to form the output 3D image trace.

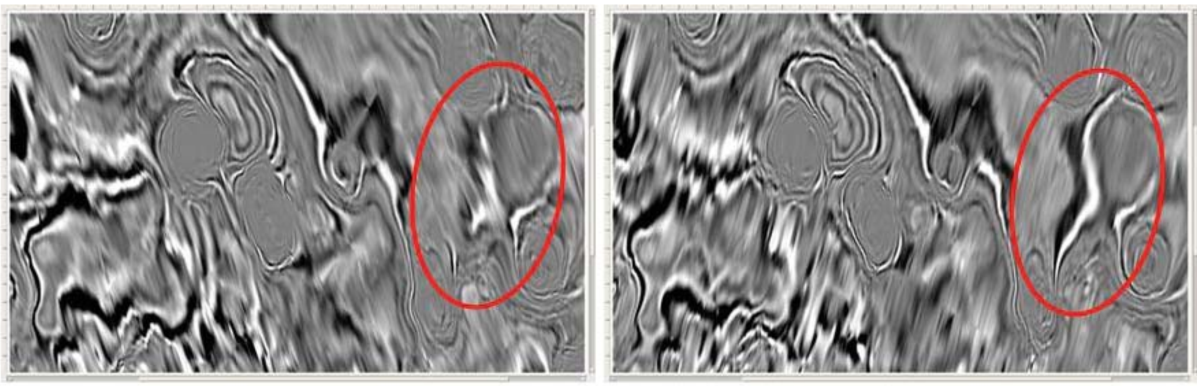

Figure 3. *Examples of interpolated traces if only those traces on certain azimuthal searching orientation are used. A) along -20 degree; B) along +20 degree*

Since we try to interpolate the demigrated seismic traces, it is important and challenging to maintain the steep dip or diffraction events to the greatest extent possible. Those complex events have much better correlation over larger distances in the structural strike direction as compared with the dip direction. Therefore we need to consider azimuth in determining interpolation weights. Figure 3 shows an example of images formed if we choose to stack only contributions from input locations which fall inside a narrow azimuth swath relative to the output location. Comparing Figures 3A and 3B, in the highlighted area, the structure is properly interpolated if the traces used are along the strike direction, but the structure is not interpolated well if it is done on an azimuth other than along the strike direction. This highlights the importance of azimuth in the enhanced interpolation process. The method of selecting traces and assigning stacking weights has been found to be a key in getting a realistic looking and plausible output volume. These are perhaps the most important enhancements to the methodology.

The last step is post-stack migration using any choice of algorithm. A unified 3D velocity model is then needed. The velocity model is generated by passing the 2D migration velocities through a workflow similar to that used to generate the output seismic cube.

Examples

In the following we will use an existing commercial processing project from the North Sea to demonstrate the effectiveness of this methodology.

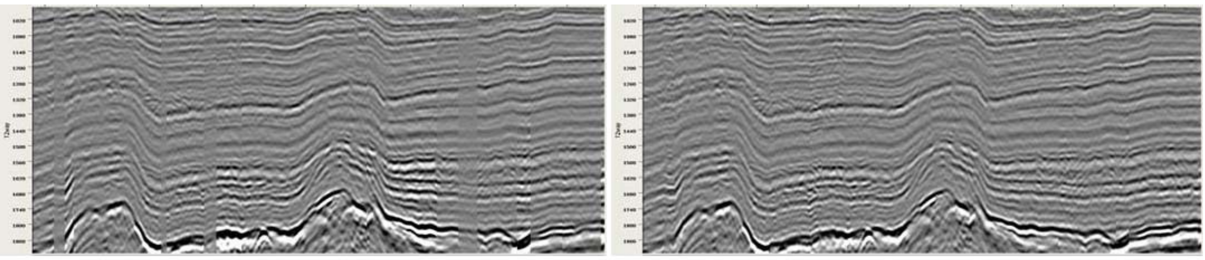

Figure 4. *2D Demigrated Zigzag Section – A) Before and B) After survey matching and automatic intersection tying*

Figure 2 is a survey map of all the available 2D surveys in the study area. There are multiple sets of 2D survey orientations including azimuths in every azimuth quadrant, NE, NW, SE, and SW. The line spacings range from approximately 2 km to 5 km.

Figure 4 shows the 2D demigrated zigzag section before and after survey matching and automatic intersection based tying to correct for amplitude, phase, and time-shift differences. Figure 5 is an example of a 2D geologic time model, and Figure 6 shows the interpolated, demigrated seismic data.

Figure 7 is the 3D geologic time model which is used to interpolate the 2D demigrated seismic traces. Figure 8 is the corresponding demigrated output volume from the 3D seismic interpolation process.

Figure 9 shows a 2D migrated 2D line that was acquired primarily along the strike direction. Figure 10 shows the result of the 2D$^{\text{cubed}}$ technique. It is a 3D migrated image of the 3D interpolated result where we have extracted the traces along the same 2D line for comparison to the conventional 2D migration. Many improvements to the structure and continuity are seen. The cross dipping events are placed more properly due to the consideration of 3D effects.

Conclusions

We have developed an enhanced methodology to create a 3D seismic migration volume from a set of 2D seismic lines. Generating an accurate geologic time map to guide the interpolation is critical. By more directly incorporating the seismic data into the geologic model building process, horizon drift relative to the true geologic layering can be improved relative to previous approaches that rely solely on measured dips. Additionally, by considering directionality and careful selection of weights, the character of the output image more closely represents that of the input data. Combining these enhancements leads to improved output image quality and interpretability while also increasing the distance scale over which interpolation can be performed. Successful application of the enhanced methodology to a field data example from the North Sea demonstrates its effectiveness.

Acknowledgements

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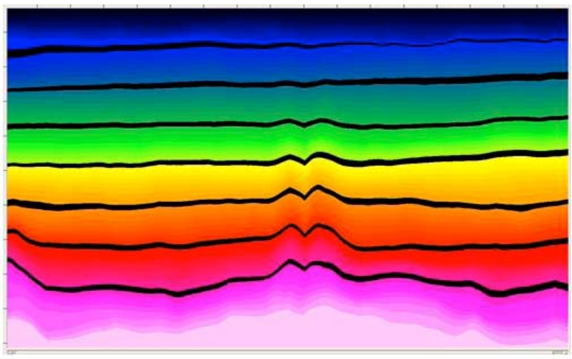

Figure 5. *2D geological time model which ties at all intersections with all other 2D lines*

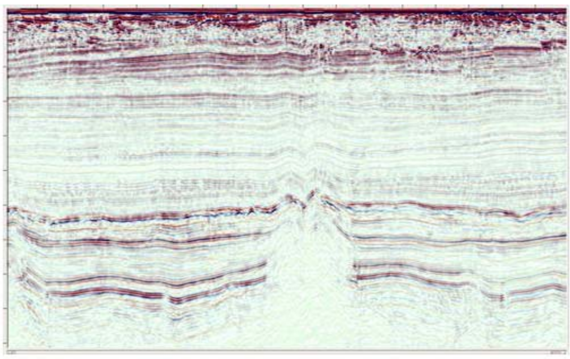

Figure 6. *2D interpolated demigrated seismic data.*

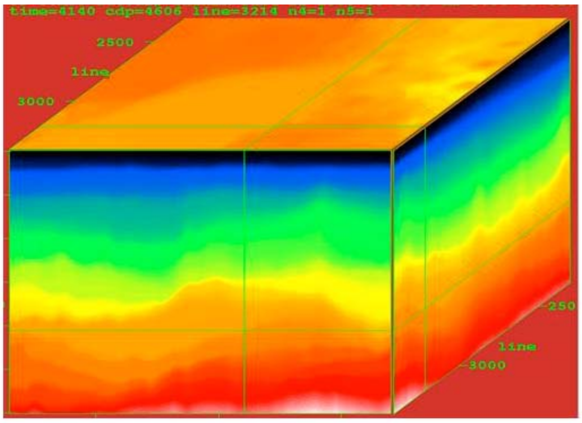

Figure 7. *3D geological time model which are used to interpolate a 3D demigrated sesimic traces.*

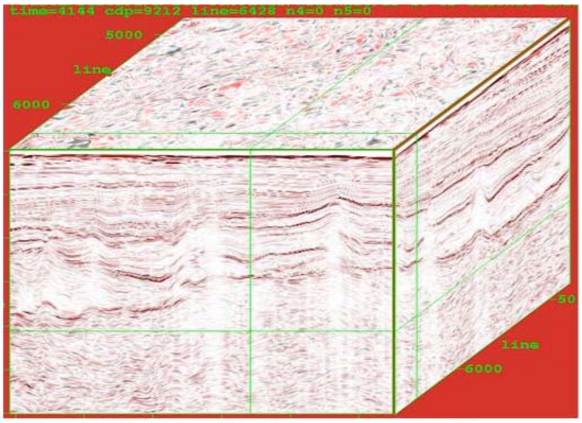

Figure 8. *3D interpolated traces using the 3D geological time model and 2D Cube methodology described in this paper.*

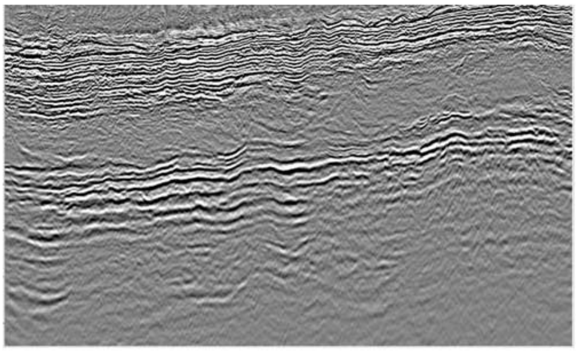

Figure 9. *2D migration image using the single 2D input data.*

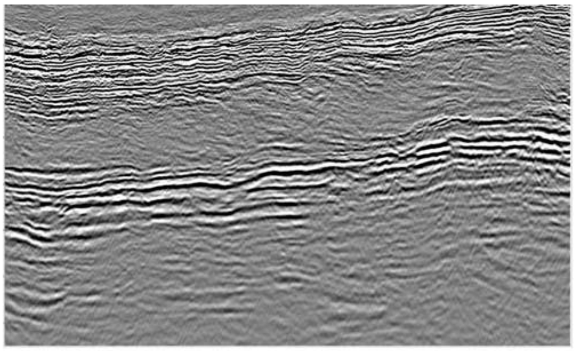

Figure 10. *2D section from the 3D migration image cube produced by 2D Cubed methodloogy.*