

Merging Surveys with Multidimensional Interpolation*

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Search and Discovery Article #41552 (2015)

Posted February 23, 2015

*Adapted from extended abstract prepared in conjunction with a presentation given at CSPG/CSEG/CWLS 2008 GeoConvention, Calgary, AB, Canada, May 12-15, 2008, CSPG/CSEG//CWLS/Datapages © 2015

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Abstract

Surmont is a large bitumen field in the Athabasca accumulation. Of the nine 3D seismic surveys on the lease, eight were acquired in an orthogonal geometry with close to 10×10 m bins. The presence of the ninth caused a problem when it was desired to perform a prestack merge of the surveys. Since we hope to use the merged data for quantitative interpretation, good continuity and faithful amplitudes were paramount. For this reason, we extended existing methodologies to complete a simultaneous interpolation in five dimensions: offset, azimuth, inline, crossline and frequency. The biggest challenges were posed by the low original: interpolated data ratio, and the constraints placed by the need for AVO-compliance on noise attenuation. The result was a fully resampled dataset, which could be seamlessly added to the prestack merge, giving the interpreters a valuable new perspective on the asset.

Introduction

The Surmont field is a very large bitumen accumulation about 50 km southeast of Fort McMurray. It is about six townships in total, or about 600 km², about two-thirds of which is covered by 3D seismic data, mostly multi-component. Surmont is a Steam Assisted Gravity Drainage (SAGD) development, in which steam is injected into the uppermost well of many horizontal pairs. Optimal field performance necessitates detailed reservoir description at a range of scales. In particular, we are attempting to image thin, discontinuous heterogeneities and subtle lateral and vertical facies changes.

The Surmont area will eventually be covered by eleven 3D surveys; nine of these have already been acquired over the past six years, at a total cost of about \$75M dollars. Having 3D seismic means the delineation requirement drops from 16 to eight wells per section. This in itself could save well over 1,000 - 2,000 wells on the lease, so the net savings from 3D seismic are about half a billion dollars.

To have a single, consistent set of prestack time-migrated gathers for interpretation stacks and quantitative interpretation for the whole Surmont area, we chose to perform a pre-stack merge of all the data in the area. This process required putting all the seismic onto the finest possible common grid.

Almost all the surveys in this field are orthogonal with a 9×12 m or 10×10 m grid. The only survey in the field that does not support the fine 10×10 m CMP binning is the Surmont North 3D with a native bin size of 15×30 m. In addition, this survey is parallel instead of orthogonal and therefore has different azimuth/offset coverage from the others, causing problems (for example, in migration antialias filtering). To avoid reshooting this survey, it was attempted to reduce its bin size by interpolation. Several target geometries were tested, and the best result was obtained by adding new shots and receivers, preserving the original data while transforming the geometry from parallel to orthogonal.

Multidimensional Interpolation

To build new shots and receivers and reduce the bin size, we use a five-dimensional interpolator based on Fourier reconstruction. The method consists of solving an inverse problem where the unknown (the “model”) is a supersampled seismic data set that contains the target geometry. The acquired data maps to the model through a sampling operator. The constraint that generates the missing data is the five-dimensional Fourier spectra of the data (offset, azimuth, inline, crossline and frequency). This method finds a model that has a 5D spectrum consistent with the input data. The numerical kernel is explained in Liu and Sacchi (2004). Applications to four spatial seismic dimensions have been presented in several meetings (e.g. Trad 2007).

This multidimensional interpolation method has been widely used for the last few years to create new shots and receivers without moving the original data. Because of the multidimensional nature of the process, information from different dimensions can be used simultaneously to infill missing data. Interpolating simultaneously in the four spatial dimensions of offset, azimuth, inline and crossline instead just the latter two fully exploits the redundancy of 3D data, significantly improving the spatial sampling. Any one of these dimensions, with the other three fixed, has very poor spatial sampling. To illustrate this point, think of how poor the sampling along a crossline is when the inline is fixed and the offset and azimuth values are limited to small ranges. At the same time, every CMP is redundantly sampled with different offsets and azimuths. Amplitudes change with offset and azimuth, but in general amplitude variations in these directions are smooth in a four dimensional sense (notice that AVO/AVAz studies use supergathers, assuming no change of these properties in a short distance along inline/crossline). Multidimensional interpolation has the capability to capture amplitude variations along all the dimensions simultaneously and create new data consistent with that information, and it does assume amplitude variation on all directions, as opposed to supergathers.

The potential for multidimensional interpolation is large. While not intended in any way to allow compromises to acquire adequate data for processing, this technology can be applied to obtain the benefits of tighter acquisition sampling patterns (higher fold and/or smaller bin size) with a fraction of the field acquisition cost. These benefits have impact in both pre- and post-stack processing (pre- /post-stack migration, AVO/AVAz interpretation, velocity analysis, etc.).

Pushing the Limits

Many interpolation projects for land data consist of doubling the number of shots or/and receivers in fairly high-quality data before migration. This project, in contrast, required tripling the number of both shots and receivers. In addition, because this is a high-resolution AVO project, noise attenuation was performed only with AVO friendly processes, which are less aggressive than non-AVO compliant tools.

Poor original/interpolated ratio: Reducing the bin size from 15×30 m to 10×10 m implies an increase of the data volume by 2:9. However, to maintain the original data it was necessary to support a finer bin size of 5×10 m that gives an original/interpolated ratio of 1:9. In order to work in five dimensions simultaneously, the method requires working in finely sampled regular grids. This makes the original:interpolated ratio even lower than that calculated purely from geometry considerations. In addition, parallel geometries have poorer sampling in azimuth than orthogonal surveys and therefore they present an extra challenge to interpolate missing azimuths.

Increasing resolution implies upsampling the data in the inline and crossline domains. Because these dimensions are regular, any difference in the energy between original and interpolated traces becomes very evident in time slices as a high frequency pattern. In this survey, the problem was even harder for two issues: a) only every third trace along both dimensions was live; b) the project was intended for AVO and therefore pre/post interpolation scaling was not an option.

Noise issues: Interpolation is very susceptible to noise because it is designed to preserve all details in the input even if they are weak and not well sampled across space. Slightly coherent noise can be interpreted as poorly sampled signal and therefore propagated into the new traces making it more coherent. Because this project requires AVO analysis, there are only a limited set of noise attenuation tools that can be applied. To address this issue the data had to be interpolated in very large groups to improve the statistics and additional signal:noise separation had to be included during the interpolation.

Results

Although the full supermerge project is still underway, we show some intermediate results that illustrate the ability of the method to predict very complex amplitude variation of the data even in a very low original:interpolated ratio. [Figure 1a](#) shows a CMP with zero traces inserted where the interpolation is required. [Figure 1b](#) shows the same CMP after interpolation. We chose this CMP to show because it has enough original traces to illustrate the fidelity of the method, but most CMPs show much poorer sampling than this one. In fact, seven of nine CMPs have no data at all. This apparent ‘magic’ is possible because of the multidimensional nature of the process. That is, the CMP on [Figure 1a](#) is not the only input used to produce [Figure 1b](#).

[Figure 2](#) shows a time slice obtained from three different stacked sections. In [Figure 2a](#), the original data were stacked to a 10×10 m grid. Notice the poor coverage since the acquisition was designed to infill a coarser grid of 15×30 m. [Figure 2b](#) shows the same time slice from the stack of interpolated data. The coverage is now complete, with plenty of detail not visible in the previous figure. As a comparison, [Figure 2c](#) shows this time slice from the stack of the original data but using the original bin size of 15×30 m. The coverage is complete but the resolution poorer than in [Figure 2b](#). The rebinning is necessary for processing to a common grid of 10×10 m.

Conclusions

In most situations, it is possible to create additional data from what has been acquired with surprising apparent fidelity. In this case, we were able to deliver a reliable image and enable the progress of the merge. However, it is important to keep in mind that, accurate interpolation for undersampled complex data is not guaranteed or sometimes even possible. Other difficulties with undersampled data include noise attenuation and velocity analysis.

Oil sands projects require high resolution seismic, which implies tighter acquisition patterns than usual. Tight patterns cost a lot of money because they require a large number of shots and receivers. Data are often pushed to fulfill needs for which they were never intended. If we can simulate a dense acquisition in terms of interpretability, fold, etc., with interpolation, the potential cost savings are huge.

Acknowledgements

We thank ConocoPhillips Canada Ltd, Total E&P Canada, and CGGVeritas for permission to present this paper, and the many colleagues involved in this work for their contributions.

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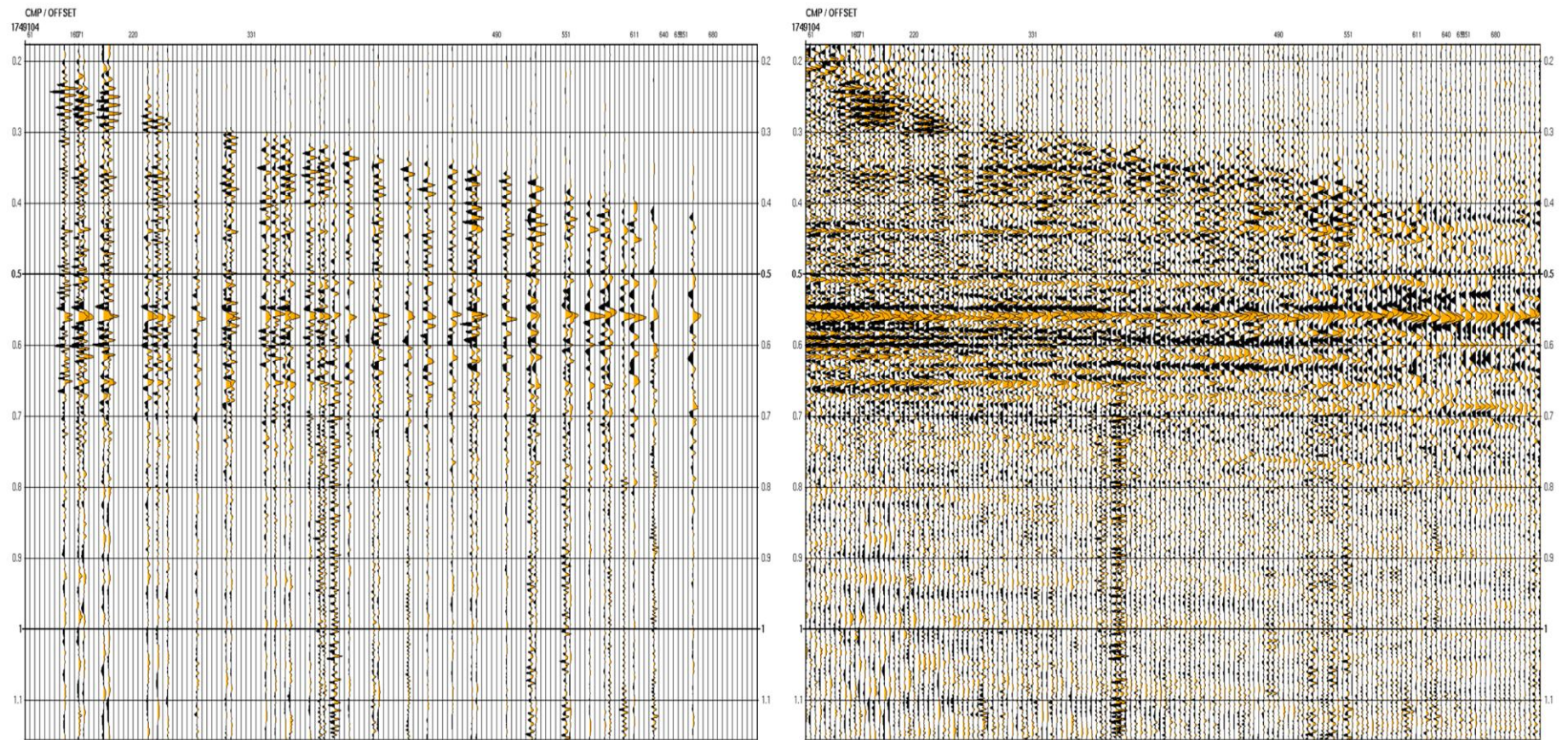


Figure 1. a) CMP before interpolation with zero traces where interpolation is required to match the new geometry, b) the same CMP after filling the zero traces using 5D interpolation along inline/crossline/offset/azimuth and time.

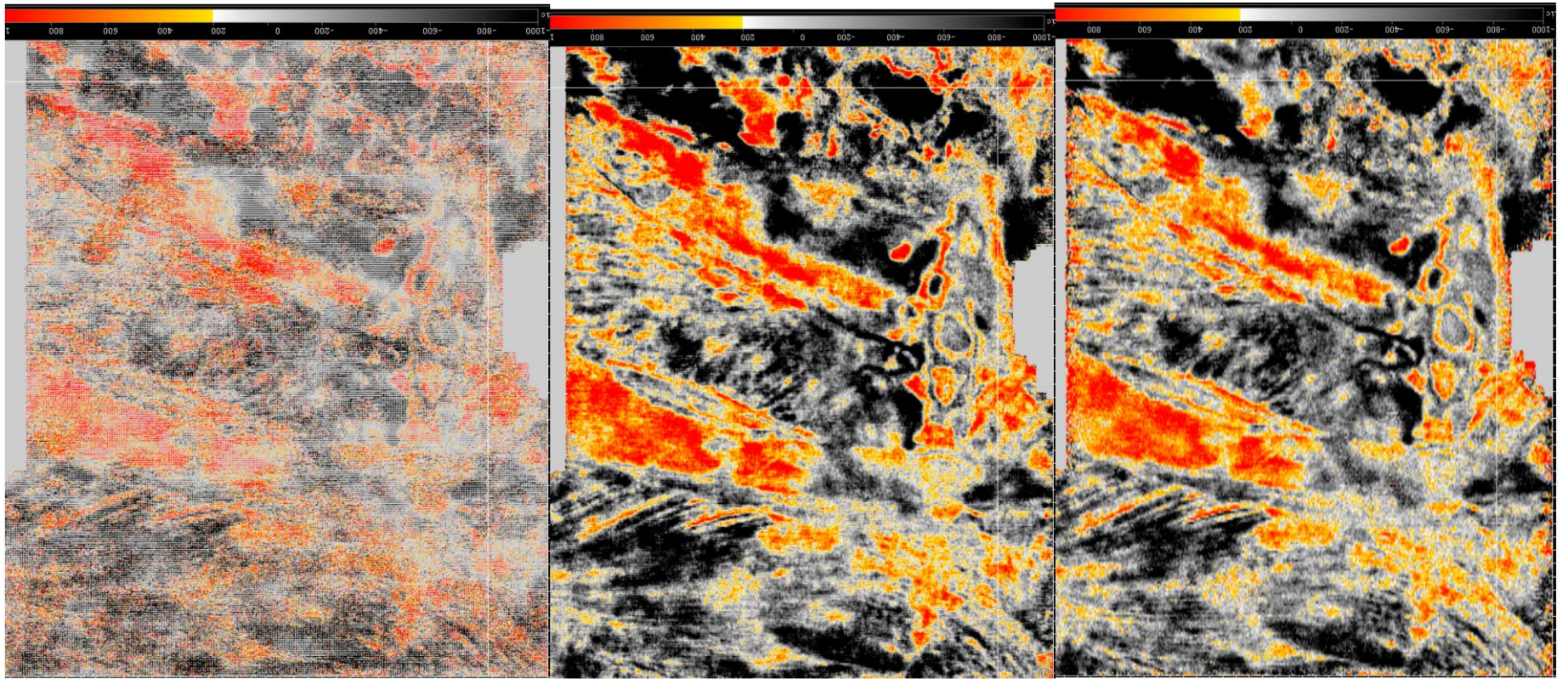


Figure 2. a) Time slice from stack binned into 10×10 grid without prestack interpolation, b) the same time slice from stack obtained from interpolated data, c) the same as a) but in the original bin size 15×30 .