GC5-D Interpolation Fills in Missing Data*

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Search and Discovery Article #41136 (2013)
Posted June 30, 2013

*Adapted from the Geophysical Corner column, prepared by the author, in AAPG Explorer, June, 2013, and entitled "Finding the Path Past „Attribute Footprints'". Editor of Geophysical Corner is Satinder Chopra (schopra@arcis.com). Managing Editor of AAPG Explorer is Vern Stefanic.

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General Statement

Three-D seismic surveys usually are designed in a way that the subsurface features are regularly sampled in different dimensions, comprising the spatial coordinates, offsets and azimuths. Many processing algorithms require this regularity for their optimum performance. For example:

- Marine acquisition suffers from platforms, shallow shoals, and tides and currents that give rise to feathering, all of which result in irregularity in spatial sampling of the data. For older marine surveys, inlines are well sampled while crosslines are more coarsely spaced.

- Land acquisition encounters a different suite of obstacles, such as highways, buildings and lakes. Such obstacles, coupled with limited recording capacity and greater cost, results in missing data or "holes" in seismic data coverage.

- Finally, recording equipment malfunctions and noise bursts during acquisition may add more missing traces to the usable recordable data.

Sparse or missing data create problems while processing, as the different algorithms applied pre-stack or post-stack demand regularity in the offset and azimuth dimensions for optimum performance. Non-uniformity in offsets and azimuths leads to inconsistencies in fold that follow a regular pattern we refer to as "acquisition footprint." This imprint is an undesirable artifact that masks geologic features or amplitude variations seen on time slices from the seismic data, especially at shallow times. Besides, the seismic data-derived attribute volumes also show acquisition footprint and other artifacts. Obviously, the ideal way to fill in the missing data gaps would be to reshoot the data in those areas – although such infill acquisition would be extremely expensive per data point, if the equipment could be made available for such a small time in the field.

Such problems have been addressed at the processing stage since the advent of digital processing. The most common preconditioning of seismic data improves the signal-to-noise ratio of the seismic data by removing spatial noise or enhancing the coherency and alignment of the reflection events, without unnecessary smoothing or smearing of the discontinuities. Although we usually think of removing unwanted features, we also can improve the signal-to-noise ratio by predicting unmeasured signal, such as dead traces and lower-fold areas corresponding to unrecorded offsets and azimuths in the gathers.

Interpolation

Prediction or population of missing traces in seismic data is referred to as interpolation. Initial interpolation methods used localized information, such as creating a missing trace by taking the lateral average of measured adjacent traces.

These methods worked well on stacked data volumes. A geologic feature seen on seismic data has three dimensions – time, an easting (x) and a northing (y). However, modern seismic processes such as prestack impedance inversion uses a fourth dimension of source-receiver offset (h), while azimuthal anisotropy uses a fifth dimension of source-receiver azimuth. The gap between the measured traces of a given offset-azimuth volume can be quite large, such that simple interpolation of spatial neighbors no longer works.

During the last decade or so, more sophisticated methods for data interpolation have evolved that interpolate the missing traces using not only in with neighboring samples in t, x and y, but also in offset and azimuth. Such "5-D" interpolators operate simultaneously in all dimensions, and are able to predict the missing data with more accurate amplitude and phase variations. As expected, these methods are compute intensive and have longer runtimes than the simplistic interpolation methods.

Example

We demonstrate here the application of one such method of 5-D interpolation on seismic data and show how it aids some of the seismic attributes derived from them. In Figure 1a we show a representative vertical slice through a merged 3-D amplitude volume that has many dead traces. Such dead traces are seen on other inlines as well.

The location of this inline is shown in Figure 2a, where we show a horizon slice through the corresponding coherence volume. The dead traces result in the speckled pattern indicated with yellow ellipses. To regularize the data, 5-D interpolation was run on the seismic data prior to migration with the equivalent displays shown in Figure 1b and Figure 2b, respectively. Notice in Figure 1b that not only are the missing traces interpolated, but the overall signal-to-noise ratio and reflector continuity is improved. Similarly, note the absence of the speckles associated with the missing traces and the greater continuity of the channel and other discontinuity features as indicated by the red arrows.

The inference we draw from this example is that regularization by 5-D interpretation yields better-focused images. Interpretation carried out on such attributes will definitely be more accurate than the one carried out on data without regularization.

As 5-D interpolation discussed above regularizes the geometry of the seismic data, it addresses the root cause of the footprint arising due to the acquisition irregularities. In Figure 3a we show time slices at 158 ms, where the acquisition footprint appears prominently on the coherence attribute as striations in the NE-SW direction, masking the reflection detail behind them. Figure 3b shows the equivalent coherence slice after 5-D regularization exhibiting considerable improvement in data quality.

Conclusion

Seismic data usually have geometry regularization issues that give rise to artifacts on geometric attribute displays. Five-D interpolation methods adopted during processing help address issues such as missing data pockets and acquisition footprint striations. Coherence and curvature attributes computed on regularized seismic data yield displays clear of these artifacts, and so lead to more confident displays.

Acknowledgement

We thank Arcis Seismic Solutions, TGS, for encouraging this work and for permission to present these results.

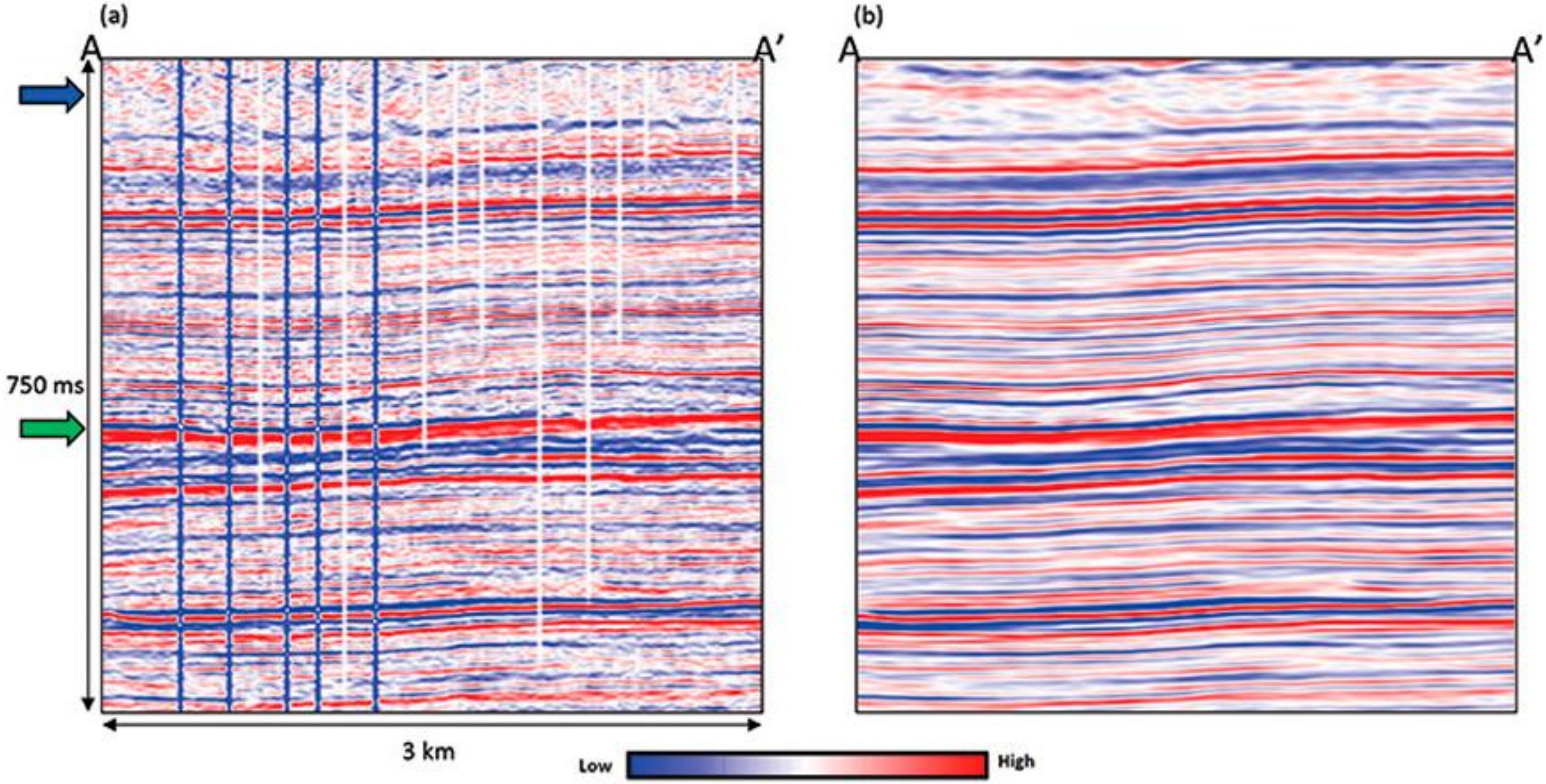

Figure 1. Vertical seismic sections through the seismic volume (a) before, and (b) after 5-D interpolation.

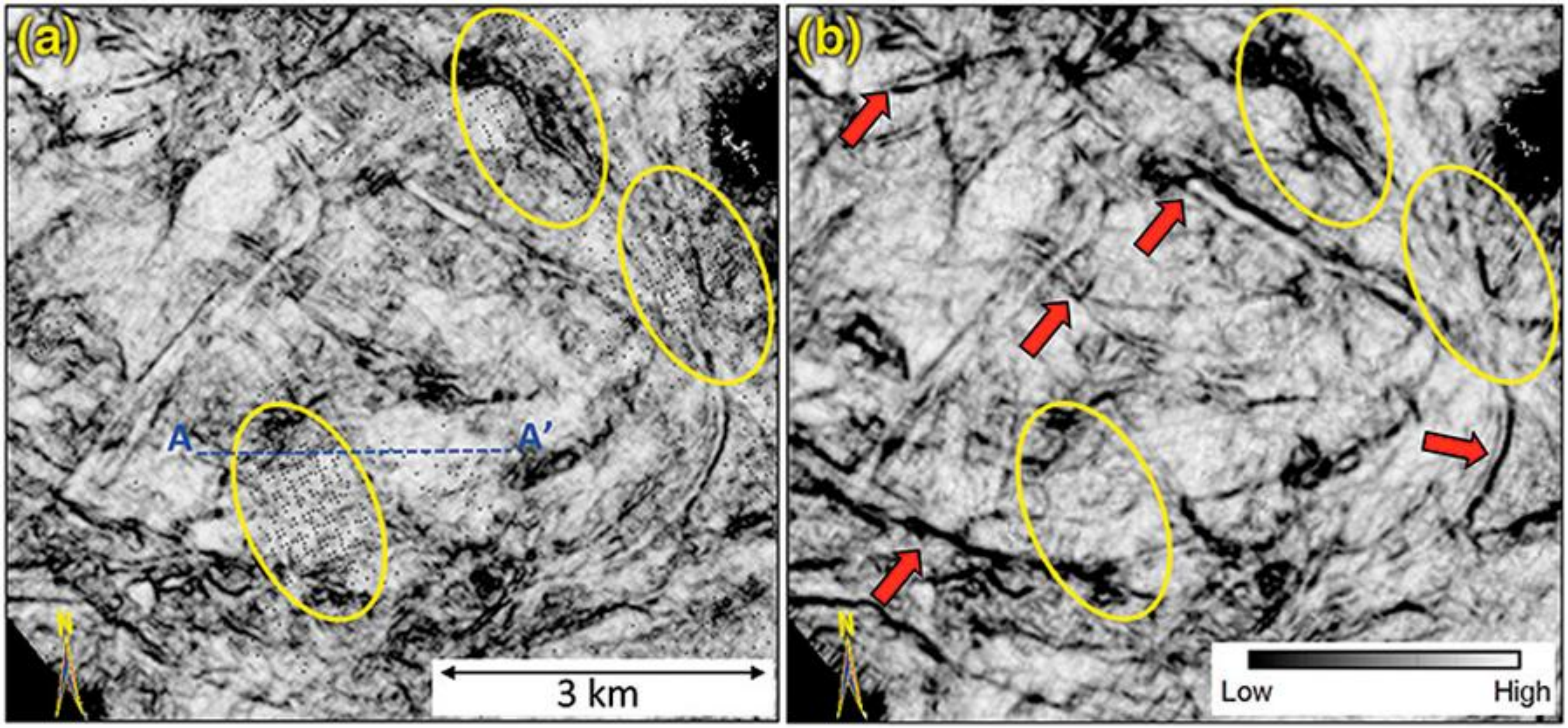

Figure 2. Horizon slices a few milliseconds above the marker indicated with the green arrow in Figure 1a, from the coherence volumes computed from seismic data (a) before, and (b) after 5-D interpolation.

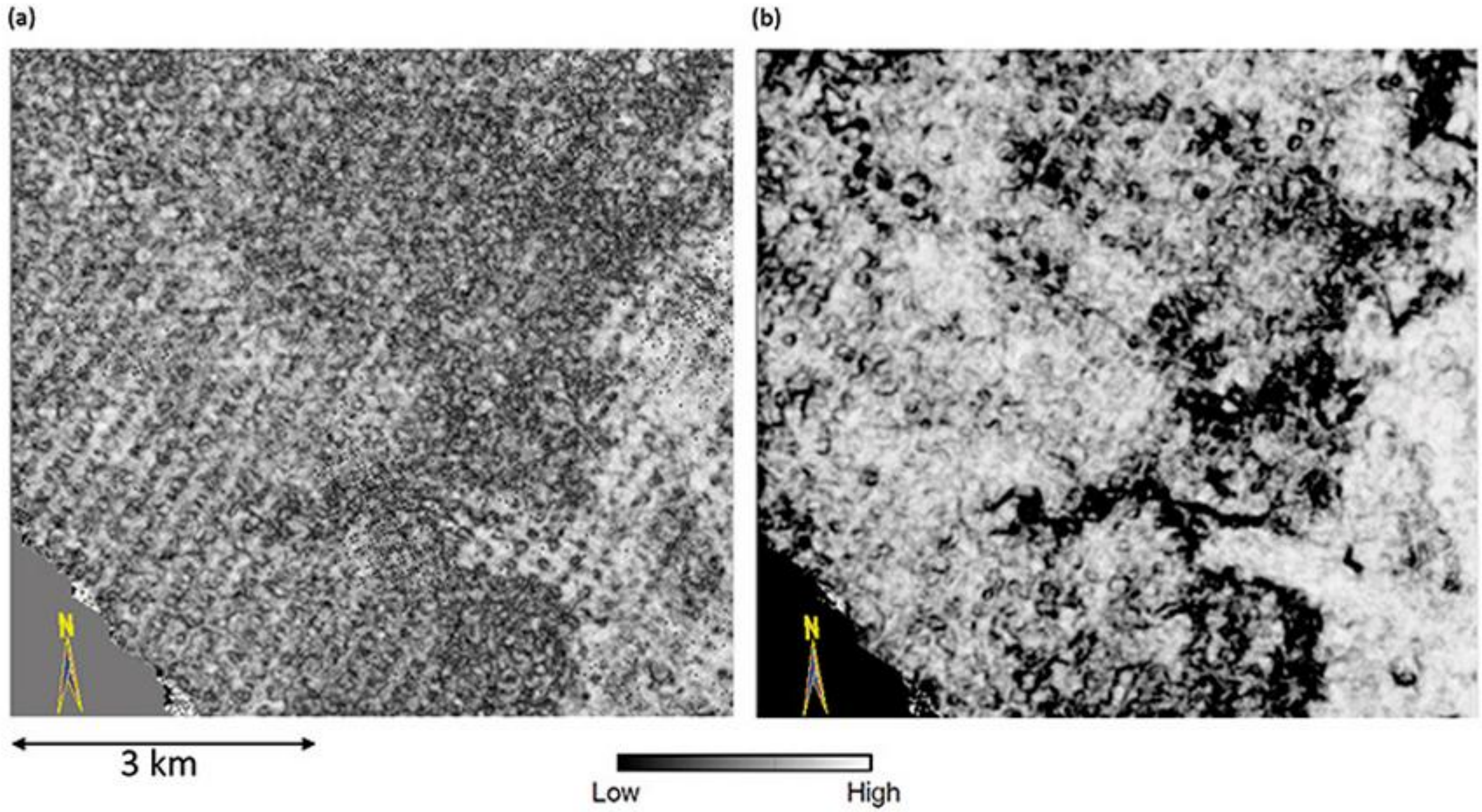

Figure 3. Time slices at the level of the blue arrow in Figure 1a, through the coherence volumes computed from seismic data (a) before, and (b) after 5-D interpolation.