[GC]Enhancing Vertical Seismic Resolution with Seismic Frequency Restoration and Attributes*

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General Statement

The development of interpretation software is a direct consequence of ongoing advancements in geoscientific technology, which helps in their application to seismic data. It might be assumed that this proliferation of knowable attributes would be helpful to interpretation, but in several cases this is not true, as many of the seismic attributes are redundant, and seismic interpreters are often confused by the incredible scope of attributes they can use in their work projects and the different options that are available therein.

One of the first questions a seismic interpreter must ask is how to recognize and characterize the reservoir. Understanding the geology and the depositional history of the area is a good start. Identification of the zones of interest is next, when well log data are integrated with the seismic data. Once one or more target zones are identified and the objectives for their characterization outlined, then the interpreter turns to seismic attribute computation to better visualize the data and enhance their description, both in the temporal and spatial directions.

Such objectives could vary from the understanding of the geological relationship of the target reservoir with the architectural subsurface elements of defining the reservoir in terms of fluid/lithology distribution, or a physical property such as porosity, or to describe the geometrical or discontinuity patterns the reservoir is set in. Seismic attributes are selected accordingly and included in the workflow adopted for their generation.

This is a key step in understanding the seismic response corresponding to subsurface geological features; knowledge about the seismic attributes and confidence in their application are some factors that can help in such situations. Often it is advantageous to keep the attribute applications simple, with just the “right” number of attributes employed in a project and keeping the end goal in mind.

Enhancing Vertical Seismic Resolution

In order to understand the stratigraphic patterns or their behavior from seismic data, it is imperative that the amplitude and frequency are preserved while the data go through the different processing steps. Thus, the seismic data processing must be carefully supervised by the interpreters and calibrated with geological information. Any variation in the shape of the basic wavelet in the seismic data that is not related to the subsurface needs to be eliminated. Multiples and random noise will undermine the integrity of the results. All these steps are important and need to be carried out before any attribute computation is attempted on seismic data, or even before their frequency enhancement is attempted. It is also imperative to consider the assumptions on which the individual processes are based, at least for qualitative interpretation of attributes. For a more quantitative seismic interpretation, well log modeling and seismic correlation is required.

For frequency enhancement of seismic data, a simple and a somewhat newer approach could be followed. The first step in such an approach is to subsample the seismic data: if the input seismic data has a two-millisecond sample interval, it is subsampled to 0.5 milliseconds using the Nyquist frequency as a limit. For the next step, the temporal derivative of seismic data is computed and each change of sign of the temporal derivative in the seismic trace is replaced by a pulse of equal magnitude and sign, indicating the point of change. This generates a new seismic trace for each input seismic trace that is formed from dispersed random pulses and has a higher bandwidth. This step is followed by a variable spectral balance in time and a bandpass filter in the range of expected frequencies. For the latter step, the frequency band is usually chosen within the original seismic sweep that is injected into the ground by the vibrators or the observed frequency range of the raw explosive-acquired seismic data. Finally, a random multichannel noise filter (FXY) is applied to the seismic data, taking care to avoid any artifacts. Figure 1A shows the results of the above-mentioned workflow applied to the input seismic data. Such frequency-restored results, exhibiting better vertical and lateral definition, help the interpreter to bring in more precision in the interpretation.

In Figure 2 we illustrate the application of this frequency enhancement process for prestack time migrated seismic data (PSTM) from Neuquén Basin of Patagonia, Argentina. The figure shows a vertical seismic section to the right from PSTM seismic data, and to the left is the same data after restoration of frequencies with the proposed method. Notice the difference in the frequency content and resolution of the two displays. The target zone is around the picked horizon within the Vaca Muerta Formation as indicated. The synthetic seismograms are generated with the before and after frequency restoration process, and using wavelet extracted from the respective seismic datasets using a statistical process, are shown to the right (B) and left (A) respectively. Notice the higher level of reflection detail after frequency restoration as compared with the input. We contend that the proposed method is important for defining the sweet spots in unconventional reservoirs and for generation of geomechanical attributes subsequently.

Besides the aforementioned method, another commercially available and commonly used method is called “spectral bluing.” In this method, the seismic data and well log reflectivity are compared and a digital matching filter is extracted and applied to the seismic data. This method resurrects the attenuated frequencies in the subsurface.

Second-Derivative Method for Accurate Structural Interpretation

Often the bandwidth of the seismic data being interpreted does not exhibit enough continuity or resolution for a satisfactory interpretation. In such cases, the second derivative computation of the input seismic data can help. It may be mentioned here that when the first derivative is generated, its phase gets rotated by negative 90 degrees. When the second derivative is generated, the phase of the seismic data gets rotated by negative180 degrees. Visually, this means that the polarity of the traces is inverted, or that the peaks become troughs, and vice-versa. In terms of interpretation, we notice enhanced reflection continuity in the seismic data, which is helpful, particularly in areas with disrupted or poor reflections, or for data with diminished lateral variations, where horizon picking is difficult.

We illustrate this aspect in Figure 3, which shows a segment of a seismic section (Figure 3a) from a 3-D seismic volume in the north flank of Golfo San Jorge Basin, Patagonia, Argentina. The equivalent section with the second derivative run on it is shown in Figure 3b. Notice the overall enhanced continuity as well as the individual reflections around the interpreted reservoir (above the picked blue horizon), which appears as tuned in the PSTM section in Figure 3a.

Sometimes, instead of running the second derivative on the PSTM seismic data, if it is run on the amplitude envelope attribute, the resulting attribute can minimize thin-bed tuning and aid the interpretation of major depositional strata or lateral lithologic variations. In Figure 3c we show a 3-D perspective view correlation for a PSTM sections to the left, and the second derivative attribute section to the right. The picking of the horizon is facilitated on the section to the right. A considerable enhancement in the frequency content and enhanced signal-to-noise ratio are noticed, which are beneficial for interpretation of greater detail as well as more insight into the geological context of the zone of interest.

Multiple Attribute Co-Visualization Aids Subsurface Interpretation

In subsurface areas that exhibit complex faulting, it is useful to blend seismic amplitudes with geometric attributes for more accurate interpretation. In the recent article Interpreting Seismic Amplitude Volume Technique Attributes, Search and Discovery Article #42051, the authors described how the AVT (amplitude volume technique), and its higher frequency variants (AVTHF) help in differentiating geological contents in terms of definition of elements in a complex reservoir system.

In Figure 4a we show a multiple attribute co-visualization of AVTHF ant tracking, the instantaneous phase of AVTHF, and AVTHF from seismic data (Note: all of AVTHF were calculated on far angle stack volume). The display exhibits the fault system very clearly as well as the effect of pseudo-weathering relief (light blue arrows). In Figure 4b the AVTHF on far angle stack as well as the instantaneous phase on the same data are shown co-visualized. Notice the visual impact of the intrusive body (black arrows) shown in green color, fitting the feeder zone, and going up to the final emplacement.

Conclusion

In conclusion, we present some easy-to-implement seismic frequency restoration methods and attributes that can be adopted in the interpretation workflow so as to resolve geometry of stratigraphic patterns, rock properties and other characteristics of reservoirs. It is strongly advised that proper quality checks be put in place for each process described. For example, in the frequency restoration process described, a synthetic seismogram should be generated and correlated with the frequency restored seismic data. Such an exercise can be repeated in other wells so as to gain confidence in the interpretation of the frequency restored data or attributes generated thereon. The processes or attributes described in this article will be helpful for an interpreter and enable the task to be accomplished in less time. The saved time can be devoted to reinforcing the play concept and/or refining the interpretation.

Acknowledgement

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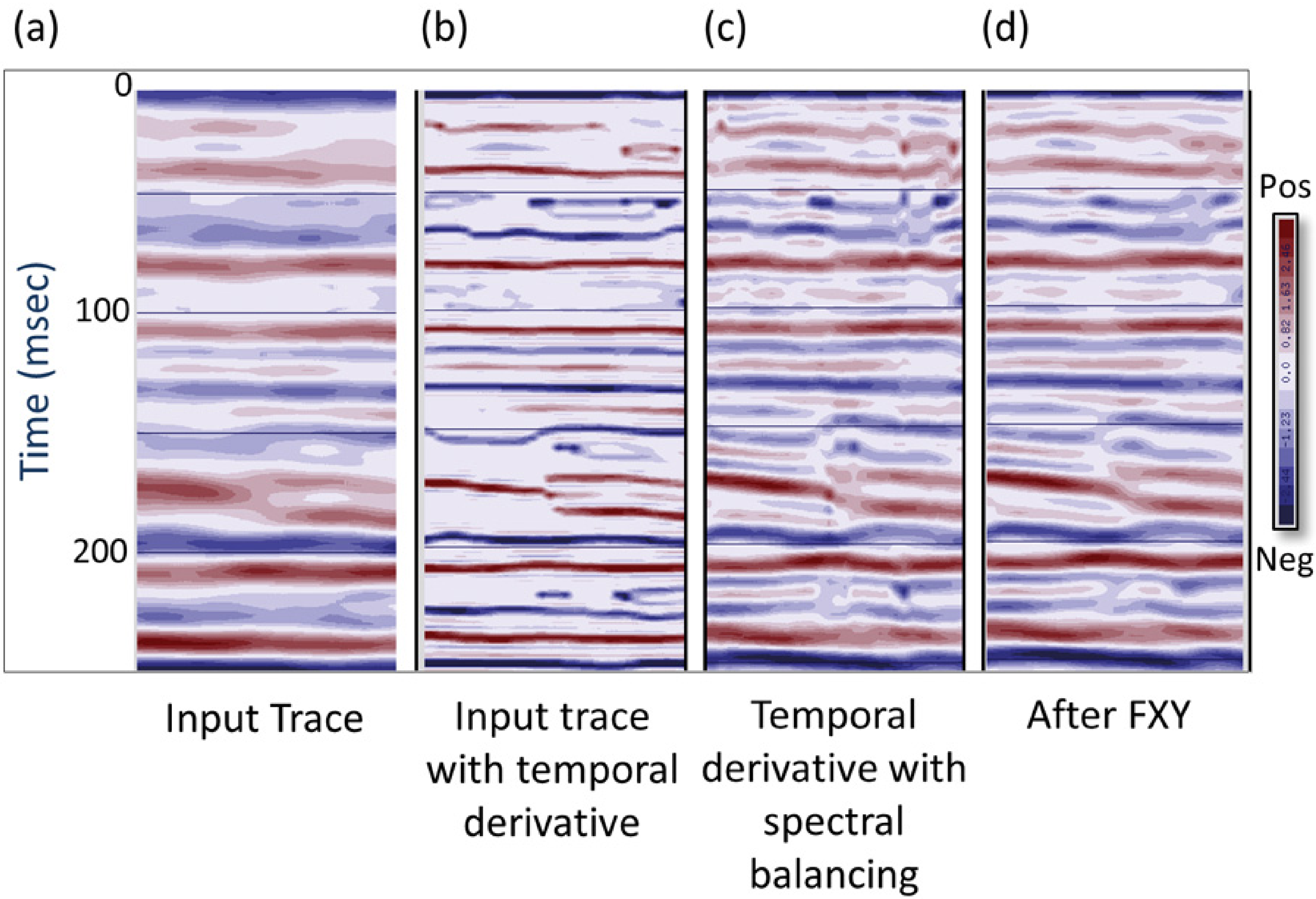

Figure 1. Workflow for seismic frequency restoration process, which exhibits a result with overall higher resolution.

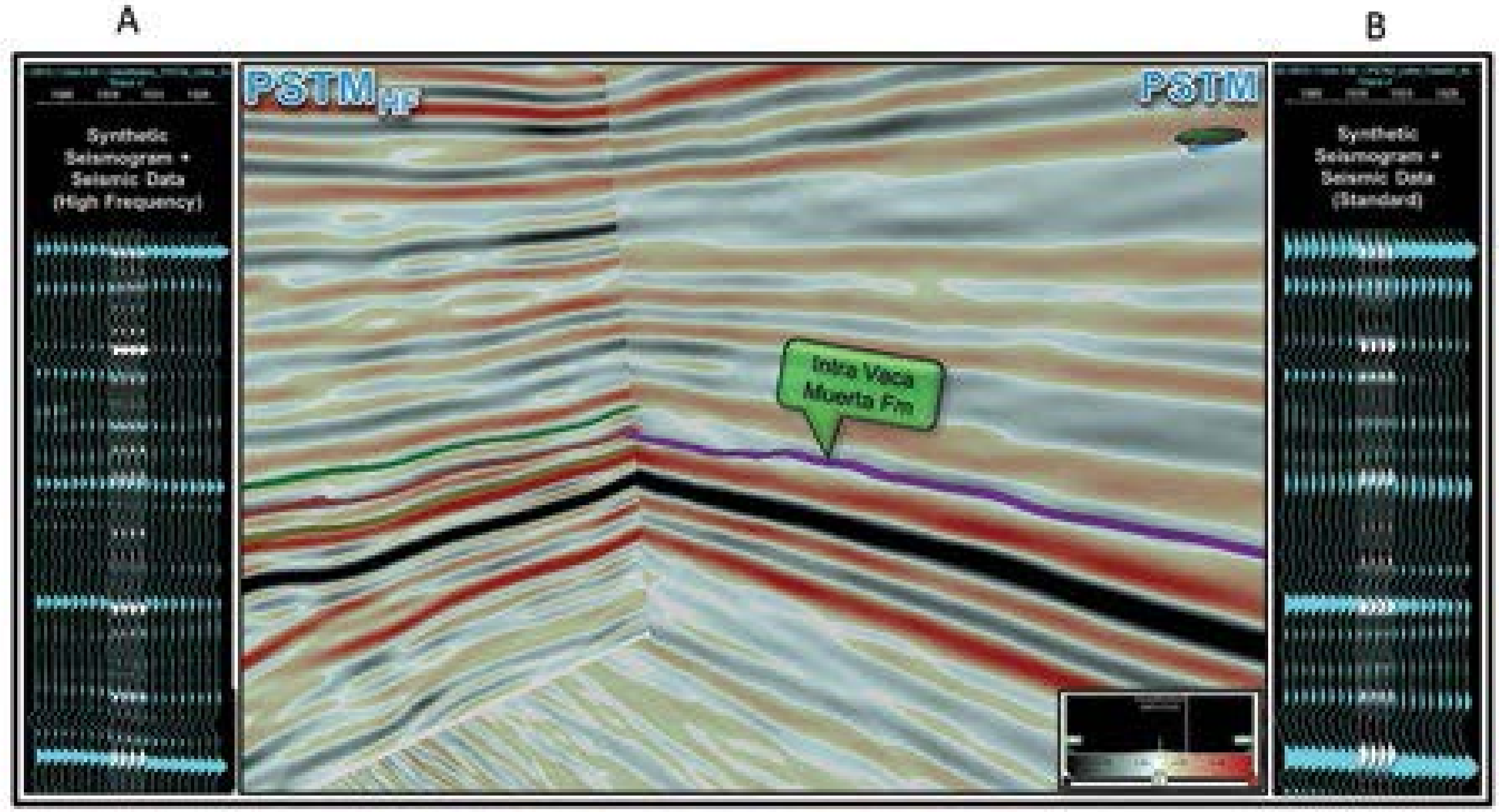

Figure 2. 3-D perspective view showing a crossline to the right from the PSTM 3-D seismic data volume. The data is from the Neuquén Basin, Patagonia, Argentina. An inline from the frequency-restored 3-D seismic data volume is shown to the left. Notice the enhanced frequency content on this inline. Synthetic seismograms generated from the input and frequency-restored data are shown on the sides respectively. The high correlation seen on the frequency-restored data lends confidence in the process used therein.

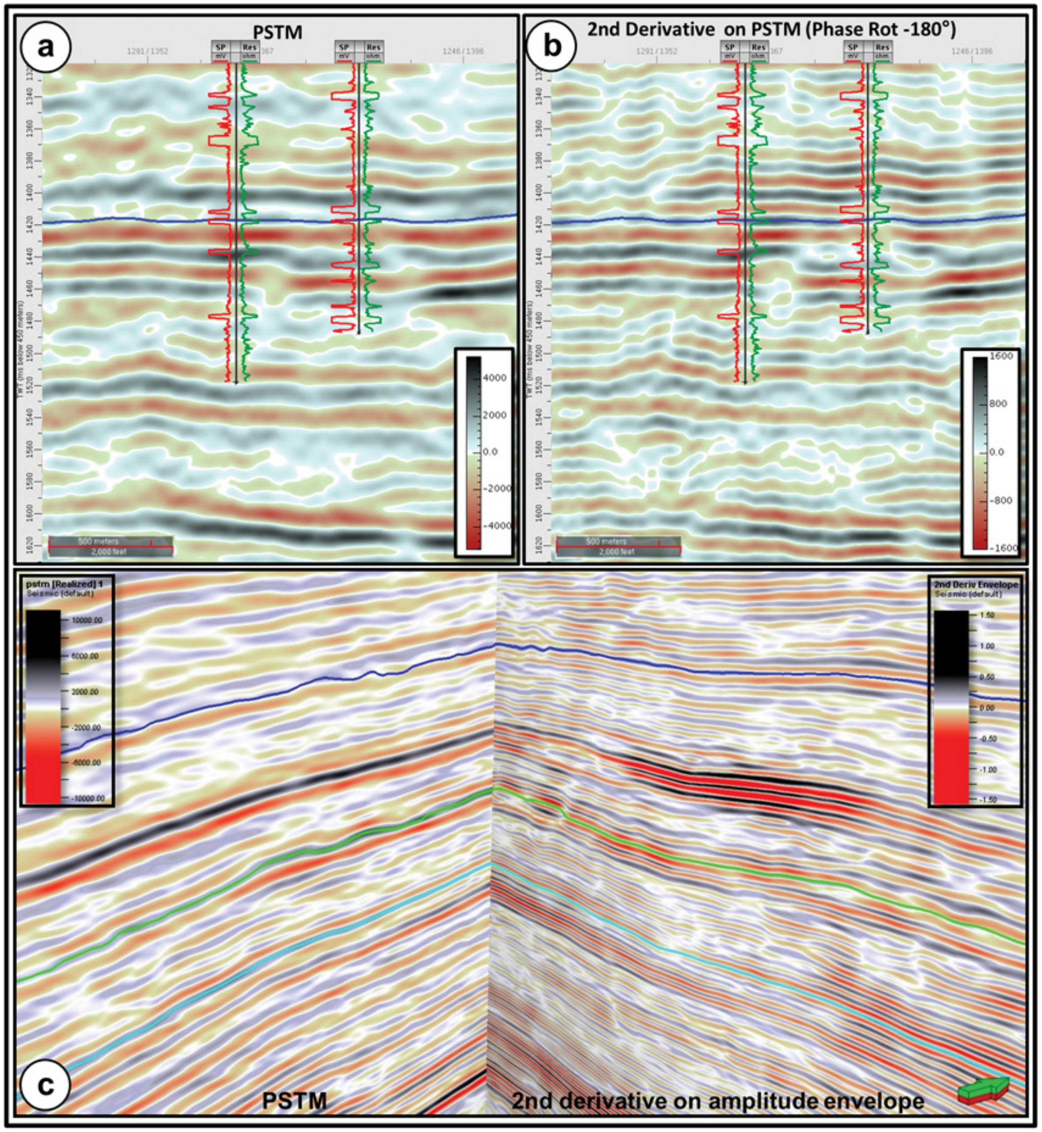

Figure 3. (a) Segment of a seismic section from 3-D seismic data volume from the north flank of Golfo San Jose Basin in Patagonia, Argentina. (b) The equivalent section as in (a) but from the second-derivative attribute derived from the 3-D seismic volume. (c) 3-D perspective view comprising the PSTM seismic inline to the left, and a crossline from the second derivative of envelope attribute to the right. The increased frequency content seen on the right could result in somewhat lower signal-to-noise ratio, but the data helps in facilitating horizon picking through the volume. The greater reflection detail seen on the frequency enhanced data helps with better understanding of the geological context.

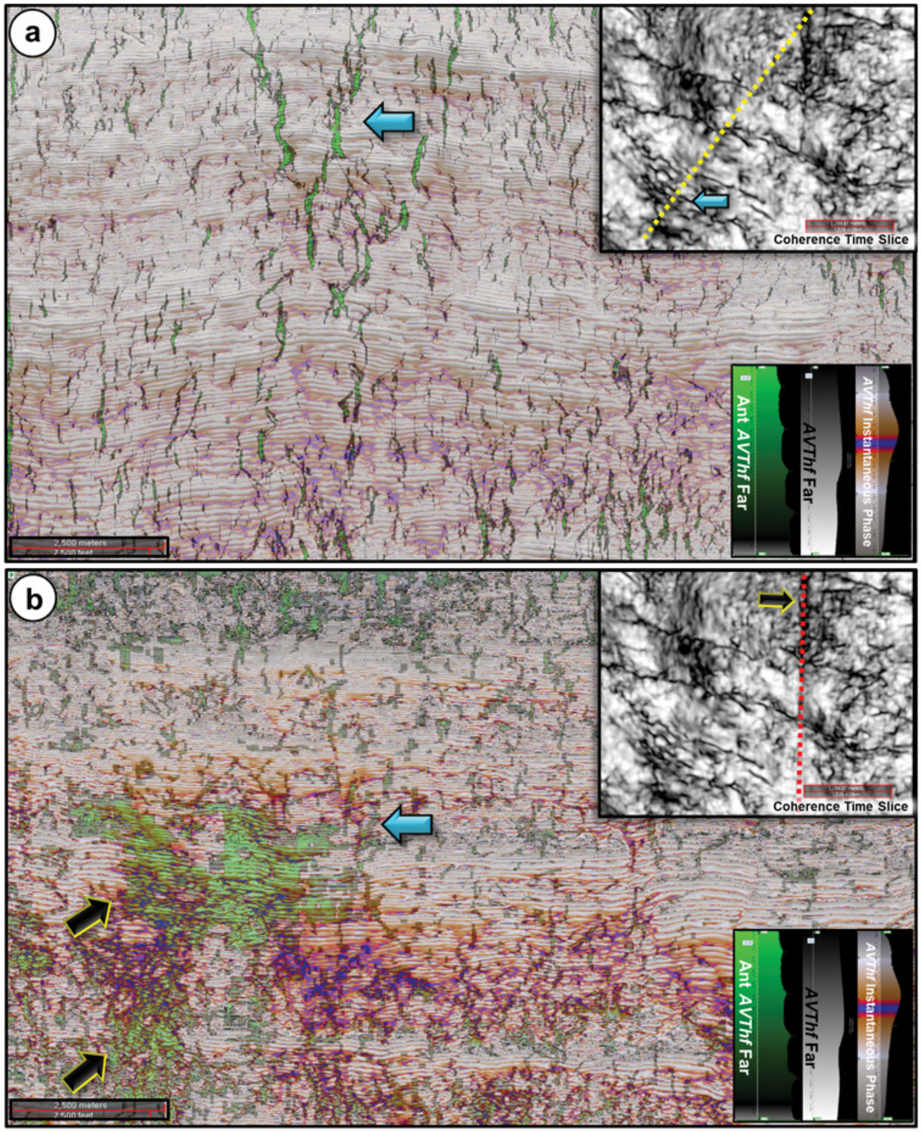

Figure 4. Co-visualization of AVTHF far angle stack, instantaneous phase of AVTHF far and ant tracking on AVTHF far, from 3-D seismic data of Golfo San Jorge Basin, Patagonia, Argentina. Such co-visualization is useful for more accurate interpretation, as well as for understanding the subsurface model. In Figure 3a, the fault system is seen clearly (marked with light blue arrows), as well as the effect of pseudo-weathering relief. Coherence time slices in the inset indicate the position of sections. Figure 3b shows the visual impact of the intrusive body filling the feeder zone and going up to the final emplacement (light green colored zone, pointed with black arrows). The structural events of different order are also seen.