The Geophysical Corner is a regular column in the EXPLORER, edited by Satinder Chopra, chief geophysicist for Arcis Seismic Solutions, TGS, Calgary, Canada, and a past AAPG-SEG Joint Distinguished Lecturer.

Assessing the Influence of Untrackable Horizons on Impedance Inversion

By SATINDER CHOPRA, RITESH KUMAR SHARMA and KURT J. MARFURT

Seismic data can be described as the convolution of the seismic source wavelet with a suite of reflection coefficients. The location and strength of these reflection coefficients are directly related to changes in impedance between adjacent rock units. Conventional seismic mapping is based on picking that part of the seismic waveform (such as a peak, trough, or zero-crossing) that ties the well across the survey, thereby defining a seismic reflector horizon separating different rock units. Because of this relationship, the definition of accurate horizons is critical to the construction of the low-frequency component of the impedance model used in seismic impedance inversion.


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Some horizons are easy to pick while others are challenging. Some of the more important horizons are those that span the entire seismic survey, with higher amplitude carbonate and volcanic ash reflectors being relatively easy to pick, and with maximum flooding surfaces somewhat more difficult to pick, but key to sequence stratigraphic mapping. Because the reflectivity changes from positive to negative to zero, according the to the impedance of the layers below the horizon, unconformities are the most difficult to pick.

Horizons may have a consistently high amplitude displaying high lateral continuity, or may have a weak discontinuous amplitude exhibiting little continuity. These characteristics of horizons depend on the depositional environment for the subsurface intervals from where they originate, the lateral changes in the overburden, whether they represent a lithologic interface or a sequence stratigraphic boundary, as well as on the signal-to-noise ratio of the seismic data.

Pros and Cons of 3-D Autotracking

In general, 3-D autotracking of horizons works well for interpolating a sparse grid of manually picked lines. In contrast, 3-D autotracking provides disappointing results when attempting to extrapolate picks away from the control points, at least for land data. More commonly, the interpreter first picks a grid of every 20th inline and 20th crossline using 2-D autotracking, correcting errors as they occur and otherwise helping the process. Today's autotrackers can be quite sophisticated, using more than one "attribute" (including phase, continuity and correlation coefficient) in addition to attributes to provide more robust picks.

Once defined, the 2-D grid of horizon picks serve as seed points for the 3-D autotracker.

Other attributes such as volumetric estimates of reflector dip, coupled with optimization algorithms, provide a means to semi-automatically pick a dense suite of intermediate horizons between those picked by an interpreter. Commercial software packages such as PaleoScan from Eliis and the Horizon Cube from OpendTect generate "relative geologic time" surfaces that approximate the Wheeler diagrams we learned in geology class. Such software holds great promise in advancing seismic chronostratigraphy. In the absence of access to such software, the quantitative seismic interpreter still wants to pick as many horizons as possible to construct an accurate low impedance background model.

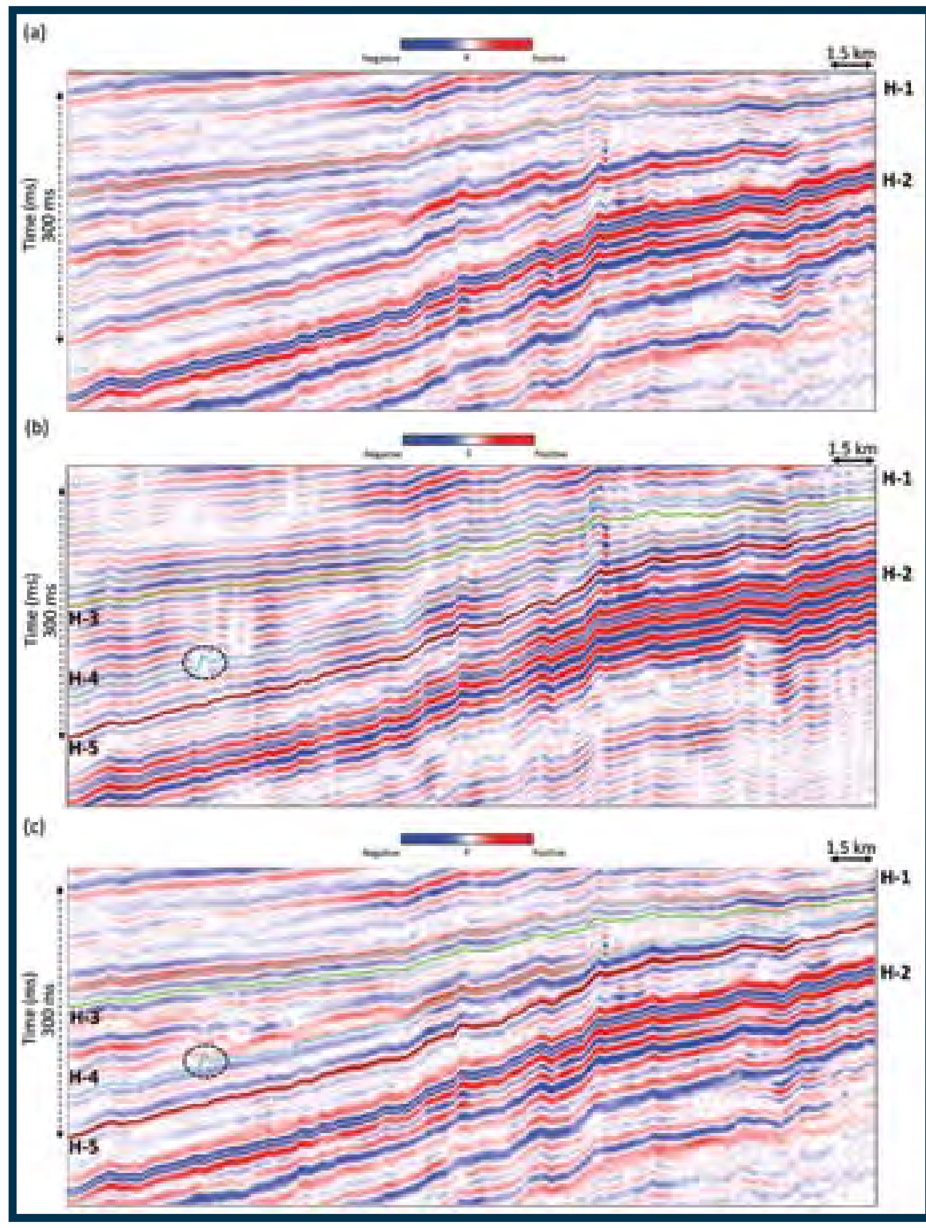

Figure 1: (a) Segment of a seismic section from a 3-D seismic volume from Oklahoma showing a divergence of reflection events from right to left. Horizons H-1 and H-2 are the trackable markers that can be easily autotracked on the data, and the horizons in-between these two markers are difficult to track on the seismic data, even if attempted manually. (b) Equivalent section from the 50 hertz voice component derived from the input seismic data. The intermediate horizons H3, H-4 and H-5 can now be tracked conveniently, though not autotracked in one go. (c) The same section as shown in (a) with the overlay of intermediate horizons. Notice these tracked horizons do not look out of place. Should some unresolved events as shown in the black dashed circle be present in the data, it will need to be smoothed out before generating stratal slices or for running the impedance inversion. (Data courtesy: TGS, Houston)


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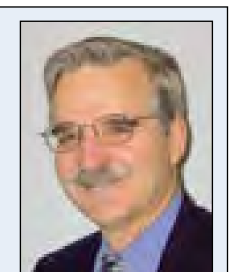
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Computing the second-derivative of seismic data shifts its frequency spectrum toward higher frequencies, and thus can define some reflections better, making them amenable for tracking. A better alternative for horizon tracking is to make use of voice components. In the March 2015 Geophysical Corner, the authors discussed the generation of spectral voice components from seismic data. Along with spectral magnitude and phase components, voice components are easily computed using a continuous wavelet transform, and are equivalent to a suite of band-passed filtered versions of the data long used in seismic data processing. In interpretation, workers have recently recognized that different voices give rise to improved (or at least different) coherence images. Sometimes the displacement lines up two similar reflectors along the fault, resulting in a "hole" in the coherence anomaly. Such alignment changes with different frequencies, resulting in coherence images computed from these now misaligned voice components illuminating the fault.

In this note, we use spectral components in the opposite manner: "Can we find components that result in more continuous reflectors across the zone of interest?"

Such continuity can be a function of the (frequency dependent) signal-to-

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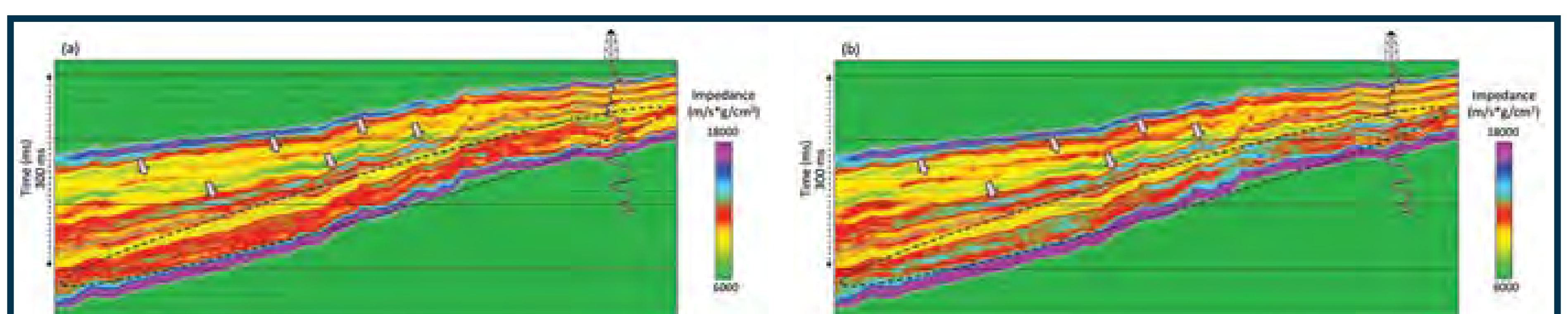

Figure 2: Equivalent impedance sections for the data shown in figure 1. The impedance inversion was generated for a window bigger than the one shown here to avoid edge effects. (a) The impedance section when only H-1 and H-2 markers were used for constraining the low-frequency impedance model derived from well log data. The log overlay to the right is the filtered impedance log through which the section traverses. (b) Equivalent impedance section but now constraining the low-frequency impedance model by including horizon H-4 in addition to markers H-1 and H-2. Notice the overall impedance section shows better-defined stratal layers as marked with pink arrows and also included in the black dashed highlighting ellipses. (Data courtesy: TGS, Houston)

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noise ratio or to complex tuning effects associated with the underlying geology. If we examine the individual voice components of the input seismic data, we note that a horizon tracked on them may not all fall on the horizon tracked on the input. However, if we pick a horizon on that voice component which is closer to the peak frequency of the input seismic data, the horizon overlaps the one tracked on input data.

We demonstrate the application of voice components for picking horizons that otherwise are difficult to pick on the input seismic data.

Horizon Tracking the Woodford Shale

In figure 1a we show a segment of a seismic section for a 3-D seismic data volume from Oklahoma. It shows a diverging set of stratigraphic reflections from right to left. Horizon H-1 is an easy-to-pick high amplitude limestone marker. H-2 is the top of the Woodford Shale, and is another strong marker. Between these two main markers fall the Meramec and other siltstone horizons that are more difficult to track, with many of the horizons pinching out to the right. Our goal is to define a sufficient number of intermediate horizons to guide the interpolation of the low frequency background impedance model

In figure 1b we show the 50-hertz spectral voice component computed from the seismic section shown in figure 1a. Note that while horizon H-2 consistently follows a peak, horizon H-1 starts as a peak on the left of the image, and ends as a zero-crossing on the right of the image. More important, notice that now several reflections span the survey as continuous events, allowing the construction of horizons H-3, H-4 and H-5. Picking these horizons on a coarse grid and then interpolating them using a 3-D autotracker provide three additional surfaces to use in constructing a stratigraphically aware background impedance model. Plotting these picked horizons on the original seismic data (figure 1c) we note that we could have picked H-5 on the original data. In contrast, H-3 and H-4 would be more tedious to pick, but are consistent with an interpretation of onlapping surfaces.

Figure 2 shows the impedance sections equivalent to the sections shown in figure 1, but for the impedance inversion section shown in figure 2a, markers H-1 and H-2 only were used for constraining the low-frequency impedance model. The impedance section shown in figure 2b is drawn from the impedance inversion that used a low-frequency model that utilized horizon H-4 in addition to the two markers H-1 and H-2. Horizons H-3 and H-5 were too close to the main markers and so were left out. Notice that the impedance section in figure 2b exhibits more well-defined strata as indicated with the pink arrows as well as the black dashed ellipses.

In conclusion, we emphasize the importance of constraining the low-frequency models properly so as to better define the subsurface stratigraphic geometries in our areas and intervals of interest. Such geometrical patterns may not be amenable to horizon tracking on the input seismic data. Tools such as spectral voice components can be used for this purpose, and one or more horizons may be tracked on these data and brought into the impedance inversion. The inversion stands to benefit from doing so as we have illustrated. E