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Geophysical Corner

Utilizing Far Angle Stacks for Seismic Interpretation of Gas Anomalies

In the early days of analogue recording, geophysicists used seismic data primarily to map structure. However, improvements in data quality by the late 1960s led to the identification of lateral changes in amplitude as well. When the drill bit revealed that some of the higher amplitude events correlated to gas-bearing zones, interpreters started taking them seriously. These streaks of high amplitudes seen on seismic sections were christened "bright spots."

The initial excitement was tempered by the realization that not all bright spots correspond to gas. Positive amplitude bright spots that corresponded to igneous intrusions and to oyster beds required care and could be avoided by determining the polarity of the seismic data. However, lower impedance coal stringers produced a strong negative amplitude response similar to gas. Furthermore, as interpreters examined the seismic response of deeper reflections, "compaction" effects could result in higher impedance shales overlying wet sands, which could also give rise to a negative reflection.

Mixed Results with AVO

Digital recording further improved seismic acquisition and interpretation. In 1982, Bill Ostrander demonstrated that the bright spots associated with gas anomalies can be distinguished from other types of bright spots by examining the seismic amplitude variation with offset or AVO response. In fact, he showed in the shallower Tertiary section, negative reflection gas sands became more negative with increasing offset, with wet sands exhibiting a different response. These differences can be attributed to not only the differences in the fluid that fills the pore space that modify the P-wave impedance, but also to differences between S-wave impedances of different lithologies. The seismic experiment is insensitive to changes in S-wave impedance at normal incidence but becomes progressively more sensitive to S-wave impedance with increasing angles of incidence that occurs with increasing source-receiver offset. Because of migration stretch, these farther offset images exhibit lower vertical resolution; nevertheless, most of the leverage in determining fluid and lithology is provided by comparing the farther offset to the nearer offset response.

Though the technique looked promising, the years following the introduction of AVO produced a great deal of disappointment, with the amplitude variation at the target horizons providing inaccurate predictions. With time, geophysicists realized that many of the processing techniques perfected to produce good structural images negatively effected the amplitude and were inappropriate for AVO analysis.

Specifically, more robust statistical scaling processes like amplitude gain control should be avoided and replaced with careful corrections for geometric spreading, angle of incidence at the recording surface, and ensemble versus trace-by-trace deconvolution. Land data were even more challenging with recent advances in surface-consistent statics and deconvolution leading us to what is now called "relative amplitude preservation" processing workflows. With the success in mapping direct hydrocarbon indicators, interpreters realized that almost all reflections exhibit some kind of AVO effect, leading to the integration of AVO analysis with rock physics, adopting appropriate processes for enhancing the signal-to-noise ratio of prestack data, and bringing in more quality controls while processing.

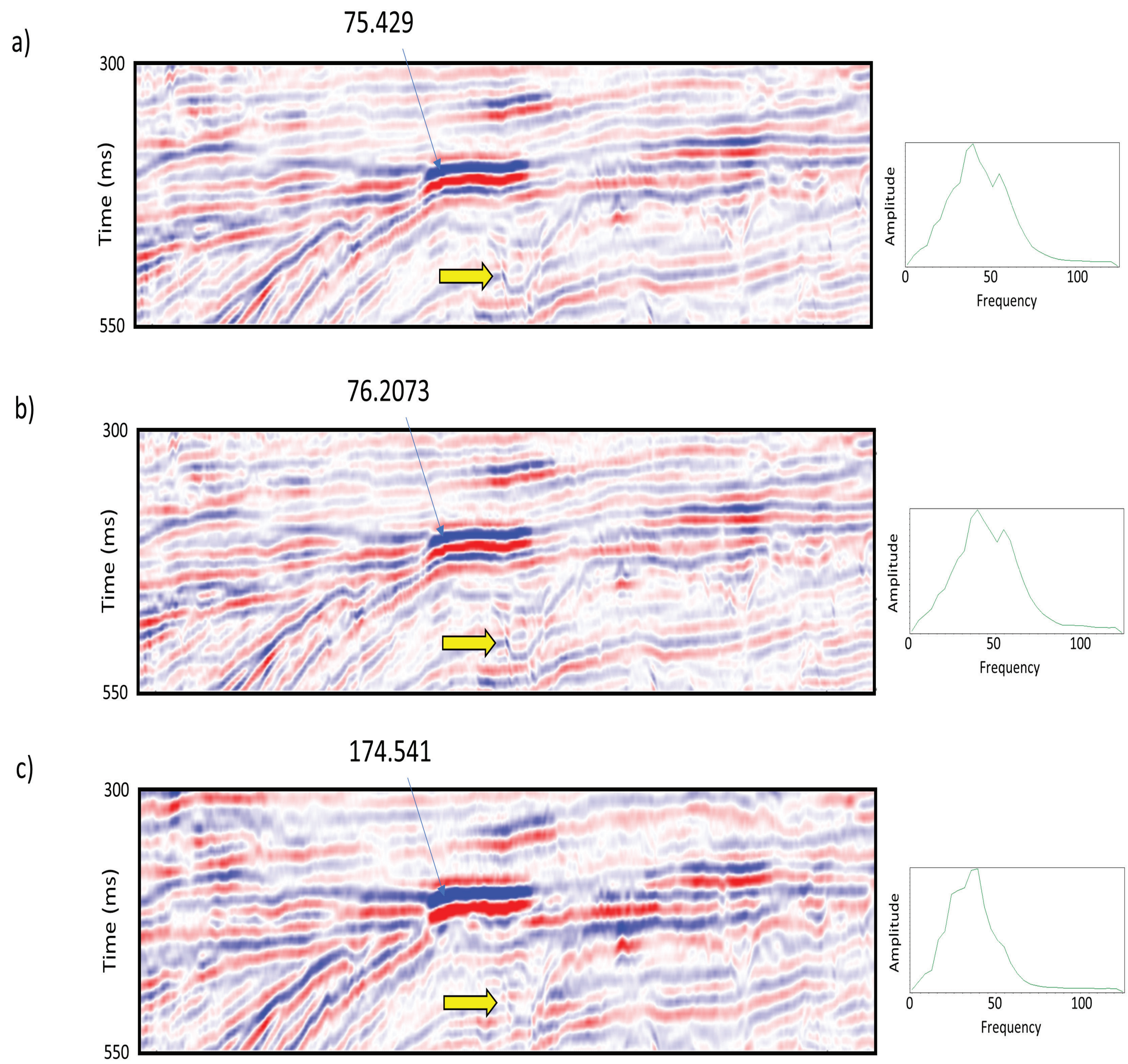

Figure 1: Equivalent vertical slices through the (a) full stack volume, (b) near-angle stack and (c) far-angle stack volumes showing a high amplitude anomaly. The amplitude values at the same voxel show a lower amplitude at the near-angle stack and higher amplitude at the far-angle stack. Note the decrease in vertical resolution for the far-angle stack as confirmed by its lower frequency spectrum. The yellow arrow indicates a deeper incised channel that is clear on the near-angle stack but difficult to see on the far-angle stack.

Analyzing Relationships between Parameters

The theoretical formulation for the partitioning of energy at an interface was given by Zoeppritz in 1919. These equations give the reflection and transmission coefficients for plane waves as a nonlinear function of the angle of incidence and the three independent elastic parameters on each side of the reflecting interfaces: the P-impedances, S-impedances and densities. These relations can be linearized, such that if the reflection amplitude is measured as a function of the angle of incidence, we can estimate the changes in the elastic parameters across the interface. For this reason, AVO analysis starts with converting the data from the source-receiver offset to angle-of-incidence domains, typically using simple ray tracing for relatively flat stratigraphy, where the necessary velocities are estimated by converting the stacking velocities to interval velocities.

Although a technology group or service provider may use a hundred or more traces in the migrated gather for AVO analysis, most interpreters will use three or four angle-limited near-, mid- and far-angle stacks, as well as the full stack for their analysis, which are generated during processing of seismic data using the seismic velocity field among other parameters. These three volumes can be used to estimate the slope and intercept terms described in March 2019 installment of Geophysical Corner.

Examples from the Pipeline Seismic Survey

In addition to slope and intercept, the angle-limited stacks themselves provide complementary images of the subsurface. In general, the near-angle stack will provide greater vertical resolution and, depending on the subsurface impedances, illuminate features poorly imaged by the far-angle stacks, such as the incised channel indicated by the yellow arrow in figure 1. Low impedance gas sands encased within higher impedance shales will usually show a brightening of amplitudes with angle of incidence. Such anomalies can be readily detected by simply animating between vertical or horizon slices through the near- and far-angle stacks, which can provide a quick indication of potential targets meriting more detailed AVO analysis and petrophysical modeling.

The comparison of the near-, far- and

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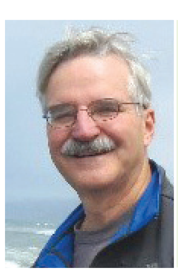

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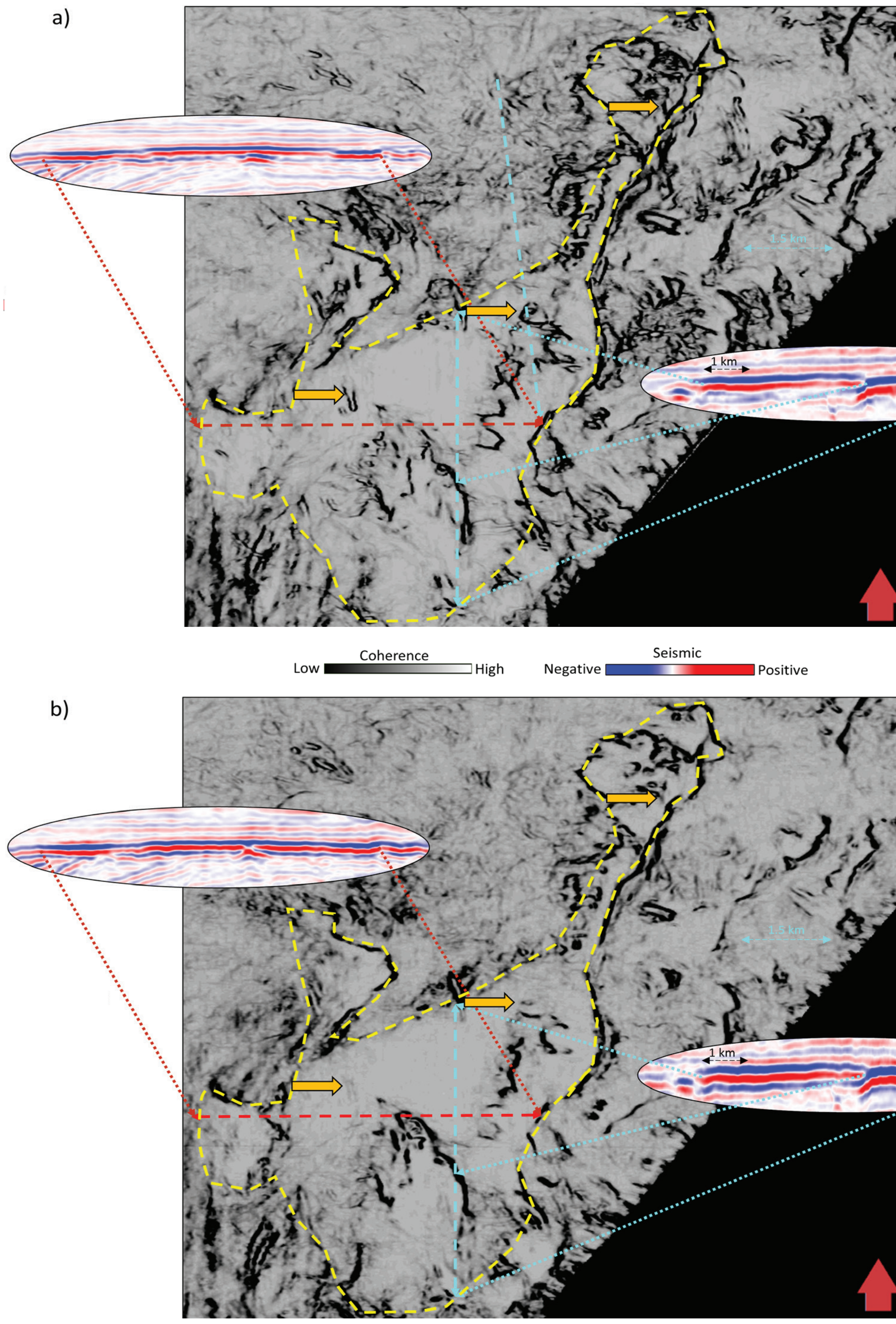
Figure 2: Time slice at t = 408 milliseconds through multispectral coherence attribute volumes computed from the (a) full-stack and (b) far-angle stack amplitude data. Red and cyan dashed lines indicate the location of the seismic inset images. Even though the far-angle stack exhibits reduced vertical resolution, it better defines the stratigraphic edges indicated by the yellow dashed polygon. In contrast, the effect of gas on the far-angle stack overwhelms the weaker lateral changes in stratigraphy seen on the near-angle stack indicated by the orange arrows.



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full-angle stacks from the Pipeline 3-D seismic survey acquired in the Taranaki Basin of New Zealand clearly show the change in amplitude over the shallow hydrocarbon anomaly. The lateral change in amplitude has at least three causes: structural changes that give rise to a gas-water contact, a change in porosity and gas saturation, or a lateral change in lithology common with incised channels.

The lateral changes in amplitude are often accompanied by a lateral change in phase. For this reason, the coherence images computed from the near- and far-angle stacks can be different. Often, the presence of gas will be sufficiently strong to mask smaller lateral changes in lithology, resulting in the high coherence anomaly seen inside the yellow polygon in figure 2b. In contrast, the edges of the gas anomaly itself are stronger on the coherence computed from the far-angle stack. (More detail on multispectral coherence can be found in the July 2018 installment of Geophysical Corner.) A comparison of the seismic amplitude signatures in the insets along the indicated directions on the coherence display shows the edges of the gas-charged zone on the far-angle stack to be not only stronger, but with better defined breaks in spite of the reduced vertical resolution. Integrating these two attributes (the change in amplitude between the near- and far-angle stacks and coherence) with geometries consistent with a geologic model of deepwater deposition further confirms the hypothesis of a gas-charged sand.

Conclusions

Angle-limited stacks provide not only a rudimentary indication of the AVO response, but also provide complementary images that allow more detailed mapping of stratigraphy. The far-angle stacks are less sensitive to multiple activity as their suppression improves due to mis-stacking and reflection point smearing at that angle range. Hydrocarbon anomalies, especially gas accumulations at shallower levels and found in unconsolidated sediments in the Gulf of Mexico or the Barents Sea, among other areas of the world, could be easily detected on far-angle stacks. The areal extent of these anomalies can also be detected on multispectral coherence attribute displays as has been shown in this article. E

(Editors Note: The Geophysical Corner is a regular column in the EXPLORER, edited by Satinder Chopra, founder and president of SamiGeo, Calgary, Canada, and a past AAPG-SEG Joint Distinguished Lecturer.)