Experiment on the Selection of Time-Transgression Predictive Seismic Attributes*

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Abstract

Both previous theoretical discussion and case studies have shown that seismic reflections do not necessarily follow the geologic time lines. In this study, we design a reproducible experiment to select seismic attributes that would favor the prediction of the time-transgression for a target seismic event. Our Tertiary example in South Texas manifested an increasing tendency of time-transgressive reflections, generated by chaotic "labyrinth" velocity model with the most lateral lithofacies variation, compared with smooth "layered-cake" velocity model with the least lateral lithofacies variation. Conforming to this tendency, three-dimensional seismic volumes with known intensiveness and magnitude of time transgression could be prepared accordingly. Afterward, a quantitative criterion to select time-transgression predictive seismic attributes was proposed. Time transgression for a given event is quantified by "peak-picked error", and the distributions of candidate seismic attributes are estimated within a defined window, centering that event. We inferred that the correlation between a candidate seismic attribute and the "peak-picked error" could serve as one of the quantitative criteria.

Introduction

Seismic reflections were assumed to follow chronostratigraphic surfaces, thus can be linked to dateable globally significant tectonoeustatic events (Vail et al., 1977 a, b; Mitchum et al., 1977). This assumption works relatively well for low-order (up to third order) seismic sequence stratigraphy (Mayer, 1979 a, b; Mayer et al., 1986), while is somehow subjected to doubt when extended to high-order seismic sequence stratigraphy (Aigner et al., 1989; Biddle et al., 1992; Lawrence et al., 1990; Tipper, 1993).

The modern geostatistical modeling and seismic visualization techniques provide a platform to investigate into the seismic time transgression phenomenon in a three-dimensional perspective, with the ability to describe subtle lithofacies changes. In this study, we used 3D geostatistical modeling to construct velocity models with increasing lateral lithofacies variation and generate the corresponding seismic records with different intensiveness and magnitude of seismic time transgression. Afterward, a quantitative criterion was defined to select the seismic attribute, which favors the prediction of time transgression for a given event.

Model Construction

Modern 3D geostatistical modeling provides a quick and reproducible approach to construct models with different complexity of lithofacies variation, lying foundations for massive and repetitive experiments for the selection of time-transgression predictive attributes. In this part, we were aimed at building geologic models with increasing lateral lithofacies variation, and make observations on the tendency of seismic time-transgression in the synthetic seismic records, as the idealized, perfectly migrated seismic representations.

To represent generality, four wells with sonic logs were randomly chosen from the Tertiary of South Texas as the conditional data, and manually spaced one kilometer away from each other. The sonic velocity was assumed solely dependent on lithology, so that the velocity model could be viewed as the proximity of lithofacies. Within the pseudo horizontal chronostratigraphic correlating scheme, a set of velocity models with increasing lateral lithofacies complexity (Model I, II and III) were constructed in depth domain (Figure 1A), then converted to time domain (Figure 1B). 30-Hz synthetic seismic data (Figure 1C) were utilized here as the normal-frequency seismic representation. We make observations on tendency for time-transgression, basing on comparisons between the zoomed-in sections of the synthetic seismic records, versus the time-domain velocity models (Figure 1D).

Overall, there is an increasing tendency for seismic time-transgression, generated by chaotic "labyrinth" velocity model, compared with the smooth "layered-cake" velocity model. The smooth "layered-cake" velocity model (Model I) with the least lateral lithofacies variation is prone to generate time-equivalent reflections, whereas the chaotic "labyrinth" velocity model (Model III) is prone to generate more time-transgressive reflections, which may better fit to the lithostratigraphic surfaces. In addition, the seismic volume for the intermediate velocity model (Model II) is featured with a mixture of time-equivalent and time-transgressive reflections. Conforming to this tendency, models with known different intensiveness and magnitude of time transgression could be purposely constructed in the following experiment stage.

Experiment Design

At this stage, we purposefully constructed models with known time transgression have been ready for the selection of the seismic attributes, which favors the prediction of local seismic time transgression. As the procedure contains massive and repetitive experiments, here we will concentrate on setting a quantitative criterion for reference. In this experimental stage, another suite of wireline logs from Miocene, Tiger Shoal area, offshore Louisiana were chose as the conditional data, considering the completeness of sonic and density logs with apparent log signature for a confident chronostratigraphic correlation.

Time transgression for a target seismic event in the synthetic seismic records can be quantified by the "peak-picked error", which was defined by the difference between the between the peak-picked seismic reflector and the true chronostratigraphic surfaces in the time domain (Zeng, 1994, Figure 2). Time-parallel events (aa', bb' and ee') had been inferred to have no significant changes of standard deviation error with changing frequency, although the threshold for "no significant change" remains arbitrary and subjective to the interpreter.

Similarly, within a defined window centering the target seismic event, statistically there is also a distribution for a single-/ multi-seismic attribute. We are now testing the correlation between the distributions of "peak-picked error" and candidate seismic attributes in synthetic seismic volumes with increasing time-transgressive reflections, for the sake of selecting seismic attribute, which would be most favorable to predict the time-transgression of a given event.

Preliminary Conclusions and Future Works

From our descriptive case study in the Tertiary example of South Texas, there is a potential increasing tendency for seismic time-transgression to occur in chaotic "labyrinth" velocity model with the most lateral lithofacies variation, compared with the smooth "layered-cake" velocity model with the least lateral lithofacies variation. Conforming to this tendency, the seismic models with known different intensiveness and magnitude time transgression could be prepared. And we are experimenting on the selection of time-transgressive predictive seismic attribute, with a defined quantitative criterion, which requires a good correlation between the distribution of the "peak-picked error" of a target event and the distribute of a candidate single-/ multi- seismic attribute within a window centering that event. After selecting time-transgressive predictive seismic attribute with massive and repetitive experiments, we plan to extend the experiment procedures to models that are more geologically realistic. Digital outcrop models (DOMs) will replace the wireline logs as the conditional data for model construction, given their confidently mapped chronostratigraphic surfaces and well-defined sequence stratigraphic framework.

Acknowledgments

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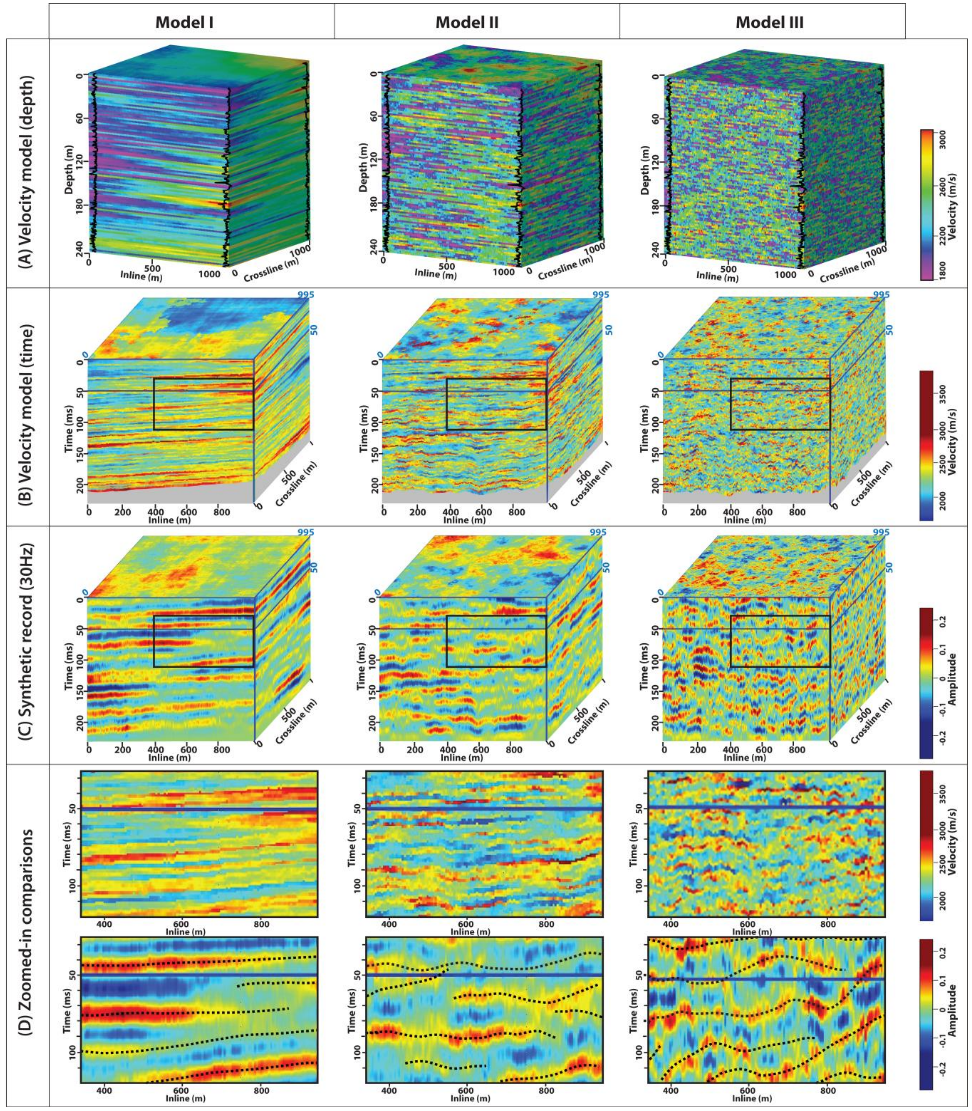

Figure 1. Velocity models in depth (A) and time (B) domain, synthetic seismic records (C) and zoomed-in comparisons for time-transgression phenomenon (D) in the Tertiary example of South Texas. The dashed line in (D) represent manually peak-picked horizons. Chaotic “labyrinth” velocity model with the most lateral lithofacies variation (Model III) tends to generate more and larger-scale time transgressive reflectors, compared with the smooth “layered-cake” velocity model with the least lateral lithofacies variation (Model I). This observed tendency could be utilized accordingly, to construction seismic models with known different intensiveness and magnitude of time transgression in the following experiment stage.

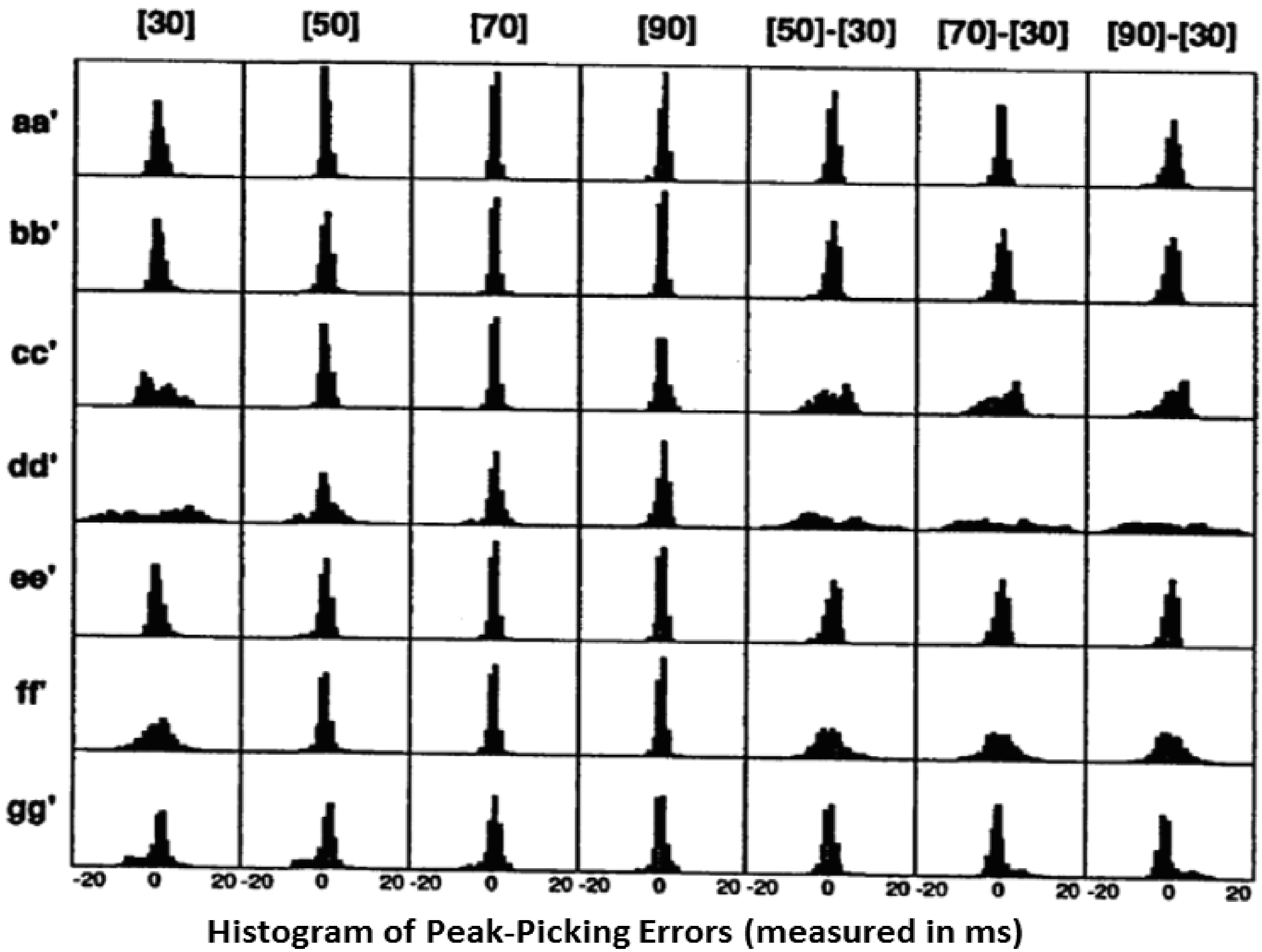

Figure 2. The histogram of "peak-picking error", as a parameter to quantify time transgression (Zeng, 1994). Peak-picking error was defined as the difference between the pick-picked seismic reflector and the corresponding chronostratigraphic surface in the time domain. Seven events (aa'-gg') were selected for analysis. Column 1-4 contain the histogram for the peak-picking error between chronostratigraphic surface and nearest picks from 30-, 50-, 70- and 90 Hz synthetic data. Column 5-7 compare the difference between the above histograms for 50-, 70- and 90 Hz, versus 30 Hz. It was inferred that the STD error for time-parallel events (aa', bb' and ee') have no significant change with frequency, although the threshold remains arbitrary and subjective to the interpreter.