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Seismic Stratigraphy Via Attribute Analysis, Brooks County, Texas

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ABSTRACT

Recent subsurface interpretation of a lower Vicksburg sequence-parasequence section in a 3D seismic survey in Brooks County has demonstrated the effectiveness of post-stack attributes. In a reprocessed 1980s-vintage survey, large- and small-scale features were identified by vertically oriented attributes as well as time slice and horizon oriented views. In this study, well control has been added and serves as a guide to interpretation of amplitude and extracted attributes. The goals for interpreting the attributes include: (A) Identification of parasequence stratigraphy on a bed by bed basis; (B) Within tuning limits, spectral decomposition methods to highlight small- to large-scale geobodies; (C) Cascaded attribute generation for both matrix and pore fluid estimation; and (D) Cross-plotting of attributes in order to identify potential undrilled reservoirs. These same goals will also be applied to the geologic section outside the volume of interest to catalog possible new drilling locations. This volume and its relationship to regional Cenozoic tectonic evolution is also interpreted to predict other sequence-parasequence locations in the lower Vicksburg.

INTRODUCTION

The Oligocene Vicksburg Formation in South Texas has long been a prolific resource for oil, condensate, and gas production (Combes, 1993). It is interpreted as a clastic depositional event with provenance to the southwest, in the Sierra Madre Mountains (Whitbread et al., 2001). Initially a simple delta lobe deposited in lower Vicksburg time, the sediments were transported basinward (southeast) over the Vicksburg Fault Zone. This is a decollement that developed in the underlying Eocene Jackson strata (Whitbread et al., 2000; Turner, 2020). A series of 'ridges' and 'valleys' has developed along this slide plane due to post-tectonic movement. Recent work

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has concentrated on the effects of faulting on reservoir integrity and distribution within the lower Vicksburg formation (Turner, 2020).

A 3D seismic dataset that includes lower Vicksburg stratigraphy was donated to Texas A&M University–Kingsville for research purposes. This data come from Brooks County in South Texas near the border with Mexico (Fig. 1). Project objectives are to perform individual and cascaded post-stack attribute analysis of the seismic volume as provided by the donor. In particular, the goal is to provide a processing flow that enhances the visualization of the stratigraphy of lower Vicksburg events.

In this study, standard migrated (post-stack) amplitude data are processed to highlight foreset thickness and distribution. The strategy employed is a combination of standard post-stack attributes, curvature attributes, and coherence. Results are evaluated for each individual attribute and for cascaded processes.

A time slice through the target area displays a difference in character with respect to regional trend. Figure 1 displays a southeast trend of deposition in the bulk of the survey. To the northeast, however, a counter-trend of a west-trending package of beds is observed. It is this region that this investigation is centered.

This project was motivated by previous work on conformable lower Vicksburg foreset beds that yielded interesting post-stack attribute signatures (Schneider, 2019). From the input data, this appears to be a portion of a sequence that has elements of both toplap and offlap, rolling into a downlap-dominated base that has been influenced by movement along the basal decollement. This infers syn-depositional sea level rise and fall, creating unique sedimentary packages encompassing specific time periods. This is superposed on a reflector that dips in the opposite direction. This reflector is interpreted to be the underlying Jackson Shale decollement surface.

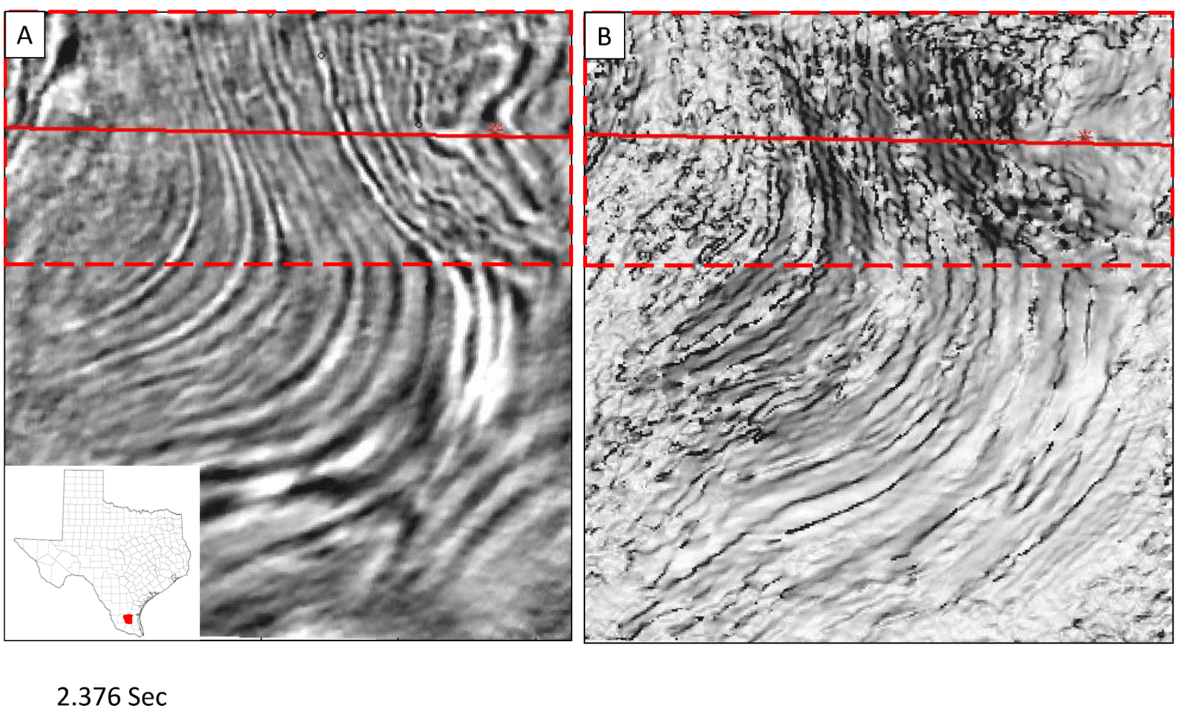

Figure 1. Location and view of reflectors. (A) Time slice of amplitude data, approximately 2.38 sec below the surface. (B) Time slice of coherence attribute, same location. The study area is outlined by the red dashed box. The solid red line corresponds to the vertical profile in all vertical sections for this paper. Location of Brooks County is shown in the insert.

METHODS

Study of this 1985 vintage data volume has revealed strong conformable reflection signatures with some imaging interference (Fig. 2A). No attempt was made to improve the signal-to-noise (S/N) value, the frequency content, or the pre-stack processing flow for this study. A (dip direction) curvature attribute, derived from Figure 2A, is displayed in Figure 2B. Several distinct post-stack attribute transforms were applied to the amplitude data, including curvature, spectral decomposition, and instantaneous phase. Subsequently, cascaded attribute analysis was undertaken, the output of one attribute serving as input to the next. An attribute "processing flow" was then adopted with the goal to produce new seismic stratigraphic profiles with unique properties.

RESULTS

Initial extraction of curvature attributes reveals higher frequency reflectors relative to the parent data. Further, these high-frequency reflectors appear in larger distinct packages, the edges of which are defined by the dip of maximum similarity (coherence) attribute (Fig. 2B). Amplitude-based semi-horizontal events seen below the decollement (arrows) are absent in the curvature data. Similarly, dipping reflectors near the arrows in Figure 1A are reduced in amplitude in Figure 1B. The curvature reflectors above the decollement surface in Figure 1A are therefore interpreted to highlight actual stratigraphy. The reduction and loss of amplitude reflections below the decollement indicate that curvature does not support actual stratigraphic packages.

Vertical profiles of coherence are not oftentimes studied as are corresponding time slices. In this case, however, the appearance of vertically-bounded regions of similar reflective character is of interest (Fig. 3A). By highlighting these boundaries using black lines, it is observed that they match individual curvature attribute boundaries (Fig. 3B). Moreover, strong antithetic re-

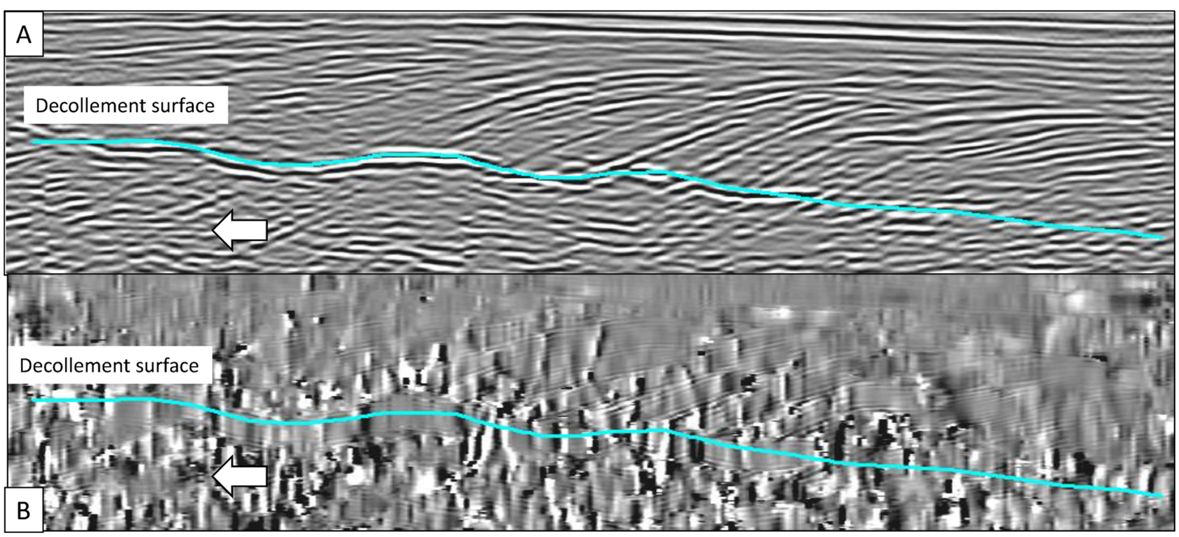

Figure 2. Cross-section showing seismic profile across the foreset sequence. Orange line defines the top of the sequence. Blue horizon indicates the decollement in Jackson Formation (Eocene) shale. (A) Reflection profile showing strong imbricate foreset beds in the right-hand half. (B) Curvature (in dip direction) attribute, based on reflections, displaying high-resolution coherent events related to reflections.

flectors appear within the coherence data and are not similarly defined in the curvature plot. It is of interest to note that some coherent packages (green arrows in Figure 3B) clearly show an expanding sequence downward (green arrows), while others (e.g., red arrows) reveal constant thickness to downward thinning sequences. This indicates that the actual dip of the foreset beds was changing over time, likely due to the packages relationship to the slippage over the decollement below.

In an attempt to enhance the edges of individual foreset beds, several variations of spectral decomposition were processed on the input data. To prepare for the proper limits of spectral detection, the amplitude spectrum within the study area was calculated and plotted (Fig. 4).

Based on this spectrum, an initial envelope series using octave-based decomposition windows was extracted from 5–40 Hz. Eight individual bandwidth calculations were made and assessed. The results showed a well-illuminated Vicksburg fault surface over several different frequency bands, but few individual bed packages left amplitudes that were both above background and also coherent (Fig. 5). Nevertheless, an examination of all envelope sub-bands indicated that a new set of sub-band extractions employing trace sub-bands might produce superior results.

Results of a six-trace decomposition, sub-bands from 15–30 Hz, provided an improved understanding of foreset body thickness. From these, the 15 Hz central bandwidth was used for the rest of the study (Fig. 6). This extraction preserves the stratigraphy and Vicksburg fault zone. Note that by the nature of the decomposition, beds of nearly equal thicknesses (geobodies) are displayed.

At this point, each attribute calculator provides additional information to the interpreter. It is also of interest to investigate cascaded attribute analysis. For example, the curvature in the dip direction of the 15 Hz spectral decomposition can be extracted for viewing. The results are shown in Figure 7. The relatively high-frequency reflectors within each stratigraphic unit are better imaged than with the amplitude source, and the “packages” of individual depositional parasequence is retained.

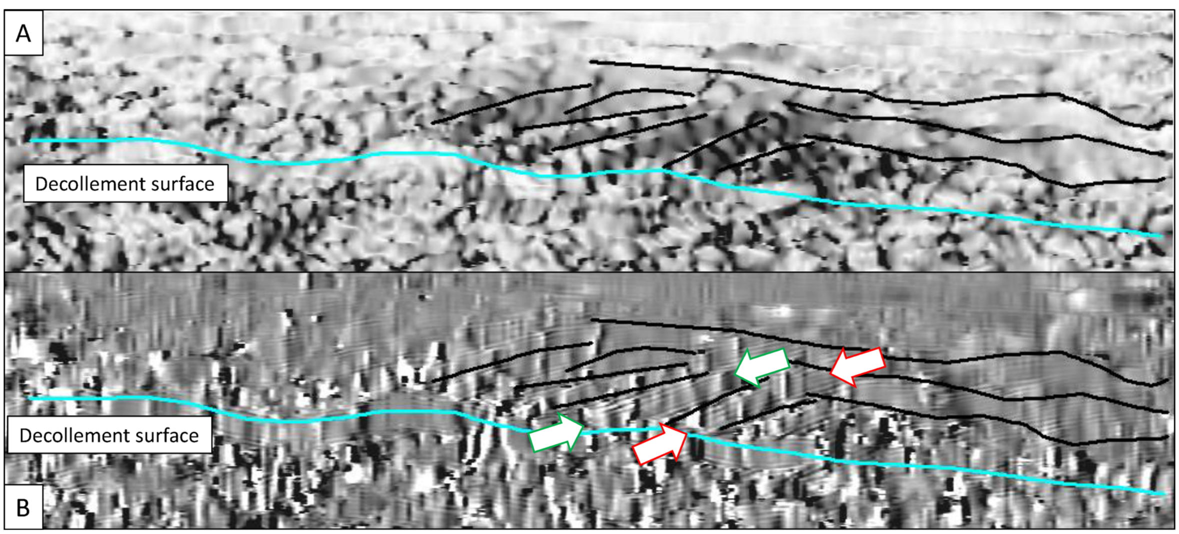

Figure 3. Comparison of (A) dip of maximum similarity (coherence). Specific packages of similar internal coherency are observed and interpreted by black lines. Strong counter-dipping amplitude events appear in many, but not all of individual foreset packages. (B) Curvature in dip direction,same location in (A) The black lines now serve as boundaries for curvature data packages. Note that some foreset beds expand downward (green arrows), while others display thinning downward or no change at all (red arrows).

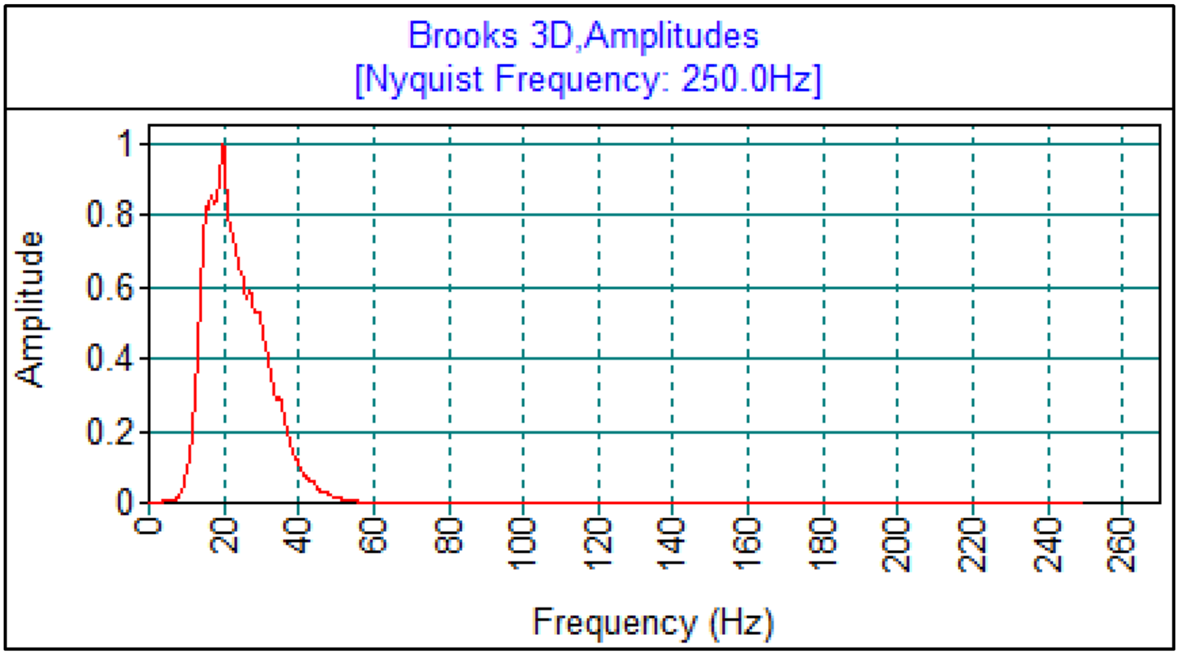

Figure 4. Amplitude spectrum of amplitude data that served as input to spectral decomposition.

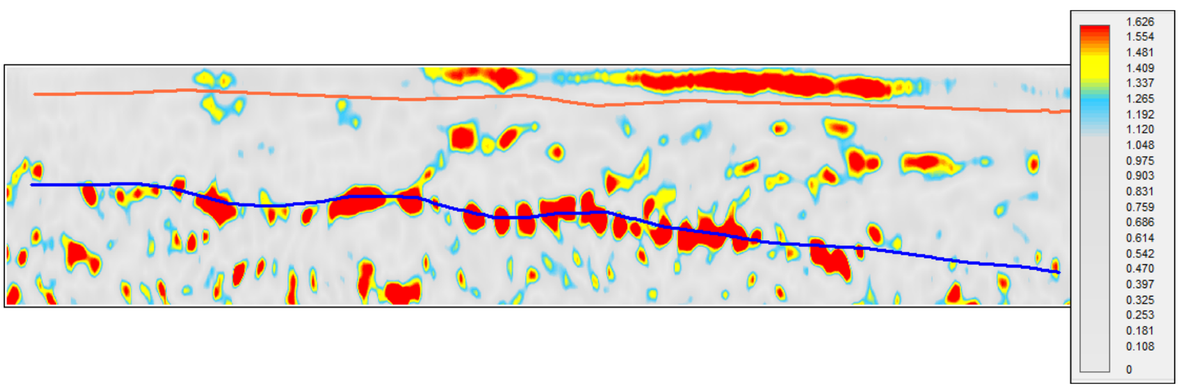

Figure 5. Example of spectral decomposition, trace envelope option, center frequency is 18 Hz. The Vicksburg Fault Zone is well defined, but onlap and toplap packages do not stand out from the background. Top (orange) and base (blue) of lower Vicksburg are included for reference.

An instantaneous phase transform was applied to the decomposed-curvature data, providing the view displayed in Figure 8. Note that for this initial 15 Hz spectral extraction, it is easy to interpret depositional sequences. Moreover, flat-lying reflectors within each depositional sequence lead to an understanding of either sub-depositional stratigraphy or potential fluid boundaries.

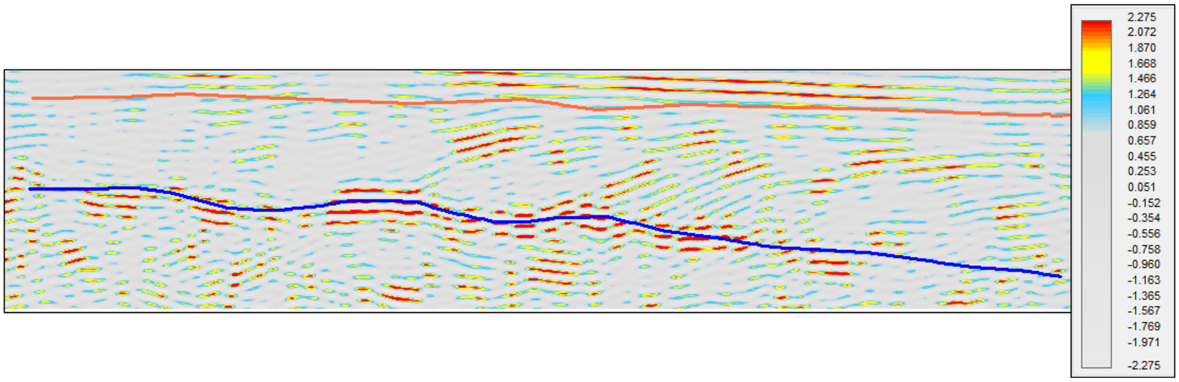

Figure 6. Spectral decomposition, trace calculation, 15Hz center band. Onlaps, toplaps, downlaps, and Vicksburg fault zone are clearly preserved and enhanced with respect to Figure 5.

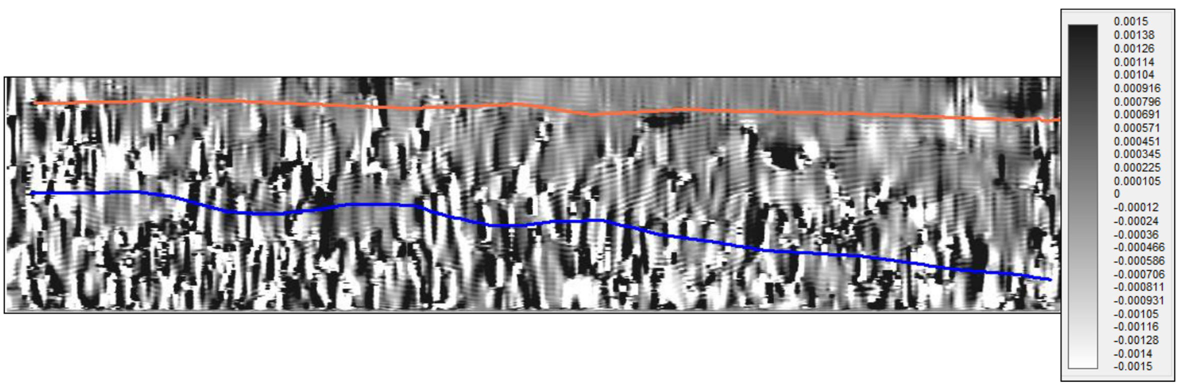

Figure 7. Curvature in dip direction using 15 Hz trace decomposition as input. As in Figure 2, the dipping strata continue to be enhanced throughout the lower Vicksburg and are almost absent below the glide plane.

SUMMARY AND CONCLUSIONS

One must practice caution with just this set of images. The same analytical technique could be made using other central bandwidths from the decomposition. Higher central bandwidths could be used to investigate thinner beds and/or flat spots of smaller reservoirs. A full analysis of all available data would be required before a decision to drill. However, this might also have applications in thin bed analysis using old data.

Note that this project has not led to reservoir prediction. It is merely an exercise to determine the ability for modern attribute analysis to contribute to volumes of older vintage. Future work will include tying this information back to the borehole for geologic control. The key is to first understand the data, the geological setting, the objectives, and the available data for input.

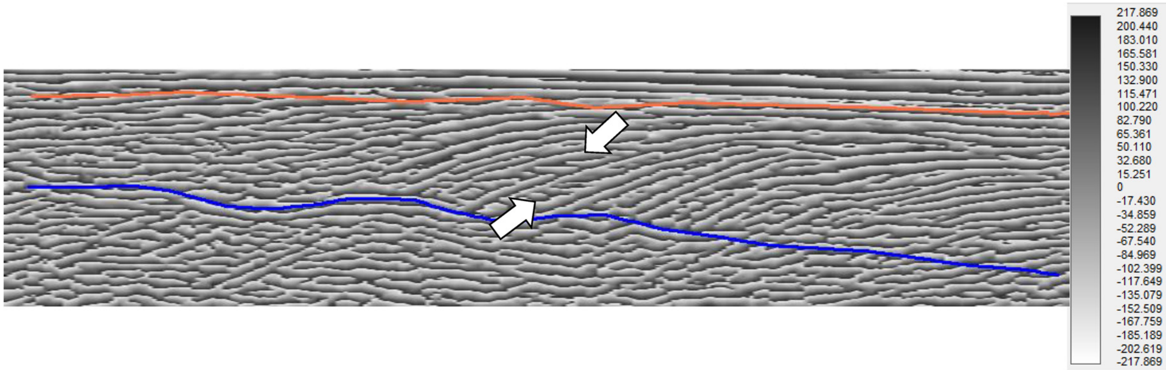

Figure 8. Instantaneous phase extraction from data displayed in Figure 7. Depositional features in the lower Vicksburg sediments are with rare exceptions absent from above or below. Flat reflectors (white arrows) have either stratigraphic or fluid implications (or both). Note that they do not penetrate to adjacent stratigraphy, so that confidence is high that these flat spots are real.

ACKNOWLEDGMENTS

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NOTES