Interpretation of Deep Complex Structure in a Limited-Quality 3-D Seismic Image

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Abstract

A study funded by the U.S. Department of Energy, the Gas Research Institute, Mobil Exploration and Producing U.S., and Altura Energy was done to determine geologic controls on deep, prolific Ellenburger gas reservoirs at Lockridge, Waha, West Waha, and Worsham-Bayer fields in Pecos, Reeves, and Ward Counties in West Texas. A major component of the data base amassed for the study was a 176-mi^2 3-D seismic survey extending across these fields. Ellenburger (Ordovician) reservoirs occurred at depths of 17,000 to 21,000 ft (5200 to 6400 m) over most of the study area. The eastern half of the 3-D seismic survey was covered with a thick (500 to 2000 ft [150 to 600 m]) variable layer of low-velocity Tertiary fill underlain by a varying thickness of high-velocity salt/ anhydrite. These near-surface conditions attenuated seismic reflection signals from deep targets and made static corrections of the data difficult.

The 3-D seismic data acquired in this study are thought to be some of the best quality data produced over these fields, yet the 3-D image of the deep pre-Pennsylvanian targets was of limited quality because of the combined effects of complex, attenuating, near-surface layers and weak reflection signals from deep seismic targets. The principal interpretation objective was to construct the complicated tectonic structure related to these fields to determine genetic relationships between faults and deep gas production. The challenge was to construct this structural picture from a 3-D seismic image that did not provide a clear, unambiguous picture of the fault systems.

Petrophysical analyses of logs from wells drilled at key structural locations were invaluable in interpreting fault geometry by identifying overturned beds and repeated sections. Once 3-D seismic horizon and fault interpretations were done across the complete 176-mi^2 area, depth maps of key pre-Pennsylvanian horizons were made, and vertical depth sections were constructed across critical structural areas. The seismic interpreted structures were then restored to pre-deformation conditions to verify that the pre- and post-deformation lengths of these key horizons were consistent, and thereby determined if the seismic fault interpretations were structurally valid.

These methods of integrating petrophysical analyses and section reconstructions into the interpretation of 3-D seismic data should be helpful to others who are confronted with the challenge of constructing complex structural models from limited-quality 3-D seismic images.

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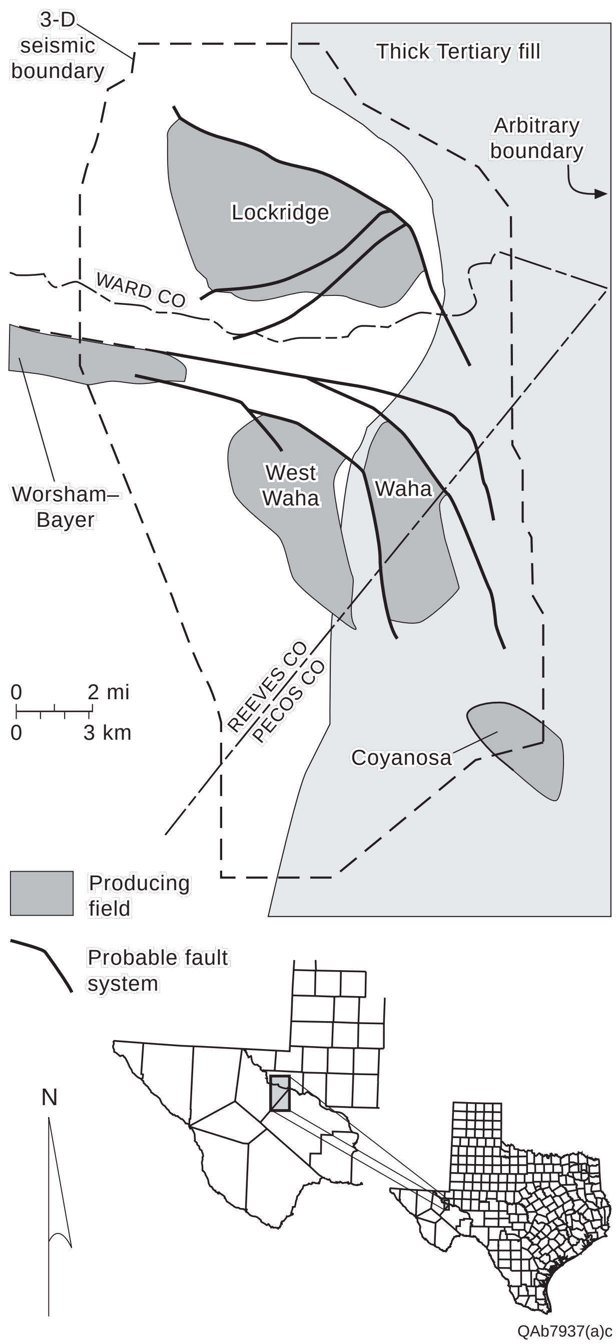

Figure 1. Location map of study area. The eastern portion of the study area was covered by a thick, complex surface layer that creates difficult static corrections that are referred to the Tertiary-Fill Problem. The labeled stippled areas are gas fields. The dark lines bounding, or crossing, these labeled gas fields identify where fault systems were suspected to be before this study was done.

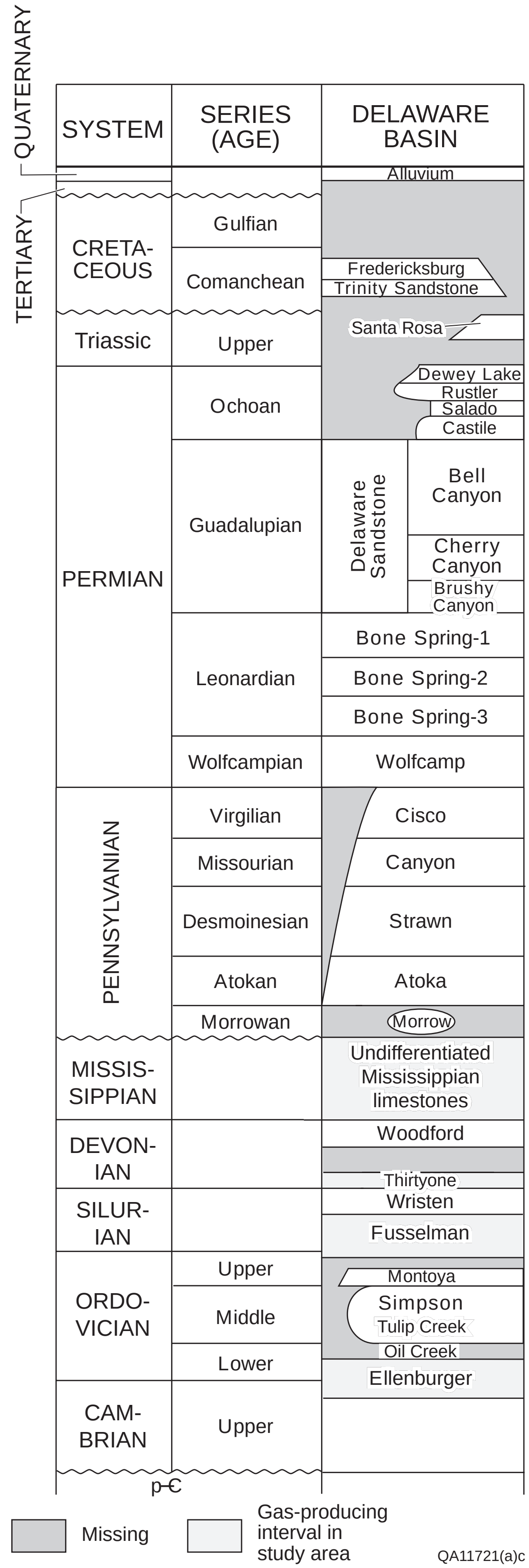

Figure 2. Stratigraphic column of the Delaware Basin. Gas production in the study area comes from reservoirs of the Ellenburger Group, Fusselman Formation, Thirtyone Formation, and Mississippian limestones. Note the missing section from the late Permian through Cretaceous, which is filled with Tertiary alluvium to form a thick, complex, near-surface layering.

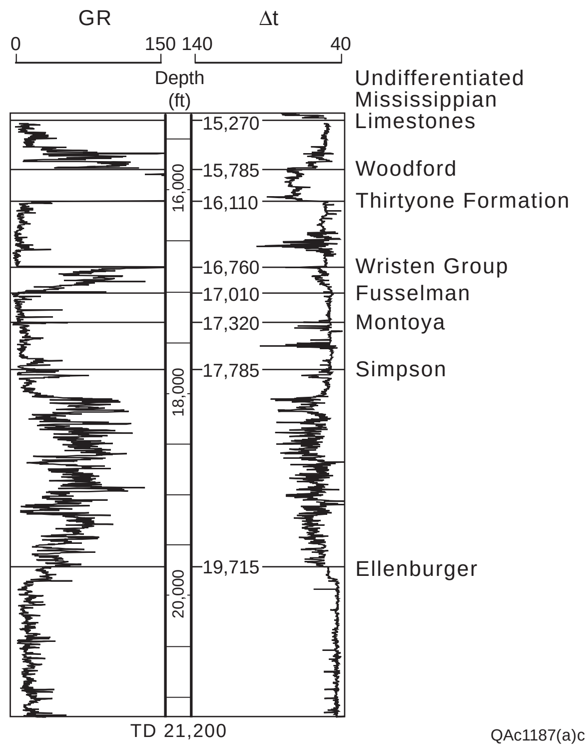

Figure 3. Type log from well no. 29 (Fig. 4) through deep imaging targets within the area of the 3-D seismic image. Note the gradual ramp increase in formation velocity associated with the top of the Ellenburger, the principal gas-producing interval that was to be studied.

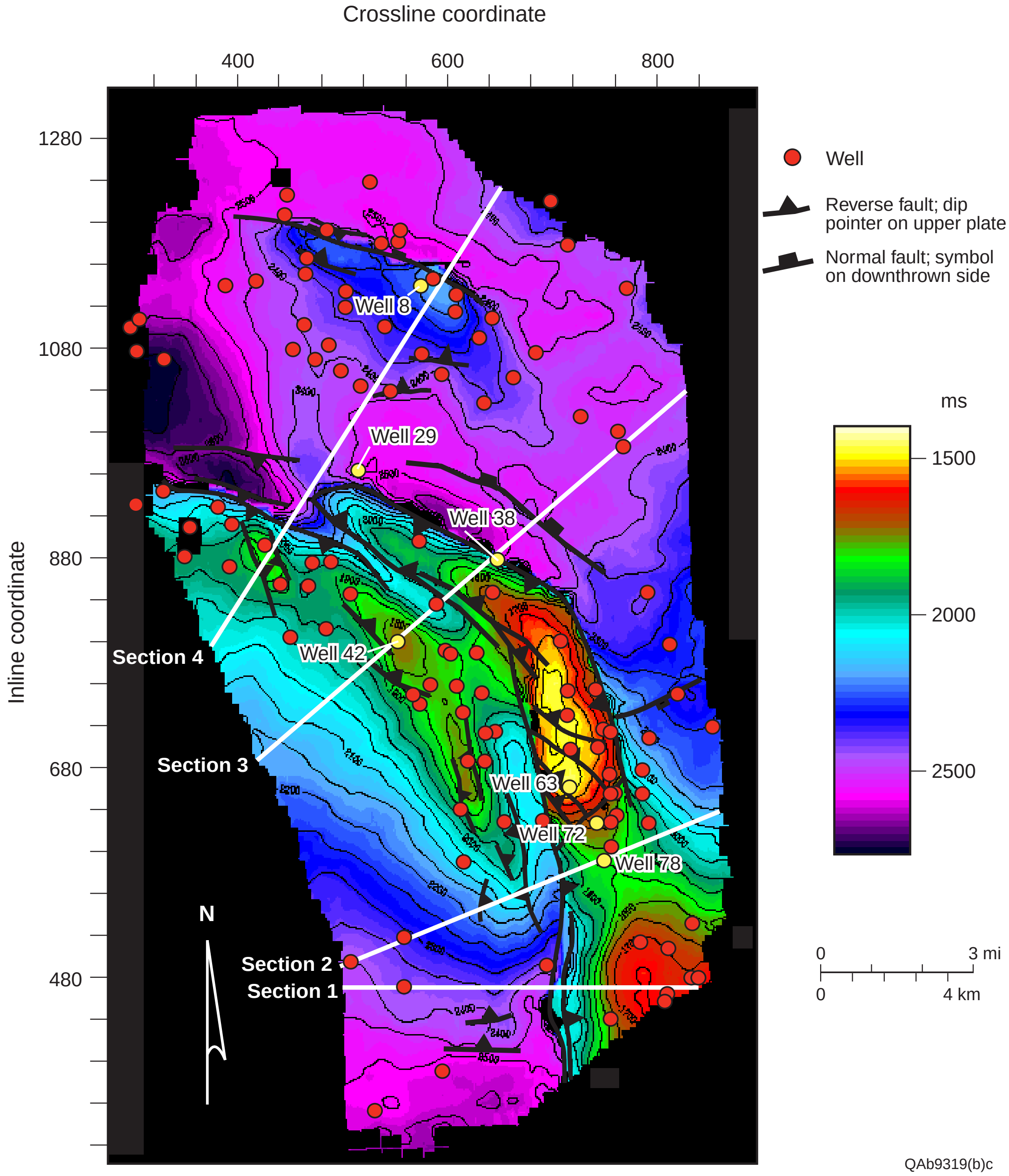

Figure 4. Locations of key wells and restoration cross-sections 1 through 4. The background map is the time structure of the interpreted Devonian surface.

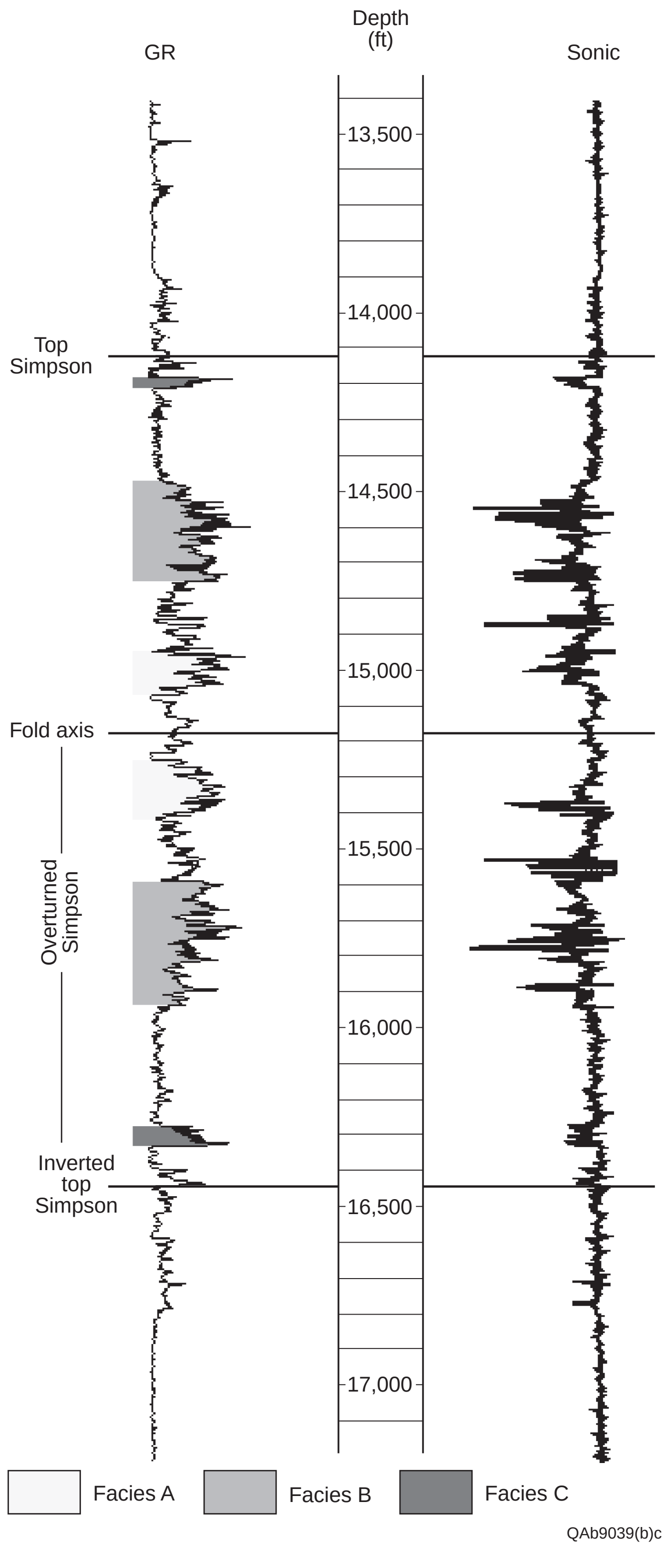

Figure 5. Example of overturned Simpson section, well 78 (Fig. 4).

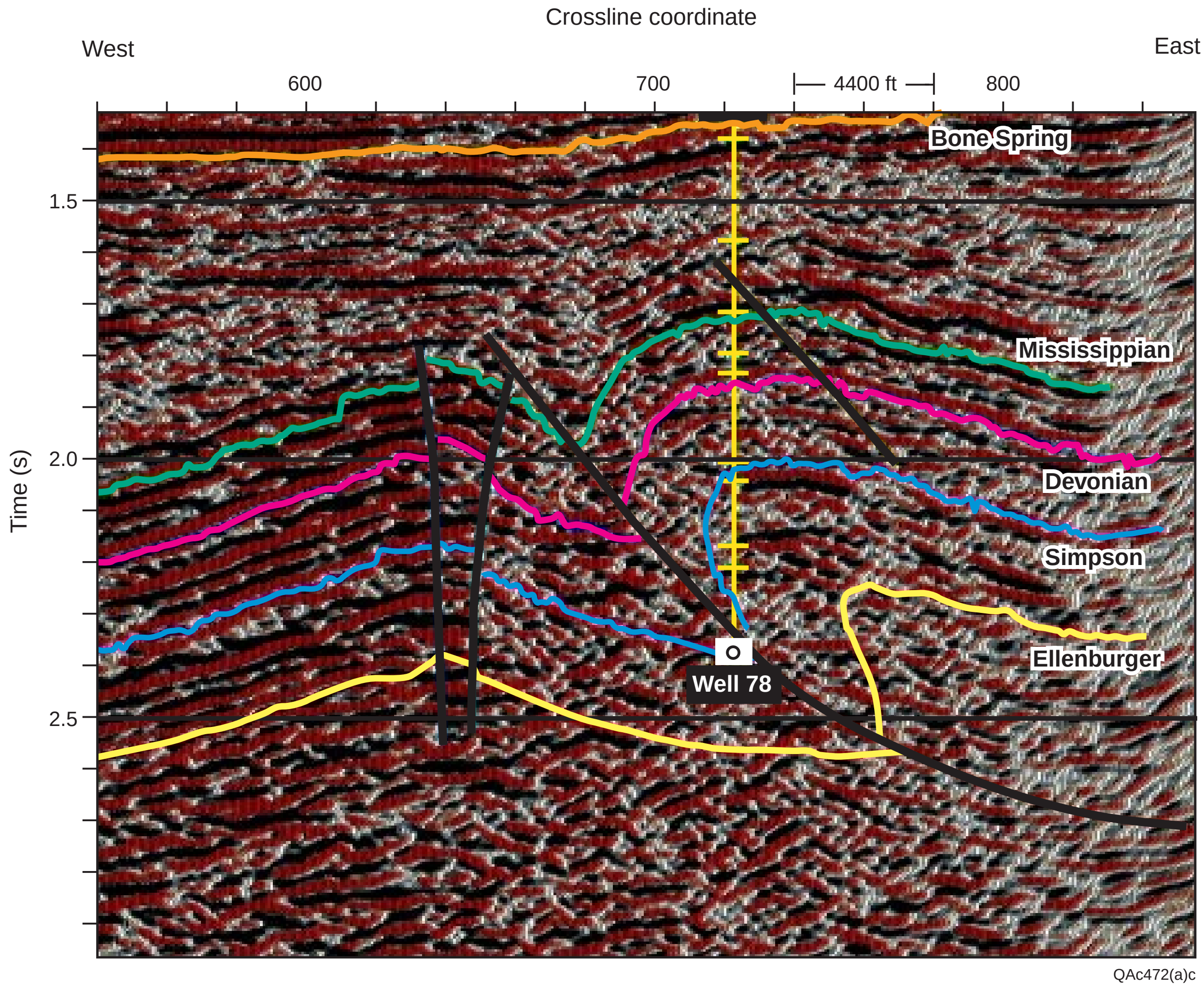

Figure 6. Seismic section (inline 576) passing through well 78. This seismic profile illustrates the overturned Simpson section that would have to be incorrectly interpreted as Ellenburger if the industry-provided formation tops were honored. The original (and incorrect) log-defined top of Ellenburger is the well tic at 2.22 seconds. Each labeled horizon identifies the top of that particular unit, regardless of whether the label is above or below the horizon. Phantom horizons have to be constructed across poor image areas.

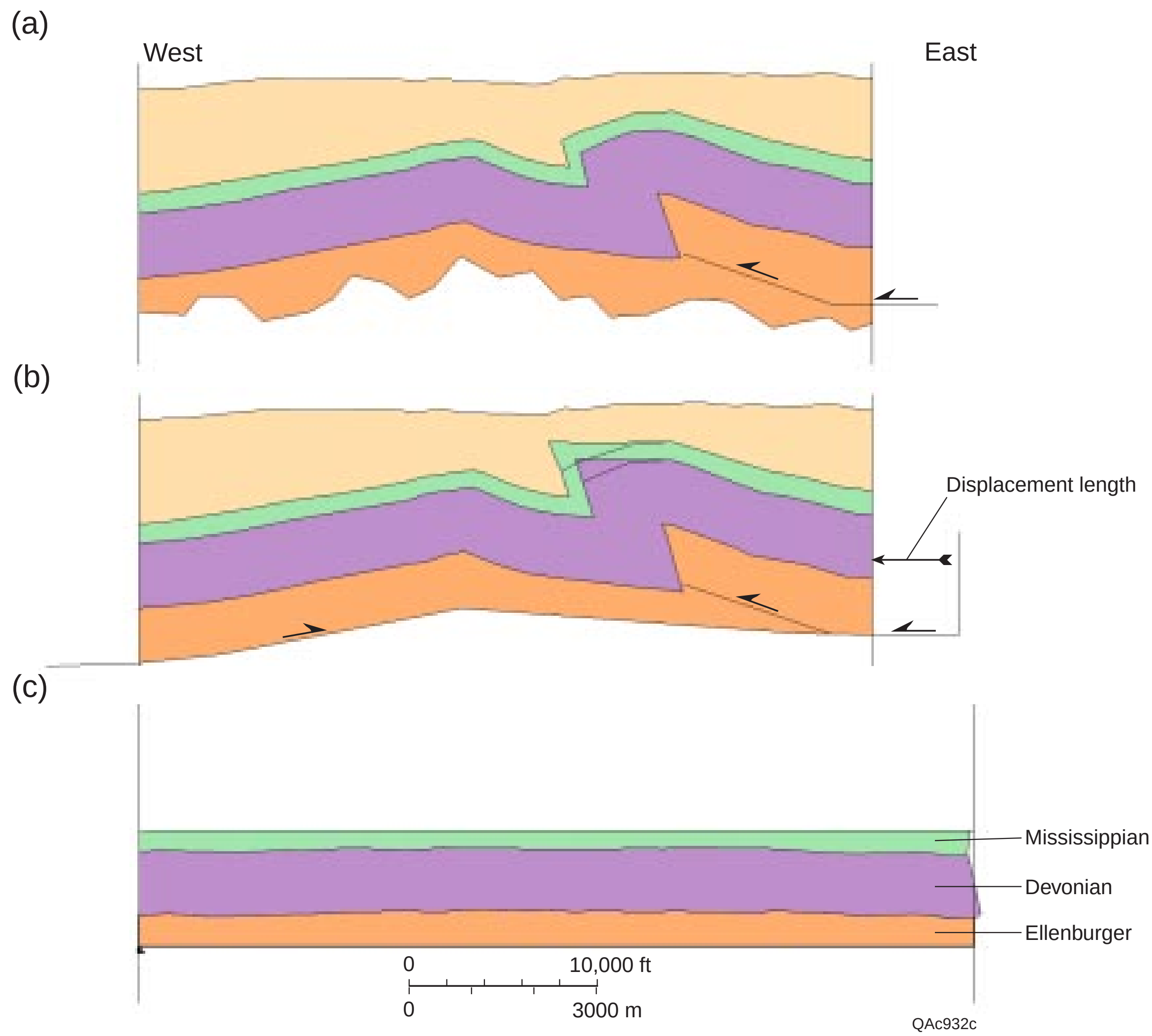

Figure 7. (a) Section 2 (Fig. 4) converted to depth with minor structures removed and overturned Mississippian and Devonian horizons added on front limb of fold to match deeper overturned beds recorded in well logs. The blind thrust shown is the type that formed the overturned fold. Base of section chosen at an arbitrary level. (b) Section shown in (a) modified to include thrust beneath the west part of the section and Mississippian and Devonian horizons inferred from forward modeling of folding above the blind thrust. Full arrow on east end of section indicates displacement needed to produce the fold shown. (c) Section in (b) restored to an undeformed Mississippian horizon. The section was pinned at the west boundary, so the uneven restored east boundary shows the deviation from constant bed lengths.