

# *Mississippian Barnett Shale, Fort Worth basin, north-central Texas: Gas-shale play with multi-trillion cubic foot potential: Reply*

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We thank Tom Ewing for his informative discussion to our recent article on the Barnett Shale. Ewing provides an excellent, useful review of geologic data concerning uplift and burial history in the Fort Worth basin. His discussion of this specific topic improves upon our own, adding significant detail that should aid future analyses of the Barnett. In particular, his inclusion of a major Mesozoic erosional event as a correction to our burial history curve for Eastland County (figure 7) is welcome. We also credit Ewing for noting the limits to existing data. He emphasizes that the amount of late Paleozoic subsidence and the precise timing of post-Permian uplift remain unknown, and that, as a consequence, reconstructions of burial history must therefore include both facts and inferences.

At the same time, we find problematic other interpretations in Ewing's discussion. One of these involves the use of burial history information (sedimentary and tectonic loading) to explain maturation patterns in the Barnett Shale. The other issue of concern relates to the westward extent of Ouachita thrusting.

As emphasized in our article, Barnett maturity levels in many parts of the Fort Worth basin are too high

and variable to be explained by the present-day basin setting. No consistent relationship exists between depth of burial and maturity level. For example, as shown in Figure 1, areas in the eastern part of the basin (Denton and Wise counties) at similar depths can exhibit widely different maturities, as measured by vitrinite reflectance data. Even using a logarithmic scale for the  $R_o$  data of Figure 1 yields a nonlinear plot, emphasizing the degree of variation. In several areas of the basin, rapid increases in maturity, from the oil to the dry gas window ( $R_o$  1.1 to >1.7%), occur over relatively short distances (e.g., 12 km [7.5 mi]). To help explain this phenomenon, we presented an explanatory scheme involving multiple episodes of subsidence and uplift (primary and secondary hydrocarbon generation), coupled with elevated heat flow associated with hot fluids generated by the Ouachita thrust front in the late Paleozoic. Such fluids we interpret to have migrated westward along preexisting zones of weakness, such as the Mineral Wells fault zone (shown in our original figure 1), which corresponds distinctly with one of the mentioned areas of elevated maturity. In his discussion of our article, Ewing offers an alternative interpretation, attributing the high-maturity areas to the effects of tectonic loading. He proposes that, in these areas, the thrust front originally extended tens of kilometers to the west from its present position, creating extra loading and a possible thermal lid that enhanced maturity in the subthrust (pre-upper Pennsylvanian) section.

Whereas both interpretive schemes are important to consider, we would argue that Ewing's approach is deficient in two respects. First, as shown by our iso-reflectance map (figure 6), the noted areas of elevated maturity do not easily support an explanation of thrust loading. These areas are distinctly linear or narrowly lobate and extend 30–50 mi (48–80 km) west of the mapped Ouachita front, into western Bosque and north-eastern Palo Pinto counties. The shape and dimensions of these areas are not consistent with structural patterns (e.g., salients) associated with thrust fronts, including other parts of the Ouachita system (see, for example, Thomas, 1977, 1991; Moreno et al., 2000). However, migration of thermal fluids from the Ouachita front and other thrust-fold systems has been established as a significant phenomenon (e.g., Appold and Nunn, 2005) with important geochemical effects including ore mineralization and, in some cases, remagnetization (Van Alstine et al., 1997; Elmore et al., 2000). Specific mechanisms for such migration include gravity (topography)-driven fluid flow and overpressuring in deep foreland basin settings (Appold and

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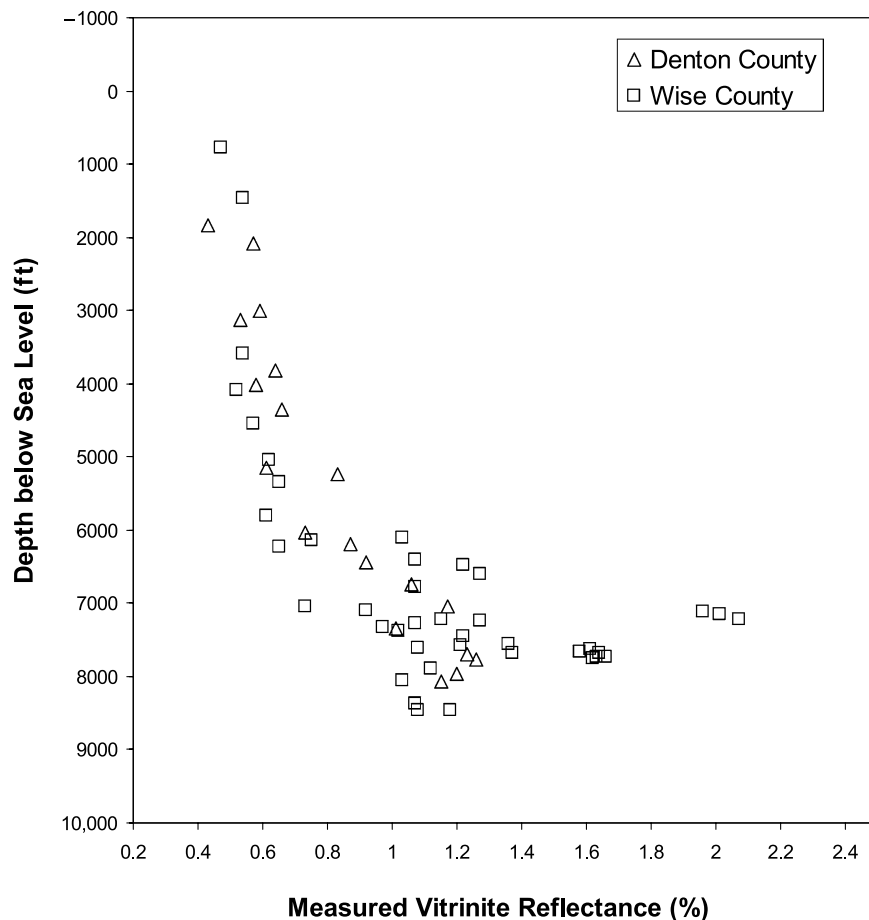
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**Figure 1.** Plot of vitrinite reflectance (in %) versus depth (relative to sea level) for the Barnett in Denton and Wise counties, north-central Texas.



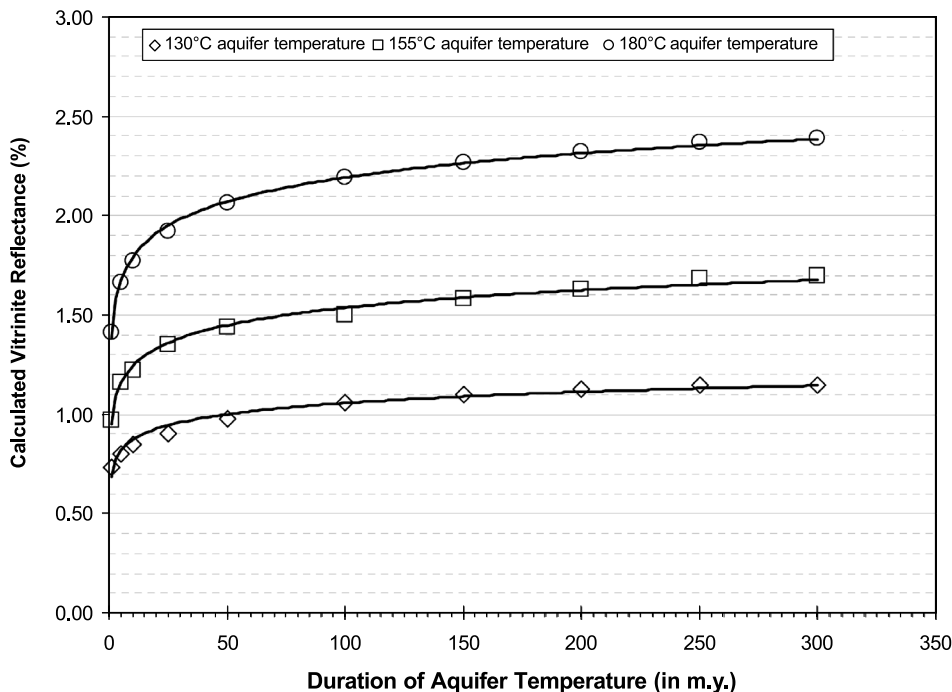
Nunn, 2005). Conduits include fault zones and fracture networks.

In this regard, hot water flow below the Barnett Shale, through parts of the karsted and fractured Ordovician Ellenburger, is currently being modeled by D. M. Jarvie to determine the potential effects on maturity levels. Preliminary results from this modeling are shown in Figure 2. These results indicate a rapid increase in vitrinite reflectance levels even over relatively brief periods of 5–10 m.y., with a larger degree of increase at higher temperatures. Detailed analyses of Ouachita deformation in north-central Texas are lacking, but regional tectonic studies suggest multi-phase deformation spanned most or all of the Pennsylvanian (~39 m.y. according to Harland et al., 1990), ending in the latest Pennsylvanian or earliest Permian (Poole et al., 2005). From Figure 2, it can be inferred that maturity patterns in the Fort Worth basin would have been significantly raised by repeated pulses of thrust-related fluid migration.

With regard to Ewing’s proposed westward extension of Ouachita thrusting, meanwhile, we would point out that this is countered by actual well and seismic

data. Such data show that, like other major thrust-fold systems, the Ouachita deformational front displays a well-defined terminal triangle zone in relevant foreland basins (Valderrama et al., 1996), including the Fort Worth trough. Dipmeter information from the Chevron 1 Mildred Atlas in eastern Johnson County, for example, indicates that the lower Pennsylvanian Atoka section dips 5–30° west-northwest, clearly showing that this location is near the western edge of the terminal triangle zone (note that our isoreflectance map of figure 6 misplots the location of this well 14 mi [22 km] to the west). Proprietary seismic data confirm that thrust-related thickening is entirely absent only several kilometers west of the Mildred Atlas well. Thus, thrust loading cannot be invoked to explain observed high maturity levels.

Unfortunately, relevant well and seismic data remain confidential and were not available for use in this report. We realize, of course, that such data are entirely necessary to substantiate the above discussion. We strongly hope that future studies of the Barnett will be able to incorporate this information and extend our knowledge of the Barnett further. Finally, we are



**Figure 2.** Modeling results regarding the influence over time of elevated fluid temperatures on vitrinite reflectance levels in the Barnett Shale.

indebted to Ewing for his contribution, thoughtfulness, and interest in correcting our work and inspiring continued fruitful debate about this extremely important unconventional gas reservoir.

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