Facies, Stratigraphic Relationships, and Fracturing in the Wapanucka and Spiro Formations (Pennsylvanian)

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Although gas production in the frontal Ouachita Mountains has been primarily from the Spiro Sandstone, limestone of the underlying Wapanucka Formation is locally a gas reservoir and thus is a secondary objective. An outcrop study of imbricate thrust sheets forms a basis for predicting the character of rocks in the subsurface.

The Wapanucka limestone crops out in the frontal Ouachita thrust system along the Choctaw fault (Fig. 1). The study area includes approximately 150 mi^2 along the northern margin of the Ouachita Mountains. Here, the Wapanucka–Spiro crops out as repeated thrust ridges in a narrow belt approximately 50 mi long and 5 mi wide just south of the Choctaw fault in Pittsburg, Atoka, and Latimer Counties in southeastern Oklahoma.

This paper is derived from the work done on a Master of Science thesis at Baylor University (Mauldin, 1996). The purpose of this Wapanucka study was to determine (1) detailed classifications by hand-sample and thin-section examination; (2) facies relationships; (3) distribution and geometry of each facies, particularly to define more precisely the location of the Wapanucka shelf margin; and (4) depositional environments. In addition, fractures were studied to determine their orientation, extent and intensity, and relationship to each lithofacies in the Wapanucka and Spiro. Five cross sections (see Mauldin, 1996) were constructed to demonstrate the vertical and lateral relationships of the Wapanucka, a middle shale (sub-Spiro), and the Spiro (Figs. 2,3).

Seven lithofacies were recognized in the Wapanucka out-

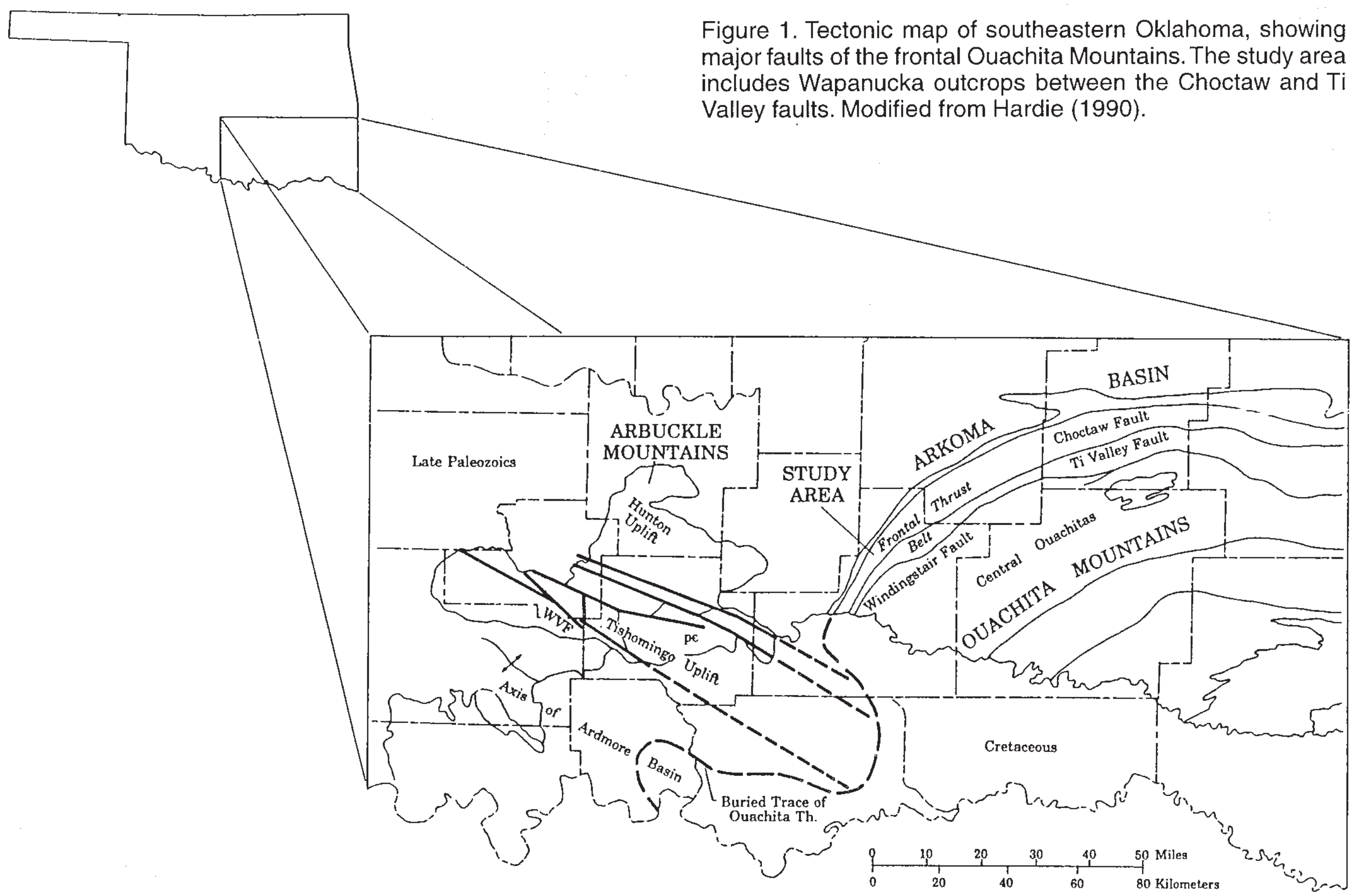

Figure 1. Tectonic map of southeastern Oklahoma, showing major faults of the frontal Ouachita Mountains. The study area includes Wapanucka outcrops between the Choctaw and Ti Valley faults. Modified from Hardie (1990).

Mauldin, D. L., 2000, Facies, stratigraphic relationships, and fracturing in the Wapanucka and Spiro Formations (Pennsylvanian), *in* Johnson, K. S. (ed.), Platform carbonates in the southern Midcontinent, 1996 symposium: Oklahoma Geological Survey Circular 101, p. 219–222.

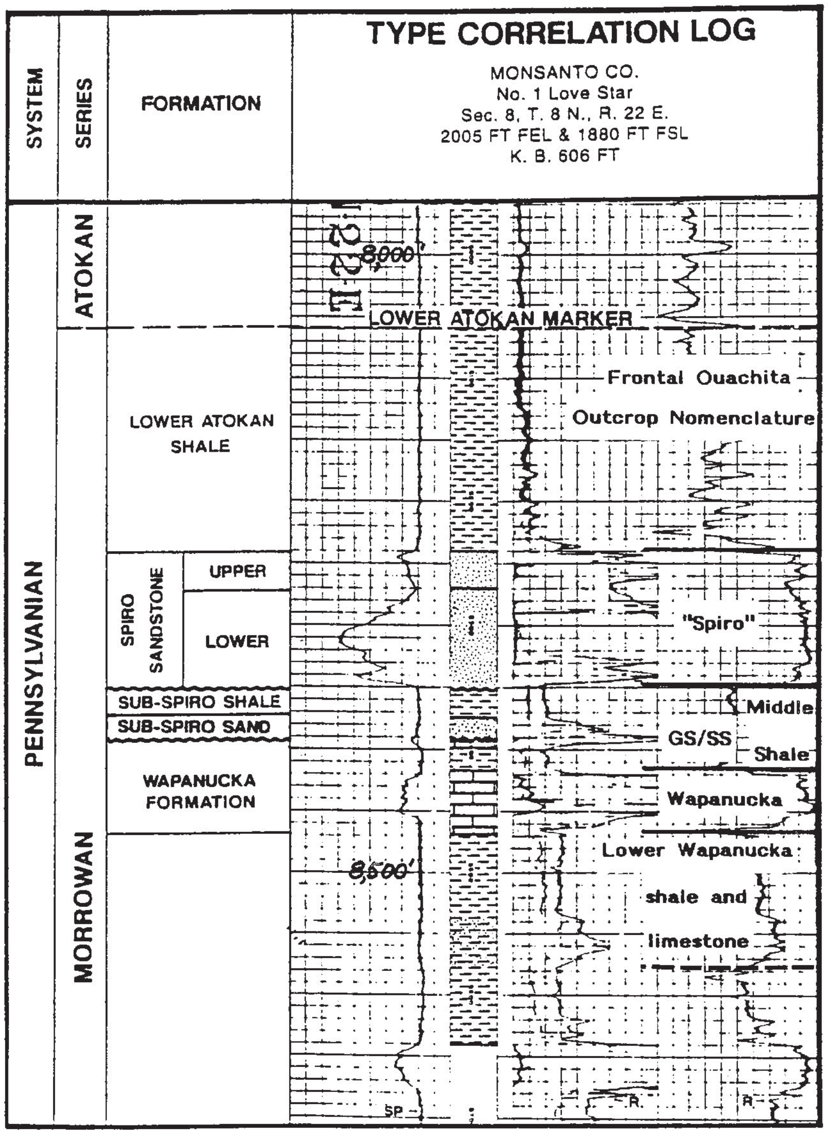

Figure 2. Frontal Ouachita outcrop nomenclature compared with a type correlation log for the Wapanucka and Spiro units. The right column shows the divisions and nomenclature for outcrops in this paper. The rest of the figure shows the subsurface nomenclature, age relations, lithologic character, and log character of upper Morrowan and lower Atokan units in the Arkoma basin and northern Ouachita Mountains (from Fritz and Hooker, 1994). Notice that the sub-Spiro sand of the subsurface is equivalent to the middle shale grainstone/sandstone (*GS/SS*) found at many outcrops. Also, the Wapanucka sequence in outcrop does not include any of the shale above the Wapanucka limestone, which has been included with the Wapanucka Formation for the subsurface. In addition to inclusion of the outcrop nomenclature with this figure, the Morrowan–Atokan series boundary has been moved up because the Atokan foraminifer *Profusinella* was not found in the Spiro either in outcrop (Groves and Grayson, 1984) or subsurface (Robert C. Grayson, Jr., personal communication, 1993).

crops. With the exception of the shale facies, deposition is generally a function of water energy and depth. From what are interpreted as roughly the shallowest to deepest water deposits, these facies are, in order: (1) "beach and near-beach," (2) oolitic calcarenite, (3) bioclastic grainstone/packstone, (4) foraminifer peloid packstone, (5) spiculitic limestone and sponge boundstone, (6) algal micritic limestone, and (7) shale.

The Wapanucka limestone is commonly characterized by upward-shoaling sequences. At the shelf margin (Fig. 4), these subtidal cycles are capped by shoaling carbonate sand bodies such as bioclastic and oolitic grainstones. In areas of paleotopographic highs, these shoal deposits can build up above sea level and form island beaches. Subaerial exposure is evidenced by the abundance of trees that grew on the islands, which are now preserved as large carbonaceous plant fragments that occur in the beach deposits. Foraminifer peloid packstones occasionally were formed as moderately agitated deposits on the flanks of the grainstone shoals.

Sponge boundstones and spiculitic limestones formed adjacent to the shelf margin, while phylloid algal bioherms formed in slightly deeper water (Fig. 5). Isolated sponges and sheetlike mats of sponge bioherms grew in fairly shallow water. Encrusting phylloid algae were abundant in localized areas. They formed in growth position in open-marine waters with tubular algae, and some of the phylloid-algal plates were found as higher energy bioclastic debris. Tubular algal (*Donezella*) boundstones were abundant in the deeper open-marine waters and occasionally formed small banks. Sponge spicules and fine clastics were transported to the lower shelf slope and deposited as spiculites and shale in the Chickachoc Chert (Fig. 4).

To gain a more thorough understanding of lithologic characteristics, lateral and basinward facies relationships, and the nature of depositional sequences is important, because well control and seismic data do not provide this kind of information. The detailed surface work performed in this study, however, has led to more complete information. These data could be used in association with subsurface geology to aid in hydrocarbon exploration.

The Wapanucka limestone contains several facies that are potential hydrocarbon-reservoir rocks. Therefore, a significant contribution of the study was identification of lithologies that might preserve primary porosity or those that might preserve fracture porosity and thus constitute possible reservoir facies.

The Wapanucka contains several facies associated with grainstone-shelf bars and phylloid-algal deposits that are possible reservoirs. These might contain primary or diagenetic porosity in the subsurface. Spiculitic limestones are highly fractured in outcrop, so they may contain fracture porosity in the subsurface.

Fracturing is believed to be of major importance to the reservoir potential of the Wapanucka limestone (Mauldin and Grayson, 1995). Studying the characteristics of fractures in imbricate-thrust outcrops of the Wapanucka allows the prediction of subsurface fractures. Numerous fractures in the frontal Ouachitas cut through bedding, and most of these are oriented perpendicular and/or parallel to strike.

This study proposes a new theory for depositional settings for spiculitic and algal limestones. Previous studies of the Wapanucka and other Paleozoic limestones of the Midcontinent usually assume that algal limestones are produced in very shallow water in lagoonal environments and that sponge and spiculitic limestones are deposited in deeper water, possibly even in a basinal environment. In the Wapanucka limestone, algal boundstones, wackestones, and mudstones were the deepest in-situ carbonate deposits, and the sponge boundstones and the spiculitic-limestone facies were deposited in shallow water, mostly near the shelf margin (Fig. 5).

An understanding of the stratigraphic boundaries and lithofacies of the Wapanucka, the middle shale (termed *sub-Spiro shale* for the subsurface), and the Spiro will lead to a better prediction of the location of potential petroleum reservoirs. Although the Spiro rests uncon-

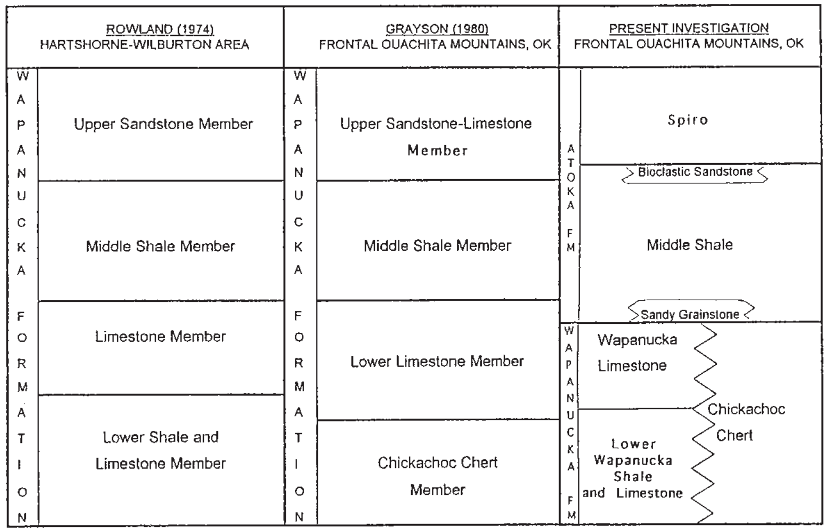

Figure 3. Stratigraphic divisions of this study and previous studies. Earlier informal stratigraphic subdivisions of the Wapanucka, middle shale, and Spiro are compared with those recognized in this study (at right). Modified from Grayson (1980).

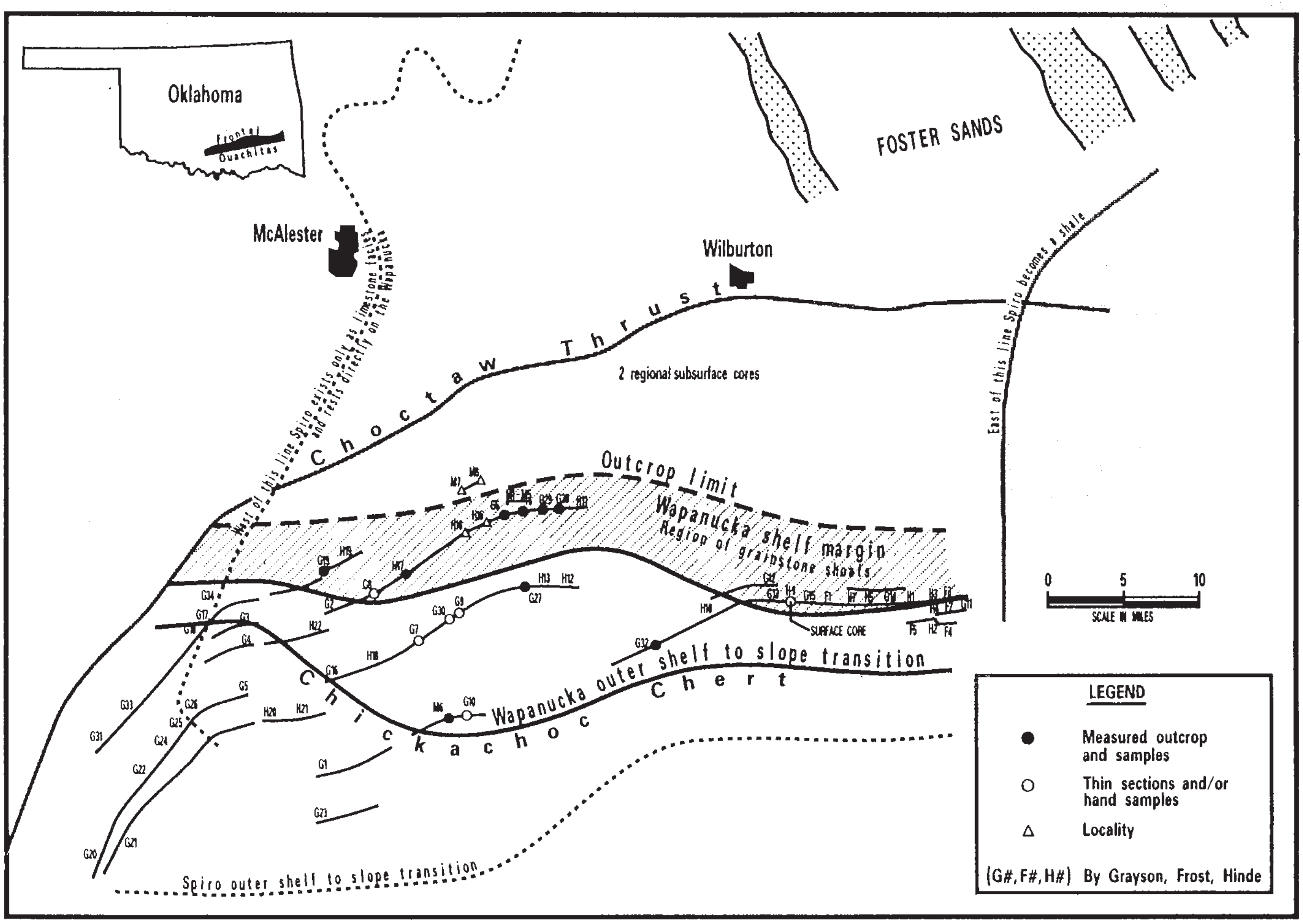

Figure 4. Palinspastic restoration of the Wapanucka shelf and outcrop locations in the frontal Ouachitas, southeastern Oklahoma. (Sample sites and outcrops are shifted 5–20 mi south of present position owing to palinspastic restoration.) The Wapanucka limestone contains grainstone shoals that were deposited as shelf bars on the outer part of a broad platform. Sponge-boundstone and algal-boundstone facies were deposited basinward of the shelf margin. The Chickachoc Chert was deposited on the lower shelf slope (adapted from Hinde, 1992). Locality number prefixes: *M* numbers denote localities described in this study; *H* numbers are from Hinde (1992); *F* numbers are from Frost (1981); *G* numbers are from Grayson (1980).

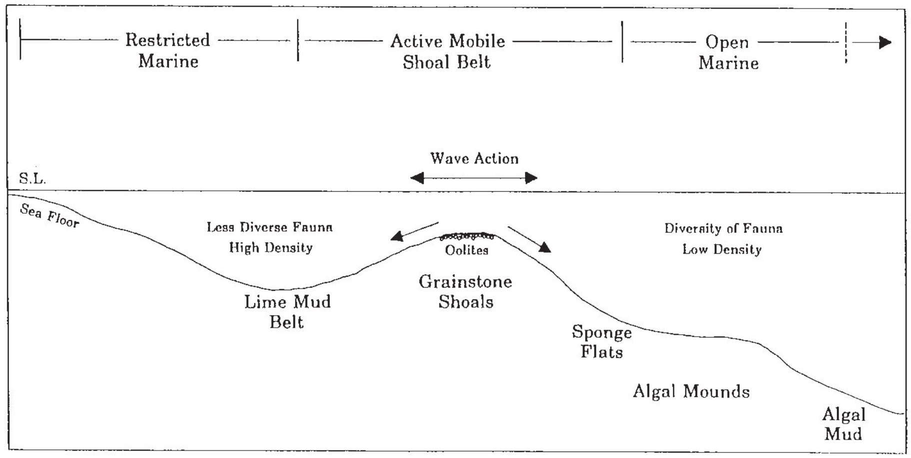

Figure 5. Generalized depositional model for Wapanucka limestones. *S.L.* = sea level. Grainstone shoals and basinward deposits of the Wapanucka crop out in the frontal Ouachitas of southeastern Oklahoma.

formably on the Wapanucka in some parts of the Arkoma basin, the base of the Spiro and the top of the Wapanucka are conformable surfaces throughout the frontal Ouachita outcrops. Small, discontinuous deposits of cross-bedded sandy calcarenites and bioclastic sandstones commonly occur within the middle shale sequence (Fig. 3). These are commonly referred to as the *sub-Spiro sand* for the subsurface (Fig. 2) and can make distinguishing the base of the Spiro and the top of the Wapanucka difficult.

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