CHAPTER 7:

CONCLUSIONS

Eastern Kansas is the setting of active coalbed gas exploration and development. Desmoinesian Stage (Middle Pennsylvanian) strata in the Bourbon arch contain numerous thin (<2 ft. [0.6 m]) coal seams at sufficient depth (>100 ft [>30m]) for coalbed gas production. However, continued development and expansion into the study area is hindered by the lack of both geologic data and clear resource evaluation. Mapping coal seam extents, distributions, and thicknesses; evaluating coal quality, gas content trends, and coalbed gas resource; interpreting depositional environments of coals and adjacent strata; and placement of coal-bearing strata into a sequence stratigraphic framework may permit better understanding of the geologic controls on coalbed gas. The following conclusions summarize the findings of this study:

1. Cherokee and Marmaton group strata of the Bourbon arch are classified into 13 lithofacies. The coal facies (1) formed from peat accumulation, burial, and coalification in non-marine mires. The underclay facies (2) is interpreted as paleosols formed from pedogenic alteration of existing deposits. Many paleosols in the Desmoinesian of the Bourbon arch are weakly developed and immature. The black shale facies (3) was deposited by low energy sediment fallout in anoxic to dysoxic deep-marine shelf environments, whereas the gray shale facies (4) was deposited in more proximal marginal-marine estuarine basins or offshore transition areas by periodic sedimentation and sediment fallout. The heterolithic siltstone (5) and sandstone (6) facies formed by tidal

processes of varying energies in flats or channels in estuaries and coastlines. The mudstone-wackestone limestone facies (7) formed in low-energy open marine or subtidal to intertidal marine carbonate environments. The packstone-grainstone limestone facies (8) formed in higher energy carbonate settings such as intertidal shoals, channels, or as overbank deposits; or as open-marine storm deposits. The Chaetetid boundstone-rudstone facies (9) formed in shallow, high-energy, open-marine settings; or by subaerial exposure or high-energy current reworking of such deposits. The conglomerate facies (10) is residuum from weathering of Mississippian Limestone, or as bar deposits in fluvial channels. The cross-bedded sandstone facies (11) formed from high-energy unidirectional traction currents as migrating dunes in fluvial channels. The interbedded siltstone-sandstone facies (12) was deposited in non-tidal prodelta or deltafront settings by periodic unidirectional traction current sedimentation and sediment fallout processes. The bioturbated sandstone facies (13) formed by current or biological sediment reworking during transgression or storm action.

2. Bourbon arch coals have elongate, lenticular, circular, and pod-like seam geometries. In the Bourbon arch, coal seam extents range from 1150 to 4250 square miles (2980 to 11,010 km^2) and extend into adjacent basins. Coal continuity ranges from approximately 230 to 3990 square miles (600 to 10,340 km^2). In the study area, average coal thickness ranges from 0.4 to 1.5

feet (0.1 to 0.5 m) and the maximum observed coal thickness is 3.8 feet (1.2 m; Croweburg coal). The Bevier is the most extensive, continuous, and overall thickest coal. Coal thickness in the Bourbon arch is lower than in the Cherokee basin.

Ash content ranges from 6.6 to 74.1 % (moisture-free weight percent). Sulfur content ranges from 2.0 to 8.7 % (moisture-free weight percent). Bourbon arch coals have caloric values (moist, ash-free) ranging from 12731 to 14912 Btu/lb, and rank from high-volatile C- to A-bituminous.

3. Coalbed gas contents (without residual gas) from core and cuttings samples in the Bourbon arch region range from 5.2 to 142.8 scf/ton (as received) and 16.7 to 181.3 scf/ton (moisture-, ash-free basis). Average gas contents for individual coal seams range from 5.2 to 98.6 scf/ton (as received) and 20.2 to 114.2 scf/ton (moisture-, ash-free basis). Coals in the Bourbon arch with the highest gas contents include the Riverton, Neutral, Rowe, Scammon, Mineral, Bevier, Lexington, and Mulberry. In general, gas contents of coals in the Bourbon arch are less than gas contents of coals in the Cherokee basin. Coalbed gas content increases with increasing average coal thickness, increasing coal rank, and with increasing depth in the Bourbon arch. Gas contents are higher in the southern and western portions of the study area. Several individual coals exhibit weak trends of increasing gas content with

increasing ash content. However, no correlation exists between gas and ash content for eastern Kansas coals when compared collectively.

4. Original gas in place (OGIP) estimated for 14 individual coal seams (>1 ft [0.3 m] thickness) in the Bourbon arch ranges from 12.0 bcf (Summit coal) to 489.6 bcf (Bevier coal). The total original gas in place (TOGIP) is 2.07 tcf. Based on available gas content and volumetric data, coals with the greatest coalbed gas potential include the Bevier, Riverton, Scammon, Mulky, Mulberry, Neutral, and Mineral. Across the Bourbon arch, total net coal ranges from 0 to 22 feet (0 to 6.7 m) thick, averaging 9.0 feet (2.7 m).

5. Gas isotope analysis suggests that Bourbon arch coal gas samples originate from a mixed thermogenic and microbial origin. Dominantly microbial gas is present in some shallow coals and shales in structurally updip parts of the study area. Some coals with shallow indigenous microbial gas have higher gas contents than deeper coals within the same well or have the highest gas contents within a single well. Thermogenic origin of coalbed gas increases westward and southward with structural depth. Thermogenic gas typically generates higher gas contents than does microbial gas.

6. Numerous variables influence coalbed gas potential and expansion northward into the Bourbon arch. Factors include the probability of encountering

numerous coals within a single well, pre-existing pipeline infrastructure, inexpensive formation water disposal, low drilling costs, increasing demand and prices for natural gas, fallback and upside opportunities, and the industry-friendly nature of eastern Kansas.

7. Nine sequences were identified across the Bourbon arch. Two sequences in the Marmaton Group and 6 sequences in the Cherokee Group are regionally correlative across eastern Kansas. One sequence occurs in Atokan(?) strata below the Riverton coal and onlaps the Mississippian Limestone of the Bourbon arch from Forest City basin to the north. Transgressive systems tract (TST) and highstand systems tract (HST) deposits dominate sequences in the Bourbon arch. Lowstand systems tract (LST) deposits were infrequently observed in core or well log.

   Sequence stratigraphy provides insight to the lateral extent, distribution, and continuity, and relative thickness of Bourbon arch coals. Mapping Bourbon arch coals reinforces the hypothesis of Aitken (1994) that 1) the thickest, best-developed coals occur adjacent to the maximum flooding surface (MFS)—a position defined by high accommodation and slowly rising sea level; and 2) coals tend to thicken and become better developed through the LST and TST up to the MFS, while coals tend to thin and be less developed above the MFS. LST coal development is hindered by low accommodation, channel incision, and net erosion during the relative sea-level fall. Decreasing accommodation, high sediment supply, and the increased likelihood of removal by overlying incision during sea-level fall hinders HST coal development. The Riverton, Tebo, Mineral, Croweburg, Bevier, and Mulky coals are the best-developed coals within the Bourbon arch. These coals are all associated with MFS black shales.

8. Depositional models were created using interpretations of surrounding strata and coal seam characteristics. The surface separating coal from underlying strata represents a significant depositional hiatus. As a result, coal and underlying sediments are not contemporaneously related. Underlying strata provide a framework for peat accumulation rather than directly influence deposition. Bourbon arch coals formed in a variety of peat-forming environments including association with pre-Pennsylvanian topography, coastal plain settings, estuarine incised valleys, and ensuing transgression following marine regression. Depositional environments do not influence coal seam characteristics (average thickness, extent, and continuity). Depositional environments are related to ash content. Marine regression coals typically have higher ash contents than other depositional environments due to peat accumulation proximal to active deposition.

   In the northern Bourbon arch, three coals (Summit, Mulky, and Lexington) were influenced by minor NW-SE and SW-NE-trending, syndepositional fault movements. These three coals exhibit similar NW-SE isopach trends that correlate to magnetic and gravity gradients of basement rocks.

9. The most significant controls on coalbed gas in the Bourbon arch are depth, stratigraphic position, and depositional environment. Discerning the degree of control each factor has on gas content is difficult given the complex interaction of these variables. Gas content increases with depth, except for microbial gas fairways in shallower parts of the Bourbon arch. Sequence stratigraphic position, at first glance, does not appear to influence coalbed gas content. However, gas content increases with greater average coal seam thickness—a characteristic influenced by proximity to the maximum flooding surface within a depositional sequence. Additional sampling may lead to more direct correlation between gas content and sequence stratigraphy. Depositional environments of coal-bearing strata appear to be correlative to coalbed gas content, where marine regression coals have lowest gas contents, estuarine and coastal plain environments have relatively intermediate gas contents, and coals influenced by pre-Pennsylvanian topography have the highest gas contents. However, this correlation is strongly dictated by coal seam depth and relative stratigraphic position within the Cherokee and Marmaton groups. Marine regression coals are biased towards the younger and shallower upper Cherokee and lower Marmaton groups. Coastal plain and estuarine environments are positioned in the mid-Cherokee and at

intermediate depths. Pre-Pennsylvanian topographic-influenced coals are biased to the lower Cherokee Group, and are typically the deepest coals in eastern Kansas.

The Bourbon arch of eastern Kansas may provide a considerable supply of natural gas. This study provides refined coal isopach maps, improved understanding of the geologic controls on gas content, and resource evaluation.