CHAPTER 1:

INTRODUCTION

1.1 Introduction

The Middle Pennsylvanian Series in east-central Kansas includes numerous coal seams within both siliciclastic and mixed carbonate-siliciclastic sedimentary successions, or "cyclothems" (Jewett et al., 1968). Of 32 identified coals in the Pennsylvanian, the majority is found in the Cherokee and Marmaton groups (Desmoinesian Stage). Pennsylvanian strata in eastern Kansas are estimated to contain 53 billion tons (48 billion metric tons) of "deep" (>100 ft [>30m]), but thin (<2 ft. [0.6 m]) coal ranging in maturity from high-volatile C- to A bituminous. Coals with the largest resources are the Riverton, "Aw", Weir-Pittsburg, Mineral, and Bevier (Harris, 1984; Brady, 1997). Coals discussed in this study include the aforementioned, as well as the Mulberry, Lexington, Summit, Mulky, Croweburg, Scammon, Tebo, Dry Wood, Rowe, and Neutral coals (Fig. 1.01).

Eastern Kansas, particularly southeastern Kansas, is the setting of an evolving coalbed gas play (Newell et al., 2002). The northward expansion of this play from the Cherokee basin into the Bourbon arch region may be aided by the objectives of this thesis project. These objectives include:

1. Lithologic description and interpretation of the depositional environments of Desmoinesian coals and surrounding strata;
2. Mapping of the regional extents and thicknesses of significant Middle Pennsylvanian coals;
3. Evaluation of coals and surrounding sediments using current sequence stratigraphic concepts;

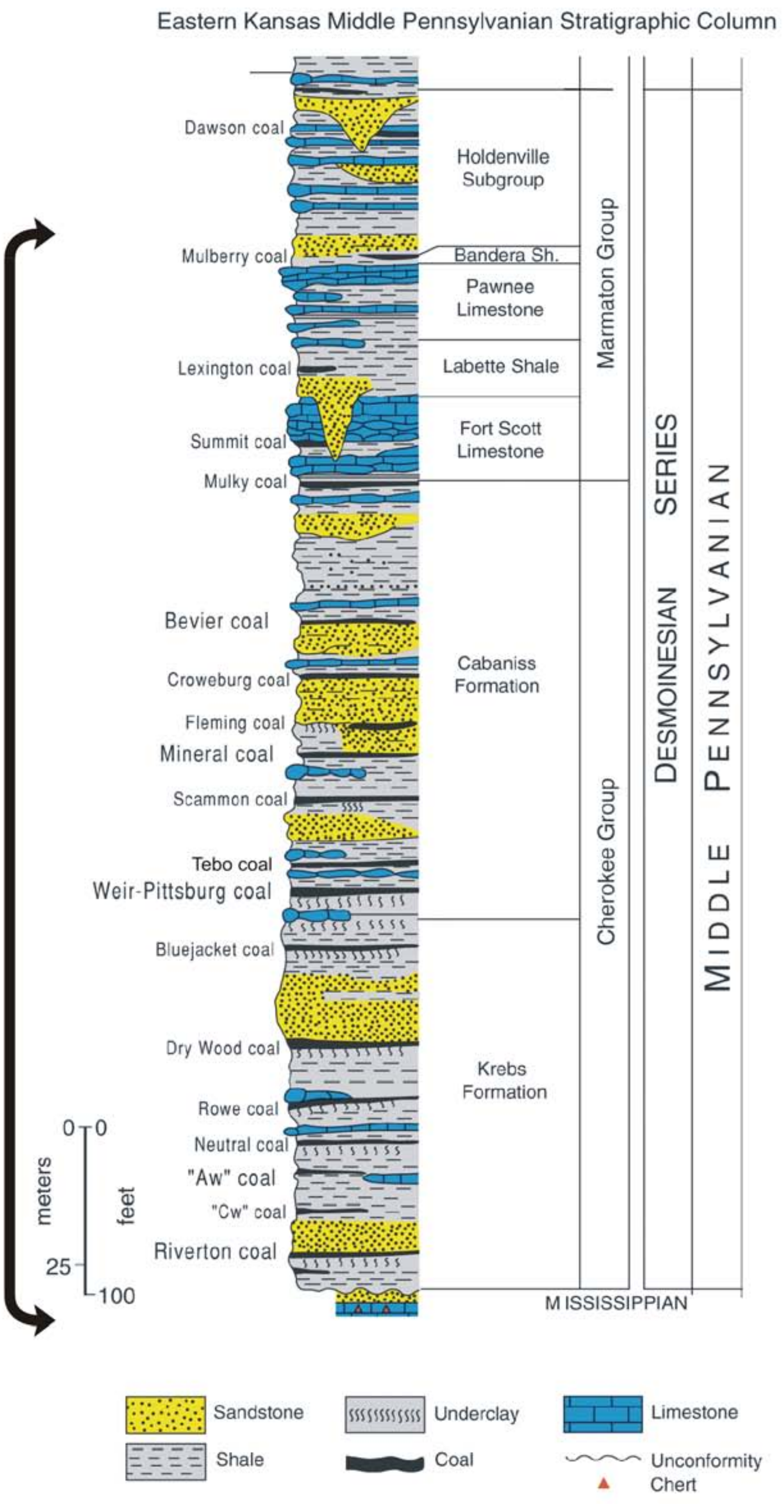


Figure 1.01 Desmoinesian stratigraphy in Kansas (modified from Zeller, 1968). Arrows indicate stratigraphic limits of the current study.

4. Discerning trends in gas contents across the study area and attempting to better understand the distribution of coalbed gas;
5. Assessing the coal gas resource potential for the study area utilizing estimates of original gas in place and coal isopach maps;
6. Determination of possible controls on coalbed gas productivity including depositional environments of the coals and their sequence stratigraphic position;
7. Developing a more comprehensive picture of the depositional history of eastern Kansas.

This study is second in a series of graduate research theses at the Kansas Geological Survey, Lawrence, KS, with the common objective to evaluate coalbed gas resources in eastern Kansas. Lange (2003) authored the initial study with a coalbed gas resource investigation of the Cherokee basin. This study extends the investigation northward into the Bourbon arch region. A third study by W.M. Brown (in progress) will extend this research northward into the Forest City basin. At the time of this writing, the Kansas Geological Survey anticipates additional research encompassing all of eastern Kansas to integrate the three regional Master's theses, as well as including previously unevaluated counties flanking the Nemaha uplift (T.R. Carr, personal communication, 2004).

1.2 Study Area

The area of investigation encompasses approximately 4040 square miles (10,463 sq. km; 2,585,000 acres) across 132 townships and eight counties in east-central Kansas (Fig. 1.02). Counties in the study area are: Johnson (townships 14 and 15 south; ranges 21, 22, 23, 24, and 25 east), Franklin, Miami, Anderson, Linn, Woodson (townships 23, 24, 25, and 26 south; ranges 15, 16, and 17 east), Allen, and Bourbon. Geologically, the study area covers the Bourbon arch and its flanks. Coal of the upper Cherokee and Marmaton groups is exposed at the surface along a NE-SW trending belt through eastern Bourbon and southeastern Linn counties (Fig. 1.02).

1.3 Geologic Background

1.3.1 Tectonic History

The Bourbon arch, located in east-central Kansas, is a low, WNW-ESE-trending structural feature that separates the Forest City basin from the Cherokee basin (Fig. 1.02; Jewett, 1951). The Bourbon arch and adjacent basins are bound by the Nemaha uplift to the west, the Ouachita foldbelt to the south, and the Ozark uplift to the east. The Ozark uplift is post-Mississippian, pre-Pennsylvanian (Morrowan) in age, and contemporaneous with the Central Kansas uplift and Cambridge arch in central Kansas and Nebraska (Fig. 1.03; Rascoe and Adler, 1983). It remained a positive tectonic feature well into the Permian and was a source of sediment for the study area.

The Wichita Orogeny was responsible for larger-scale orogenic features in the mid-continent such as the ancestral Front Range, Arkoma basin, and Ouachita Mountains, as well as more regional, interrelated tectonic features such as the Nemaha uplift, Bourbon arch, and the Cherokee basin (Rascoe and Adler, 1983). The

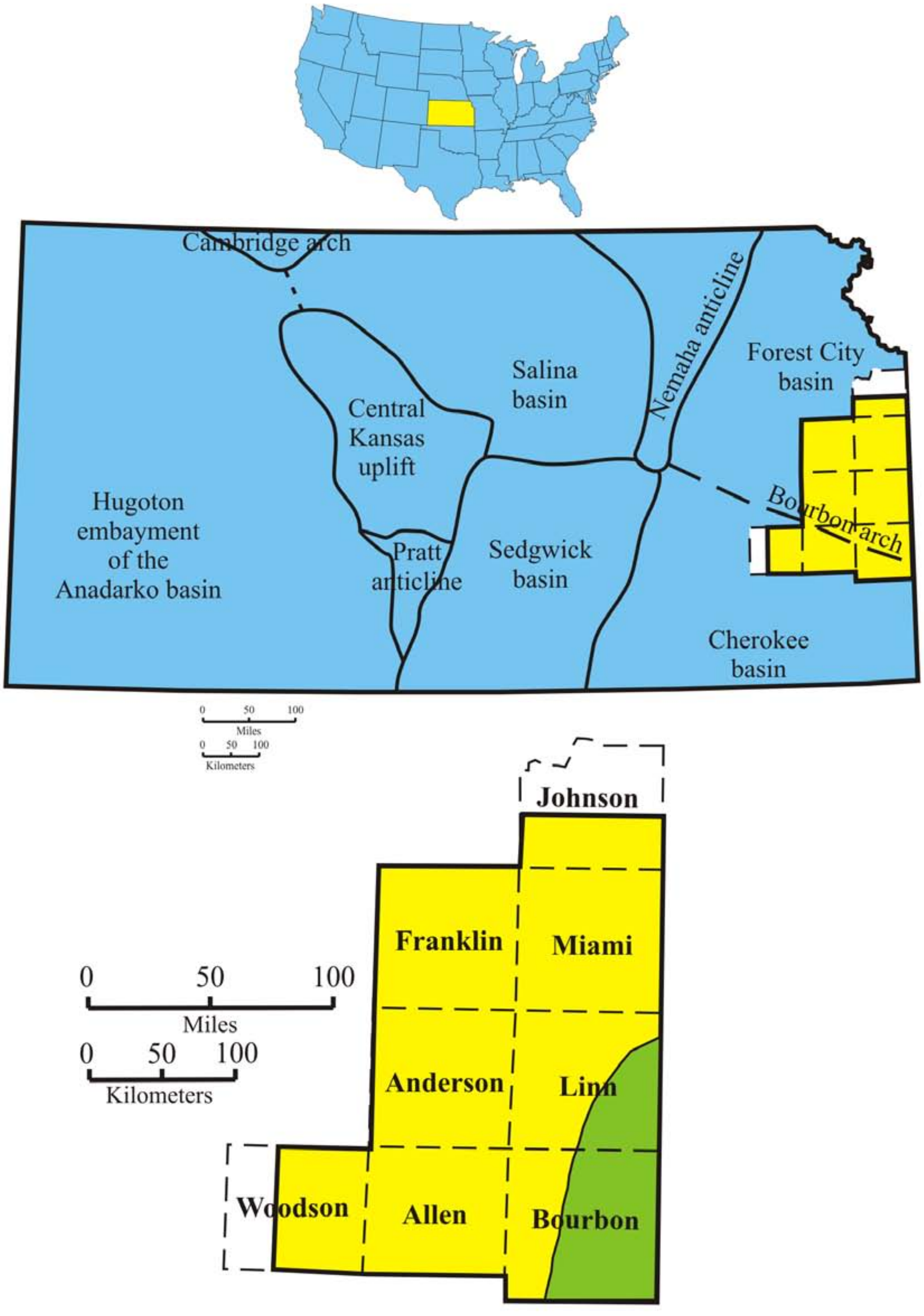


Figure 1.02 Generalized tectonic map of Kansas showing the study area limits (yellow counties) and outcrop region of the Marmaton and Cherokee groups (green; modified from Jewett, 1951).

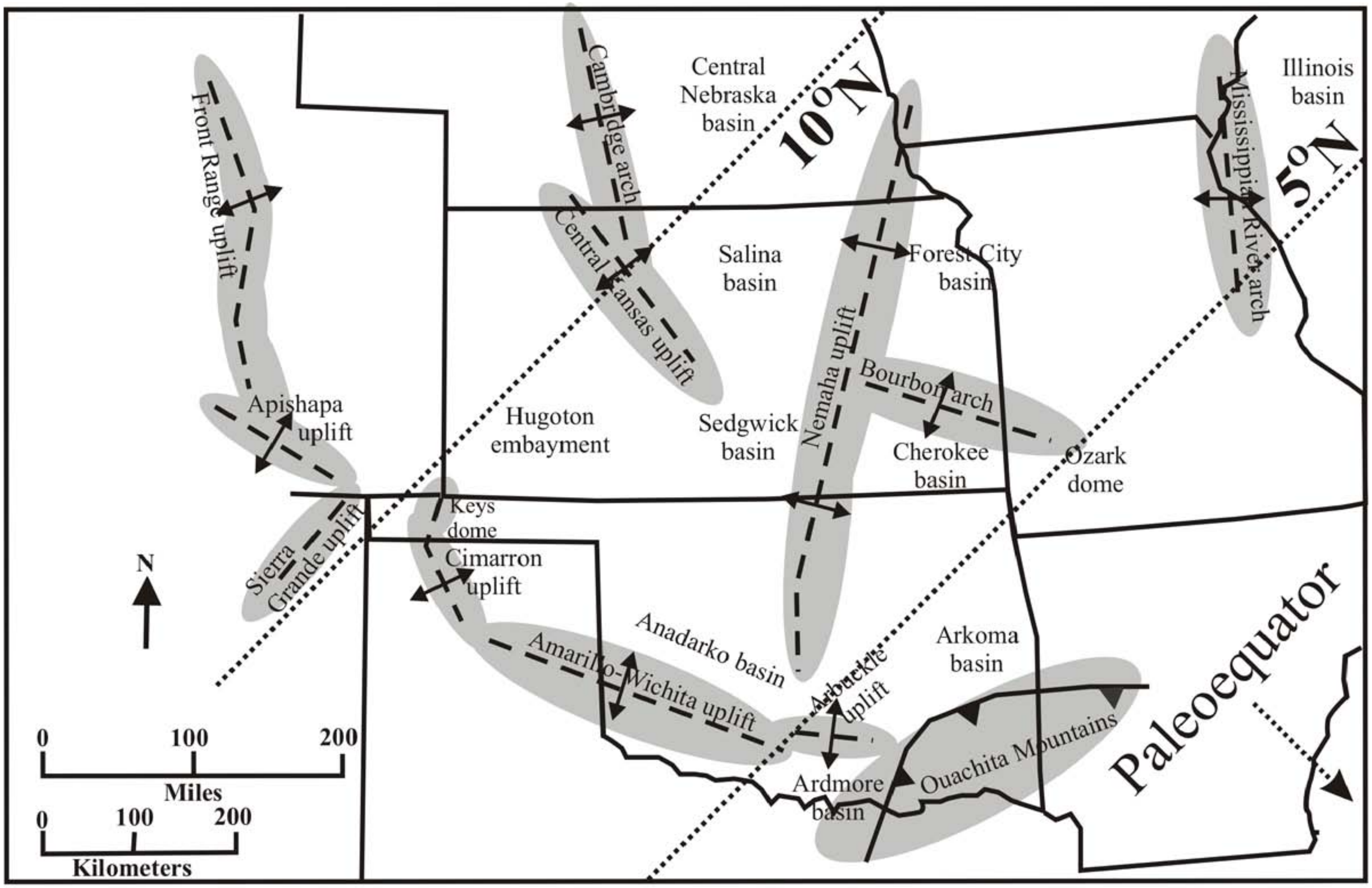


Figure 1.03 Interpreted paleolatitude and major structural features of the midcontinent during the Pennsylvanian Period (modified from Wanless, 1969; Heckel, 1977; and Lange, 2003).

Wichita Orogeny has been interpreted as part of a continent-arc collision between the North and South American plates during Middle Pennsylvanian (late Morrowan to early Desmoinesian; Fig. 1.03). Initial subsidence in the Forest City and Arkoma basins coincided with late Morrowan to early Atokan activity along the Ouachitas in present-day southern Oklahoma. The Nemaha uplift also became active at this time and divided the Forest City basin from the Salina basin. During the early Pennsylvanian, the Bourbon arch and Cherokee basin remained subaerially exposed, developing a karsted surface on Mississippian carbonates. Morrowan, Atokan, and Desmoinesian sediments onlap the karsted Mississippian surface northward from the Arkoma basin. Atokan and younger sediments onlap this karst surface southward from the Forest City basin (Lee, 1943; Anderson and Wells, 1968; Rascoe and Adler, 1983).

The Cherokee basin (known as the Cherokee shelf in Oklahoma) formed north of a hinge-line of the Arkoma basin. This hinge-line migrated shelfward (northward) due to subduction of the North American plate in the late-Atokan and early Desmoinesian (Rascoe and Adler, 1983). In the early Desmoinesian, a cratonic sea transgressed northward and sediments began infilling the Forest City, Cherokee, and Arkoma basins (Lee, 1943; Anderson, 1965). Sediments in the region are postulated to have a north- to northeasterly provenance during the Desmoinesian (Rascoe and Adler, 1983). The Nemaha uplift reached maximum structural development at the end of Desmoinesian and remained a positive feature until inundated during Missourian deposition of the Kansas City Group (Lee, 1943).

1.3.2 Desmoinesian Stratigraphy

Desmoinesian stratigraphy in Kansas has been extensively researched and classified for more than a century—the latest by researchers at the Kansas Geological Survey (Harris, 1984; Killen, 1986; Staton, 1987; Huffman, 1991; and Lange, 2003). Recent studies have focused on numerous aspects of Desmoinesian stratigraphy including correlation, nomenclature and classification, coal and sandstone occurrence and thickness variation, depositional environments, and sequence stratigraphy.

The first published description of the Cherokee Group by Haworth and Kirk (1894) was based on study of outcrops along the Neosho River in Cherokee and Labette counties, southeastern Kansas. Haworth and Crane (1898) made first use of coal marker beds to describe Cherokee strata. Others followed suit with various classification schemes, however, the first application of cyclic sedimentation concepts to Middle Pennsylvanian strata in this region was by Weller (1930) with his development of the Illinois-type cyclothem. Soon afterward, Moore (1931) applied the cyclothem concept to Upper Pennsylvanian of Kansas. Moore (1936) extended the "Kansas-type" cyclothem concept to Middle Pennsylvanian strata. Abernathy (1936) defined 15 cyclic units in the Cherokee Group. Howe (1956) defined 18 cyclothems in the Cherokee Group and suggested that each be considered a separate formation. Jewett et al. (1968) established the current stratigraphic classification. More recent investigations by Heckel (1977) refined the concepts of "Kansas-type" cyclothems by redefining the point of maximum transgression from within fusulinid-bearing limestone to within the phosphatic black shale (Fig. 1.04).

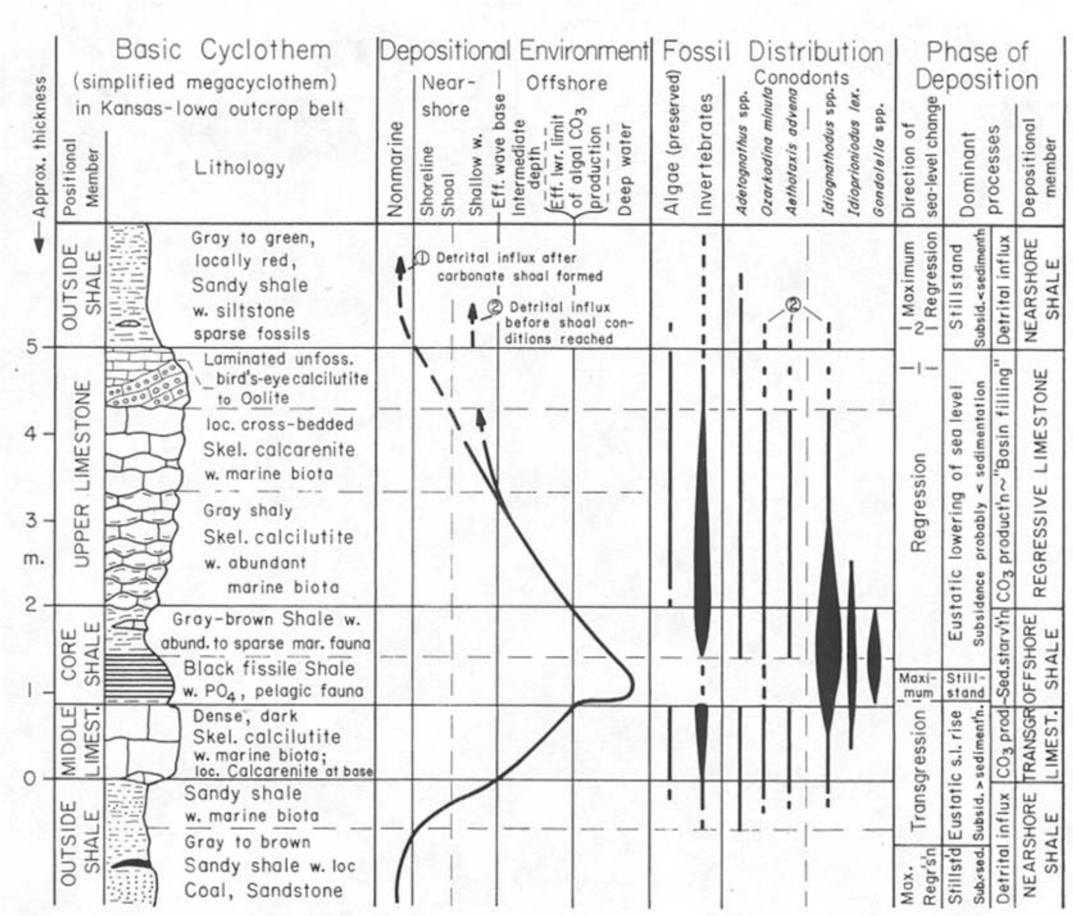


Figure 1.04 The four major lithological components of a typical Kansas cyclothem (outside shale, middle limestone, core shale, and upper limestone) and their relation to depositional environment, sea level, and fossil distribution (from Heckel, 1977).

The "typical" Kansas-type cyclothem consists of the following lithologies, in ascending order, 1) a sandy to shaley "outside" shale of nearshore to nonmarine origin, possibly including a coal at the top, 2) a dense, dark "middle" transgressive limestone, 3) a black, fissile, sometimes phosphatic offshore "core" shale, and 4) a thick, regressive "upper" marine limestone, which is overlain by another marginalmarine to nonmarine “outside” shale and possible coal (Fig. 1.04; Heckel, 1977). Given fluctuating sea levels, any part of the cyclothem may be missing; either eroded or not deposited.

1.3.3 Paleoclimate

Paleogeographic reconstructions of North America during the Pennsylvanian place eastern Kansas in an equatorial climate between 0° and 10° N latitude (Fig. 1.03; Heckel, 1977; Golanka et al., 1994). All major coal deposits of the Pennsylvanian are found within 8° north and south of the interpreted paleoequator, which paralleled the Appalachian orogenic belt. Redbeds and evaporites are found between 8° and 15° N. A near-equatorial Pennsylvanian climate is evident in eastern Kansas from the numerous coal seams, which required enough fresh water to sustain a high water table for peat formation, as well as the semi-vertic, and pedogenically-zoned nature of underlying paleosols (this study). Although coal itself is not an indicator of any particular paleoclimate, these surrounding sedimentary features indicate a very wet, humid climate with seasonally heavy rainfall (McCabe, 1984; Retallack, 2001).

The Pennsylvanian Period can be characterized as a time of transition from seasonally wet, humid environment in Early Pennsylvanian, to a wet and dry, but more arid environment by the end of Late Pennsylvanian. This transition is evident by the presence of highly humic, organic-rich sediments directly overlying a well-developed Mississippian carbonate karst surface; increasing occurrence of limestone and decreasing occurrence of coal and unoxidized paleosols through the

Pennsylvanian; and the appearance of red, oxidized paleosols and evaporites by Late Pennsylvanian and Early Permian (Cecil, 1990).

1.4 Hydrocarbon Significance

In recent years eastern Kansas has been the setting of a developing coalbed gas play (Newell et al., 2002, 2004). Although the majority of the activity is concentrated in the Cherokee basin of southeastern Kansas, northward expansion across the Bourbon arch and into Forest City basin is underway (Fig 1.05A). The direction of expansion is partly controlled by pre-existing pipeline infrastructure (Fig. 1.05B). Although coalbed gas operations and pilot projects have evolved in eastern Kansas for over a decade — especially during the past three years — exploration and development programs are still hindered by the lack of data and clear resource evaluation (Newell et al., 2002). The objectives of this study — specifically the mapping of coal extents and thicknesses; evaluation of coal gas contents, trends, and quality; understanding the geologic factors associated with coalbed gas production; and an improved coalbed gas resource assessment—may further aid in play assessments. With greater information, there may be renewed interest and production in a petroleum province once thought to be in the declining stages (Newell et al., 2002; Johnson et al., 2003).

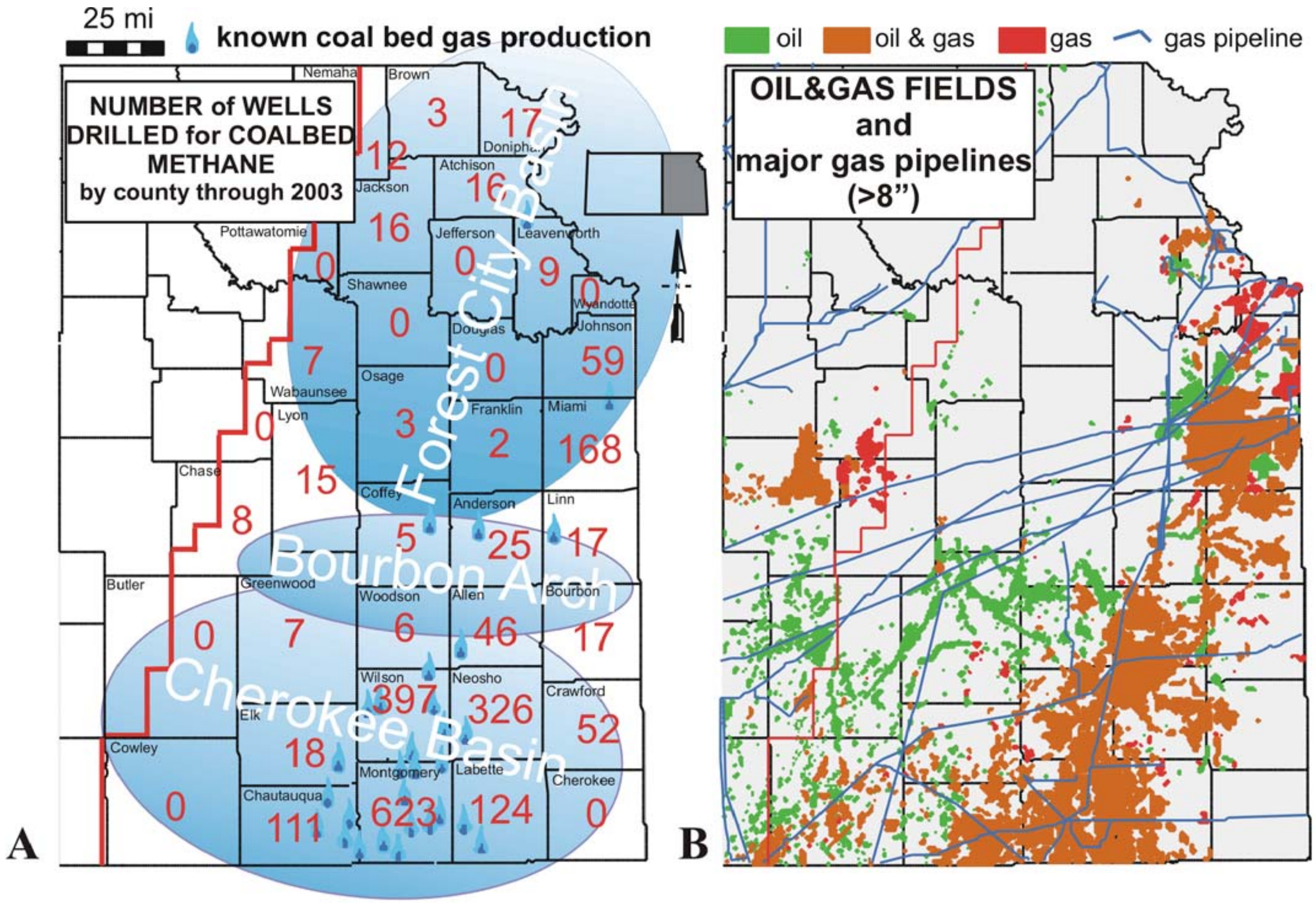


Figure 1.05 (A) map of eastern Kansas showing the distribution by county of coal bed methane wells drilled between January, 1999, and December, 2003; and (B) the same map showing the distribution of conventional oil, gas, and mixed reservoirs in eastern Kansas, along with the existing pipeline infrastructure (modified from Newell et al., 2002, Lange, 2003).

1.5 Methods of Investigation

This study focuses on geologically significant (laterally extensive and correlative) coals with possible large resource potential in eastern Kansas. The methods used in this investigation are based on core description and interpretation, well-log correlation, digital subsurface mapping, and coalbed gas desorption and quality analysis.

Lithologic descriptions of two continuous cores located within the study area and their accompanying compensated density logs are the foundation for regional interpretation and correlation of approximately 860 other compensated density, neutron/density-porosity, and more numerous gamma ray-neutron logs (Fig. 1.06). Log correlation allows for creation of regional cross sections, coal and non-coal subsurface isopach maps, and structure contour maps. Cross sections, isopach maps, and structure maps, in addition to sedimentary and stratigraphic core interpretation, were used to interpret depositional environments and construct a sequence stratigraphic framework of coals and surrounding strata. Coal samples from both core and drill cuttings were analyzed for gas content and coal quality.

The interrelation of coal quality and gas content, depositional environments of peat and surrounding strata, sequence stratigraphic position, among other variables were used to better discern the geologic controls on coalbed gas productivity across the region. Coal isopach maps and determination of gas contents ranges were used to assess coalbed gas resource potential for the Bourbon arch of eastern Kansas.

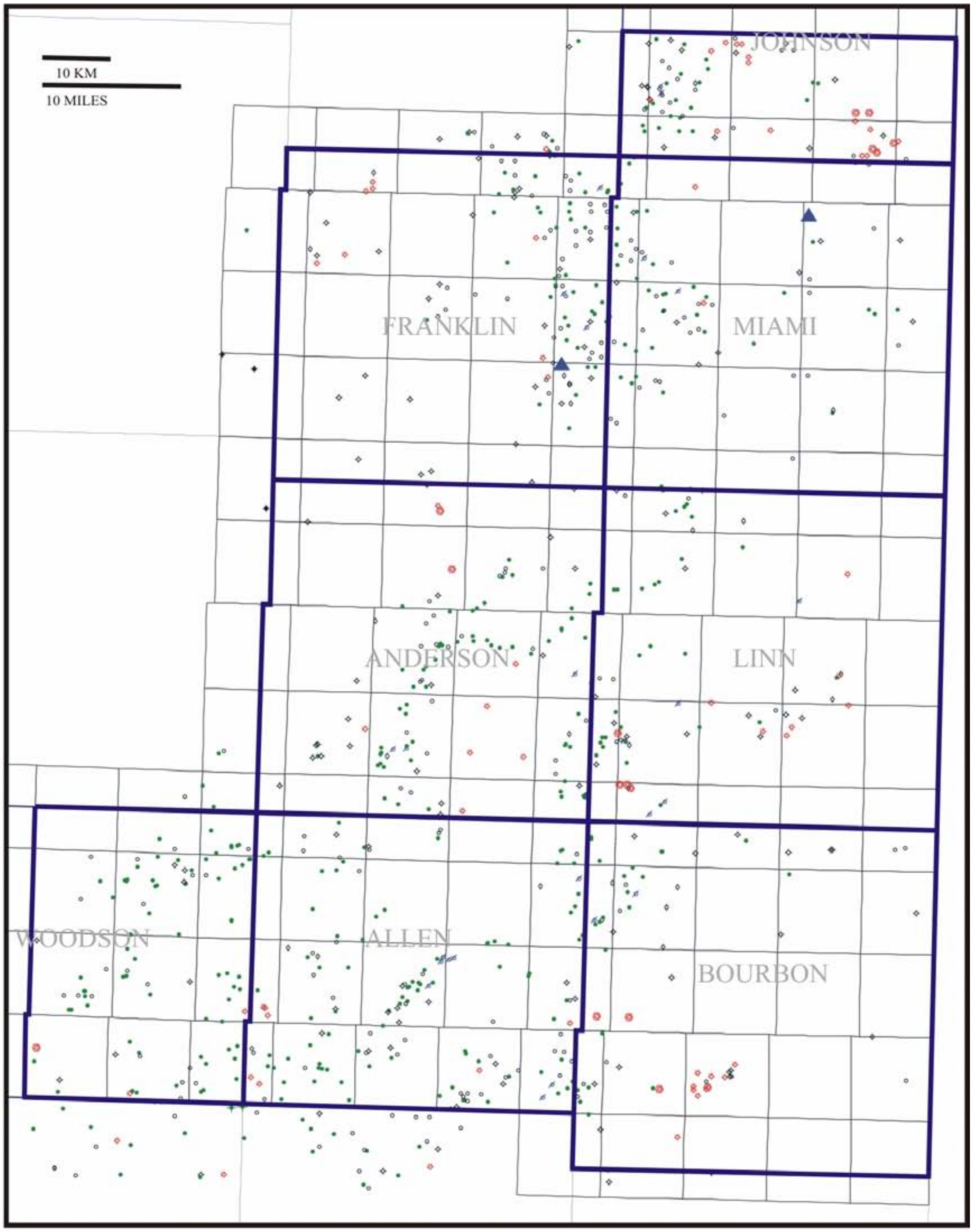


Figure 1.06 Map of the Bourbon arch study area showing described continuous core wells (blue triangles) and wells with correlated raster logs (all other symbols). Data from approximately 860 wells were used in the study.

1.5.1 Lithologic Analysis

Two continuous surface-to-Mississippian cores were drilled within the study area. The two cores are approximately 28 miles (45.1 km) apart and are a source of lithologic, sedimentological, stratigraphic, and coal property and gas content data (Fig. 1.06).

- Rose Hill #1-6 provided by Osborn Energy, L.L.C./Layne Energy: a 3-inch (7.6 cm) diameter core from a 1059-ft. (323 m) total depth cored well, located in the NE SE SW of section 6, T16S, R24E, Miami County, Kansas.
- A proprietary well (hereby known as "the Franklin County well [or core]") drilled by the Kansas Geological Survey in cooperation with an unnamed operator: a 1.5-inch (3.8 cm) diameter core from a 1056-ft. (322 m) total depth core hole, located in an undisclosed township in Franklin County, Kansas. Specific information regarding this well is scheduled for release in November of 2005.

Following core recovery, coals were measured, marked, and photographed before being placed into airtight canisters for desorption. The remaining core was measured, marked, boxed, and brought back to the KGS for further description. Limestone and sandstone intervals, and shales intervals to a lesser extent, were slabbed and polished for more detailed description. Friable underclays and fissile shales were placed into cardboard tubes and impregnated with transparent plastic resin prior to slabbing. Cores were digitally photographed and systematically described based on thickness, wet color, lithologic characteristics (lithology, average grain size, sorting, and roundness), distinctive composition (e.g. micaceousness), sedimentary structures and bedding features, nature of overlying and underlying contacts, body and trace fossils, and post-depositional and/or diagenetic features. Core descriptions and photographs of the Rose Hill #1-6 well are found in Johnson (2004). Core descriptions and photographs of the Franklin County well are found in Appendix A.

1.5.2 Log Analysis

Core descriptions were compared to their respective well logs—a gamma ray-compensated neutron-density/compensated density porosity log for Rose Hill #1-6 (Fig. 1.07), and a gamma ray-compensated density porosity log for the Franklin County core. These two core-associated logs, as well as previously correlated logs from township 27-south in southeastern Kansas (Lange, 2003), served as the starting point for correlation of 864 other logs throughout the study area (Fig. 1.06). In all, wells with log data average approximately 6.5 per township or one log for every 5.5 sections.

Although rare throughout the study area, neutron density-density porosity logs (compensated or uncompensated) were preferred due to their accurate lithologic response and dependability for coal and lithologic identification. These logs, along with the slightly more abundant compensated density logs, were used as guides and standards for correlation of gamma ray-neutron logs—by far the most common log type in eastern Kansas. The gamma ray tool detects the natural gamma radiation emitted by a rock formation. Coals tend to have low to moderate gamma ray counts

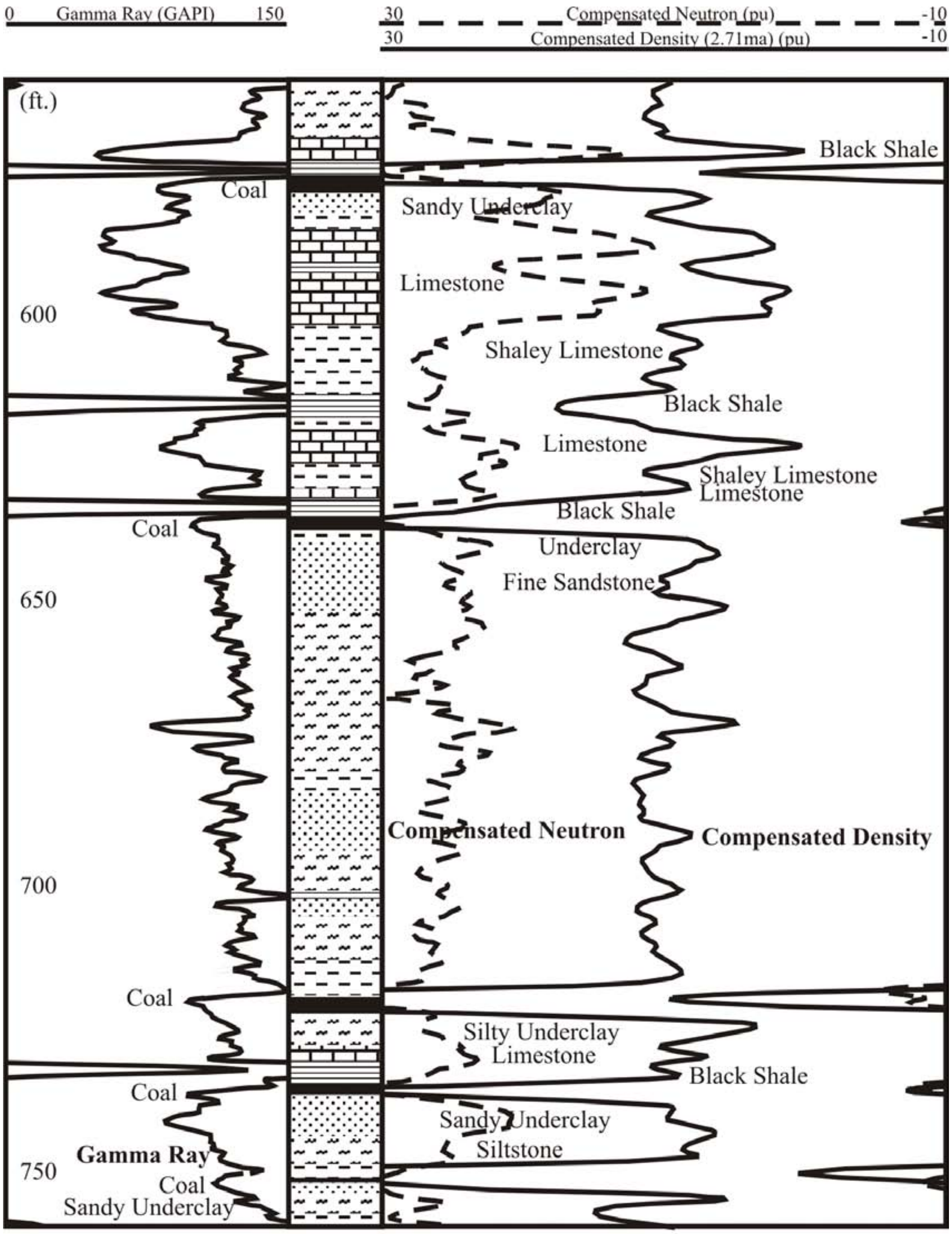


Figure 1.07 Gamma ray and compensated neutron/density log of the Osborne/Layne Rose Hill #1-6 well located in Miami County showing log responses to described lithology (Johnson, 2004).

(40-100 API units) relative to lithologies with higher, naturally occurring radioactive elements such as in black shales (> 150 API units) and shifts to the left on a gamma ray log. The neutron tool emits and measures neutrons through a formation, detecting the presence of hydrogen, which indirectly relates to higher porosity. Coal, with high hydrogen content, responds as having high relative porosity (30 - 45%) and results in a leftward shift on a neutron log. The coal response in a combination gamma ray-neutron log exhibits a distinct and correlative expression whereby both the gamma ray and neutron shift to the left. Finally, the radioactive-sourced density-porosity tool emits constant energy gamma rays that travel through the formation and back to offset gamma ray detectors. The formation density is a function of the detected gamma ray flux; fewer gamma rays will be detected in high-density (low-porosity) formations whereas more will be detected in low-density (high-porosity) formations. Typical Kansas coal has low density (~1.6 g/cc) and high porosity (30 - 45%), and results in a leftward shift on the density log (Scholes and Johnston, 1993; J.H. Doveton, personal communication, 2004).

1.5.3 Computer Applications

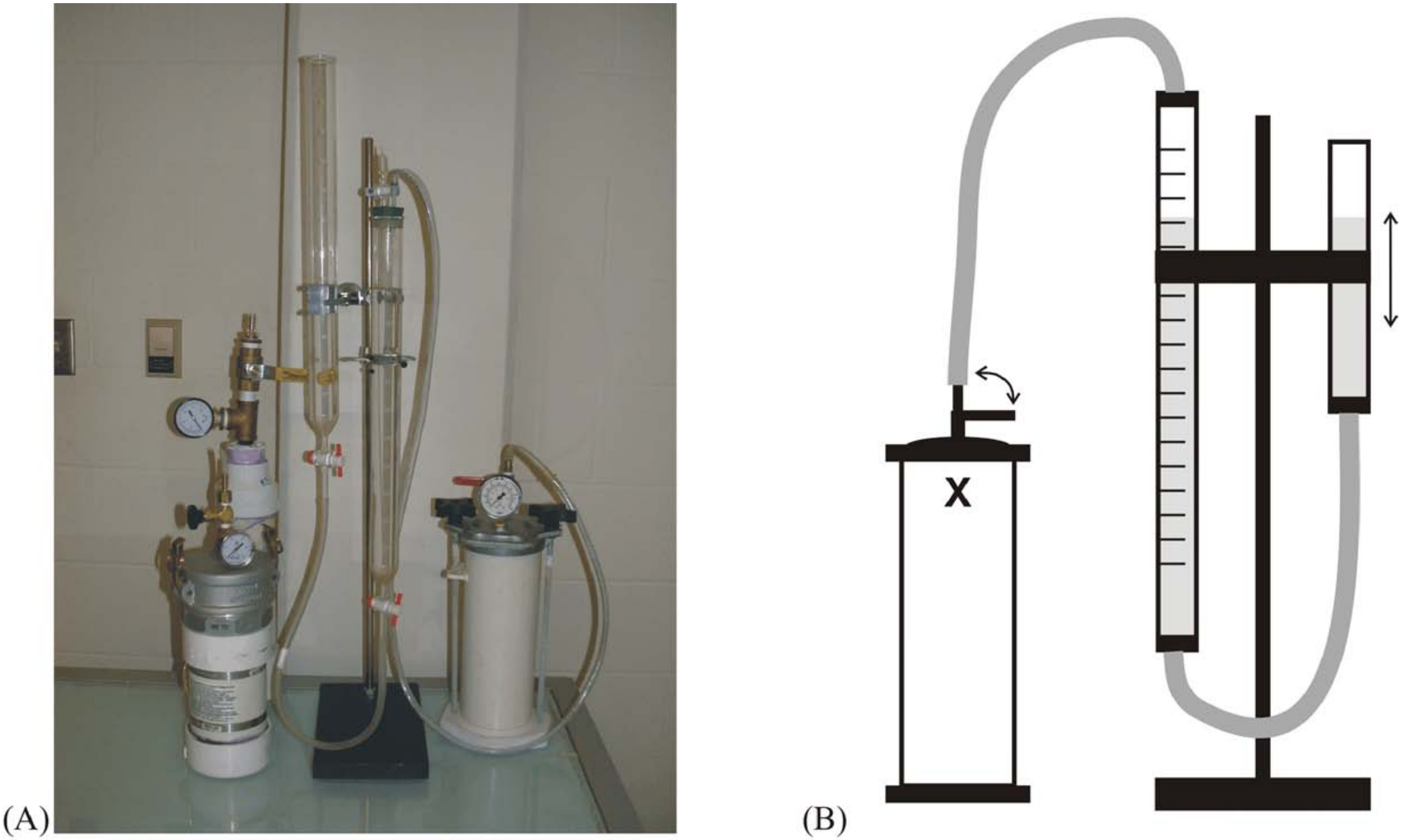
Well data utilized in this study was acquired from the Kansas Geological Survey's relational database. Spreadsheets containing well locations, formation tops, and other properties were constructed using database queries. Well and formation top spreadsheets were then imported into a digital subsurface mapping system (GIS). Paper logs from the Kansas Geological Survey's log library were scanned and calibrated as raster images, and imported into the GIS project.

Interpretation and correlation of both regional and closed raster log cross sections in the subsurface GIS project provided the majority of formation data points. Correlation and formation picking followed a tiered system. First, regionally persistent black shales (e.g. Tebo, Excello, Anna, and ‘V’ shales) were interpreted and correlated as datums. Once referred to black shale markers, second tier stratigraphic horizons between the top of the Mulberry coal and bottom of the Tebo coal were interpreted and correlated. Finally, regionally discontinuous, and more difficult third tier stratigraphic horizons between the base of the Tebo coal and the top of the Mississippian Limestone were interpreted and correlated. It is important to note that coal tops and bases were interpreted and correlated based on the log response inflection points rather than specific log value cutoffs. Absolute log response may be affected by numerous factors (e.g. tool calibration and bore hole conditions), and log value cutoffs may incorrectly estimate coalbed thickness. The inflection point correlation method accounts for the averaging of log measurements, especially when thin coals are overlain by radioactive black shale. To offset incomplete or nonexistent well data, Mississippian formation top data points from paper strip logs, available at the Kansas Geological Survey, were manually entered into the GIS project. All data points were then used to create regional depositional strike- and dip-oriented cross sections as well as coal and non-coal isopach and formation structure-contour maps.

1.5.4 Gas Desorption and Analysis

Total coalbed gas content consists of three components: lost gas—gas released prior to canistering; desorbed gas—gas released within the canister under controlled conditions; and residual gas—unextractible gas left over after the desorption process (McLennan et al., 1995). Coal samples were collected from both cores and cuttings. Cores were taken from both conventional and wireline operations and cuttings from both air and mud-drilled operations. When working with core, coals were selected from the cored interval, marked and photographed, and placed into airtight PVC or aluminum desorption canisters (Fig. 1.08A). With cuttings, samples were collected with kitchen strainers at the end of the buoy line or within a sediment trap, and placed into separate piles on a flat plastic surface. After all possible coal was collected for a given interval, cuttings were segregated based on greatest coal content and canistered. Following desorption and decanistering, cuttings were inspected to better determine coal content.

Immediately after canistering, coal samples were placed in water baths approximating formation temperature and allowed to equilibrate. In the field, constant formation temperature was maintained by using aquarium heaters or ice (when needed) and aquarium circulators. Initial desorption measurements were taken in the field. Measurements were continued in a more controlled environment at the Kansas Geological Survey. Desorbed gas was measured using a volumetric displacement apparatus prescribed by Yee et al. (1993) and McLennan et al. (1995). The apparatus is composed of two water-filled burettes connected by rubber tubing



(A)

(B)

Figure 1.08 (A) Examples of desorption canisters and apparatus used in the Kansas Geological Survey's coalbed methane research program. (B) Diagram of a connected desorption apparatus (closed graduated burette on the left and open level burette on the right).

(Fig.1.08B). The first burette is graduated and is directly connected to the desorption canister by another long, rubber tube. When the desorption canister valve is opened the first burette fills with evolved gas from the coal, while displacing liquid. The second burette compensates for the compression that occurs when the evolved gas displaces the liquid in the first burette. Equalizing the water levels between the two burettes by adjusting the second burette reduces the pressure within the first burette to that of the atmosphere. The volume displaced within the first graduated burette is recorded as desorbed gas. The desorbed gas is a function of time, temperature, and pressure—which are also recorded at time of measurement and entered into a spreadsheet program (K.D. Newell, personal communication, 2004).

Lost gas was calculated for each sample by incorporating drilling times (e.g. the time the sample started “off bottom” and the canister time for cores; and “lag times” for drill cuttings) into a linear regression of desorbed gas back to the initial time that the coal was cut in the bore hole and began degassing. Residual gas was not measured for any samples in this study.

1.5.5 Coal Quality Analysis

Following the decanistering process, coal samples were weighed (both wet and dry weights) and slabbed. Half of each sample was sent to a commercial laboratory for proximate analysis (moisture, ash, volatile matter, and fixed carbon contents; and calorific value in BTU/lb) and sulfur content analysis. Within every batch of samples an unmarked duplicate sample was included for quality control purposes. Proximate and sulfur analysis techniques follow ASTM guidelines (ASTM, 2002).

1.5.6 Units of Measurement

Due to the standard practice in the petroleum industry, English units are the primary units of measurement of this study. English units were used to measure core and well log depths and thicknesses; compute of isopach thicknesses and contour map intervals; report aerial distances and areas; and report coal gas contents and coal quality data. In other cases English measurements were converted to metric units. Conversion factors were 0.328084 for feet to meters, 1.61 for miles to kilometers, and 2.54 for inches to centimeters. For core and log measurements, metric conversion would have introduced unnecessary error. Metric units were primarily used to describe sedimentary features (e.g. lamination and bed thickness, and clast size) observed in core.