

# Subsurface Geology of the Nemaha Anticline and the Humboldt Fault in an Area Around Wamego, Kansas

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## TABLE OF CONTENTS

|   | Page |
|---|------|
| Summary .....   | 1    |
| Introduction .....  | 2    |
| The Wamego, Kansas, Study Area and Data .....             | 5    |
| Methodology Used for Lithostratigraphic Correlation ..... | 5    |
| Structural Development in the Wamego Study Area .....     | 9    |
| Pennsylvanian Sedimentation and Tectonics .....           | 10   |
| Conclusions .....   | 11   |
| References .....  | 14   |

## LIST OF FIGURES

|  |   |
|--|---|
| Figure 1. Generalized tectonic map of Kansas showing major basins and uplifts .....  | 2 |
| Figure 2. Successive stages in inferred history of the Nemaha Anticline in east-central Kansas between the Sedgwick and Cherokee Basins .... | 3 |
| Figure 3. Index map showing locations of wells having gamma-ray logs from near surface to near basement .....                                | 6 |
| Figure 4. Stratigraphic column showing formal names and Sloss cratonic sequence names for units in study area .....                          | 7 |
| Figure 5. Detailed stratigraphy of part of Upper Pennsylvanian sequence ...  | 8 |

## TABLE

|   |   |
|---|---|
| Table 1. Well names and locations ..... | 4 |
|---|---|

## LIST OF PLATES (in pocket)

- 1A. First cross section from the north, sea level datum
- 1B. First cross section from the north, top of Topeka Limestone datum
- 2A. Second cross section from the north, sea level datum
- 2B. Second cross section from the north, top of Topeka Limestone datum
- 3A. Third cross section from the north, sea level datum
- 3B. Third cross section from the north, top of Topeka Limestone datum
- 4A. Fourth cross section from the north, sea level datum
- 4B. Fourth cross section from the north, top of Topeka Limestone datum
- 5A. First cross section from the west, sea level datum

(LIST OF PLATES)

- 5B. First cross section from the west, top of Topeka Limestone datum
- 6A. Second cross section from the west, sea level datum
- 6B. Second cross section from the west, top of Topeka Limestone datum
- 7A. Third cross section from the west, sea level datum
- 7B. Third cross section from the west, top of Topeka Limestone datum

# SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE AND THE HUMBOLDT FAULT IN AN AREA AROUND WAMEGO, KANSAS

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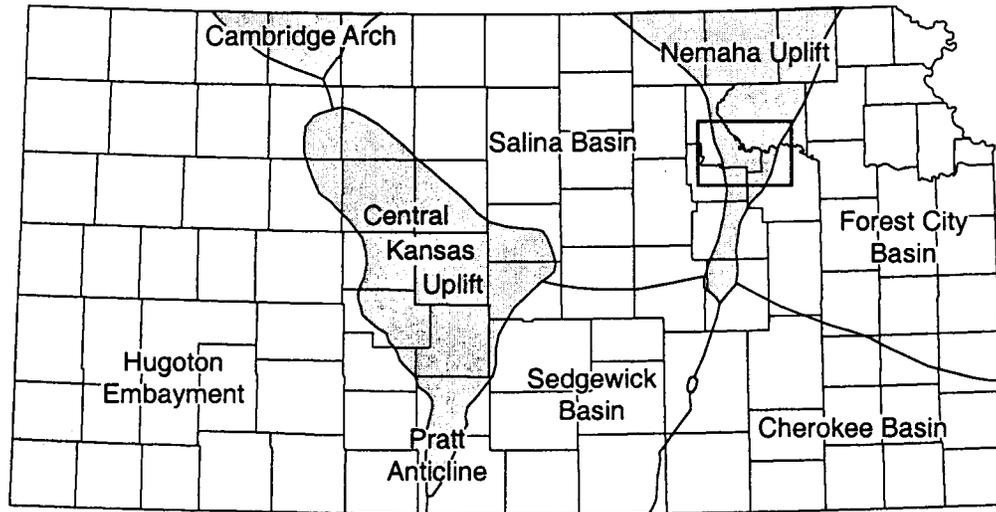
## Summary

Seven stratigraphic and structural cross sections, based on gamma-ray well logs, were constructed to characterize stratigraphic and lithofacies changes within a 1019 mi<sup>2</sup> (2640 km<sup>2</sup>) area of the Nemaha Uplift in northeastern Kansas. Internally consistent high-resolution lithostratigraphic correlations at a vertical resolution of 0.5 ft (the sampling density of the digitized well logs) were determined between 55 wells using the CORRELATOR computer program. The cross sections, augmented with information from well cuttings, were used to interpret the structural, stratigraphic, and lithofacies variability in this part of the Uplift.

The Nemaha Uplift is an asymmetric anticline with a faulted east flank and a gently dipping west flank and is approximately 3 to 6 mi wide in the study area. The east side of the Uplift consists of a north-northeast trending fault called the Humboldt Fault. An east-west trending graben containing a smaller embedded horst block cuts across the Uplift. The west-east graben forms a major divide that separates the Uplift into a broad northern section and a narrower southern section.

High-resolution lithostratigraphic correlations show stratigraphic onlaps, top laps, downlaps, and fault truncations—evidence that the depositional topography changed throughout the Paleozoic as a result of episodic structural movement that at times was contemporaneous with sedimentation. The structural movement corresponds to previously known late Mississippian and early Pennsylvanian tectonic events associated with development of the Nemaha Uplift. The cross sections show evidence of additional early to mid-Paleozoic episodes of both uplift and subsidence over the Nemaha Uplift. The episodes correspond to those recognized by Lee (1943) and include: (1) thinning and uplift in post-Arbuckle-pre-Simpson time reflecting movement along the Southeast Nebraska Arch; (2) minor thickening of Late Ordovician Viola Limestone and Maquoketa Shale linked to initial development of the North Kansas Basin; (3) more pronounced thickening of the Siluro-Devonian Hunton Group and the Late Devonian–Early Mississippian Chattanooga Shale indicating development of the North Kansas Basin; and (4) local thickening of Mississippian Osage rocks in the graben crossing the Nemaha Uplift, substantiating Lee's observation that initial uplift of the Nemaha began in early Mississippian time (Lee, 1943, 1956). Development of the graben was an important control on lithofacies development in Mississippian rocks surrounding the Uplift. Minor, but stratigraphically significant episodes of structural movement representing small-scale reactivation of the Nemaha Uplift are noted in the high-resolution cross sections. Resolving these subtle structural movements and the associated changes in lithofacies and thicknesses of strata may aid in the exploration for oil and gas.

## Subsurface Nemaha Anticline & Humboldt Fault, Wamego, KS



**Figure 1.** Generalized tectonic map of Kansas showing major basins and uplifts. Box indicates Wamego study area.

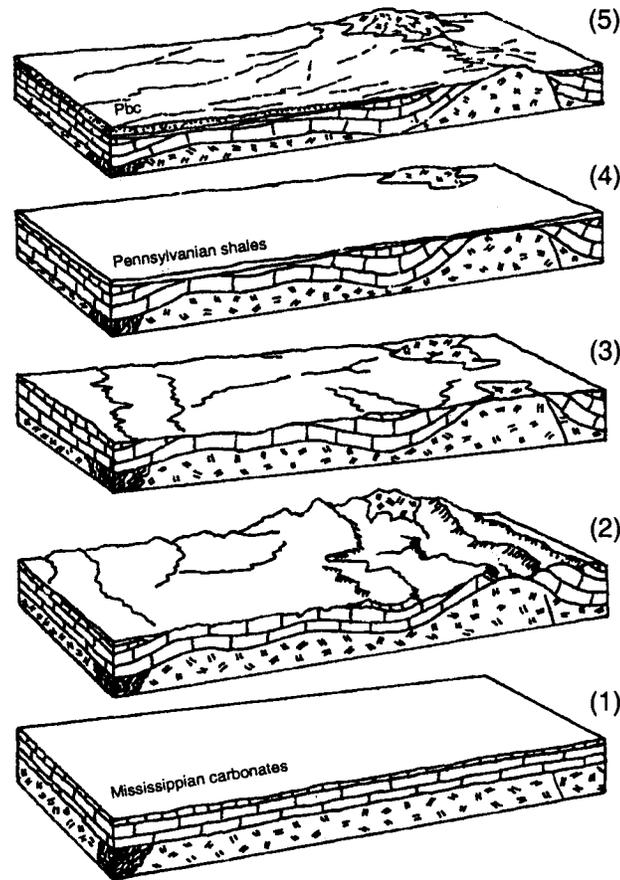
### Introduction

The Nemaha Uplift is a major Paleozoic structure in the Midcontinent that extends in a southwest direction from southeastern Nebraska to north-central Oklahoma (Fig. 1). The structure is asymmetric and slopes gradually upward on its western flank and is terminated abruptly on the east by the Humboldt Fault, a major high-angle normal fault with its downthrown block to the east (Moore, 1923; Lee, 1943; Bickford, *et al.*, 1979).

In Kansas, the Nemaha Uplift has been recognized for many decades and has been delimited by drilling, especially along its southern extent where large oil and gas fields have been discovered. The general timing and duration of major structural activity on the Uplift have been determined. Nevertheless, questions remain about details of structural activity, and answers to these questions may provide clues to the locations of additional accumulations of oil and gas. Also, resolving the nature and timing of minor structural events along the Uplift and the impact of these events on sedimentation will improve knowledge of the geologic history of Kansas.

This study is based on the interpretation of high-resolution lithostratigraphic cross sections based on gamma-ray logs from exploratory holes and oil wells. The cross sections provide detailed correlations that reveal spatial and stratigraphic variations across a small area of the Nemaha Uplift in northeast Kansas. The lithostratigraphic sections were prepared for comparison with two east-west seismic reflection profiles acquired in this area.

The Nemaha Uplift parallels the eastern edge of the Midcontinent Rift System and is believed to represent reactivation of a fault that was part of the 1100(?) Ma rift system (Berendsen, *et al.*, 1988). The fault-bounded eastern side of the Uplift and the adjacent basin (the Forest City Basin in this study area and the Cherokee Basin farther south) have been referred to as *yoked basins*. Such features developed



**Figure 2.** Successive stages in inferred history of the Nemaha Anticline in east-central Kansas, between the Sedgwick and Cherokee basins (modified from Moore, 1923). (1) Cambro-Ordovician and Mississippian deposits laid down over the future anticline. (2) Late Mississippian and early Pennsylvanian orogeny partly erodes Mississippian and Ordovician strata and Precambrian granite. (3) Erosion continues until the relief is subdued. (4) Invasion of the Pennsylvanian sea. (5) Renewed uplift, producing rough topography and accentuating relief along the anticline.

on the craton side of Late Paleozoic thrust belt-foreland basin complexes such as the Arkoma and Ouachita Mountain belt of Oklahoma and Arkansas. The evolution of the Nemaha Uplift is portrayed for an area south of the Wamego study area in Figure 2, modified from Moore (1923). Strike-slip and reverse faulting on the Humboldt Fault in Kansas and Oklahoma is interpreted as a response to oblique compressional forces affecting the craton, particularly during late Mississippian-early Pennsylvanian orogenic activity to the south (Berendsen, 1997).

## Subsurface Nemaha Anticline & Humboldt Fault, Wamego, KS

**Table 1.** Well names and locations.

| Well   | Location                      | County       |
|--|-------------------------------|--------------|
| 1. Barnett Oil, Inc. 1 Howe                  | W2 SE NW sec 28 T10S R7E      | Riley        |
| 2. Rupp-Ferguson 1 Miller                    | APP SE SE sec 22 T10S R7E     | Riley        |
| 3. Corb Bedell 1 Schepp                      | SE SE SE sec 35 T 10S R 8E    | Riley        |
| 4. Venus Oil 1 Pageler                       | SW SE NW sec 24 T10S R10E     | Wabaunsee    |
| 5. Transocean Oil Inc. 1 Wild                | APP SE SW sec 27 T10S R11E    | Wabaunsee    |
| 6. Roxy Resources 1-26 Arand                 | SW SW sec 28 T10S R11E        | Wabaunsee    |
| 7. Rains & Williamson 1 McKenna              | SE NE SE sec 30 T10S R12E     | Wabaunsee    |
| 8. Rains & Williamson 1 Morris               | SE SE SE sec 25 T12S R10E     | Wabaunsee    |
| 9. Dunlapp & Cornell 1 Gnadt                 | APP NW NE sec 30 T12S R11E    | Wabaunsee    |
| 10. Transocean Oil Inc. 1 Stuewe             | APP W2 SE SE sec 18 T12S R11E | Wabaunsee    |
| 11. Roxy Resources 1-18 Capoun               | SW SE NE sec 8 T12S R11E      | Wabaunsee    |
| 12. Mack Oil Co. 1 Wolgast                   | SW NE SW sec 7 T12S R11E      | Wabaunsee    |
| 13. Phillips Petroleum Co. 1 Newbury ST      | W2 SW NW sec 16 T11S R11E     | Wabaunsee    |
| 14. Rains & Williamson 1 Blessed Virgin Mary | NW SW SW sec 4 T10S R12E      | Pottawatomie |
| 15. Rex & Morris & Franco 1 Greishaber       | NE SW sec 20 T9S R12E         | Pottawatomie |
| 16. Sooner Oil Co. 1 Clark                   | SW NE sec 5 T9S R12E          | Pottawatomie |
| 17. Spurlock & Spines 1A Reiners             | SW NW NE sec 26 T10S R11E     | Wabaunsee    |
| 18. Pendleton 1 Mulligan                     | NW NW sec 16 T9S R12E         | Pottawatomie |
| 19. Anadarko & Diamond Shamrock 1A Hudson    | N2 NW NW sec 14 T12S R8E      | Wabaunsee    |
| 20. Brandt Production 1 Hudson               | S2 SE SW sec 35 T11S R8E      | Riley        |
| 21. McCulloch & Venus & McCoy 1 Carr         | W2 SW SW sec 6 T9S R10E       | Pottawatomie |
| 22. McCulloch & Venus & McCoy 1 Willig       | SW SW NE sec 23 T11S R8E      | Riley        |
| 23. City Service Oil Co. 1 Haylett           | SW SE NE sec 14 T11S R8E      | Riley        |
| 24. Francis-Kaiser 1 Glenn                   | SW SW SW sec 35 T9S R8E       | Pottawatomie |
| 25. McCulloch & Venus & McCoy 1 McCoy        | SW NE NW sec 26 T9S R8E       | Pottawatomie |
| 26. Kaiser-Francis 1 Roesener                | SE SW SW sec 14 T9S R8E       | Pottawatomie |
| 27. Barbara Oil Co. 1 Meseke                 | NW NE SE sec 29 T12S R9E      | Wabaunsee    |
| 28. Adair Oil Co. 1 Schmitt                  | NE NE NE sec 21 T12S R9E      | Wabaunsee    |
| 29. Pendleton 1 Gillum                       | NE NE NW sec 10 T11S R10E     | Wabaunsee    |
| 30. Anadarko & Diamond Shamrock 1A Straub    | SE SE SE sec 29 T9S R11E      | Pottawatomie |
| 31. McCulloch & Venus & McCoy 1 Ebert        | SE NE NW sec 2 T9S R9E        | Pottawatomie |
| 32. McCulloch & Venus & McCoy 1 Worthing     | APP S2 SE NW sec 1 T9S R10E   | Pottawatomie |
| 33. Anschutz 1 Marshall                      | SE NE sec 12 T9S R12E         | Jackson      |
| 34. North Plains Corp. 2 Alfred              | SE SW SE sec 17 T11S R11E     | Wabaunsee    |
| 35. Francis-Kaiser 1 Unterberger             | SE SE SE sec 24 T9S R8E       | Pottawatomie |
| 36. Tennessee Gas & Oil 1 Burgess            | SW SW NW sec 24 T9S R9E       | Pottawatomie |
| 37. Tennessee Gas & Oil 1 Mansfield          | NW NW NE sec 19 T9S R10E      | Pottawatomie |
| 38. McCulloch & Venus & McCoy 1 Umscheid     | NE SW sec 16 T9S R10E         | Pottawatomie |
| 39. Ferguson 1 Bandel                        | SE SW SE sec 6 T12S R10E      | Wabaunsee    |
| 40. Cimarron Petroleum Corp. 1 Simpson       | SW NW sec 15 T12S R7E         | Geary        |
| 41. Cities Service Oil Co. 1 Salazar         | SE NE SE sec 11 T12S R7E      | Geary        |
| 42. Olin Oil & Gas Corp. 1 Fox               | SW NW sec 6 T12S R8E          | Geary        |
| 43. Brandt Oil 1 Durein                      | NW NE NW sec 7 T12S R9E       | Geary        |
| 44. Kern-Landes 1 Wenderott                  | NE NE sec 4 T12S R9E          | Wabaunsee    |

(continued)

## Methodology Used for Lithostratigraphic Correlation

**Table 1.** (concluded) Well names and locations.

| Well                                     | Location                     | County    |
|--|------------------------------|-----------|
| 45. Pendleton 1 Hafenstine               | SE SW NW sec 2 T12S R9E      | Wabaunsee |
| 46. Berentz Drilling 1 Mienhardt         | SE NW SE sec 9 T12S R11E     | Wabaunsee |
| 47. FMF 1 Mienhardt                      | NE NE sec 10 T12S R11E       | Wabaunsee |
| 48. FMF 1 Adams                          | SW NW sec 14 T12S R12E       | Wabaunsee |
| 49. Cities Service Oil Co. 23A Yaege     | APP SW NE NE sec 26 T11S R8E | Riley     |
| 50. Oxy USA 32A Yaege                    | SW SW SW sec 25 T11S R8E     | Riley     |
| 51. Phillips Petroleum Co. 2 Newbury ST  | SW SW NW sec 35 T10S R11E    | Wabaunsee |
| 52. Pickrell & Barbara Oil Co. 2A Meseke | NW SW SE sec 29 T12S R9E     | Wabaunsee |
| 53. Johnston 1 Deep Creek Ranch          | SW NW SW sec 32 T10S R9E     | Riley     |
| 54. Adair Oil Co. 1 Humphreys            | SE SE SW sec 32 T12S R9E     | Wabaunsee |
| 55. Natural Gas & Oil 1 Whitacre         | NE NE SE sec 2 T12S R9E      | Wabaunsee |

### THE WAMEGO, KANSAS, STUDY AREA AND DATA

Figure 3 is an index map showing locations of all drill holes in the study area that have a gamma-ray log extending from near surface to near the basement. Of these, the 55 wells in Table 1 could be arranged into a network of seven cross sections identified by circled numbers. Four cross sections are aligned roughly east-west and three are approximately north-south. The log traces from the wells were digitized at a regular interval of two readings per foot and are stored in an Internet-accessible database maintained by the Kansas Geological Survey at

<http://magellan.kgs.ukans.edu/Logs/index.html>

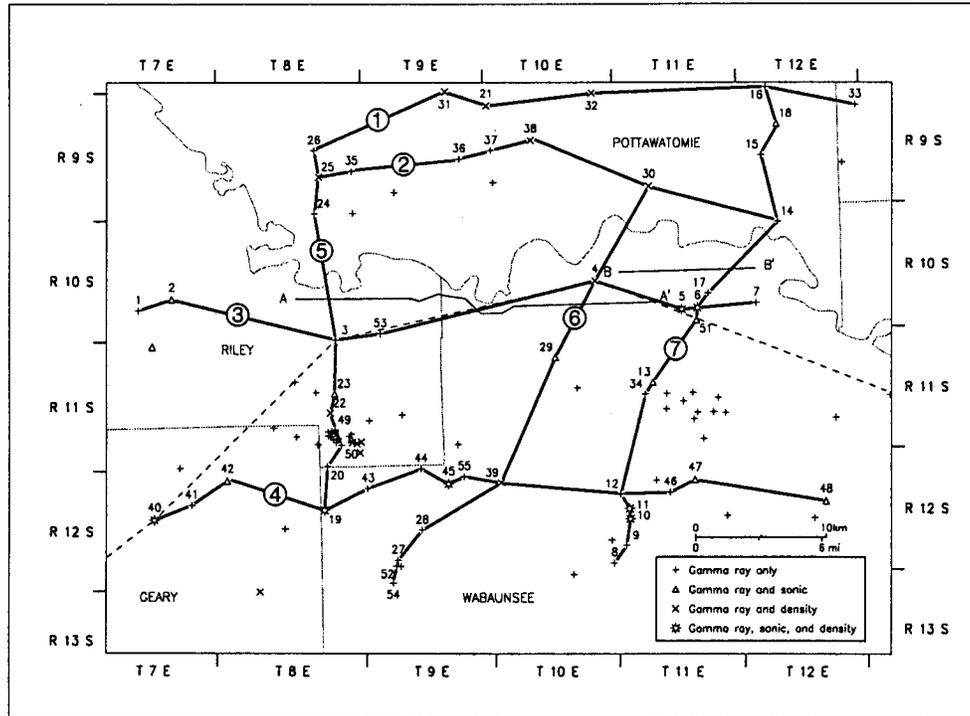
Figure 4 is a stratigraphic column showing the major Paleozoic rock units penetrated by drill holes in the study area. Figure 5 shows details of the Upper Pennsylvanian stratigraphic units encountered in these wells.

### METHODOLOGY USED FOR LITHOSTRATIGRAPHIC CORRELATION

Geological correlations of wireline logs from wells along the line of section were made using the CORRELATOR computer program (Olea, 1988). The program searches for correlations by comparing pairs of wireline logs from adjacent wells along the transect. To clarify the following discussion, the well with log traces placed on the left side of a display is called the "reference well" and the "matching well" refers to the well and log traces on the right side of the display. From each well, CORRELATOR ordinarily utilizes two different log traces that are referred to as the "shale log" and the "correlation log." In this study, only one gamma-ray log was used to serve as both the shale log and the correlation log.

In the reference well, a correlation interval of length  $(2n + 1)$  readings is centered around a depth  $z_i$ . The shape of the log trace within this interval is compared to the shape of the log trace in all possible intervals of the same length in the matching well. The comparison is made by computing weighted correlations between the intervals in the two wells. CORRELATOR automatically selects as the correlating position in the matching well the depth  $z_{k_{best}}$  at which the weighted correlation coefficient is the maximum.

## Subsurface Nemaha Anticline & Humboldt Fault, Wamego, KS



**Figure 3.** Index map showing locations of wells having gamma-ray logs from near surface to near basement. Numbers identify wells listed in Table 1. Solid heavy lines are cross sections in this study, identified by circled numbers. Dashed line is a regional cross section in KGS Open-File Report 97-81 (Olea, 1997). Lines AA' and BB' indicate reflection seismic lines shot by KGS Exploration Services in the summer of 1998.

The standardized shale similarity  $\alpha_{1,3}(i, k; n)$ , the covariance  $\text{cov}_{2,4}(i, k; n)$ , and the standard deviations  $s_2(i; n)$  and  $s_4(k; n)$  are first calculated over the intervals being compared, which are centered at log interval  $i$  in the reference well and at log interval  $i + k$  in the matching well. The difference in log intervals between the two wells is the offset,  $k$ ,

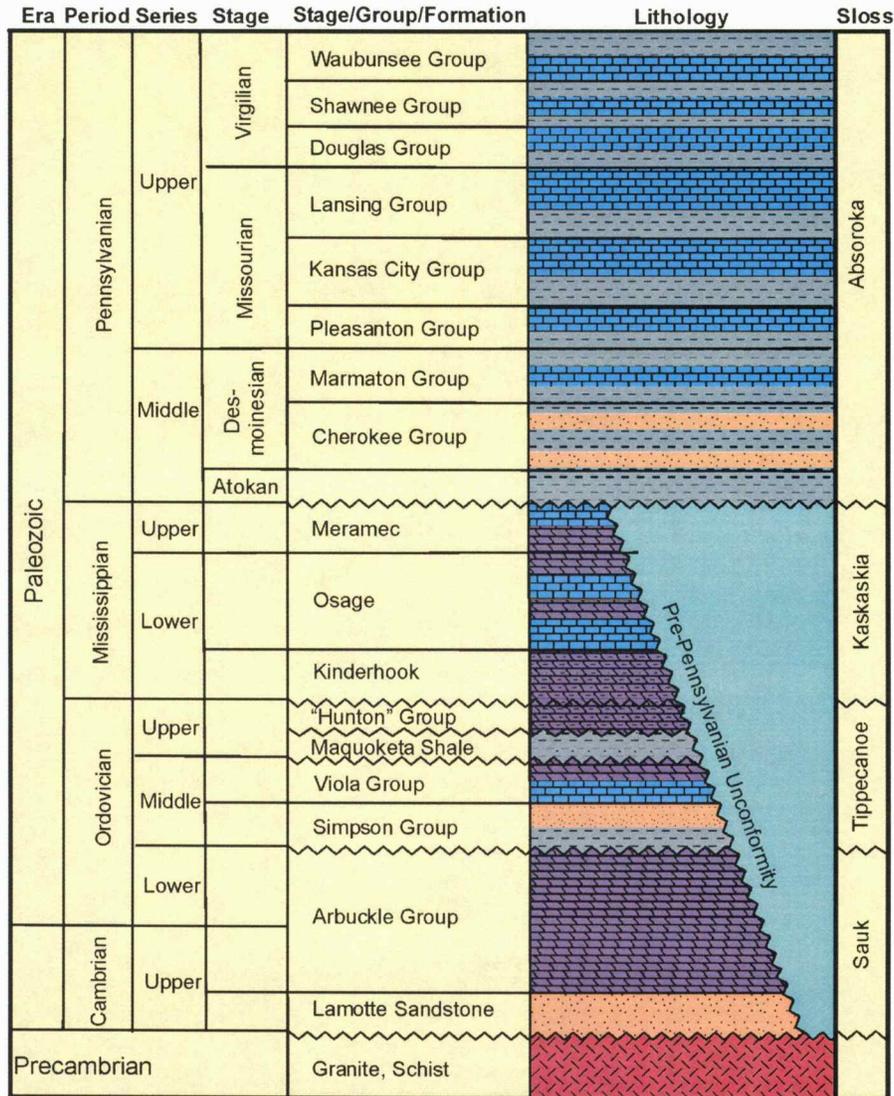
shale similarity =

$$\alpha_{1,3}(i, k; n) = 1 - \left( \frac{1}{2n+1} \sum_{j=i-n}^{i+n} \left| \frac{\lambda_1(j) - \lambda_{shale 1}}{\lambda_{min 1} - \lambda_{shale 1}} - \frac{\lambda_3(j+k) - \lambda_{shale 3}}{\lambda_{min 3} - \lambda_{shale 3}} \right| \right)$$

covariance =

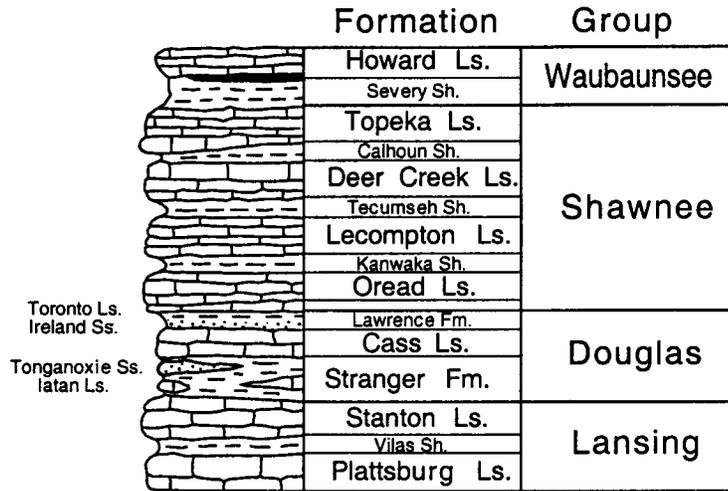
$$\text{cov}_{2,4}(i, k; n) = \frac{\sum_{j=i-n}^{i+n} \lambda_2(j) \lambda_4(j+k) - \left( \sum_{j=i-n}^{i+n} \lambda_2(j) \right) \left( \sum_{j=i-n}^{i+n} \lambda_4(j+k) \right)}{2n+1}$$

## Methodology Used for Lithostratigraphic Correlation



**Figure 4.** Stratigraphic column showing formal names and Sloss cratonic sequence names (Sloss, 1982) for units in study area. Blue = limestone, purple = dolomite, gray = shale, orange = sandstone. Wavy line cutting across underlying strata indicates pre-Pennsylvanian unconformity; other wavy lines indicate unconformities, some corresponding to boundaries between Sloss cratonic sequences (modified from Cansler and Carr, 2001).

Subsurface Nemaha Anticline & Humboldt Fault, Wamego, KS



**Figure 5.** Detailed stratigraphy of part of Upper Pennsylvanian sequence with names used in the text. Stratigraphic positions of lenticular sandstones in the Ireland and Tonganoxie sandstones are indicated.

standard deviation =

$$s_2(i; n) = \sqrt{\frac{\sum_{j=i-n}^{i+n} \lambda_2(j)^2 - \left[ \left( \sum_{j=i-n}^{i+n} \lambda_2(j) \right)^2 / 2n + 1 \right]}{2n}}$$

The standard deviation,  $s_4(k; n)$ , of the correlation trace within the interval being compared in the matching well is found in a similar fashion. The covariance and the two standard deviations are used to compute the Pearsonian correlation coefficient,  $r_{2,4}(i, k; n)$ , which is a measure of similarity in shape of the two correlation log traces within the intervals being compared:

$$\text{correlation} = r_{2,4}(i, k; n) = \frac{\text{cov}_{2,4}(i, k; n)}{s_2(i; n) s_4(k; n)}$$

The weighted correlation coefficient  $\omega_{1,2,3,4}(i, k; n)$  is defined as the product of the standardized shale similarity coefficient  $\alpha_{1,3}(i, k; n)$  between the shale logs from the two wells and the correlation coefficient  $r_{2,4}(i, k; n)$  between the correlation logs from the two wells:

$$\text{weighted correlation} = \omega_{1,2,3,4}(i, k; n) = \alpha_{1,3}(i, k; n) \times r_{2,4}(i, k; n)$$

## Structural Development in the Wamego Study Area

This measure reflects the degree of similarity in shape of the correlation log traces within the intervals being compared from the two wells, weighted by their similarity in lithology in terms of their relative proportions of shale. Maximizing the weighted correlation coefficient requires specifying an additional parameter, the interval  $k_{\min} \leq k \leq k_{\max}$  over which the search for a best match is made. Maximizing the weighted correlation coefficient always yields a single largest value  $\omega_{1,2,3,4}(i, k_{\text{best}}, n)$  for every elevation  $z_i$  in the reference well. These best matches are tentative stratigraphic correlations. However, not all of these best matches will be retained. In an initial step the system discards all matches whose correlations are weak, that is, below a specified threshold value. In a subsequent step an expert system algorithm checks for global consistency of correlations and identifies any lines of correlation that cross other lines of correlation, or that deviate significantly from the trend in correlations between other intervals. The expert system interactively displays these suspect matches and suggests why they may be erroneous.

After comparing the initial two wells and storing the acceptable matches in a file, CORRELATOR compares the next well in the line of section to one of the original wells and the correlation process is repeated. By adding wells successively to the end of the growing cross section, a file of correlations is constructed. CORRELATOR can display all of these stratigraphic correlations at once: as a cross section showing the tops and bottoms of lithostratigraphic units; as a cross section showing the correlated intervals that are present in all wells at the same lithostratigraphic level; or as a cross section that shows lateral changes in the amount of shale within intervals. A variety of display conventions can be selected by the user. For example, the strength of each correlation can be shown by color coding the lines of correlation; or, the lithology can be displayed by drawing stratigraphic intervals that are predominantly shale in green, and "clean" (*i.e.*, clay-free) stratigraphic intervals in red. Intervals of intermediate composition are shown in yellow or orange colors.

Cross sections in this report are presented in two forms: (1) constructed with a sea-level base to show the present structural configuration, and (2) with a datum at the contact between the Shawnee and Wabaunsee Groups to show structural configuration in Late Pennsylvanian time (Plates 1-7). On the plates, numbers inside circles above well names identify intersecting cross sections which are numbered 1 to 4 from north to south and 5 to 7 from west to east.

## STRUCTURAL DEVELOPMENT IN THE WAMEGO STUDY AREA

The Nemaha Uplift is a major Phanerozoic tectonic feature in Kansas. Trending generally north-northeast, the Nemaha Uplift separates the Forest City and Cherokee basins on the east from the Salina and Sedgwick basins on the west. In the study area in northeast Kansas, the western flank of the Nemaha Uplift borders the Salina Basin. The eastern flank of the Uplift is formed by the nearly vertical Humboldt Fault, which abruptly separates the Uplift from the western margin of the Forest City Basin. In the study area, displacement on the Humboldt Fault ranges from over 2000 ft (610 m) in pre-Pennsylvanian rocks to 250 ft (76 m) in the upper units of the Shawnee Group.

A broad ancestral uplift called the Southeast Nebraska Arch developed over and on either side of the northern portion of the Nemaha Uplift and affected the northern part of the study area. Post-Arbuckle and pre-Simpson Group (Middle Ordovician) movement associated with deposition of the upper Sauk cratonic sequence (Sloss, 1982) caused the Arbuckle Group to be thin or absent (Figure 4). The

## Subsurface Nemaha Anticline & Humboldt Fault, Wamego, KS

southern edge of the North Kansas Basin (Lee, 1943, 1956; Merriam, 1963) developed during the Tippecanoe cratonic sequence and is reflected in the study area as a northward thickening of the Hunton Group (Figure 4).

In contrast, overlying Lower Mississippian carbonates within the Kaskaskia cratonic sequence thin to the north along the western margin of the Forest City Basin (Plates 6 and 7). The thinning is a result of both stratigraphic attenuation and erosion associated with a broad, gentle uplift that preceded the major uplift of the Nemaha in Late Mississippian-early Pennsylvanian time. Similar movements of Mississippian age have been inferred from lithofacies changes along the Central Kansas Uplift (Franseen, personal communication, 2001).

A broad anticline crosses the easternmost north-south cross section within the Forest City Basin (Plate 7) east of the graben that bisects the Nemaha Uplift. Height of closure on the anticline increases with depth, especially below the basal Pennsylvanian unconformity where Mississippian carbonates are partly truncated (Plate 7). Beds in the Pennsylvanian Shawnee Group limestone and shale succession thin over the anticline, and the Hunton Group and Chattanooga Shale also thicken to the north beyond the crest of the anticline (Figure 4).

The study area is located where the Nemaha Uplift changes from a broad feature in the north to a narrow anticline in the south; this change corresponds with the location of an east-west trending graben that is developed in the southern part of the study area. The graben contains a smaller horst of Siluro-Devonian Hunton Group carbonates encased in subcropping Devonian-Mississippian Chattanooga Shale and shales of the Middle Pennsylvanian Cherokee Group (Plate 5). Oil is produced from the Hunton in the Yaeger Field located on the horst. The graben extends eastward into the Forest City Basin where its development is locally associated with greater subsidence (Plate 6). The graben is filled with Lower and Middle Pennsylvanian sedimentary rocks which have no equivalents outside the graben.

The core of the Nemaha Uplift is marked by uplifted pre-Pennsylvanian rocks that subcrop beneath the basal Pennsylvanian unconformity. In places, Precambrian basement rocks lie directly beneath the unconformity. The oldest Pennsylvanian strata that cover the unconformity are clastics of the Cherokee Group; locally, carbonates and shales of the Marmaton Group lie above the unconformity in the higher parts of the Uplift.

## PENNSYLVANIAN SEDIMENTATION AND TECTONICS

Episodic structural activity and the existence of paleotopographic relief over the Nemaha Uplift are indicated in Pennsylvanian strata by (1) thinning and onlap of strata against the uplift; (2) presence of thicker intervals of clean carbonate beds and localized carbonate buildups over and flanking the uplift, with associated downlap off the flanks of the uplift; and (3) the presence of thick, channel-form deposits of sandstones adjacent to the Uplift. Evidence of depositional topography occurs intermittently through the Pennsylvanian stratigraphic section and can be seen on the cross sections. The relationships suggest episodic reactivation of the uplift and associated subsidence in adjoining basins and grabens.

Differential compaction also is apparent, particularly above the thick intervals of the Tonganoxie and Ireland sandstones, which were deposited in large incised valleys in eastern Kansas (Archer, *et al.*, 1994) (Figure 5). The orientation and characteristics of the incised valleys have been related to reactivation of subtle basement

## Conclusions

structures in the eastern Forest City Basin, 80 mi (129 km) to the east (Beaty, Watney, and Martinez, 1999).

The Humboldt Fault offsets all of the Pennsylvanian strata included in the cross sections. Local, small offsets of Pleistocene strata are associated with the Humboldt Fault in Nemaha County (Denne *et al.*, 1998), indicating that the fault has been active in Recent time.

Onlap, toplap, and downlap geometries appear on the cross sections in Pennsylvanian strata, including onlap in the Pleasanton Group on Plate 7, in the Kanwaka Shale on Plate 4, and in the Douglas Group on Plate 2. Toplap is apparent in the Kansas City Group on Plate 5 and downlap can be seen above the Lecompton Limestone on Plate 6 and above the Kansas City Group on Plate 3. These relationships accompany changes in thicknesses and lateral transitions between lithofacies and document recurring structural deformation and the influence of local depositional topography which affected deposition and compaction.

Additional geologic studies are needed to (1) reinterpret KGS seismic lines shot in 1998, (2) examine well cuttings and petrophysical logs to verify lithologic changes, and (3) demonstrate the three-dimensional relationships between stratigraphy and structure by isopach mapping of key stratigraphic intervals. Still unresolved at present is the sequence stratigraphic framework needed to interpret paleogeographic evolution and the relationship of the cross-cutting graben and other local structures to basement tectonics.

## CONCLUSIONS

The effects of previously known tectonic events associated with development of the Nemaha Uplift can be recognized on the cross sections. The prominent uplift of the Nemaha in late Mississippian and early Pennsylvanian time is clearly shown by thinning of units along the east-west cross sections. Subsidence of the graben cross-cutting the Nemaha Uplift in the study area is clearly evident. Early to mid-Paleozoic episodes of both uplift and subsidence over the current Nemaha Uplift corresponding to episodes recognized by Lee (1943, 1956) can be identified. Numerous additional episodes of uplift or subsidence having limited temporal-spatial extent and smaller amplitude are indicated by onlap, offlap, toplap, thickening and thinning of units, and by lateral changes in gamma-ray values in the Mississippian and Pennsylvanian intervals.

Thinning associated with the major Late Mississippian-Early Pennsylvanian uplift appears to have begun in Early Mississippian (Osagean) time (Plate 2). Contemporaneously, thickening of units occurred in the cross-cutting graben. Early Mississippian carbonate rocks surrounding the uplift may have developed favorable lithofacies with the potential for undiscovered oil and gas resources. Resolution of subtle structural movements along the Nemaha Uplift and associated changes in thicknesses and lithologies may aid in the exploration for oil and gas. Geologic observations in the study area may be summarized as follows:

- (1) Uplift and thinning of strata occurred in post-Arbuckle time prior to deposition of the Simpson Group, reflecting Early to Middle Ordovician movement along the Southeast Nebraska Arch (Lee, 1943, 1956; Merriam, 1963; Berendsen *et al.*, 1992; Doveton *et al.*, 1994).
- (2) Minor thickening of the Late Ordovician Viola Limestone and Maquoketa Shale is associated with the initial development of the North Kansas Basin.

## Subsurface Nemaha Anticline & Humboldt Fault, Wamego, KS

- (3) More pronounced thickening of the Siluro-Devonian Hunton Group and Late Devonian-Early Mississippian Chattanooga Shale indicates more rigorous, defined development of the North Kansas Basin.
- (4) Local thickening of Mississippian (Osagean) carbonates in an east-west graben that crosses the Nemaha Uplift corroborates Lee's (1943, 1956) observation that initial uplift of the Nemaha began in the early Mississippian. This also compliments maps of Early Mississippian Boice Shale oolitic ironstones (Dove-ton *et al.*, 1994) that were interpreted as delimiting local topographic highs and shoreline conditions developed over the Nemaha Uplift.
- (5) Minor, but stratigraphically significant episodes of structural movement during Early Mississippian through Late Pennsylvanian time represent small-scale, subtle reactivation of the Nemaha Uplift. The major episode of uplift of the Nemaha Uplift is related to Late Mississippian to Early Pennsylvanian deformation. Pre-Pennsylvanian rocks ranging from Lower Mississippian carbonates to Precambrian igneous rocks were uplifted. The ensuing erosion led to progressive truncation of rock units across the Nemaha Uplift. (On Plates 1-7, the 50× vertical exaggeration greatly distorts the effects of tectonic activity; for example, an apparent dip of 75° on the Plates represents a dip of only 1° in the subsurface.)
- (6) An east-west trending graben and smaller embedded horst cross the Nemaha Uplift near the southwest edge of the study area. Mississippian strata thicken locally near the graben. Pre-Cherokee clastics of Pennsylvanian age (probably Atokan) fill a small, 4 mi (6.4 km) wide graben up to 885 ft (270 m) deep along the eastern flank of the Nemaha Uplift. The filled graben lies on trend with the horst and graben system associated with the Yaeger Field. The horst is locally closed at the level of the Siluro-Devonian Hunton Group, forming the carbonate reservoir of the Yaeger oil field. The trapping seal of the field is formed by Pennsylvanian shales.
- (7) The Arbuckle Group is absent over the uplift in the study area, having been removed by erosion.
- (8) Shales of the upper Cherokee Group (Pennsylvanian) were deposited on the basal Pennsylvanian unconformity over the Uplift. Locally, sediments as young as the middle portion of the Middle Pennsylvanian Marmaton Group overlie the basal Pennsylvanian unconformity. The greatest differences in thickness of Pennsylvanian strata across the Nemaha Uplift occur in the Cherokee Group. Lower Pennsylvanian shales and carbonates lap out toward the west from the Nemaha Uplift.
- (9) Intervals of localized thinning of strata across the Nemaha Uplift occur in the Cherokee, Marmaton, Pleasanton, and Douglas Groups, and in the Kanwaka Shale of the Lower Shawnee Group. Strata in the Upper Shawnee Group are most uniform in thickness across the Uplift. Pre-Wabaunsee Upper Pennsylvanian sediments are relatively uniform in thickness, suggesting that the Humboldt fault was dormant during this time.
- (10) Onlap and truncation of strata is most pronounced, both in stratigraphic and areal extent, to the north of the east-west graben system (Plates 1-3). To the south, there is less onlap and truncation of strata, suggesting there was less local topographic relief south of the graben (Plate 4).

- (11) Facies changes across the Nemaha Uplift include:
- (a) Limestone beds in the Lansing and Kansas City Groups are thicker and contain less noncarbonate material (lower gamma-ray intensities) than do stratigraphically equivalent intervals in the Forest City Basin to the east where the limestones are more shaly and interbedded shales are thicker. Individual carbonate beds in this interval downlap into the Forest City Basin (Plate 3).
  - (b) There are local, prominent buildups in the Toronto and Iatan Limestones along the flanks of the Uplift and along the edges of thick, underlying sandstones (Plate 3, 4, and 5).
  - (c) Thick, lenticular beds of the Ireland and Tonganoxie Sandstones within the Douglas Group are restricted to the eastern flank of the Nemaha Uplift (Plate 1-4). Farther south, the thicker sandstones occur closer to the Uplift.
  - (d) The thickest intervals of the Ireland and Tonganoxie Sandstones are stacked above one another in an area immediately north of the east-west graben system (Plate 6). These thick sandstone units are flanked by overlying buildups in the Toronto Limestone and directly overlain by locally thick shales in the Shawnee Group.
- (12) Pennsylvanian strata exhibit a regional dip to the southwest on the structural cross sections. There are two areas of exceptions: Narrow anticlinal dip reversals can be seen on the north-south section in Plate 5 and along the southwest-north section in Plate 6, and a reverse dip is associated with a broad antiform in the easternmost south-north cross section (Plate 7).
- (13) Wells on opposite sides of the Humboldt Fault are 2 mi or more apart (Plate 4A); at this resolution, there is no evidence of multiple subparallel faults or a system of faults, so the Humboldt Fault is shown as a single fault on the plates.

Structurally active areas such as the Nemaha Uplift are economically important, because they may serve as a locus for favorable hydrocarbon and mineral host rocks, and contain geometries that could serve as traps and seals for hydrocarbons or mineralized fluids. The largest oil field in Kansas, the El Dorado Field, is located on the crest of the Nemaha Uplift in Butler County, 90 mi (149 km) south of the study area. Truncated carbonate strata that subcrop along the Nemaha Uplift also serve as petroleum reservoirs in the region. Cross-structure, east-west oriented grabens and horsts also have led to the entrapment of oil, as for example, in the Yaege Field. Lenticular sandstones that cross small anticlines in the adjoining Forest City Basin form potential combination structural-stratigraphic hydrocarbon traps. The sandstones occur in incised valleys in paleotopography that seem to be related to structural deformation along the Nemaha Uplift.

## Subsurface Nemaha Anticline & Humboldt Fault, Wamego, KS

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LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE IN AN AREA AROUND WAMEGO, KANSAS  
 FIRST CROSS SECTION FROM THE NORTH, DATUM SEA LEVEL

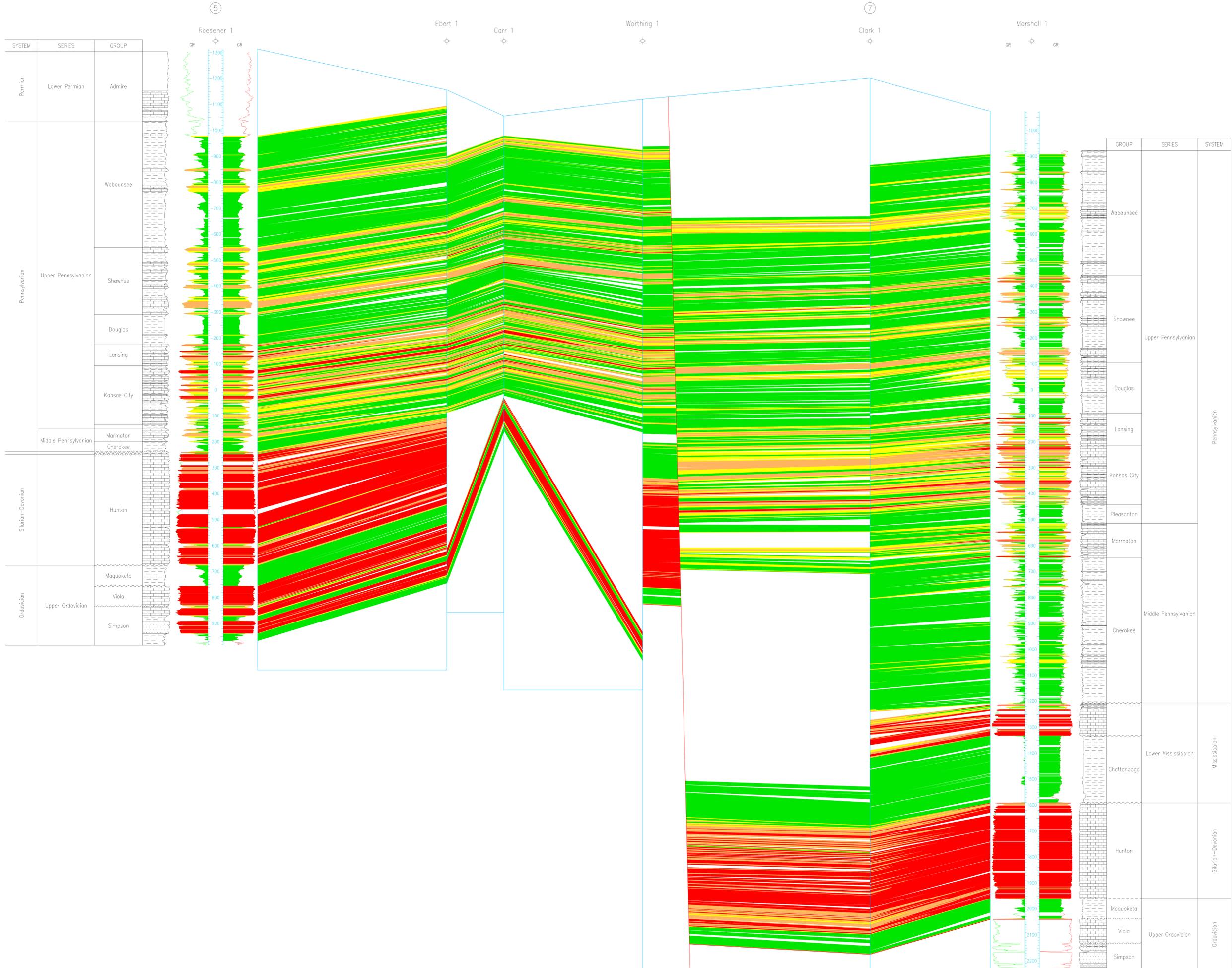
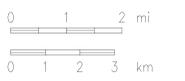


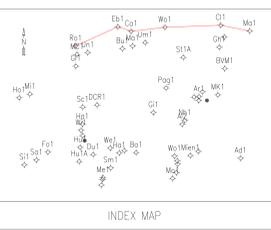
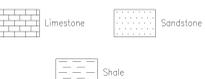
PLATE 1A

Shale content, percentage  
 0.0 100.0

Vertical exaggeration: 50X



LITHOLOGY SYMBOLS



KANSAS GEOLOGICAL SURVEY

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 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE  
 IN AN AREA AROUND WAMEGO, KANSAS  
 FIRST CROSS SECTION FROM THE NORTH,  
 DATUM SEA LEVEL  
 JANUARY 31, 2002

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LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE IN AN AREA AROUND WAMEGO, KANSAS  
 FIRST CROSS SECTION FROM THE NORTH, DATUM SEA LEVEL

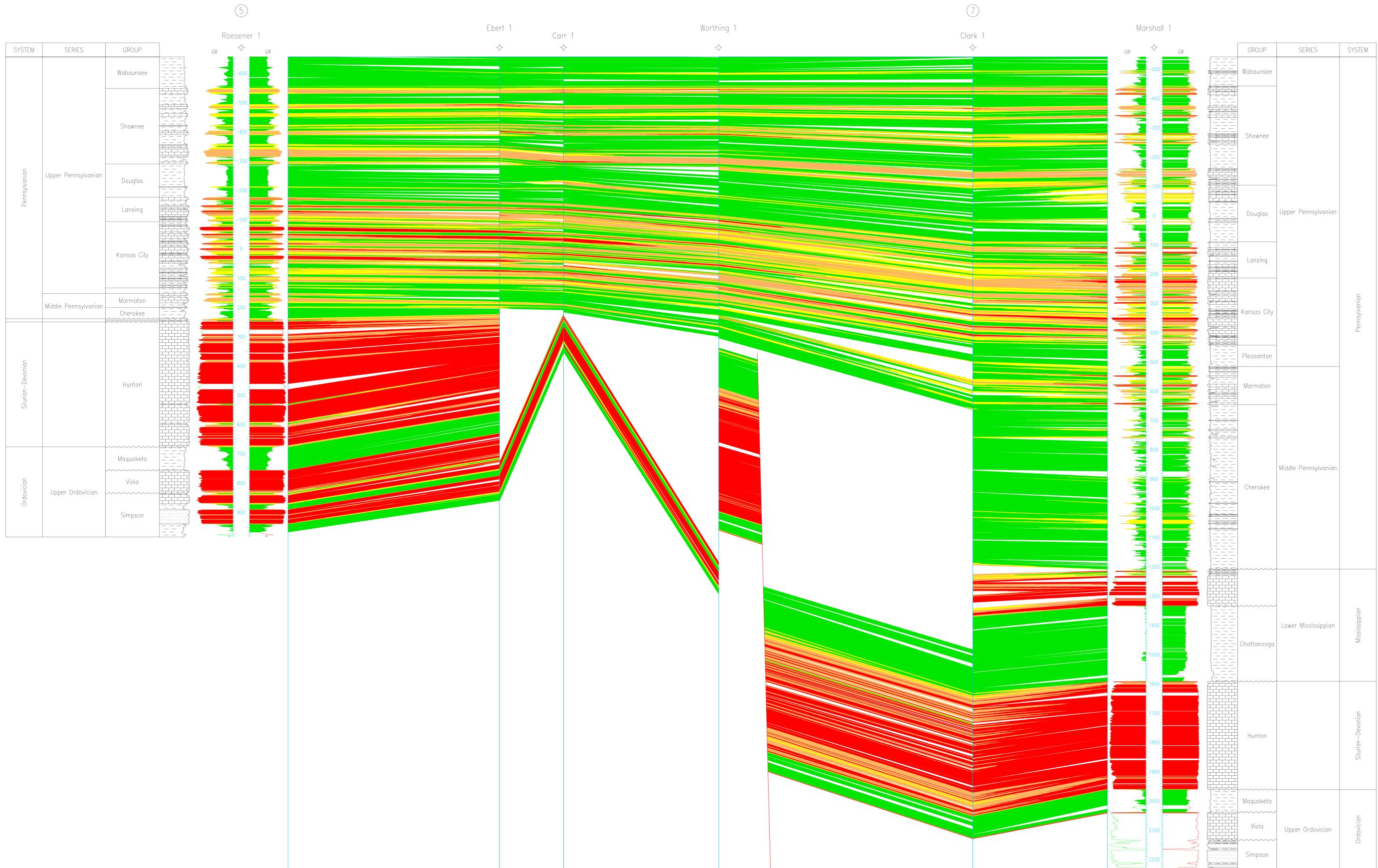
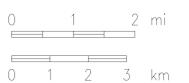


PLATE 1B

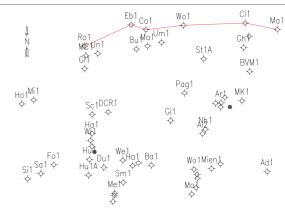
Shale content, percentage



Vertical exaggeration: 50X



LITHOLOGY SYMBOLS



INDEX MAP

KANSAS GEOLOGICAL SURVEY

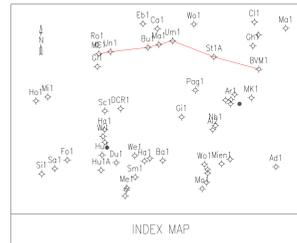
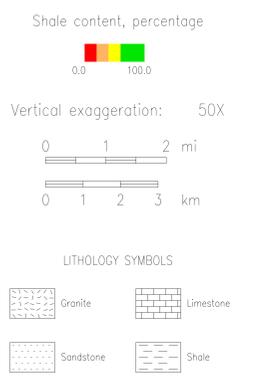
LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE  
 IN AN AREA AROUND WAMEGO, KANSAS  
 FIRST CROSS SECTION FROM THE NORTH, DATUM  
 SEA LEVEL  
 JANUARY 31, 2002

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LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE IN AREA AROUND WAMEGO, KANSAS  
 SECOND CROSS SECTION FROM THE NORTH, DATUM SEA LEVEL



PLATE 2A



KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE  
 IN AREA AROUND WAMEGO, KANSAS  
 SECOND CROSS SECTION FROM THE NORTH, DATUM  
 SEA LEVEL  
 JANUARY 29, 2002

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LITHOSTRATIGRAPHY  
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 SECOND CROSS SECTION FROM THE NORTH, DATUM TOP OF TOPEKA LIMESTONE

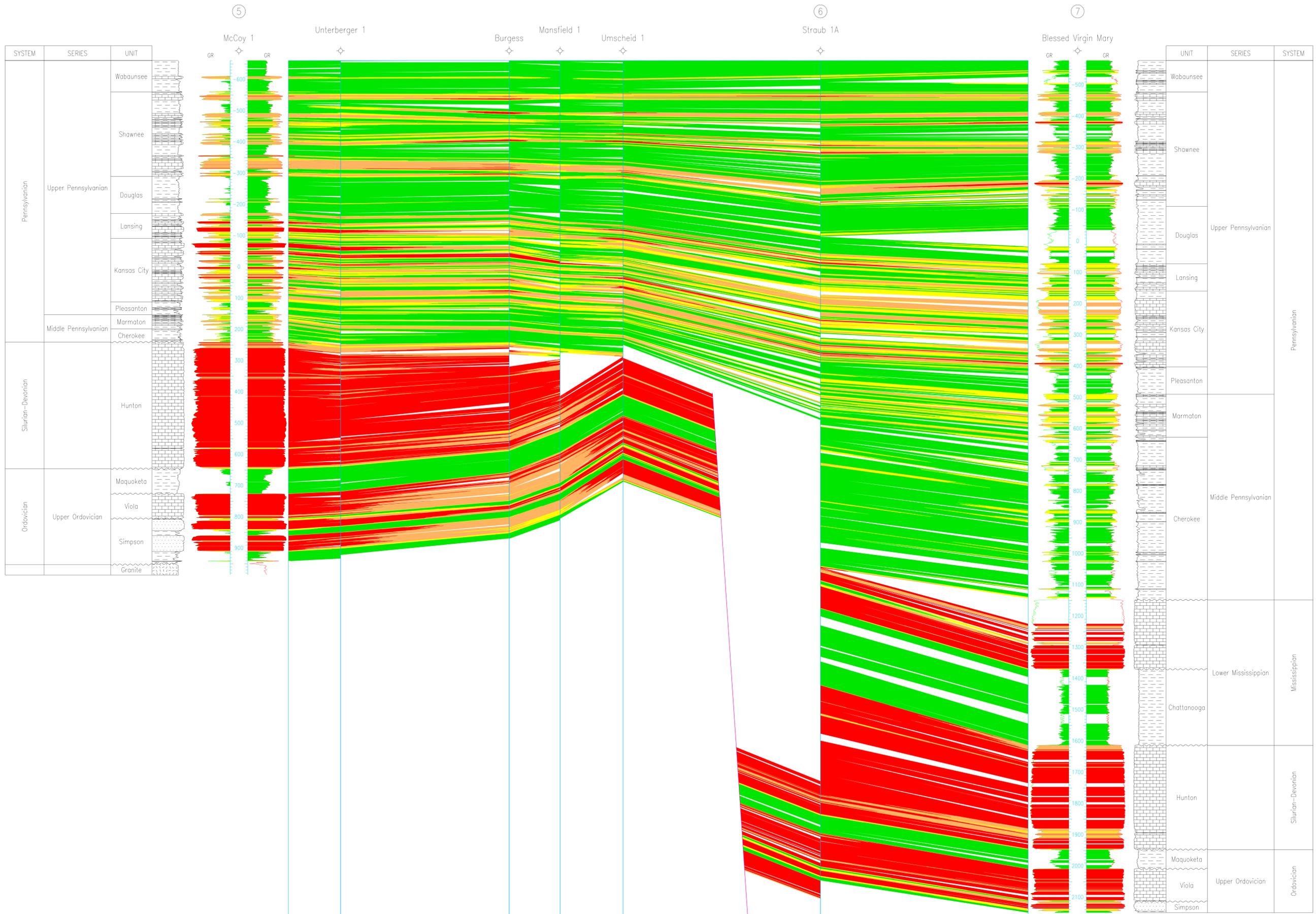


PLATE 2B

Shale content, percentage  
 0.0 100.0

Vertical exaggeration: 50X

0 1 2 mi  
 0 1 2 3 km

LITHOLOGY SYMBOLS

- Granite
- Limestone
- Sandstone
- Shale

INDEX MAP

KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE  
 IN AREA AROUND WAMEGO, KANSAS  
 SECOND CROSS SECTION FROM THE NORTH, DATUM  
 TOP OF TOPEKA LIMESTONE  
 JANUARY 29, 2002

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 PROCESSED BY: R.A. Olea, W.L. Watney & J.C. Davis

GEOLOGIC CROSS SECTION  
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 SECOND CROSS SECTION FROM THE NORTH, DATUM SEA LEVEL

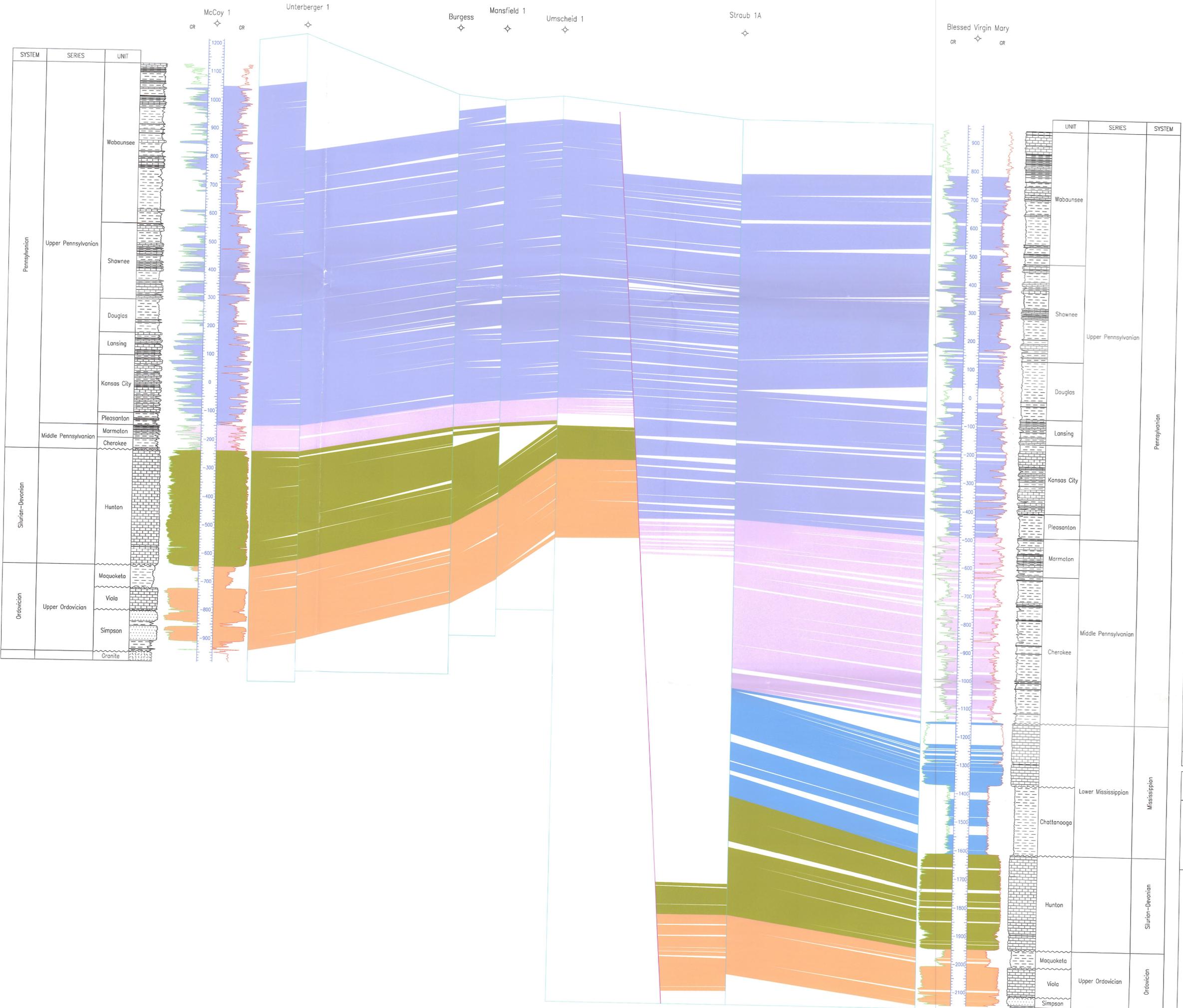
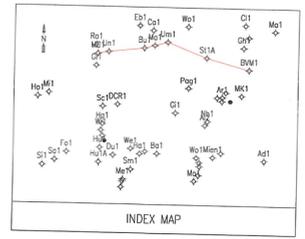
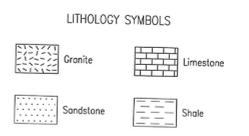
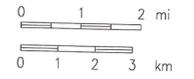


PLATE 2C

Vertical exaggeration: 50X



KANSAS GEOLOGICAL SURVEY

GEOLOGIC CROSS SECTION  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE  
 IN AREA AROUND WAMEGO, KANSAS  
 SECOND CROSS SECTION FROM THE NORTH, DATUM  
 SEA LEVEL  
 MARCH 27, 2002

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LITHOSTRATIGRAPHY  
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 THIRD CROSS SECTION FROM THE NORTH, DATUM SEA LEVEL

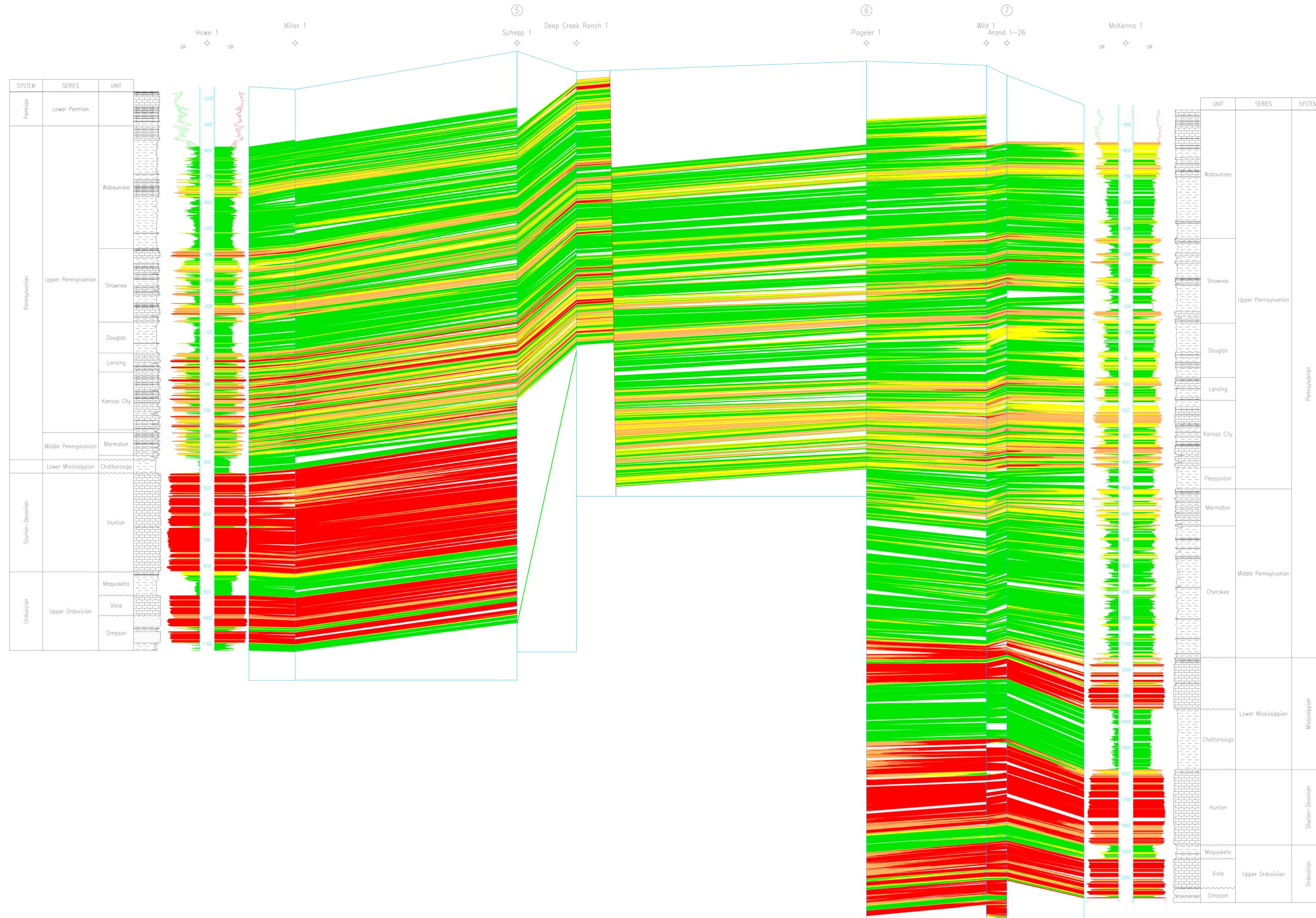
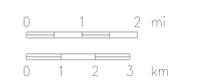


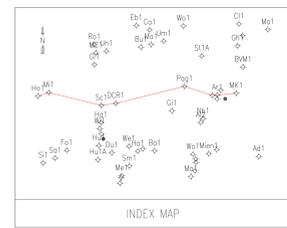
PLATE 3A

Shale content, percentage  
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Vertical exaggeration: 50X



LITHOLOGY SYMBOLS  
 Limestone Sandstone  
 Shale



KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE  
 IN AN AREA AROUND WAMEGO, KANSAS  
 THIRD CROSS SECTION FROM THE NORTH, DATUM  
 SEA LEVEL  
 JANUARY 31, 2002

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LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE IN AN AREA AROUND WAMEGO, KANSAS  
 THIRD CROSS SECTION FROM THE NORTH, DATUM TOP OF TOPEKA LIMESTONE

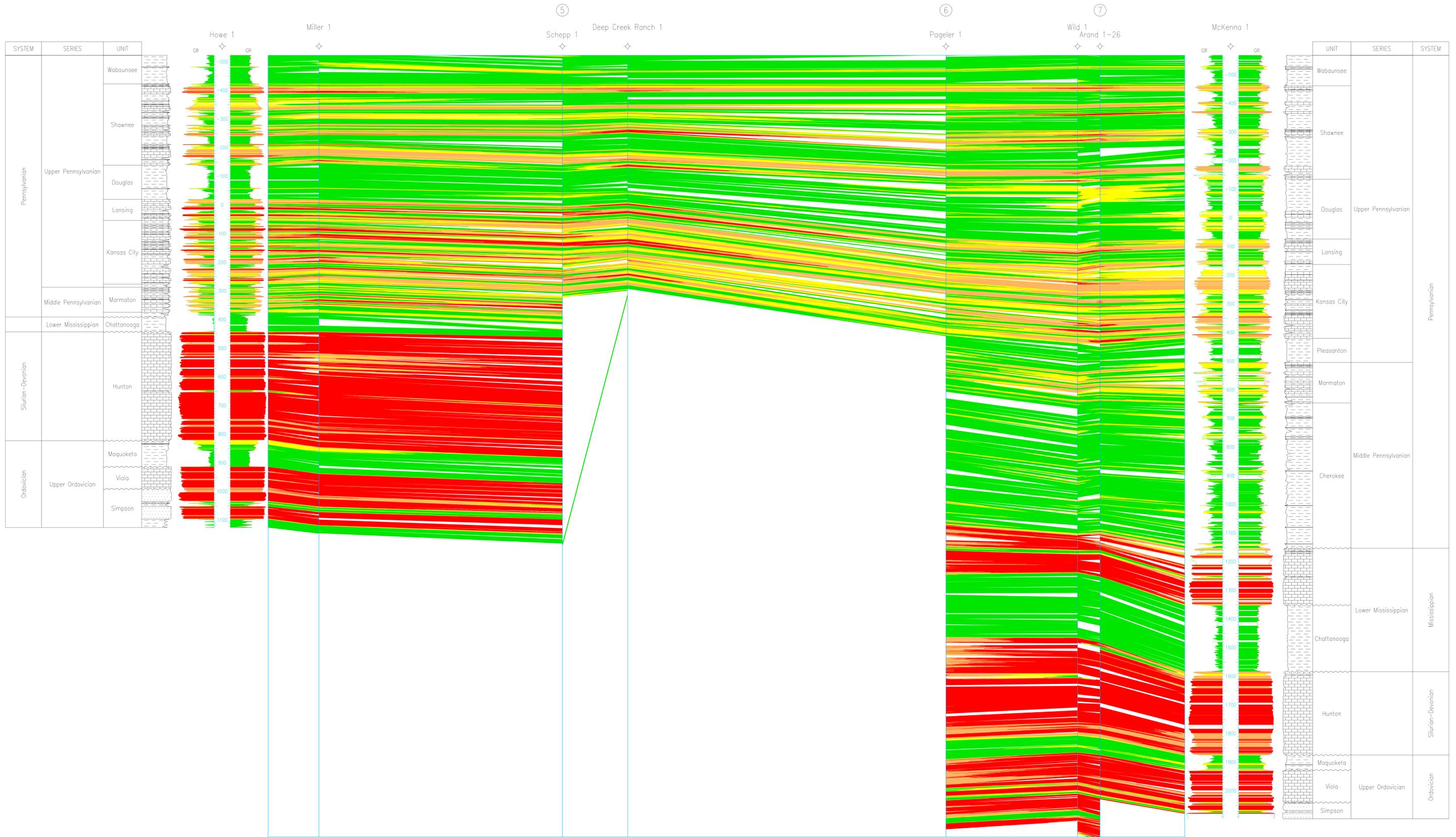
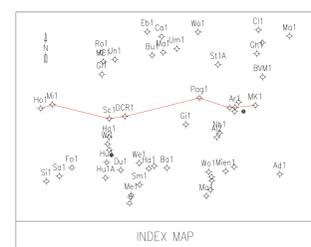
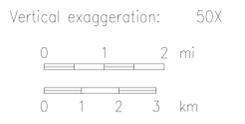


PLATE 3B



KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE  
 IN AN AREA AROUND WAMEGO, KANSAS  
 THIRD CROSS SECTION FROM THE NORTH, DATUM  
 TOP OF TOPEKA LIMESTONE  
 JANUARY 31, 2002

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LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE IN AN AREA AROUND WAMEGO, KANSAS  
 FOURTH CROSS SECTION FROM THE NORTH, DATUM SEA LEVEL

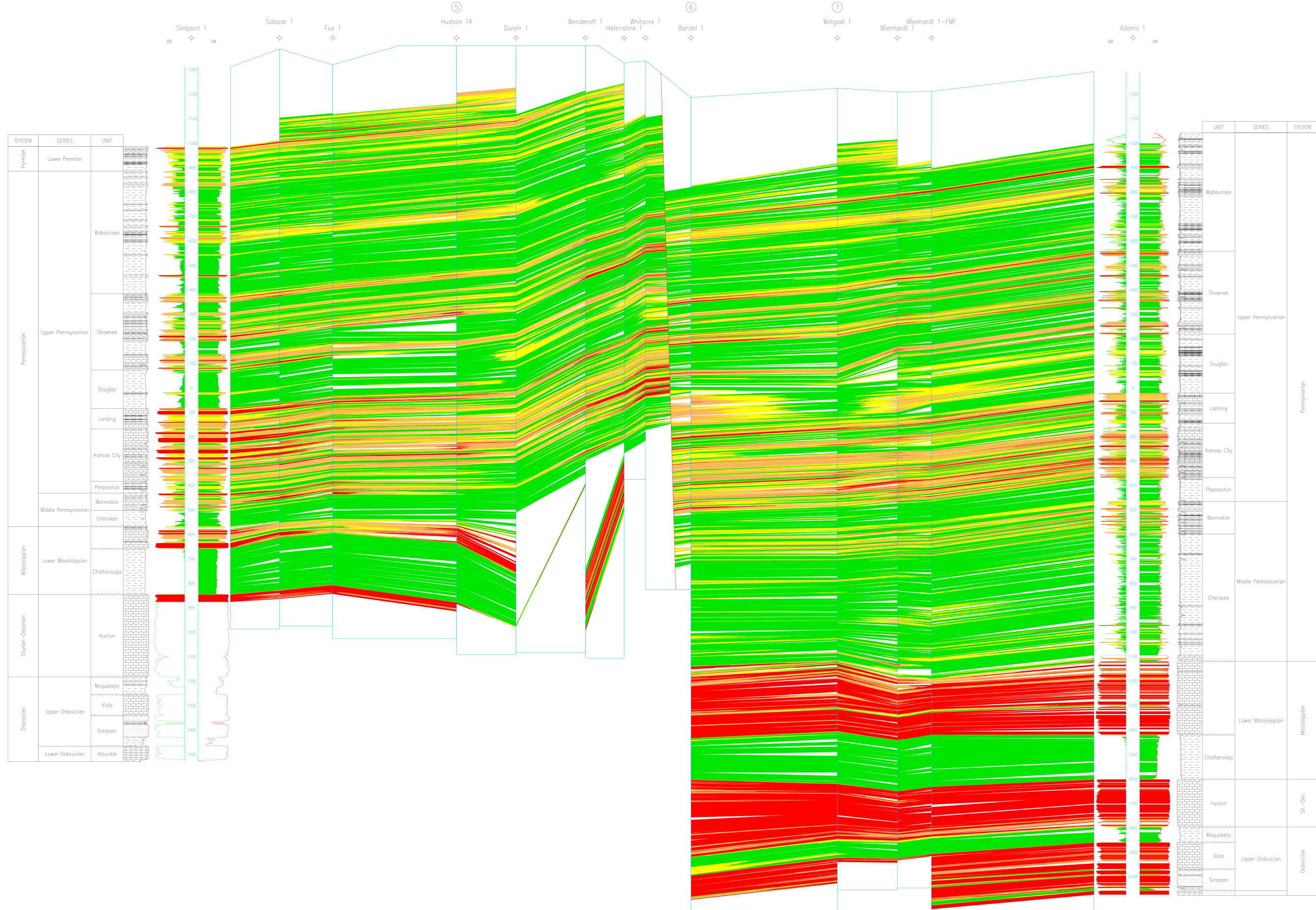


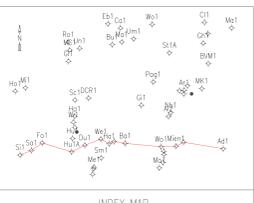
PLATE 4A

Shale content, percentage  
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Vertical exaggeration: 50X



LITHOLOGY SYMBOLS



KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE  
 IN AN AREA AROUND WAMEGO, KANSAS  
 FOURTH CROSS SECTION FROM THE NORTH, DATUM  
 SEA LEVEL  
 JANUARY 29, 2002

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LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE IN AN AREA AROUND WAMEGO, KANSAS  
 FOURTH CROSS SECTION FROM THE NORTH, DATUM TOP OF TOPEKA LIMESTONE

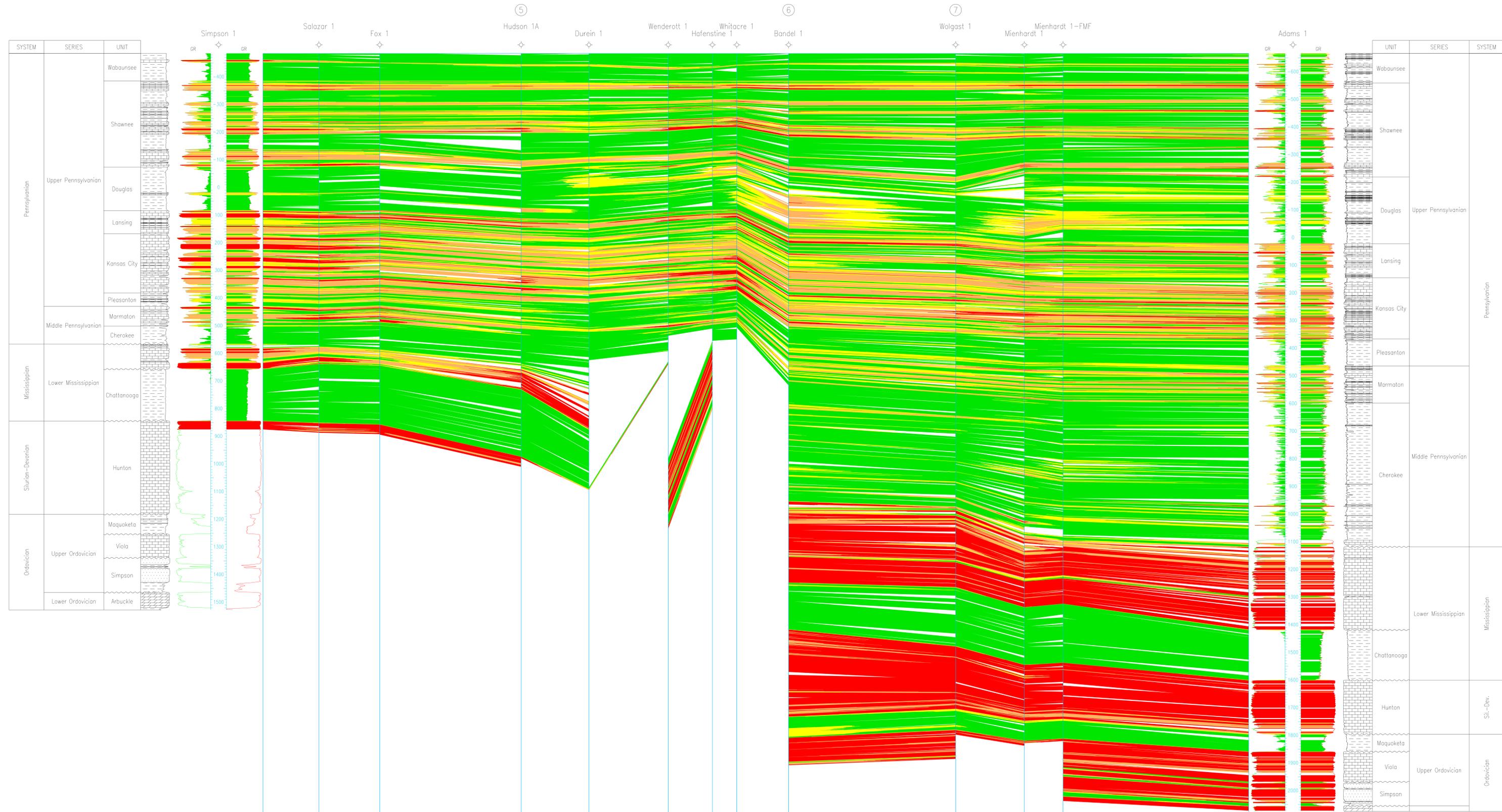


PLATE 4B

Shale content, percentage  
 0.0 100.0

Vertical exaggeration: 50X

0 1 2 mi  
 0 1 2 3 km

LITHOLOGY SYMBOLS

- Dolomite
- Limestone
- Sandstone
- Shale

INDEX MAP

KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE  
 IN AN AREA AROUND WAMEGO, KANSAS  
 FOURTH CROSS SECTION FROM THE NORTH, DATUM  
 TOP OF TOPEKA LIMESTONE  
 JANUARY 31, 2002

WELL DATA FILE: H.WLDB  
 SPECIFICATION FILE: XS4B.SP  
 SOURCE FILE: XS4.SOUR  
 STRATIGRAPHIC COLUMN FILES:  
 RIGHT: AD1.SCR  
 LEFT: SI1.SCL  
 DATUM FILE: SHAWNEE4.DATUM  
 PLOTTING FILE: XSECTION4B.PS  
 PRINTING FILE: PRINT.COR  
 PROCESSED BY: R.A. Olea, W.L. Watney & J.C. Davis

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE IN AN AREA AROUND WAMEGO, KANSAS  
 FIRST CROSS SECTION FROM THE WEST, DATUM SEA LEVEL

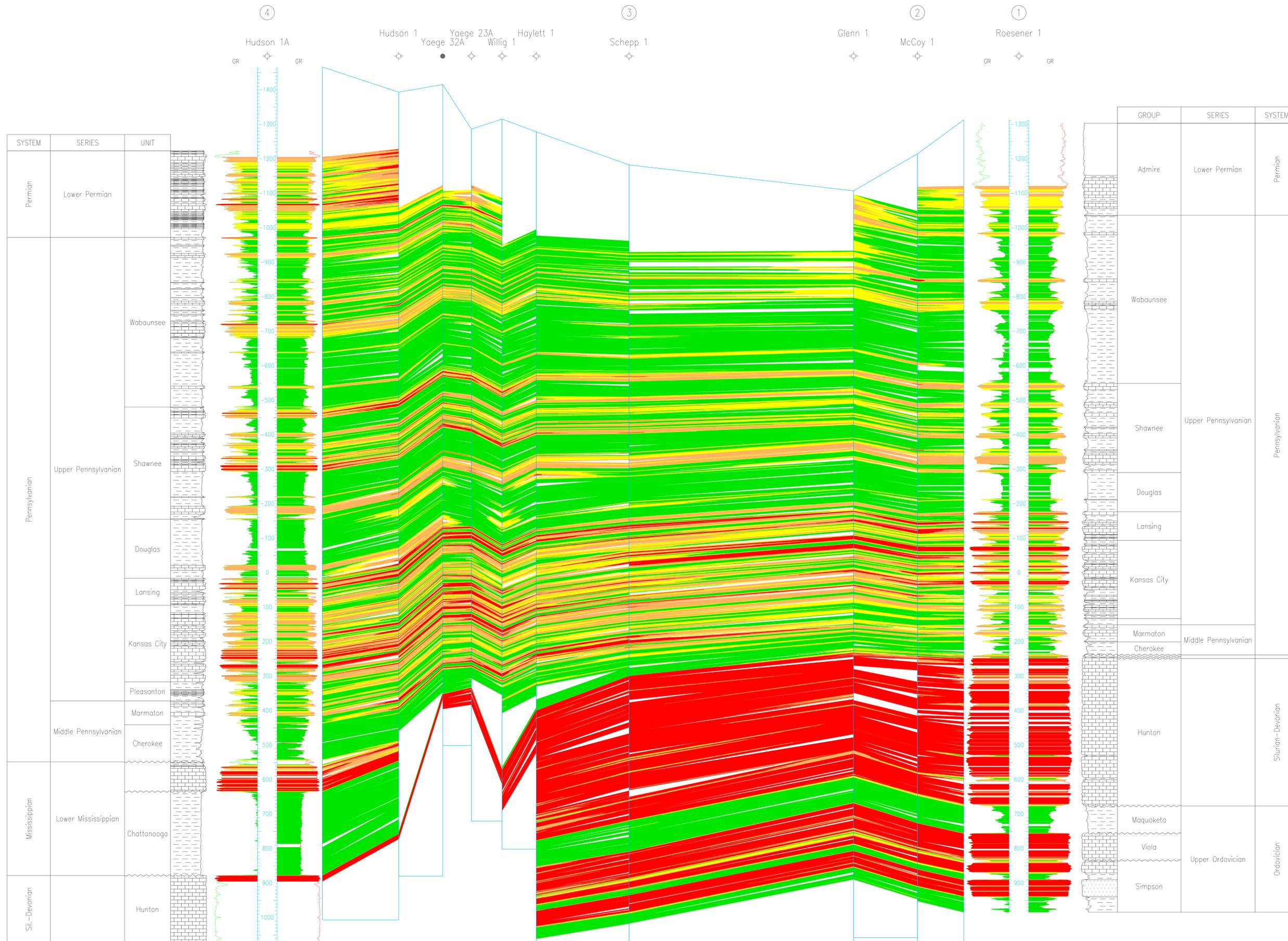


PLATE 5A

Shale content, percentage  
 0.0 100.0

Vertical exaggeration: 50X

0 1 2 mi  
 0 1 2 3 km

LITHOLOGY SYMBOLS

Limestone Sandstone  
 Shale

INDEX MAP

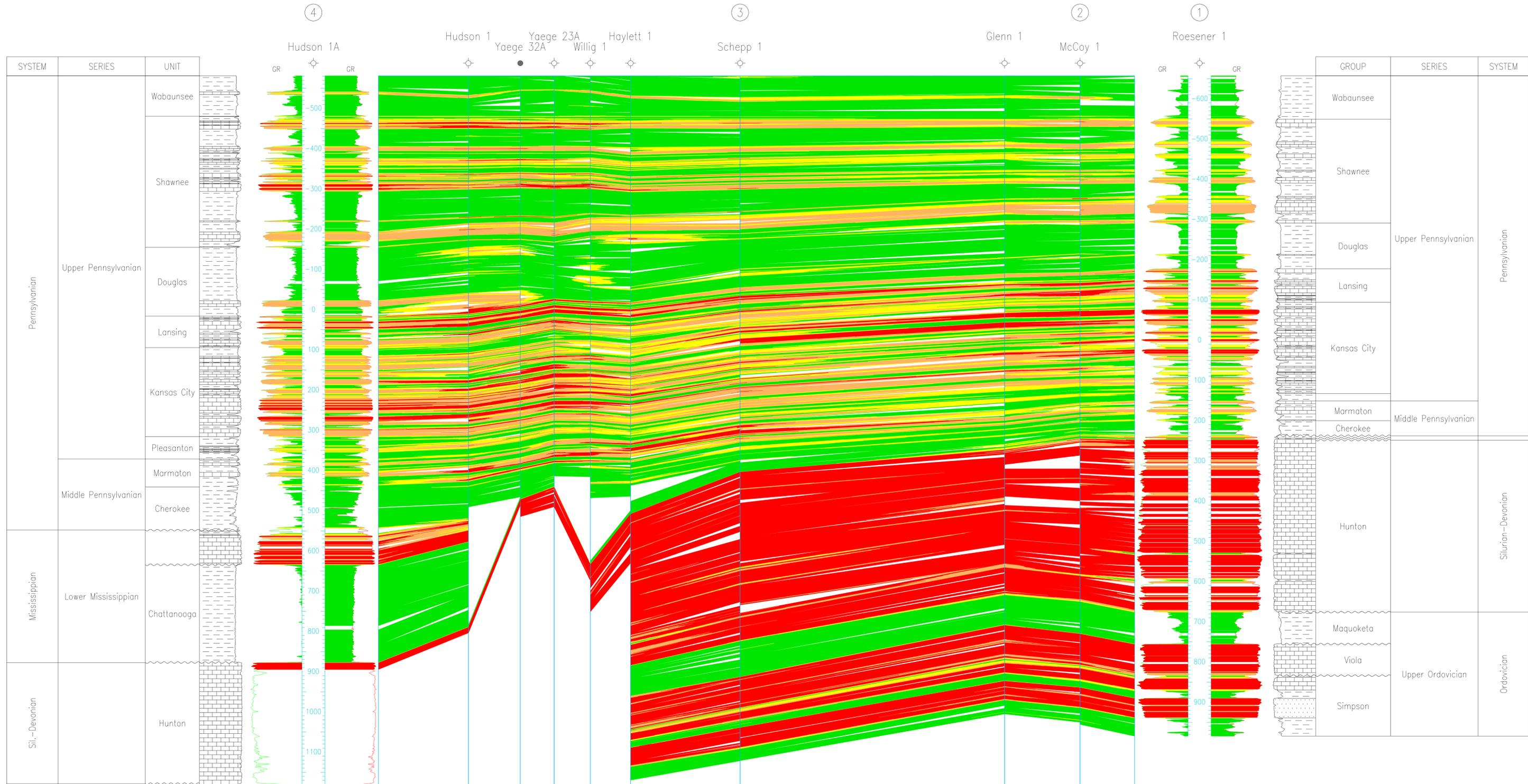
KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE  
 IN AN AREA AROUND WAMEGO, KANSAS  
 FIRST CROSS SECTION FROM THE WEST, DATUM  
 SEA LEVEL  
 JANUARY 29, 2002

WELL DATA FILE: H.WLDB  
 SPECIFICATION FILE: XS5A.SP  
 SOURCE FILE: XS5.SOUR  
 STRATIGRAPHIC COLUMN FILES:  
 RIGHT: R01.SCR  
 LEFT: HUIA.SCL  
 PLOTTING FILE: XSECTIONA.PS  
 PRINTING FILE: PRINT.COR  
 PROCESSED BY: R.A. Olea, W.L. Watney & J.C. Davis

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE IN AN AREA AROUND WAMEGO, KANSAS  
 FIRST CROSS SECTION FROM THE WEST, DATUM TOP OF TOPEKA LIMESTONE

PLATE 5B



Shale content, percentage  
 0.0 100.0

Vertical exaggeration: 50X

0 1 2 mi  
 0 1 2 3 km

LITHOLOGY SYMBOLS  
 Limestone Sandstone  
 Shale

INDEX MAP

KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE  
 IN AN AREA AROUND WAMEGO, KANSAS  
 FIRST CROSS SECTION FROM THE WEST, DATUM  
 TOP OF TOPEKA LIMESTONE  
 JANUARY 29, 2002

WELL DATA FILE: H.WLDB  
 SPECIFICATION FILE: XS5B.SP  
 SOURCE FILE: XS5.SOUR  
 STRATIGRAPHIC COLUMN FILES:  
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 LEFT: HU1A.SCL  
 DATUM FILE: SHAWNEES.DATUM  
 PLOTTING FILE: XSECTION5B.PS  
 PRINTING FILE: PRINT.COR  
 PROCESSED BY: R.A. Olea, W.L. Watney & J.C. Davis

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE IN AN AREA AROUND WAMEGO, KANSAS  
 SECOND CROSS SECTION FROM THE WEST, DATUM SEA LEVEL

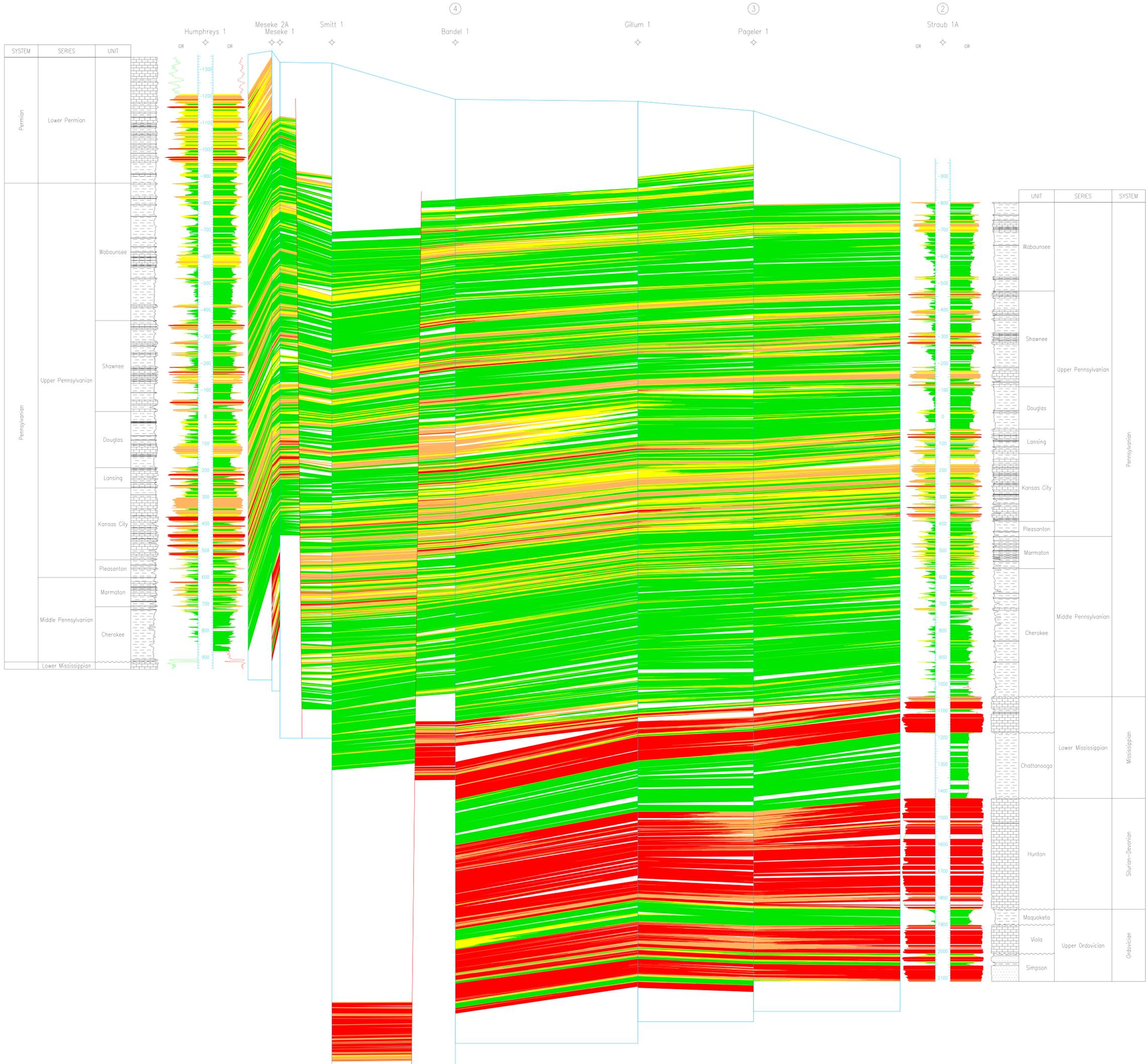
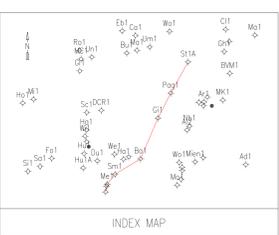
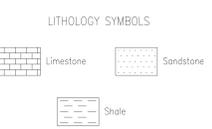
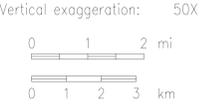


PLATE 6A



KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE  
 IN AN AREA AROUND WAMEGO, KANSAS  
 SECOND CROSS SECTION FROM THE WEST, DATUM  
 SEA LEVEL  
 JANUARY 29, 2002

WELL DATA FILE: H.WLDB  
 SPECIFICATION FILE: XS6A.SP  
 SOURCE FILE: XS6.SOUR  
 STRATIGRAPHIC COLUMN FILES:  
 RIGHT: ST1A.SCR  
 LEFT: HU1.SCL  
 FAULT FILE: XS6.FT  
 PLOTTING FILE: XSECTION6A.PS  
 PRINTING FILE: PRINT.COR  
 PROCESSED BY: R.A. Olea, W.L. Watney & J.C. Davis

# LITHOSTRATIGRAPHY

## SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE IN AN AREA AROUND WAMEGO, KANSAS

### SECOND CROSS SECTION FROM THE WEST, DATUM TOP OF TOPEKA LIMESTONE

Vertical exaggeration: 50X  
Shale content, percentage

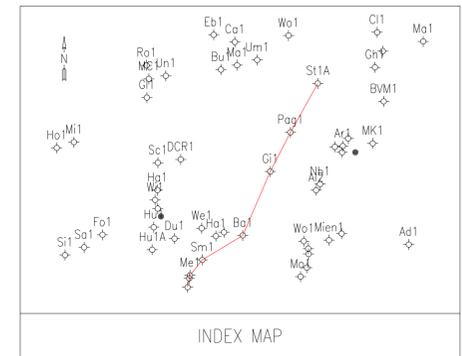
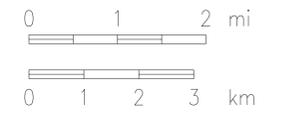


| SYSTEM        | SERIES               | UNIT        |
|---------------|----------------------|-------------|
| Pennsylvanian | Upper Pennsylvanian  | Wabausee    |
|               |                      | Shawnee     |
|               |                      | Douglas     |
|               |                      | Lansing     |
|               |                      | Kansas City |
|               | Pleasanton           |             |
|               | Middle Pennsylvanian | Marmaton    |



| UNIT        | SERIES               | SYSTEM        |
|-------------|----------------------|---------------|
| Wabausee    | Upper Pennsylvanian  | Pennsylvanian |
| Shawnee     |                      |               |
| Douglas     |                      |               |
| Lansing     |                      |               |
| Kansas City |                      |               |
| Pleasanton  |                      |               |
| Marmaton    | Middle Pennsylvanian |               |

PLATE 6B

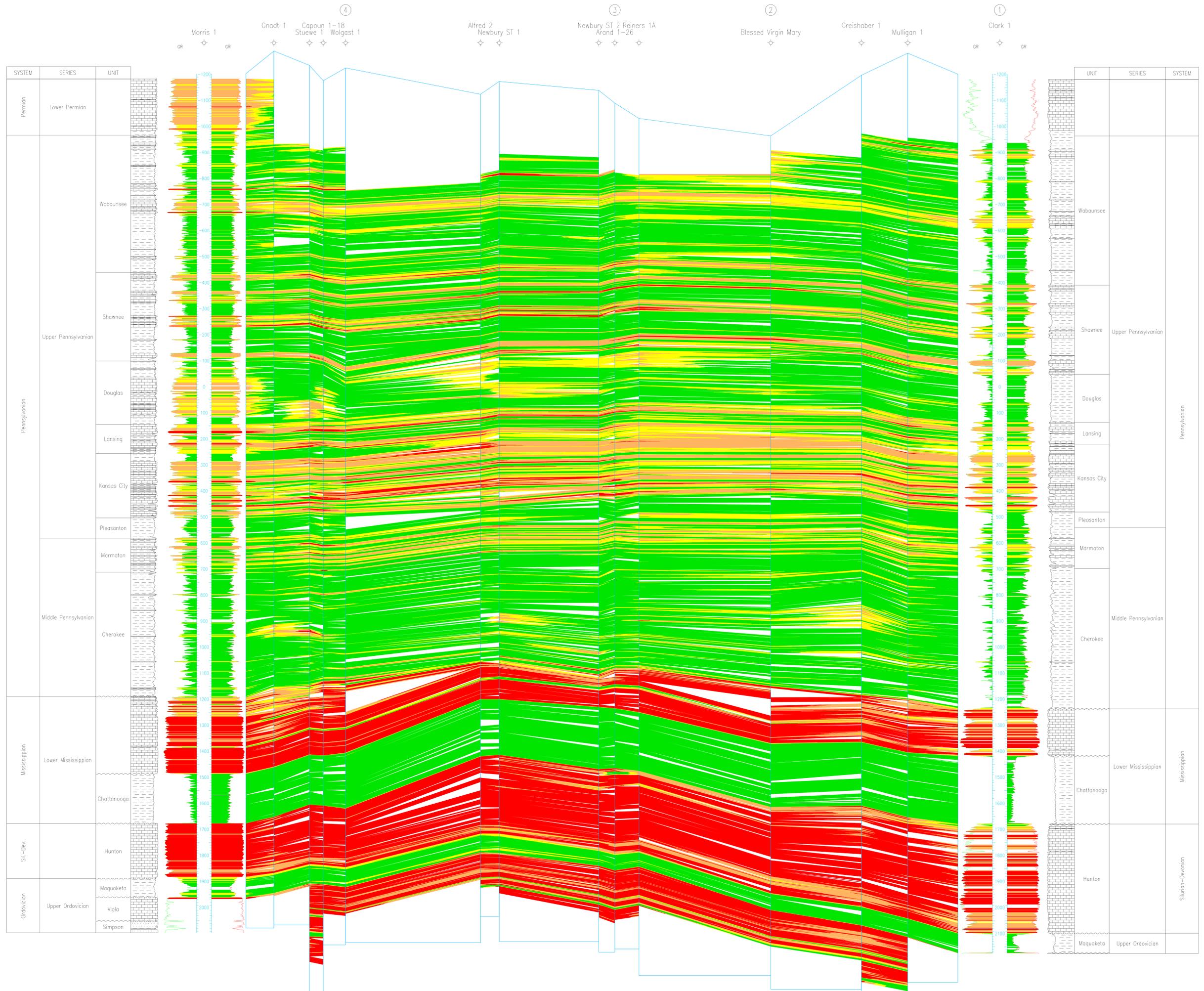


KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
SUBSURFACE GEOLOGY OF THE NEMAHA ANTICLINE  
IN AN AREA AROUND WAMEGO, KANSAS  
SECOND CROSS SECTION FROM THE WEST, DATUM  
TOP OF TOPEKA LIMESTONE  
JANUARY 29, 2002

WELL DATA FILE: H.WLDB  
SPECIFICATION FILE: XS6B.SP  
SOURCE FILE: XS6.SOUR  
STRATIGRAPHIC COLUMN FILES:  
RIGHT: ST1A.SCR  
LEFT: HU1.SCL  
DATUM FILE: SHAWNEE6.DATUM  
PLOTTING FILE: XSECTION6B.PS  
PRINTING FILE: PRINT.COR  
PROCESSED BY: R.A. Olea, W.L. Watney & J.C. Davis

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE IN AREA AROUND WAMEGO, KANSAS  
 THIRD CROSS SECTION FROM THE WEST, DATUM SEA LEVEL



| SYSTEM        | SERIES               | UNIT        |
|---------------|----------------------|-------------|
| Permian       | Lower Permian        |             |
| Pennsylvanian | Upper Pennsylvanian  | Wabounee    |
|               |                      | Shawnee     |
|               |                      | Douglas     |
|               |                      | Lansing     |
|               |                      | Kansas City |
|               | Middle Pennsylvanian | Pleasanton  |
|               |                      | Marmaton    |
|               |                      | Cherokee    |
|               |                      |             |
|               |                      |             |
| Mississippian | Lower Mississippian  | Chattanooga |
|               |                      |             |
| Sil.-Dev.     |                      | Hunton      |
|               |                      | Maquoketa   |
| Ordovician    | Upper Ordovician     | Viola       |
|               |                      | Simpson     |

| UNIT        | SERIES              | SYSTEM               |
|-------------|---------------------|----------------------|
|             |                     |                      |
| Wabounee    |                     | Pennsylvanian        |
| Shawnee     | Upper Pennsylvanian |                      |
| Douglas     |                     |                      |
| Lansing     |                     |                      |
| Kansas City |                     |                      |
| Pleasanton  |                     | Middle Pennsylvanian |
| Marmaton    |                     |                      |
| Cherokee    |                     |                      |
|             |                     | Lower Mississippian  |
| Chattanooga |                     |                      |
|             |                     | Silurian-Devonian    |
| Hunton      |                     |                      |
| Maquoketa   | Upper Ordovician    |                      |

PLATE 7A

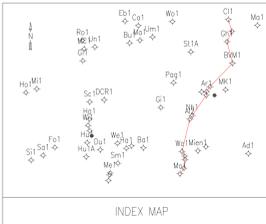
Shale content, percentage  
 0.0 100.0

Vertical exaggeration: 50X

0 1 2 mi  
 0 1 2 3 km

LITHOLOGY SYMBOLS

Limestone Sandstone  
 Shale



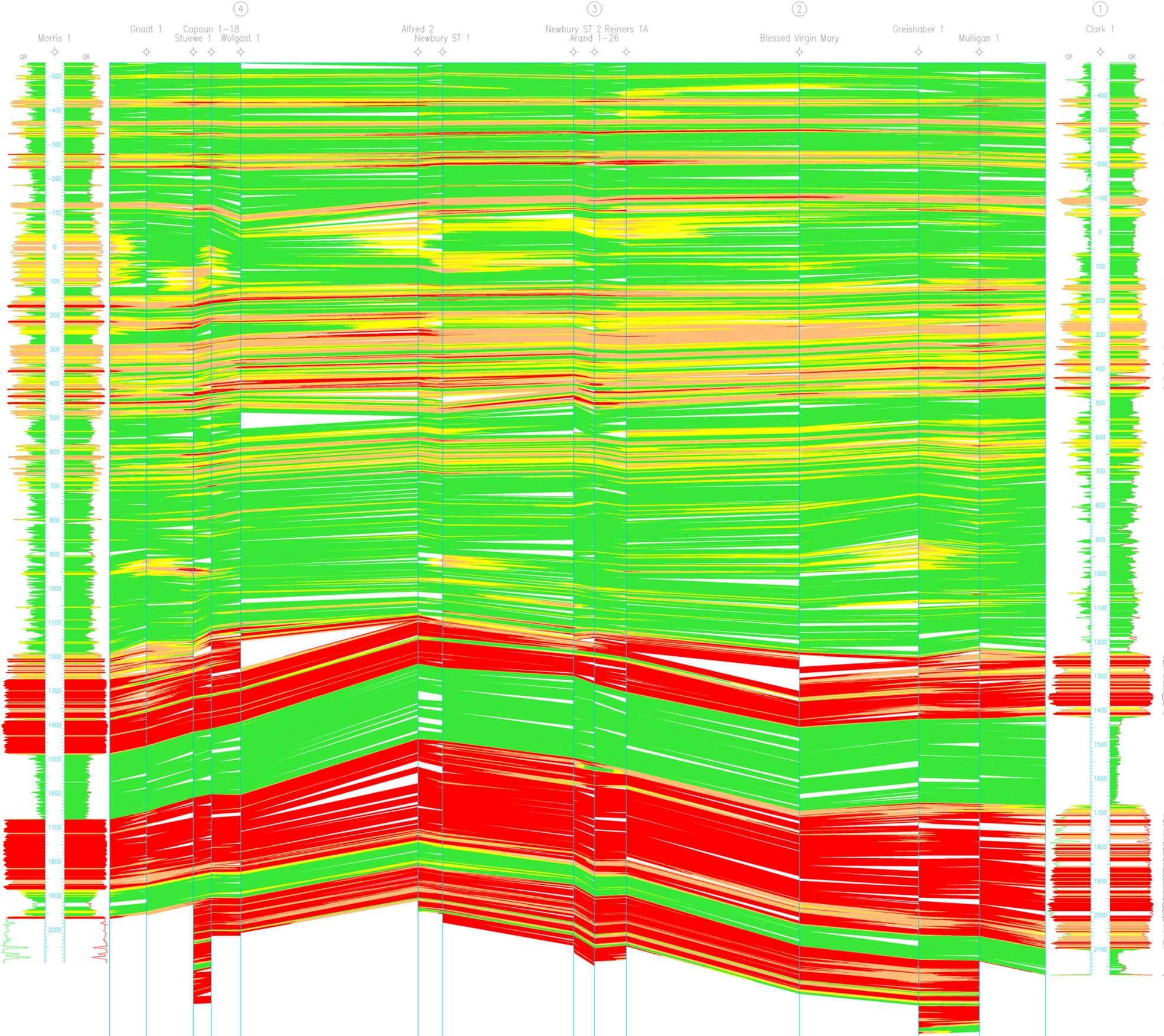
KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE  
 IN AREA AROUND WAMEGO, KANSAS  
 THIRD CROSS SECTION FROM THE WEST, DATUM  
 SEA LEVEL  
 JANUARY 29, 2002

WELL DATA FILE: H.WLDB  
 SPECIFICATION FILE: X57A.SP  
 SOURCE FILE: X57.SOUR  
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 RIGHT: M01.SCR  
 LEFT: M01.SCL  
 PLOTTING FILE: XSECTION7A.PS  
 PRINTING FILE: PRINT.COR  
 PROCESSED BY: R.A. Olea, W.L. Watney & J.C. Davis

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE IN AREA AROUND WAMEGO, KANSAS  
 THIRD CROSS SECTION FROM THE WEST, DATUM TOP OF TOPEKA LIMESTONE

| SYSTEM        | SERIES               | UNIT        |
|---------------|----------------------|-------------|
| Pennsylvanian | Upper Pennsylvanian  | Wabausee    |
|               |                      | Shawnee     |
|               |                      | Douglas     |
|               |                      | Lansing     |
|               |                      | Kansas City |
|               |                      | Pleasanton  |
|               | Middle Pennsylvanian | Marmaton    |
|               |                      | Cherokee    |
|               |                      |             |
|               |                      |             |
| Mississippian | Lower Mississippian  | Chattanooga |
|               |                      |             |
|               |                      |             |
| Sil.-Dev.     |                      | Hunton      |
|               |                      |             |
| Ordovician    | Upper Ordovician     | Maquoketa   |
|               |                      | Viola       |
|               |                      | Simpson     |



| UNIT        | SERIES               | SYSTEM            |
|-------------|----------------------|-------------------|
| Wabausee    |                      | Pennsylvanian     |
| Shawnee     |                      |                   |
| Douglas     | Upper Pennsylvanian  |                   |
| Lansing     |                      |                   |
| Kansas City |                      |                   |
| Pleasanton  |                      |                   |
| Marmaton    |                      |                   |
| Cherokee    | Middle Pennsylvanian |                   |
|             |                      |                   |
|             |                      |                   |
|             |                      | Mississippian     |
|             | Lower Mississippian  |                   |
| Chattanooga |                      |                   |
|             |                      | Silurian-Devonian |
| Hunton      |                      |                   |
| Maquoketa   | Upper Ordovician     |                   |

PLATE 7B

Shale content, percentage  
 0.0 100.0

Vertical exaggeration: 50X

0 1 2 mi  
 0 1 2 3 km

LITHOLOGY SYMBOLS

Limestone Sandstone  
 Shale

INDEX MAP

KANSAS GEOLOGICAL SURVEY

LITHOSTRATIGRAPHY  
 SUBSURFACE GEOLOGY OF NEMAHA ANTICLINE  
 IN AREA AROUND WAMEGO, KANSAS  
 THIRD CROSS SECTION FROM THE WEST, DATUM  
 TOP OF TOPEKA LIMESTONE  
 JANUARY 29, 2002

WELL DATA FILE: H\WLD8  
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 SOURCE FILE: X57.SOUR  
 STRATIGRAPHIC COLUMN FILES:  
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 LEFT: M01.SCL  
 DATUM FILE: SHAWNEE7.DATUM  
 PLOTTING FILE: XSECTION7B.PS  
 PRINTING FILE: PRINT.COR  
 PROCESSED BY: R.A. Olea, W.L. Watney & J.C. Davis