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PRELIMINARY INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS  
AND STRATIGRAPHY OF THE DAKOTA FORMATION IN PARTS OF  
WESTERN AND EASTERN ELLIS COUNTIES

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**KANSAS GEOLOGICAL SURVEY**  
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## Introduction:

The Dakota Formation in central Kansas consists of sandstones, fine-grained argillaceous rocks, and lignites deposited in a diversity of non-marine and marine environments during the Cretaceous Period. Traditionally, this formation has been difficult to understand stratigraphically due to the lack of a usable stratigraphic framework combining the temporal and spacial elements of sediment depositional patterns. Meaningful correlations of the Dakota Formation in Kansas with the Dakota Group of the Denver basin has not been attempted because of the inability to successfully tie surface and subsurface sections west of the outcrop in central Kansas. In order to develop a useful framework for the Dakota Formation in Kansas, it is important to understand the effect of a shifting strand line and local tectonics on Dakota sediment deposition patterns. This level of regional understanding makes prediction of lithologies on a more local level possible in areas of the subsurface that have not been thoroughly explored. By employing this approach, it is possible to guarantee the success of mineral or ground-water resource exploration programs to locate potential reservoirs and aquifers in the Dakota Formation.

This study is part of the Kansas Geological Survey's Dakota aquifer Program and was conducted as a pilot project. The project began as an attempt to answer questions concerning the size and shape of the fluvially-deposited channel sandstones of the Dakota Formation in the subsurface. In order to determine the geometry of these sandstone bodies, a small, well-studied area adjacent to the surface outcrop of the Dakota Formation was chosen in eastern Ellis and western Russell counties. As work began on this project, it became clear that the Dakota Formation in the study area could be subdivided into mappable units (electrofacies) that had some stratigraphic significance. Review of the literature also indicated that upward changes in lithology and electrofacies could be related to sea level change (eustasy) during the period of deposition of the Dakota Formation in central Kansas. With this insight, the pilot project was completed producing some preliminary results. The purpose of this paper is to present a preliminary interpretation of depositional environments and stratigraphy of the Dakota Formation in the study area with emphasis on sandstone distribution. It is anticipated that as more is learned about the Dakota Formation, the preliminary results of this pilot project will be

revised, if needed, and eventually incorporated into the regional stratigraphic framework of the Dakota Formation in Kansas.

### Study Area Description and Geologic Setting:

The study area is located in western Russell and eastern Ellis Counties, T11-13S, R14-19W (Fig. 1). The eastern part of the area overlaps part of the Dakota Formation outcrop belt in Russell County. Westward of the outcrop belt, the Dakota Formation is covered by younger strata. In the subsurface, the Dakota Formation is bounded above and below by the Graneros Shale and the Kiowa Formation, respectively. Thickness of the Dakota Formation in the study area ranges from 225 feet in southeast T13S, R15E, up to 390 feet in T11-12S, R18W.

This part of Kansas is located east of the axis of the Cretaceous western interior seaway. Prior to the deposition of the Dakota Formation, eustatic change caused the Kiowa shoreline to rapidly retreat westward into Colorado, initiating a period of stream erosion (Franks, 1966, 1975; Weimer, 1984). Later, a coastal, low-relief, terrestrial to brackish water environment prevailed in this part of Kansas and non-marine fluvial sediments were deposited in a regional unconformity on top of the Kiowa Formation. This period ended with the beginning of the Greenhorn cycle of deposition near the top of the Dakota Formation (Hattin and Siemers, 1987). These transgressive and regressive episodes are largely the result of eustatic changes and have influenced the style and character of Dakota deposition in this part of Kansas by controlling the base level of streams on the eastern side of the seaway. The effect of these fluctuations on sediment deposition has been further modified locally by slight, deep seated tectonic movements (Franks, 1965; Sonnenberg and Weimer, 1981).

Figure 2 shows the elevation of the Graneros Shale top in the study area. This datum was chosen because this formation boundary is more readily identified on gamma ray logs of boreholes in the study area. The top of the Graneros is recognized as a time-transgressive horizon (Hattin and Siemers, 1987). However, the amount of truncation that occurred at the top of the Graneros is relatively minor compared to the amount of structural relief in the study area. The top configuration of the Graneros Shale shows a predominate north-south structural trend that developed after the deposition of the Graneros Shale. Locally, the dominant geologic structure is the Central Kansas uplift. The Fairport-Natoma anticline

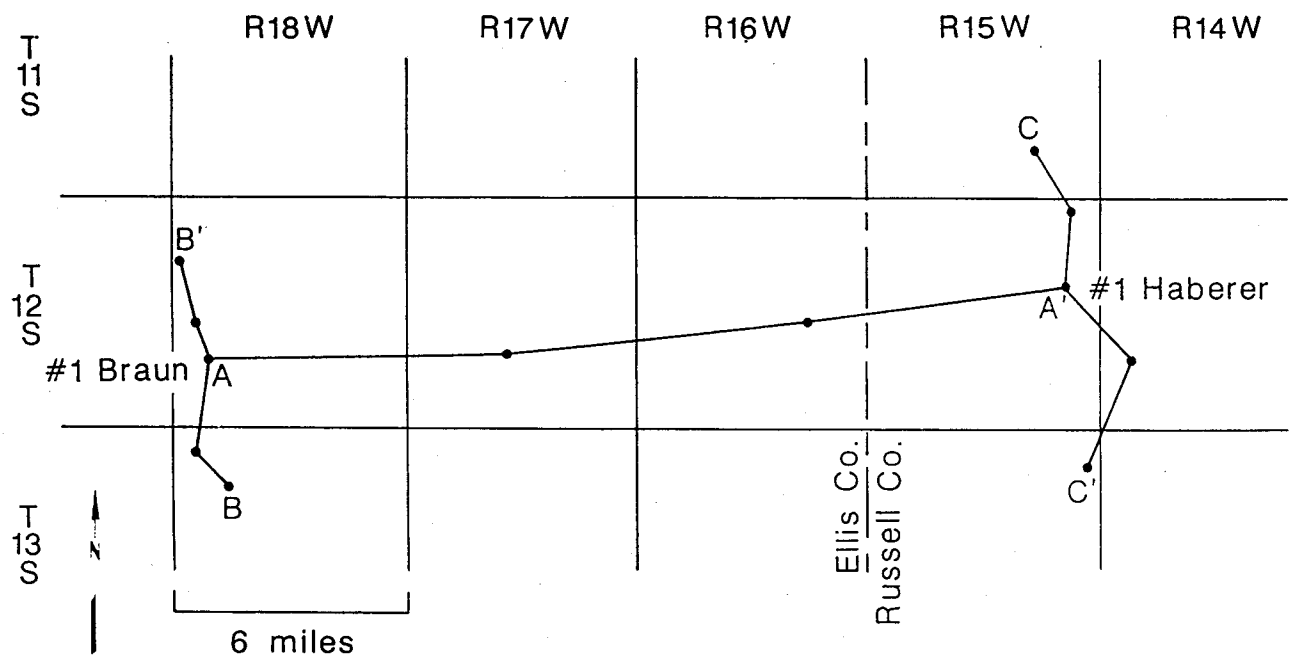


Figure 1. Location of the study area, cross-sections, and test holes in eastern Ellis and western Russell counties.

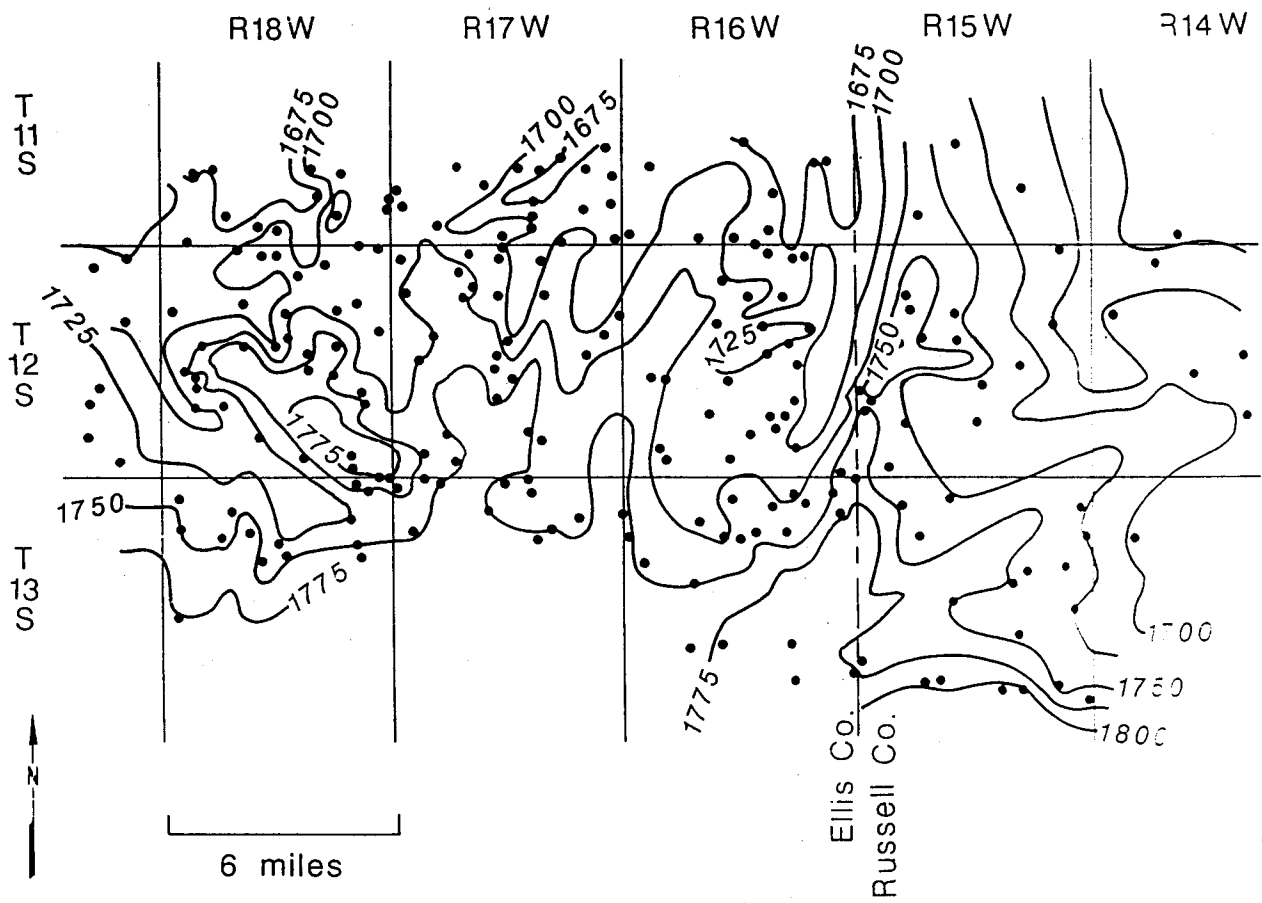


Figure 2. Structure contour map on top of the Graneros Shale, western Russell and eastern Ellis counties.

crosses the study area near the Ellis-Russell County line in a north-south direction. The outline of this structure is clearly seen on the Graneros Shale top configuration map (Fig. 2), and on Merriam's (1958) map of the underlying Permian Stone Corral Formation top.

### Methodology:

Test holes were drilled and logged in Ellis Co. (KGS #1 Braun, NE NE NE Sec. 30, T12S, R18W) and in Russell Co. (KGS#1 Haberer, NE SE NE Sec. 14, T12S, R15W) (Fig. 1). The #1 Braun penetrated part of the Upper Cretaceous and all of the Lower Cretaceous down into the Lower Permian Cedar Hills Sandstone. Dakota Formation thicknesses penetrated by the #1 Haberer and #1 Braun are 280 and 299 feet, respectively. The #1 Haberer test hole did not penetrate all of the Lower Cretaceous section. It is believed that drilling ceased in the Kiowa Formation or the Cheyenne Sandstone, just above the Permian/Cretaceous unconformity.

Each test hole was logged by Schlumberger, a commercial well-logging company to interpret lithologies and petrophysics properties. Logging runs in the #1 Braun were made to produce logs of dual induction-SFL, spectral gamma ray, neutron-density, and photoelectric absorption index measurements. A similar log suite was produced for the #1 Haberer except for the photoelectric absorption index log. An attempt was made to continuously core the #1 Haberer with limited success. Cores were recovered from the upper 142 feet of the Dakota Formation. Very little sandstone was recovered during the coring process due to the friability of the sandstones. Lithology of the sediments penetrated by the #1 Braun was deduced from examination of the cuttings and analysis of the borehole logs (Macfarlane et al., in press). Mineralogy in the #1 Braun was determined from an analysis and interpretation of the lithodensity-neutron and photoelectric absorption index logs described below. Similarly, the lithologies penetrated by the #1 Haberer were deduced from examination of the cuttings, interpretation of the borehole logs and examination of the core. Figure 3 shows the computed gamma ray, Th/K, and Th/U logs and interpreted mineralogy of the Dakota Formation penetrated by the #1 Braun and the computed gamma ray, Th/K, and Th/U logs of the #1 Haberer. The computed gamma ray curve is shown for each test hole instead of the measured trace because the computed log is a more accurate reflection of the amount of clay in the rocks (Rider, 1986).

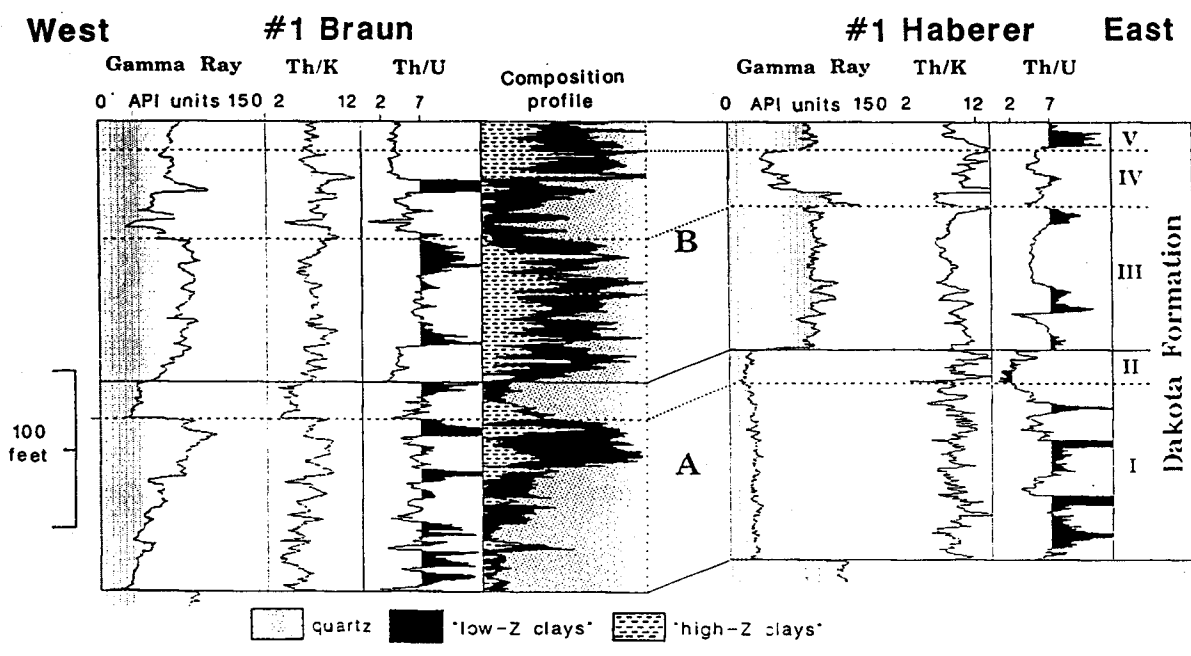


Figure 3. Computed gamma ray, Th/K, Th/U, and RHOMAA-UMAA composition logs for the KGS #1 Braun and computed gamma ray, Th/K, and Th/U logs for the KGS #1 Haberer in the Dakota Formation.

The Dakota Formation was subdivided into five electrofacies (I through V) based on log response and interpreted lithology (Fig. 3). Each electrofacies shows similar log response patterns and is interpreted to signify rocks deposited under similar environmental conditions (e.g., alluvial valley, deltaic, etc.). To the extent possible, field work was conducted in the outcrop areas of the Dakota Formation in Russell, Lincoln, and Ottawa counties to verify the interpretation of depositional environment. These five units were combined into two groups, A and B, on the basis of Weimer's (1984) sea level curve for the western U.S. and the interpreted vertical changes of depositional environment. Referring to Weimer's sea level curve in Figure 4, the boundary between the A and B subdivisions of the Dakota Formation occurs at the close of deposition of the Mowry Shale (M) and prior to the deposition of the "D" Sandstone (D) on the western side of the western interior seaway. We interpret the fining-upward succession of lithologies in electrofacies I and II as the result of fluvial deposition during a period of transgression at the end of the Lower Cretaceous. We believe that the Graneros Shale of the Denver Basin is correlative in time with the upper half of the Dakota Formation in central Kansas (subdivision B).

Correlation of electrofacies I through V across the study area was done by constructing an east-west cross-section (Fig. 5) between the two test holes using available borehole logs (measured API gamma ray) for petroleum-related wells in the area. Figure 1 shows the locations of all cross-sections in the study area. Additional north-south sections through the two test holes were also constructed to establish a correlation network (Fig. 6, 7). These cross-sections also serve to show lateral changes of lithology and depositional environment within electrofacies. Additional wells were added to the network and correlated in order to map sand thickness within each of the various electrofacies (I through V). Sandstones were considered to have an API gamma ray intensity of less than 60 on the basis of the data from the two test holes. Approximately 250 well logs were used to produce these maps.

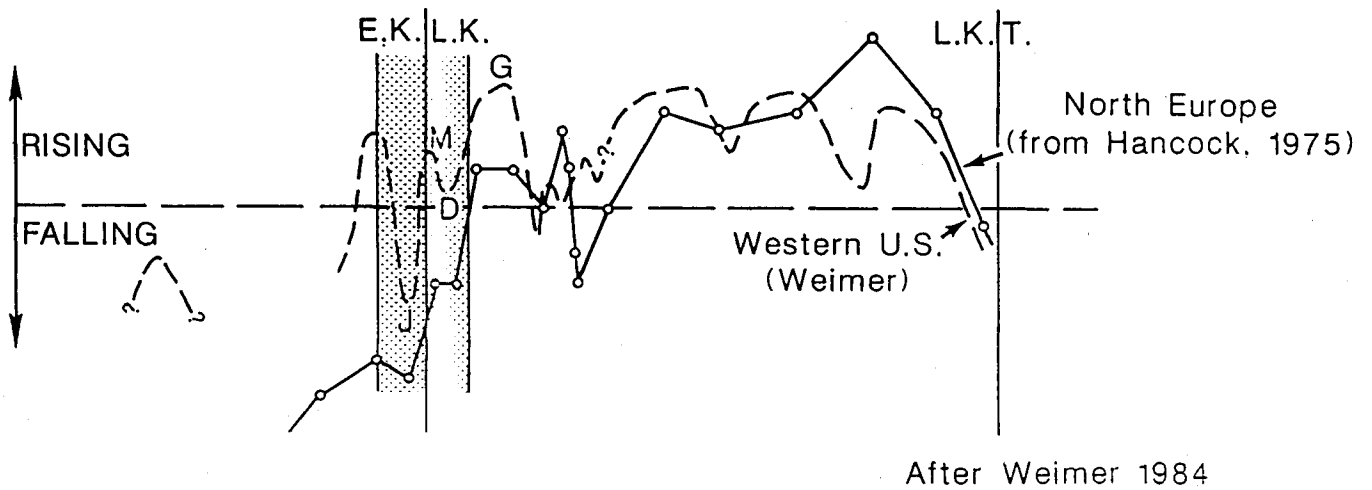


Figure 4. Relative changes in sea level elevation during the Cretaceous Period, western United States and northern Europe. (After Weimer, 1984).

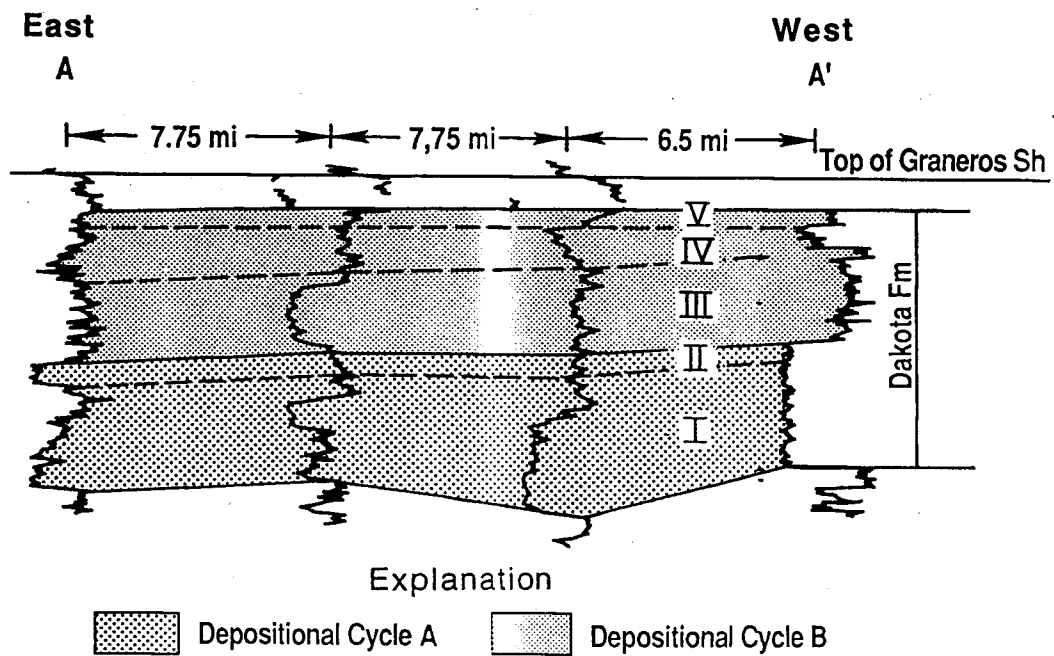


Figure 5. East-west subsurface cross-section, Graneros Shale and Dakota Formation from the KGS #1 Haberer to the KGS #1 Braun.

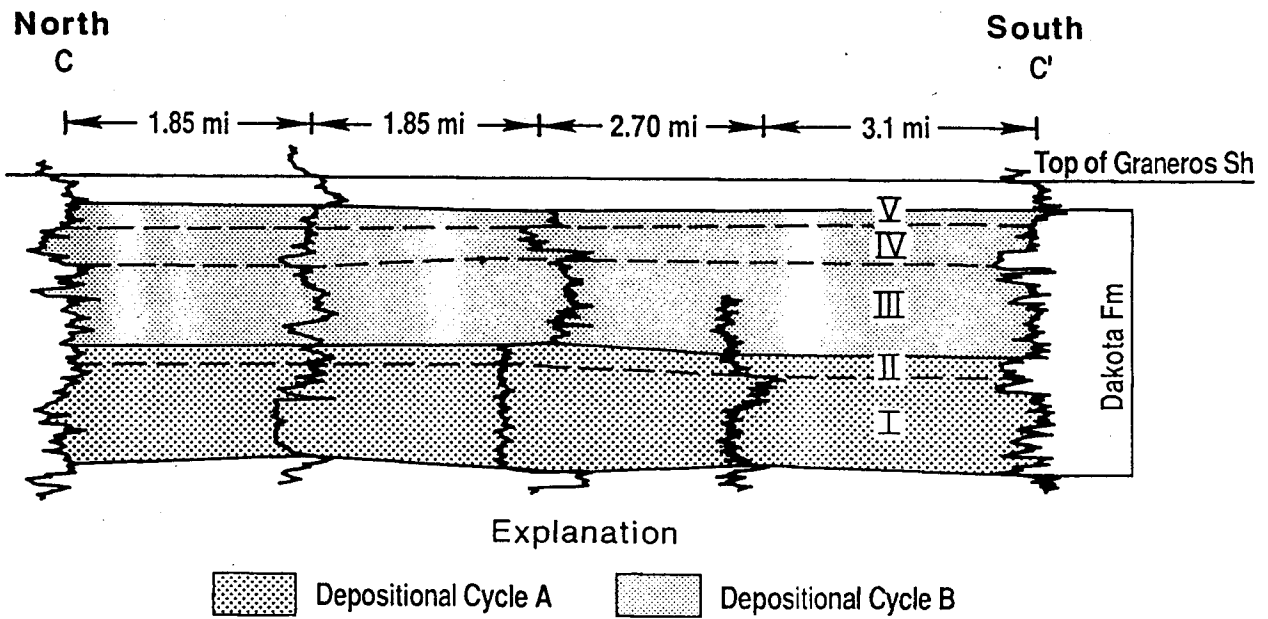


Figure 6. North-south subsurface cross-section through the KGS #1 Haberer, Graneros Shale and Dakota Formation.

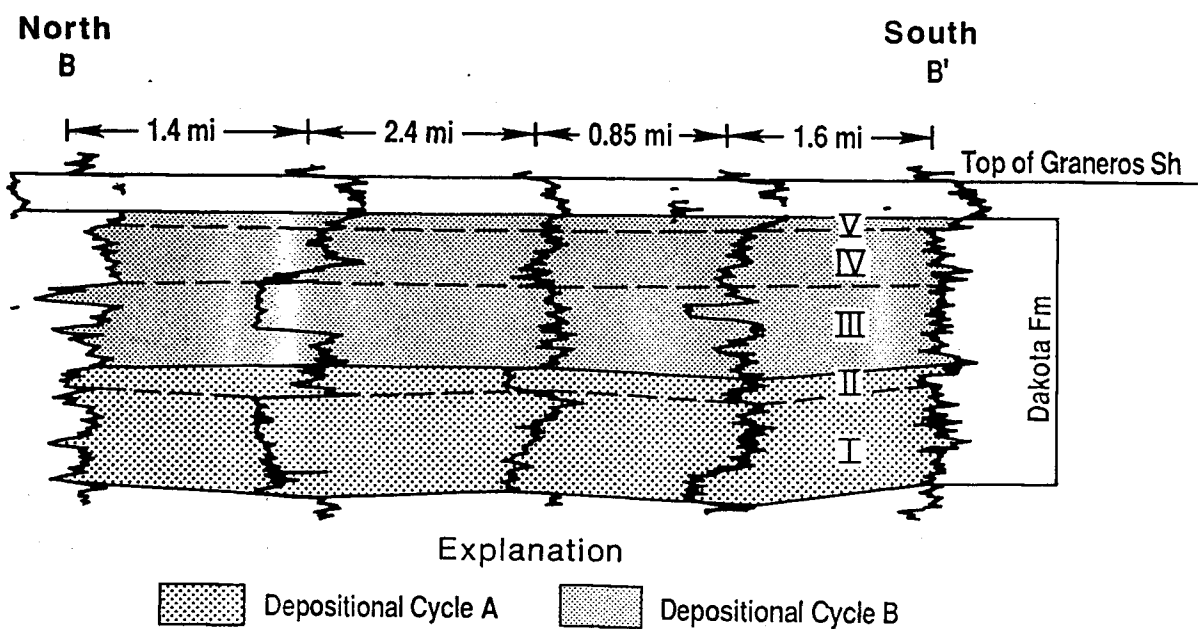


Figure 7. North-south subsurface cross-section through the KGS #1 Braun, Graneros Shale and Dakota Formation.

## Analysis of the Lithodensity-Neutron and Gamma-Ray Spectral Logs from the #1 Braun and #1 Haberer

Natural gamma radiation in rocks is almost entirely attributable to potassium-40 and radioactive isotopes of the uranium and thorium families. A conventional gamma ray log records the total intensity of gamma radiation from a broad range of sources. In the design of the spectral tool, "windows" are set to count gamma radiation within specific energy ranges. The spectral measurements are processed by computer to convert the raw count rates to concentration of the three major radioactive sources.

In sedimentary rocks, thorium is almost exclusively restricted to aluminosilicate minerals. Consequently, the thorium curve is a good indicator of the bulk proportion of clay minerals within logged formations. The thorium-potassium ratio (Th/K) provides a generalized index of potassium richness related to thorium, and so is useful for broad discrimination between radioactive minerals. Relatively low-ratio (high K) feldspars and micas are distinguished from higher-ratio clay minerals, which range from illite through smectite to kaolinite and chlorite in decreasing potassium content (Hassan et al., 1976).

The thorium-uranium ratio (Th/U) has also proved to be useful in the recognition of "geochemical facies" (Adams and Weaver, 1958). The Th/U ratio is an indicator of redox-potential. Uranium has an insoluble tetravalent state that is fixed under reducing conditions, but is transformed to the soluble hexavalent state which may be mobilized into solution. In contrast, thorium has a single insoluble tetravalent state which is geochemically associated with uranium and is therefore a useful standard for comparison purposes. On the basis of outcrop measurements, Zelt (1985) showed close relationships between Th/U and transgressive/regressive cycles in the Upper Cretaceous rocks of Colorado, Utah, and New Mexico.

In Figure 3, Th/K and Th/U were plotted as logs for the two test holes together with the computed gamma-ray log for each test hole. The simultaneous consideration of these data throughout the sequence reveals striking and readily interpretable patterns. The Th/K log shows fluctuations in value which reflect changes in the volumetric proportions and types of clay minerals, micas and feldspars. Schlumberger (1988) gives generalized ranges for minerals found in the Dakota Formation

(Franks, 1966). These are listed in Table 1. The Th/K for both test holes shows that the clay fraction of the Dakota Formation is composed of illite, chlorite, montmorillonite, and kaolinite. Oscillations of the Th/K log reflect volumetric variations of the proportions of those minerals that are possibly linked with changes of depositional environment. The Th/U ratio log was indexed with the diagnostic values of 2 and 7 suggested by Adams and Weaver (1958) to facilitate interpretation of depositional environment through its use as an oxidation-potential indicator. In the Dakota Formation, stacked repetitions of high and medium Th/U ratios probably reflect high lateral variability environments expected in nonmarine settings. These ratios may also reflect the interplay between mostly brackish and fresh-water environments of coastal regions.

Mineral/Mineral Group	Th/K
Feldspar	0.5 -0.6
Glauconite	0.6 -1.3
Muscovite	1.3 - 2.0
Illite	2.0 -3.5
Montmorillonite/mixed layer clays	3.5 -12
Kaolinite, chlorite	12 -28

Table 1. Th/K values for minerals commonly found in the Dakota Formation.

The spectral gamma-ray log analysis gives good indications of generalized clay-mineral associations. However, the similarity of the potassium and thorium levels of some clay minerals and the mixture of clay minerals that characterizes of most shales causes ambiguities of interpretation. Consequently, additional diagnostic information from other logs is useful, particularly for detailed work on clay-mineral identification and facies recognition within the Dakota Formation.

The recent introduction of the photoelectric cross-section as a supplementary curve to the conventional neutron and density logs has substantially improved the log recognition of mineralogy. The

photoelectric cross section is a measure of the absorption of low-energy gamma rays by the formation in the borehole wall. More important, the measurement is a direct function of the aggregate atomic number (Z) of elements within the formation, and thus is a sensitive indicator of mineralogy. The display of lithodensity-neutron data on a RHOMAA-UMAA crossplot is the most direct means to ascertain rock compositions from this log combination (McCall and Gardner, 1982). RHOMAA is the hypothetical density of the rock matrix computed as a mathematical projection of the rock's bulk density, which eliminates the effect of the fluids in the pore space. UMAA is the theoretical volumetric photoelectric absorption index of the matrix, calculated from the photoelectric factor by using similar considerations. The cross-plotted range between values for low-Z clays (kaolinite, smectite, and muscovite) and high-Z clays (illite and chlorite), and along with quartz can be represented reasonably by a composition triangle. Any single point on the plot may then be recast as proportions of the three end members. The RHOMAA-UMAA data for the Dakota Formation rocks were transformed to a proportional log of these three components by a matrix algebra computer algorithm described by Doveton (1986). The result is shown in Figure 3 for the #1 Braun. The RHOMAA-UMAA log of the Dakota Formation shows the progressively increasing effects of marine transgression at the beginning of the Greenhorn cycle. Near the middle of the Dakota, the proportion of high-Z clays (illite and chlorite) increases significantly and is a major component of the clay fraction in the upper half. Franks (1975) noted increases in the illite and chlorite fraction of the clays in the upper-most part of the Dakota along the outcrop in central Kansas. Nearer the Denver Basin in northwest Kansas, Merriam et al. (1959) found that the majority of the clays in the Dakota are illite and chlorite.

#### Description and Interpretation of Depositional Environment for Facies I Through V:

ELECTROFACIES I: The rocks that belong to this unit consist of fluviially-deposited fining-upward sequences of sediments (as in #1 Braun) or stacked sequences of channel sandstones (as in #1 Haberer). Electrofacies I is bounded below by a regional unconformity that separates the Dakota Formation from the underlying Kiowa Formation and above by electrofacies II. The total thickness of sediments in this facies

does not vary appreciably across the study area except where erosion has cut deeply into the underlying Kiowa Formation. Figure 8 shows the aggregate thickness of sandstone for electrofacies I. Sandy sediments were deposited in meander belts 4 to 7 miles wide in the study area and are as much as 120 ft. thick in T12S and in T11S, R17-18W. The east-west trend of these meander-belt sandstones in the study area is consistent with the overall west-southwest trend or direction of sediments in the outcrop areas (Franks, 1966) and with the direction of tilting of the central Kansas uplift inferred by Merriam (1963) during the Permian through Cretaceous. Several exposures of 30 to 70 ft-thick channel sandstones occur in the outcrop areas of southeastern Ottawa County in T11-12S, R3W. In the #1 Haberer cyclical changes in the Th/K reveal repetitive changes in clay mineralogy and suggest stacking of individual channel sandstones. Farther west in the #1 Braun, medium to coarse-grained, channel sandstones present near the base of this unit grade upward into fine-grained rocks containing low-Z clays (kaolinite, smectite, and muscovite) and minor high-Z clays (illite and chlorite). These changes in lithology and clay mineralogy signal a rise in sea-level during the latter part of the Early Cretaceous (Fig. 4). Interchannel sediments consist of interbedded shale, siltstone, sandstone, and lignite.

**ELECTROFACIES II:** This part of the Dakota Formation represents deposition under paralic/deltaic conditions during a still-stand of sea level. Within this unit the API gamma ray activity tends to decrease upward in the study area suggesting a coarsening upward sequence. A coarsening-upward sequence is also implied in the #1 Braun where the proportion of quartz sandstone increases upward within this unit. In the #1 Haberer the upper part of this facies consists of well-rounded and well-sorted fine-grained quartz sandstone. The contact between this and the underlying facies may be gradational or abrupt depending on local scouring prior to the deposition of this unit. The sandstone isoliths outline several linear interconnected sandstone bodies and suggest the outline of distributaries within a deltaic complex (Fig. 9). Retallick and Dilcher (1986) have proposed a tide-dominated, deltaic environment for the upper part of the Dakota Formation which could apply equally well to this electrofacies depositional environment. Most of these interconnected sandstone bodies are situated directly above thick accumulations of channel sandstone in electrofacies I. The total thickness of electrofacies

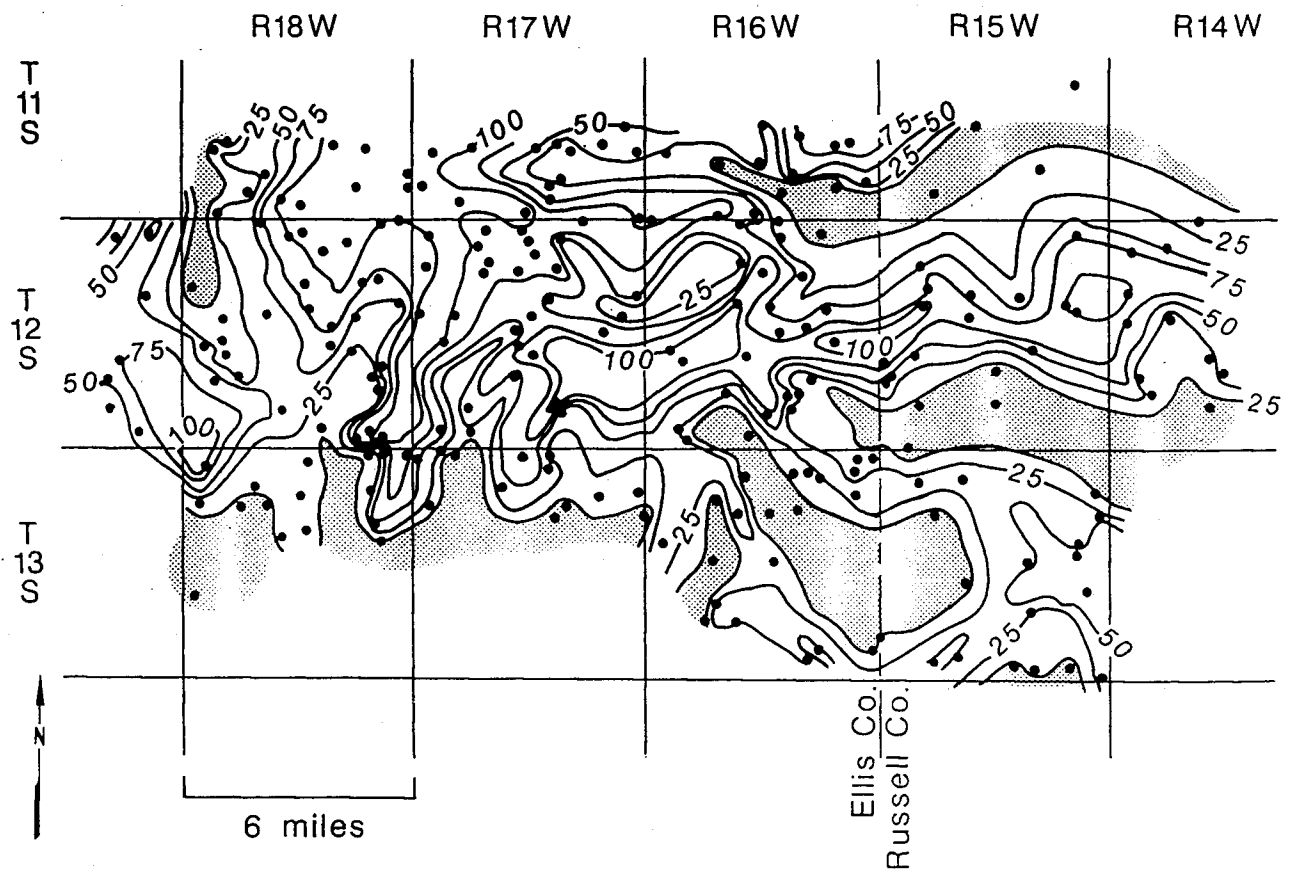


Figure 8. Sandstone isolith map of electrofacies I.

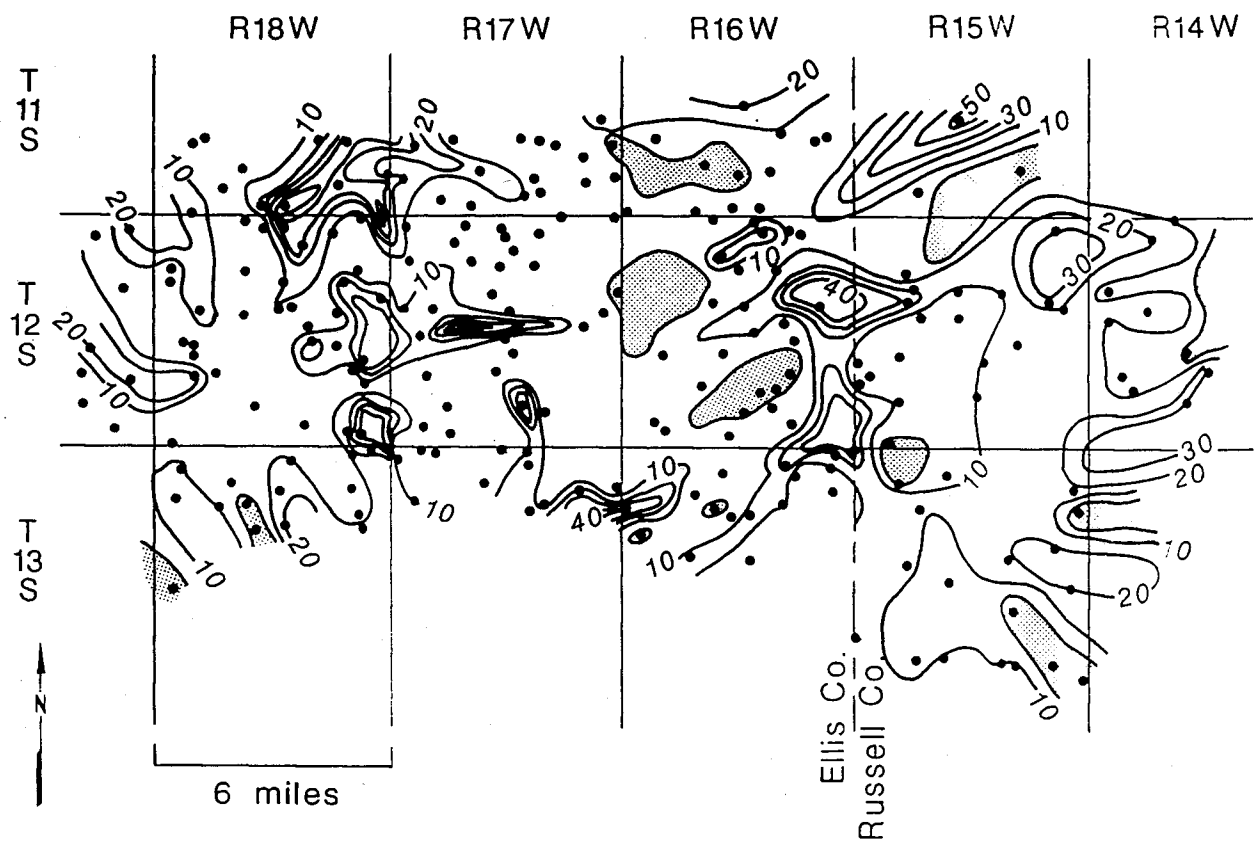


Figure 9. Sandstone isolith map of electrofacies II.

II sediments ranges from 22 to 70 ft in the study area. Aggregate sandstone thickness ranges up to 70 ft.

**ELECTROFACIES III:** The rocks in this electrofacies were deposited in a floodplain closer to base level than during most of electrofacies I deposition. At this point in time, a slight drop in sea level rejuvenated streams emptying into the western interior seaway and fluvial processes briefly became a dominating factor in this part of Kansas. Siemers (1971, 1976) has described the upper part of this facies in considerable detail where it outcrops at the surface in Russell County. The primary lithology of this unit is interbedded, gray clay shale and siltstone with minor amounts of fine to very fine-grained sand. Red mottling is common in the lower part of this unit. Beds of lignite and disseminated plant debris are also present. Siemers has interpreted these fine-grained sediments as floodplain overbank deposits. The increasing influence of the marine environment during the deposition of electrofacies III sediments is evident from the upward increase in the proportion of illite in the clay fraction in the #1 Braun. Farther east, increases in the Th/K near the top of electrofacies III in the #1 Haberer indicates a change in clay mineralogy from mixed layer-montmorillonitic clays to kaolinite. Kaolinitic mudrocks are present in the outcrop areas of western Russell County. The contact between electrofacies II and III is probably transitional over a short distance, suggesting that the environment of deposition was near sea level. On the other hand, the contact between electrofacies III and IV may be transitional or abrupt depending on whether local scouring took place prior to the deposition of electrofacies IV sediments. The total thickness of electrofacies III sediments varies little across the study area. Several channel sandstones, including the Rocktown Channel Sandstone of Rubey and Bass (1925) and Siemers (1971, 1976) occur in this unit. These sandstones outcrop in Russell County along the Saline River. This informal member of the Dakota Formation consists of stacked, crossbedded, elongate, fluvial sandstone bodies that occur in belts approximately one to two miles wide. Figure 10 is a sandstone isolith map of the Rocktown Channel-equivalent sandstones in the subsurface. This map shows an east-west trend for these highly sinuous fluvial sandstones. The total thickness of sandstone in this unit ranges up to 75 ft in T11-12S, R17W, and T12S, R18W. A comparison of Figure 10 with the sandstone isolith map of electrofacies I in Figure 8

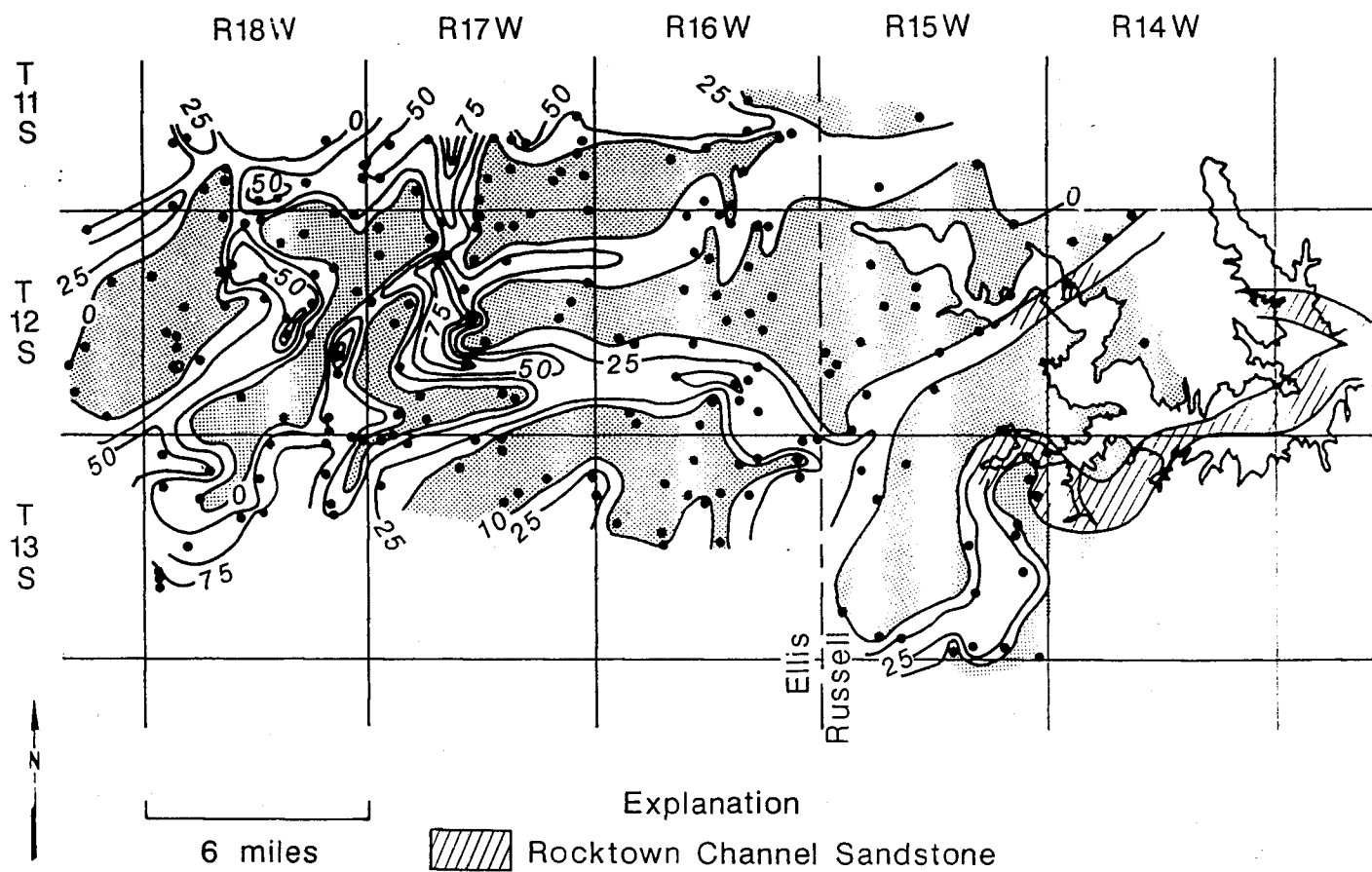


Figure 10. Sandstone isolith map of electrofacies III.

shows that the Rocktown Channel-equivalent meander belts are much narrower and thinner than those in electrofacies I.

**ELECTROFACIES IV:** Sediments assigned to this unit were deposited in a brackish water, shallow-marine environment as sea level continued to rise during Late Cretaceous time in response to renewed transgression at the beginning of the Greenhorn cycle. Exposures of electrofacies IV sediments occur in Russell County and have been described extensively by Siemers (1971, 1976) and Hattin and Siemers (1987). Electrofacies IV sediments consist of tabular- to blanket-shaped bodies of bedded sandstone and interbedded sequences of siltstone and shale. Sandstones in this section are fine-grained and well-sorted, containing disseminated carbonized plant debris. These sandstones are laminated and show tabular cross-bed sets. Locally developed scours cut into underlying electrofacies IV sediments and filled with sandstone also occur. Sandstones in this facies contain locally abundant trace and brackish water fossils. Cross-section A-A' shows that this unit gradually thickens from 34 ft in the #1 Haberer to 60 ft in the #1 Braun (Fig. 5). East to west thickening of electrofacies IV suggests that southwesterly tilting of the central Kansas uplift was actively taking place during deposition. The interbedded sandstone and shale sequence in the lower part of this facies in the #1 Braun is stratigraphically lower than the interbedded sandstone and shale sequence found in the #1 Haberer. The sandstones of electrofacies IV in the #1 Haberer are the subsurface equivalent of the flat-bedded sandstones of Siemers. Figure 11 is a sandstone isolith map of electrofacies IV in the study area. Aggregate sandstone thickness ranges up to 40 ft. The isolith map shows that this facies is devoid of sandstone in several parts of the study area and in the southern part of T11S, R17-18W the aggregate sandstone distribution has a NE-SW grain. This distribution and the field evidence from outcrop studies suggests that bottom currents were actively transporting sediments during electrofacies IV deposition possibly winnowing fine-grained sediments from local submarine highs. These bodies of sandstone occur either in association submarine highs associated with draping over the underlying fluvial sandstones or with deep-seated underlying structures in the Precambrian. Many of these structures are reflected in the Graneros top configuration map (Fig. 2) and on the structured top of the Stone Coral Formation (Merriam, 1959). Low-Z clays (kaolinite, smectite, and muscovite) dominate the lower part of electrofacies IV in the #1 Braun,

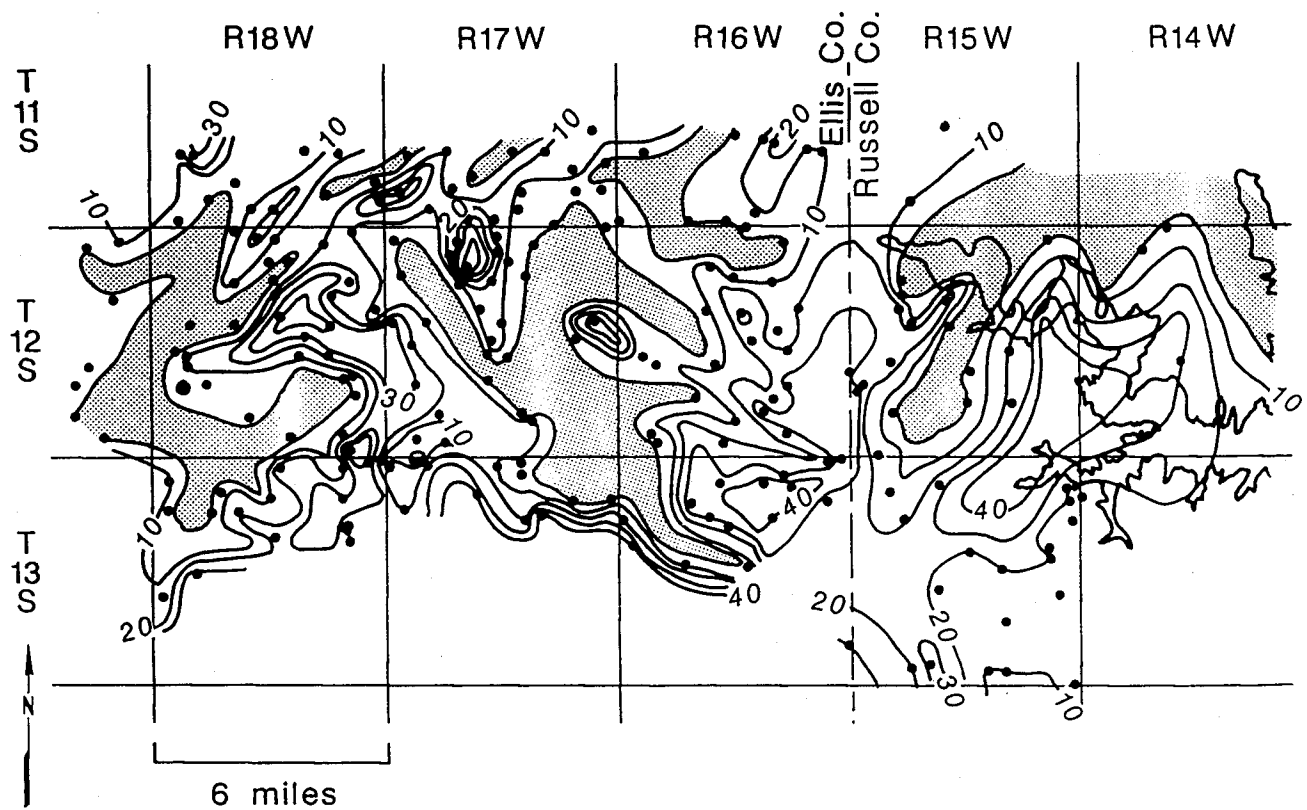


Figure 11. Sandstone isolith map of electrofacies IV.

whereas high-Z clays dominate the upper part (Fig. 2). The boundary between electrofacies IV and V is transitional in the study area.

**ELECTROFACIES V:** This group of rocks represents a transition between the marginal marine electrofacies IV and the shallow marine Graneros Shale. Rocks within this part of the Dakota Formation consist of marginal to shallow marine, fossiliferous, interbedded sandstones, gray siltstones and dark gray shale with thin lenses of clay ironstone and lignite (Siemers 1971; 1976 and Hattin, 1966). The top of electrofacies V is transitional with the overlying Graneros Shale. In the #1 Braun, the clays are composed of approximately equal proportions of low and high-Z clays (Fig. 3). Franks (1966) reports that appreciable amounts of illite (a high-Z clay) and montmorillonite (a low-Z clay) are generally present near the top of the Dakota Formation in electrofacies V in the outcrop areas. In northwest Kansas, nearer the axis of the western interior seaway, Merriam et al. (1959) found that illite was the dominant clay mineral with minor amounts of kaolinite and chlorite in the upper part of the Dakota Formation. The total thickness of electrofacies V varies little across the study area.

#### Preliminary Conclusions:

The results of this pilot project indicate that with a usable stratigraphic framework the Dakota Formation subsurface mapping of electrofacies and sandstone thickness is possible. Diverse suites of wireline logs, and descriptions core and drill cuttings combined with detailed field description of outcrops can provide important data to define electrofacies. Within the pilot project area five electrofacies were defined and sandstone isolith maps constructed to show areal distribution. Essential to this process was the recognition that sea level fluctuations and local tectonics have played an essential role in the processes responsible for Dakota sediment deposition. Interpreting the electrofacies succession in the Dakota Formation as the result of eustatic changes and local tectonics has made possible a first-cut regional correlation of the Dakota Formation of central Kansas with the Dakota Group of the western side of the Cretaceous interior seaway. Further refinement is possible by extending the local framework westward into the Denver basin. Applying this methodology on a larger scale will make possible prediction of depositional environments in the area covered by

Dakota sediments and hence, sandstone body occurrence, lithology, and geometry.

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