INTERIM TECHNICAL REPORT TO THE KANSAS LEGISLATURE ON THE FIRST YEAR OF THE DAKOTA AQUIFER PROGRAM

Submitted by

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EXECUTIVE SUMMARY

The Kansas Geological Survey is conducting a comprehensive, multi-year research program on the Dakota aquifer in Kansas to fulfill the future water-information needs of planners and managers in local and state agencies. The goal of the program's first year is to develop a research plan that fulfills the Dakota aquifer water-information needs of the future by characterizing the geology and hydrology of the Dakota aquifer and assessing the suitability of various tools for collecting geologic and petrophysical data. To accomplish this KGS is critically examining what is already known about the Kansas part of this aquifer system. The purpose of this report is to show the progress made thus far in the Dakota aquifer program during the first year by describing the various activities and tasks being undertaken by KGS, the U.S. Geological Survey, and other agencies or institutions and by presenting any preliminary results.

During the first year of the Dakota aquifer program KGS is: (1) working with other local, state, and federal agencies to develop hydrologic and geologic data bases that will be used to regionally characterize the Dakota aquifer, including a wireline log data base; (2) conducting short-term field studies to provide insight into various hydrologic and geologic aspects of the Dakota aquifer system in Kansas, including stream/aquifer interaction in Russell County, an areal reconnaissance of the Codell Sandstone aquifer with Fort Hays State University; and examining energy use in high capacity wells along with the U.S. Geological Survey and the Kansas Energy Extension Service at Kansas State University to develop guidelines and realize energy conservation benefits; (3) defining the regional geologic framework of the Dakota aquifer and associated rock units; and (4) determining the feasibility of using seismic reflection methods to provide data in areas of sparse coverage.

Thus far in the first year of the program KGS has found that: (1) development of the Dakota aquifer is presently restricted to areas where the aquifer is in the near-surface environment of northern, south-central, and southwest Kansas, where the aquifer is a major source of water for irrigation, public water supply, and industrial use; (2) subsurface mapping of the thickness and geometry of the sandstone aquifers in the Dakota aquifer is possible if a sufficient density of data is available and the regional geologic framework can be extended to the more local level of the mapped area; and (3) the potential for upward migration of saline waters into freshwater zones in the Dakota aquifer and surface waters is high in parts of central Kansas especially where fresh and saltwater aquifer systems are hydraulically connected. From these findings KGS has concluded that: (1) the focus of the first few years of the Dakota aquifer program should be in the developed areas of northern, south-central, and southwest Kansas where local and state water-planners and managers need updated information on this aquifer system; (2) a thorough understanding of the geologic framework coupled with a sufficient density of data can be used to predict the likelihood of finding water; and (3) attention must be paid to the vertical hydraulic relationships between aquifer systems as they promote the upward movement of saline waters into freshwater zones and the pathways of migration of these saline waters.

INTRODUCTION

Since the beginning of FY89, the Kansas Geological Survey has been conducting a comprehensive, long term program of research on the Dakota aquifer in Kansas to address future water- resources management and planning needs of local and state agencies. The Dakota aquifer system is an integral part of future water-resources planning for western and south-central Kansas in the coming decades. It is the second most extensive aquifer in Kansas after the High Plains aquifer (Ogallala and associated alluvial aquifers). Figure 1 shows the areas of Kansas underlain by the rocks that comprise the Dakota aquifer. Figure 2 is a schematic stratigraphic column showing the major geologic units that comprise the Lower Cretaceous rocks and the Dakota aquifer in Kansas. In the future, depletion of the High Plains aquifer due to overdevelopment and insufficient recharge will cause critical water shortages to occur in several areas of western Kansas. The Dakota aquifer will be the next available source of water for the region.

The goal of the first year of the program is to develop a research plan that fulfills the Dakota aquifer water-information needs of the future. In order to accomplish this goal KGS is: (1) regionally characterizing the Dakota aquifer in Kansas using existing information; (2) broadly defining the geologic framework of the aquifer and adjacent geologic units, and (3) assessing the feasibility of using various geologic and geophysical techniques to describe the Dakota aquifer, especially in areas of sparse data coverage. The methodology being used is to critically examine what is already known about this aquifer system and to develop a set of tools to provide useful information. As part of this work, several water-related and geologic data bases are being developed that will be accessed and expanded as the Dakota aquifer program proceeds. Most of this information will be made available to users through the Kansas Water Data Base. Since the first year of this program is funded from the Kansas portion of the oil-overcharge, KGS is working with the U.S. Geological Survey and the Kansas Energy Extension Service to address energy conservation issues related to high-capacity wells and irrigation systems that withdraw water from the Dakota aquifer.

The Kansas Geological Survey's involvement in the Dakota aquifer began with a study evaluating the continued suitability of shallow underground injection of oil-field brines in the Cedar Hills Sandstone

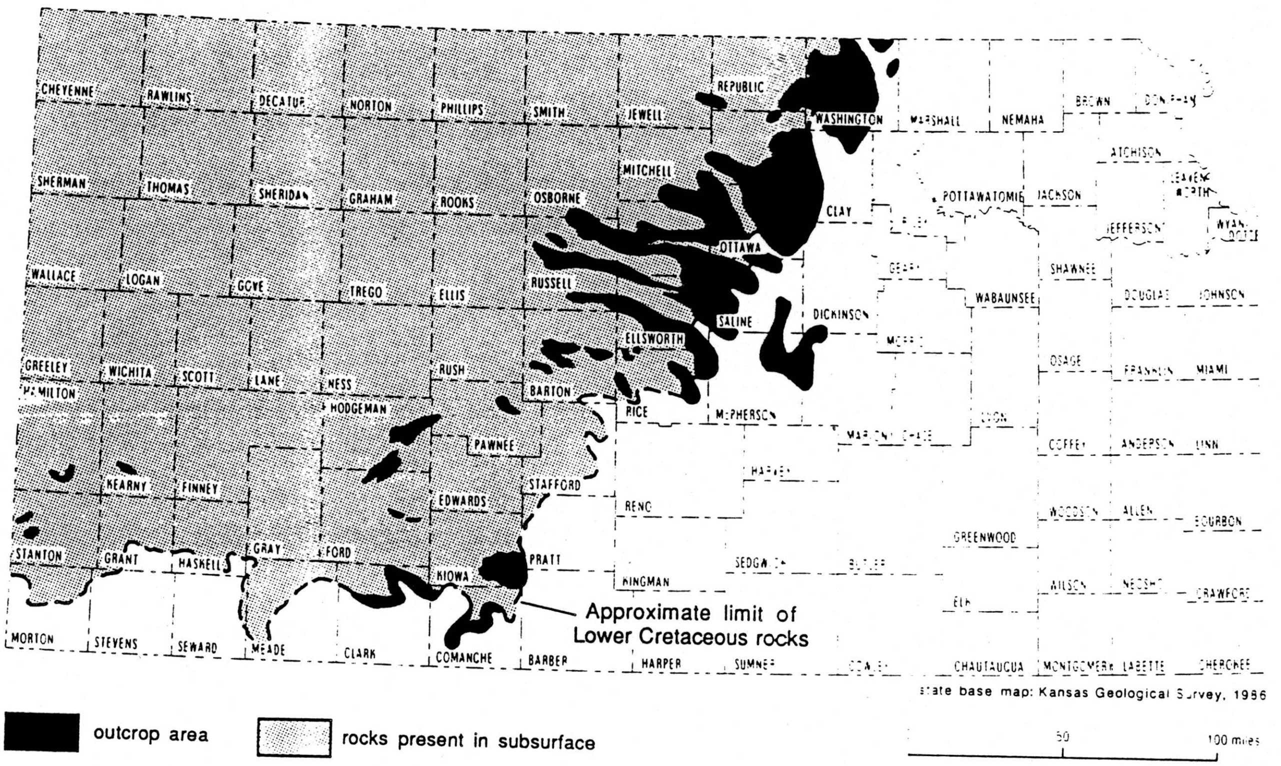

Figure 1. Distribution of the Lower Cretaceous rocks that comprise the Dakota aquifer in Kansas.

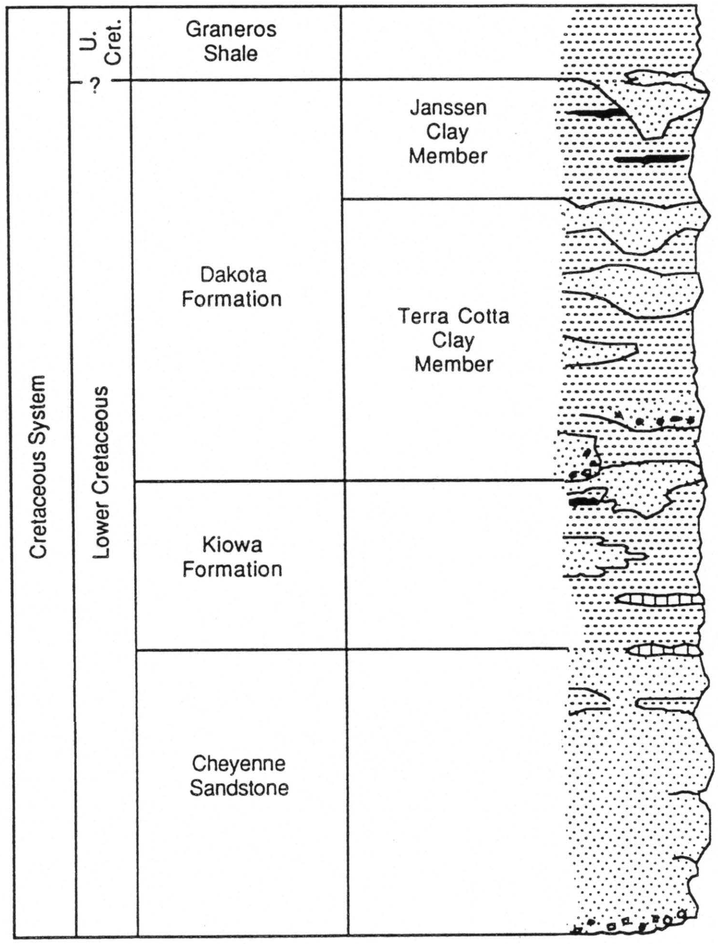

Figure 2. Schematic stratigraphic column showing the distribution of rock types and sandstone aquifers in the Lower Cretaceous rocks.

in central Kansas for the Kansas Corporation Commission. This involved defining the geology, hydrology, and water chemistry of the Cedar Hills and overlying aquifer units, including the Dakota aquifer. Much of our effort was guided by the Interagency Dakota Technical Committee whose members include representatives of all of the local, state, and federal water- related agencies. Appendix A is the abstract of the report on this research that was submitted to the Kansas Corporation Commission this year. Appendix B is an abstract of a paper on the hydrogeochemical evidence of hydraulic connection between the Dakota aquifer and the Cedar Hills in the study area.

It became clear that insufficient information concerning the Dakota aquifer was a limiting factor in the state water management and planning process. For the most part, this has resulted from a lack of research structure and coordinated effort that has precluded the integration of research results into a consistent picture of the Dakota aquifer. The KGS with Committee support decided that a significant coordinated research effort on the Dakota aquifer is needed to develop a sound technical basis on which future water-management and planning efforts can depend.

Responding to this need, the Kansas Geological Survey proposed to conduct a comprehensive multi-phased, multi-agency study of the Dakota aquifer system in Kansas. The proposed objectives of the program are: (1) to develop a usable and detailed geologic framework of the Dakota aquifer and related rocks that extends from the outcrop areas of central Kansas to the Colorado and Nebraska state lines; (2) to develop a better understanding of the structural configuration of the aquifer; (3) to characterize water availability, the movement of ground water and the variation of water chemistry within the Dakota aquifer system on a regional and sub-regional basis; and (4) to assess the effects of various water-management scenarios on the performance of the Dakota aquifer using three-dimensional mathematical simulations (ground-water models). In order to facilitate the execution of the Dakota aquifer program a memorandum of understanding was signed by all of the local, state, and federal water-related agencies in Kansas pledging their support for the program. This program was to be undertaken in several phases over a period of 14 years. However, it appears that considerably less time may be required for completion of the program due to an accelerated research program schedule over the next two years. KGS is already committing a considerable portion of its resources to ensure the successful completion of this research program and expects to continue this effort.

Funding for the first year of the Dakota aquifer Program became available in August, 1988, from the Kansas portion of the U.S. Department of Energy-managed oil-overcharge fund. In anticipation of the oil-overcharge funding, KGS began work on the Dakota aquifer program at the beginning of the fiscal year using its own and other budget resources. Even though the funding was delayed, KGS has concentrated its efforts to maintain a research schedule to meet many of its scheduled deadlines.

The purpose of this report is to describe in detail the activities of the KGS and USGS in the Dakota aquifer program since receipt of the oil-overcharge funding and present some preliminary results. Research papers describing in detail the results from the Dakota aquifer program are provided in the appendices at the end of this summary.

SUMMARY OF ONGOING RESEARCH ACTIVITIES IN THE DAKOTA AQUIFER PROGRAM

ACQUISITION OF A DATA BASE MANAGEMENT SYSTEM AND GEOGRAPHIC INFORMATION SYSTEM

In the planning process for the Dakota aquifer program, KGS recognized the need for a relational data-base management and display system that could effectively store and manipulate geographic data. Use of this system enhances the capability to associate multiple attributes with point, line, and area features. As a result it is possible to quickly and efficiently manipulate and summarize spatial data to produce maps and cross-sections of geographic areas. Equally important is the ability to transfer data electronically between computer systems and agencies. As a result KGS will be able to update the Kansas Water Data Base periodically with information from the data bases developed during the Dakota aquifer program.

Funding from the first year of the Dakota aquifer program is being used to obtain the ARC-INFO software package, a relational data-base management geographic information system marketed by Environmental Research Systems, Inc. It is anticipated that ARC-INFO will made operational on the KGS MV-20000 computer by January, 1989. However, prior to use of this software system additional computer memory will need to be purchased in order to accommodate the Dakota aquifer program and other Survey needs.

DATA BASE DEVELOPMENT

Future research directions for the Dakota aquifer program will depend on developing a regional, coherent picture of the aquifer based on information from previous studies. KGS is presently collecting all available data from local, state, and federal water-related agencies, private industry, and the literature in order to develop new data bases pertaining to the Dakota aquifer in Kansas. As the data are being collected, care is being exercised to ensure that each piece of information is thoroughly documented. This is being done to minimize the possibility of including erroneous information. These new data bases will aid in developing a regional characterization of water quality, flow, and availability in the Dakota aquifer.

Data are being collected from the following sources: U.S. Geological Survey (USGS) Kansas District Office, the USGS Central Midwest Regional Aquifer Systems Analysis (CMRASA) Program, KGS, Kansas Department of Health and Environment (KDHE), the Kansas Corporation Commission (KCC), the Kansas Board of Agriculture Division of Water Resources (DWR), and the groundwater management districts (GMD). These sources are being contacted in order to obtain all of the pertinent data that might be useful for this characterization. Specific types of data are being used in this effort. These include: the water-well record forms (WWC-5 Record forms) submitted to KDHE by water-well contractors at the completion of a water well; water-use and appropriation records maintained by DWR; records of water quality from the municipal well-water data file, U.S. EPA STORET data, and the Kansas Water Data Base maintained by KDHE; working, project and map files and documentation from the CMRASA study of the Kansas Great Plains aquifer system study and WATSTORE data housed and maintained by USGS; and miscellaneous water-quality data from the files and publications of KGS.

The KDHE files on public water supplies are not computerized and are divided into three categories: (1) water-quality samples collected during the period of record; (2) engineering reports on selected wells for some of the cities; and (3) public correspondence records that include historical information on application permits for siting wells, problems with water quality, or citations for violating water-quality standards. Each of these records must be searched individually to determine if the city in a prospective area might have a Dakota well. We are using the KGS County Bulletin series to try to determine in advance the likelihood of finding public water supplies that withdraw water from the Dakota aquifer. Searching through these records is time-consuming. So far, KGS has examined and collected data on 5 counties in central Kansas.

In addition to the historical records on the wells, the chemical analysis group at KDHE has records from 1945 to present on actual analyses performed on municipal water supplies. Once we have a list of cities with known Dakota wells we will obtain the historical records from this section of KDHE. This will probably be accomplished early in 1989.

The STORET data obtained from KDHE includes only the Dakota wells in the water-quality observation well network which KDHE operates cooperatively with USGS. The records are from 1978, when the network began, to the present. There have been modifications to the original network so the completeness of the record varies according to the specific well. The data are assumed to be the same as the information acquired from USGS WATSTORE but it was felt worthwhile to obtain this information from KDHE to insure completeness of the data set.

During the initial phase of the Dakota study for the Kansas Corporation Commission in 1986, KGS obtained available WATSTORE data on the Dakota and associated units up until 1986. The data set included approximately 200 wells in the eight county area of the study. This data is being compared with the data obtained from the USGS RASA study that was completed in 1987. By comparing the two sets of data we hope to determine if there was any duplication of information due to variation in the method of originally inputing the data. This way KGS hopes to develop a complete record of information without duplication of records.

Copies of selected data files of water quality generated by the U.S. Geological Survey (USGS) for the Kansas portion of the Central Midwest Regional Aquifer System Analysis have been and are being obtained from the District Office of the USGS. The data extracted are for the Dakota Formation. There are three types of files: the working file composed of all the water-quality data assembled, the project file including representative analyses from the working file, and individual database and map files used for preparing maps of certain chemical parameters. The USGS is providing documentation on the content of the files and the procedures used in selecting data for the project and map files.

During 1986 to 1988 approximately 100 samples of Dakota waters have been analyzed by the Chemical Analytical Services Section at KGS. These analyses, plus the historical data published in the KGS Bulletin series constitute the available water quality data from the KGS. The historical records will be compared with the USGS data files to determine if the KGS records have been incorporated into existing data sets.

A database system for chemical analyses of ground waters is being developed on the KGS Data General computer that will allow access and processing by the available software, including a geographic information system and automated cartography. The data will be stored and accessed using the INFO database system in a form that will allow ties to other information on the KGS computer for the wells for which water quality data exists. Programs are being written to translate USGS files in both

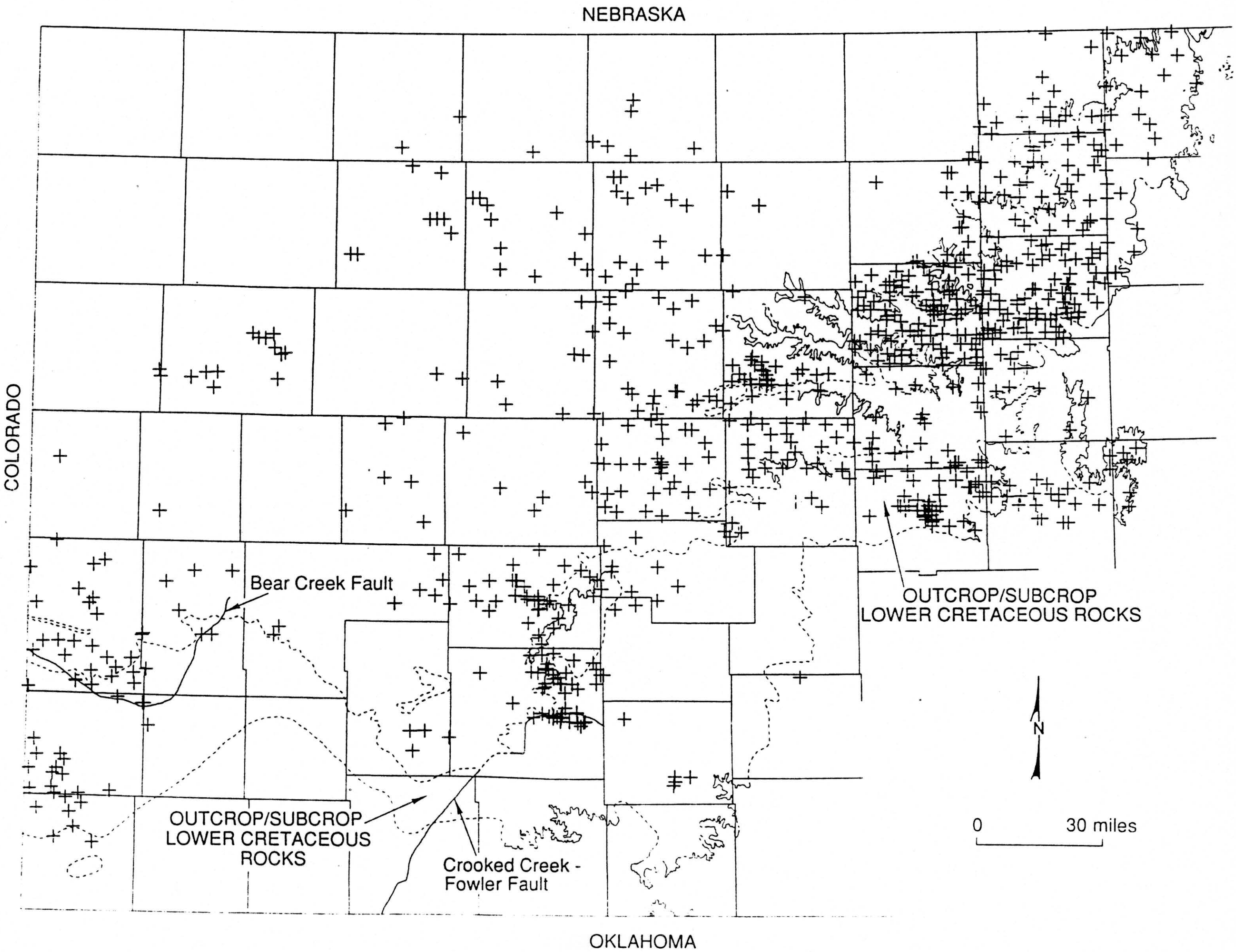

Figure 3. Distribution of water-quality data for the Dakota aquifer, collected as of December, 1988.

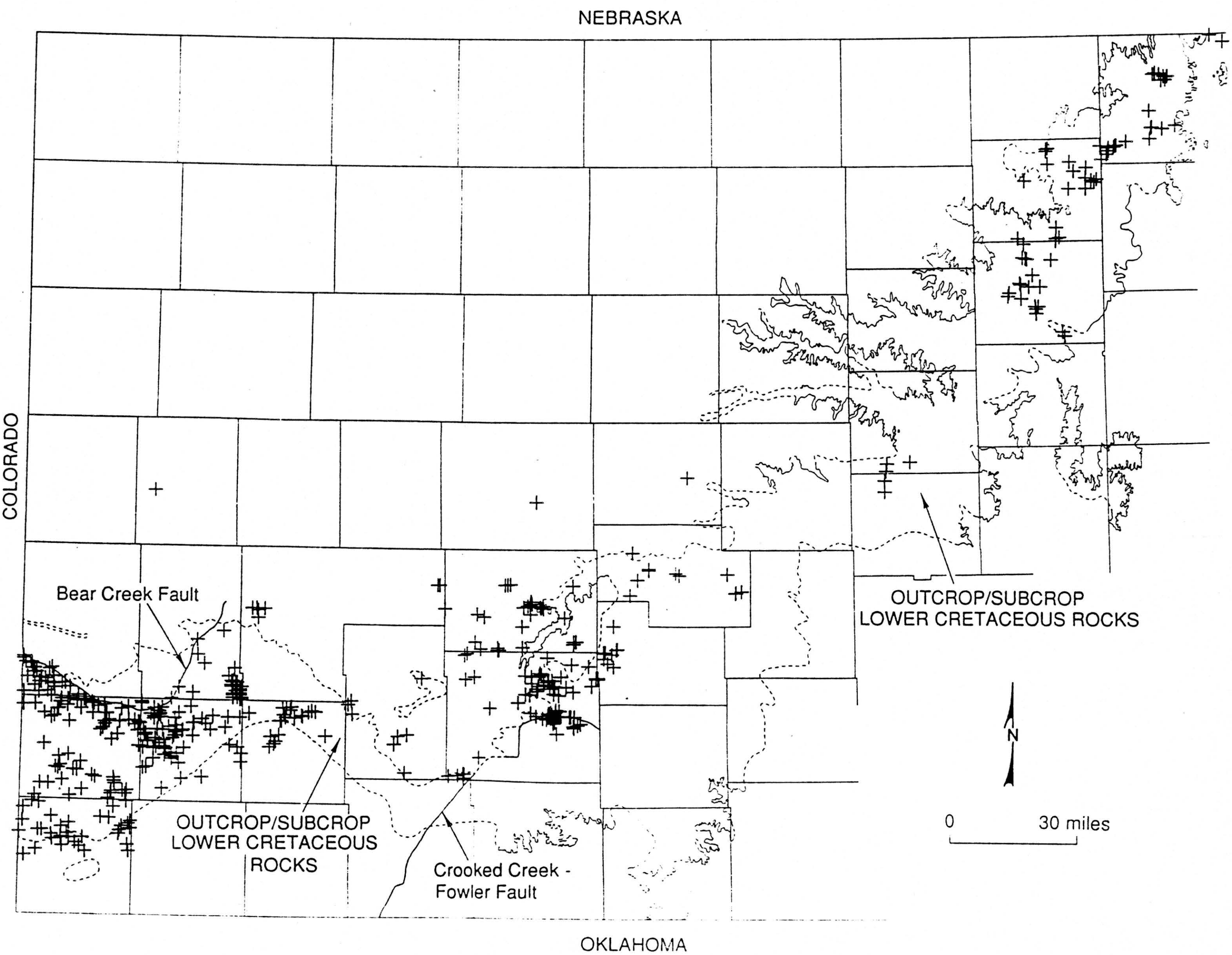

Figure 4. Distribution of irrigation wells that obtain water from the Dakota and, if available, other aquifers. Data collected as of December, 1988.

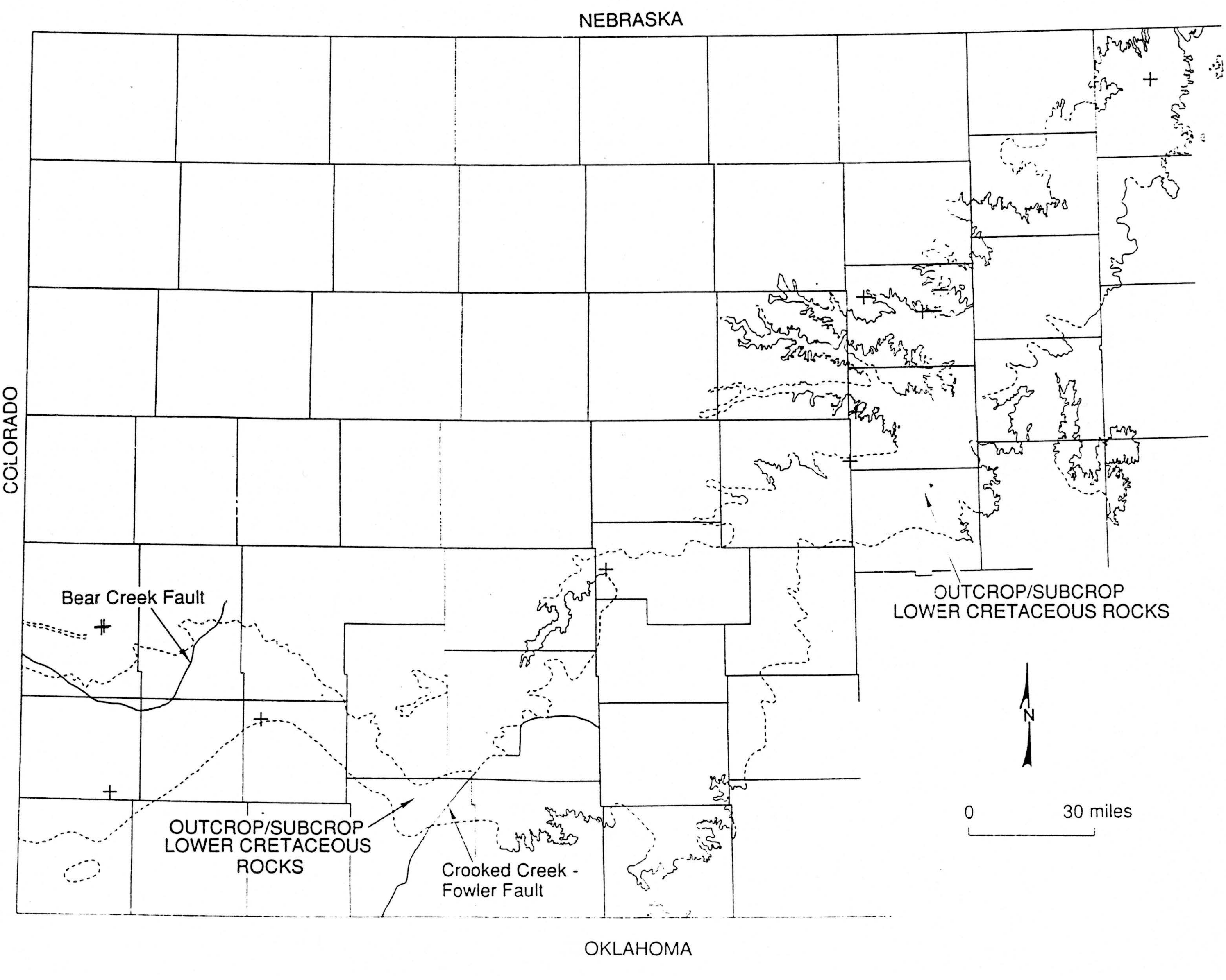

Figure 5. Distribution of feedlot wells that obtain water from the Dakota and, if available, other aquifers. Data collected as of December, 1988.

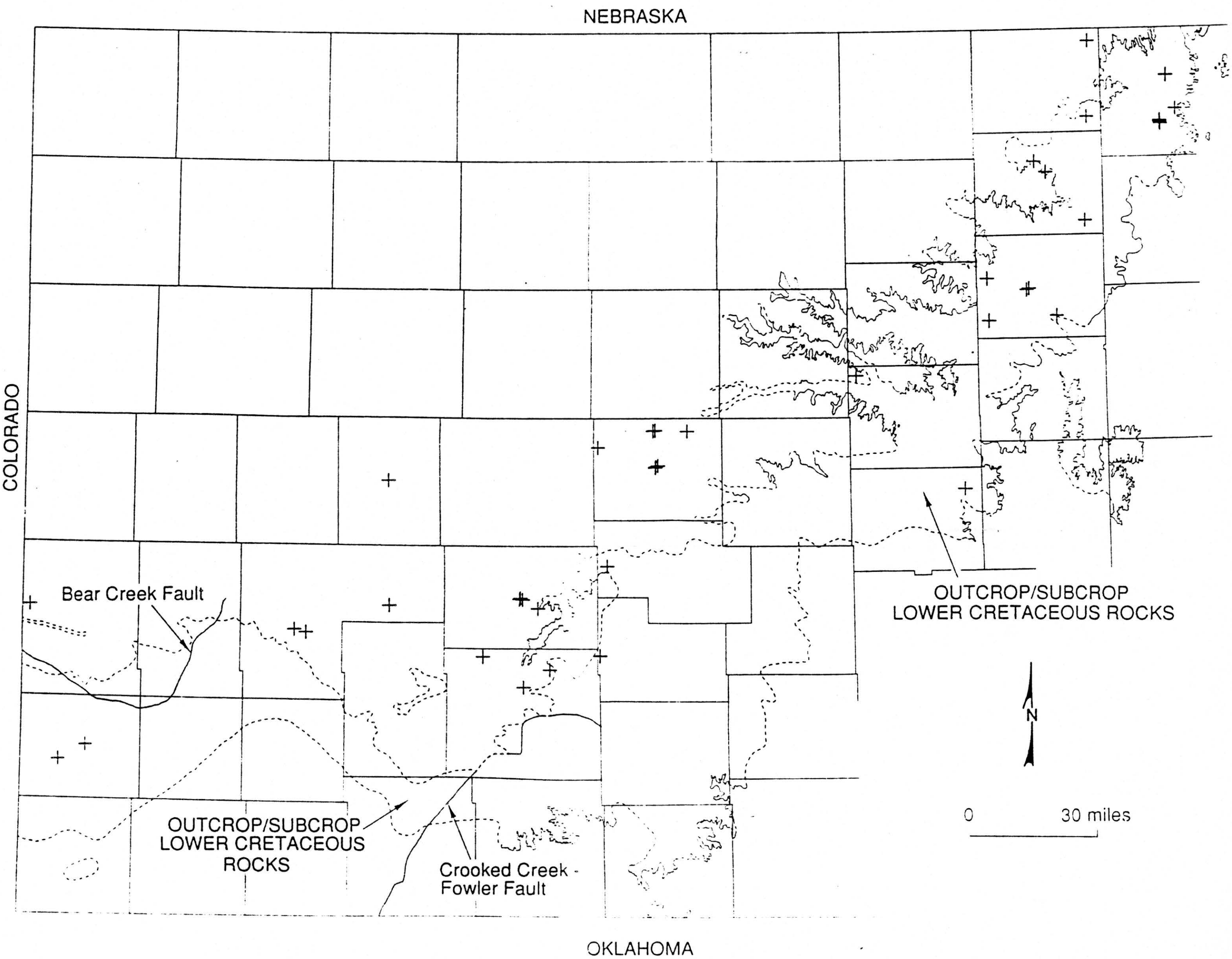

Figure 6. Distribution of public water supply wells that obtain water from the Dakota and, if available, other aquifers. Data collected as of December, 1988.

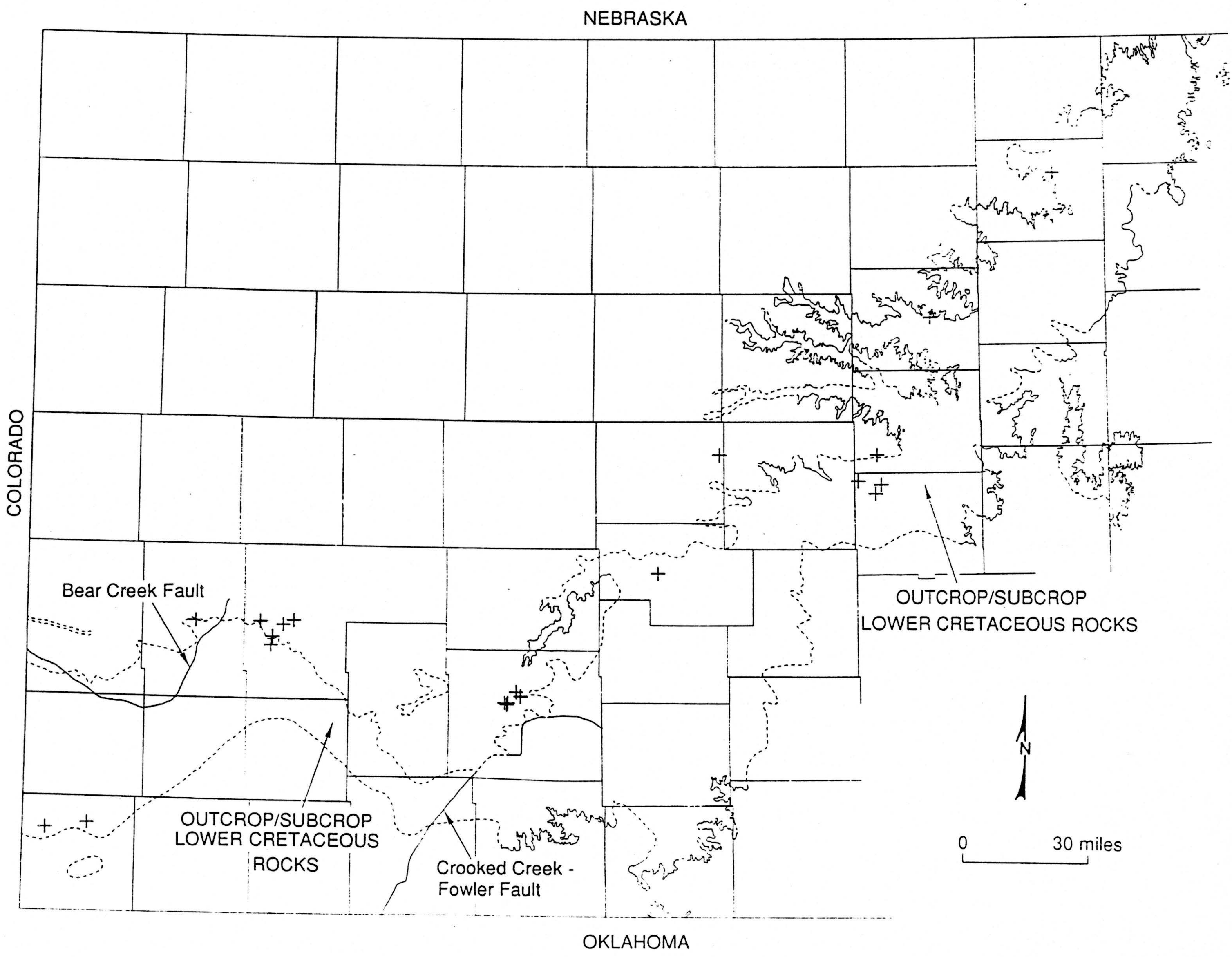

Figure 7. Distribution of industrial wells that obtain water from the Dakota and, if available, other aquifers.

the WATSTORE and MIDAS formats and the Kansas Water Database files of the KDHE to the KGS system and vice versa. The identification of data, data values, and analytical characterization for individual chemical properties and constituent concentrations are based on the USGS parameter code, value string, and remarks codes. Standards agreed upon for state databases by the Kansas Water Data Committee are being used during the development of the system. Implementation of the system will begin when the ARC/INFO software is installed on the Data General MV-20000 computer of the Survey.

Recently, a composite data file of water analyses has been compiled from the KDHE STORET, USGS WATSTORE, and USGS CMRASA computerized data sets. Figure 3 shows the distribution of the locations sampled in the Dakota aquifer of Kansas. Chemical quality data for approximately 750 sample sites have been located at this time.

KGS is also developing an inventory of high-capacity wells obtaining water from the Dakota aquifer. Figures 4 through 7 show the locations of these wells in Kansas subdivided by water-use catagories. From the figures it is evident that the Dakota aquifer is widely used where the aquifer is in the near-surface environment of southwest and north-central Kansas. Also, the distribution of wells shows that irrigation is the dominant large-volume water use in all areas where the Dakota aquifer is undergoing development. Figures 8 through 10 show the well-completion practices for the high capacity wells withdrawing water from the Dakota aquifer. The high-capacity wells tend to be screened in the Dakota and adjacent aquifers if available, especially in the southwest and in small areas of northern Kansas where there are multiple aquifers. However, it is important to note that water may be contributed to the well from zones above the screened interval. This is because, in most cases, the gravel pack around the well casing extends farther up toward the surface than the well screen and provides a permeable pathway for water movement.

A wireline (borehole geophysical) log data base is being developed primarily to establish a regional stratigraphic and structural framework of the Dakota and related aquifer units. KGS found that the most readily available logs of boreholes are gamma ray, resistivity, SP, and neutron porosity. After some careful consideration of the data needs of the program and the costs of digitizing well-log data, KGS determined that a gamma-ray log is generally the most useful wireline log for identifying geologic units and lithology. These benefits are magnified considerably if the gamma-ray logging tool is calibrated in API units. Using the KGS well-log library, one calibrated gamma-ray log per township (36 square miles) was selected to be digitized if a suitable log could be obtained. Figure 11 shows the distribution of digitized well logs in the area of Kansas underlain by the geologic units that comprise the Dakota aquifer (Dakota Formation, Kiowa shale, and Cheyenne sandstone). In all, 836 gamma ray logs were selected for digitizing. This work is being done by RLB Consultants, a private contractor. The digitizing process is scheduled to be completed by the end of December, 1988 and the wireline log data are available for use in the Dakota aquifer program and by state agencies.

SHORT-TERM FIELD STUDIES

Several short-term field studies related to the geology and hydrology of the Dakota aquifer were initiated during the first year of the program. It is anticipated that the additional field data collected during these short-term studies will provide insight into various hydrologic and geologic aspects of the Dakota aquifer system in Kansas. This section of the interim report is a description of these field investigations. The results of these studies, if already completed, are described more fully in the "Preliminary Results" section of this report.

Stream/Aquifer Interaction: Recognizing the need to understand the hydrologic interaction of the Dakota aquifer with surface waters, KGS initiated a study of a salt marsh in the Saline River valley of northwest Russell County. In this area, natural saltwaters are discharging from the Dakota aquifer into a small drainage that is a tributary to the Saline River. Several such salt marshes are located in north-central Kansas and southeast Nebraska and are associated with discharge of saline waters from the Dakota aquifer. The source of the salt water in these marshes is usually a deeper horizon in rocks older than those comprising the framework for the Dakota aquifer. During the course of the study, monitoring wells were installed in the Dakota aquifer and in the marsh sediments. Two monitoring wells were installed at different depths in the Dakota aquifer and eight shallow piezometers in the marsh sediments. Water levels were measured to determine the lateral and vertical variation of hydraulic head in the marsh sediments and the Dakota aquifer. Surveys of surface and ground water specific conductance, an indicator of total dissolved solids concentration, were run in the marsh and in the

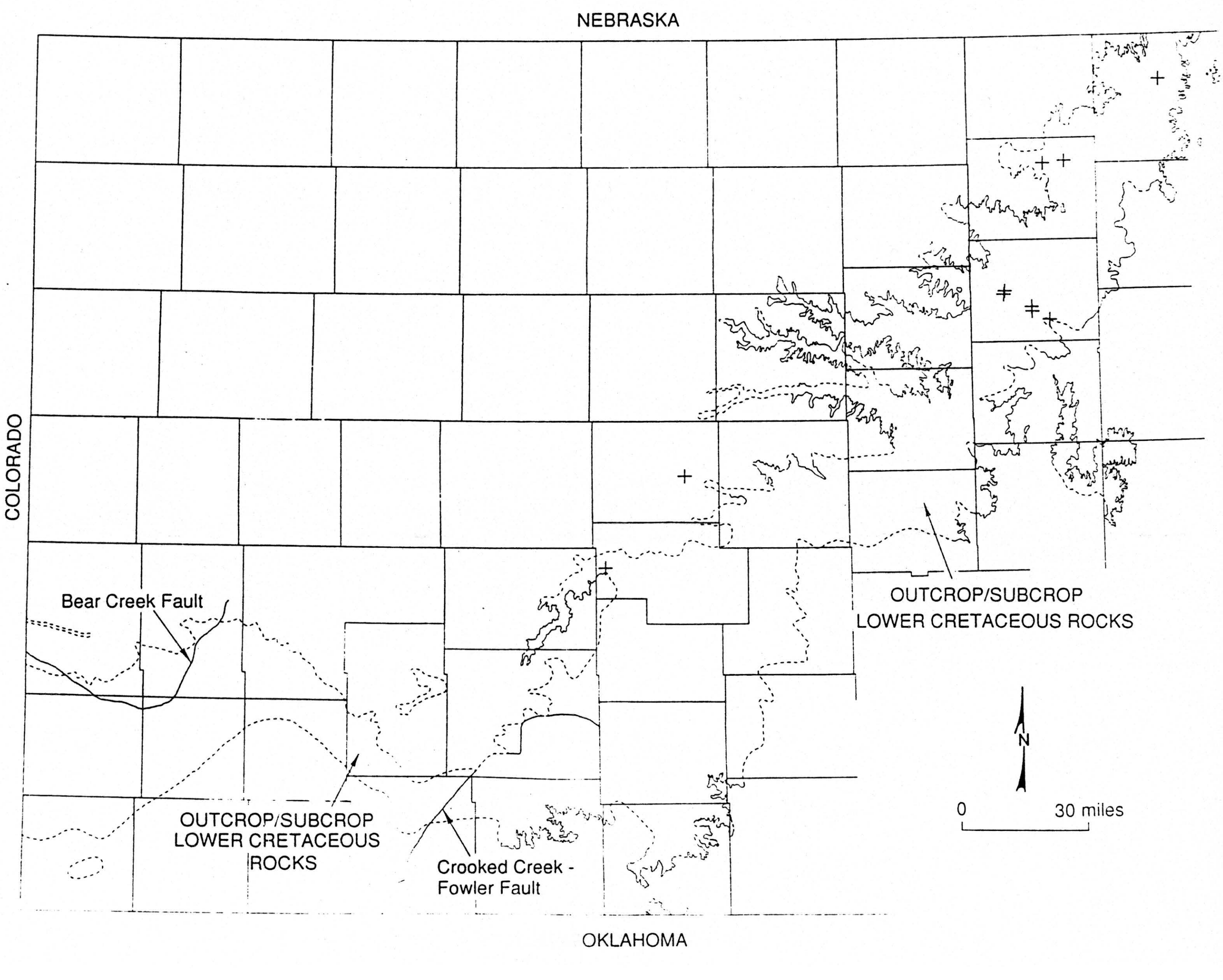

Figure 8. Distribution of high-capacity wells obtaining water from the Dakota and stream/aquifer systems. Data collected as of December, 1988.

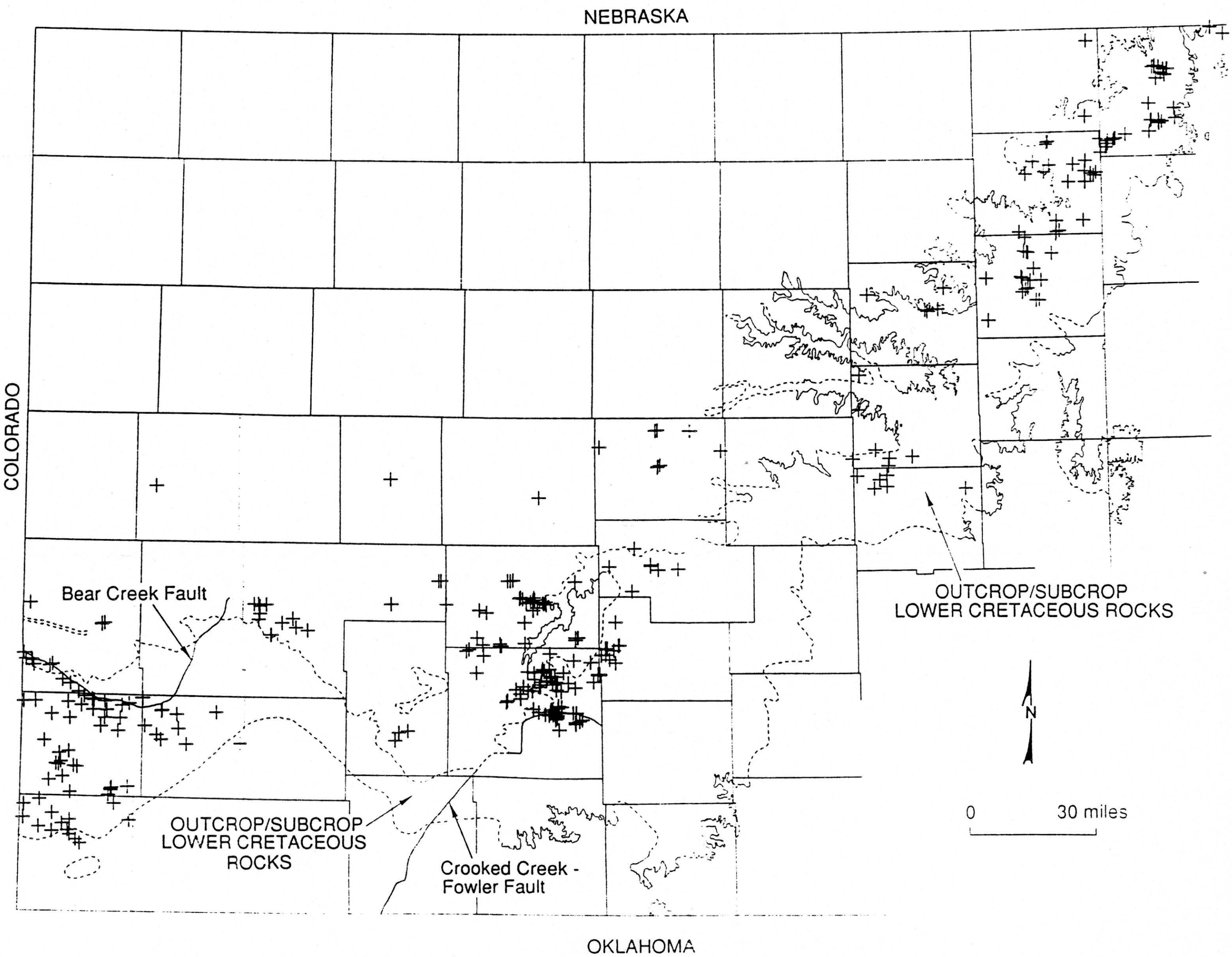

Figure 9. Distribution of high-capacity wells obtaining water from only the Dakota aquifer in Kansas. Data collected as of December, 1988.

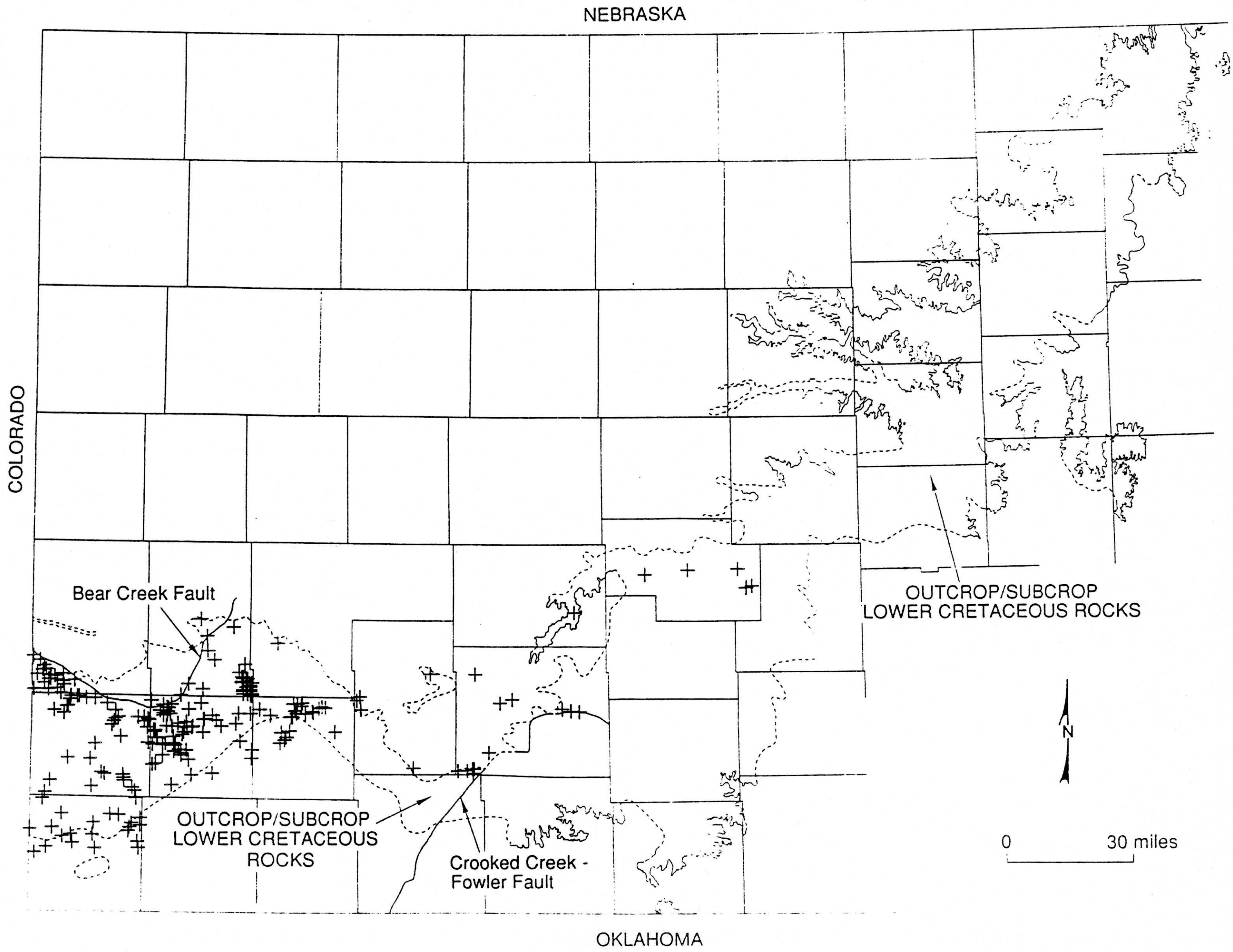

Figure 10. Distribution of high-capacity wells obtaining water from the Dakota and High Plains aquifers in Kansas. Data collected as of December, 1988.

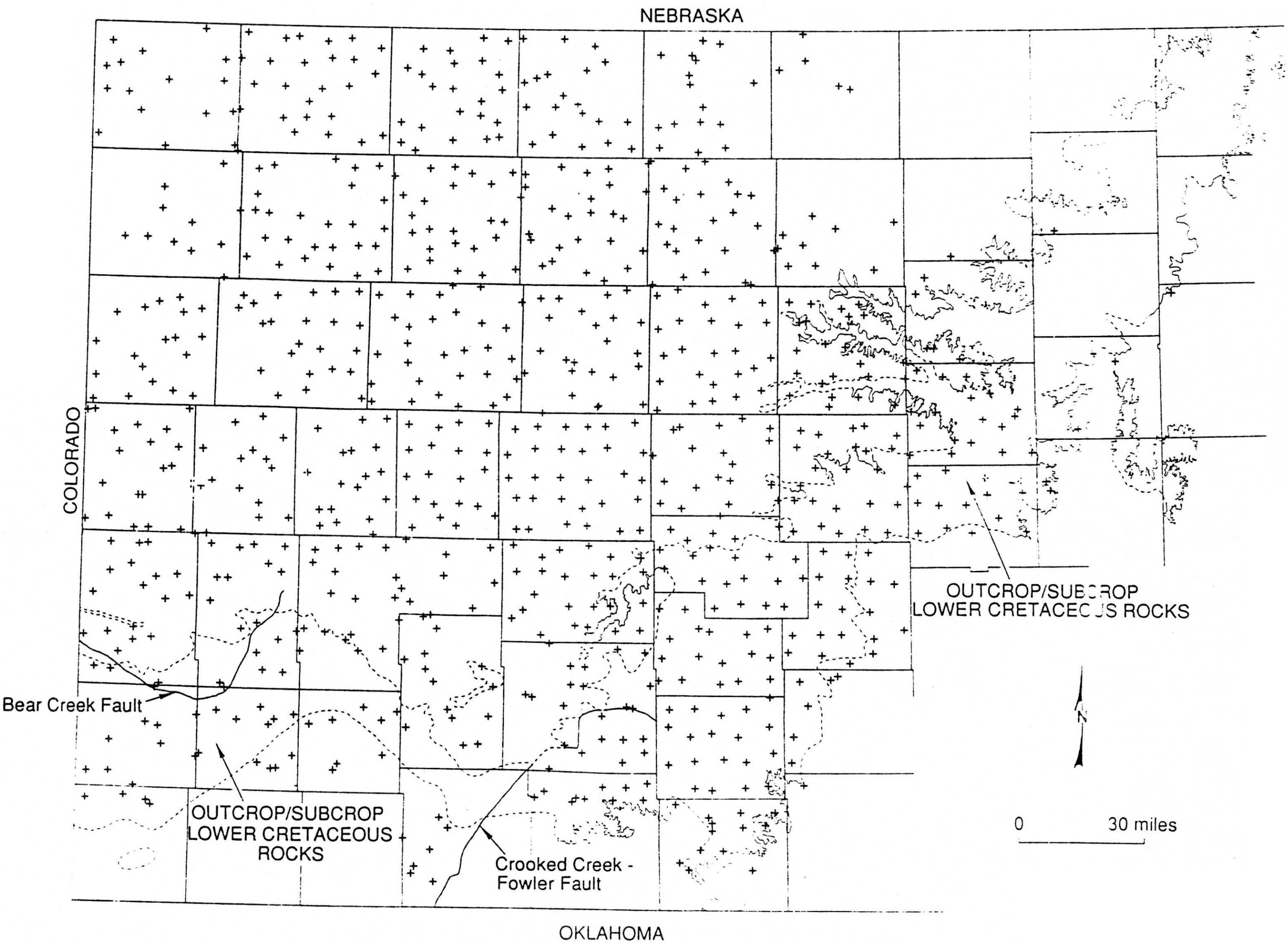

Figure 11. Distribution of gamma ray logs digitized for the KGS wireline-log data base.

Saline River. Water samples from the streams crossing the marsh, the Saline River, and Salt Creek, a nearby tributary to the Saline River, were also collected and analyzed for selected major, minor, and trace constituents and stable isotopes to characterize the water chemistry of the Dakota aquifer and the marsh sediments. In addition, a reconnaissance of the surface and subsurface geology was also completed to determine the source and pathways of movement of the saltwater. KGS is presently reviewing the field data and expects to include data on this area in the report on the first year of the Dakota aquifer program.

The salinity of the Saline River increases substantially from upstream to downstream of the salt marsh. The total-dissolved-solids concentration of ground waters from the shallow marsh wells and the Dakota Formation wells ranges from about 40% to 55% that of seawater. The marsh stream has a total-dissolved-solids load approximately 70% of seawater indicating concentration by evapotranspiration in the marsh. Although the Saline River water appreciably dilutes the discharge of saline waters into the river in the vicinity of the marsh, the discharge causes a nearly 50% increase in the dissolved-solids content of the river to a value 4-5 times that recommended for drinking waters. Saline discharges from the Dakota Formation into nearby Salt Creek also cause a marked increase in the salinity of the stream; total-dissolved- solids concentrations reach as much as 60% of seawater. The data indicates that discharge of waters from the Dakota Formation in the marsh region varies in salinity and has an appreciable effect on surface waters that depend upon ground water for base-flow recharge. Although oil production surrounds the marsh area, geochemical identification of the salinity source for ground waters from the alluvium, the Dakota Formation and surface waters indicates that there is no detectable pollution from disposal of oil-field brines. The salinity source is primarily solution of evaporites (halite or rock salt and gypsum or anhydrite) and is similar to that for the Dakota Formation as described in the report on central Kansas for the Kansas Corporation Commission (Appendix A).

Test-Hole Drilling: In the vicinity of the salt marsh study, a deep test hole was drilled to obtain wireline logging information and rock core of the Dakota aquifer and lower geologic units. The purpose of collecting this data is to extend the stratigraphic framework of the Lower Cretaceous rocks (Dakota Formation, Kiowa Formation, and Cheyenne Sandstone) from the outcrop areas of the Dakota in central Kansas westward into areas where these rock units are covered by younger strata. The test-hole drilling, coring, and logging of the KGS #1 Haberer was completed over a period of three weeks in the latter part of August, 1988. The test hole was drilled to a depth of 445 feet below surface and penetrated all of the Dakota and most of the Kiowa Formations. Rock cores were collected from the upper half of the Dakota Formation and most of the Kiowa Formation. At the completion of the drilling and coring, Schlumberger, a commercial wireline logging service, logged the hole with a variety of logging tools. Presently, the core obtained from the KGS #1 Haberer is being examined in considerable detail. Along with previously collected data from wells drilled in western Kansas, KGS is using the geologic information from the #1 Haberer to define the regional stratigraphic framework of the Dakota Formation and associated Lower Cretaceous rock units in Kansas from the Colorado border to areas in central Kansas where these rock units are present at the surface. This is described in greater detail below under the section, "Statewide Definition of the Geologic Framework".

Codell Sandstone Study: Several years ago, concern was expressed by water-well drillers that contamination of Dakota water wells may result from the use of improper water-well completion techniques in west-central Kansas. The cause for this concern was the presence of saline waters in the Codell Sandstone Member of the Carlile Shale, a geologic unit located above the Dakota Formation. Addressing this concern, KGS is working cooperatively with Fort Hays State University to conduct an areal reconnaissance of the Codell Sandstone in parts or all of Graham, Rooks, Logan, Gove, Trego, Ellis, Lane, Ness, and Rush Counties. Included in this effort will be a gathering of water-level data and water samples that will be processed by KGS. The water-level and water chemistry data will be used to determine ground-water flow directions in the Codell, including the potential for downward flow into the Dakota aquifer, and the chemistry of Codell ground waters.

Energy Use in High Capacity Wells: Kansas Geological Survey is also working closely with the U.S. Geological Survey and the Kansas Energy Extension Service to determine the energy use factors involved in high-capacity well systems. The goal of the project is to realize energy conservation benefits by improving well efficiencies through physical plant modifications or maintenance procedures. The targeted audience that will benefit most from this research is the irrigated agriculture community although others, such as public water supplies, are also expected to benefit. Field work will be conducted by the U. S. Geological Survey to determine various hydrologic and physical parameters associated with high capacity well systems in areas where: (1) the Dakota aquifer is the sole source of water to these wells; and (2) the Dakota and High Plains aquifers are both the source of water. The field data will be analyzed to determine the relationship between energy use and the hydrologic and physical parameters. The field work for this project will be undertaken during the Summer, 1989, and a report will be prepared and submitted by the following October.

STATEWIDE DEFINITION OF THE GEOLOGIC FRAMEWORK

A thorough understanding of the geologic framework of the Dakota aquifer in Kansas is necessary in order to: (1) predict water availability and the flow of water and dissolved constituents in the Dakota aquifer; (2) identify areas where the Dakota aquifer is hydraulically connected with other adjacent aquifers; and (3) map the depth to the top of the Dakota aquifer from land surface as this factor may affect use. In Figure 2 the geologic units that comprise the Dakota aquifer are schematically shown. These rocks are composed of interbedded sandstones and shales that were deposited under marine and terrestrial conditions during the early part of the Cretaceous Period (approximately 100-110 million years ago). As a result, the distribution of these sandstones, which are the primary aquifers within the Dakota, and the shales is extremely complex, as indicated by the coarsely and finely stippled patterns in the figure.

At present, KGS is working to correlate the rocks that comprise the Dakota aquifer in Kansas with similar rock units in eastern Colorado, southwestern Wyoming, and western Nebraska, where the geologic controls on the deposition of these sandstones aquifers are better understood. The purpose of this work is to extend a regionally well understood geologic framework eastward into Kansas. Studies in these western areas have shown that the primary controls on sandstone deposition during the early part of the Cretaceous Period were fluctuations of sea level modified by earth movements along specific zones of weakness. These parameters are important because they control the nature and movement of sediment eroded from land areas and transported to and deposited in the developing interior seaway by rivers.

By extending our understanding of these shifting depositional environments through time it is possible to predict the hydrologic properties and water availability of the Dakota aquifer in Kansas.

As part of this research effort on the geologic framework of the Dakota aquifer, KGS conducted a small pilot study in a portion of eastern Ellis and western Russell counties to determine the stratigraphy and feasibility of mapping the geometry and thickness of sandstone bodies in the Dakota Formation. The distribution and thickness of these sandstone bodies are important factors determining water availability because these are the aquifer units. The Ellis-Russell County area was chosen because an adequate wireline (borehole geophysical) log data base was available including the logs from the test holes drilled by KGS. Moreover, a well-studied outcrop area is proximal to the eastern side of the pilot project area to support the subsurface database. As work began on this project, it became clear that the Dakota Formation could be subdivided into mappable units in the subsurface that appear to have stratigraphic significance. This would not have been evident without the data from the two test holes in the study area. Equally important, deposition of the sediments in these subsurface mapping units could be related to sea level fluctuations in the Cretaceous Period.

Figures 12 and 13 show the distribution of two fluvially-deposited (deposition in stream channels) sandstones in the study area in two of the subsurface mappable units. The maximum thickness of the lower fluvially-deposited sandstone is approximately 100 feet, averages approximately 50 feet, and occurs in zones four to ten miles wide in the project area. The maximum thickness of the upper fluvially-deposited sandstone is approximately 75 feet and averages approximately 40 feet in the pilot project area, and occurs in distinct belts one to two miles wide.

Figures 14 and 15 show the distribution of sandstone bodies deposited in the vicinity of deltas under marine/nonmarine and marine environments, respectively. The distribution of these sandstones is more sheet-like in the project area and generally much thinner than the channel sandstones. The maximum thickness of the lower of the two sandstones is 70 feet and averages approximately 20 feet in the project area. The maximum thickness of the upper sandstone is 65 feet and averages approximately 35 feet.

The results of this pilot project indicate that the sandstone aquifers of the Dakota Formation can be mapped in the subsurface. This is possible

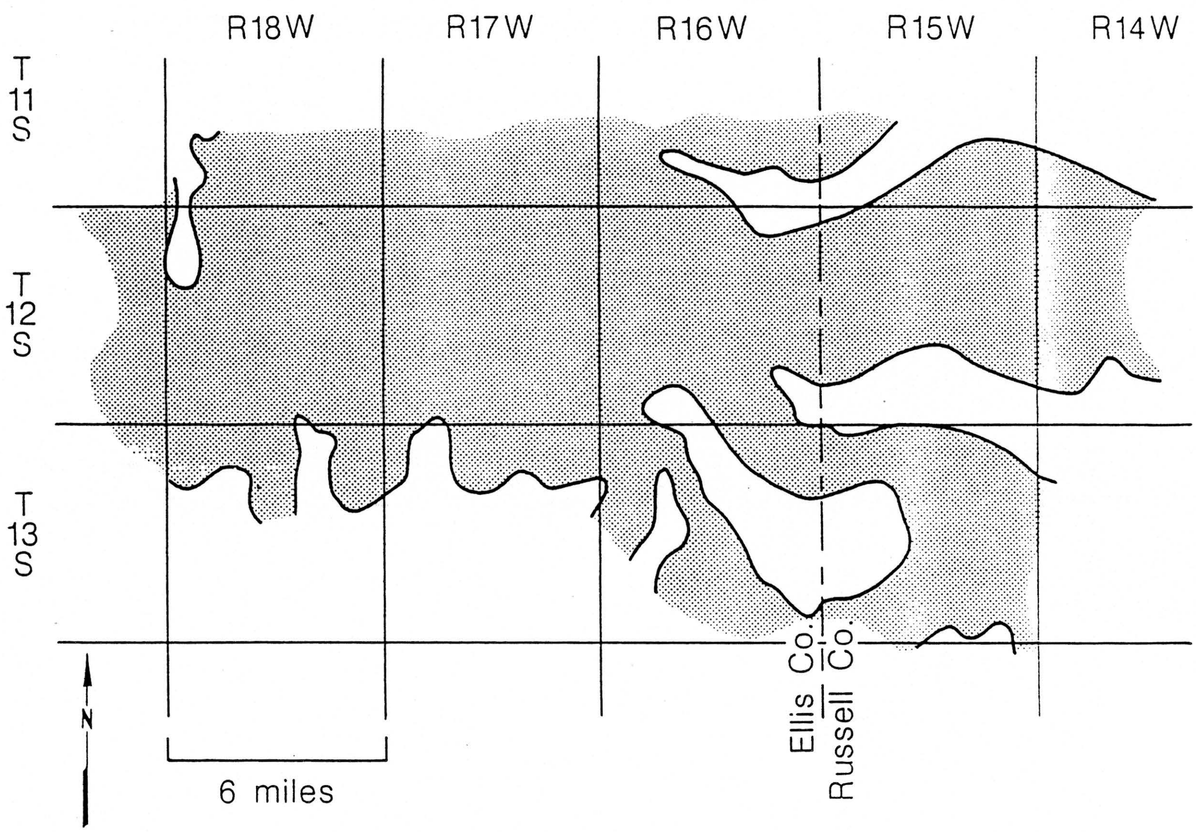

Figure 12. Location of the lower fluvially-deposited (deposition in stream channels) sandstone aquifers in the Dakota Formation, western Russell and eastern Ellis counties. Areas of sandstone accumulation are shown in stippled pattern.

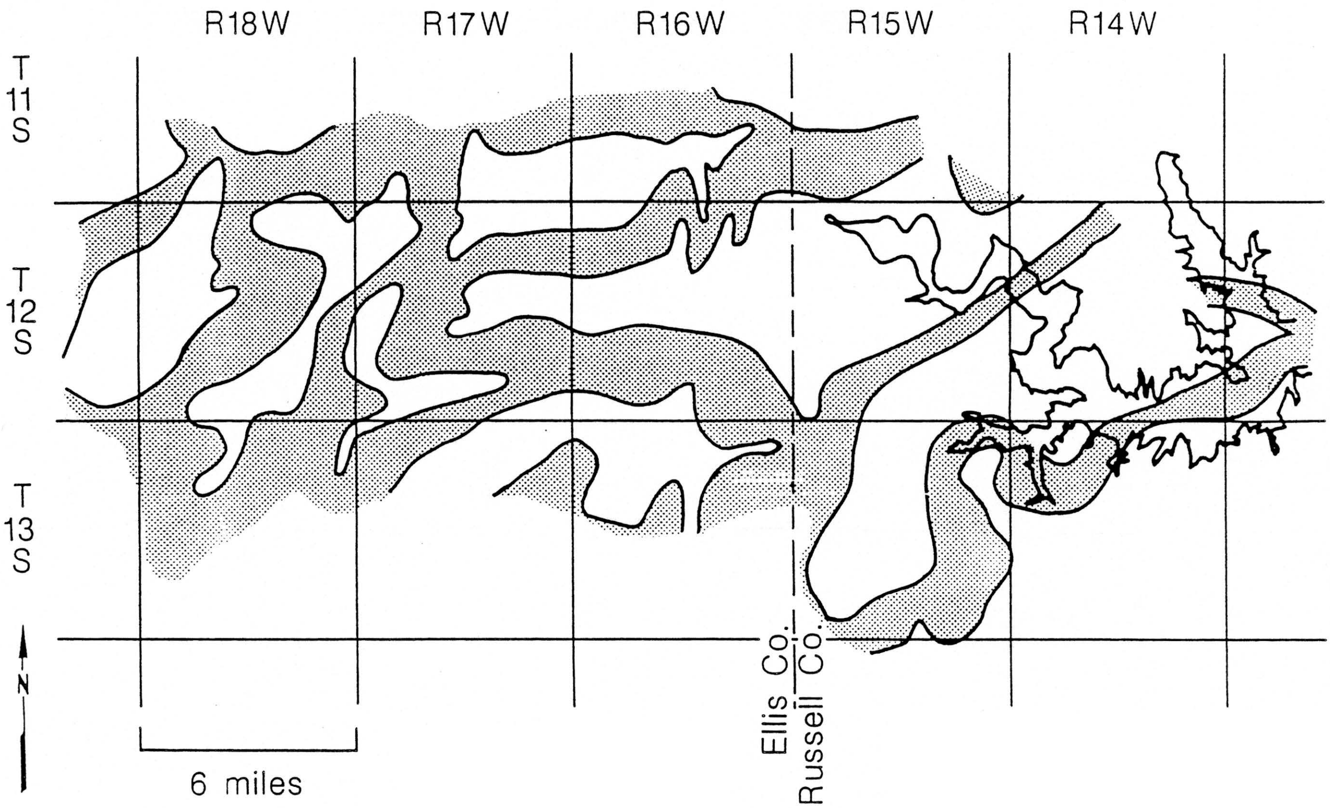

Figure 13. Location of the upper fluvially-deposited (deposition in stream channels) sandstone aquifers in the Dakota Formation, western Russell and eastern Ellis counties. Areas of sandstone accumulation are shown in a stippled pattern.

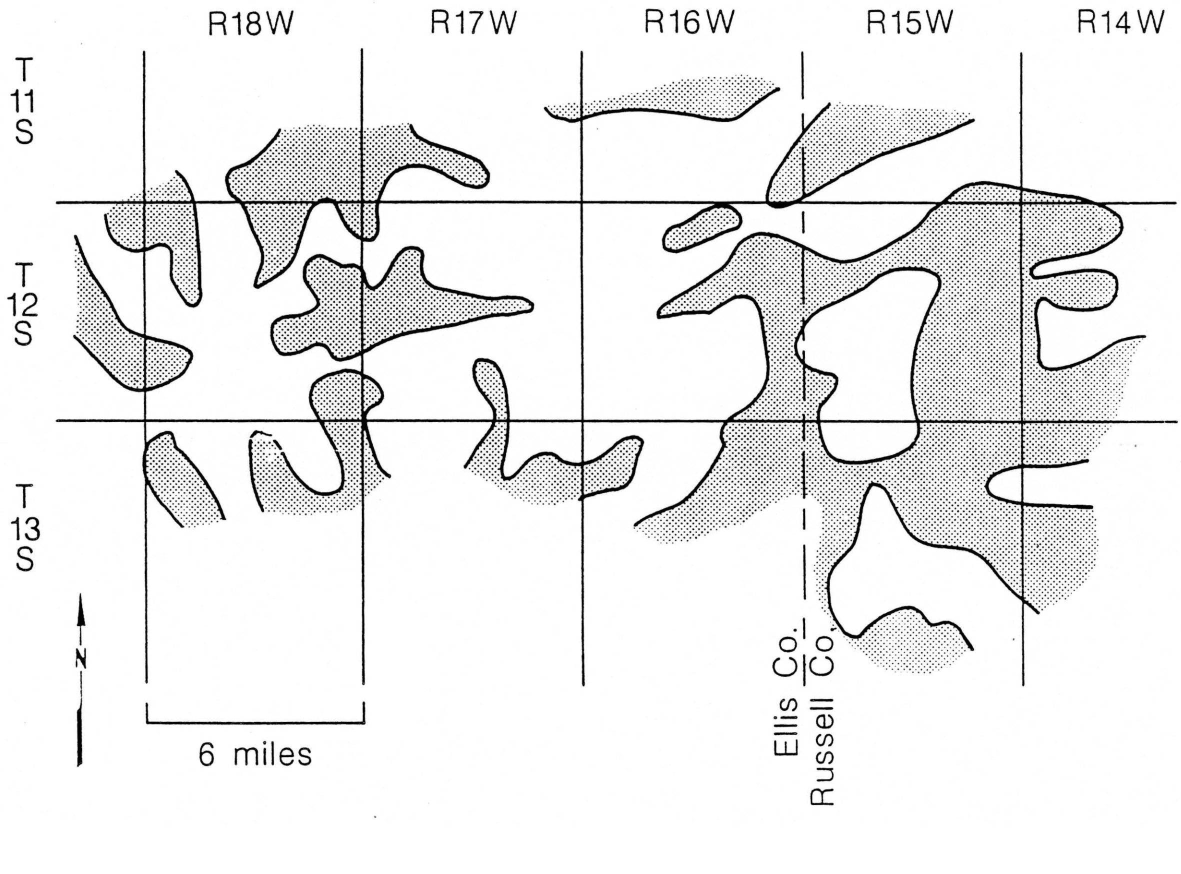

Figure 14. Distribution of sandstone aquifer units deposited in the vicinity of deltas during the Cretaceous Period, middle part of the Dakota Formation. Areas of sandstone accumulation are shown in a stippled pattern.

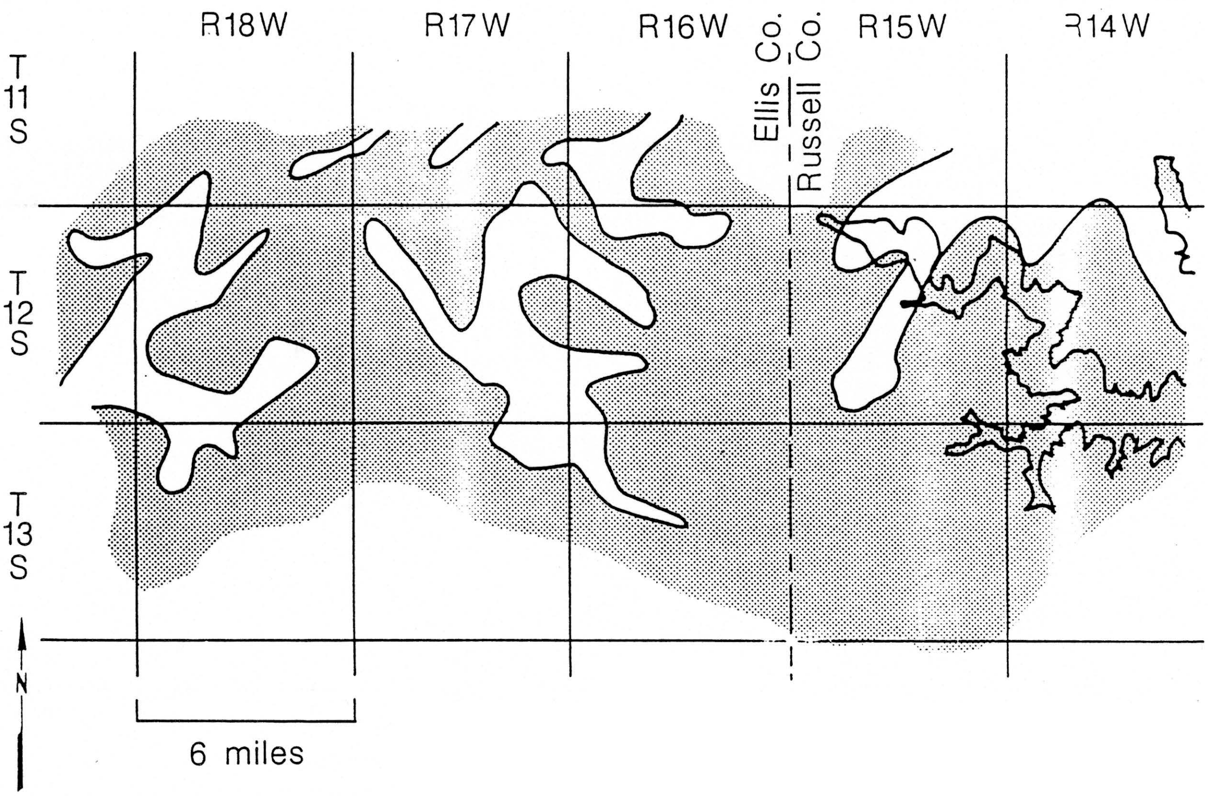

Figure 15. Distribution of sandstone aquifer units deposited in the vicinity of deltas during the Cretaceous Period, uppermost part of the Dakota Formation. Areas of sandstone accumulation are shown in a stippled pattern.

only if sufficient surface and subsurface data are available and can be integrated into a geologic framework that takes into account the primary geologic controls on sediment deposition. Recognition of these controls on sediment deposition is the primary function of the regional stratigraphic framework. Details pertaining to this pilot project and related research are included with this report as Appendices C and D.

FEASIBILITY OF USING SEISMIC STRATIGRAPHIC METHODS

The seismic-reflection method has been used by the petroleum industry for the past 60 years to determine subsurface geologic structure to depths of several thousand feet. Refinements in seismic-reflection technology in the past 20 years have allowed for examination of stratigraphic variations by seismic methods, commonly called seismic stratigraphy. Work at the Kansas Geological Survey has refined the resolution capability of the method to be very effective at depths of less than 1500 feet. Because the Dakota is present throughout much of Kansas at depths of less than 1500 feet, the methodology exists to examine both the gross geologic structure and the stratigraphy of the Dakota.

During October, 1988, a seismic test line was shot in northwest Russell County where thick sandstone bodies are present in the subsurface. The purpose of gathering data along this line was to determine how well the sandstone bodies could be defined using standard seismic-reflection techniques. After the data was processed, several seismic reflectors were noted on the seismic cross-section that are deeper than the sandstone bodies in the Dakota Formation. As a result, KGS has concluded that some modifications must be made to the standard technique in order to "see" the shallow sandstone bodies. After these adjustments are made more seismic data will be collected from the test site to verify the adjustments. If successful, the adjustments will be incorporated into the method and a longer line will be shot and the seismic data processed in the early Spring, 1989.

PRELIMINARY RESULTS

The following is a summary of research results from the Dakota aquifer program during the first year and from the Kansas Corporation Commission central Kansas Dakota aquifer study. Further details on these preliminary research findings can be found in Appendices A through D.

1. Development of the Dakota aquifer is presently restricted to areas where the aquifer is in the near surface environment of northern, south-central, and southwestern Kansas. In these areas, the Dakota aquifer is a major source of water for irrigation, public water supply, and industrial use. Development in these areas is a function of the availability of sandstone aquifers, and water quality in the Dakota aquifer and the availability of other overlying aquifers.
2. Subdivision of the Dakota Formation into mappable units is possible provided that adequate surface and subsurface data are available and can be integrated into the regional geologic framework. The Dakota Formation is one of the principal geologic units comprising the Dakota aquifer in Kansas. The regional framework portrays the shifting patterns of deposition of sediments during the Early Cretaceous in response to sea-level fluctuations and the effects of repeated local deep-seated geologic movements of the earth along zones of weakness. An adequate density of data is required to reasonably define the major zones of sandstone accumulation. Interpretation of sandstone body depositional environment and geometry comes from extension of the regional framework to the local level of investigation.
3. The potential for upward migration of saline waters into freshwater aquifers and surface water bodies is high especially where fresh and saltwater aquifer systems are hydraulically connected. Interconnections between aquifers may occur naturally, as a result of geologic processes, or anthropogenically, as a result of improperly plugged boreholes or excessive fluid pressure buildup from fluid injection. In the Dakota aquifer discharge areas of central Kansas, rapid water-quality transitions commonly occur in the near-surface and significantly impact surface waters.

APPENDICES

APPENDIX A

HYDROGEOLOGY AND WATER CHEMISTRY OF THE GREAT PLAINS (DAKOTA, KIOWA, AND CHEYENNE) AND CEDAR HILLS AQUIFERS IN CENTRAL KANSAS

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ABSTRACT

Shallow underground disposal of oil-field brines in the Cedar Hills has prompted concern related to induced upward migration of the brines into freshwater zones of the Great Plains aquifer in central Kansas. Within this area, 460 wells are actively being used to dispose of oil-field brines into the Cedar Hills aquifer. The estimated average rate of disposal was 550 bbls. per day per well during 1975-1983. In order to evaluate the potential for upward migration of these brines, the Kansas Geological Survey conducted a subregional hydrogeologic investigation of the Great Plains and Cedar Hills aquifers to assess the geologic and hydrologic factors affecting containment of the disposed and naturally-occurring brines. Sandstones, shales and mudstones of the Dakota Formation, Kiowa Formation, and Cheyenne Sandstone comprise the framework of the Great Plains aquifer. Sandstone, siltstone, and shale of the Cedar Hills Formation comprise the framework of the Cedar Hills aquifer. In the eastern half of the area, the Cedar Hills aquifer directly underlies the Great Plains aquifer, but in the western part relatively impermeable Jurassic and Permian strata separate these two aquifer systems. Ground-water flow in the Great Plains aquifer is generally from the deeper part of the Western Kansas basin and southern outcrop areas towards the Smoky Hill and Saline Rivers. Ground-water flow in the Cedar Hills aquifer is subparallel to the flow in the Great Plains aquifer where they are in contact. Elsewhere in the western part of the area the configuration of the Cedar Hills potentiometric surface has been affected by fluid injection. Total dissolved solids concentrations of ground waters in the Cedar Hills and lower Great Plains aquifers are generally greater than 20,000 mg/l and decrease vertically upward into the upper part of the Great Plains aquifer. Throughout the central Kansas area, the

hydrologic data from the monitoring sites indicates vertically upward movement of fluids from the Cedar Hills and into the Great Plains aquifer. This is supported by the similarity of general water chemistry, Br/Cl versus Cl mixing curves, and the stable isotope data between aquifers. Hydrologic testing suggest that upward movement of brines may be facilitated locally by fractures. These results indicate that shallow underground disposal of oil-field brines should be discontinued in the area of interconnection between the Cedar Hills and Great Plains aquifers.

APPENDIX B

GEOCHEMICAL AND GEOLOGIC INDICATORS OF VERTICAL MIXING BETWEEN PERMIAN AND CRETACEOUS UNITS IN CENTRAL KANSAS

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ABSTRACT

Mixing of natural and oil-field brines in the Permian Cedar Hills and the Cretaceous Cheyenne sandstones of central Kansas with fresh waters in the overlying Cretaceous Dakota Formation is a matter of concern. Delineation of lineaments from areal photography in addition to the absence of the Permian confining unit, the Flower-pot Shale, in the study are provide potential vertical flow pathways between the units. The potentiometric surface of the Cedar Hills Sandstone shows a marked difference between areas overlain by the Flower-pot Shale and those where the shale is absent. Water-level measurements over a 1-1/2 year period indicate flow from the Cedar Hills to overlying units. Vertical mixing of ground waters is indicated by the similarity of general water chemistry, Br/Cl versus chloride mixing curves, and the isotopes of ^{18}O and δD values for all of the units are depleted by up to -3‰ and -30‰ respectively west to east across the study area and indicate that water at the eastern end of the general-flow gradient is least affected by recharge, may indicate a colder climate, and may reflect mixing with more isotopically depleted brines.

APPENDIX C

INTERPRETATION OF LITHOLOGIES AND DEPOSITIONAL ENVIRONMENTS OF CRETACEOUS AND LOWER PERMIAN ROCKS USING A DIVERSE SUITE OF LOGS FROM A BOREHOLE IN CENTRAL KANSAS

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ABSTRACT

As part of an extensive research program, a borehole was drilled to extend sedimentary facies models of the Cretaceous into the subsurface on the eastern side of the Western Interior Cretaceous basin in Kansas. Lithodensity-neutron and spectral gamma-ray logging runs were completed to facilitate interpretation of rocks penetrated by the borehole. Th/K, Th/U, and composition profile logs based on apparent grain density and photoelectric absorption index were prepared and used to show vertical changes in geochemical facies and clay mineralogy. These logs were compared with the gamma ray log and drill cuttings to interpret depositional environments. The Th/K log sharply defines the Cretaceous/Permian boundary and, together with the Th/U log, emphasizes the contrast between marine Upper Cretaceous rocks of the Greenhorn depositional cycle and nonmarine to transitional rocks of the Lower Cretaceous. The long-term cyclic pattern of the Th/U log is an excellent indicator of a broad transgression/regression during the Greenhorn cycle on an open marine shelf, whereas extreme fluctuations of Th/U in the Lower Cretaceous rocks suggest a high degree of short-term environmental variability. Interpretation of the RHOMAA-UMAA compositional profile in the Dakota Formation indicates several pulses of marine transgression and regression prior to the initiation of the Greenhorn cycle in central Kansas.

INTRODUCTION

Sedimentary rocks of Cretaceous age are present in much of central and western Kansas. Upper and Lower Cretaceous units have been described extensively along the outcrop belt e.g., see Hattin and Siemers, 1987; Latta, 1946; Franks, 1980. These rocks record several transgressive/regressive cycles that occurred during deposition of the western interior Cretaceous section. Hattin and Siemers (1987) have recognized cycles of transgression and regression in the Upper Cretaceous rocks beginning with the upper part of the Dakota Formation. Franks (1980) has described cyclical patterns of deposition in the Lower Cretaceous Kiowa Formation of central Kansas.

Although these rocks have been studied in detail where they crop out, very little work has been done to trace depositional environments and lithofacies into the subsurface. This is particularly true of the Lower Cretaceous rocks, which are relatively unknown where they are covered. Franks (1979, 1980) and Scott (1970) have noted problems regarding nomenclature and correlation between surface and subsurface sections of Lower Cretaceous rocks in the Western Interior. Recently, as part of an extensive research program on the Kansas Lower Cretaceous a borehole was drilled that penetrated part of the Upper Cretaceous, all of the Lower Cretaceous and part of the Lower Permian (Fig. 1). The purpose of drilling this hole was to extend knowledge of Lower Cretaceous sedimentary facies into the subsurface toward the axis of the western interior Cretaceous basin.

To accomplish this task, lithodensity-neutron and spectral gamma-ray logging runs of the borehole were completed to supplement information from drill cuttings. The logs were processed using techniques described by McCall and Gardner (1982) and Schlumberger (1988) in order to graph vertical changes in mineralogy and geochemical fluctuations as indicators of depositional environments in these rocks.

SPECTRAL GAMMA-RAY LOG ANALYSIS

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. The gamma-ray spectral log records curves of thorium and uranium which are both scaled in parts per million, together with potassium in percent.

In sedimentary rocks, thorium is almost exclusively restricted to alumino-silicate 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.

The Th/K and Th/U ratios were plotted as logs together with the gamma ray trace and compared with a graphic lithology log (Fig. 2). 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. An abrupt shift occurs at the Cretaceous-Permian contact (top of the Cedar Hills Sandstone) and highlights clearly a major unconformity at the base of the Cretaceous. Petrographic descriptions based on outcrop samples (Swineford, 1955) and core (James, 1972; Holdoway, 1978) have characterized the Cedar Hills Sandstone as a quartz-feldspar-illite assemblage. The Th/K log within this unit is restricted to the theoretical range of ratio values between 0.5

and 3.5 suggested for a feldspar-illite mixture by Schlumberger (1988). In contrast, the shift to higher Th/K values in the Lower Cretaceous is caused by the change in mineralogy to illite-smectite-kaolinite, reported from petrographic studies of these units in outcrop (Franks, 1979). Schlumberger (1988) gives the generalized ranges for these minerals as 2-3.5 (illite), 3.5-12 (smectite), and 12-28 (kaolinite). These data collectively explain the reason for the abrupt discontinuity in the Th/K log at the unconformity at the base of the Cretaceous. They also suggest that the oscillations of the Th/K log within the Lower Cretaceous formations may reflect volumetric variations of illite and kaolinite that are possibly linked with marine and deltaic freshwater environments, respectively. The Th/K ratio trace in the Graneros Shale overlaps the range of the Lower Cretaceous curve. However, there is a distinctive bias toward higher Th/K ratios in the Graneros that probably reflects the increased importance of smectite as a significant component. Th/K fluctuations in the Upper Cretaceous units appear to be caused by changes in illite, smectite, and mixed-layer clays as products of predominantly marine environments; these are the clay mineral components reported in X-ray diffraction analyses of insoluble residues (Arthur et al., 1985). High-amplitude Th/K variations in the Graneros Shale and the Greenhorn Limestone may reflect the occurrence of bentonites (observed in the drill cuttings) interbedded with normal illitic marine shales. These bentonites represent altered ash deposits generated from volcanic events in the Idaho-Montana and New Mexico-Arizona regions.

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. The ratio indicates an oxidizing environment for much of the Cedar Hills Sandstone, which was interpreted to have been deposited in an eolian setting by Holdoway (1978). The occurrence of glauconite in drill cuttings from the upper part of the formation is a strong indicator of marine origin and is matched by decline Th/U to a neutral range. This section may reflect deposition in shallow bodies of water that were linked to an ephemeral sea, as suggested by Holdoway (1978) for the overlying Flower-pot Shale.

Above the Cretaceous/Permian boundary, the Th/U log exhibits a high-frequency character in the Cheyenne, but is consistently greater than 7. This is compatible with an oxidizing terrestrial environment of deposition by alluvial processes. The overlying Kiowa Shale marks a transgressive phase and is generally considered to represent a transitional to shallow-marine environment in Kansas (Franks, 1980). The average Th/U ratio in the Kiowa is lower than in the Cheyenne, but shows only a weak trend in the intermediate range. This feature is a pale shadow of strong signals recorded in the spectral ratio of Upper Cretaceous transgressive strata in this well. However, the subdued character of the Kiowa section is in accordance with a peak-transgression paleogeographic map, on which the well site would be located close to the shoreline (Vuke, 1981). Stacked repetitions of high and medium Th/U ratios characterize the overlying Dakota Formation. These probably reflect the high lateral variability of environments expected in nonmarine settings as well as the interplay between mostly brackish and fresh-water regimes of deltaic environments.

In contrast to the Dakota trace, relatively smooth, long-term cyclic pattern of the Th/U log characterizes the Upper Cretaceous marine sequence and is an excellent indicator of a broad transgressive/regressive couplet on an open marine shelf. In fact, the broad sine-wave feature conforms precisely with the outcrop interpretation of the Greenhorn cycle as a classic example of a symmetric, third-order tectonoeustatic cycle (Glenister and Kauffman, 1985). Hattin (1985) was able to correlate demonstrably time-parallel beds in the Greenhorn from outcrops in Kansas to locations in Colorado and New Mexico. He concluded that the exceedingly widespread deposition of relatively thin units implied a regionally flat, gently sloping seafloor. This interpretation would account for the strong simple transgressive/regressive signal that appears in the ratio log from the top of the Dakota Formation to the base of the Niobrara Formation. The transgressive phase of the cycle started during the deposition of the uppermost part of the Dakota, continued through the Graneros Shale, and reached maximum development in the Greenhorn Limestone. The regressive hemicyclotherm was initiated near the end of Greenhorn deposition and continued through the Carlile Shale to terminate in the Codell Sandstone Member.

An abrupt break occurs in the Th/U log at the boundary between the Codell Sandstone Member and the overlying Niobrara Chalk. This contact is thought to represent a long period of nondeposition followed by a major transgression (Hattin and Siemers, 1987). The Th/U log shows this second transgression clearly, but also indicates a distinctive regressive event within the Fort Hays Member. The regional extent of this anomaly is indicated by the occurrence of a similar peak on the Th/U log from a well in the Denver Basin of Colorado (Zelt, 1985).

ANALYSIS AND INTERPRETATION OF THE LITHODENSITY-NEUTRON AND PHOTOELECTRIC ABSORPTION INDEX LOGS

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 Lower Cretaceous units.

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, and is measured in units of barns per electron. 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.

A RHOMAA-UMAA crossplot of digitized data from the Lower Cretaceous formations is shown in Fig. 3. This plot is indexed with the approximate locations of standard clay minerals (Schlumberger, 1988) which, in reality, show ranges of variability as a consequence of differing compositions and morphologies from their ideal. The data cloud shows a wedge pattern whose upper vertex is sited at the coordinates of quartz. The range in UMAA values of the clay minerals is an expression of their differences in elemental composition and aggregate atomic number (Z). The data range between values for low-Z clays (kaolinite, smectite, and muscovite) and high-Z clays (illite and chlorite), and 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 Lower Cretaceous 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 Fig. 4, together with the Th/U ratio logs.

The RHOMAA-UMAA log of the Lower Cretaceous shows the progressively increasing effects of marine transgression at the beginning of the Greenhorn cycle within the Dakota Formation. The proportion of high-Z clays increases significantly near the middle of the formation and composes most of the clay fraction in the upper half. Franks (1979) noted increases in the illite and chlorite fraction of the clays in the upper 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.

Using RHOMAA-UMAA, gamma ray, and Th/U logs of the Dakota, it is possible to delineate several pulses of marine transgression and progradation by streams. In the lower part, a stacked sequence of channel sandstones indicate progradation by streams during retreat of the Kiowa seas. Rapid alternations of the Th/U ratios in this interval suggest varying depositional environments ranging from channel to backswamp. Fining upward of these channel deposits and the predominance of low-Z clays in the clay- and silt-size fractions of the rocks indicates a renewed phase of marine transgression. Above this sequence deposition of more high-Z clay-rich, less well-developed channel sandstones signals a progradation of terrigenous deposits across the Lower Cretaceous shoreline. Low Th/U ratios in the upper part of this channel sandstone suggest an extended period during which the environment of deposition was not well oxygenated. The clastics above these channel sandstones are predominantly fine grained, the proportion of high-Z clays increasing upward until only these clays make up the fine fraction of the Dakota sediments. These fine-grained deposits appear to be more marinelike and indicate another transgressive pulse by the Lower Cretaceous seas. Renewed progradation is indicated by a unit consisting of interbedded sandstones and low-Z clays. This signifies possibly the last progradational episode prior to inundation by the Upper Cretaceous seas at this location. The fluctuations of the gamma-ray curve, the presence of glauconite from the driller's log, together with the predominance of illite in the sediments above and below this unit suggest that these coarser sediments were deposited just offshore in a marine environment as a delta-front sheet sand similar to the tabular flat-bedded sandstones described by Siemers (1976). Above these coarser delta-front sandstones are the rocks with low and relatively stable Th/U together with high proportions of illite, indicating an offshore marine environment with higher water salinities similar to that described by Hattin and Siemers (1987).

In the Kiowa Formation and the Cheyenne Sandstone, the RHOMAA-UMAA log shows that these units consist of interbedded high and low-Z clays and sandstones. Overall, the appearance of this log, together with the total gamma-ray and the Th/U and Th/K logs indicates that there is very little difference in the depositional environment between time of formation of the Kiowa Formation and Cheyenne Sandstone. This supports the observations of Franks (1980) that the Cheyenne of southern Kansas is very similar to the Kiowa of central Kansas.

CONCLUSION

These results show that much useful information on lithologies and environments of deposition can be gained through an analysis of the spectral gamma-ray, lithodensity-neutron, and photoelectric absorption index logs of rock sequences. In this study, contrasts between marine and nonmarine Cretaceous environments in the central Kansas borehole are strongly indicated by the nature of the fluctuations in the Th/U log. This reflects the mobility of these elements under varying oxidation-reduction conditions as well as sources for these elements. Variations in the concentrations of Th, U, and K also reflect environmental changes that occurred during the Greenhorn cycle. Comparison of Th/U ratio logs from the borehole in central Kansas with the ratio logs of outcrops and boreholes in Colorado and Utah show marked similarities. In the Lower Cretaceous Dakota Formation, several distinct sedimentary depositional packages have been delineated using the RHOMAA-UMAA and Th/U ratio logs. These packages appear to be related to periods of marine transgression and progradation by streams during the early development of the western interior Cretaceous basin.

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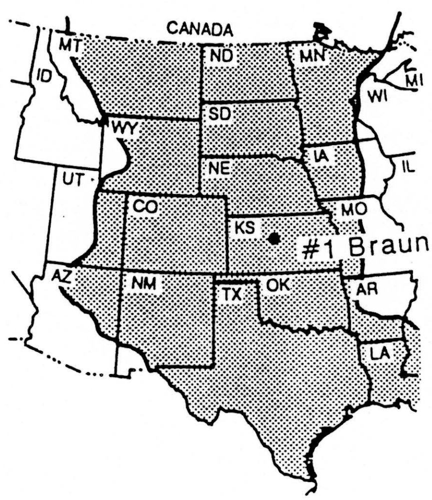
Figure 1. Location of the #1 Braun borehole with respect to the Cretaceous western interior seaway (Early Turonian).

Figure 2. Computed gamma ray, Th/U, and Th/K logs from the borehole KGS Braun #1 30-12S-18W, Ellis County, Kansas.

Figure 3. RHOMAA-UMAA crossplot of digitized data from Lower Cretaceous rocks in #1 Braun borehole indexed with approximate locations of clay minerals (Schlumberger, 1988).

Figure 4. RHOMAA-UMAA proportional lithology log of Lower Cretaceous rocks in #1 Braun borehole. Arrows mark interpreted transgressive (to right) and regressive (to left) trends.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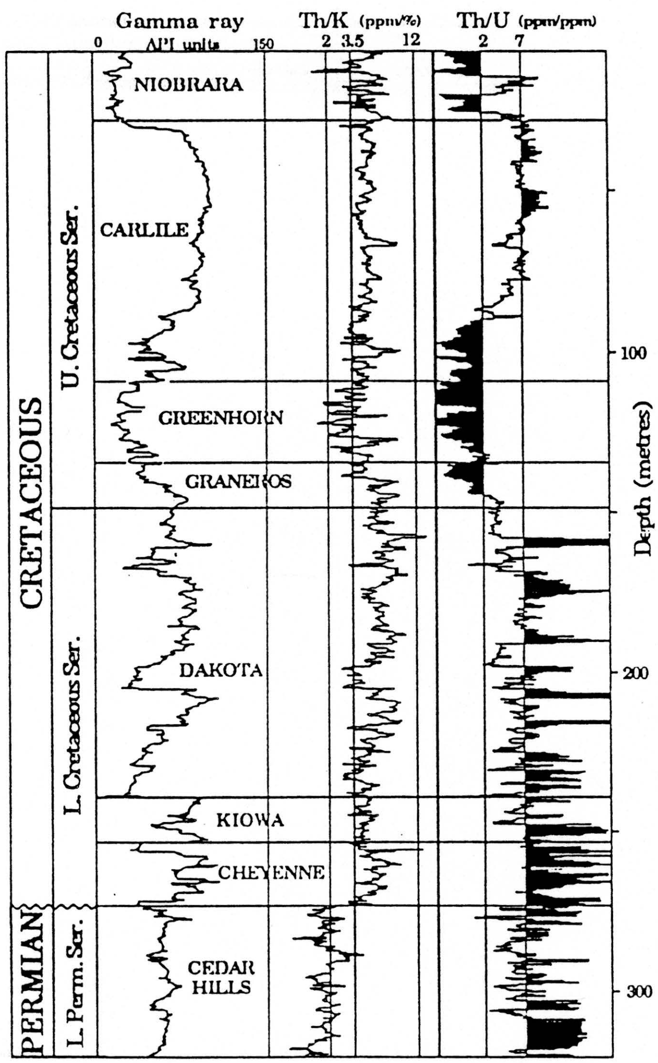
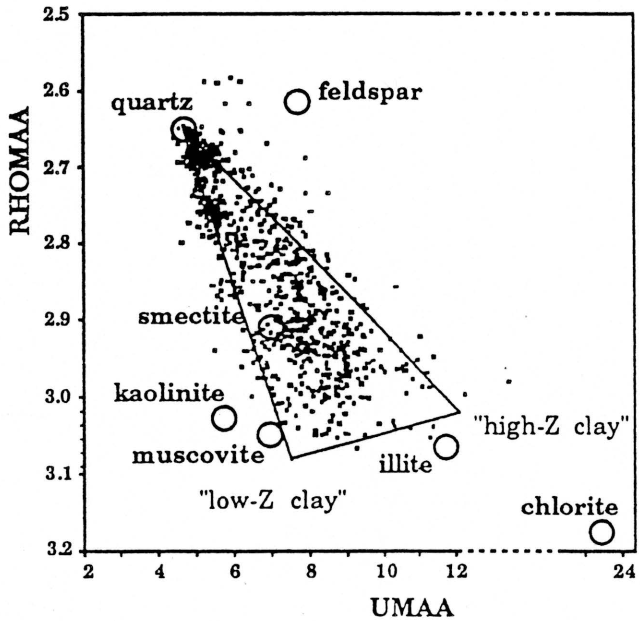
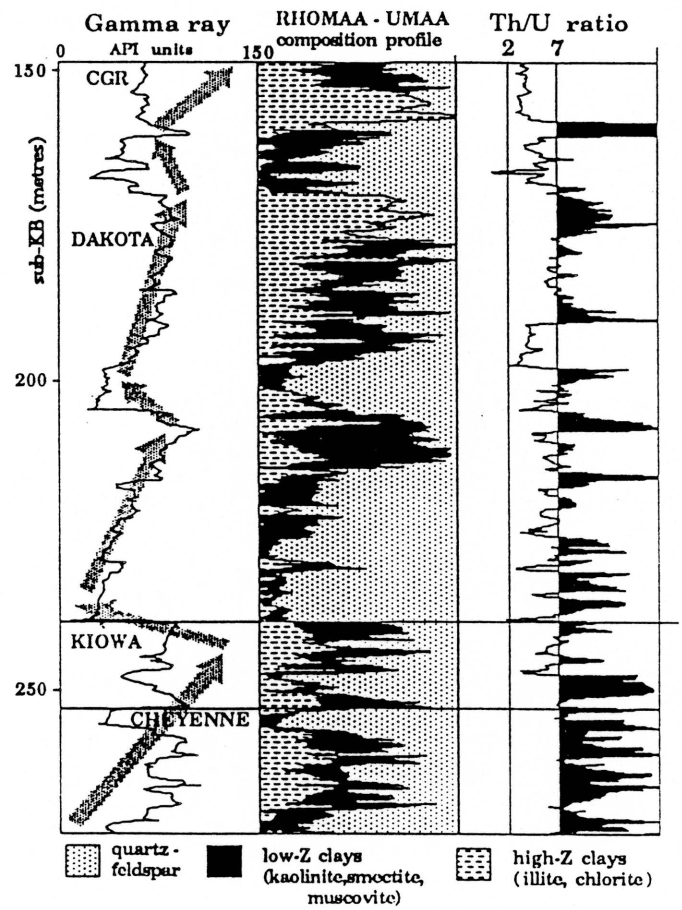


Gamma ray
0
API units
150
Th/K (ppm/%)
2 3.5
12
Th/U (ppm/ppm)
2 7
CRETACEOUS
PERMIAN
U. Cretaceous Ser.
L. Cretaceous Ser.
L. Perm. Ser.
NIOBRARA
CARLILE
GREENHORN
GRANEROS
DAKOTA
KIOWA
CHEYENNE
CEDAR HILLS
100
200
300
Depth (metres)



RHOMAA
UMAA
2.5
2.6
2.7
2.8
2.9
3.0
3.1
3.2
2
4
6
8
10
12
24
quartz
feldspar
smectite
kaolinite
muscovite
illite
chlorite
"high-Z clay"
"low-Z clay"


Gamma ray
0 API units 150
RHOMAA - UMAA
composition profile
Th/U ratio
2 7
150
200
250
sub-KB (metres)
CGR
DAKOTA
KIOWA
CHEYENNE
quartz - feldspar
low-Z clays (kaolinite,smectite, muscovite)
high-Z clays (illite, chlorite)

APPENDIX D

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

by

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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 (eustacy) 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 on a regional unconformity on top of the Kiowa Formation. This period ended with the initiation 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

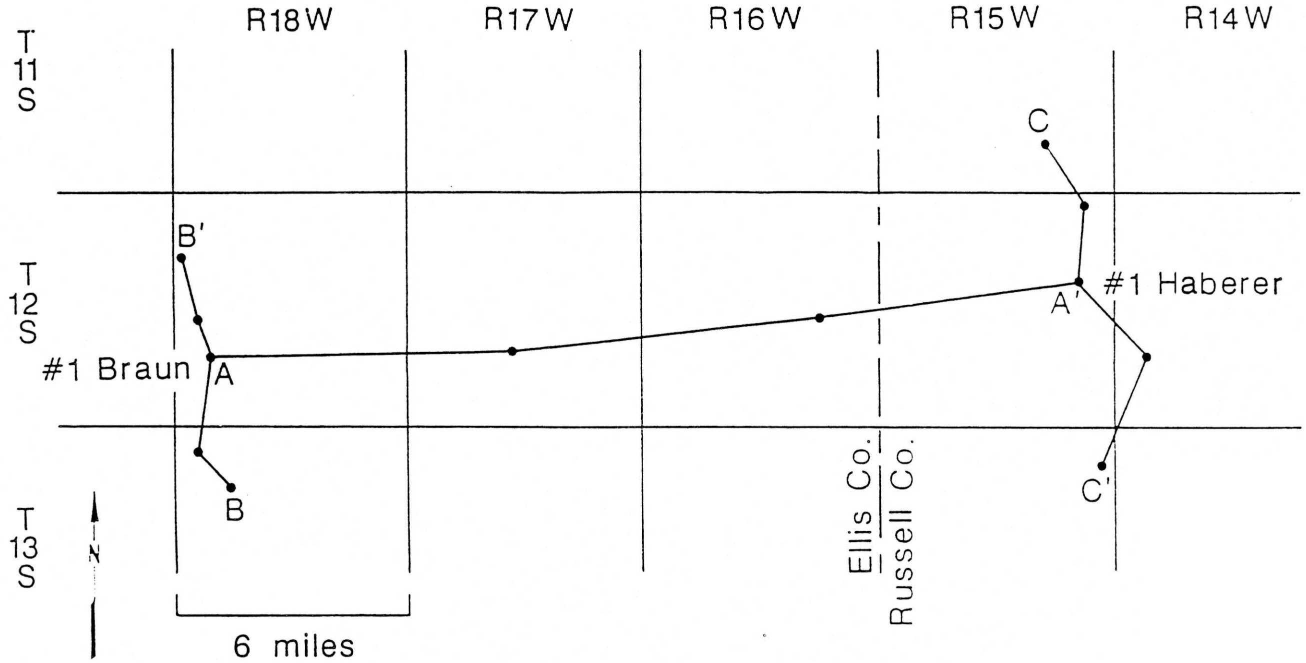

Figure 1. Location of the study area, cross-sections, and test holes in eastern Ellis and western Russell counties.

on sediment deposition has been further modified locally by slight, deep seated tectonic movements or differential subsidence (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 configuration on the top of the Graneros Shale shows a predominate north-south structural trend that developed after the deposition of the Graneros Shale. The dominant geologic structure affecting all of the mapped areas is the Central Kansas uplift. The Fairport-Natoma anticline 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 upper surface of the Graneros Shale (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

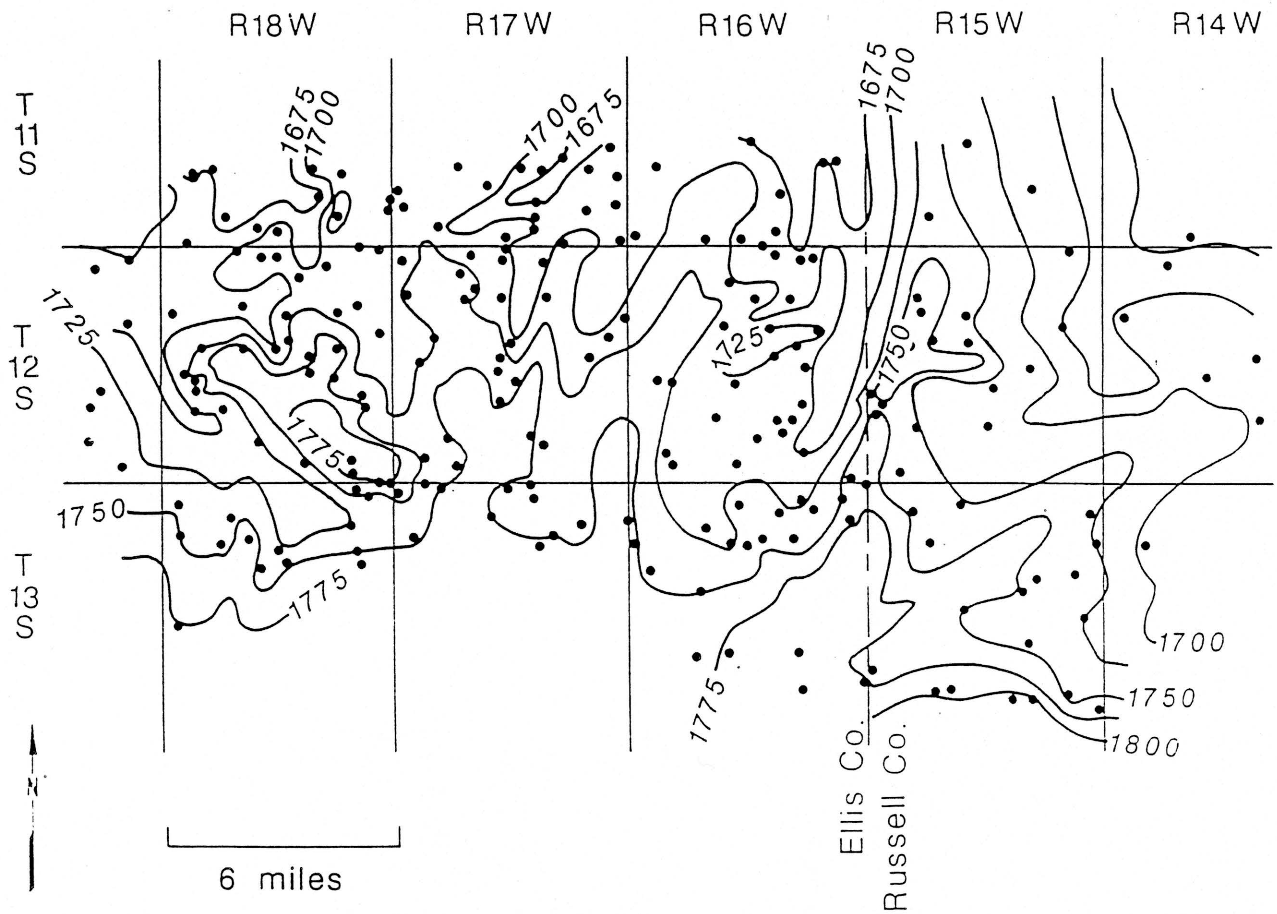

Figure 2. Structure contour map on top of the Graneros Shale, western Russell and eastern Ellis counties.

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).

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

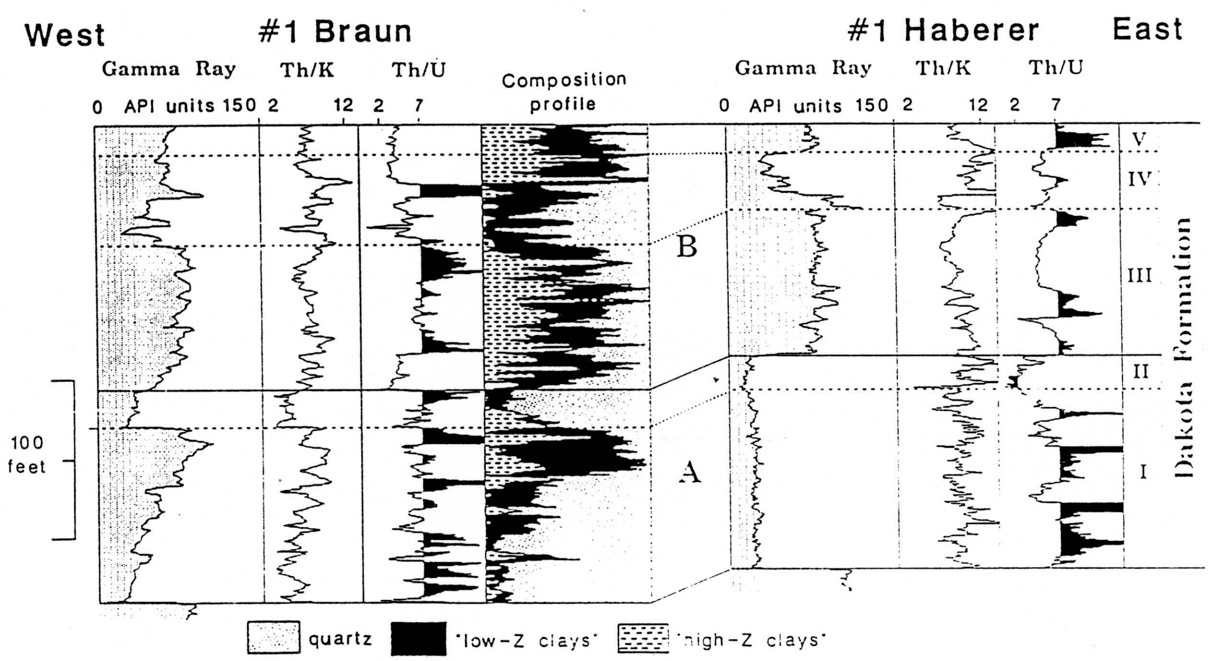

Figure 3. Computed gamma ray, Th/K, Th/U, and RHOMAA-UMAA composition logs for the KGS #1 Braun and computed gamma ray, Th/K, and Th/U logs for the KGS #1 Haberer in the Dakota Formation.

the 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 electro-facies. 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.

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 alumino-silicate 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

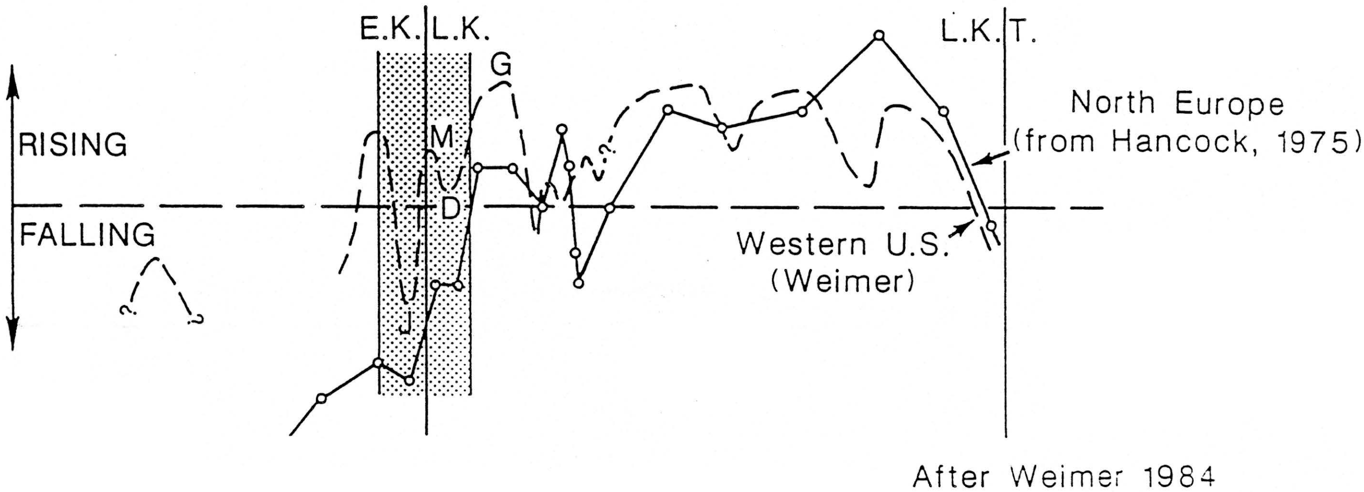

Figure 4. Relative changes in sea level elevation during the Cretaceous Period, western United States and northern Europe (after Weimer, 1984).

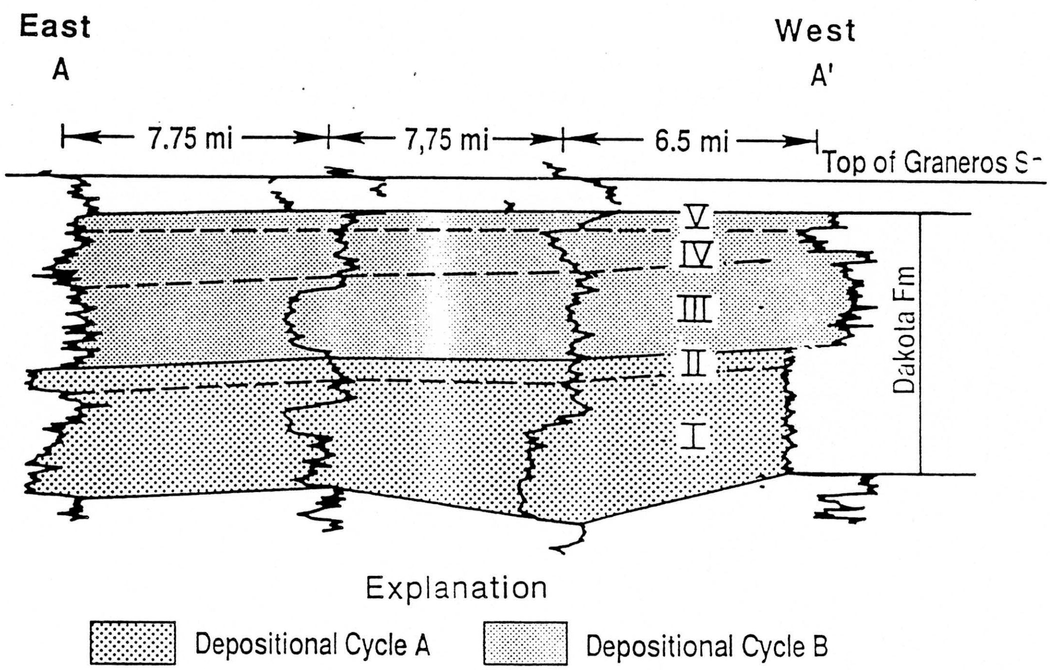

Figure 5. East-west subsurface cross-section, Graneros Shale and Dakota Formation from the KGS #1 Haberer to the KGS #1 Braun.

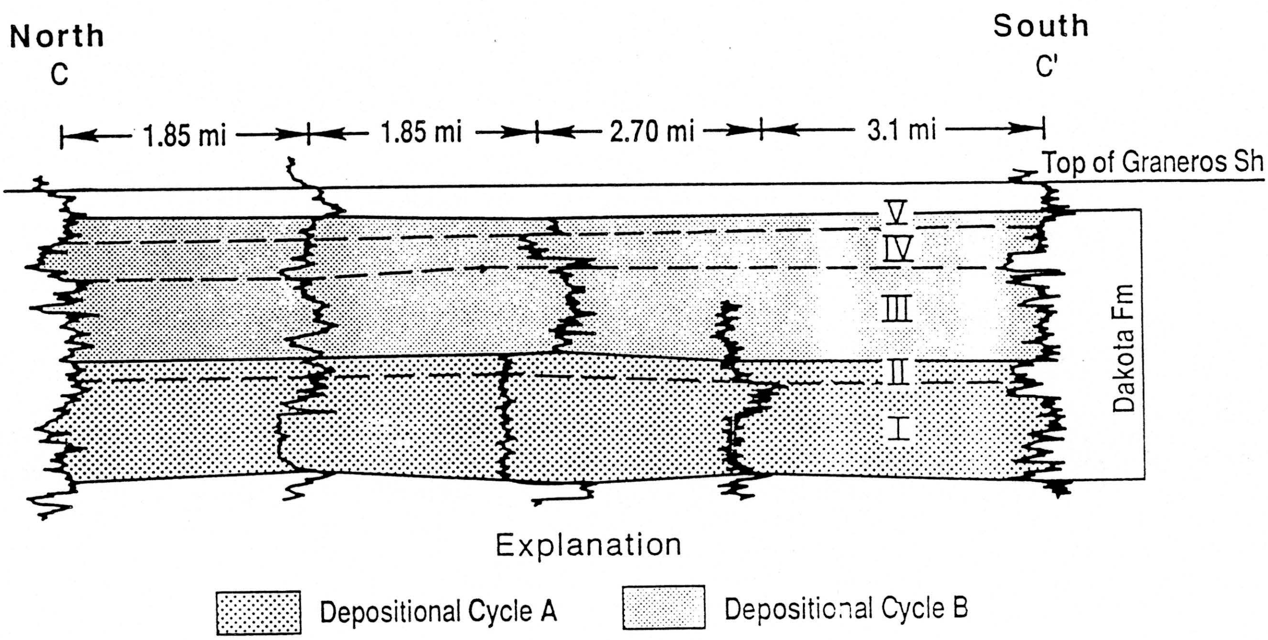

Figure 6. North-south subsurface cross-section through the KGS #1 Haberer, Graneros Shale and Dakota Formation.

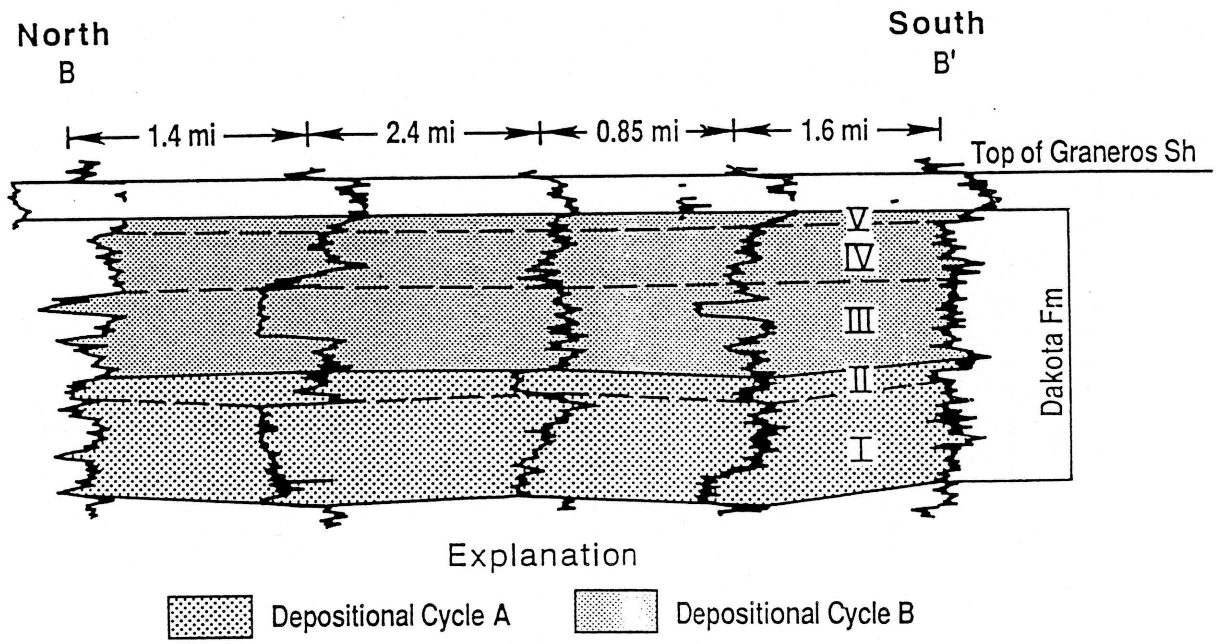

Figure 7. North-south subsurface cross-section through the KGS #1 Braun, Graneros Shale and Dakota Formation.

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.

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 -12.0
Kaolinite, chlorite	12.0-28.0

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

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.

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 fluvially-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 the western portion of the mapped area (interchannel sediments consist of interbedded shale, siltstone, sandstone, and lignite). The east-west trend of these meander-belt sandstones in the study area is consistent with the overall west-southwest trend interpreted for the channel systems in the outcrop areas (Franks, 1966) and with the westerly tilting of the central Kansas uplift inferred by Merriam (1963) during the 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).

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

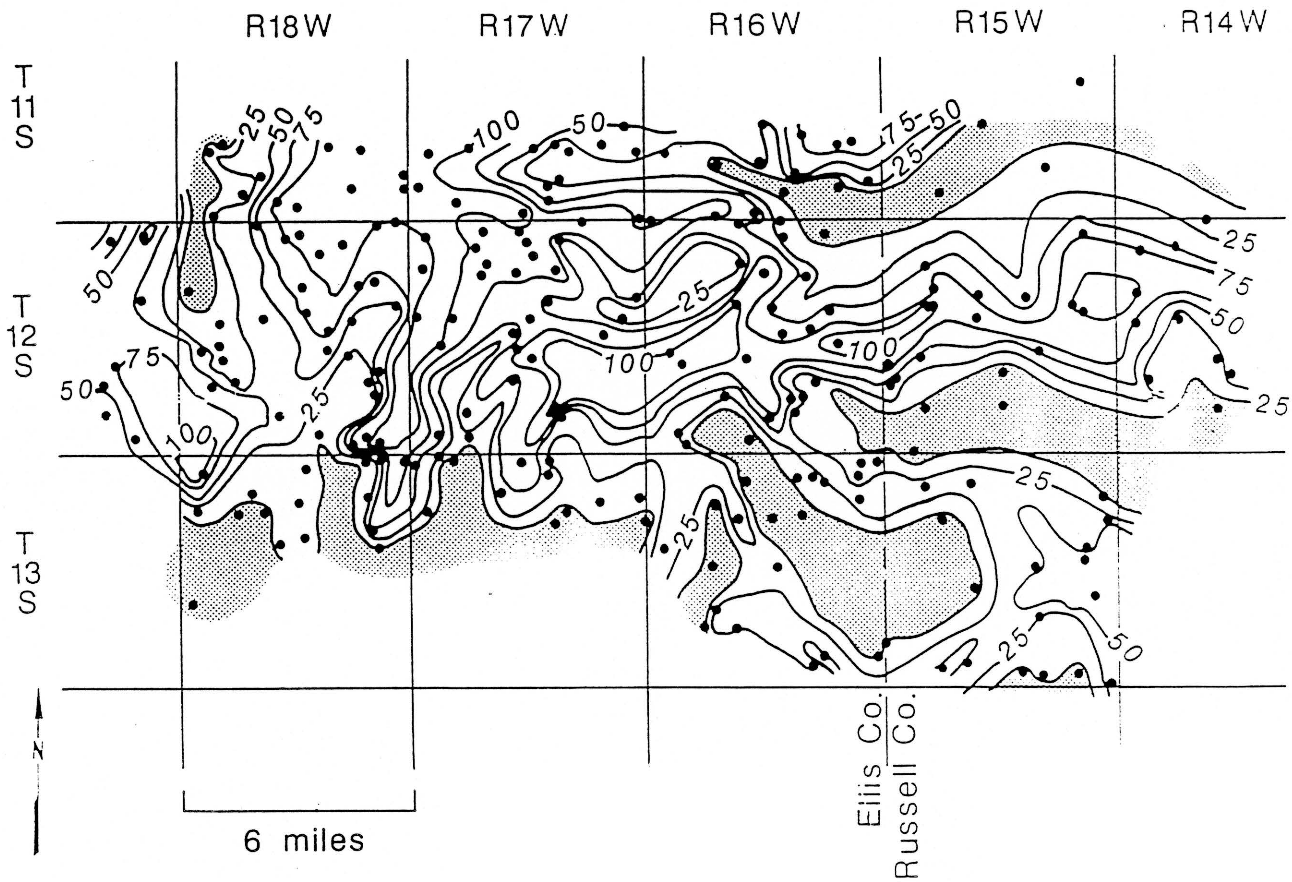

Figure 8. Sandstone isolith map of electrofacies I.

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. Alternatively, these accumulations may have resulted from shallow marine reworking and piling of sand along trends of distributing channels. Most of these interconnected sandstone bodies are situated directly above thick accumulations of channel sandstone in electrofacies I. These shallow marine sand buildups may be situated on paleotopographic highs created by differential compaction of underlying sandstone and adjoining fine-grained deposits. The total thickness of electrofacies 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 nearer sea level than during most of electrofacies I lower stand. 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

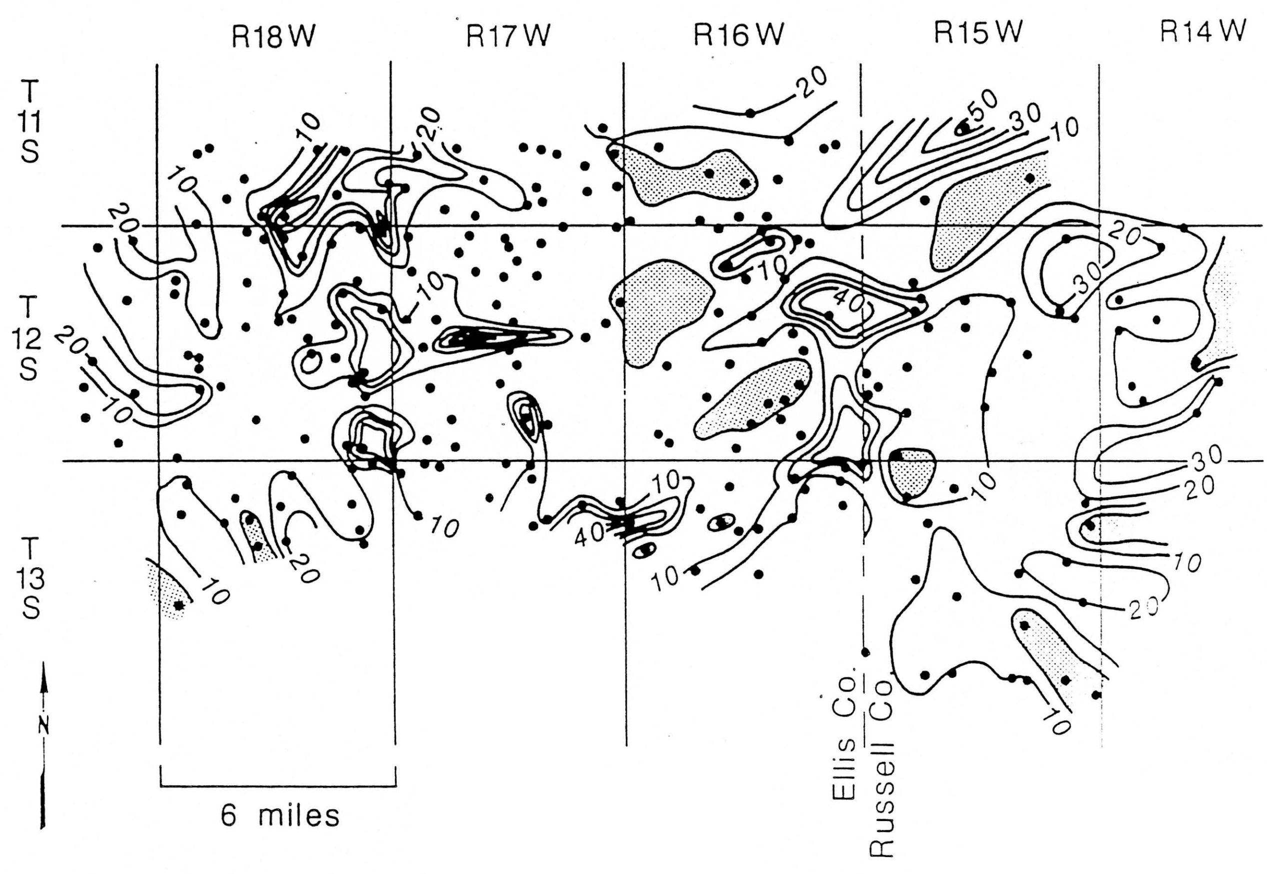

Figure 9. Sandstone isolith map of electrofacies II.

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 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

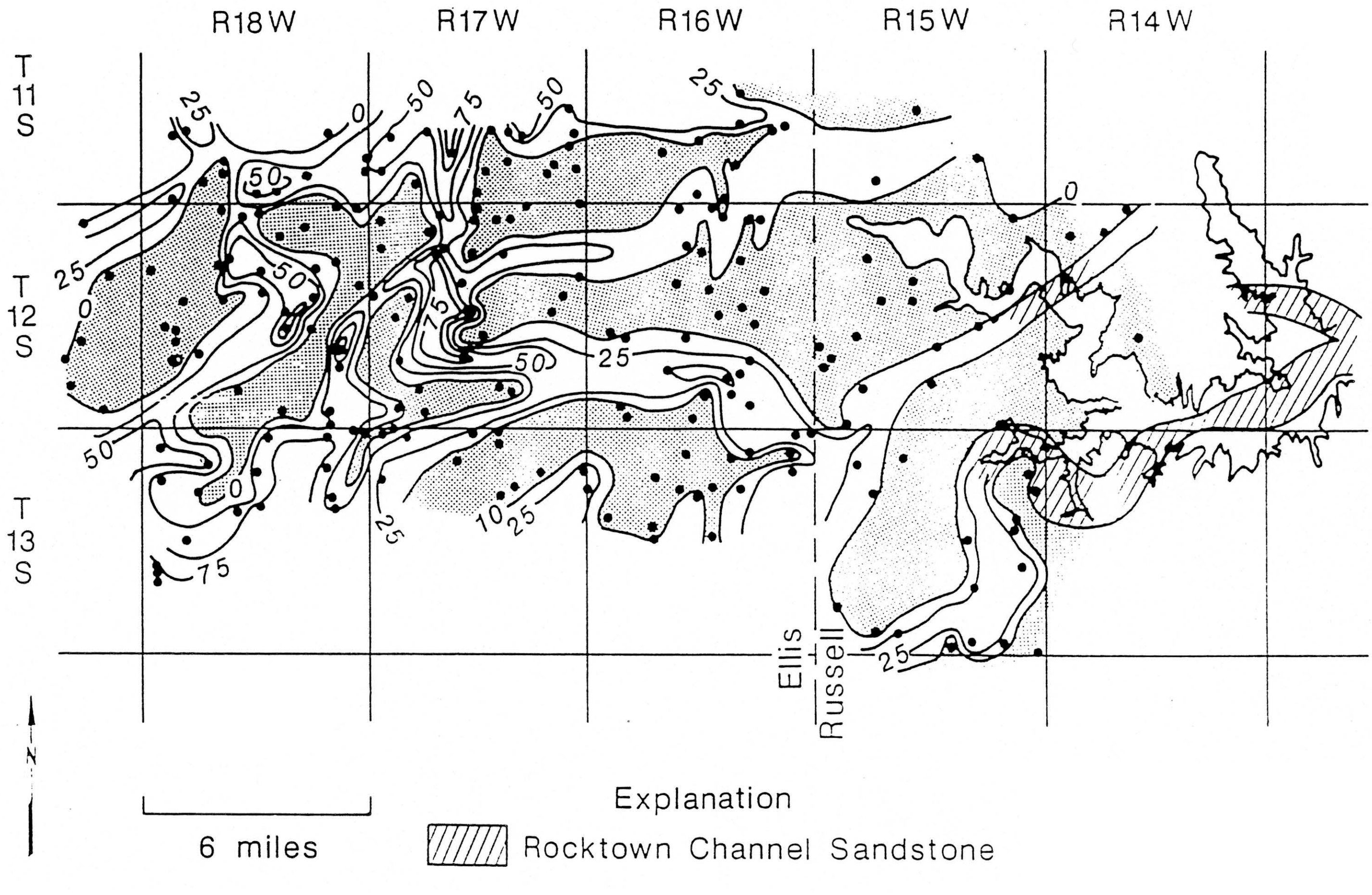

Figure 10. Sandstone isolith map of electrofacies III.

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 caused by differential compaction of underlying sandstone and fine-grained deposits or with deep-seated underlying structures in the Precambrian. Many of these structures are reflected in the configuration of the top of the Graneros Shale (Fig. 2) and on the structural configuration of the top of the Stone Corral Formation (Merriam, 1959). Low-Z clays (kaolinite, smectite, and muscovite) dominate the lower part of electrofacies IV in the #1 Braun, 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 refined stratigraphic framework of the Dakota Formation is obtained using combined wireline-log, core, cuttings, and outcrop information. Subsurface mapping of electrofacies and sandstone thickness in the

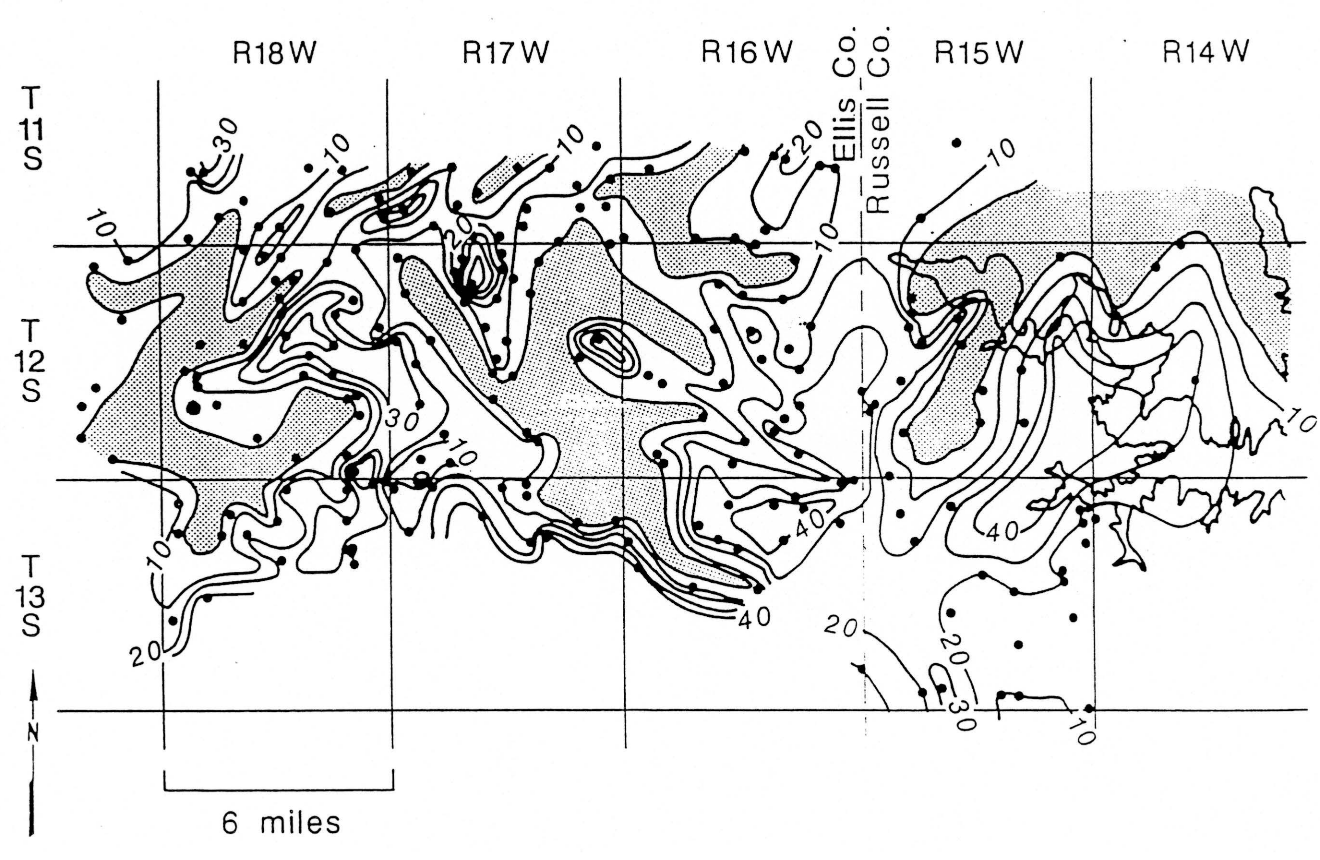

Figure 11. Sandstone isolith map of electrofacies IV.

Dakota is facilitated by this stratigraphic packaging. Electrofacies can be defined by diverse suites of wireline logs, and descriptions core and drill cuttings combined with detailed field description of outcrops. Five electrofacies were defined Within the pilot project area. Sea level fluctuations and local tectonics played an essential role in the processes responsible for Dakota sediment deposition. A laterally correlable electrofacies succession and its inferred depositional significance fits a pattern of region-wide relative sea level fluctuations. Together these data suggest 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 will be 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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