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Depositional Environments and Diagenetic History of the Nolans Limestone (Upper Wolfcampian), Rice County, Kansas

by

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DEPOSITIONAL ENVIRONMENTS AND DIAGENETIC HISTORY OF THE NOLANS LIMESTONE (UPPER WOLFCAMPIAN), RICE COUNTY, KANSAS

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ABSTRACT

The Nolans Limestone is the uppermost formation of the Chase Group (Upper Wolfcampian) in Kansas. In consists of upper and lower carbonate members, the Herington and Krider respectively. Carbonate members are separated by a shale or shaly carbonate member, the Paddock. In Rice County, Kansas, the Nolans occurs only in the subsurface and is, with few exceptions, completely dolomitized. Anhydrite is common throughout but is especially common in the upper portion of the Herington Member. Anhydrite occurs as blue nodules, as isolated fibers within the matrix, as a cement, and as a replacement of skeletal grains. Porosity in the Nolans in Rice County is fairly low and rather uniform throughout.

Deposition of the Nolans Limestone occurred on a stable, broad, flat intercontinental shelf. Intermittent flooding of the shelf produced a cyclic sequence of sediments that may be analogous to the cyclic model described for the Pennsylvanian. Sediments of the Krider were deposited during an advance of the sea thus in an environment of continually deepening water, and may be correlated to the transgressive phase of the Pennsylvanian cyclic model. The Paddock Member is recognized by an increased amount of shale in the rocks. The shale is the result of an increased influx of terrigenous material into the area and is distributed throughout, suggesting relatively good circulation. This member may be correlated to the marine shale of the Pennsylvanian cyclic model. The Herington Member is characterized by environments of deposition in which water was continually shallowing. As water shallowed, circulation became restricted and hypersaline conditions developed resulting in a restricted fauna, establishment of algal mats, and precipitation of large quantities of calcium sulphate. The Herington Member may be correlated to the regressive

phase of the Pennsylvanian cyclic model. Completing the analogy of cyclic deposition, the outside shales of the Pennsylvanian model are represented in this section as the Odell Shale below the Nolans and the varicolored shales of the Wellington Formation above the Nolans.

Diagenesis of the Nolans is dominated by one episode. During this episode nearly all carbonates were dolomitized and large volumes of calcium sulphate were precipitated. This episode occurred while much of the sediment was still unlithified and possibly was the result of hypersaline water, created during deposition of the upper portion of the Herington, reacting with sediments of the Nolans.

A second episode of diagenesis subsequent to the dolomitization phase resulted in dissolution of minor amounts of carbonate material and introduction of silica as a replacement mineral. Dissolution of carbonate resulted in a rather uniform, relatively low porosity throughout the Nolans. Local areas of moldic porosity developed where a higher percentage of skeletal grains accumulated. Silica, as a replacement, often is selective of anhydrite and crinoidal debris.

Economically significant accumulations of natural gas exist in the Nolans in Rice County. These areas are coincident with structurally high areas. High areas are believed to have existed throughout deposition of the Nolans and were the sites of grain-supported sediment accumulation. Development of minor amounts of moldic porosity in these area, along with the structural setting have made modest however economic accumulations of natural gas possible.

TABLE OF CONTENTS

LIST OF FIGURES

APPENDICES

LIST OF PHOTOGRAPHS

Acknowledgements

I must express my appreciation to all those who helped me through this ordeal. A special thanks to Dr. W.J. Ebanks, Jr., and W. Lynn Watney whose assistance throughout this project was invaluable, to Robert Daugherty, Great Bend, Kansas, for providing core samples and data which made this work possible, and to George H. Bruce, Sr., Wichita, Kansas, for providing data regarding production of natural gas in Rice County.

INTRODUCTION

The goal of this study is the interpretation of environments of deposition and diagenetic history of the Nolans Limestone (Upper Wolfcampian) in Rice County, Kansas, including an understanding of the distribution of porosity and accumulation of hydrocarbons in the Nolans.

The Nolans is the uppermost formation of the Chase Group in Kansas (figure 1). It consists of two carbonate members separated by a shale or shaly carbonate member and is everywhere less than fifty feet thick. Directly overlying the Nolans is the Wellington Formation (Lower Leonardian), a thick sequence of varicolored shales, evaporites and carbonates. Directly below the Nolans is the Odell Shale Formation, a relatively thin sequence of red and green siltstones and shales. These formations crop out in eastern Kansas and trend north-south across the state (figure 2).

Large volumes of natural gas have been produced from the Nolans Limestone especially in the Hugoton gas area of southwestern Kansas (figure 1), but little attention has been given to details of the Nolans origin and subsequent diagenesis. Within the last decade the Nolans has become a primary objective of exploratory wells in other parts of Kansas as well, and much more data are now available for study.

Rice County, Kansas, was selected for study because of the availability of subsurface samples, a result of drilling in recent years by several exploration companies, and because of new discoveries of gas there. Rice County lies on the eastern flank of the Central Kansas Uplift adjacent to the Salina and Sedgwick basins (Jewett, 1951; figure 2), in both of which these Permian formations are well developed. Better understanding of the Nolans may lead to more effective exploration for natural resources in other, similar units of the Permian in Kansas.

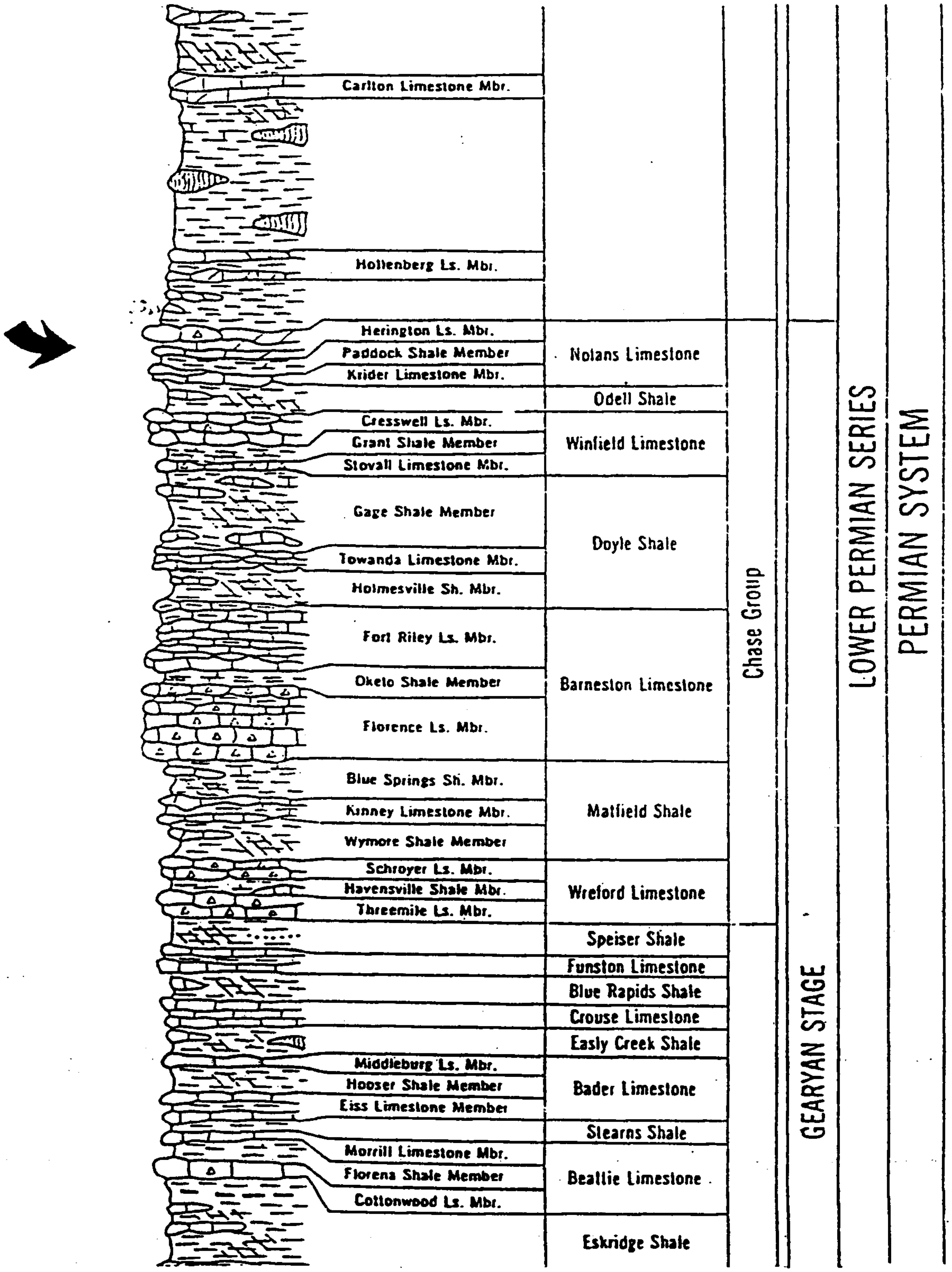


Figure 1: Stratigraphic Column of Lower Permian in Kansas

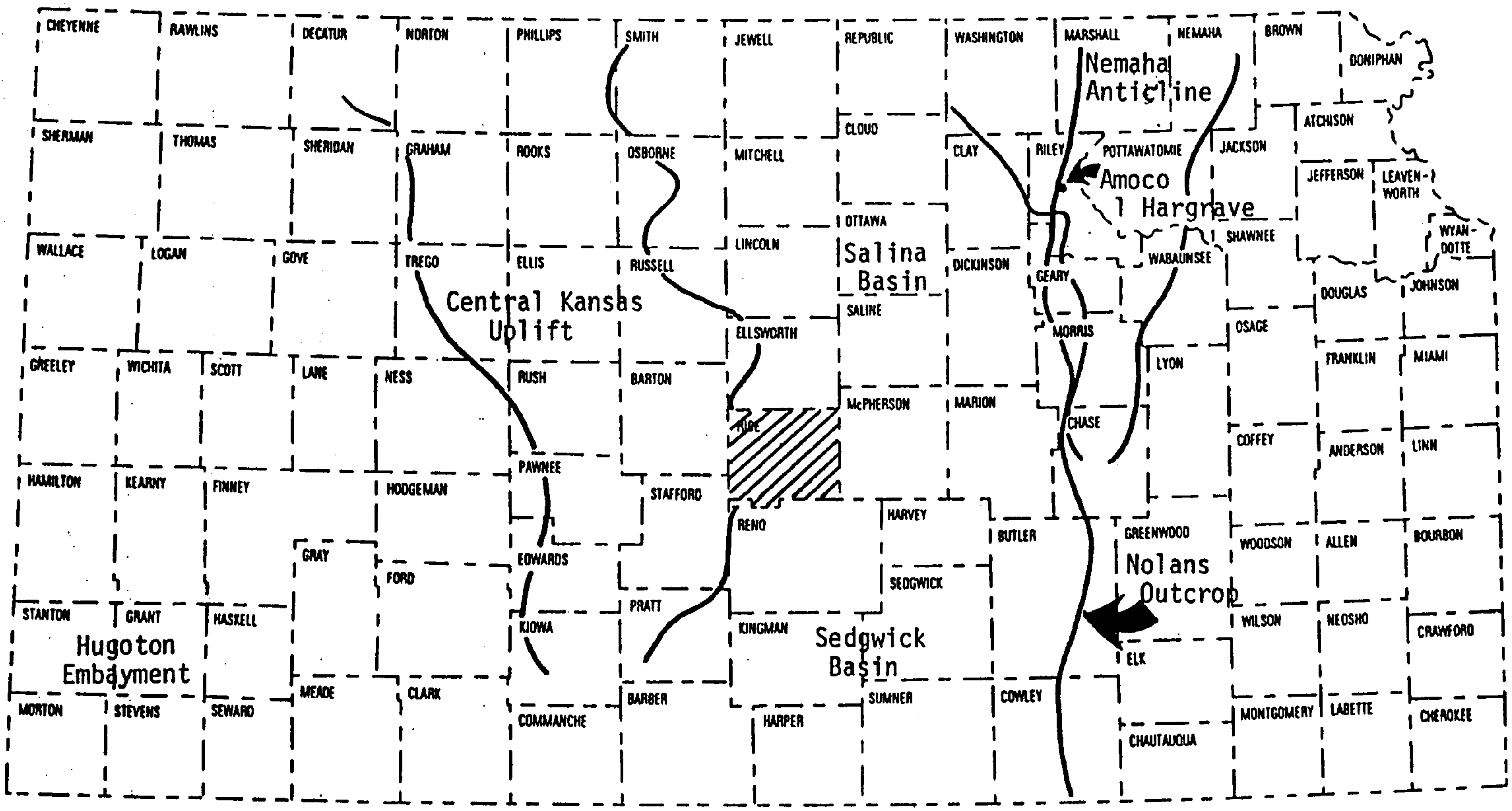


Figure 2: Index Map of Kansas Showing Study Area and Major Structural Features in Kansas (Merriam, 1963)

▨ Study Area

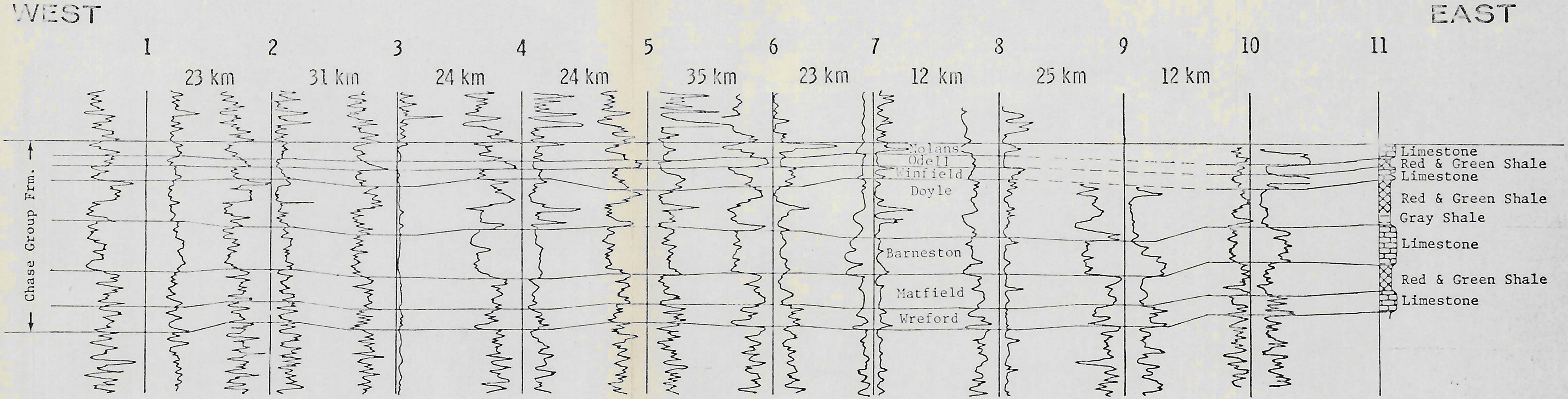
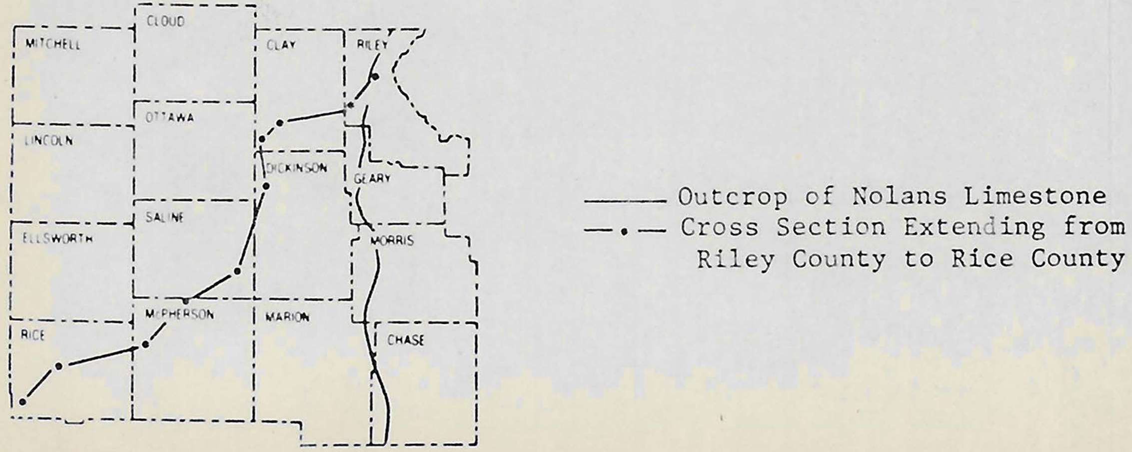


Figure 3: Regional Stratigraphic Cross Section Extending from Outcrop in Riley County, Kansas to Rice County, Kansas



METHODS

Prior to the work on subsurface material from Rice County a surface reconnaissance of the Chase Group was done. Outcrops of all Chase Group formations were examined and samples collected at previously measured sections in Riley County, Kansas (Jewett, 1941). Outcrop samples were correlated with core samples from a well near the outcrop, the Amoco #1 Hargrave, Sec. 32-T7S-R6E (figure 2). Core samples from this well were correlated with a radioactivity log from the same well to determine the log signatures characteristic of each formation. The radioactivity log was then correlated with other, similar logs to develop a network of cross sections extending from Riley County to the study area (figure 3). This network provides a means of more accurate identification of established formations in the subsurface.

In Rice County, the subsurface study was based on core samples from five boreholes, four of which are complete sections of the Nolans Limestone, with the fifth core including only the lower portion of the Nolans. Each core was cut and fresh surfaces were etched for twenty seconds in a solution of 20% HCl. Etched surfaces were examined (Appendix 1) and tested for calcite with Alizarin-Red S (Dickson, 1965). Samples of the cores, which are representative of various facies of the Nolans, were selected and polished. Thin sections were made at intervals representing the various facies throughout each core. Each thin section was tested for calcite and iron with a solution of Alizarin-Red S and potassium ferricyanide (Dickson, 1965). Thin sections were examined and photomicrographs were made. Negative photographs of thin sections were made, using the thin section directly in a photographic enlarger.

Radioactivity logs were used to construct the various maps and cross sections in the study area. Core samples were correlated with logs; then log correlations were made throughout the study area. Stratigraphic and structural cross sections were constructed with well logs (figures 4 & 5) and by using structural and isopachous maps from log data in the whole study area. Distribution of logs in the study area is not uniform. In areas where there is hydrocarbon production, there is a higher density of logs available, as compared to non-productive areas. In order to make the distribution of log data more uniform, selected logs were used in areas of more dense drilling. In this study, the classifications of environments of deposition by Wilson (1975) and carbonate rock classifications of Dunham (1962) are used.

Two maps of facies were constructed, a map of the lower Nolans, including the Krider and Paddock members, and of the upper Nolans, including the Herington Member. These maps portray the percentage, in each interval, of grain-supported carbonates versus mud-supported carbonates plus shale. Core samples are the basis for these maps; moreover they are the only useable rock samples available. Boreholes cutting samples from the Nolans Limestone are not common and, when available, sample collection intervals are too large to allow accurate facies definition. The extensive recrystallization and dolomitization of the Nolans also inhibits recognition of facies in cutting samples.

Data obtained from logs were used to construct the facies maps. Cross-plotting of gamma ray logs with neutron logs shows a separation of mud-supported and grain-supported rocks (figure 6). The hypothesis is that the mud-supported rocks, by virtue of their environments of deposition, will contain a greater concentration of radioactive materials than grain-supported rocks, and this difference is evident on gamma ray and neutron log cross-plots and in the signature response of the same logs

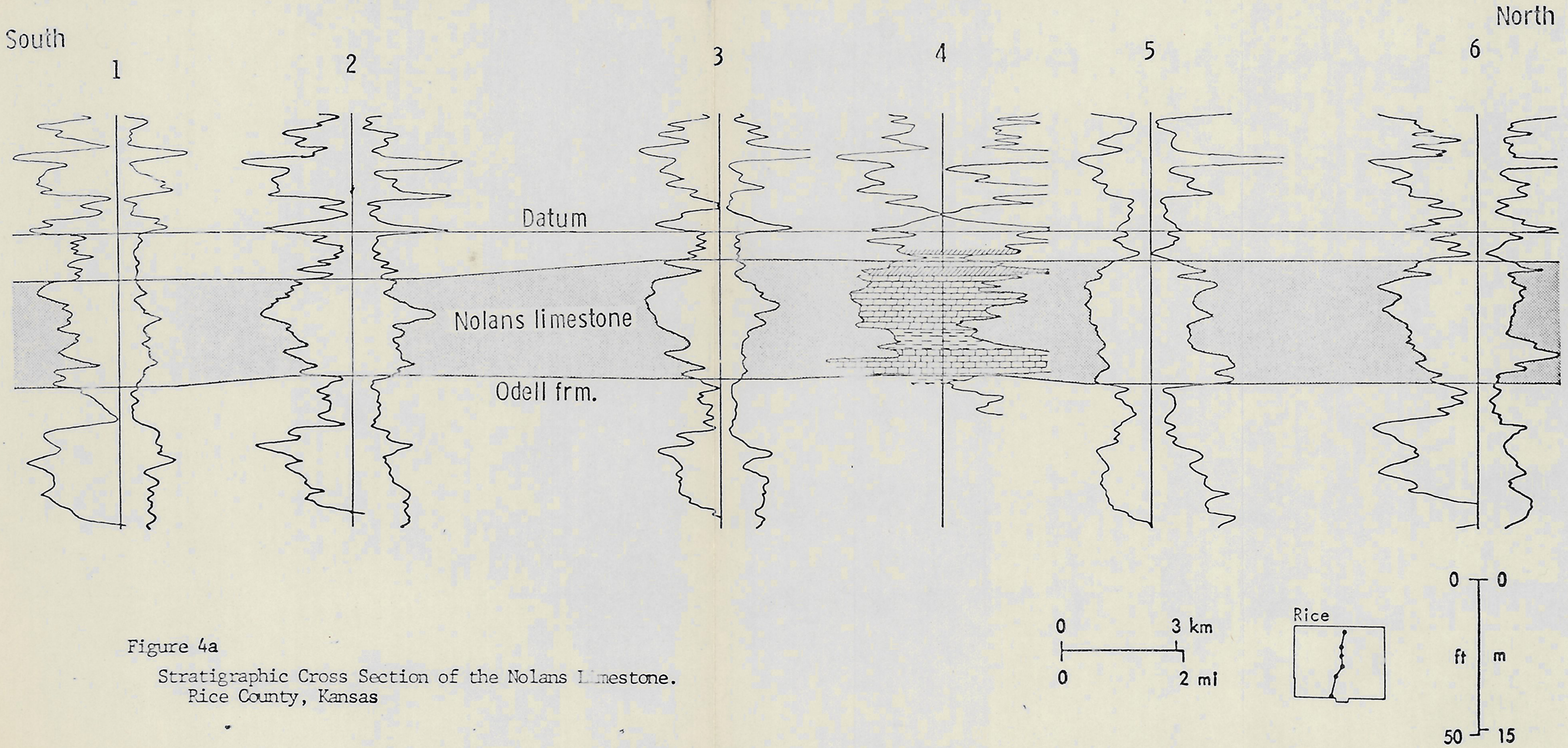


Figure 4a

Stratigraphic Cross Section of the Nolans Limestone.
Rice County, Kansas

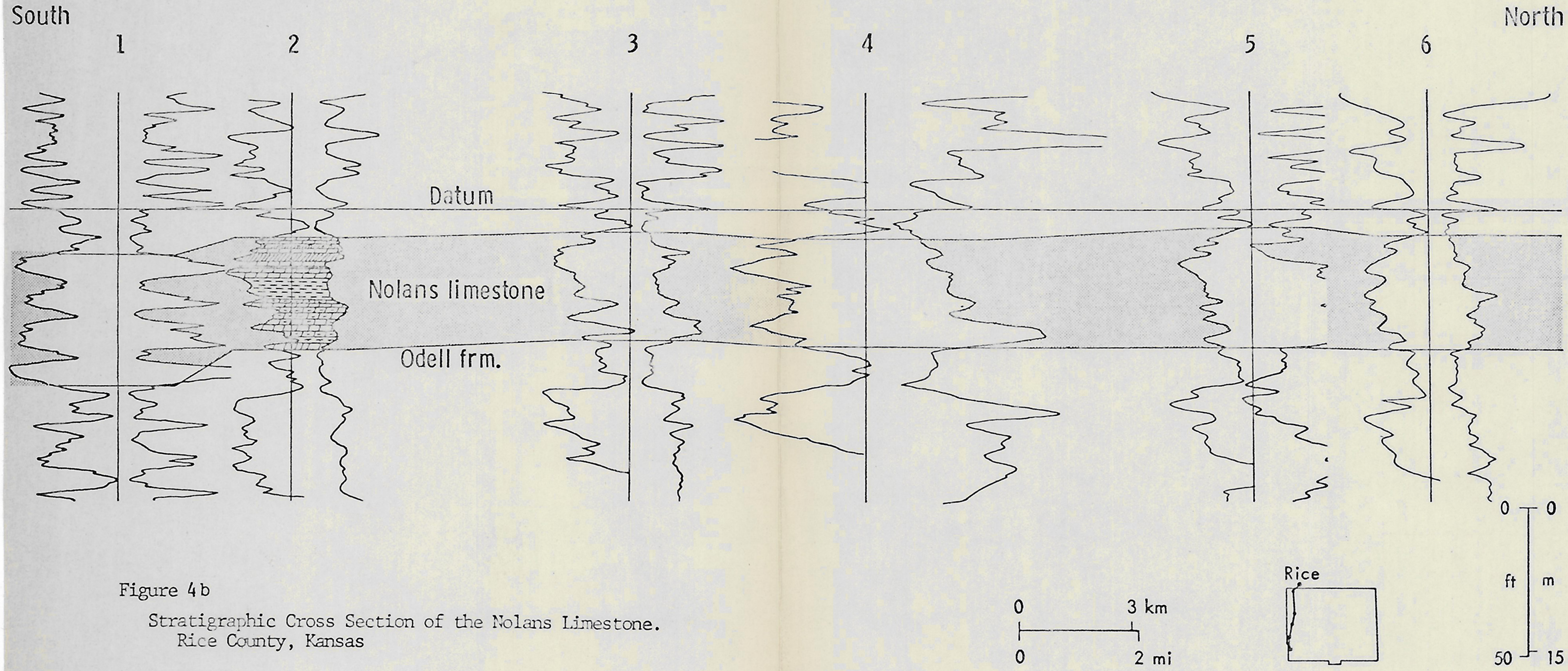


Figure 4b

Stratigraphic Cross Section of the Nolans Limestone.
Rice County, Kansas

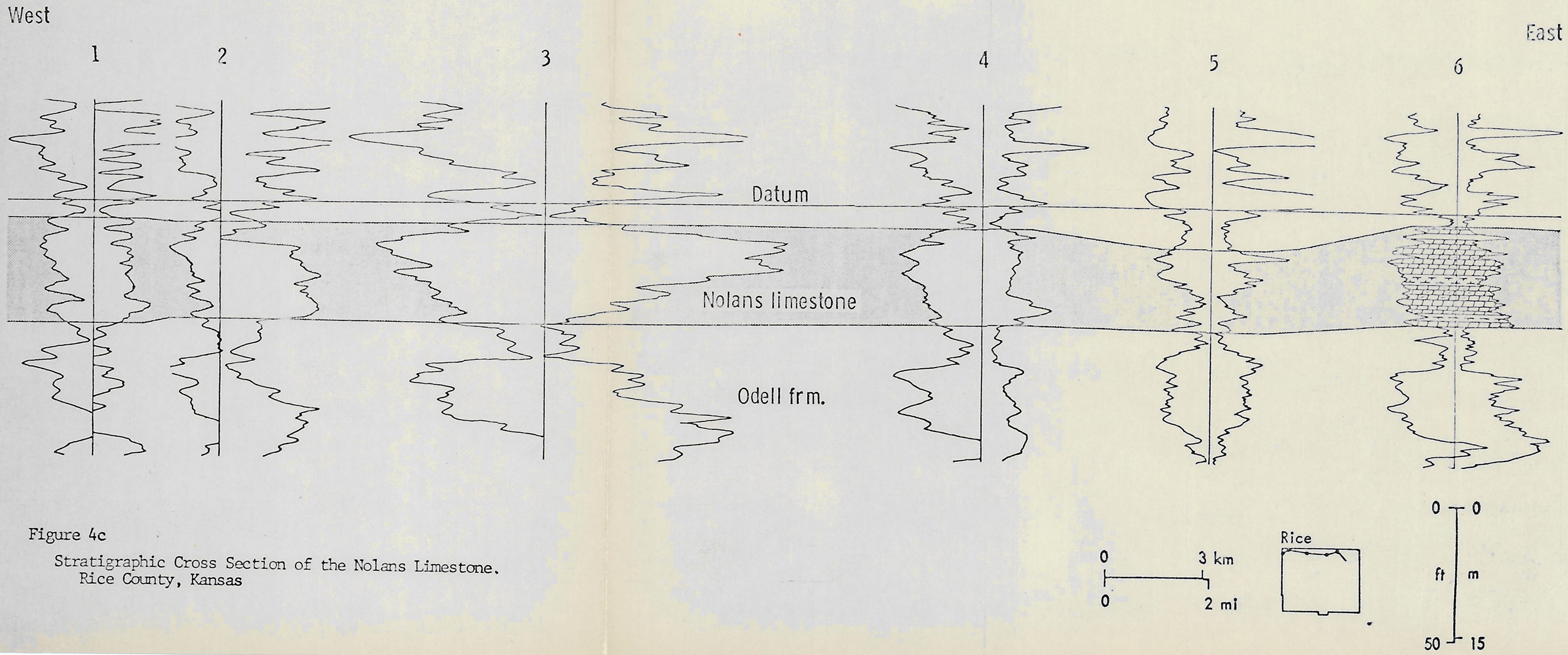
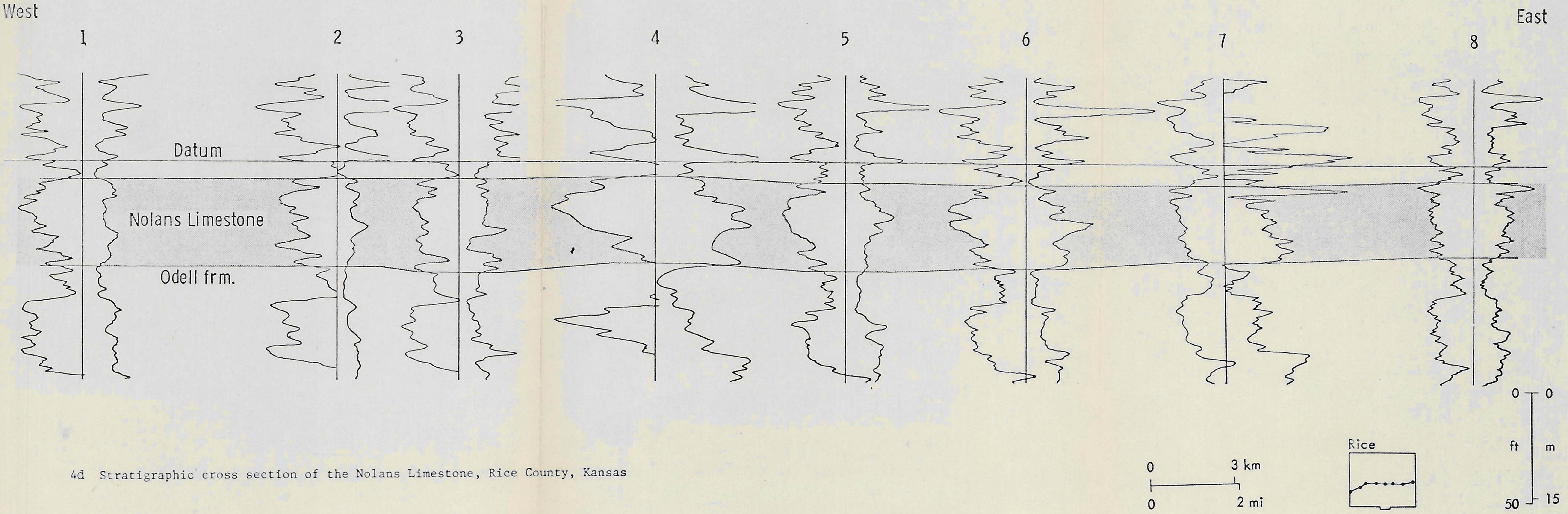


Figure 4c

Stratigraphic Cross Section of the Nolans Limestone.
Rice County, Kansas



4d Stratigraphic cross section of the Nolans Limestone, Rice County, Kansas

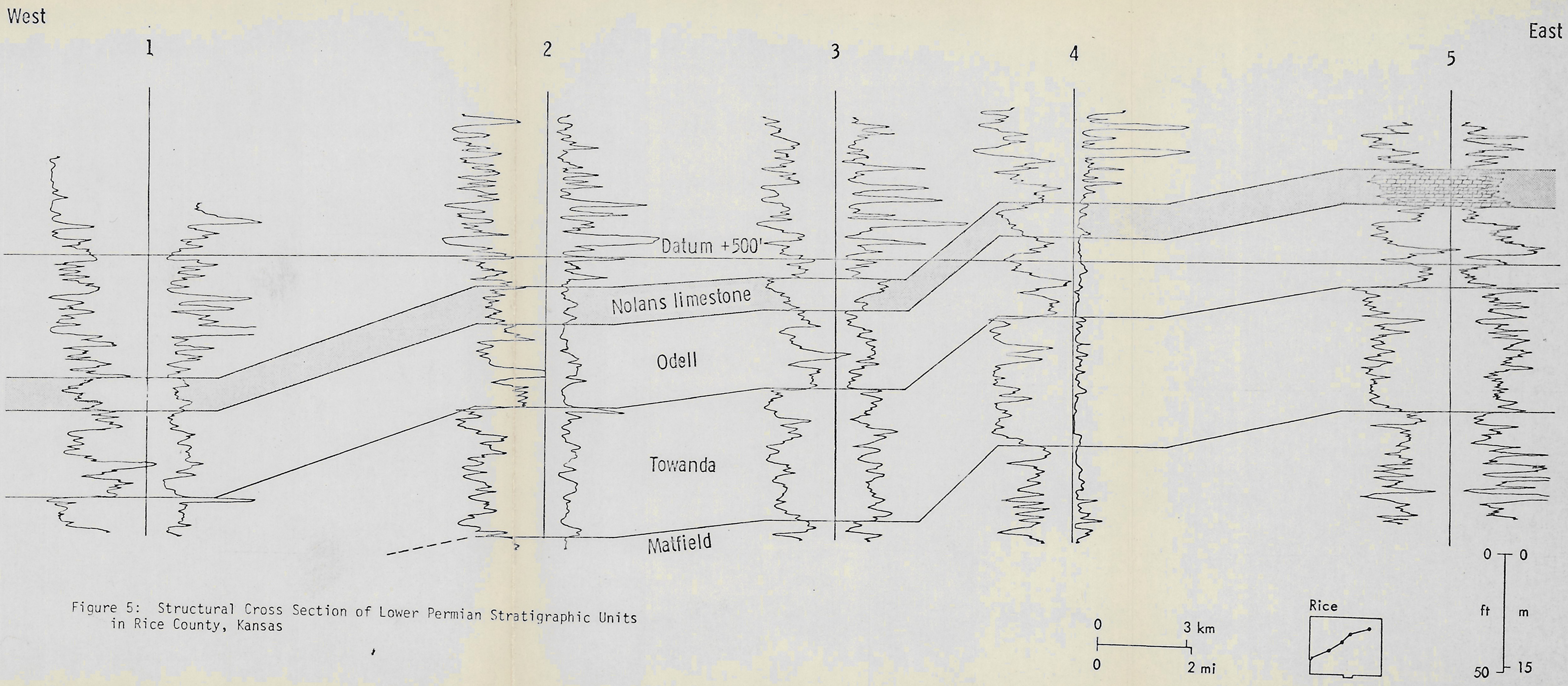


Figure 5: Structural Cross Section of Lower Permian Stratigraphic Units in Rice County, Kansas

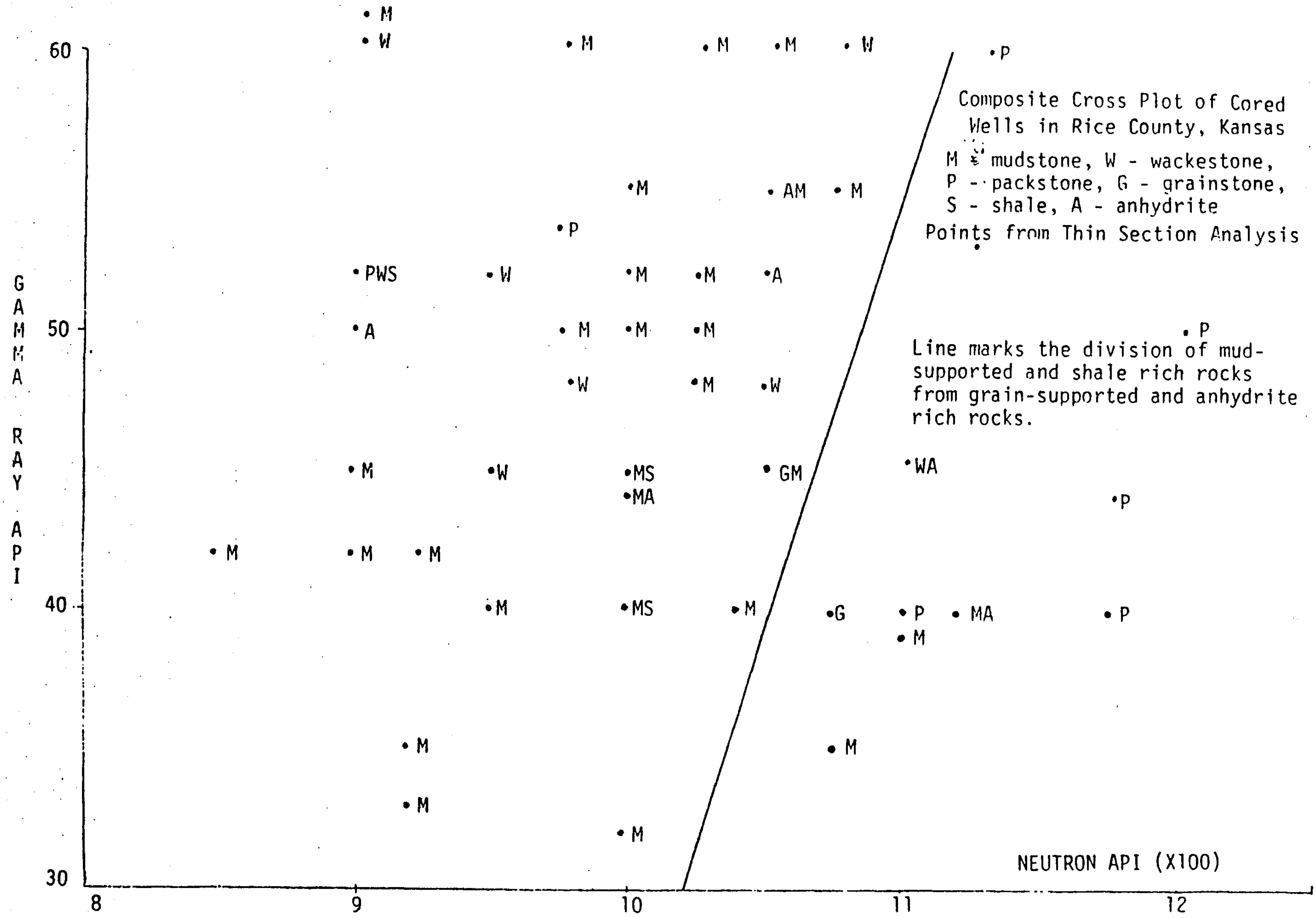


Figure 6: Gamma Ray and Neutron Log Cross Plot of Cored Wells in Rice County, Kansas

(figure 6). Low porosity rocks, such as those characteristic of the Nolans, are particularly well suited to this analysis because the effects of fluids are at a minimal minimum; so logs will closely represent the rock types present (Doveton, unpublished; McFadzean, 1973; Watney, 1978). Eight samples representing both the mud-supported and grain-supported rocks were examined. Percentage of insoluble residue and bulk mineralogy of these samples were determined (Appendix 2). Samples from the same parts of cores were tested for insoluble components using both hydrochloric and acetic acids. Results from both tests were similar, and showed that the mud-supported rocks contain a greater amount of insoluble material. It is assumed that higher radioactivity will be associated with greater amounts of fine terrigeneous material, as indicated by observations of log responses of shales within and adjacent to the Nolans. This assumption allows distinguishing rocks deposited in low energy environments of deposition (mud-supported and shales) from those deposited in high energy environments of deposition (grain-supported rocks), on the basis of gamma ray and neutron log cross-plots and log signature responses. In addition to gamma ray and neutron logs, resistivity, sonic, and density logs were used to aid discrimination of anhydrite-rich intervals. Gamma ray and neutron log cross-plots have been used to define major facies (Watney, 1978), but application of this technique to more specific definition of facies is not well documented. Neither can facies interpretation be done on the basis of log signatures alone, independent of lithologic control. A good understanding of a particular lithology must be available before this method of assignment of facies can be used.

Gas production data and field hisotry data were obtained from records at the Kansas Geological Survey and by consultation with representatives of oil and gas producing companies that are active in the study area.

REGIONAL GEOLOGY

The area of present-day Kansas was part of a stable, flat, broad, intracontinental shelf, intermittently flooded by epeiric seas throughout the Late Paleozoic. In these seas, sediments were deposited in extensive but relatively thin layers. These sediments later became what are now the rocks of the upper Paleozoic section in Kansas. A vertical repetition of distinctive lithologies (cyclothems) is recognized in this section and is the result of numerous trangressions and regressions of the epeiric seas. This style of deposition is characterized by a relatively thin transgressive limestone followed by a marine "core" shale, then a relatively thick regressive limestone. Completing this cyclic model are "outside" shales and sands indicative of maximum regression. This cyclic model is well described by Irwin (1965) and Heckel (1980).

During the Early Permian, several structural features were important in affecting patterns of sedimentation. These features included the Nemaha Anticline, the Central Kansas Uplift, the Hugoton Embayment, the Apishapa and Las Animas Arches and the Central Kansas Permian Basin (figure 7). The Las Animas and Apishapa Arches were the western boundaries of the Central Kansas Basin, the Nemaha Anticline was the eastern boundary. The southern boundary was in Oklahoma and included the Arbuckle and Wichita positive elements. From these boundary areas were shed minor amounts of detritus; influx if detritus reached a maximum during deposition of the Paddock Member.

Lithofacies of the Early Permian are dominated by carbonates and shales in Kansas and in much of the Midcontinent region. Coarser terrigeneous clastics are found only immediately adjacent to major source areas, especially in the west (Mamper, 1963; Mudge 1967; Silver, 1969; figure 8a).

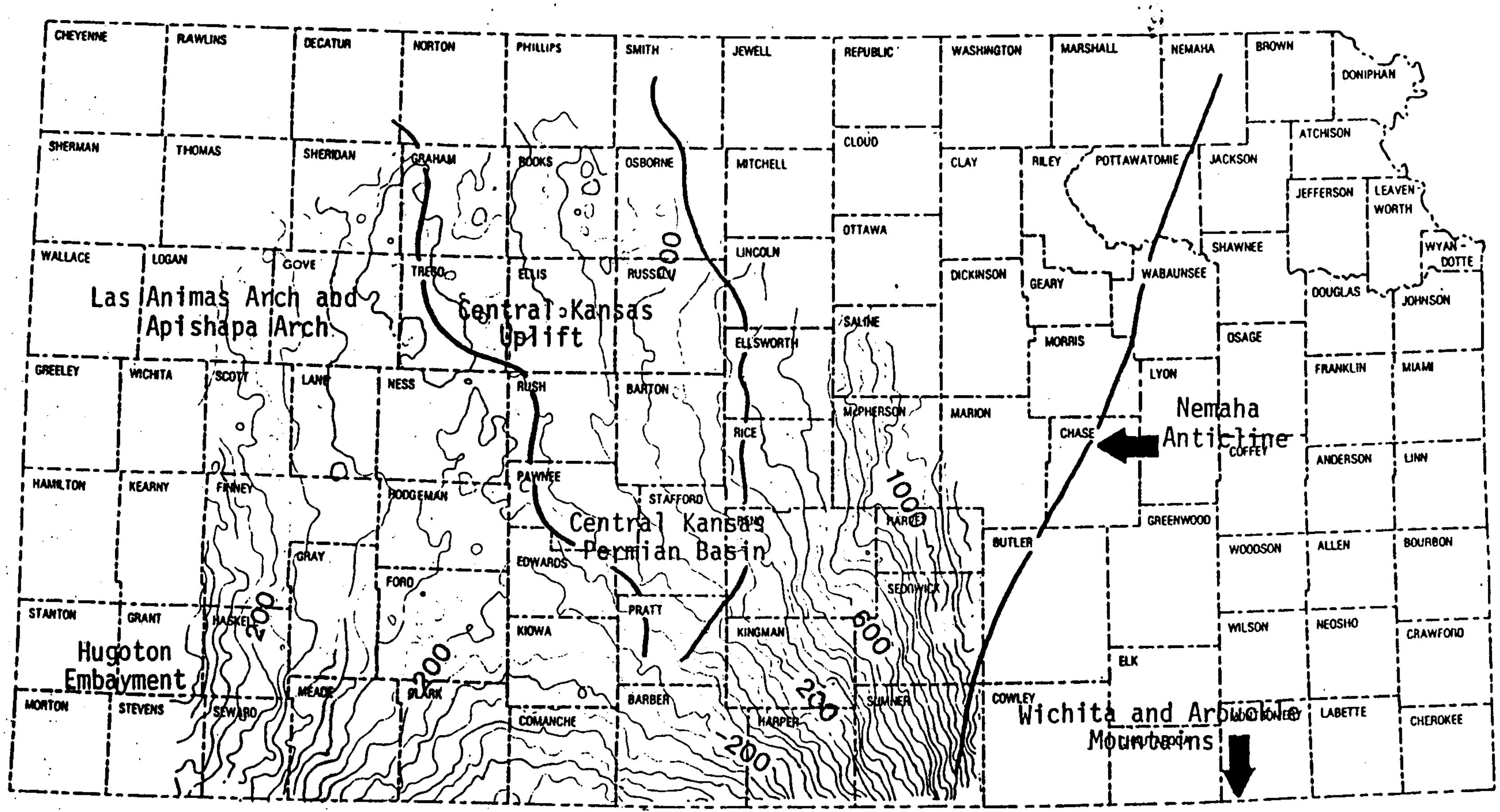


Figure 7: Structural Contour Map, Top Chase Group (Nolans LM.) in Central and Western Kansas (Watney and Paul, 1980) and Prominent Structural Features of the Lower Permian (Merrian, 1963)

Contour Interval 50 Feet

The Early Permian was characterized by broad, low-relief topographic and bathymetric features. This period marks the end of an episode of deformation in Kansas that began in Early Mississippian (Lee, 1956). The amount and size of terrigeneous clastics delivered to the Central Kansas Basin declined, and deposition of carbonates was widespread (Momper, 1963; Mudge, 1967). At the end of the Wolfcamp, the climate had begun to change and was becoming more arid (Mudge, 1967). This change in climate influenced uppermost Wolfcampian sediments, so that evaporites were precipitated and carbonates often were dolomitized (Momper, 1963; Mudge, 1967). The Nolans Limestone was deposited during this climatic transition to arid conditions and is the last extensive, carbonate-dominated formation of Permian age in Kansas. Most carbonates of the Nolans are completely dolomitized and contain an abundance of anhydrite. The reflects the establishment of arid climatic conditions that were characteristic of the Leonardian (Mudge, 1967).

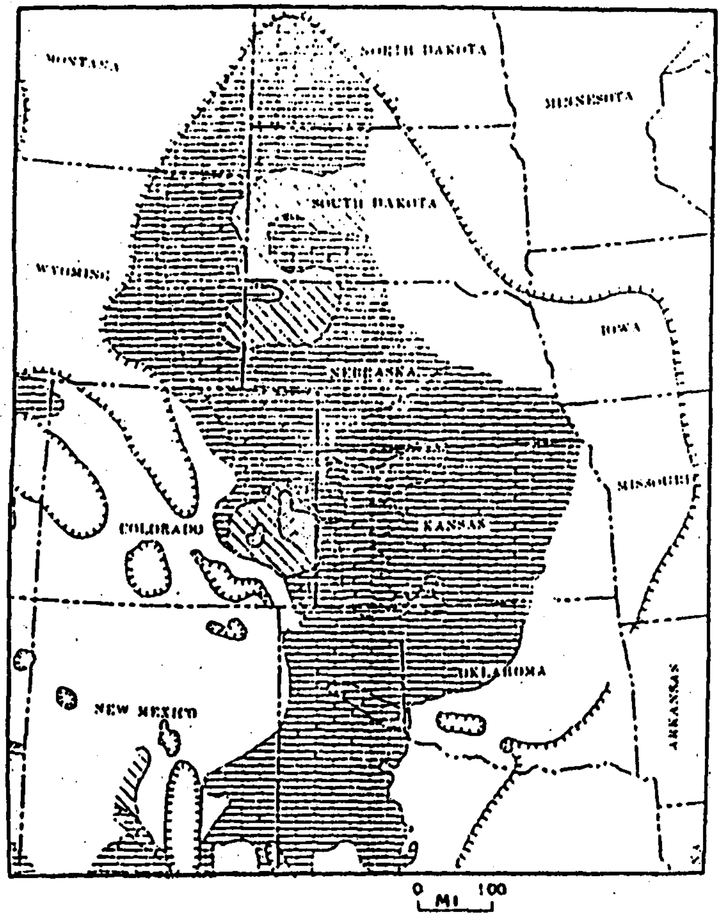


Figure 8: Lithofacies of Midcontinent Region (Mudge, 1967)

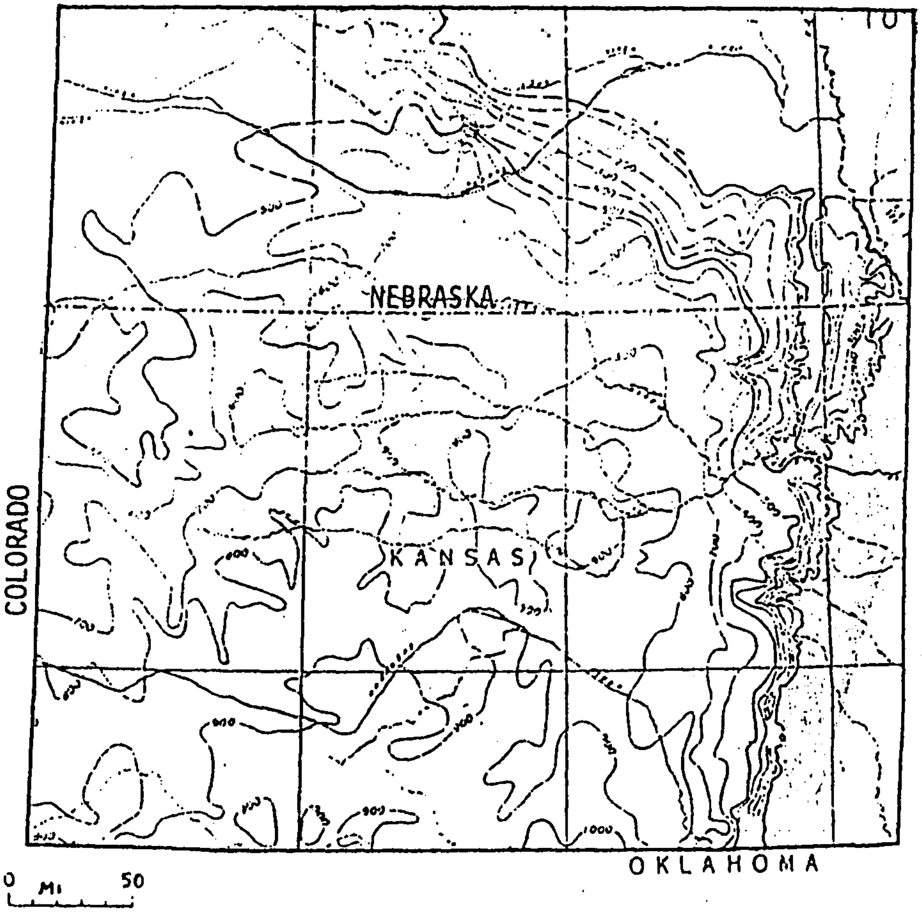
▤ Limestone

▨ Anhydrite and gypsum

Land area

▤ Dolomite

☐ Halite



Isopach of Wolfcampian Rocks (Mudge, 1967)

Contour Interval 100 Feet

SEDIMENTARY PETROLOGY

Where it crops out, the Nolans Limestone is described as having upper and lower limestone members, the Herington and Krider respectively. These members are separated by the Paddock Shale Member. The members are well defined in northern Kansas, but in southern and central Kansas the boundaries between members are indistinct (Zeller, 1968). Throughout the subsurface of Kansas the Nolans Limestone is persistent, ranging in thickness from 9m to 15m.

In Rice County, Kansas, the Nolans Limestone occurs only in the subsurface. The nearest surface exposures are approximately 90km to the east. Surface exposures of the Nolans are dominantly limestone and shale; however, in the subsurface of Rice County the carbonates are, with few exceptions, completely dolomitized. The Paddock Shale Member, in Rice County, is most commonly a fine-grained argillaceous dolomite. Rarely does it occur as a pure shale. Anhydrite is present throughout this formation, but it is especially abundant in the upper portion of the Herington Member. Anhydrite commonly occurs as light blue nodules ranging in size from coarse sand-size to cobbles several centimeters in size (photograph 1). Nodules are aggregates of small needlelike crystals (photograph 2). Anhydrite also occurs as a void filling cement, as a replacement, and as isolated needles within the matrix.

The Krider Limestone Member, the lower carbonate member, is thin, generally less than 7m thick, and consists of alternating pure carbonate beds and argillaceous carbonate beds. Rarely a pure shale layer will occur, usually in the upper half of this member. Carbonates of the upper portion of the Krider are dominantly dolomitized wackestones and mudstones (photograph 3) whereas packstones and wackestones are common in the lower portion of the Krider (photograph 4). These rocks are light to medium brown, becoming gray brown where silt content increases. Beds are dominantly massive, and contain peloids (fecal ?), some burrows, and various amounts of fossil debris. Current-formed structures are rare. Algal-laminated rocks are rare, but may occur in the lowermost portion of the Krider. Portions of this member are dominated by gastropods, others by pelecypods or brachiopods, and bryozoans. Fossils are rarely whole, and most of the fragments are completely recrystallized. Some ostracodes and foraminifera (Milliolid ?) are present; these also are recrystallized and difficult to distinguish from the matrix. Crinoidal debris occurs in minor amounts. The packstones of the lower Krider can be classified according to the types of skeletal grains they contain. The lower portion of the Krider is dominated by gastropods, whereas the upper portion is dominated by fragments of brachiopods and bryozoans (photograph 5). The best preserved samples are from the AEC #1 Test Hole, Sec. 26-T19S-R8W. In these samples, all skeletal grains are Osagia coated. Anhydrite occurs as small, blue, nodules that are often slightly flattened. Nodules that are assoicated with thin beds, deform the bedding such that beds appear to be draped over the nodules (photograph 1). Small amounts of phosphatic bone fragments are present in the Krider. Replacement by silica is not common, but when its occurs, anhydrite and crinoidal debris are aften selectively replaced. Quartz silt is rare, as is pyrite. Porosity is generally low throughout, and is dominated by pinpoint-size pores. Fossil moldic and fracture porosity are rare. All porosity is of secondary origin.

The Paddock Shale Member is the middle member of the Nolans Limestone. It is a gray calcareous shale in part of the study, but, more commonly, it is an argillaceous, fine grained dolomite (photograph 6).

Thickness of this member is approximately 3 to 4m. Bedding ranges from beds of shales to massive beds of argillaceous dolomites containing peloids (fecal ?) with minor amounts of burrows and fossil debris. Gastropods, pelecypods, and ostracodes (?) are present, and when they occur they are often massed together forming thin argillaceous beds. All fossil debris is recrystallized. Anhydrite is least common in this member. It occurs as small blue or gray-white nodules and as a void filling cement. Shales of the Paddock contain very little anhydrite suggesting that the abundance of anhydrite is inversely proportional to the shale content of the rocks. Pyrite is common in this member, especially in the shale units where it occurs as small anhedral crystals. It is also disseminated throughout the shale and carbonate units. Quartz silt is more common in the Paddock, especially where total silt content increases. Porosity throughout the Paddock is low.

The Herington Limestone Member is the upper member of the Nolans Limestone. It is composed of dolomitized mudstones and wackestones, with rare packstones or grainstones, and an abundance of anhydrite. It is the thickest member of the Nolans Limestone, averaging approximately 7 to 8m. The Herington is light to medium brown becoming gray-brown where silt content increases. The lower portion is more argillaceous than the upper portion, especially where it overlies shales of the Paddock Member. Elsewhere, the lower Herington is similar to the upper Krider Limestone Member (photograph 7). Silt content decreases upward through the Herington, but occasional shale partings may exist anywhere within this member. Bedding is massive in the lower Herington, beds are thick, peloid rich (fecal ?), and they contain variable amounts of fragmented skeletal grains (photograph 11). Burrows are rare. Fossils include fragments of pelecypods, gastropods, brachiopods (?), some foraminifera, ostracods, and minor amounts of phosphatic bone fragments. Upward through the section, thick massive bedding is replaced by thin bedding. Algal laminated and rare rippled beds are present in the uppermost portion of the Herington (photograph 1). Phosphatic bone fragments become more common and the amount of skeletal debris decreased in the upper Herington. Intraclasts are rarely present, and often are associated with algal-laminated beds. Anhydrite is most common in this member as compared to the other members of the Nolans. The abundance of anhydrite reaches a maximum in the upper portion of the Herington, where it forms one or more thin, discrete layers. The anhydrite layer is probably the result of consolidation of numerous nodules, not of primary deposition (Maiklem, 1969). The blue anhydrite nodule is the most common form of anhydrite, and the size of the nodules ranges from coarse sand to cobbles several centimeters in size. Anhydrite nodules often are in close proximity to one another and may aggregate forming a single large nodule (photograph 8). Anhydrite nodules are almost exclusively composed of fine needle-like fibers but rarely blocky crystals are present. Anhydrite also occurs as a replacement of skeletal grains and as fracture-and pore-filling cement. Isolated needle-like fibers of anhydrite occasionally occur in the matrix. Where anhydrite nodules occur associated with thin beds, often that bedding is deformed about the nodules (photograph 1). Quartz silt is a minor, but relatively consistent, fraction of the Herington and is especially common near algal-laminated beds. Secondary silica is rare, but, when it does occur, is often selectively replaces anhydrite. Rare occurrences of secondary silica have replaced carbonates. Pyrite is most common in proximity to shale partings and argillaceous units, but it occurs in trace amounts. Porosity throughout the Herington is low. Pinpoint-sized pores are most common, but there are a few fractures and some moldic porosity.

ENVIRONMENTS OF DEPOSITION

The Nolans Limestone section is a carbonate-shale-carbonate sequence, bounded above and below by red and green shales. This vertical sequence suggests cyclic deposition similar to the model presented by Irwin (1965) for epeiric clearwater sedimentation. Cyclic deposition of Pennsylvanian rocks in Kansas is well documented by Watney (1978) and Heckel (1980). The Nolans Limestone is significantly different, however, than the cyclic motifs presented for the Pennsylvanian rocks. Individual facies of the Nolans are less well defined, generally thinner, and contain a relatively greater abundance of evaporitic minerals, dolomite, and less diverse faunal assemblage.

The Krider Limestone Member

Sediments of the Krider Limestone Member were deposited in a normal marine environment in which water continually deepened throughout deposition of this member. Algal-laminated sediments found in the lowermost Krider are indicative of intertidal to supratidal environments of deposition. Packstones and wackestones deposited directly above the algal-laminated units reflect a deepening of water, with deposition occurring on a lower intertidal to subtidal shelf with open-circulation. The lack of any apparent wave-generated cross bedding suggests intertidal zones were of relatively low energy. Extensive burrowing, possibly enhanced by soft sediment compaction as described by Shinn (1980), may also account for the conspicuous lack of cross-bedded units. The packstone facies is best displayed in samples from the AEC Test Hole #1, Sec. 26-T19S-R8W, where sediments were not extensively dolomitized or recrystallized. In these samples the dominating fossil type changes vertically. The lowermost packstones are gastropod-rich, and, upwards through the Krider, samples become dominated by fragments of pelecypods, then by fragments of brachiopods and bryozoans. In all other core samples this sequence is not so clearly displayed, because a thick packstone facies was not deposited everywhere. Circulation patterns influenced sedimentation; high energy currents washed fine materials depositing them in areas of lower energy. Deposition of grain-supported sediments, indicative of high energy environments, was primarily confined to bathymetric highs; highs were the result of subtle structures existing prior to Krider deposition. Mudstones and wackestones were deposited adjacent to the highs and in areas of poor water circulation. These factors are responsible for the variation of grain-supported rock percentages observed on the facies map of the study area (figure 9). Figure 8 shows a wide distribution of areas having a relatively high percentage of grain-supported rocks indicative of relatively unrestricted circulation across this area throughout much of this period. The lack of a more extensive distribution of grain-supported rocks may not necessarily be the result of sedimentary processes. Extensive dolomitization and recrystallization has destroyed much of the original skeletal debris, which may have caused grains to have become indistinct from the matrix and cements (photograph 9).

This sequence of deposition is interpreted to represent a transgression of the sea, that is, earliest Krider beds represent near shore environments of deposition and mid-to-upper Krider beds were deposited in increasingly deepening water. Bathymetric highs existed throughout deposition of the Krider, and these areas remained above or near wave base. Skeletal grains accumulated on these highs, and currents washed fine material to areas of lower energy. Elsewhere in the study area, environments of deposition went below wave base and, in these areas of lower energy, fine grained carbonates and shales accumulated.

Shale beds present in some core samples and indicated on some radioactivity logs represent low energy environments of deposition. These areas received relatively greater amounts of terrigeneous silt than did areas of higher energy. Silt was introduced to the area primarily by rivers, and shale accumulations may represent proximity to distal deltas. There is little question, however, that throughout the deposition of the Krider Limestone, the sea was continually deepening. Vertical changes in dominant skeletal fragments support this idea. The lower Krider is dominated by gastropods, with some algal laminated beds. These are generally associated with very shallow water environments of deposition. The mid-to-upper Krider is dominated by pelecypods, then brachiopods and bryozoa with some crinoidal fragments. These organisms suggest the existance of water deeper than that indicated to exist during deposition of the lower Krider. The deeper water environment probably was normal marine with unrestricted circulation of clear water. The shales of the Krider, as those of the Paddock Shale Member, may only represent a shifting of distal deltas or encroachment of those deltas during period of increased silt influx. The contact between the Krider Limestone and the Paddock Shale is gradational with shale gradually becoming a greater proportion of the rocks.

Paddock Shale Member

The Paddock Shale Member was deposited on a shelf having open circulation, but was receiving large amounts of terrigenous silt. The silt was distributed throughout the area and formed localized thick (2m) shale beds, or it was incorporated in carbonate beds. Circulation of water was both widespread and effective in distributing silt throughout the area. The abundance of silt was probably the main modifier of the environment by inhibiting growth of carbonate producing organisms; however, the presence of carbonates throughout the Paddock indicates that carbonate production was never completely halted. During deposition of the Paddock, water depth was probably as deep as any during deposition of the Krider; there is no evidence that the advance of the sea ended before the beginning of this period. The wide distribution of shale and argillaceous carbonates indicate an effective circulation pattern that would accompany deepening of water. Skeletal debris of the Paddock carbonates also do not indicate a shallowing of water. Towards the gradational contact between the Paddock Shale and the Herington Limestone Members, the abundance of shale declines and relatively shale-free carbonates were deposited.

Herington Limestone Member

The Herington Limestone Member is composed mainly of mud-supported rocks with few grain-supported rocks as compared to the Krider (figure 10). Argillaceous mudstones and wackestones of the lowermost Herington were deposited directly over the shales of the Paddock, reflecting declining importance of silt in lower Herington sediments. Relatively silt-free mudstones and wackestones were deposited above carbonates of the Paddock Member.

An overall regression had begun during deposition of the Paddock, and by the time the lower beds of the Herington were being deposited water had shallowed significantly. Shoals which generally coincided with those which existed during the Krider developed (figures 9 & 10). Shoals developed during deposition of the Herington are an expression

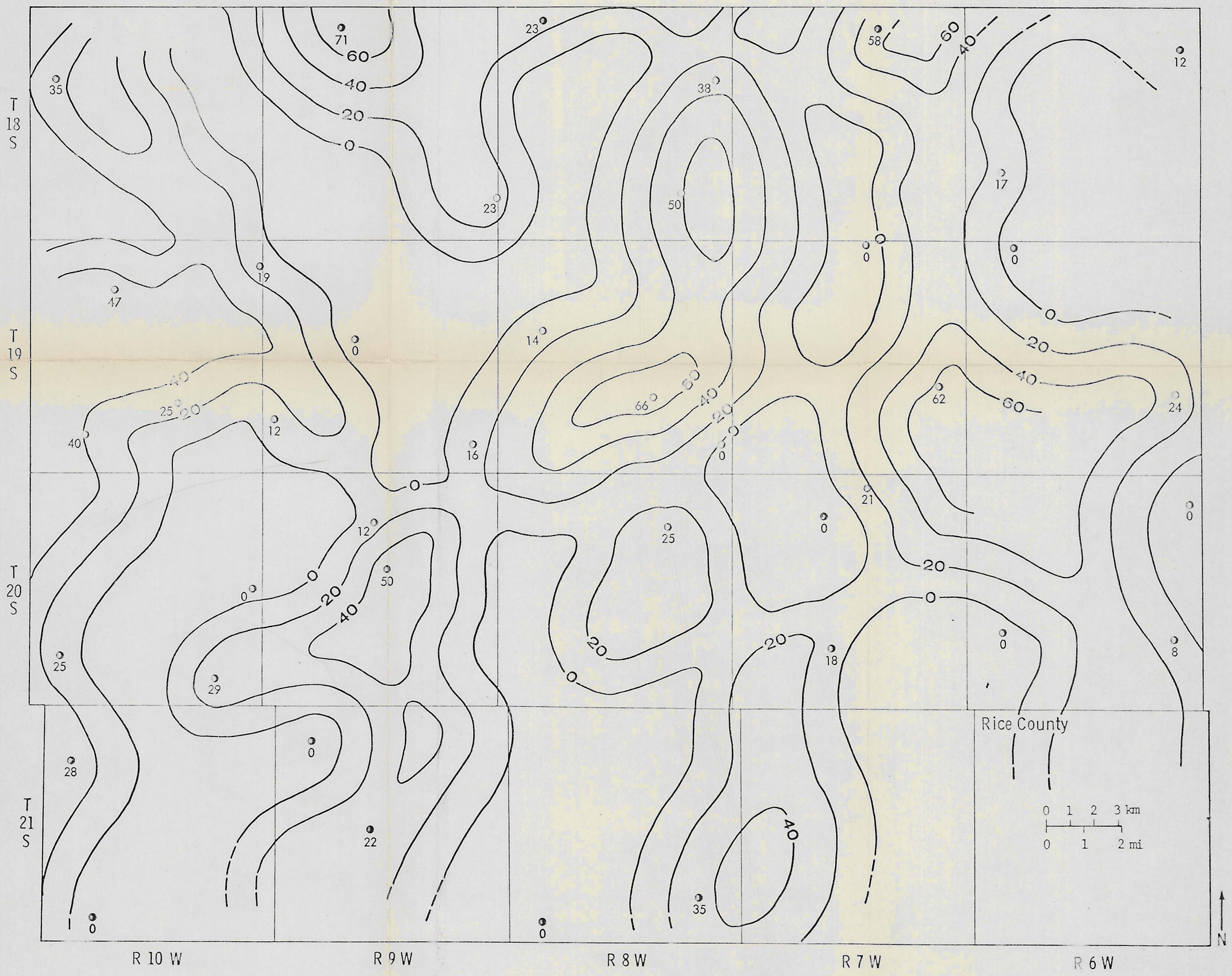


Figure 9

Facies Map of Lower Portion of the Nolans Limestone. Contours portray percentage of Mud-supported Carbonates versus Grain-supported Carbonates. CI=20'

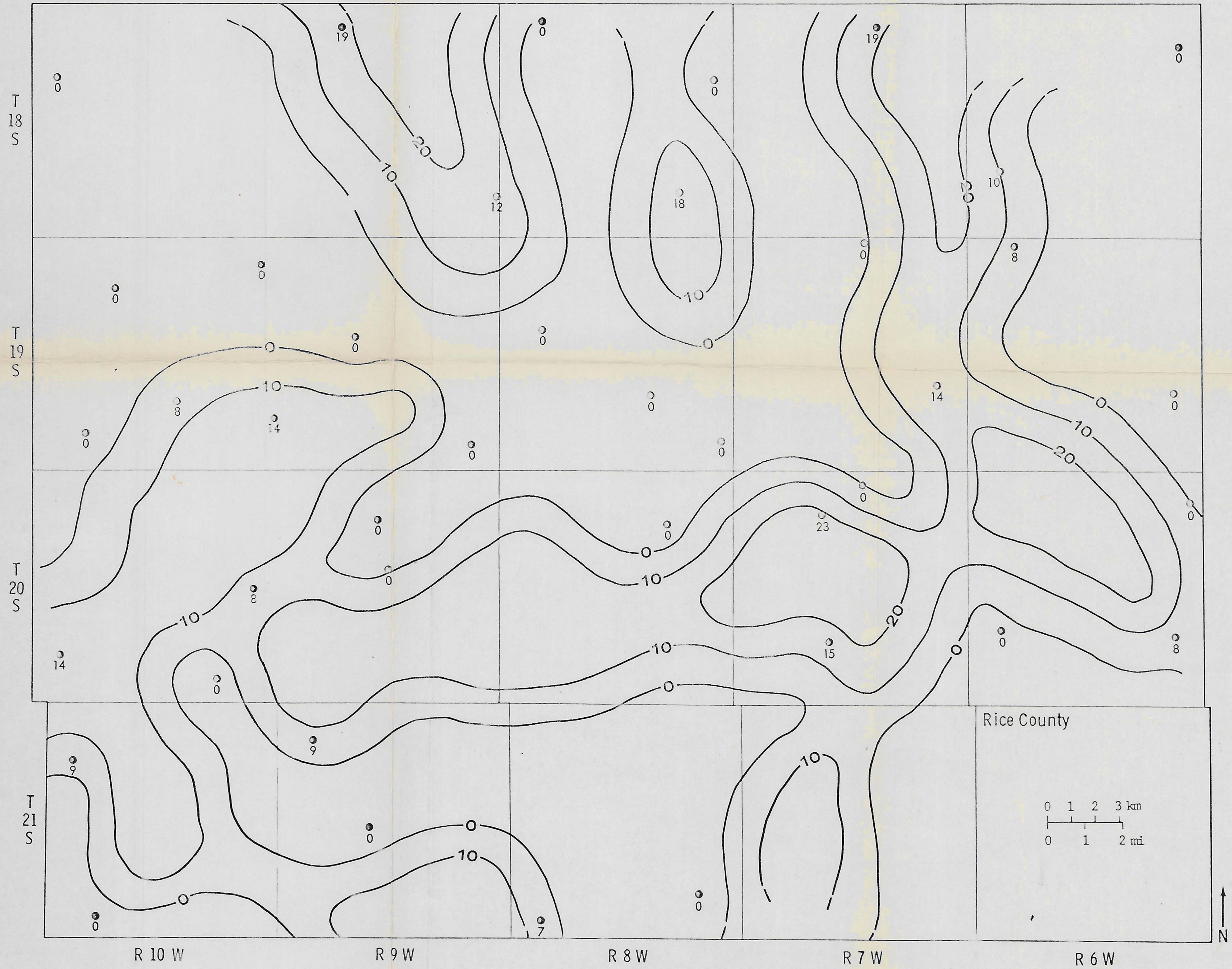


Figure 10

Facies Map of Upper Portion of the Nolans Limestone. Contours portray percentage of Mud-supported Carbonates versus Grain-supported Carbonates. CI=10' of bathymetric highs which caused shoals to develop early during deposition of the Krider. The shoals were sites for accumulation of grains, both skeletal and non-skeletal, and indicate that at least some of the shoals were in very high energy environments.

Beds in much of the lower portion of the Herington are generally thick and homogeneous. Peloids are abundant, with few burrows and some gastropod and pelecypod fragments. Bioturbation is the main cause of the homogeneity of the lower Herington beds. As the sea continued to shallow, thinner bedding became more common and these were interbedded with thin (several cm) algal-laminated beds. The uppermost beds of the Herington are composed of algal-laminated rocks (photograph 1) with rare intraclasts; a few zones are rippled. This is indicative of intertidal to supratidal environments of deposition reflecting a nearly complete withdrawal of the sea. A great abundance of secondary anhydrite is present in the upper Herington and all of the carbonates are dolomitized. The presence of anhydrite and dolomite, of extensive algal-laminated rocks, and lack of a diverse faunal assemblage all indicate the existence of a stressful, hypersaline environment. This environment was present on a shelf having restricted circulation and reflects the establishment of arid conditions that were characteristic of the Middle Permian.

Environments of deposition of the upper Herington were probably similar to those which exist on the modern Trucial Coast in the Persian Gulf (Curtis, 1963; Kinsman, 1966; Butler, 1969; Bush, 1973). A cross section of the Trucial Coast includes a sabkha with a prograding shore line, restricted lagoons and offshore islands, and highly saline waters of the Persian Gulf. The sabkha is a flat plain only slightly above sea level and is composed of sediments derived from the gulf and lagoons.

Extreme temperatures and intense evaporation causes water within these sediments to become hypersaline, resulting in the precipitation of aragonite and calcium sulphate, and the conversion of limestone to dolomite and, rarely, magnesite. Water is replenished to the sabkha primarily by flooding from the gulf or lagoons. Other, similar, depositional environments probably existed during deposition of Permian shelf sediments in New Mexico and Texas (Kerr, 1963) and on Laguna Madre of the modern coast of south Texas (Masson, 1975).

Deposition of sediments in the Herington Limestone prograded from the northeast to the southwest. It is likely that the entire area was filled more or less uniformly; however, a somewhat thinner pile of sediment accumulated on structural highs. Core samples from the Aspen 1 Hodgson in the northeast portion of the study area display a thicker vertical sequence of rocks deposited in intertidal and supratidal environments, suggesting that these environments existed there longer than in other areas. Throughout the study area however, the thickness of rocks from these environments of deposition is fairly uniform. In each core a layer of anhydrite is present, always within the upper few feet of the Herington. This also suggests the existence of rather uniform environments of deposition throughout the study area.

The presence of stable conditions throughout the study area is displayed by the subtle thickness changes shown in figure 11. Variations in thickness are attributed mainly to pre-existing structures. Locally, high areas were the sites of grain accumulations because of colonization by organisms. The predominance of grain-supported sediments at these sites was enhanced by winnowing of fine-grained sediments from the highs. The general trends of structurally high and low areas (figure 12) in the

Nolans are shared with other formations, above to the Stone Corral and below to the Pennsylvanian (Merriam, 1955).

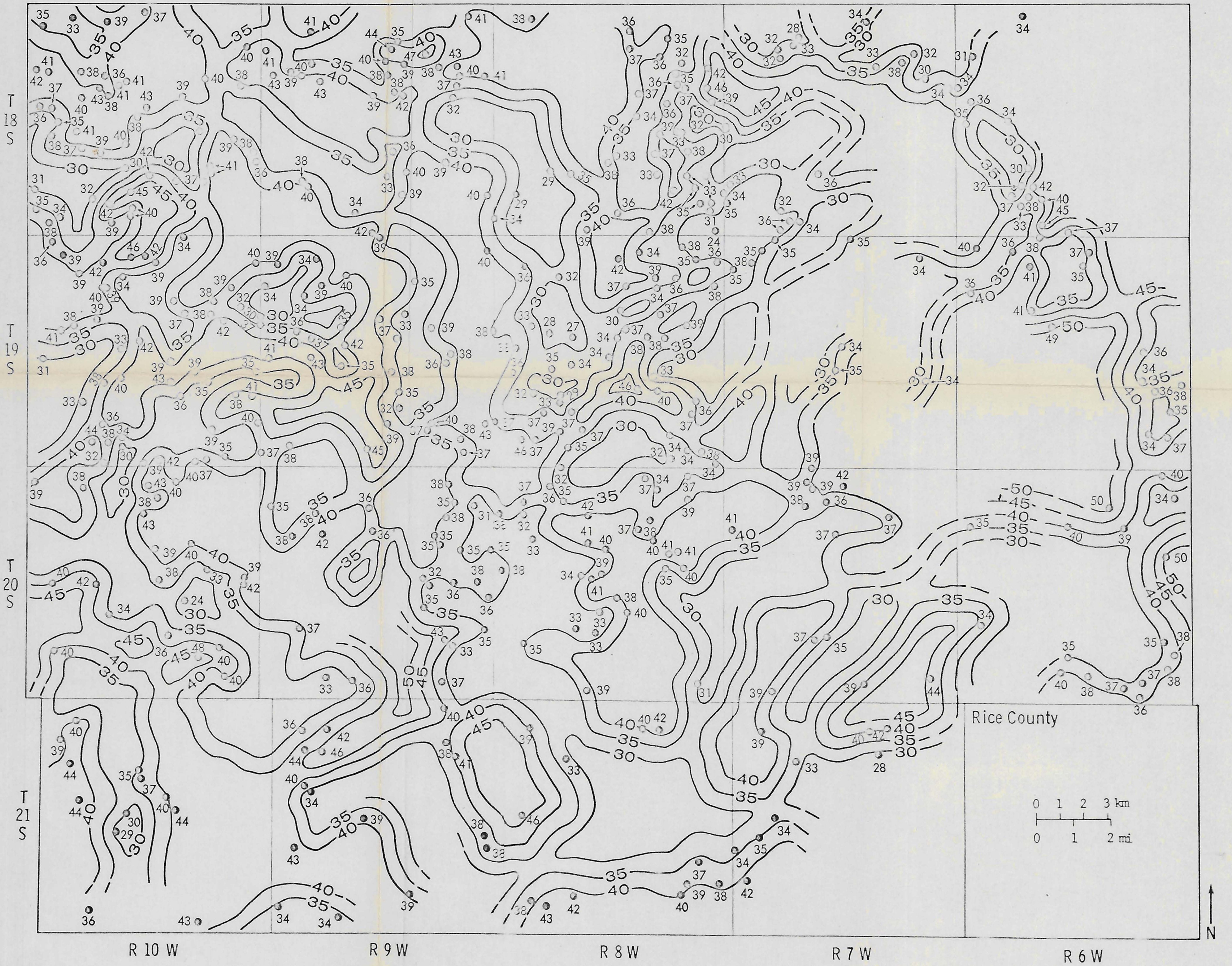


Figure 11

Isopach Map of the Nolans Limestone CI=5'

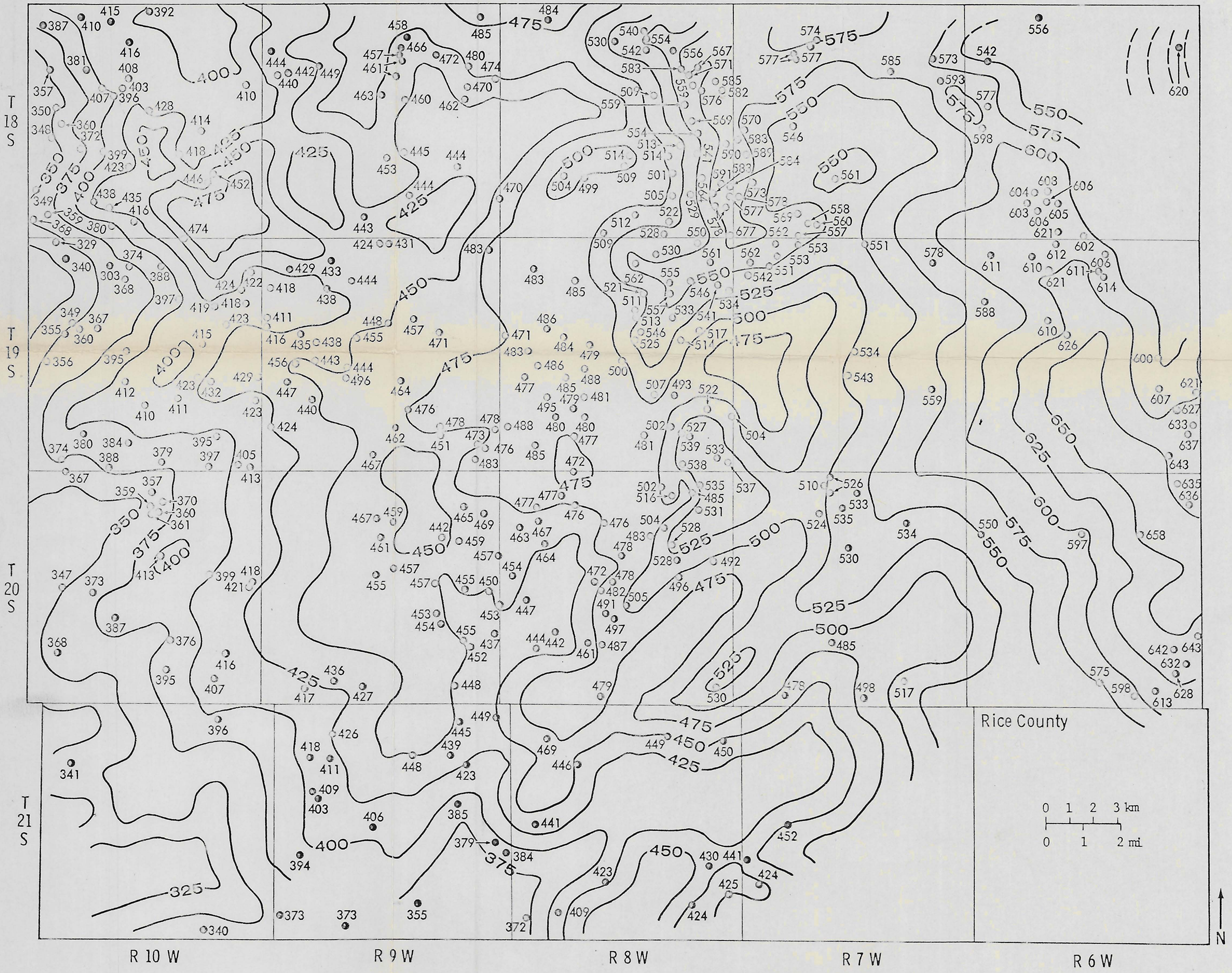


Figure 12

Structural Map of Top of Nolans Limestone CI=25'

DIAGENESIS

The Nolans Limestone has been subjected to two episodes of diagenesis. The first occurred prior to lithofication and resulted in near complete dolomitization of the carbonates and precipitation of large quantites of calcium sulphate. The second episode involved dissolution of minor amounts of carbonate and the introduction of silica as a replacement mineral.

Dolomitization and Calcium Sulphate Precipitation

Dolomitization of nearly all carbonates and precipitation of large quantities of calcium sulphate occurred penecontemporaneous with deposition of the Nolans. Similar diagenetic changes have been reported from the Trucial Coast (Kinsman, 1966; Shearman, 1966; Butler, 1969; Bush, 1973) where carbonate sediments are dolomitized by water; depleted in calcium sulphate because of precipitation of gypsum and anhydrite. However, the sabkha model of diagenesis on the Trucial Coast does not adequately explain the diagenetic features that characterize the Nolans Limestone in that the Nolans displays no evidence of subaerial exposure.

The Krider Member of the Nolans Limestone is mainly dolomite. Anhydrite is present throughout this member but in lesser quantities than in the upper Nolans. This episode of diagenesis apparently took place after deposition of the Paddock and Krider Members. Dolomitization is incomplete in the Krider especially where it directly underlies thick (1m) shales of the Paddock. Precipitation of anhydrite affected bedding in the Krider little.

The Paddock Member of the Nolans Limestone also was affected by this episode of diagenesis. All carbonates of the Paddock were dolomitized and modest amounts of calcium sulphate were precipitated. The shales of this member show little evidence of this episode of diagenesis except for rare occurrances of small, isolated anhydrite nodules.

The Herington Member of the Nolans Limestone was completely dolomitized during this episode of diagenesis and a large quantity of calcium sulphate was deposited. Beds in the upper portion of the Herington are "draped" about anhydrite nodules suggesting that calcium sulphate precipitated, in unlithified sediments. Brines responsible for this episode of diagenesis were presumably formed during deposition of the overlying Herington sediments.

Silica Replacement and Dissolution of Carbonate

Precipitation of silica and minor dissolution of carbonate characterize the second episode of diagenesis of the Nolans Limestone.

Silica is commonly length-slow, a trait described by Folk (1971) to be indicative of silica replacement of anhydrite; silica commonly partially replaces anhydrite nodules and both minerals may be present in a single nodule. Silica also replaces fossil fragments, primarily crinoids and brachiopods (photograph 10); silica also rarely occurs as thin (less than 1cm) beds.

Dissolution of carbonate during this episode of diagenesis resulted in development of minor porosity. Porosity generally is not associated with particular depositional facies, however, moldic porosity is most common in grain supported rocks.

HYDROCARBONS

Gas was first produced in Rice County in 1888. The Kansas Natural Gas and Oil and Mineral Products Company drilled an exploratory well in the Lyons Township (Sec. 34-T19S-R8W) and discovered natural gas at 403m below ground level. This depth places the gas bearing horizon within the Nolans Limestone. Natural gas produced from this well was used locally in the town of Lyons until an explosion, soon after use began, ended all production. A second test well was drilled again near Lyons but there is no record of any hydrocarbons having ever been produced. At the same time as these tests were being drilled, activity in southeastern Kansas was accelerating, providing investors and operators a more lucrative economic situation. The first phase of hydrocarbon exploration on Rice County came to an end and 35 years passed before any activity resumed (Koester, 1934).

Exploratory and field development drilling is presently very active in Rice County. Few drilling tests, however, seek the Nolans or any other Permian formations as primary objectives. Instead, they seek the Arbuckle, Mississippian, Lansing-Kansas City and other, deeper, more prolific, hydrocarbon bearing intervals (Beene, 1978) with the shallower beds being secondary zones of interest.

Chase Group formations, including the Nolans, have, however, been the primary objective of many drilling tests in the Hugoton Gas Area of southwest Kansas (figure 2). The Hugoton Gas Area covers a large portion of southwestern Kansas and extends southward into Oklahoma and Texas. This gas area, discovered in the 1920's, is a prolific producer of natural gas, ranking among the largest gas reserves of the world. Production in the Hugoton area is primarily from porous dolomitic facies (Hilpman, 1958).

This is the only region in Kansas where production of gas from Permian rocks occurs in such economically attractive volumes. Modest amounts of gas are, however, produced from these rocks throughout the western two-thirds of the state (Beene, 1978).

Gas has been produced recently in Rice County in many tests drilled to the Nolans Limestone. A few boreholes have also tested the slightly deeper Winfield and Barneston Limestones, but little gas or oil has been recovered. More than 40 shallow boreholes were drilled in a narrow, north-south trending corridor in central Rice County. The extent of this producing area is not yet fully defined and may extend well into adjacent counties (Bruce, G., 1980, personal communication). The township of Lyons is included in the corridor, which bears the name Lyons Gas Area.

Production is limited to natural gas, which comes primarily from the mid-to-lower portion of the Nolans. No oil has been tested. The amount of natural gas produced from this trend is modest. Initial completions are approximately 200 thousand cubic feet per day (MCFPD), but all rates quickly drop, stabilizing at an average of 20 MCFPD. The quality of the natural gas produced is low, with a BTU rating of approximately 800 (Bruce, 1980). On one hand, the low production rates and low BTU rating make the Nolans Limestone less attractive as a prospect than many other hydrocarbon bearing zones found in Kansas. It, on the other, does not require deep drilling, being only 300 to 500m below ground level. This latter factor enhances the attractiveness of the Nolans Limestone for hydrocarbon exploration. Further incentive for drilling comes from improved economics for natural gas producers. Production of natural gas from this formation in Rice County, however, will undoubtedly remain modest because of the poor reservoir quality.

Economic accumulation of natural gas is controlled by existing structures; boreholes drilled off structures have tested gas-cut water and are not economical (Bruce, G., 1980, personal communication). Porosity throughout the Nolans appears to be uniformly small in Rice County and effects of lateral facies or diagenetic changes on porosity distribution are probably small. This interpretation is based on the seemingly homogeneous reservoir quality characteristic of the Nolans in Rice County. Porosity and permeability are low and wells often require stimulation before they will yield significant amounts of gas.

Currently, production from the Nolans Limestone accurs within a three to four section wide fairway trending north-south (figure 13). This area coincides with a structurally high trend (figure 12), with areas of higher percentages of grain-supported rocks (figures 9 & 10), and with relatively thin areas on the isopachous map (figure 11). Exploration for natural gas should be directed toward areas with similar relationship of data from these various maps. This is, however, a regional study and provided only an indication of where hydrocarbons may exist in economically significant accumulations.

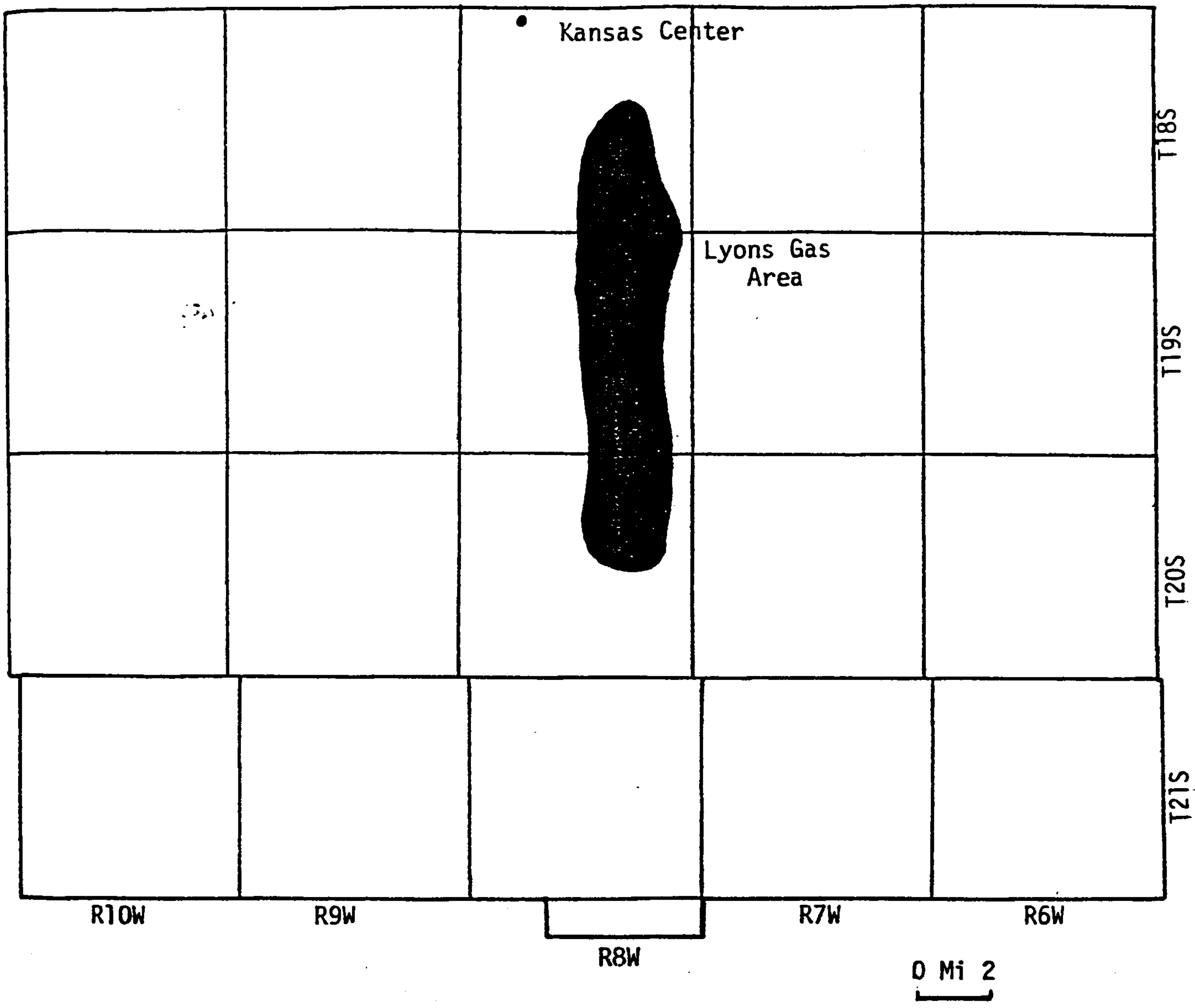


Figure 13: Natural Gas Production from the Nolans Limestone, Rice County, Kansas

CONCLUSIONS

The Nolans Limestone displays a cyclic depositional motif. Rocks of the Krider Member were deposited during the transgressive phase, rocks of the Herington were deposited during the regressive phase. Rocks of the Paddock were deposited during portions of both transgression and regression and represents a transitional phase.

Earliest Krider rocks were deposited from shallow water having somewhat restricted circulation and represent a low energy, near-shore environment of deposition. Water depth increased until, during deposition of mid and upper Krider, open circulation, normal marine environments existed. Energy levels were sufficient to transport grains and locally to wash fine grain material from skeletal grains leaving a significantly greater proportion of grain-supported sediments. Many of the grains are completely Osagia coated. An increased influx of silt into the basin modified the environments of deposition, excluding many carbonate producing organisms. This influx reached a climax during deposition of the Paddock Member.

Deposition of the Paddock Member was during a transition from transgressive conditions to regressive conditions. A large influx of silt partially masks this transition as nearly all carbonate producing organisms were excluded from this environment. By the end of deposition of the Paddock Member and initial deposition of the Herington Member water depth had shallowed significantly. Shallowing of water inhibited circulation, environments of deposition became slightly restricted and energy of those environments declined. Restriction of the environment, of circulation and decline in energy levels continued throughout deposition of the Herington until, during deposition of the uppermost portions, sedimentation occurred in very shallow, hypersaline water. No evidence of subaerial exposure was seen.

Above and below the Nolans Limestone are red and green siltstones. The presence of these siltstones adds to the Nolans cyclic depositional motif and allows an analogy to be made between cyclic deposition of the Nolans Limestone and the cyclic model of the Pennsylvanian carbonates. The red and green siltstones may be corrolated to the outside shales of the Pennsylvanian, the Krider Member to the transgressive stage, the Herington Member to the regressive stage, and Paddock Member to the marine shale. Differences do exist and a direct analogy is not suggested here. Examination of cyclic deposition displayed by other formations of the lower Permian must be made.

Two episodes of diagenesis of the Nolans Limestone were seen. The first is recognized by the near complete dolomitization of all carbonates and the precipitation of large quantities of calcium sulphate. The second episode is recognized by the introduction of silica as a replacement mineral and the dissolution of carbonate material.

Dolomitization affected all carbonates of the Nolans Limestone and nearly all carbonates were completely dolomitized. Only one occurrance of partially dolomitized carbonate was seen. Calcium sulphate, now represented as anhydrite is present throughout this section.

This episode is the result of sediments reacting with hypersaline water. Diagenesis, similar to this is described from present environments characterized by arid climates and hypersaline environments. The chemical reactions are similar between the Nolans and the present day analogies. Direct analogy between the present environments and the Nolans Limestone cannot be made.

The second episode of diagenesis involved the introduction of silica as a replacement mineral and dissolution of carbonate material. Silica is seen selectively replacing anhydrite throughout the section and replaces crinoidal debris and, rarely brachiopod fragments. Dissolution of carbonate material resulted in the creation of uniform but relatively low porosity throughout the Nolans. Locally, where grain-supported sediments accumulated, moldic porosity developed. Areas where grain-supported rocks are found commonly are also areas of significantly greater porosity than other portions of the Nolans.

Structurally high areas, currently present in the Nolans Limestone, were present during deposition of the Nolans. Areas which appear thin on an Ispoachous map of the Nolans correspond well with areas mapped as structural highs. Facies maps, those contoured as grain-supported rocks versus mud-supported rocks and shale also display a close relationship between areas of relatively high percentages of grain-supported rocks, isopachous thins and structural highs. This indicates that the structural highs were present throughout deposition of the Nolans Limestone and that these areas acted as shoals where skeletal grains could accumulate. Furthermore, the structural highs can be expected to be locations of significantly greater porosity development due to dissolution of grains. The existance of porosity on structures provides two necessary parameters for production of hydrocarbons, the reservoir and the trip. The third parameter is the presence of economically sufficient quantities of hydrocarbons. Hydrocarbons produced from the Nolans Limestone in Rice County, Kansas, are confined to natural gas. Production is modest indicating that, in areas that have been sufficiently tested, accumulation of natural gas is the limiting factor of this horizon.

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Appendix I

Descriptions of Cores and Thin Sections from Rice County, Kansas

CORE DESCRIPTION

Aspen 1 Heitschmidt Sw Ne Sec. 26-T19S-R10W

1370	Dolomite, medium brown-gray brown, very thin laminations in discontinuous sets in sharp contact with shale, dark gray-black, interbedded dolomite and shale units - 2m beds, burrowed, abundant flattened gray blue anhydrite nodules
1371	Shale, medium-dark gray/black, mudstone, siltstone in part, few anhydrite nodules, fractured, abundant organic material, dolomitic
1375	Dolomite, light-medium brown/gray brown, massive, abundant organic (?) debris, silty, few small anhydrite nodules, crystalline anhydrite (?)
1378	Dolomite as above, trace anhydrite
1379	Dolomite, light gray, massive, trace anhydrite, crinoid grainstone in part, crinoid debris (?), packstone, - wackstone, massive, trace anhydrite, shaly mudstone.
1381	Dolomite, medium gray, subtle horizontal to subhorizontal planar thin beds, becoming mottles in part, abundant black shale partings, no anhydrite
1383	Few large anhydrite nodules, light gray-white deformation of horizontal beds about nodules
1384	Very thin interbedding of light to medium brown with light brown units
1386	Dolomite, medium gray, mottled bedding, very silty
1387	As above, massive abundant skeletal fragments, burrowed, no anhydrite, crinoids, forams, pellets, bivalves
1389	Trace white anhydrite, nodular with some fracture filling
1391	Dolowackestone, as above, trace bedding, trace anhydrite
1392	Increasing amount silt
1395	Increasing amount skeletal fragments, mollusks (?)
1396	Shale, gray-green

CORE DESCRIPTION

Atomic Energy Commission 1 Test Hole NeNeNe Sec. 26-T19S-R8W

1251	Dolomudstone, dark gray, interlaminated with black shale. Gradational into 1252
1252	Dolomudstone, light to medium brown, mottled bedding-wavy in part, trace of horizontal or low angle planar cross beddings, few shale partings, fractures in part, some pinpoint-size porosity
1254	As above, becoming interbedded with dark argillaceous dolomite, wavy to horizontal laminations, few shale partings and laminations intraclasts in part
1255	Anhydrite, blue, abundant brown shale (clay) partings-"fish net" appearance
1256	Dolomudstone and shale as above, convoluted thin beds, intraformational conglomerate in part, little anhydrite
1258	Dolomudstone, light to medium brown, laminated, abundant black shale partings, few small blue anhydrite nodules, several thin (2-3cm) black chert beds
1260	Shale, black to dark gray, becoming laminated with light brown dolomudstone, chert in part, bedding becomes thicker, massive
1261	Dolomudstone-wackestone as above, thin current laminated units, dessication cracks (?) burrowed in part, abundant skeletal fragments
1263-66	Missing
1266	Dolomudstone, medium brown to gray-brown, massive, mottled bedding, abundant gray-white anhydrite nodules
1268	As above, becoming dolowackestone to dolograinstone, intraclasts in part
1269	Dolomudstone, medium to dark gray, massive, horizontal bedding to mottled bedding, some anhydrite nodules increasing skeletal debris (gastropods)
1274	Shale, dark gray, slightly dolomitic, few black shale partings, monotonous
1283	Wackestone to packstone, wavy bedding, abundant skeletal fragments, abundant gray shale

Core Description (Cont.) AEC 1 Test Hole NeNeNe Sec. 26-T19S-R8W

1285	As above, trace chert, some anhydrite, increasing amount of skeletal debris downward
1289	Shale, light gray to green gray, massive, caliche-like in part

CORE DESCRIPTION

Mapco 1 Miller Ne Sec. 7-T21S-R10W

99	Shale, gray, red, green, laminated to massive, minor amount of anhydrite
1401	Dolomudstone, medium gray-green, mottled to thin bedded, low angle cross bedding with algal laminations (?), burrowed, minor amount anhydrite
1403	As above with trace amount mudstone intraclasts, minor amount black shale as partings, disseminated green shale in part
1405	Anhydrite, blue, massive 4-5 inch "bed", brown mud and shale, bed appears to be a consolidation of nodules
1405.5"	Dolomudstone, light brown, caliche-like mottled bedding, with shale, gray green
1406	Dolomudstone, medium brown, thin planar cross bedding to mottled units with relict bedding, some black shale commonly as partings - very shaly in part
1407	Dolomudstone, light brown, massive, few green shale partings, minor amount anhydrite most commonly as void filling, some fenestral fabric (?)
1408	As above with thin sets of cross laminated mudstone, abundant chert, replacing anhydrite in part, carbonates in part
1409	Dolomudstone, as above, with minor amount of chert, abundant large blue anhydrite nodules, trace bivalve debris, increasing shale content downward
1411	Dolomudstone, medium gray, wavy horizontal and mottled bedding, common small anhydrite nodules, increasing number of black shale partings, anhydrite "bed" at 1414
1422	Dolowackestone, medium gray and medium gray-brown, massive to mottled bedding, few large blue anhydrite nodules, minor amount fossil debris, packstone in part, burrowed - large burrows filled with blue anhydrite nodules
1425	Dolomudstone, medium gray, mottled with relict horizontal bedding, burrowed in part, peloidal, intraclasts as flat pebbles, localized wackestones and packstones with some moldic porosity, minor amount of anhydrite
1436	As above with increasing shale - partings and disseminated shale

Core Description (Cont.) Mapco 1 Miller Ne Sec. 7-T21S-R10W

1439	Dolomudstone, light brown, caliche-like, mottled with green shale
1440	Shale, green gray, massive

CORE DESCRIPTION

Aspen 1 Hodgson C E2 Ne Sec. 30-T18S-R6W

1068	Dolomudstone, light brown, massive with localized horizontal bedding and algal laminations, anhydrite-blue to blue white nodules, replacing fossil debris in part
1069	As above, becoming green-gray and shaly in part
1069.9"	Anhydrite, blue with light brown carbonate and shale "string-like" partings
1071	Dolomudstone, light brown, locally abundant gray-green shale, mottled to thin bedding, minor amount of anhydrite as nodules and fracture fullings
1072.6"	Dolomudstone, light to medium gray brown, very thin algal laminations (?), abundant anhydrite-blue, as nodules and thin "beds"
1075	Dolomudstone, medium brown, increasing amount gray-green shale, medium sets of thin bedded shale and mud, wavy in part, burrowed in part (?), abundant small anhydrite nodules, chert replaced in part
1089	Dolomudstone, medium gray brown, burrowed, anhydrite as small blue nodules
1094	Shale, green gray
1095	Dolomudstone, medium gray-brown, burrowed with trace bedding, few large anhydrite nodules - associated with burrows (?)
1098	As above, increasing shale content
1099	Shale, medium gray, calcareous
1100	Dolomudstone, medium brown to gray, mottled bedding, burrowed, minor amount anhydrite
1101	Shale and siltstone, light green minor amount anhydrite, calcareous-caliche like

CORE DESCRIPTION

Mapco 1 Kowalsky C Se Sec. 30-T20S-R10W

1376	Shale, gray, red, green, massive to laminated, locally abundant anhydrite
1378	Dolomudstone, light gray, mottled bedding and thin horizontal bedding, minor amount blue anhydrite nodules, gray-green shale partings
1382	Anhydrite, blue, massive "bed", some brown mud partings-irregular, bed appears to be a consolidation of nodules
1383	Dolomudstone, medium gray brown, mottled bedding with some tin, horizontal to low angle bedding, anhydrite as blue nodules, locally forming incomplete layers, irregular black shale partings, fractured
1385	Anhydrite, blue, as above, with several inch dolomudstone parting
1386.5"	Dolomudstone, light brown, wavy parallel but discontinuous beds-current and algal laminations, abundant small blue anhydrite nodules, locally abundant gray shale-disseminated shale
1388	Dolomudstone, light to medium brown with gray-brown, mottled bedding to thin sets of planar, low angle cross bedding, small scale through cross bedding in part, burrowed, becoming massive at 89, minor amount anhydrite, several thick beds of dark gray chert replacing carbonate, few localized shale partings
1396	Dolomudstone, as above, mottled bedding is predominate, increasing black shale content abundant partings, minor amount anhydrite
1401	Dolomudstone-wackestone, light gray, massive with wavy brown shale partings, burrowed, minor amount of bivalve debris, locally abundant small gastropods, few intraclasts
1407	As above, large burrows filled in part with small, massed anhydrite nodules
1408	Dolomudstone to packstone, light brown, mottled bedding with some wavy horizontal bedding, locally abundant fossil debris-moldic porosity in part, minor amount anhydrite as nodules and void fillings
1416	Dolomudstone, light gray, and shale, gray-green mottled bedding-caliche like in part

Core Description (Cont.) Mapco 1 Kowalsky C Se Sec. 30-T20S-R10W

1416 Shale, gray green, mottled bedding

THIN SECTION DESCRIPTION

WELL: Kowalsky DATE: 4/80

SAMPLE DEPTHS: 1387 1392.6

CONSTITUENTS:

Microxln dolomite and dolomicrite, peloid rich, algal or current laminations, abundant anhydrite as nodules and individual crystal, trace fine grain pyrite

ENVIRONMENT:

Intertidal to supratidal

DIAGENESIS:

Dolomitization recrystalization and calcium sulphate precipitation, silica replacement and limited solution of carbonate

THIN SECTION DESCRIPTION

WELL: Kowalsky DATE: 4/80

SAMPLE DEPTHS: 1397.8 1392 1395.5

CONSTITUENTS:

Microxln dolomite, peloid rich, trace mudclasts, burrows, trace pyrite, some anhydrite, some phosphatic bore debris, generally massive

ENVIRONMENT:

Lower intertidal, normal to near normal marine

DIAGENESIS:

Dolomitization and precipitation of calcium sulphate, silica replacement and dissolution of carbonate

THIN SECTION DESCRIPTION

WELL: Kowalsky

DATE: 4/80

SAMPLE DEPTHS: 1400 1401 1404 1405 1409

CONSTITUENTS:

Microxln dolomite and dolomicrite, peloids, mollusk debris, trace amounts of quartz silt, pyrite, some anhydrite nodules, some phosphate debris, generally massive, burrowed

ENVIRONMENT:

Subtidal, normal to near normal marine

DIAGENESIS:

Marine cement, dolomite and calcium sulphate precipitation, silica replacement and dissolution

THIN SECTION DESCRIPTION

WELL: Kowalsky DATE: 4/80

SAMPLE DEPTHS: 1382

CONSTITUENTS:

Dolomicrite, peloidal, anhydrite-blocky crystalline and fine crystalline, some silica replacement, generally massive

ENVIRONMENT:

Subwave base, lagoon, moderate to low energy

DIAGENESIS:

Dolomitization, precipitation of calcium sulphate, silica precipitation and dissolution of carbonate

THIN SECTION DESCRIPTION

WELL: Kowalsky

DATE: 4/80

SAMPLE DEPTHS: 1411 1415 1402

CONSTITUENTS:

Dolomicrite and microxln dolomite, peloidal, abundant fossil debris, pelecypods, brachiopods, bryozans, gastropods, mostly all thick shells, some anhydrite, trace phosphatic bone debris, trace pyrite, generally massive, some thin cross bedding

ENVIRONMENT:

Above wave base, intertidal-shoal, normal to near normal marine, shallow open circulation shelf

DIAGENESIS:

Calcite cement (?), dolomitization-recrystalization and calcium sulphate deposition, silica replacement and dissolution of carbonate

THIN SECTION DESCRIPTION

WELL: Miller

DATE: 4/80

SAMPLE DEPTHS: 1430 1434 1438

CONSTITUENTS:

Dolomicrite and microxln dolomite, few coated gastropods and bivalves, some anhydrite, trace phosphatic bone debris, generally massive

ENVIRONMENT:

Subtidal, moderate to low energy, possible shoal flank

DIAGENESIS:

Dolomitization rexln and precipitation of calcium sulphate, silica replacement and dissolution

THIN SECTION DESCRIPTION

WELL: Miller

DATE: 4/80

SAMPLE DEPTHS: 1439.5

CONSTITUENTS:

Microxln dolomite and dolomicrite, pelleted, abundant quartz silt, Osagia coated grains, abundant fine grained pyrite, trace intraclasts (?)

ENVIRONMENT:

Tidal flat to upper intertidal zone, moderate energy

DIAGENESIS:

Dolomitization recrystalization and calcium sulphate precipitation

THIN SECTION DESCRIPTION

WELL: Miller DATE: 4/80

SAMPLE DEPTHS: 1422 1424

CONSTITUENTS:

Dolomicrite and microxln dolomite, pelleted in part, gastropod, pelecypod debris - coated in part, crinoid, brachipod (?) and some phosphatic bone (?) debris, much debris is anhydrite replaced, some debris is micritized

ENVIRONMENT:

Shoal or near shoal, high energy probably normal to near normal marine

DIAGENESIS:

Micritization, possibly normal marine cement in minor amounts, dolomitization- recrystalization and precipitation of calcium sulphate, silica replacement and dissolution of carbonate

THIN SECTION DESCRIPTION

WELL: Miller

DATE: 4/80

SAMPLE DEPTHS: 1414 1417.5 1420 1429 1431

CONSTITUENTS:

Massive with some laminations, dominated by peloids, minor amounts of quartz silt, phosphatic bone debris, intraclasts

ENVIRONMENT:

Low energy, subtidal to supratidal

DIAGENESIS:

Precipitation of calcium sulphate and dolomitization, dissolution and replacement of anhydrite

THIN SECTION DESCRIPTION

WELL: Miller

DATE: 4/80

SAMPLE DEPTHS: 1410

CONSTITUENTS:

Dolomicrite, pelleted, massive to current laminated, dark to opaque organic (?) debris, fine grain pyrite, minor amounts of anhydrite, abundant quartz silt and replacement silica

ENVIRONMENT:

Intertidal, moderate energy

DIAGENESIS:

Dolomitization and recrystalization, precipitation of calcium sulphate, silica replacement and dissolution

Appendix 2

Weight Percentages of Insoluble Residue and Gamma-Ray and Neutron Log Cross-Plots

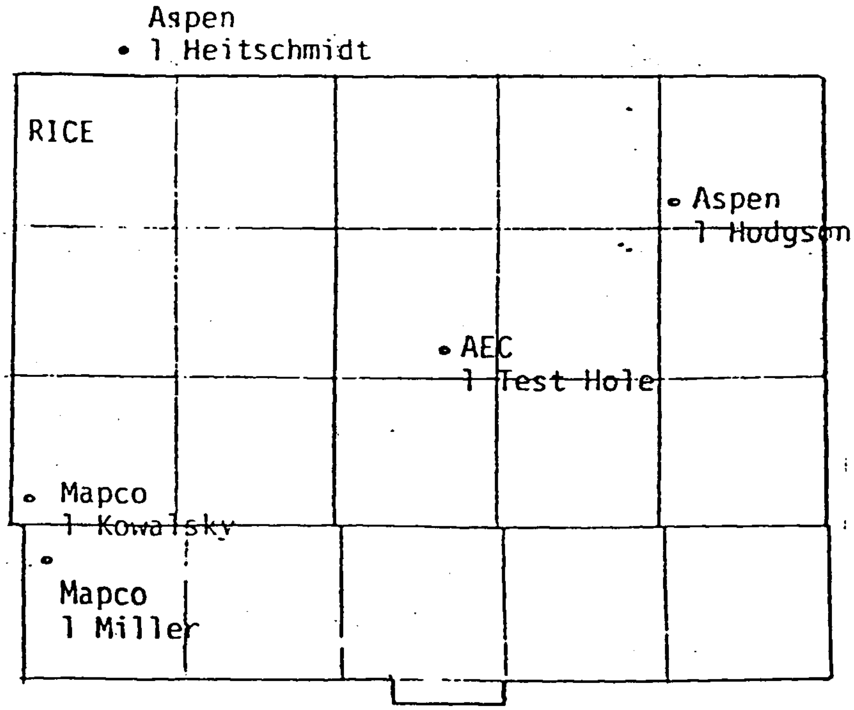
APPENDIX 2

Included in this appendix are gamma ray and neutron log cross plots constructed from logs from selected wells in the study area (see map, next page), and data from insoluble residue tests.

Samples of cores were selected in two sets, one set based on the visual core examination and thin section examination, the other set based on log signatures of gamma ray and neutron logs. Each set contained four members. A portion of each sample was dissolved in HCl, a second portion in HOAc to determine the percentage of insoluble residue in each sample. This procedure showed that mud-supported rocks contained a greater fraction of fine grained terrigeneous clay minerals than grain-supported rocks. It is assumed that more radioactive material will be associated with greater concentrations of clay minerals and other fine terrigeneous materials and that this will be evident on gamma ray and neutron log cross plots and on log signatures.

Cross plots of data from core samples and selected gamma ray and neutron logs from Rice County were made and these show a separation of mud-supported rocks from grain-supported rocks. Shales and silt-rich rocks commonly contain a higher percentage of radioactive material, hence, the gamma ray log will tend to register a higher gammy ray count, while the neutron log will tend to register a lower radioactivity count because of high hydrogen ion concentrations. Conversely anhydrite, which contains little radioactive material will tend to register lower gamma ray counts and higher neutron counts because of relatively lower hydrogen ion concentrations.

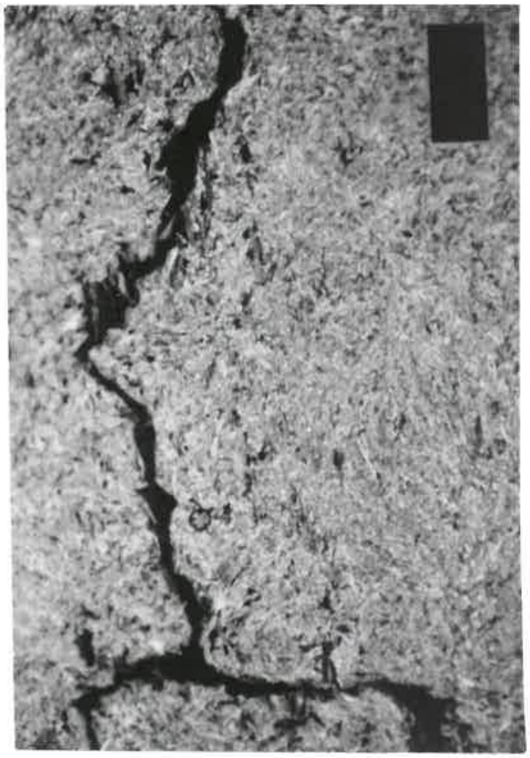
Cross plots include one composite plot of rock samples and log data from cores in Rice County. Sample points were marked according to Dunham's classification of depositional textures (1962). An empirical division of the cross plot was made, which places mud-supported and shale-rich rocks on the left of the plot and grain-supported rocks and anhydrite-rich rocks on the right of the plot. This empirically derived division was then used on cross plots of logs from other wells in Rice County, Kansas. Mud-supported or grain-supported classifications were then assigned to each point, and each point was then referred back to the gamma ray and neutron log signatures. Log signatures characteristic of both mud-supported and grain-supported rocks were recognized. Recognition of characteristic log signatures to define basic textural differences of rocks was then applied to other, similar logs in Rice County, Kansas. Data obtained from this procedure were used to construct the facies maps in Rice County, Kansas (figure 9 & 10).



Insoluble Residue Date for Samples and HOAc

Well	HOAc%	
AEC 88	13%	Grain-supported rock
AEC 88.5	13%	Grain-supported rock
AEC 89	13%	Grain-supported rock
Hodgson 1100	18%	Grain-supported rock
Hodgson 98	11%	Grain-supported rock
Hodgson 71	47%	Mud-supported rock
Heitschmidt 86	35%	Mud-supported rock
Heitschmidt 74	29%	Mud-supported rock

Photograph 1: Anhydrite Nodules Deforming Thin Bedding in the Herington Member

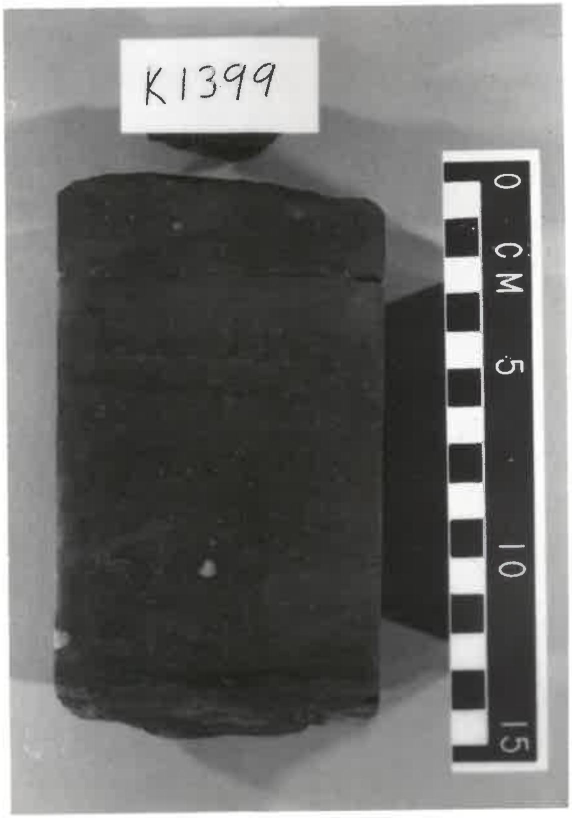


Photograph 2: Anhydrite Nodule "Felted Texture"

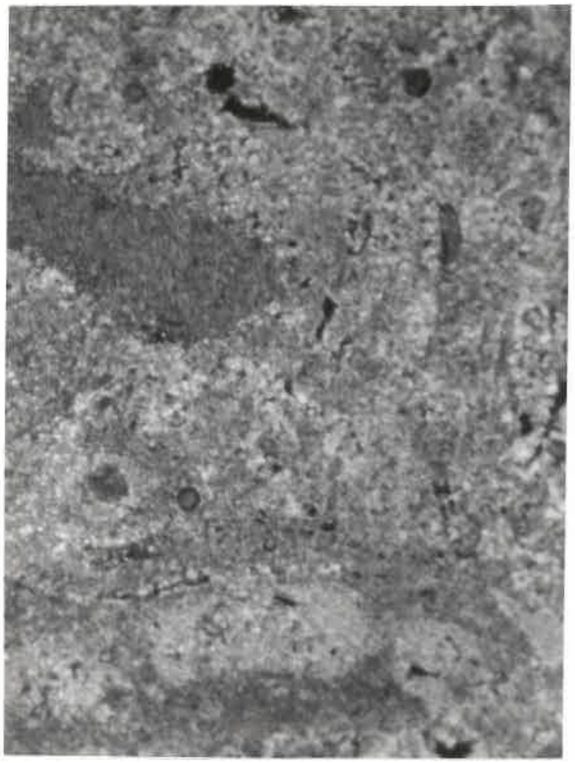
Photograph 3: Wackestone
of Upper Krider Member

Photograph 4: Wackestone
of Lower Krider Member

Photograph 5: Packstone of Krider Member

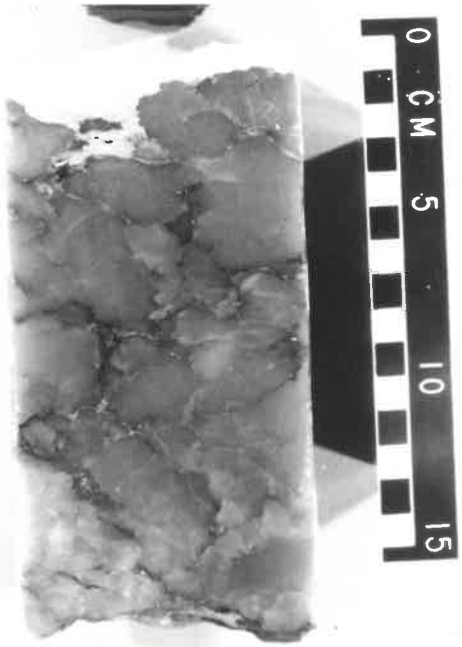


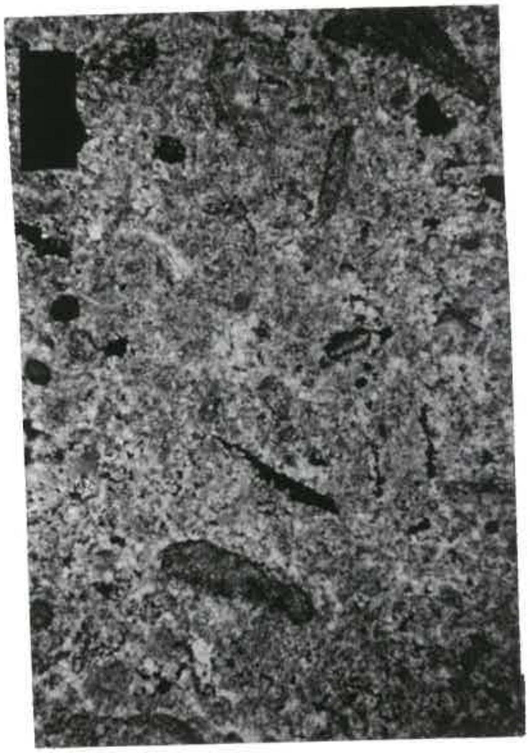
Photograph 6: Typical Paddock Member



Photograph 7: Wackestone of Lower Herington

Photograph 8: Anhydrite Layer of Upper Herington





Photograph 9: Recrystallized Packstone with Moldic Porosity

Photograph 10: Silica Replacement of Anhydrite

Wells Included in Figure 3

Stratigraphic Cross Section:

Riley County, Kansas to Rice County, Kansas

1	Holl	1 Miller	S2 Se Nw	Sec. 18-T21S-R10W
2	Barnett	1 Wright	C S2 Nw	Sec. 35-T19S-R8W
3	D. Bond	1 Durland	Sw Sw Ne	Sec. 5 T19S-R5W
4	National Coop	1 Berglund	Nw Nw Nw	Sec. 31-T16S-R3W
5	National Oil	11 Carber	Ne Ne Se	Sec. 5-T16S-R1W
6	K. Ferguson	1 Taylor	Sw Sw Sw	Sec. 30-T12S-R1E
7	Kewanee	1 Longford	Sw Sw Sw	Sec. 20-T10S-R1E
8	Jackson	1 Swenson	Sw Sw Nw	Sec. 15-T9S-R2E
9	Jones-Gebert	1 Hafner	Sw Sw Nw	Sec. 35-T8S-R4E
10	Amoco	1 Hargrave	Ne Ne Ne	Sec. 32-T7S-R6E
11	Composite outcrop section in Riley County, Kansas			

Wells Included in Figure 4a

Stratigraphic Cross Sections in Rice County, Kansas

1	Cambria	1 Smith A	Ne Sw	Sec. 31-T21S-R8W
2	Mapco	1 Smiser	C S2 Nw	Sec. 28-T20S-R8W
3	N.N.G.	11-10	Se Sw	Sec. 11-T20S-R8W
4	A.E.C.	1 Test Hole	Ne Ne Nw	Sec. 26-T19S-R8W
5	Aladdin Pet.	1 Green	Ne Sw	Sec. 3-T19S-R8W
6	Continental	13 Wood	Sw Sw Se	Sec. 12-T18S-R8W

Wells Included in Figure 4b:

Stratigraphic Cross Sections in Rice County, Kansas

1	Mapco	1-7 Sessler	Nw Se	Sec. 7-T21S-R10W
2	Mapco	1 Kowalsky	Se	Sec. 30-T20S-R10W
3	Mapco	1 Birzer	Ne Ne Nw	Sec. 32-T19S-R10W
4	Phillips	1 Milton-A	Nw Sw Nw	Sec. 9-T19S-R10W
5	BMG	1 Kaiser	E2 Se Se	Sec. 4-T18S-R10W
6	Aspen	1 Heitschmidt	Ne Ne	Sec. 26-T17S-R10W

Wells included in Figure 4c:

Stratigraphic Cross Sections in Rice County, Kansas

1	BMG	1 Zink	Sw Nw Se	Sec. 7-T18S-R10W
2	BMG	1 Kaiser	E2 Sw Se	Sec. 4-T18S-R10W
3	Isern	2 Groth	Sw Se Nw	Sec. 10-T18S-R9W
4	Continental	13 Wood	Sw Sw Se	Sec. 12-T18S-R8W
5	Pearson	2 Click	S2 Sw Ne	Sec. 3-T18S-R7W
6	Aspen	1 Hodgson	C E2 Ne	Sec. 30-T18S-R6W

Wells Included in Figure 4d

Stratigraphic Cross Sections in Rice County, Kansas

1	Mapco	1 Kowalsky	Se	Sec. 30-T20N-R10W
2	Vincent Pet.	1 Ringwald	Ne Nw Ne	Sec. 24-T20S-R10W
3	Cities Service	1 Young A	Sw Nw Se	Sec. 8-T20S-R9W
4	Champlin	1 Fox Eldridge	Se Nw	Sec. 7-T20S-R8W
5	N.N.G.	11-10	Sw Se Sw	Sec. 11-T20S-R8W
6	G. Ewonus	1 Engelland	C N2 Nw	Sec. 9-T20S-R7W
7	National Coop	1 Johannson	C Ne Sw	Sec. 7-T20S-R6W
8	Branden	1 J.W. Branden-C	Se	Sec. 1-T20S-R6W

Wells Included in Figure 5

Structural Cross Section in Rice County, Kansas

1	Mapco	1 Kowalsky	C Se	Sec. 30-T20S-R10W
2	Mapco	1 Miller	C E2 Ne	Sec. 9-T20S-R9W
3	O.A. Sutton	1 Frances	Se Ne	Sec. 29-T19S-R8W
4	Rex & Morris	1 Burdett	Ne Sw	Sec. 1-T19S-R8W
5	Aspen Drilling	1 Hodgson	C E2 Ne	Sec. 30-T18S-R6W