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**LITHOLOGIC AND STRATIGRAPHIC RELATIONSHIPS BETWEEN
THE REAGAN SANDSTONE (UPPER CAMBRIAN) AND SUB-
REAGAN AND SUPRA-REAGAN ROCKS IN WESTERN KANSAS**

by

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AND SUB-REAGAN AND SUPRA-REAGAN ROCKS
IN WESTERN KANSAS

by

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TABLE OF CONTENTS

	Page
Introduction.....	1
Purpose and scope of investigation.....	1
Previous work.....	3
Upper Mississippi Valley.....	3
Missouri.....	4
Oklahoma.....	5
Kansas.....	6
Research procedure.....	7
Acknowledgements.....	11
Description of the area.....	12
Nature and distribution of Precambrian igneous and metamorphic rocks.....	20
Introduction.....	20
Petrography, distribution, and age	20
Nature of Precambrian surface.....	24
History	26
Paleontology, age, and nomenclature of the Reagan Sandstone..	28
Lithology and petrography of the Reagan Sandstone.....	35
Quartzose sandstone	35
Dolomitic sandstone.....	47
Quartz-glaucinite sandstone.....	48
Arkose and feldspathic sandstone	50
Shale	52
Diagenesis	52

	Page
Maturity.....	56
Mineralogical maturity.....	56
Textural maturity.....	59
Thickness and distribution of the Reagan Sandstone.....	61
Stratigraphic relationships between the Reagan Sandstone and sub-Reagan and supra-Reagan rocks	65
Relation of the Reagan to sub-Reagan rocks.....	65
Sub-Reagan arkose.....	67
Rice Formation.....	73
Relation of the Reagan to supra-Reagan rocks	77
Arbuckle Group.....	77
Pennsylvanian System	81
Quantitative Analysis	84
Trend surface maps	84
Statistical correlation matrices	95
Factor analysis	99
Numerical taxonomy	107
Genesis and history of the Reagan Sandstone	114
Selected references	119
Appendix A, key for interpretation of statistical data.....	150
Appendix B, list of wells used in cross sections	152
Appendix C, list of wells for photographic figures	156
Appendix D, list of wells used in the study	158
Appendix E, list of cores used in the study	173

LIST OF ILLUSTRATIONS

Figure		Page
1	Map showing distribution of Precambrian and Upper Cambrian outcrop areas, outline of the area of study and general tectonic features of the Midcontinent region.....	2
2	Major structural features of Kansas.....	13
3	Graphic representation of structural evolution of major features in Kansas.....	15
4	Diagram showing sequence of rock units penetrated on the Central Kansas Uplift and the Cambridge Arch.....	16
5	Regional correlation chart of Cambrian rocks in the central United States.....	18
6	Map showing distribution of Precambrian rocks in western Kansas.....	21
7	Preliminary regional configuration map of the top of Precambrian basement in Kansas.....	22
8	Photomicrographs of representative Precambrian rocks.....	23
9	Stratigraphic cross section AA' from Yuma County, Colorado to Norton County, Kansas.....	30
10	Correlation of the trilobite zones of the Riley Formation with those recognized in the type Dresbachian section of Minnesota and Wisconsin, and in central Montana.....	32
11	Biostratigraphic relationships between Kansas-Colorado and Texas, Oklahoma, Missouri, and Wisconsin.....	33
12	Description of core from the Magnolia No. 1 "B" Holsman well in Rooks County, Kansas.....	36

13	Description of core from the Derby Oil Co. No. 4 Schoen in Norton County, Kansas.....	37
14	Grain size distribution on the Reagan Sandstone from selected intervals from five cores.....	41
15	Photograph of Reagan core showing variations in grain size and sorting.....	43
16	Photograph of core and photomicrographs of Reagan Sandstone showing variations in texture and cementation.....	45
17	Photomicrographs of rock types of the Reagan Sandstone.....	46
18	Photomicrographs of selected Reagan rock types...	49
19	Map showing general thickness of the Reagan Sandstone in Kansas.....	62
20	Stratigraphic diagram showing relationships between Paleozoic rocks and Precambrian rocks in northwest Kansas.....	66
21	Photographs and photomicrograph of Reagan-Precambrian contact in two well cores.....	68
22	Stratigraphic cross sections BB' showing channeling in Precambrian surface.....	70
23	Map showing known distribution of Rice formation in Kansas and its relation to -50 mgal Bouguer gravity contour.....	72
24	Bouguer gravity map showing Greenleaf anomaly, contour interval 10 mgal and map showing distribution of basement rocks.....	75
25	Stratigraphic cross section CC' showing relationship between Reagan Sandstone and Rice Formation in Kansas.....	76
26	Diagram showing proposed lithologic and overlap relationships between the Reagan Sandstone and Arbuckle Group over Precambrian "highs" in central and northwestern Kansas.....	78

27	Diagrams showing proposed relationships between Cambrian and Ordovician rocks in Central Kansas.....	79
28	Stratigraphic cross section showing relation of Roubidoux Formation to older rocks in southern Missouri and in southern Kansas.....	80
29	Stratigraphic cross section DD' showing irregular nature of Reagan Sandstone with respect to units above and below.....	83
30	Trend surface maps of the structure of the base and top of the Reagan Sandstone.....	86
31	Trend surface maps of the structure of the top of the Arbuckle Group and thickness of the Reagan Sandstone.....	87
32	Trend surface maps of Arbuckle thickness and mean grain size of the Reagan Sandstone.....	88
33	Trend surface maps of the roundness index and sorting measure of the Reagan Sandstone.....	89
34	Directions of linear trend surfaces for various factors related to the Reagan Sandstone..	90
35	Map showing distribution of wells used in factor analysis and limit of glauconite distribution.....	105
36	Dendrogram prepared by the weighted pair group method based on R-matrix of correlation coefficients transformed to Z values computed from well data.....	110
37	Map showing distribution of clusters determined at the 0.85 Z values.....	111
38	Map showing distribution of clusters determined at the 0.75 Z value.....	112

Table	Page
1 Statistical data from selected intervals from five cores of the Reagan Sandstone in the area of the Cambridge Arch and Central Kansas Uplift.....	42
2 Results of chemical analyses of fluid content of the Reagan Sandstone and porosity and permeability values of the Reagan Sandstone.....	57
3 Lower half or R-correlation matrix showing correlation coefficients among variables.....	97
4 Relative primary pattern factor loadings.....	104

Plate	Pocket
I Map showing areas characterized by sandstone types, area trend surfaced and control used in the study.....	Pocket
II Map showing Paleozoic rocks on Precambrian rocks and sub-Reagan arkose in central Kansas.....	Pocket
III Map showing Paleozoic rocks on Precambrian rocks and sub-Reagan arkose in the area of the Cambridge Arch.....	Pocket
IV Isopachous map of Precambrian-Paleozoic arkose on Cambridge Arch.....	Pocket
V Contour map of Precambrian igneous and metamorphic surface.....	Pocket
VI Paleogeologic map, base Pennsylvanian and isopachous map of the Reagan Sandstone in the Otis-Albert area...	Pocket

ABSTRACT

Samples, cores, and thin sections of the Reagan Sandstone were studied from 239 wells in central and western Kansas. Analysis of the quantitative well data was aided by trend surface maps, factor analysis, correlation matrices and a clustering method used in numerical taxonomy.

Paleontologic evidence indicates that the Reagan was originally deposited during Late Cambrian (Dresbachian) but is a time transgressive unit.

Quartzose sandstone, dolomitic sandstone, quartz-glaucanite sandstone, arkose and feldspathic sandstone are the dominant rock types. Deposition of the Reagan was rather rapid on the nearly flat Precambrian surface composed of igneous, sedimentary, and metamorphic rocks which supplied much of the material found in the Reagan. Eolian processes were important in rounding quartz grains supplied to the Reagan and in distributing quartz, mica, and feldspar to offshore areas where carbonate deposition was occurring. It is possible that alteration of the mica and feldspar produced the magnesium for conversion of the original limestone to dolomite, provided a source for the silica present as overgrowths, and was a source for the glauconite.

The Reagan was deposited as a widespread "blanket" sandstone and was overlapped on the flanks of monadnocks by the Arbuckle Group. Erosion removed the overlying Bonneterre Dolomite on

local uplifts in the area of the Central Kansas Uplift and during deposition of Ordovician rocks the Reagan was reworked and redeposited. Post-Mississippian pre-Pennsylvanian erosion removed rocks overlying the Reagan in local areas and subsequent deposition of Pennsylvanian rocks was on the eroded edges of the Reagan.

INTRODUCTION

Purpose and Scope of Investigation

Considerable geologic study has been devoted to outcrop areas in the Midcontinent where basal Paleozoic rocks (Reagan Sandstone, Lamotte Formation, Mt. Simon Sandstone) are in contact with underlying Precambrian igneous, metamorphic, or sedimentary rocks (Fig. 1). However, study of this relationship where it is concealed by younger sediments has been neglected. This neglect is seemingly not due to a lack of interest but rather a scarcity of data. Although approximately 2400 wells penetrate Precambrian rocks in Kansas, more than 90 percent of these wells are located on the Central Kansas Uplift and the Cambridge Arch.

The primary purpose of this regional study is to extend our knowledge of stratigraphic relationships between Precambrian rocks and basal Paleozoic units (primarily the Reagan Sandstone) from areas of outcrop into the subsurface of Kansas where reasonable control is available to give information from which conclusions might be made regarding the geologic problems.

In order to accomplish these purposes, the lithostratigraphic and biostratigraphic relationships between the Reagan Sandstone in Kansas and the outcrop areas needed examination and clarification. In addition, in the area of the Central

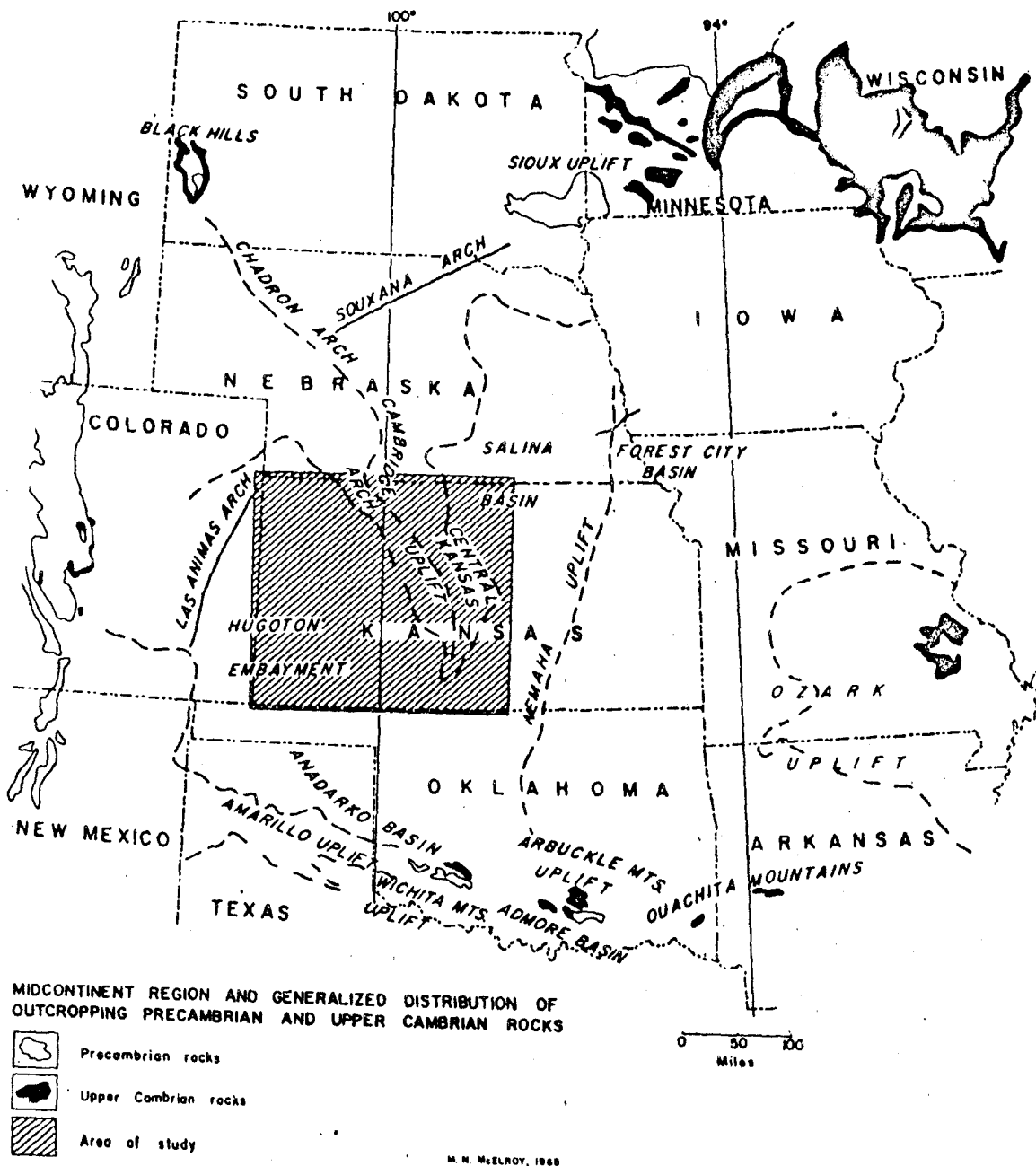


Figure 1.- Map showing distribution of Precambrian and Upper Cambrian outcrop areas, outline of the area of study and general tectonic features of the Midcontinent (Map base from Fox and Sheldon, 1957).

Kansas Uplift and Cambridge Arch it was necessary to determine the causes of lithologic variation; geometry of the Reagan; thickness changes with regard to deposition or erosion; stratigraphic relationship between units above, below and adjacent; origin, source, age, environment of deposition, and diagenesis of the Reagan.

This study is divided into a qualitative and a quantitative investigation of the Reagan. The second part serves as an aid in interpretation and as a test to evaluate the applicability of trend surface mapping, factor analysis, and the techniques employed in numerical taxonomy to stratigraphic data.

Previous Work

Upper Mississippi Valley: The type area for the Upper Cambrian in North America is located in the upper Mississippi Valley. In this area the rocks of the Croixan Series are exposed in the valley walls of the Mississippi, Minnesota, St. Croix, and Wisconsin rivers and their tributaries. The base of this series is based on the lowest faunal zone (Cedaria) recognized in Wisconsin.

Early workers noted the complex relationships between the basal Paleozoic rocks and the Precambrian rocks, but it was not until 1935 that Atwater suggested that the angular unconformity between the youngest Keweenawan beds and basal St. Croixan (Mt. Simon) is evidence for a time break of great

magnitude. Atwater and Clement (1935) expanded the earlier publication and suggested that the answer to the Precambrian-Cambrian boundary problem is to be found in the center of the Lake Superior syncline. Crowley and Thiel (1940) used heavy minerals and feldspars in an attempt to subdivide the Mt. Simon from the underlying Hinckley Sandstone. They concluded that a disconformity exists between the Mt. Simon and the Hinckley. One of the most recent publications dealing with the boundary problem in particular was written by Raasch (1950). He proposes that Bayfield rocks are continental, of Medial and maybe Early Cambrian age and suggests gradual transition to marine conditions where the Mt. Simon and Eau Claire were deposited. Hamblin (1958) defined a Lower and Middle Cambrian series (Jacobsville) between Upper Keweenawan and Upper Cambrian rocks. An excellent summary of the nomenclatural development of Upper Cambrian rocks in the upper Mississippi Valley is presented by Bell, Berg, and Nelson (1956).

Missouri: In the St. Francois Mountains of southeastern Missouri (Fig. 1), the Lamotte Sandstone, the lithostratigraphic equivalent of the Mt. Simon Sandstone and the Reagan Sandstone, is exposed. Here, as in the upper Mississippi Valley and southern Oklahoma, early work was restricted to the study of broad relationships dealing with units of greater magnitude than formations and members. Bridge (1937) correlated the Upper Cambrian sections of Missouri and Texas with the section in the upper Mississippi Valley.

Adams (1959) was among the first to give attention to the problem of the regional stratigraphic relationship between the Cambrian and Precambrian. Grenia (1959) discussed the Precambrian topography and rock types, an important contribution to the solution of problems encountered in a study of the Lamotte Formation.

Some of the publications concerned specifically with the Lamotte Formation are: Winslow (1884, first description), Keys (1895), Winslow (1896), Buckley (1908), Dake (1918), Weller and St. Clair (1928), Cordry (1929), Dake (1930), Wallace (1938), James (1951), and Markward (1952). The most complete and comprehensive study of the Lamotte Formation was made by Ojakangas (1960, 1963).

Southern Oklahoma: The Reagan Sandstone in southern Oklahoma was described, defined, and named by Taff (1902). No comprehensive stratigraphic study of the Reagan Sandstone has been made in Oklahoma at this time. For stratigraphic and paleontologic information dealing with Upper Cambrian rocks, including the Reagan, the reader is referred to the following: Taff (1902, 1904), Ulrich (1911, 1912), Walcott (1912, 1913), Decker (1933, 1934, 1939a, 1939b), Bridge (1936), Frederickson (1941a, 1941b, 1942, 1948a, 1948b, 1949, 1956), Ham (1955), Hamilton (1956), Chase, Frederickson, and Ham (1956), Hayes (1933), and Six (1929). Ireland (1944, 1955) studied the Reagan Sandstone in the subsurface of northeastern Oklahoma and related its thickness and distribution to the surface configuration of the Precambrian.

Kansas: Published geologic studies of the Reagan Sandstone in Kansas are nonexistent. The lack of subsurface control before 1935 was related to depth necessary to penetrate the Reagan and its stratigraphic position with respect to Precambrian rocks. The Reagan produces oil and gas in 21 fields. Oil companies are aware of the nature of the Reagan and its importance, and for this reason little of this information is in published form. Published data includes brief mention in stratigraphic columns and cross sections of county and regional reports; regional studies of the Precambrian and the Upper Cambrian-Lower Ordovician; structural studies on a regional scale; and studies compiled from the literature on Lower Paleozoic rocks of the Midcontinent.

Landes (1927) and Farquhar (1950) studied the petrography and distribution of Precambrian rocks in Kansas. Scott now has in progress a more complete and up to date study of sub-Reagan rocks which has been useful in the development of ideas concerning this study of the Reagan Sandstone.

Koester (1935), in his paper on the geology of the Central Kansas Uplift, devotes only a page to the "basal sand." Lee (1943, 1956) gives general lithologic and stratigraphic data and shows stratigraphic relationships. Dott (1941) and Lochman (1956) offer only general remarks on the nature of Upper Cambrian rocks in the subsurface. Perhaps one of the most informative papers is by Walters (1946) who presented much valuable information concerning the nature, distribution,

origin and stratigraphic relationships of the Reagan. Ireland (1944, 1946) gives detailed stratigraphic data on Cambrian and Ordovician rocks in northeast Oklahoma and southeast Kansas, his conclusions being applicable to the central part of Kansas. A major effort to understand Cambrian and Ordovician rocks was made by Keroher and Kirby (1948). Although limited control was used and most of their efforts were directed towards the Arbuckle Group, a general understanding of the lithology and transitional nature of the top of the Reagan is presented.

In summary, it might be said that no thorough and complete study of the Reagan Sandstone in the subsurface of the Midcontinent has been made. This paper is an attempt to fill part of this gap.

Research Procedure

As an aid in the interpretation of Kansas samples and as a basis for comparison, outcrop areas in Oklahoma and Missouri were visited. Samples of both Precambrian and Lower Paleozoic rocks were collected. Analyses of these samples are not included in this paper as the samples were used only for reference.

Rock samples were studied from 239 wells in the western ranges of Kansas during the summers of 1962, 1963, and 1964. The distribution of control is determined by the quality of the individual well samples, the distribution of wells penetrating the Precambrian, and the availability of samples.

Cable-tool samples were examined and rotary samples were used only when cable-tool samples were not available. Extremely dirty samples or incomplete samples were not used for determination of quantitative variables. When available, cores and core chips were utilized and served as "type sections" to which other wells could be correlated.

Sample logs, scout tickets, and published lithologic descriptions were used only for comparison because these data could not be satisfactorily quantified in all the aspects which were of prime interest. Wire-line surveys (electric logs, gamma-ray, neutron logs, micro logs, etc.) were used as a guide in locating the tops and bottoms of various stratigraphic units.

Thin sections of both rock samples and core chips were examined with a petrographic microscope. Heavy minerals from selected cores were isolated although separation of heavy minerals from cable-tool cuttings proved unsatisfactory. Size distribution analyses from 5 of the cores were made.

Estimates of maximum grain size, minimum grain size, concentration of sizes within selected phi limits, degree of roundness, nature of quartz surfaces and percentage of major minerals were made with a binocular microscope.

The top and bottom of the Reagan and Arbuckle were determined and the Reagan subdivided on the basis of observed lithologic changes and each interval described separately. The lithology, depth, and thickness of the Reagan and sub-

Reagan rocks were recorded and if sediments, thickness was recorded. Where possible a description of the nature of the contact between the Reagan and units above and below was made.

A numerical value was recorded to indicate the position of the well being examined with respect to structures (highs, lows, faults, etc.) as shown in the Configuration Map of Precambrian Surface in Kansas by Cole (1962).

The top and bottom of each subdivision, based on lithologic and textural similarities, were recorded and each interval described as follows: color; percent quartz; upper and lower phi size limits; total number of phi classes represented; number of phi classes represented by the modal 2/3 of the sample; a visual estimate of sorting; roundness of the largest, intermediate, and smallest grains present; percent of sample having roundness greater and percent less than 0.5 (Pettijohn, 1956, p. 59); nature of quartz grain surfaces; presence or absence of inclusions in quartz grains; type of quartz; nature and type of cement; nature and degree of porosity; presence or absence of oil or gas staining; maturity notation (see Folk, 1951); percent, roundness, size, nature, and type of feldspar; percent of dolomite, calcite, rock fragments, muscovite, biotite, clay matrix, glauconite, chert, and pyrite; and the color and hardness of the shale in the Reagan and the size, shape, and color of glauconite. Finally, a preliminary rock type notation was made for each sequence examined and the well as a whole. Collection of data in this

way not only permitted more rapid analysis but facilitated tabulation on IBM punch-cards for processing.

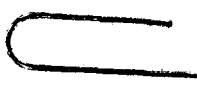
X-radiography, using a commercial hospital x-ray unit, was employed on some core sections in order to determine the presence or absence of sedimentary structures in the "homogeneous" portions of the cores. Glauconite pellets, illite laminae, shale fragments, and cementing materials were examined by means of x-ray defraction in order to determine their composition.

Ultra-sonic vibration, acids, and manual methods were used in an attempt to separate fossil materials from the matrix. None of the methods proved completely satisfactory, although fragments suitable for identification were obtained.

An IBM 7040 computer was utilized in making trend surface maps, computing the factor analysis and correlation matrices, and grouping wells using a program designed for numerical taxonomy.

Contour maps, isopachous maps, and maps showing rock units which rest on the Precambrian (lap-out, lap-on, worm's eye view) were constructed. Stratigraphic and structural cross sections were made.

All of the information collected during this study is on open file with the Kansas Geological Survey and may be examined upon request.



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Thanks is extended to Dr. W. M. Merrill for valuable suggestions and criticisms made during Dr. Ireland's leave of absence. Dr. Floyd Preston of the Department of Petroleum Engineering was very helpful in the early months of this study in helping find suitable methods for the arrangement of data for later quantitative analysis. Dr. A. J. Rowell aided in the identification of fossils.

Sincere thanks and appreciation are also extended to Dr. D. F. Merriam, who suggested the problem, and the Kansas Geological Survey for financial assistance. Gary Stewart, Rudy Lippert, Roger Kaesler, and Robert Scott of Lawrence and Virgil Cole of Wichita were helpful in many facets of the project. Numerous oil companies made available their information as did the United States Bureau of Mines in Bartlesville. Sincere thanks are extended to Mr. M. J. Reynolds of A. G. Oliphant Co. in Tulsa for his inspiration and helpful ideas and to Robert Miller of Northern Natural Gas Company for use of maps in the Otis-Albert Gas Field of Central Kansas.

Description of the Area

The study includes nearly 52,920 square miles in western Kansas. Rocks of the Paleozoic, Mesozoic, and Cenozoic Eras are exposed at the surface within the area. In southwestern Kansas approximately 8500 feet of these sediments must be penetrated in order to reach Precambrian rocks and approximately 3400 feet must be penetrated to reach Precambrian rocks on the uplifts.

The tectonic pattern of this region has changed somewhat throughout geologic time (Fig. 2), although no complete reversals of structural trends have occurred. Topographic features related to the tectonic elements shown on map A (Fig. 2) were influential during the deposition of Upper Cambrian and Lower Ordovician rocks. Minor structural elements in the basement have also played an important part in the depositional history of the Reagan Sandstone.

According to Reed (1954) the following events have taken place during the development of the Cambridge Arch:

1. Invasion of Late Cambrian and Early Ordovician seas over the area with the Cambridge Arch not yet developed.
2. The Cambridge Arch broadly upfolded at the close of Early Ordovician time and Cambro-Ordovician beds removed from the crest of the Arch.
3. Some uplift, folding, and erosion at the end of Devonian time with subsequent invasion of Mississippian seas from the east and southeast, covering the southern part of the Cambridge Arch.

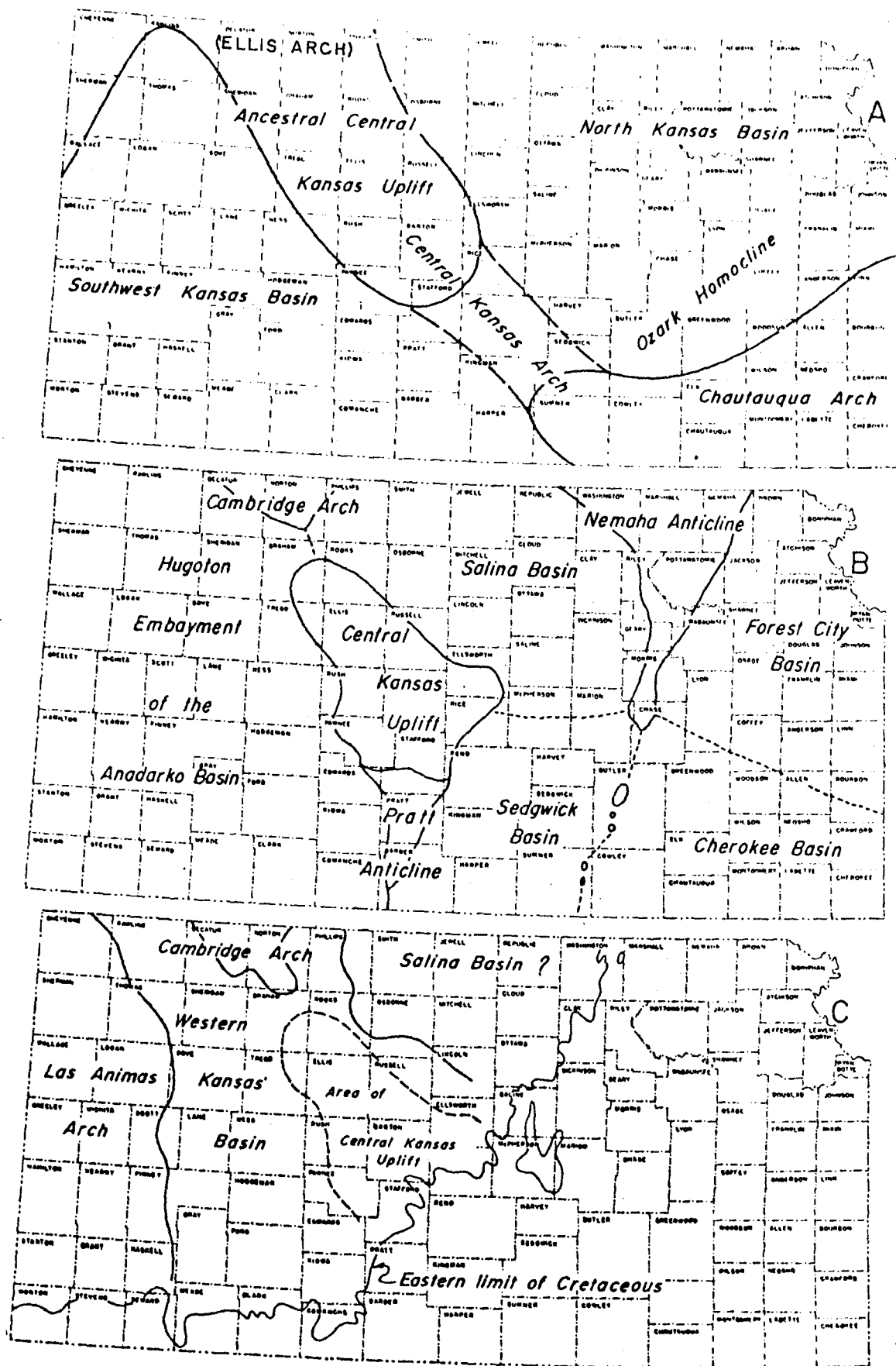


Figure 2.-Major structural features of Kansas; A, pre-Mississippian post-Devonian; B, pre-Desmoinesian post-Mississippian; C, Mesozoic (modified from Merriam, 1963, p. 178).

4. Extensive folding at the close of Mississippian deposition with the Cambridge Arch broadly uplifted and stripped of sediments.
5. Invasion of Pennsylvanian seas from the southeast, covering the Cambridge Arch and depositing progressively thinner and redder sediments toward the northwest. Some contemporaneous uplift is indicated by thinning of many subdivisions over the uplifts.
6. Some evidence of rejuvenation of the Siouxana Arch during early Permian. Generally, however, there was no interruption of sedimentation between Pennsylvanian and Permian time.
7. General uplift of the area at the close of the Permian. Triassic and Jurassic sedimentation did not reach much farther east than the west-central part of Nebraska.
8. Invasion of Cretaceous seas from the west and some uplift along the Cambridge Arch.
9. The Cambridge Arch was strongly uplifted in post-Cretaceous time, followed by extensive erosion.
10. Continental Tertiary sediments were deposited over eroded older beds with slight east to southeast tilting during post-Tertiary time following the extensive glacial activity in eastern Nebraska.

With the possible exception of a more complex Precambrian history and several additional periods of tilting, the history of the Central Kansas Uplift, a southeastward extension of the Cambridge Arch, is quite similar to that summarized above. Figure 3 shows, in graphic form, the development of these two areas relative to other structural features in Kansas.

The general sequence of pre-Permian rock units penetrated on the Cambridge Arch and Central Kansas Uplift includes rocks of Precambrian to Pennsylvanian age (Fig. 4). Rocks of the Silurian, Devonian and Mississippian Systems are

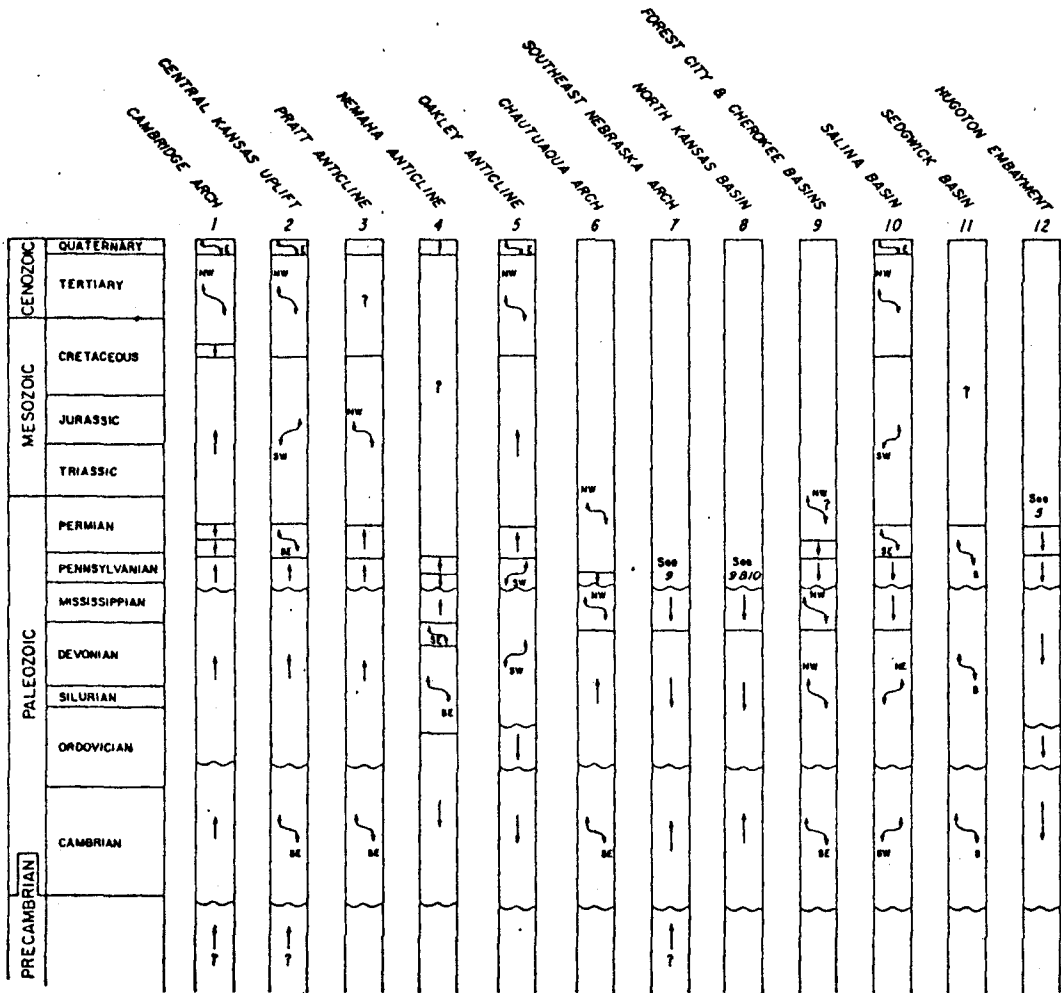


Figure 3.-Graphic representation of structural evolution of major features in Kansas. Divisions of columns indicate approximate position of stratigraphic horizons used for convergence maps by Merriam (1963). Arrows indicate the direction of movement up or down; curved arrows with directional notation indicate direction of tilting (from Merriam, 1963, p. 223).

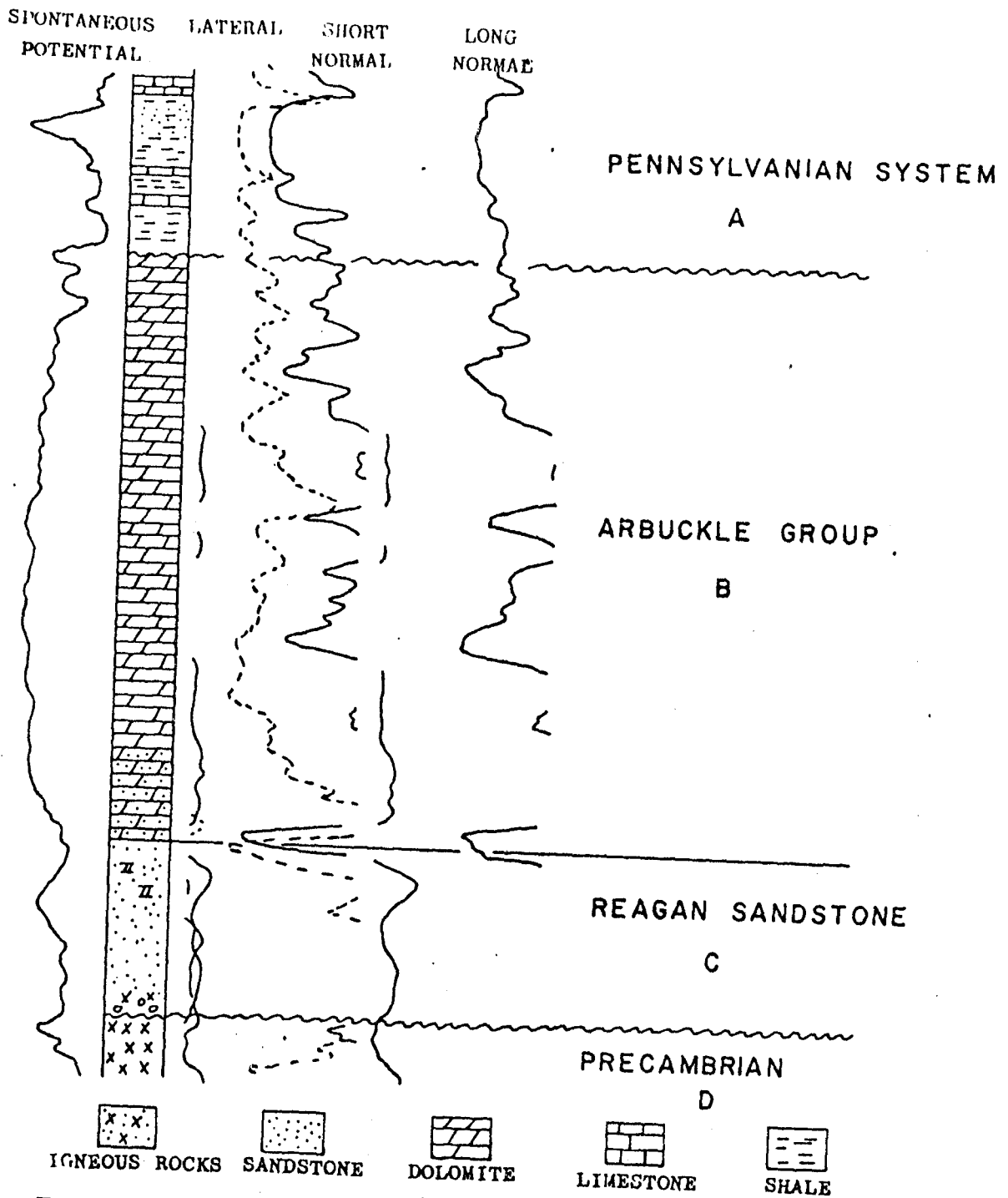


Figure 4 .-Diagram showing sequence of rock units penetrated on the Central Kansas Uplift and the Cambridge Arch. Not to scale.

absent in the areas uplift but are present in the adjacent basins. The Reagan Sandstone, Arbuckle Group, and rocks of the Pennsylvanian System can be found in contact with the Precambrian.

Ample evidence demonstrates the lithostratigraphic correlation between outcrop areas of Upper Cambrian rocks in the upper Mississippi Valley, Missouri, southern Oklahoma, Colorado, and the Black Hills. The network of cross sections shown by Fox and Sheldon (1957) also demonstrated the correlation between the Reagan Sandstone in Kansas and outcrop areas in Missouri, Oklahoma, and Colorado. This relationship is also well shown by Ireland (1944, 1955, 1956), Lee (1956), and MacLachlan (1961).

Figure 5 shows the generally accepted correlations of Upper Cambrian rocks in the Midcontinent. Although biostratigraphic correlations are implied, the primary value of this figure is to relate lithologic units. From the correlation chart it can be seen that problems concerning the base of the Upper Cambrian exist. At the present time the base of the Upper Cambrian is drawn at the base of the lowest fossil zone; thereby leaving the age of any sediments which occur below this zone in doubt. Many geologists are of the opinion that no marine rocks representing Early and Medial Cambrian time are present in the Midcontinent. The sub-Reagan sediments (Rice Formation) and arkoses are generally considered to be Precambrian in age although they equally well may represent fluvial and lacustrine deposits of Early and Medial Cambrian age.

LOCATION			FRONT RANGE COLORADO	CENTRAL MINERAL REGION, TEXAS	ARBOCKLE- WICHITA MTS OKLAHOMA	CENTRAL KANSAS (subsurface)	BLACK HILLS S. DAKOTA	OZARK REGION MISSOURI	WISCONSIN- MINNESOTA	
SYSTEM ABOVE			ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN or PENNSYLVANIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	
SYSTEM	SERIES	STAGE								
CAMBRIAN SYSTEM	UPPER CAMBRIAN	TREMPALAIAN	PERMIAN FORMATION	WILHELM'S FORMATION SAN BADA LIMESTONE XILNBURGER	BUTTERLY DOLOMITE	EMINENCE DOLOMITE	DEADWOOD FORMATION	EMINENCE DOLOMITE	JORDAN SS MEMBER	
		FRANCONIAN			SIGNAL MOUNTAIN FORMATION			ROYSER DOLOMITE	POTOSI DOLOMITE	Lodi MEMBER
	DRESDENIAN				FORT SILL LIMESTONE	ABSENT				DOE RUN DOLOMITE
		LOWER						POINT ROCK SHALE MORGAN CREEK LS ELIOT SS	ECNEY CREEK FORMATION	
				LION MTS SS CAP MOUNTAIN MEMBER REGENCY SS	REAGAN SANDSTONE	BONNETTARE DOLOMITE REAGAN SANDSTONE		FRANCONIA FORMATION	DAVIS FORMATION	FRONTON MEMBER
								BONNETTARE DOLOMITE	GALESVILLE MEMBER	
								LAMOTTE SANDSTONE	Eau Claire MEMBER	
									St. Simon SANDSTONE	
						???			???	
						RICH FORMATION				
						IGH?				
PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS										

Figure 5 .-Regional correlation chart of Cambrian rocks in the central United States (adapted from Howell et al, 1944).

The Cambrian-Ordovician boundary is transitional; however, in any one area Cambrian and Ordovician rocks are overlain by rocks of the Pennsylvanian System.

NATURE AND DISTRIBUTION OF
PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS

Introduction

The work of Landes (1927) was an early attempt to obtain information regarding the lithology and distribution of Precambrian rocks and was made before sufficient control was available. Farquhar (1957), however, with more adequate control was able to not only determine distribution of rock types but formulate a general history of the Precambrian in Kansas. Walters (1946), in his study of buried Precambrian hills, made a detailed study of the Precambrian in portions of Ellsworth and Barton Counties. Scott and Hambleton (1964) outline six lithologic terranes (Fig. 6) based on the study of samples from 800 wells in central and western Kansas. Ireland (1955) published a map of the Precambrian surface in northeastern Oklahoma and part of adjacent states which is reconstructed to the pre-Paleozoic position. Cole's (1962) map of the configuration of the Precambrian surface (arkose or next older surface) in Kansas is based on more than 4000 control points (Fig. 7).

Petrography, Distribution, and Age

The Precambrian rocks of Kansas include a metamorphic group composed of quartzite, granulite, schist, phyllite, and gneiss, which was intruded by igneous rocks of batholithic

DISTRIBUTION OF PRECAMBRIAN

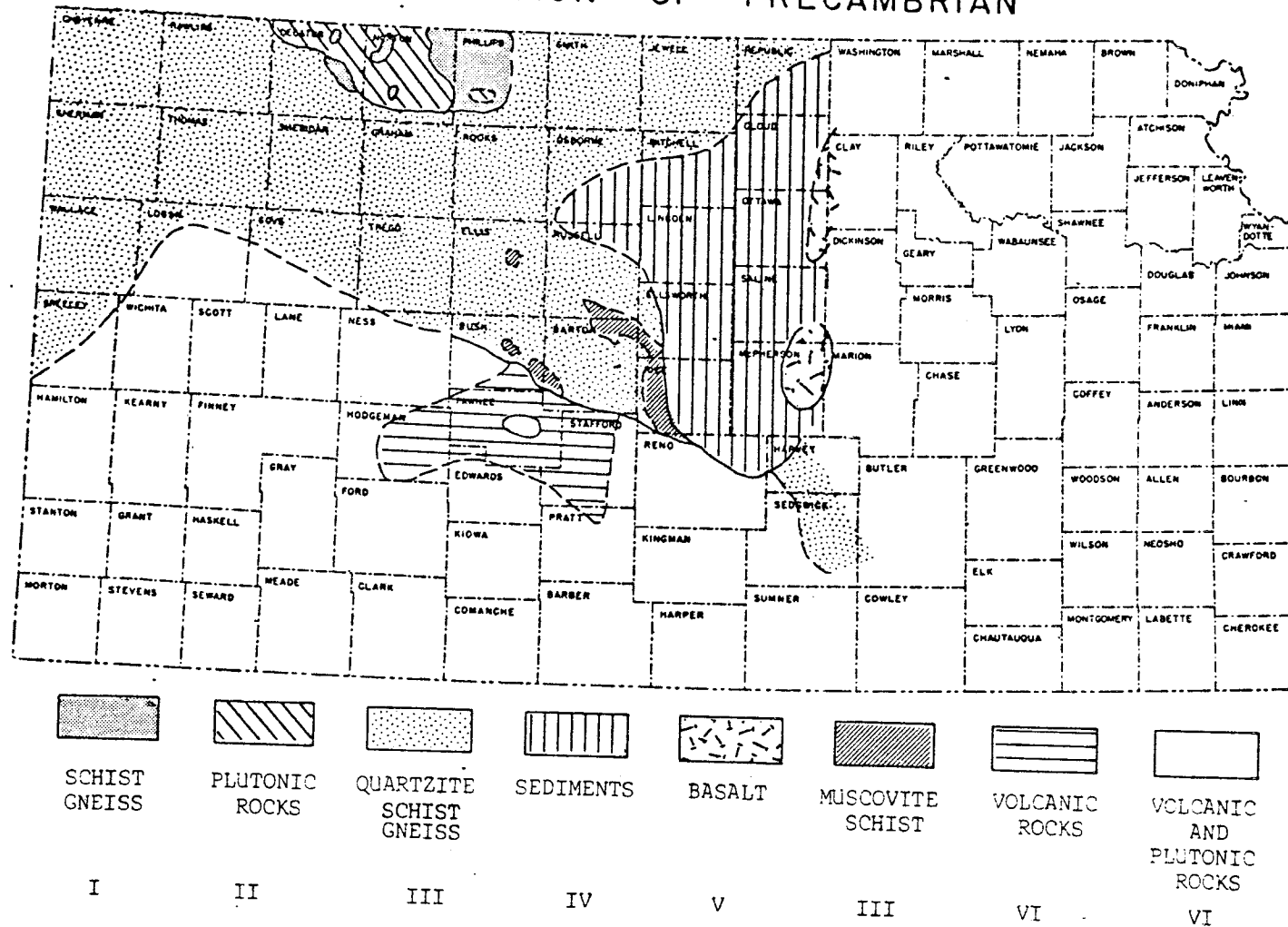


Figure 6.-Map showing distribution of Precambrian rocks in western Kansas (see text page 24 for names of areas I, II, III, IV, V, and VI.)

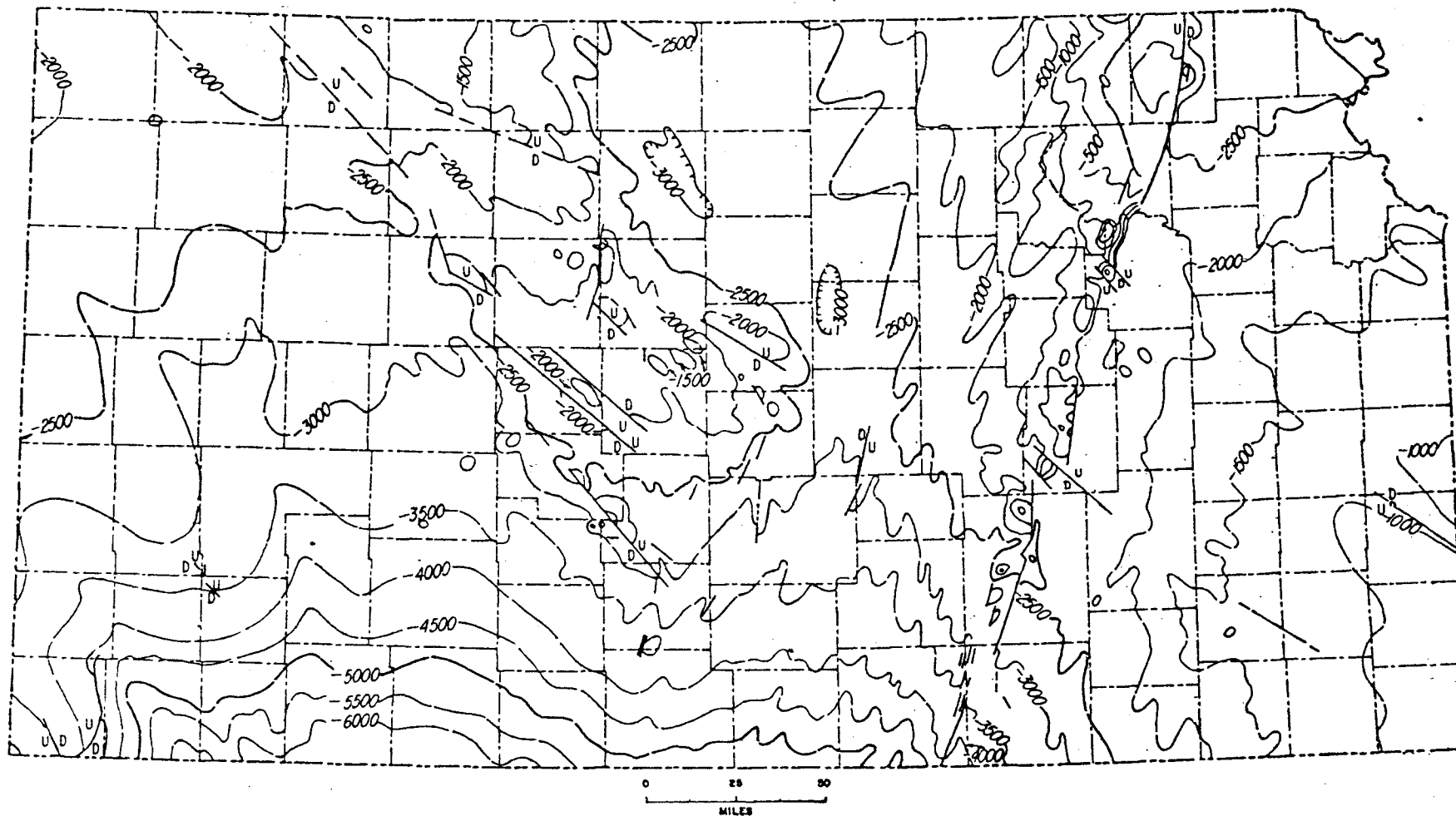


Figure 7.-Preliminary regional configuration map of the top of Precambrian basement complex in Kansas. Contour interval 500 feet (from Merriam, 1963, p. 209).



A



B



C



D

Figure 8 .- Photomicrographs of representative Precambrian rocks.
 A. Hornblende granite, Nicols crossed, X150. B. Biotite gneissic granite, Nicols crossed, X110. C. Muscovite quartzite, Nicols crossed, X150. D. Porphyro-blastic schist, section cut normal to schistosity. F, feldspar, Q, quartz, X, points where thin section has broken away. Nicols not crossed, X4.3 (from Scott and McElroy, 1965).

dimensions consisting chiefly of granite, but also including some darker magmatic rocks (Farquhar, 1957, p. 59).

Photomicrographs of representative rocks are shown in Figure 8.

The six provinces delineated by Scott and Hambleton (1964) in western Kansas are (Fig. 6): (I). the Phillips Metamorphic Terrane characterized by rocks of the almandine-amphibolite facies and granitic gneisses; (II). the Norton Igneous Terrane consisting mainly of plutonic granite, quartz monzonite, and granodiorite; (III). the Central Kansas Metamorphic Terrane characterized by rocks of the greenschist facies, and granitic gneissic and granitic plutonic rocks; (IV). the Rice Sedimentary Basin consisting of a thick sequence of unmetamorphosed arkose, feldspathic sandstone and shale; (V). the McPherson Basalt Terrane; (VI). the Southern Kansas Igneous Terrane consisting of volcanic and plutonic rocks.

Fifteen radiometric dates of rocks in western Kansas range from 1350 to 1510 m.y. for Rb-Sr and from 1080 to 1260 m.y. for K-Ar (Scott and Hambleton, 1964).

Nature of Precambrian Surface

The time span between the youngest Precambrian intrusion or metamorphic event and the encroachment of the Late Cambrian seas is recorded by a weathered zone on the Precambrian surface in some areas, a thick sequence of arkose ("granite

wash") and more than 1200 feet of arkose, feldspathic sandstone, and shales in the Rice Sedimentary Basin. Assuming our concept of geologic time is correct, approximately 530 million years elapsed during this interval (roughly equivalent to Lipozoic interval of Calvert, 1964).

The nature and distribution of Lower Paleozoic rocks indicate deposition on a surface of low relief during Late Cambrian and Early Ordovician time. Walters (1946) recognized quartzite hills which stood as islands in the Late Cambrian sea but regional relief was low.

In some areas Paleozoic sediments are found in contact with "fresh" granite. This relationship is best accounted for by the assumption that prior to the time of deposition of the overlying sediments, erosional agents were strong enough to remove the weathered detritus. It would be unlikely that this area survived any pre-deposition weathering. Generally, however, the areas underlain by granite have an upper weathered zone or are covered by "granite wash." The depth of weathering varies and thickness is probably a factor of erosion.

Along the present Cambridge Arch there is a thick layer of arkose and weathered granite with a maximum thickness of 80 feet in some places. It is difficult in some cases to determine whether the material is in place or has been transported. Criteria for such a distinction have been discussed by Scott and McElroy (1964).

Quartzite appears to be fresh in most samples in which it occurs; however, a thin mantle of stained quartzite fragments rests upon compact, clear quartzite in certain localities in Russell and Barton Counties.

History

It is evident that during Precambrian time the area now occupied by the Cambridge Arch and Central Kansas Uplift was affected by complex physical and chemical processes.

Farquhar (1957) concluded that: (1). the basement complex consists of a group of metamorphic rocks cut by members of a suite of intrusive igneous rocks; (2). regional metamorphism was moderately intense, as indicated by the presence of garnet and sillimanite in certain samples; (3). many signs of deformation are present in the foliated metasediments; (4). the regional metamorphism of the basement sediments is believed to be the result of a period of Precambrian orogeny and is not attributed to static load; (5). the steep dips as identified in certain core samples suggest lateral compression and isoclinal folding in the basement; (6). the intrusive rocks that cut the metamorphosed group are composed of "later" Precambrian granite; (7). tentative age correlation of the Precambrian rocks forming the basement complex in Kansas with those in neighboring areas of the Midcontinent suggests that regional

metamorphism in Kansas occurred about 1,500 million years ago and that some of the "later" granite was intruded 670 million years ago; (8). prior to Late Cambrian time the Precambrian rocks were eroded to a surface of low relief on which a few hills of resistant rock remained.

Scott and Hambleton (1964) propose two thermal events based on radiometric dates in western Kansas, occurred 1350-1510 m.y. and 1080-1260 m.y. ago. "...Petrographic data suggest two geological events related to the two thermal events; an earlier igneous-metamorphic event followed by a younger predominantly metamorphic event; and later, gabbro bodies and basalt were emplaced, and the Rice Basin was developed. Evidence is insufficient to line these events with a geosynclinal cycle."

Both of the proposals outlined above have merit but it is impossible at this time to select one over the other; however, the one by Scott and Hambleton is based on greater control and on radiometric dates, which were lacking in the study by Farquhar.

PALEONTOLOGY, AGE, AND NOMENCLATURE OF THE REAGAN

Because of the Reagan's stratigraphic position below known Upper Cambrian rocks in southeastern Missouri and southern Oklahoma, it is generally inferred that the Reagan is Late Cambrian in age. With an absence of faunal evidence to the contrary the assumption of Late Cambrian transgression in the Midcontinent region from southeast to northwest led to the conclusion that the Reagan in Kansas is younger than the lithostratigraphic equivalents in Missouri and Oklahoma. Lochman (1956, p. 471) states: "The occurrences of "Lamotte" throughout central Kansas are most probably the age equivalents of the lower part of the Trempealeau Dolomite in the Iowa section. The marked westward thinning and disappearance of Franconian beds in both southeastern Nebraska and Missouri makes it quite unlikely that any Franconian deposition occurred in Kansas". Recent identification of brachiopods in a well core from northwestern Kansas and trilobites in a well core from northeastern Colorado verifies the assumption of time transgression but disproves the generally accepted amount of time involved.

Three stratigraphically successive faunal assemblages in the Dresbach Formation are defined as the Cedaria, Crepicephalus, and Aphelaspis zones. According to Bell, Berg, and Nelson (1956) the lowest (Cedaria) and highest (Aphelaspis) assemblages characterize migrating and time-transgressive ecologic niches.

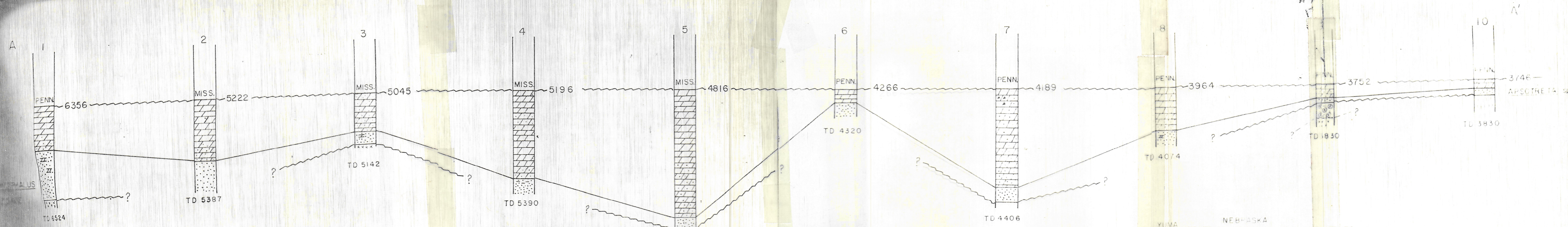
Ojakangas (1960) gives a complete summary of fossil occurrences in the Lamotte Formation of southeastern Missouri. If what are identified as trails of trilobites, in the Potsdam Sandstone of New York and the Mt. Simon of Wisconsin, are valid criteria for correlation, the Lamotte in which markings are found could be correlated with the Mt. Simon and Potsdam; however, this assumption is certainly questionable. Occurrences of Dicellomus have also been reported from the Lamotte Formation indicating a Dresbachian age. Lochman (1940) describes the lower fifty feet of the Bonnetterre Dolomite, which directly overlies the Lamotte, as containing a Late Cambrian fauna (late Cedaria fauna) of more than 61 species. This is the best evidence at present for assigning the Lamotte to a Late Cambrian (possibly middle Cedaria) age.

The only fossils known from the Reagan in Oklahoma are fragments of thick-shelled porcellaneous appearing phosphatic obolid brachiopods, which Walcott (1913, p. 577) identified as Dicellomus politus. This would relegate Reagan deposition during the Dresbachian Stage if Walcott's identification is correct (Bell, 1944). In Oklahoma additional evidence of a Dresbachian age is the Reagan's stratigraphic position below the Honey Creek Formation of the Arbuckle Group which carries fossils of the Elvinia zone. Unlike the Lamotte, which could be assigned to the middle part of the Cedaria zone, the Reagan in Oklahoma can only be placed somewhere within the Dresbachian Stage.

Fossils indicating Dresbachian age have been found in samples from a well drilled in Norton County, Kansas, and in a well in Yuma County, Colorado just west of the northwestern Kansas border. The Reagan in the California Oil Company No. 1 Mumm, NE NE sec. 1, T. 3 S., R. 48 W., Yuma County, Colorado contained trilobite molds and casts, and numerous linguloid brachiopods. The trilobites, identified as Coosella sp. and Komaspidella sp. (California Oil Company, personal communication) are characteristic of the lower part of the Crepicephalus zone indicating a Dresbachian age (Fig. 9).

In Norton County, Kansas, the Derby Oil Company No. 4 Schoen Well, C SE sec. 35, T. 3 S., R. 24 W. contains fragments of brachiopod shells in the Reagan Sandstone. At this locality the Reagan is overlain by the Bonneterre Dolomite. The fragments range from 1 to 5 mm in length and are composed of dahllite ($3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{CaCO}_3$). Identification (A. J. Rowell, personal communication) as Apsotreta sp. is certain although specimens showing the interior of the shell were rare. In addition many obolid fragments were identified.

Two species of the genus Apsotreta from the Riley Formation in central Texas have been described by Palmer (1955, p. 770). Apsotreta expansa occurs in what he describes as the post-Aphelaspis zone, which is higher than the Aphelaspis zone of Wisconsin, but still below the Elvinia zone (Fig. 10), whereas the occurrence of Apsotreta sp. in Norton County indicates a Dresbachian age for the Reagan Sandstone in the



STRATIGRAPHIC CROSS SECTION A A'
 YUMA CO., COLORADO TO NORTON CO., KANSAS

Prepared by M.N. McElroy

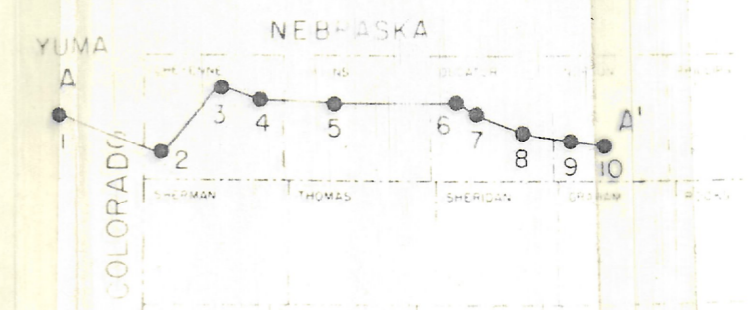
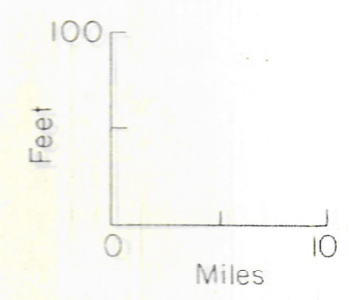
Datum Top Arbuckle Group

EXPLANATION

- | | | | |
|--|-----------------|--|-------------------|
| | Dolomite | | Sandstone |
| | Sandy Dolomite | | Weathered Granite |
| | Cherty Dolomite | | Granite |
| | Schist | | |

Figure 9

KGS OFR 65-6



Norton County area where the Reagan is overlain by Bonnetterre Dolomite. The fossils in Yuma County, Colorado, from the Crepicephalus zone increases the possibility of a Middle Dresbachian age (Crepicephalus) for the Sandstone in north-western Kansas. Apostreta orifera is found in the upper portion of Cedarina-Cedaria zone, and the Coosella zone.

If the Lamotte in Missouri is of the Cedaria zone and the Reagan of Kansas is of the Crepicephalus zone, it substantiates the time transgressive nature of the basal Upper Cambrian sandstone in the Midcontinent, as proposed by many authors; however, it does not represent as great a time interval as generally conceived (Fig. 11). Unfortunately no such relationship with Oklahoma beds can be shown because paleontological evidence is lacking.

In Kansas, nomenclature of Upper Cambrian rocks is somewhat confused. A plot of scout ticket "calls" of the "basal sandstone" on a map shows that sandstone in wells located east of the Principal Meridian is generally known as Lamotte, (from Missouri nomenclature) whereas that west of the line is called Reagan (from Oklahoma nomenclature). The name for the overlying Arbuckle Group in Kansas is extended from the type section in southern Oklahoma, but the Kansas terminology has formation and member names derived from Missouri. The catch-all term "basal Paleozoic sandstone" has been employed by some, but is not satisfactory.

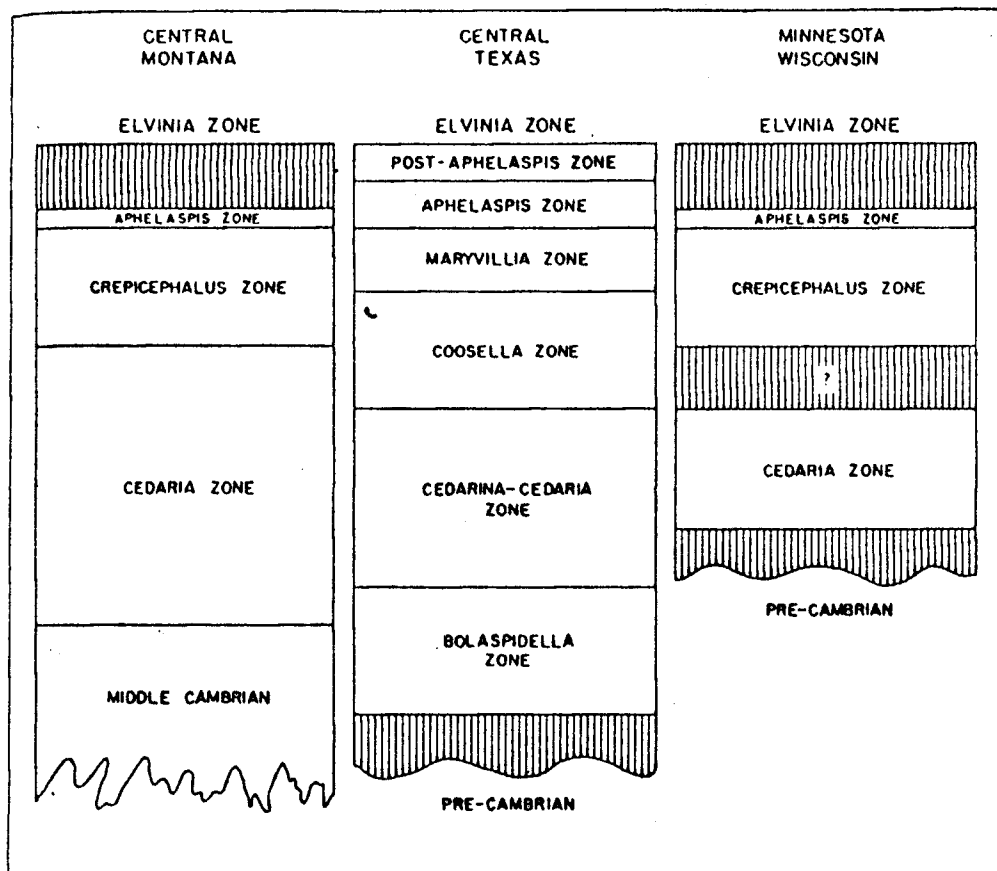


Figure 10 .-Correlation of the trilobite zones of the Riley Formation with those recognized in the type Dresbachian section of Minnesota and Wisconsin, and in central Montana (from Palmer, 1955, p. 713).

	ZONES	WISCONSIN	MISSOURI	OKLAHOMA	TEXAS	KANSAS COLORADO
DRESBACHIAN	APHELASPIS	Galesville		?	Fm.	
	CREPICEPHALUS	Eau Clair		Reagan		Reagan
	CEDARIA	Mt. Simon	Lamotte	?	Riley	

Figure 11.-Biostratigraphic relationships between Kansas-Colorado and Texas, Oklahoma, Missouri, and Wisconsin.

This paper is not concerned with the nomenclatural problem. The name Reagan will be retained and used for the quartzose sandstone overlying Precambrian crystalline rocks, arkose, and the sub-Reagan Rice Formation, and overlain by either the Arbuckle Group or Pennsylvanian rocks. The name Reagan is used for several reasons. It is better established in Kansas terminology than Lamotte and, as shown previously, there is no age criterion which would justify the substitution.

LITHOLOGY AND PETROGRAPHY OF
THE REAGAN SANDSTONE

A typical sequence of Reagan Sandstone in Kansas consists of the following rock types, from top to bottom: dolomitic sandstone, quartzose sandstone, feldspathic sandstone and arkose (Fig. 12 and 13). Locally, shale beds may be present and in the area of the Cambridge Arch quartz-glaucouite sandstone is common in the upper part of the Reagan. Orthoquartzite (used here to indicate quartzose sandstone which breaks across the grains when fractured) which results from diagenetic modification of the dolomite or quartzose sandstone types, is found in limited areas on the Central Kansas Uplift.

Seldom are all of the rock types found in samples from a single well. The thickness and distribution of all types are erratic.

Quartzose Sandstone

In the quartzose sandstone at least 90 percent of the grains are quartz. In the Reagan the remaining 10 percent is made up of feldspar, muscovite, biotite, glauconite, chert, pyrite, magnetite, illite and a highly variable assemblage of heavy minerals. With the exception of glauconite, chert and illite the percentage of minor minerals decreases upward in the Reagan. No detailed study of the

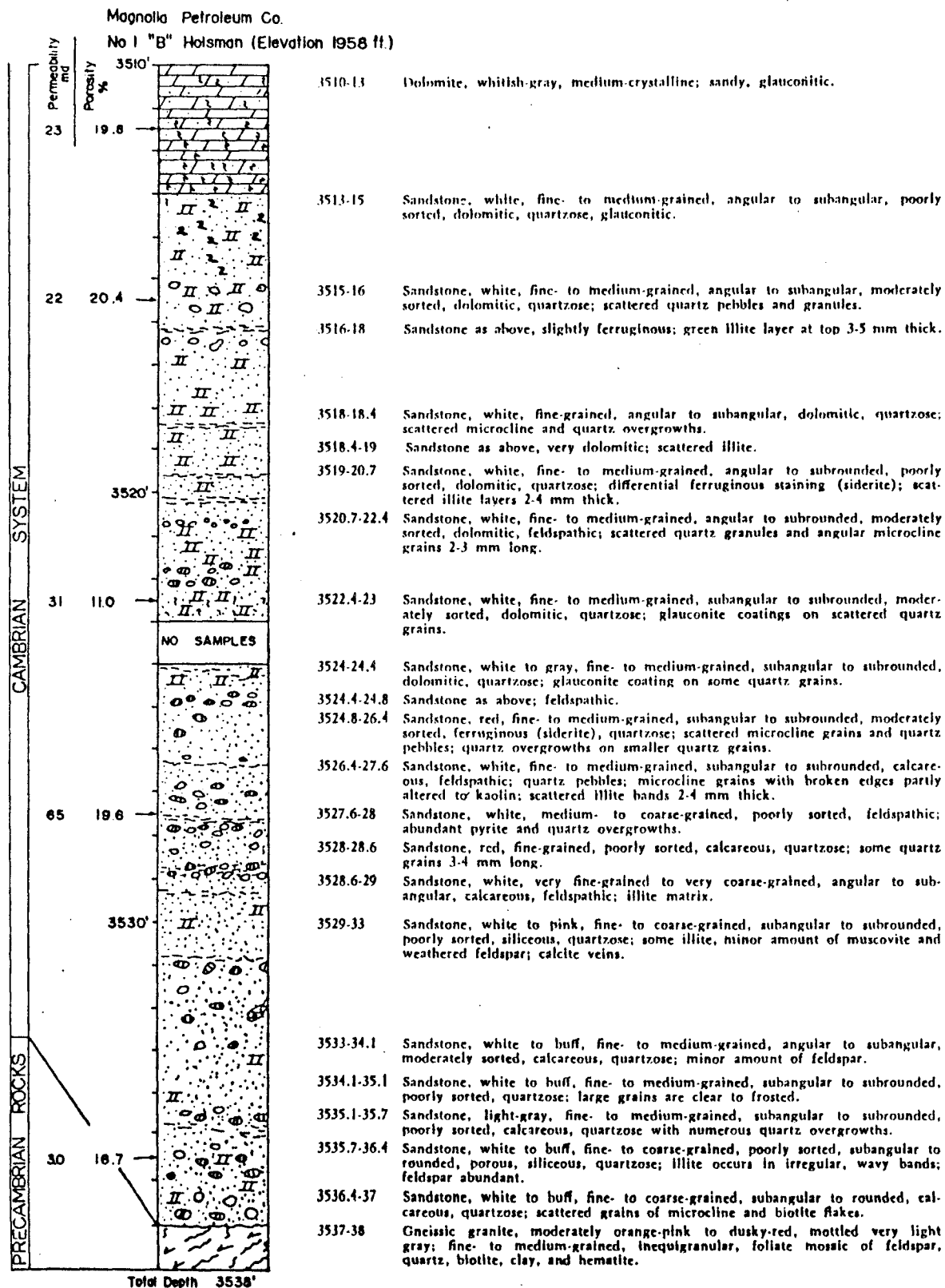
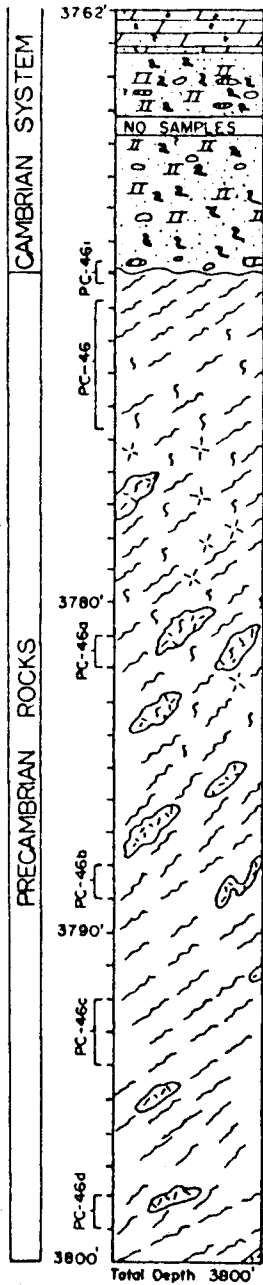


Figure 12.-Lower Arbuckle Group (3510-3513 feet), Reagan Sandstone (3515-3537 feet), and Precambrian gneissic granite (3537 feet) from Magnolia No. 1 "B" Holsman well SE NE SE sec. 15, T 7 S, R 19 W, Rooks County, Kansas (Explanation on Figure 13, from, Scott and McElroy, 1964, p. 8).

Derby Oil Company
 No. 4 Schoen (Elevation 2435 ft)



- 3762.63.2 Dolomite, gray to buff, medium-crystalline, porous, sandy, oil stained abundant glauconite.
- 3763.2-63.5 Dolomite as above; sand more abundant.
- 3763.5-65.3 Sandstone, buff, fine grained to very coarse-grained, angular to subangular, moderately sorted, dolomitic, quartzose; porous, abundant glauconite, minor amounts of muscovite, biotite, and potassium feldspar (oil stain occurs in most sandy parts).
- 3765.8-66.2 Sandstone, tan, very fine-grained to fine-grained, angular to subangular, poorly sorted, dolomitic, siliceous, quartzose; glauconite, biotite, and minor amounts of pyrite.
- 3766.2-68 Sandstone, green, fine-grained to very coarse-grained, angular to subrounded, poorly sorted, hard, dolomitic; glauconitic; scattered quartz pebbles up to 5 mm long.
- 3768-70 Arkose, gray to pink, fine- to coarse-grained, angular to subrounded, poorly sorted, hard, dolomitic; abundant biotite, quartz; some feldspar pebbles longer than 5 mm; glauconite absent.
- 3770-74 Schist, medium dark-gray, streaked light gray, fine-grained, nearly equigranular; quartz-feldspar matrix with biotite laminae 1-3 mm thick, discontinuous, and locally wavy.
- 3774-76 Schist as above; feldspar partly argillized; rock fractures parallel schistosity; fractures coated with pyrite and green, glauconitic clay.
- 3776-80 Schist as above; intercalated with lenses (5-25 mm thick) of pinkish-gray porphyroblastic feldspar in quartz groundmass, granitic lenses of medium- to coarse-grained feldspar and quartz, both paralleling schistosity; biotite laminae commonly concentrated along contact with granitic lenses.
- 3780-85 Schist, very light-gray to yellowish-gray, streaked dark-gray by biotite lenses; porphyroblasts of highly argillized feldspar in medium-grained groundmass of quartz; lenses of altered, light-gray, medium- to coarse-grained feldspar and quartz intercalated with fine-grained schist; locally, schistosity nearly parallel to core axis; degree of alteration decreases from 3783 to 3785 feet; potassium-argon age of 1.10 billion years from a granitic lens at 3783 feet.
- 3785-91 Schist, dark-gray, mottled light-gray, fine-grained, nearly equigranular; schistosity imparted by unaltered elongate quartz and biotite grains; granitic lenses with moderate-orange-red, medium- to coarse-grained feldspar and quartz paralleling schistosity make up 15-20 percent of core samples; pygmatic folds developed in some granitic lenses; fractures coated with "dead" oil, pyrite, calcite, and glauconitic clay.
- 3791-96 Schist as above; garnetiferous; granitic lenses make up 1-5 percent of core samples.
- 3796-3800 Schist as above; granitic lenses make up 5-10 percent of core samples; potassium-argon age of 1.24 billion years from schist at 3799 feet.

EXPLANATION

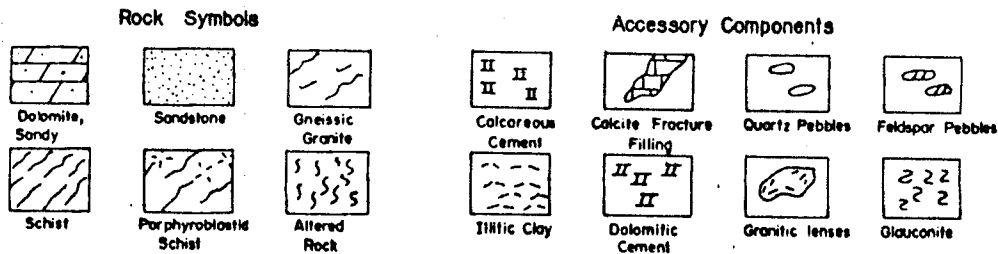


Figure 13.-Lower Arbuckle Group (3762-3763 feet), Reagan Sandstone (3763-3770 feet), and Precambrian schist (3770-3800 feet) from Derby No 4 Schoen, C SE sec. 35, T 3 S, R 24 W, Norton County, Kansas (Thin sections on file with Kansas Geological survey are indicated on left margin, from Scott and McElroy, 1964, p. 9).

heavy minerals was made. The sparse number of heavy minerals in the Reagan made attempts to collect them from cable-tool samples unsatisfactory. Minerals identified from 14 analyses of five cores included highly rounded grains of tourmaline and zircon and angular to subrounded grains of apatite, rutile, anatase, hornblende, garnet, pyrite, marcasite, magnetite, and dahllite.

Mackie (1896), Krynine (1946), and Folk (1959), have classified detrital quartz grains on the bases of inclusions, grain boundaries, extinction angles, and internal morphology. The classifications by Krynine and Folk were employed during the early part of this study but several of the "ideal types" specified by Krynine are believed to be common to more than one type of source rock. The inadequacy of quartz morphology as an indicator of source rocks was pointed out in a detailed study by Blatt and Christie (1963). They concluded that the presence or absence of undulatory extinction and polycrystallinity in clastic quartz grains is of very limited usefulness in determining the provinces of sediments. There is little doubt, however, that the underlying igneous and metamorphic rocks supplied great quantities of quartz and there is an abundance of all types in most samples of the Reagan, which would be expected considering the complex variety of source rocks available.

Quartz grains observed in the Reagan Sandstone of Kansas range from pebbles as large as 12 mm to grains as

small as .031 with the majority of grains between 2 mm and 0.0625 mm. Size of grains in a given sample is related to the size of grains available from source areas, nature and duration of the agent of transportation, the nature of the environment of deposition and the degree to which sorting processes act upon the material. Some grains in the lower part of the Reagan were derived from underlying rocks with little or no abrasion or size reduction. No relationship was observed between size of the quartz grains in the Reagan and those in underlying rocks that might be indicative of a particular source rock. The friable nature of polycrystalline quartz in both Precambrian and Cambrian rocks indicates that the underlying Precambrian rocks could serve as a source for both large and small grain sizes. Extensive abrasion would not be required to alter the size and shape of the somewhat ovoid quartz in the underlying schists to account for much of the subrounded quartz in the Reagan.

Quartz overgrowths obscured particle roundness in many samples. Shapes of quartz grains in the Reagan range from those with a low degree of sphericity to an extremely high degree, although occurrence appears to be random. Angular to well rounded grains were found throughout most samples and in the lower few feet of the Reagan both well rounded and angular grains occurred together.

Quartz grain surfaces in the Reagan are smooth, polished, frosted, and faceted. The percentage of quartz grains affected by secondary enlargement is extremely high and numerous euhedral crystals are present. Frosting can, in part, be accounted for by corrosion and by peripheral pits resulting from dolomite replacement. But the majority of frosting is believed to be the result of wind action because of the close correlation between frosting and rounding and sphericity in restricted size limits.

Sorting of the Reagan Sandstone ranged from well-sorted with 90 percent of the grains falling in two phi classes to poor sorting with 90 percent falling in more than five phi classes. Sorting increases from the bottom to the top in nearly all samples (Fig. 14 and Table 1, limits of statistical measure found in Appendix A). One well has a definite bimodal distribution and might be the remains of leached dolomite from the Ordovician Gasconade Dolomite. Variations in sorting producing graded bedding can be seen in Figure 15.

Sorting processes were not too effective on the coarser fraction Reagan Sandstone itself although eolian processes were probably important in the removal of silt, and clay from the parent material. The general upward increase in sorting results from the loss of large amounts of the coarse grains which were deposited closer to the source or shore line.

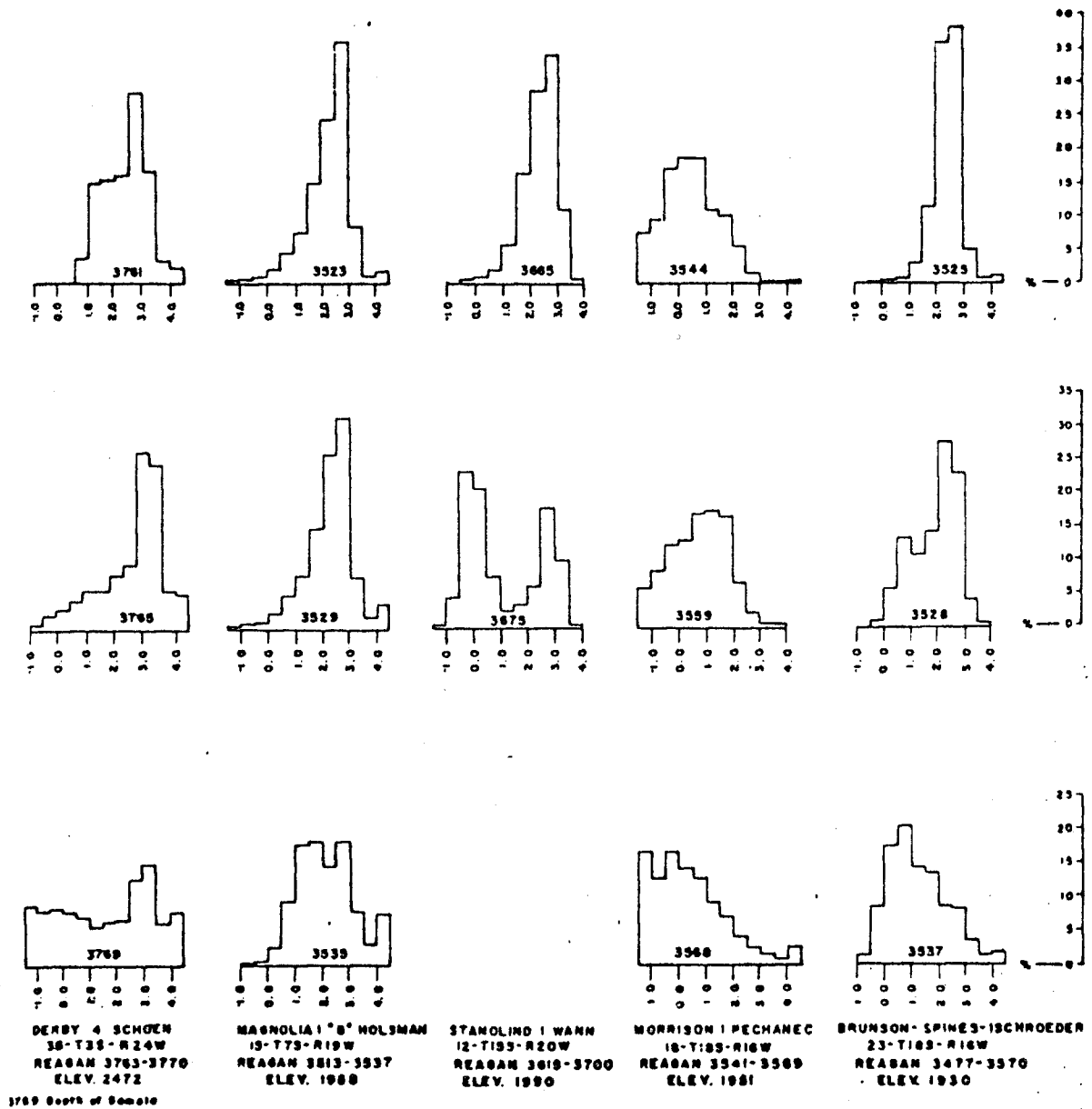


Figure 14.-Grain size distribution in the Reagan sandstone from selected intervals from five cores.

WELL	DEPTH	MEAN	MEDIAN	MODE	GRAPHIC STANDARD DEVIATION	GRAPHIC SKEWNESS	GRAPHIC KURTOSIS
I.	3961	2.4	2.5	2.5-3.0	0.87	-.111	0.922
	3765	2.3	2.7	2.5-3.0	1.21	-.368	1.120
	3769	1.5	1.7	3.0-3.5	1.85	-.280	0.727
II.	3523	2.3	2.5	2.5-3.0	0.75	-.386	1.020
	3529	2.3	2.3	2.5-3.0	0.79	-.740	1.147
	3535	2.2	2.0	1.5-2.0 & 2.5-3.0	1.07	+.230	1.135
III.	3665	2.4	2.5	2.50-3.0	.64	-.234	0.861
	3675	1.0	0.7	-0.5 -0.0	1.48	+.250	0.658
IV.	3544	0.5	0.5	0.0-0.5	1.04	0.000	1.054
	3559	0.7	0.8	1.0-1.5	1.10	-.086	0.846
	3568	0.3	0.2	-1.5--1.0 & -0.5-0.0	1.43	+.115	0.683
V.	3525	2.6	2.5	2.0-2.5	.20	-.860	1.470
	3528	1.7	2.1	2.0-2.5	.76	-.632	0.803
	3537	1.2	1.0	0.5-1.0	1.10	+.231	0.773

I. Derby No. 4 Schoen
 II. Magnolia No.1 "B" Holsman
 III. Stanolind No. 1 Penny Wann

IV. Morrison No. 1 Pechance
 V. Brunson - Spines No. 1 Schroeder

Table 1.-Statistical data from selected intervals from five cores of the Reagan Sandstone in the area of the Cambridge Arch and Central Kansas Uplift.



Figure 15.-Photograph of Reagan core from the Magnolia No. 1 "B" Holsman well, sec. 15, T 7 S, R 19 W, Rooks County, Kansas. Note size distribution of grains, illite laminae and irregular nature of illite layers (depth, 3535.6 to 3535 feet).

The term matrix refers to the material which fills the interstices between the larger grains (Krynine, 1948). It is a relative term and applies only when size range is large. It is almost completely absent in the quartzose sandstone of the Reagan in Kansas, except for a few scattered clay particles, and is indicative of the relative "high energy" environment in which the Reagan was deposited.

This is in contrast to the underlying arkose ("granite wash") and Rice Formation which are characterized by a matrix of kaolinite and other clay size particles.

Quartz, dolomite, glauconite, siderite, and a minor amount of calcite occur as cementing materials, grain coatings, pore-fillings, and in the form of quartz as distinct overgrowths.

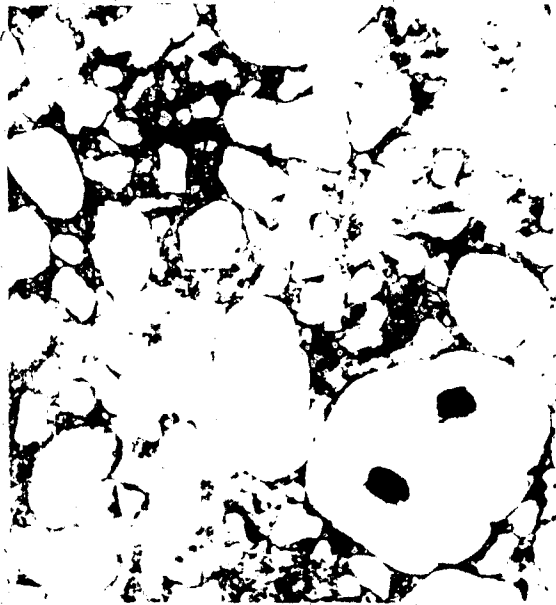
Siderite and glauconite (determined by x-ray diffraction) are relatively minor as cementing agents. Siderite is a principal cement in the lower portion of the Magnolia Petroleum Company Well No. 1 "B" Holsman (SE NE SE sec. 15, T. 7 S., R. 19 W) in Rooks County (Fig. 16).

Quartz occurs as a pore-filling cement (Fig. 16C), and as overgrowths on detrital quartz grains (Fig. 16D). Some samples demonstrate a high degree of pressure solution with little added cement (Fig. 17A). In such cases, sutured contacts between detrital grains are common.

Carbonates, particularly dolomite, and more rarely calcite, constitutes the most important cementing agent (Fig. 17C). The



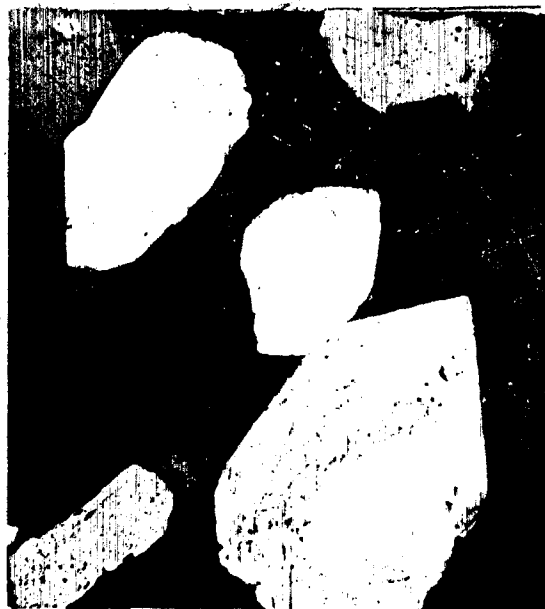
A



B



C



D

Figure 16.—Photograph of core (A) and photomicrographs of Reagan Sandstone (B-D). A. Photograph of core of Reagan Sandstone. Dark bands cemented with siderite. Light bands cemented with dolomite or cement absent. B. Quartz grains cemented with siderite. Note hornblende inclusions in well-rounded quartz grain. Nicols not crossed, X100. C. Quartzose sandstone with secondary enlargement of quartz grains, dolomite cement and chert fragment. Nicols crossed, X225. D. Quartz overgrowths on well-rounded quartz grains. Nicols crossed, X225.

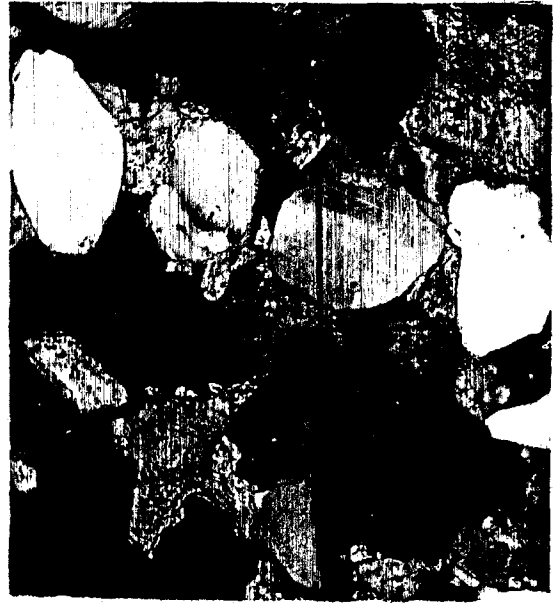
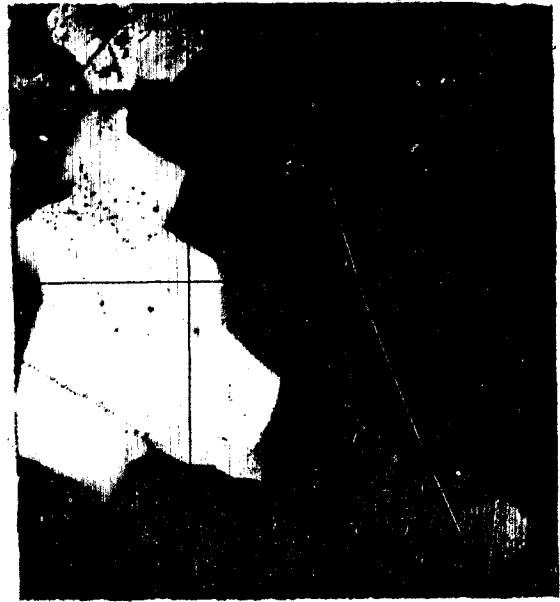


Figure 17.--Photomicrographs of the Reagan Sandstone.
 A, Orthoquartzite which resulted from pressure solution, Nicols crossed, X75. B, Sutured contact between quartz grains, Nicols crossed, X175. C, Quartz grains cemented with dolomite. Note replacement of quartz by dolomite, Nicols crossed, X150. D, Dolomite cemented sandstone, Nicols crossed, X125.

dolomite generally fills the pore spaces with a single crystal in each pore but some thin sections contained single crystals enclosing many quartz grains giving a luster-mottling effect. The quantity of dolomite increases upward.

Quartzose sandstone is present throughout the study area and is the dominant type found in Area I (Plate I). It rarely exceeds 60 feet in thickness and is transitional to sandstone types above and below. In Area II quartzose sandstone is secondary in amount to dolomitic sandstone. The quartzose sandstone in Area III is characterized by fine- to medium-sand size grains with a high degree of sorting.

Dolomitic Sandstone

The term dolomitic sandstone is used when the percent of dolomite is greater than that normally considered as cement (usually more than 10 percent and less than 50 percent of the total volume). Dolomitic sandstone comprises a major portion of the Reagan Sandstone, especially of the Central Kansas Uplift (Plate I) and accounts for the increase in thickness noted in this area. It is most abundant where the Reagan is overlain by the Arbuckle Group. Dolomitic sandstone sometimes occurs where the Reagan is overlain by the Arbuckle Group. Dolomitic sandstone sometimes occurs where the Reagan is overlain by Pennsylvanian rocks, although the thickness is generally reduced through erosion. Locally it is completely absent, especially in the area of the Cambridge Arch, possibly by erosion.

The mineralogy and the nature of quartz in the dolomitic sandstone is similar to that described for the quartzose sandstone but better sorting, more overgrowths and a much higher degree of roundness and sphericity are common. The quartz grains are commonly "floating" in the dolomite cement. It is suggested that these grains were transported not only by currents but also by offshore winds into the environment where dolomitic sandstone was being deposited.

Quartz-glaucouite Sandstone

The term quartz-glaucouite sandstone is used when more than 20 percent of the constituents are glaucouite. Glaucouite is present in much of the northern part of the Central Kansas Uplift and in the area of the Cambridge Arch. In a limited area in Norton County (T. 3, 4 S., R. 24 W.), quartz-glaucouite sandstone is the dominant sandstone type. It occurs beneath either Arbuckle or Pennsylvanian rocks (Plate I). The glaucouite occurs as green elongate, semi-spheroidal and free-form grains and as a grain coating (Fig. 18B). Glaucouite comprises up to 50 percent of the rock with the remainder being made up of quartz, feldspar, dolomite and biotite, relationships similar to those found in the quartzose sandstone.

The underlying schist in the area supplied abundant micaeous material, and glaucouite probably formed during and after deposition of the sandstone as indicated by rounded detrital grains of glaucouite, grain coatings, and partially



Figure 18.- Photomicrographs of Reagan Sandstone. A. Dolomitic sandstone, Nicols crossed, X60. B. Quartz-glaucanite sandstone. Dark patches are glauconite, dolomite cement present, Nicols crossed, X125. C. Feldspathic sandstone, Nicols crossed, X150. D. Arkose, Nicols crossed, X175.

altered biotite "books". The percent of glauconite increases upward in the samples of this small area and the abundance of glauconite decreases outward from the area of the Cambridge Arch and is almost completely absent on the Central Kansas Uplift. Precambrian rocks with sufficient biotite for its development are present in the area of the Central Kansas Uplift and it therefore can be concluded that physical and chemical factors were not conducive to glauconite formation, or that the two sandstones are different in age, environment, and history or glauconite did form and was later removed by some process.

Arkose and Feldspathic Sandstone

Arkose and feldspathic sandstone are present in the lower part of the Reagan in many of the wells examined. The arkose lies on Precambrian rocks and is transitional to the overlying feldspathic and quartzose sandstone.

Muscovite and biotite are common in the samples of arkose and feldspathic sandstone but very little is present in the thin sections.

The nature of the quartz grains and cement found in the arkose and feldspathic sandstone of the Reagan is similar to that described for the quartzose sandstone except for a higher percentage of large and of angular grains.

Most of the potassium feldspar in the Reagan is microcline and is recognized by polysynthetic twinning or tapering

"spindle-shaped" lamellae. The microcline grains range in size from 2 to 0.25 mm, are angular to subrounded, and may be fresh or altered. Sorting of the arkose and feldspathic sandstone is generally very poor with more than 4 phi sizes being represented by the quartz and feldspar. It is possible that these types are more common at the base of the Reagan than was observed because of sample loss during drilling and because of mixing with underlying granite samples. There is little doubt that the Precambrian granites and gneissic rocks, and the "granite wash" served as the source for the lower arkosic and feldspathic phases of the Reagan.

Very little orthoclase is present in the arkose and that which is found consists of small, highly altered grains. Orthoclase is almost completely absent in the Precambrian rocks of Kansas and the potassium feldspar in the Precambrian granites is mostly microcline. Plagioclase feldspar is relatively rare in the Reagan but where present albite is dominant.

Thickness of these types varies considerably but occurrence is generally restricted to the base of the Reagan except where minor local occurrences higher in the section indicate periods of influx of feldspar from nearby high areas during deposition. Arkose and feldspathic sandstone occur throughout the area but are more prominent in Area I (Plate I).

This lower arkose of the Reagan is not to be confused with the sub-Reagan arkose ("granite wash") which served as a source for the Reagan arkose and is transitional to it as

a result of reworking at the time of Reagan deposition. The Reagan arkose rarely exceeds 30 percent feldspar, contains no matrix and is usually cemented with dolomite and/or quartz (Fig. 18); whereas, the sub-Reagan arkose contains as much as 60 percent feldspar, is loosely cemented containing considerable clay matrix as well as many shale beds.

Shale

The Reagan Sandstone in southern Oklahoma contains more than 100 feet of green shale. At no place in Kansas has such a thickness been reported. Where present, shale is green or red. In samples which I examined for Kansas the maximum thickness of shale is 15 feet. It is difficult to determine the amount of shale in the Reagan using samples from rotary drill holes because of cavings from units above. No preferred distribution of shale was observed except that a greater abundance occurred in the upper part of the Reagan where overlain directly by Pennsylvanian rocks.

Diagenesis

Authigenic quartz is especially common in the form of secondary growths that occur in the sandstone throughout the area. The secondary growths are always in optical continuity with the original grain. The surfaces of many of the original grains were stained, probably with iron oxide, allowing the original outline to be extremely clear within the secondary

material. Replacement of quartz grains and quartz overgrowths by dolomite is common (Fig. 17). Authigenic feldspar is uncommon in the Reagan but was noted in some thin sections. Illite occurs in thin laminae (Fig. 15) and as a coating on quartz grains, closely associated with the laminae.

Where both quartz and dolomite cement are present together, the quartz is primary in some areas and the carbonate primary in others. Where dolomite is the major cement and the quartz grains are "floating", the precipitation of carbonate was possibly penecontemporaneous with deposition of the grains.

The silica present in orthoquartzites found in Rush County where the Reagan Sandstone is overlain by Pennsylvanian rocks is believed to be the result of pressure-solution along grain boundaries which resulted in intrastratal solution and precipitation of the silica forming the orthoquartzites.

It is obvious that the processes of dolomitization, glauconitization, kaolinization, and silication have occurred during the deposition of the Reagan. Several facts concerning these processes are worth further analysis. These facts are:

- 1). different suites of igneous and metamorphic rocks characterize the Cambridge Arch and the Central Kansas Uplift. It is possible, but untested, that iron-rich biotite is more common in one area and magnesium-rich biotite more common in the other;
- 2). glauconite is abundant on the Cambridge Arch and absent on the Central Kansas Uplift;
- 3). dolomite sandstone and sandy dolomite are more common on the Central Kansas Uplift;
- 4). quartz

overgrowths are more common and larger in areas characterized by dolomite cement and dolomitic sandstone; 5). there is very little muscovite, biotite, and feldspar in the Reagan and overlying rocks considering their abundance in Precambrian rocks, and 6). chert is lacking in the Reagan and sandy dolomite but is present in dolomite.

Before evaluating these facts it is necessary to present some information regarding diagenetic absorption of feldspar, muscovite, and biotite. The following is summarized from Calvert (1964, p. 184).

Orthoclase (and microcline) decompose under ordinary conditions of weathering to form kaolinite and silica. Kaolinite may continue to decompose into silica and gibbsite. When attacked by organic acids, muscovite decomposes slowly to form kaolinite. Magnesium biotite will decompose into kaolinite, silica, and magnesite, whereas iron-rich biotite will alter to glauconite (see Galliher, 1935, and Burst, 1958).

For the moment, let it be assumed that the iron-rich biotite is more common in the area of the Cambridge Arch and magnesium-rich biotite is more common in the area of the Central Kansas Uplift (there is some petrographic evidence for this but at present is undemonstrated). In addition, let it be assumed that the feldspar, mica, and well-rounded quartz grains were distributed in the offshore depositional environments by wind.

If the above assumptions are correct, they can, in addition to the decomposition processes, account for some of the factors

observed in the Reagan. The presence of glauconite on the Cambridge Arch can be accounted for by the greater abundance of iron-rich mica in this area. In the area of the Central Kansas Uplift the magnesium-rich biotite diagenitically converted the original limestone into dolomite by the introduction of magnesite. The silica was attracted to the quartz, thus forming overgrowths. Overgrowths on quartz are more common and larger where there are small numbers of quartz grains because there were fewer grains of quartz (than in quartzose sandstone) to which the amount of silica was attracted. Where quartz grains were few, chert formed.

As mentioned above, the magnesium-iron ratio of the biotite is unknown. The predominance of one over the other is possible, but unnecessary to account for the relationships seen because changes in environmental conditions between the Cambridge Arch and Central Kansas Uplift could account for the variations observed.

The above ideas were proposed by Calvert (1964) for pre-Trenton sediments in the Cincinnati Arch Province. It is suggested that his ideas warrant consideration in this study but further evaluation is necessary before reaching a conclusion.

The Reagan Sandstone shows no evidence of compaction and very little evidence of solution. Where the upper part of the Reagan was exposed to weathering during the several periods of post-depositional erosion, solution of the original cement

occurred, followed by later reworking and recementation of the upper part during and after deposition of the overlying rocks as indicated in part by abraided overgrowths and incorporated shale.

Primary porosity in the Reagan is controlled by the angularity of quartz grains and by the sorting. Secondary porosity is affected by cementation and de-cementation. Table 2A shows porosity and permeability values of the Reagan at various localities.

Table 2 B is a summary of chemical analyses of fluids from 19 wells on the Central Kansas Uplift. Original data were supplied by the United States Bureau of Mines.

Maturity of the Reagan Sandstone

In considering the origin of any clastic sedimentary rock, it is necessary to use some type of classification with terms to indicate various degrees of progression between "end members". If we accept (in theory) the gradual change from a graywacke or arkose to a quartzose sandstone which results from processes acting upon one to produce the other over a given period of time, some name must be applied to the various stages. The term maturity has been widely used and although various meanings are attached to it, the general concept is useful only when the limits are clearly specified.

Mineralogical maturity: This refers to the degree to which unstable components of detritus have been eliminated. The

	Sp.Gr.	H ₂ S	Ca	Mg	Na	H CO ₃	SO ₄	Cl
Maximum	1.086	Absent	8.46	2.23	36.23	3.36	6.07	61.58
Minimum	1.021	to	1.85	0.64	28.45	0.06	0.00	53.30
Mean	1.054	Present	4.62	1.14	32.20	0.76	2.05	59.18

A

	<u>Yuma Co., Colo.</u>	<u>Okla. Outcrop</u>	<u>Rooks Co., Kansas</u>
Porosity	3.1-32.7%	12-25%	16.7-20.4%
Permeability	6-49 md.	175-590 md.	3-65 md.

B

Table 2.-A, results of chemical analyses of fluid content of the Reagan Sandstone from 19 wells located on the Central Kansas Uplift and Cambridge Arch (data from U.S. Bureau of Mines). B, Porosity and permeability values from the Reagan outcrop area in southern Oklahoma, California Oil Company No. 1 Mumm in Yuma County, Colorado and Mobil Oil Company No. 1 "B" Holsman, Rooks County, Kansas.

degree of elimination depends upon the nature, intensity, and duration of the processes operating to achieve the stable state. Of the more common minerals, quartz is the most stable. Zircon, tourmaline, and rutile are the most stable of the minor minerals.

Because the degree of compositional maturity is related to minerals present, the source-rock index (ratio of K + Na feldspar to rock fragments + clay matrix) is indicative of the degree to which modifying process must act in order to achieve a stable state. Dapples, Krumbein, and Sloss (1953) have proposed a quartz index (ratio of quartz + chert to K and Na feldspar + rock fragments + clay matrix) by which the compositional maturity can be measured. Hubert (1962) proposed a zircon-tourmaline-rutile index by which the compositional maturity of a clastic sediment can be measured. The total percent of zircon-tourmaline-rutile is simply compared to the total percent of the other heavy minerals. These three minerals being the most resistant to weathering and abrasion of the heavy minerals indicates the degree of maturity.

The source-rock index of the lower part of the Reagan Sandstone is extremely high throughout all of western Kansas. The almost complete absence of rock fragments and clay matrix indicates a granitic terrane as source for most of the Reagan. The quartz index is variable and increases upward. The arkosic and feldspathic lower portions of the Reagan had a low index but never had the low index shown by the sub-Reagan arkose, which

in some cases contained more than 40 percent feldspar. Feldspar is very uncommon in all but the lower 3 to 5 feet of the Reagan and the index approaches the maximum. No percentages were obtained for heavy minerals but the zircon-tourmaline-rutile index increases upwards but heavy minerals are absent near the top. At the bottom of the Reagan in wells examined for heavy minerals, the well-rounded zircon, tourmaline, and rutile minerals were associated with angular heavy minerals.

Textural maturity: Textural maturity refers to the degree to which a rock has approached a stable textural state. Limits are usually determined on the basis of roundness, sorting, and clay matrix. The degree of textural maturity depends upon composition and the nature, intensity, and duration of processes acting upon the sediment.

Folk (1951) defines four stages of textural maturity on the basis of clay matrix, sorting, and grain roundness. He relates the stages to various degrees of "modifying energy" which is actually a rather nebulous concept. Folk defines the four stages as:

- I. Immature - much clay, not well sorted, not rounded
- II. Submature - little or no clay, not well sorted, not rounded.
- III. Mature - little or no clay, well sorted, not rounded.
- IV. Supermature - little or no clay, well sorted, grains rounded.

Stage I arbitrarily is taken to pass into stage II when the sediment comes to contain less than 5 percent detrital clay.

Stage II likewise passes into stage III when approximately two-thirds of the grains occur within one phi unit. Stage III passes into stage IV when the quartz grains of sand size attain an average roundness of more than 0.50 (Krumbein, visual chart, 1941).

Little detrital clay is found in the Reagan, which automatically removes the sandstone from stage I and places it in some higher stage. With regard to roundness and sorting the Reagan cannot be placed in stage IV. Near the top of the Reagan in some wells the sorting places it within the requirements (2/3 within one phi size) of stage IV but the degree of roundness is too low. The roundness index approaches the requirements for class IV in some local areas but in these areas the sorting index is too low. Near the bottom of the sandstone in many wells, textural inversion is indicated by large very angular grains and large well-rounded grains. Therefore, most samples of the Reagan fall within the submature (II) stage or mature (III) stage. The sandstone near the bottom of 98 percent of the wells falls in the submature stage (II) but a gradual transition to the mature stage (III) occurs upward.

THICKNESS AND DISTRIBUTION OF THE REAGAN SANDSTONE

The basal Upper Cambrian sandstones throughout the Midcontinent are thin and rather persistent units in basin areas but are erratic and discontinuous in areas which have undergone uplift and erosion. These blanket sandstones average less than 200 feet in thickness in the subsurface. At the surface the Mt. Simon Sandstone in Wisconsin is 200 feet thick at the type section and increases to over 500 feet in southeast Wisconsin. The Lamotte Formation ranges from 0 to 475 feet thick in the St. Francois Mountains in Missouri. Westward from southeast Missouri the Lamotte thins to less than 100 feet in Kansas. In Oklahoma the Reagan in the Wichita Mountains ranges in thickness from 0 to 150 feet and in the Arbuckle Mountains from 0 to 460 feet. The Sawatch Formation in the Front Range of Colorado ranges from 0 to 11 feet in thickness and in the subsurface of eastern Colorado and western Kansas it or its equivalent varies from 0 to over 100 feet.

Thickness of the Reagan Sandstone in western Kansas ranges from 0 to 175 feet (Fig. 19). A general thickening can be seen southward from the Cambridge Arch in Norton and Decatur Counties to local areas where a thickness in excess of 100 feet is reached, as seen in Russell, Ellsworth, Ellis, and Rush Counties (Plate II). Within these areas, however, the sandstone may be completely absent. In extreme southwestern

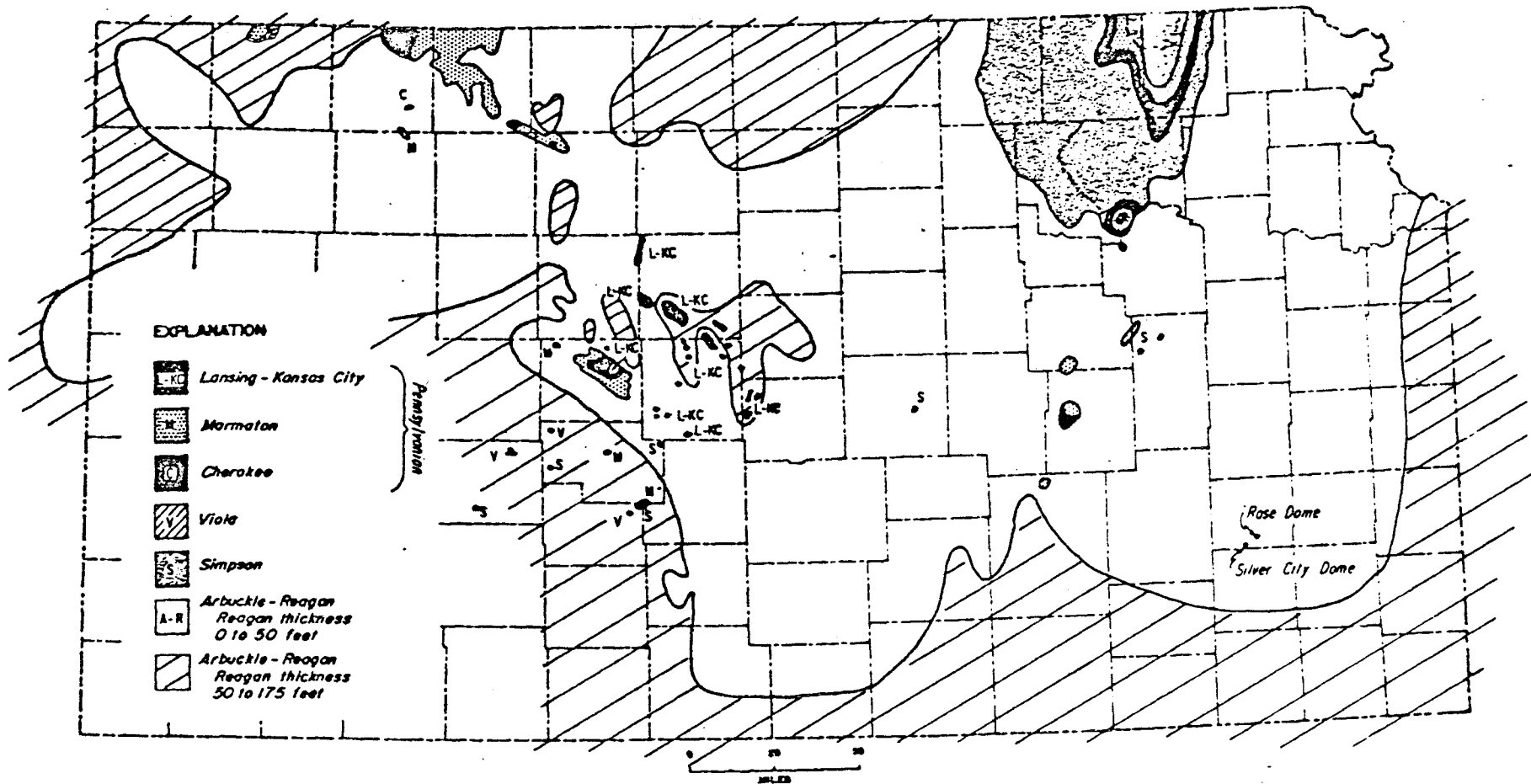


Figure 19.—Map showing general thickness of the Reagan Sandstone in Kansas. Map base shows generalized distribution of rocks which rest on the Precambrian (map base from Merriam, 1963, p. 173).

Kansas very little control is available, but that which is available indicates thickening to the southwest. The mean thickness of the Reagan Sandstone in all wells studied which were overlain by the Arbuckle Group was 45.84 feet (171 wells); whereas, the mean thickness of the sandstone in wells overlain by Pennsylvanian rocks was 31.26 feet (64 wells).

The evaluation of thickness information is highly conjectural because of limited control for constructing pre-Paleozoic paleogeographic maps and evaluating effect and extent of subsequent uplift and erosion. However, the widespread nature of the Reagan and Arbuckle gives evidence that Midcontinent topography was rather low and featureless except for local monadnocks. Bridge and Dake (1929) postulated an average of 1500 feet of relief (maximum of 2000 feet) with initial dips of 10 to 20 degrees in some areas of southeast Missouri during Cambrian and Early Ordovician time. Walters (1946) identified in Kansas monadnocks on the Precambrian surface in Kansas, with relief of about 400 feet, resulting in initial dips of Cambrian and Ordovician strata of from 3 to 5 degrees.

The absence of Reagan Sandstone locally in the area of the Cambridge Arch and Central Kansas Uplift is best attributed to post-depositional erosion of Reagan, Arbuckle, and later units prior to deposition of Pennsylvanian rocks and to overlap by the Arbuckle on monadnocks (Plates II and III).

In some places well data show that the Reagan was only partially removed or reworked as indicated by the relative abundance of shale in the upper part of the sandstone where overlain by Pennsylvanian rocks in contrast to the lack of shale where overlain by Arbuckle; and the greater mean thickness of sandstone in the wells where overlain by Arbuckle versus those overlain by Pennsylvanian rocks. The lithologic uniformity of the Reagan in adjacent wells where one is overlain by Pennsylvanian rocks and the other by Arbuckle, demonstrates continuity of the Reagan. In the area of the Cambridge Arch, remnants of the Reagan beneath Pennsylvanian rocks give evidence that the Reagan was not completely removed by erosion.

It is the opinion of the writer that except for areas where the Reagan was overlapped by Arbuckle, the sandstone formerly covered most of Kansas.

STRATIGRAPHIC RELATIONSHIPS BETWEEN THE REAGAN SANDSTONE
AND SUB-REAGAN AND SUPRA-REAGAN ROCKS

Relation of the Reagan to Sub-Reagan Rocks

Figure 20 diagrammatically illustrates stratigraphic relationships encountered in wells drilled at localities A through H.

The position of the base of the Paleozoic has received as much attention as any other single problem in geology, yet, no satisfactory conclusions have been reached which are applicable to all areas. Difficulty is encountered in any attempt to use "man made" or artificial time boundaries where no identifiable lithologic breaks exist. King (1949) phrases the problem: "The Cambrian System differs from all other systems that succeed it in that its base is identified paleontologically. In the Cambrian System, the lowest fossil zone is underlain by strata without fossils or with fossils so ambiguous a nature as to be useless for precise paleontological zonation." The base, as King stated, is usually placed just below the first occurrence of recognizable fossils. This has the virtue of precision but is certainly arbitrary, and unnecessarily restricts the inclusion of "barren" sediments within the Cambrian System. It is well known that fossil organisms are restricted to a limiting set of ecological conditions and their absence in a given rock unit does not exclude that rock unit from having been deposited at the same time as other sediments which contain fossils.

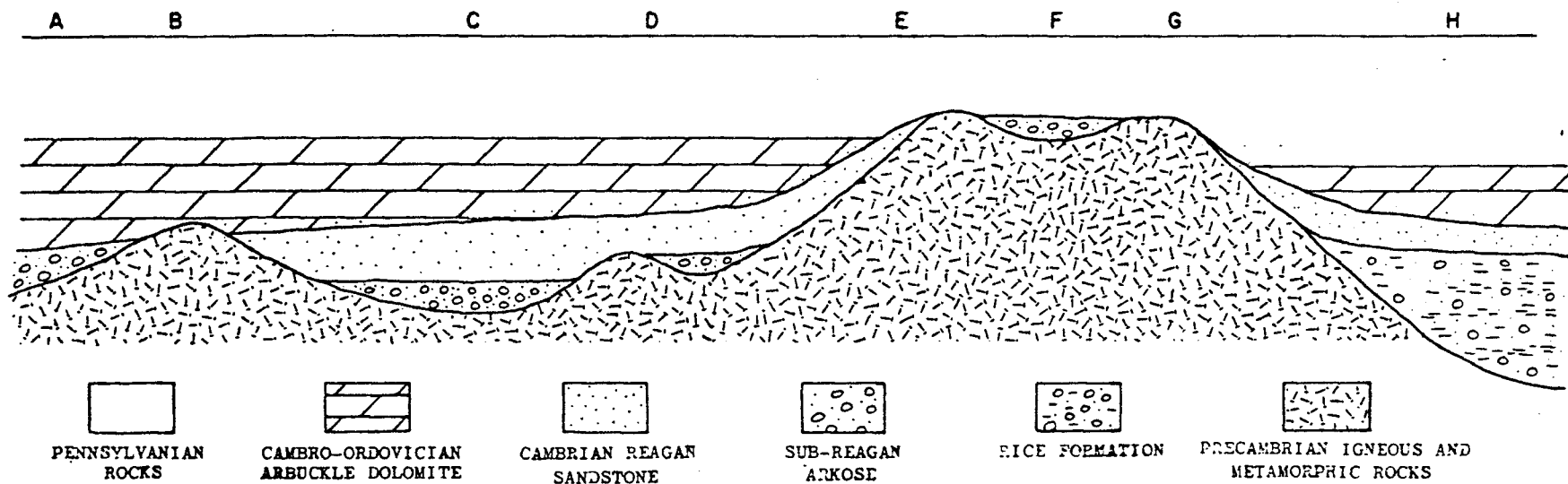


Figure 20.-Stratigraphic diagram showing relationships between Paleozoic rocks and Precambrian Rocks in northwest Kansas. Not to scale (modified from McElroy and Kaesler, 1965, p. 201).

The contact between the Reagan and Precambrian igneous and metamorphic rocks is nonconformable. Only two cores which actually show the contact have been located and these are discussed by Scott and McElroy (1964). Figure 21 shows the contact in both wells and a photomicrograph of the contact in one well. In both cores the contact between the Reagan and the Precambrian is sharp although a thin weathered zone is present in each. The Precambrian surface in the area of the Cambridge Arch is shown in Plate V.

Sub-Reagan Arkose: Arkose, generally referred to as "granite wash", overlies Precambrian igneous and more rarely metamorphic rocks in the area of the Central Kansas Uplift and Cambridge Arch. The greatest concentration is found on the Cambridge Arch and follows the general outline of the Norton Igneous Terrane (Plate IV). The arkose is overlain in various places by either Reagan, Arbuckle, or Pennsylvanian rocks, but the greatest amount is under Reagan and Pennsylvanian rocks. This arkose is present locally on the Central Kansas Uplift, but large areas and thick sequences are missing because of the different nature of Precambrian rock types. Several wells penetrate arkose which overlies quartzite, but it was probably transported there by fluvial processes.

Thickness of the sub-Reagan arkose ranges from 0 to over 80 feet and averages 25 feet. Areas where it is completely absent are shown on Plate IV. These barren areas roughly correspond to the Phillips Metamorphic Terrane (Fig. 6).

Figure 21.- (see following page) A. Core from Magnolia Pet. Co., No. 1 "B" Holsman, sec. 15, T. 7 S., R. 19 W, at 3537 feet. Dotted line is contact between Reagan and Precambrian gneissic granite. Note the graded-bedding and irregular illite laminae. A'. Core from Derby Oil Co., No. 4 Schoen. Contact between Reagan arkose and Precambrian schist. Note quartz pebbles, lighter-colored bands of calcareous cement, dark specks of biotite, and pyrite vein above calcareous band in arkose and steeply dipping schistosity in Precambrian rock. B. Photomicrograph of thin section of Precambrian-Reagan contact (arrow), Nicols not crossed, X3. B, biotite, M, microcline, Q, quartz, X, points where thin section has broken away (modified from Scott and McElroy, 1964).

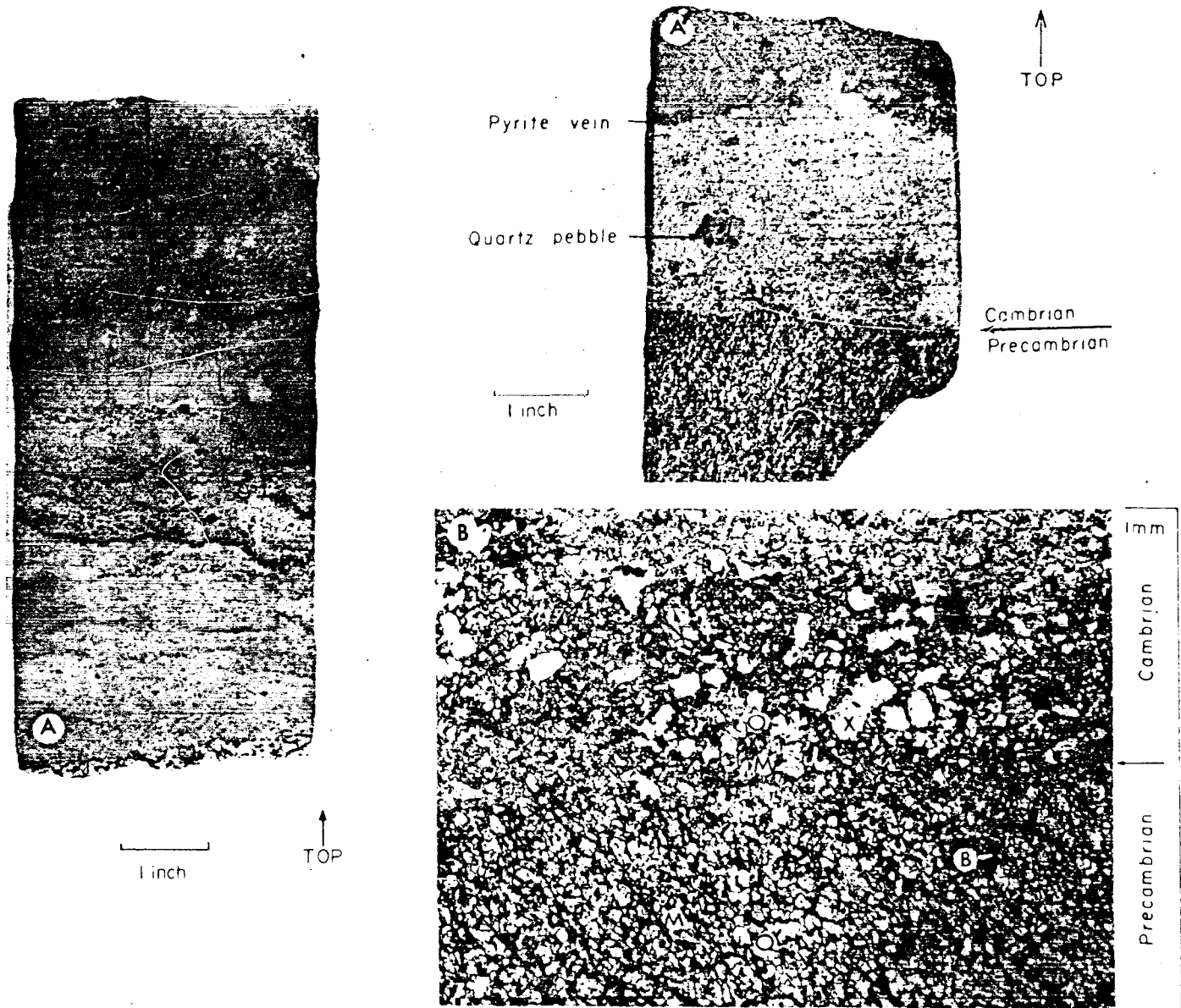


Figure 21

Isopach lines suggest a pattern similar to those of stream deposits. Figure 22 shows broad channeling in the Precambrian surface. This channel drawn to natural scale resembles the cross section of a large-scale stream with a low gradient.

Composition of the sub-Reagan arkose is quite uniform. Predominant minerals are quartz and microcline feldspar. Variations in percentages of these minerals are small with quartz ranging from 40 to 80 percent and feldspar from 20 to 60 percent. Muscovite and biotite are common but not always present. Some samples contain composite fragments of altered grains of quartz, feldspar, and biotite. Kaolinite surrounds many of the feldspar grains and is present as matrix along with red clay. Red shale is also quite common.

Grain size of feldspar ranges from 3 to .125 mm with an average of 1 mm. Quartz grains range from 4 to .125 mm and average 1.5 mm in diameter. Roundness for both quartz and feldspar ranges from angular to subrounded. Sorting is moderate. Cementation varies, but generally cement is lacking and grains are held together by clay matrix. Porosity is usually high and permeability is variable.






Origin of the basal arkose of the Lamotte Sandstone in southeastern Missouri has been discussed by Ojakangas (1960). On the basis of stratigraphic relationships such as thickness increase and primary dips into channels cut in the Precambrian surface, and cross-bedding directions indicating fluvial deposition in a direction opposite to that of the quartzose Lamotte, he concluded that the arkose was deposited

STRATIGRAPHIC CROSS SECTIONS B B'
SHOWING CHANNELING IN
PRECAMBRIAN SURFACE

Prepared by M. N. McElroy

A - Datum Top Lansing
B - Datum Top Reagan

EXPLANATION

-  Pennsylvanian Shale Limestone Conglomerate
-  Arbuckle Dolomite
-  Reagan Sandstone
-  Arkose
-  Igneous

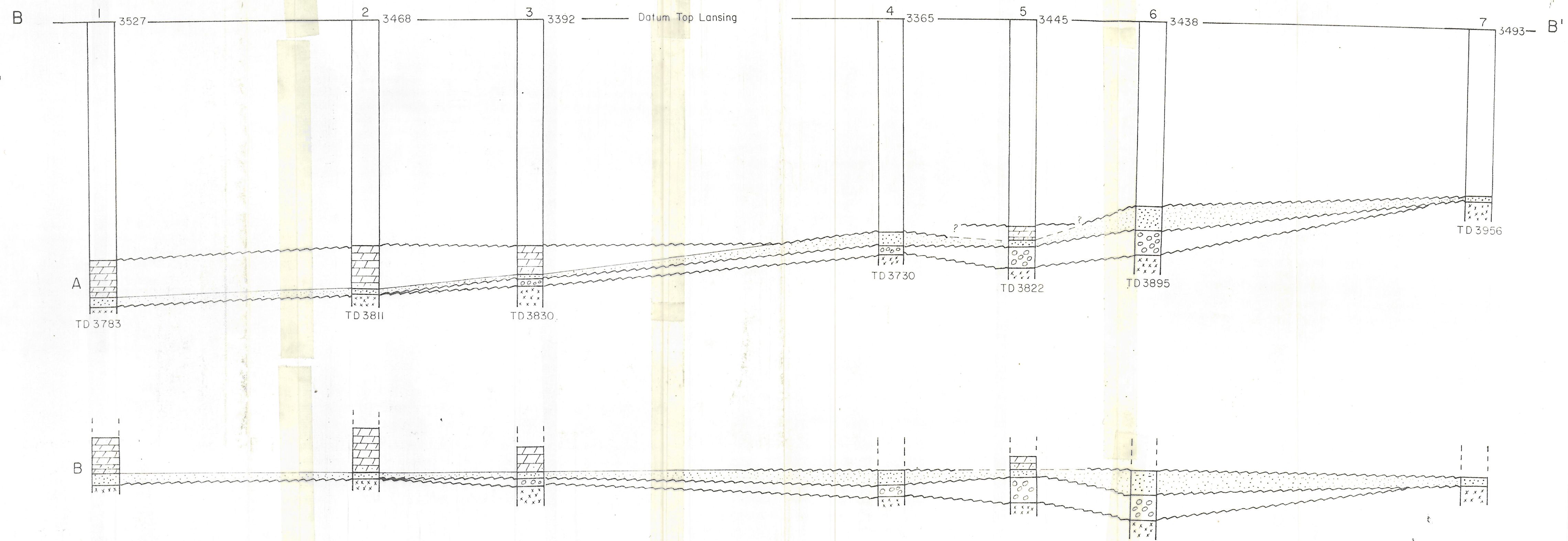
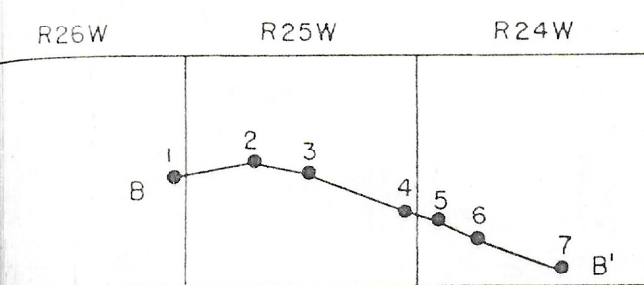
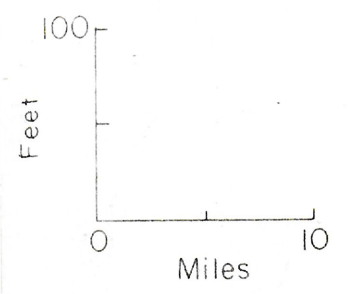


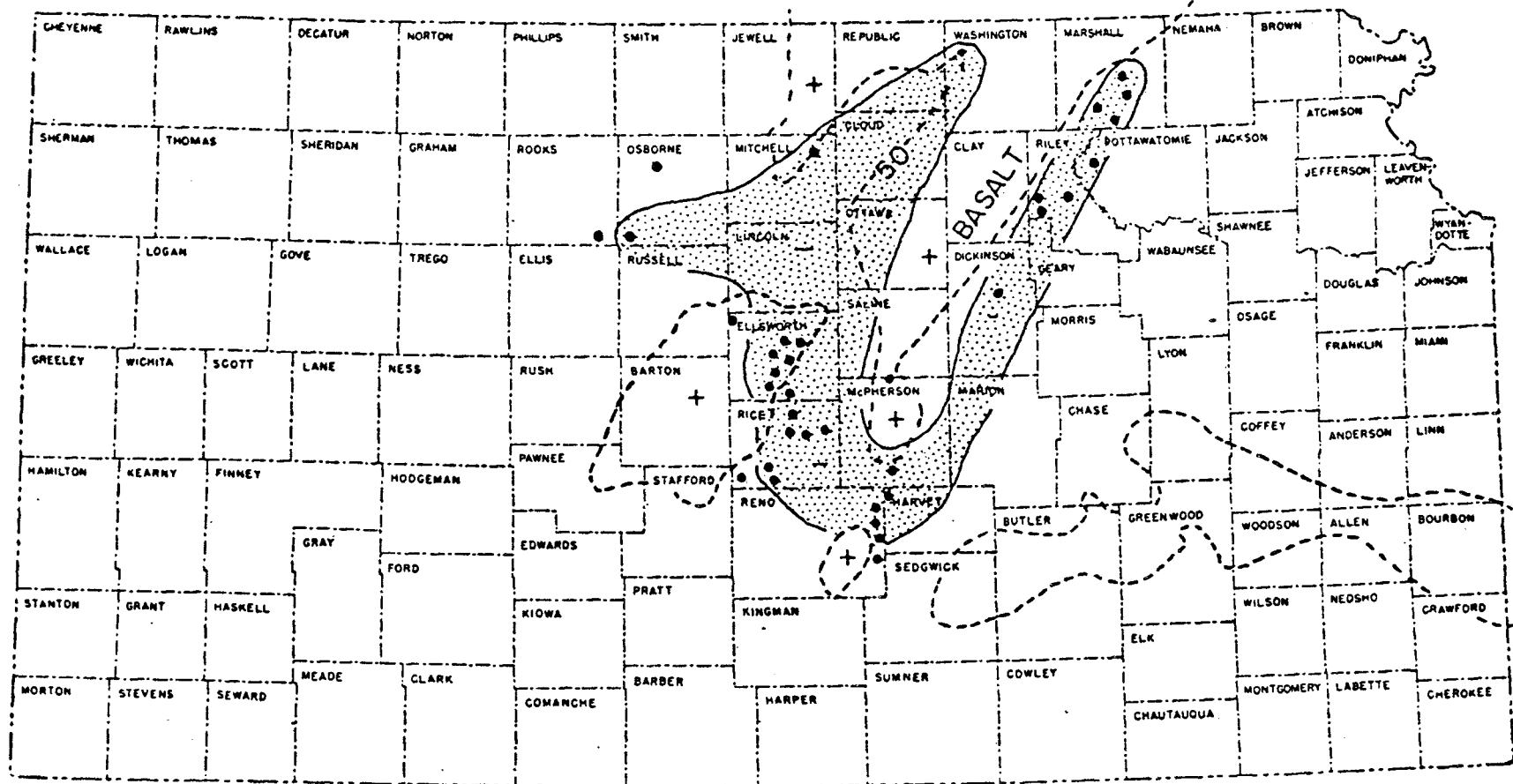
Figure 22
KGS OFR 65-6

by streams prior to the encroachment of Late Cambrian seas. It should be pointed out that although there is a clear genetic and age difference between this arkose and the overlying Lamotte quartzose sandstone, they are both included in the same formation and erroneously given the same age.

It is believed that the arkose on the Cambridge Arch was deposited in a similar manner to that described by Ojakangas. The low relief of the Precambrian had intermittent broad streams with low gradients moving from the northwest supplying detritus to the Rice Sedimentary Basin to the southeast (Fig.23). By the time the Cambrian sea invaded this region, the area must have been almost flat and very little arkosic detritus was being supplied to the sea, as indicated by the rather pure quartzose sandstone which overlies the arkose. In some areas marine currents were strong enough to rework the upper few feet of arkose developing a transitional zone.

Where Pennsylvanian lies on Reagan pre-Pennsylvanian erosion has no doubt altered the top of the arkose to a certain extent, but the Reagan and Arbuckle outliers give some indication that by the time all the post-Arbuckle and pre-Pennsylvanian rocks were removed from the Cambridge Arch, the base level must have been very low with little erosion occurring.

As discussed previously the Reagan Sandstone in this area is believed to be Late Cambrian (Dresbachian) in age. No evidence is available to indicate an age for the arkose but it is possible that it represents the Medial and Early Cambrian interval to the youngest Precambrian.



0 25 50
MILES

Figure 23.-Map showing known distribution of Rice Formation in Kansas (stippled area) and its relation to -50 mgal Bouguer gravity contour (from Scott, 1965, personal communication). Enclosed east-west area in southeast Kansas is outline of metasediments (from Muehlberger, et al, 1964).

Rice Formation: The Rice Formation, named from Rice County, Kansas, has been proposed by Scott (1965) for a sequence of sub-Reagan sediments in central Kansas (Fig. 23). Basalt, possibly 35,000 feet thick, as estimated by Muehlberger and others (1964), separates the Rice Basin into two unequal portions, distribution roughly corresponding to the -50 mgal. contour line taken from a geophysical map by Lyons (1959). Distribution is based on 56 wells. Maximum penetration was 1200 feet, and seismic data indicates that it may be as much as 15,000 feet thick.

A sequence of metasediments is present in extreme eastern Kansas although there is some question as to their thickness and distribution (Fig. 23). In Vernon County, Missouri adjacent to Bourbon County, Kansas, two wells less than a mile apart penetrated thicknesses of 1013 feet and 926 feet of sub-Reagan (Lamotte) sediments.

The Rice Formation includes red and green sandy and micaceous shales, arkose, feldspathic sandstone, and some dolomite. Quartz and feldspar grains range from 2 to .0625 mm in diameter and sorting ranges from poor to moderate. When present the cement is dolomitic and the grains are commonly held together by clay matrix. Composition varies locally and the beds are more arkosic to the north (Scott, personal communication).

Origin of these sediments is uncertain but it seems reasonable to assume that the Precambrian igneous and metamorphic rocks were the primary source and deposition was in

a subsiding basin. Illite and dolomite suggest the possibility of marine deposition (Scott, in press). Some workers (Muehlberger and others, 1964) have suggested a correlation of the basalt with the Middle Keweenaw North Shore Group of Minnesota, and the Rice Formation with rocks of the Upper Keweenaw Bayfield and Oronto Groups of Wisconsin and Michigan. It is possible that a continuous belt does exist to the west of the positive Greenleaf gravity maximum (Fig. 24). Lyons (1959) associates this maximum to the tectogene concept and suggests a complex Precambrian history.

The relation of the Reagan Sandstone to the Rice Formation is uncertain (Fig. 25). Scott (1965) reports that petrographic evidence suggests that the contact between the Rice Formation and the overlying Reagan Sandstone is unconformable. This is based on a high percent of kaolin and lack of cement (leaching?) in the upper few feet of the Rice Formation. Skillman (1948) describes an angular relationship between the Lamotte-Bonne-terre and the underlying sediments in Vernon County, Missouri. It is possible that the Rice Formation was deposited in a non-marine environment; whereas the Reagan was deposited under marine conditions. This does not rule out the possibility of continuous deposition in the center of the basin where a gradual transition from nonmarine to marine conditions could have occurred. On the basis of lithologic differences (quartzose sandstone versus feldspathic sandstone, and arkose with a high matrix content and shale) and possible unconformity (Fig. 25) between the Reagan

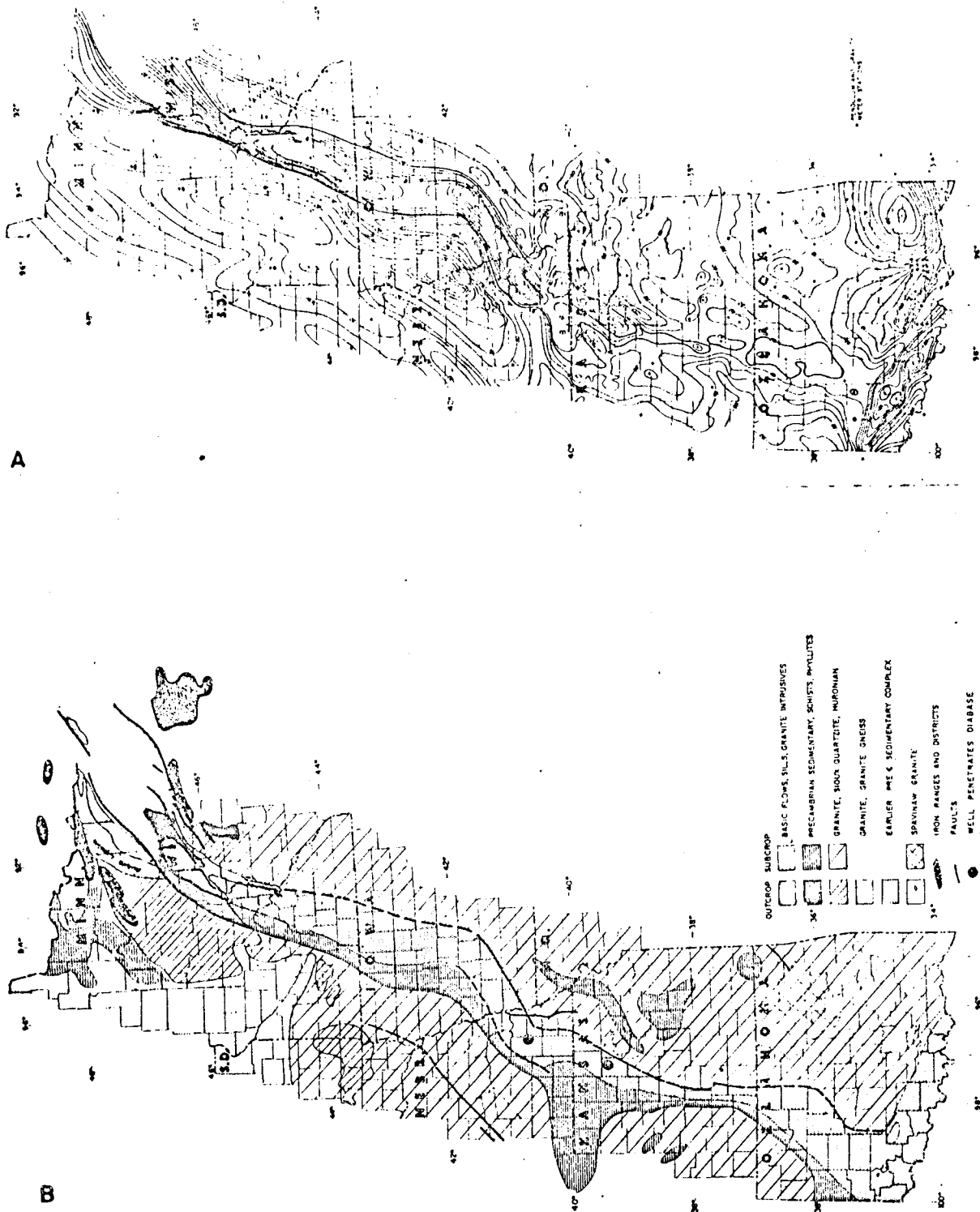
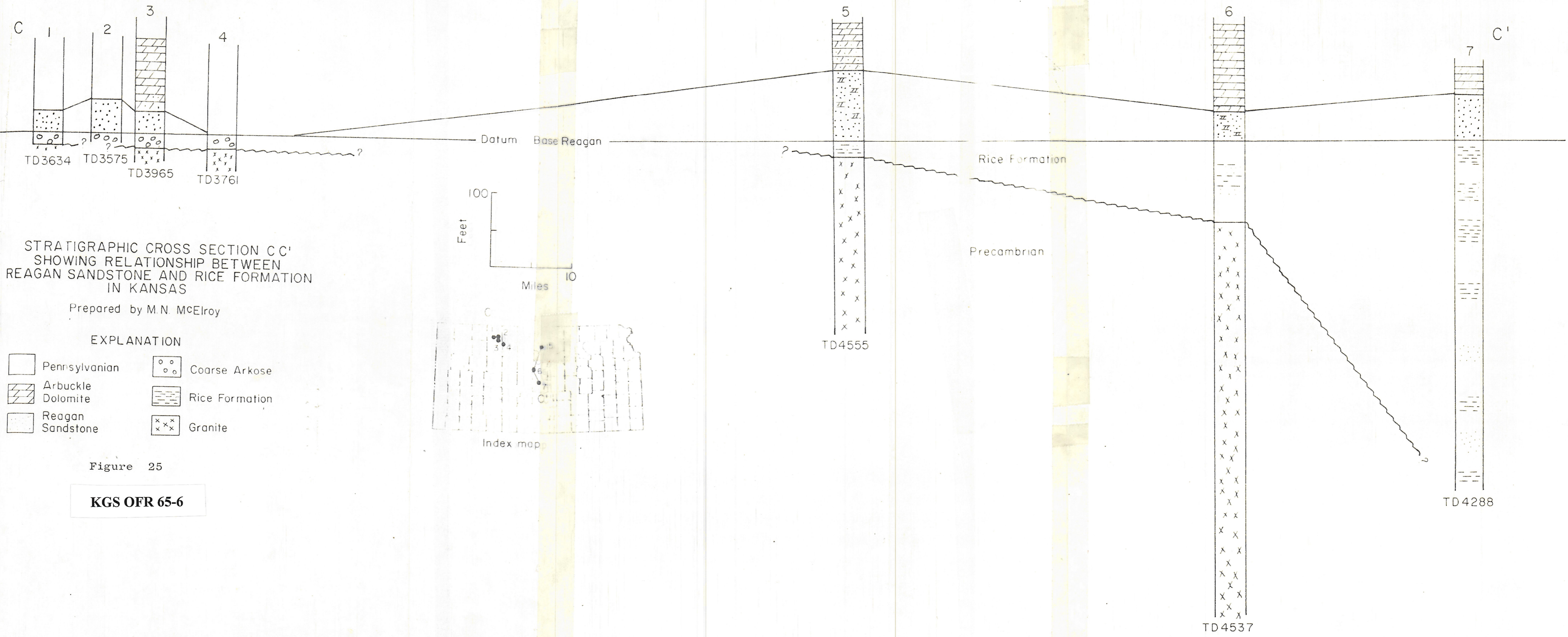


Figure 24.-A, Bouguer gravity map showing Greenleaf anomaly, contour interval 10 mgal. B, Map showing distribution of basement rocks (from Lyons, 1959, p. 106, 116).



STRATIGRAPHIC CROSS SECTION C-C'
 SHOWING RELATIONSHIP BETWEEN
 REAGAN SANDSTONE AND RICE FORMATION
 IN KANSAS

Prepared by M.N. McElroy

EXPLANATION

- | | | | |
|--|-------------------|--|----------------|
| | Pennsylvanian | | Coarse Arkose |
| | Arbuckle Dolomite | | Rice Formation |
| | Reagan Sandstone | | Granite |

Figure 25

KGS OFR 65-6

and Rice, it is proposed that the two units be separated, although one has little information on which to base an estimate of the time interval separating them.

Relation of the Reagan to Supra-Reagan Rocks

Relation to the Arbuckle Group: Where the Arbuckle Group overlies the Reagan the contact is transitional or unconformable. Locally the Arbuckle overlaps the Reagan on Precambrian monadnocks (Plates II and III and Figures 26 and 27). In the area of the Cambridge Arch only the transitional and overlap relationships are observed. The Central Kansas Uplift area is characterized by unconformable and transitional contacts in addition to overlap relationships (Walters, 1946).

The location of areas where the various relationships occur on the Central Kansas Uplift is difficult to outline because of the limited knowledge of the lithologic variations within the Arbuckle Group. Figure 28 (Lee, 1956) shows the westward thinning of various members of the Arbuckle Group. Only the Bonneterre Dolomite, the Roubidoux Dolomite and the Jefferson City-Cotter Dolomite are definitely present in the area of the Central Kansas Uplift, although it is possible that remnants of the Gasconade Dolomite and lower Gunter Sandstone Member also occur.

Thickening of the Reagan Sandstone in the area of the Central Kansas Uplift results primarily from increase in thickness of the dolomitic sandstone unit. This increase can be

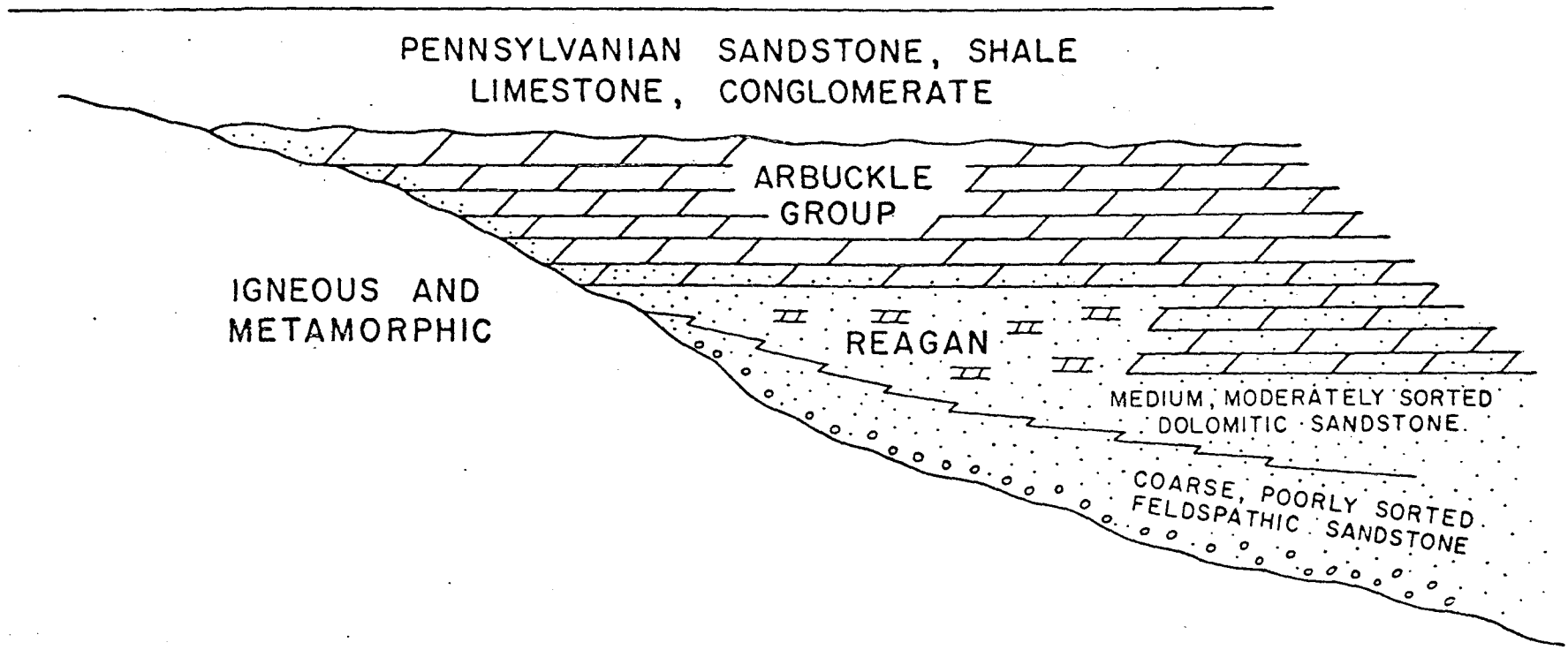


Figure 26.-Diagram showing proposed lithologic and overlap relationships between the Reagan Sandstone and the Arbuckle Group over Precambrian "highs" in central and northwest Kansas.

CAMBRIDGE ARCH

CENTRAL KANSAS UPLIFT

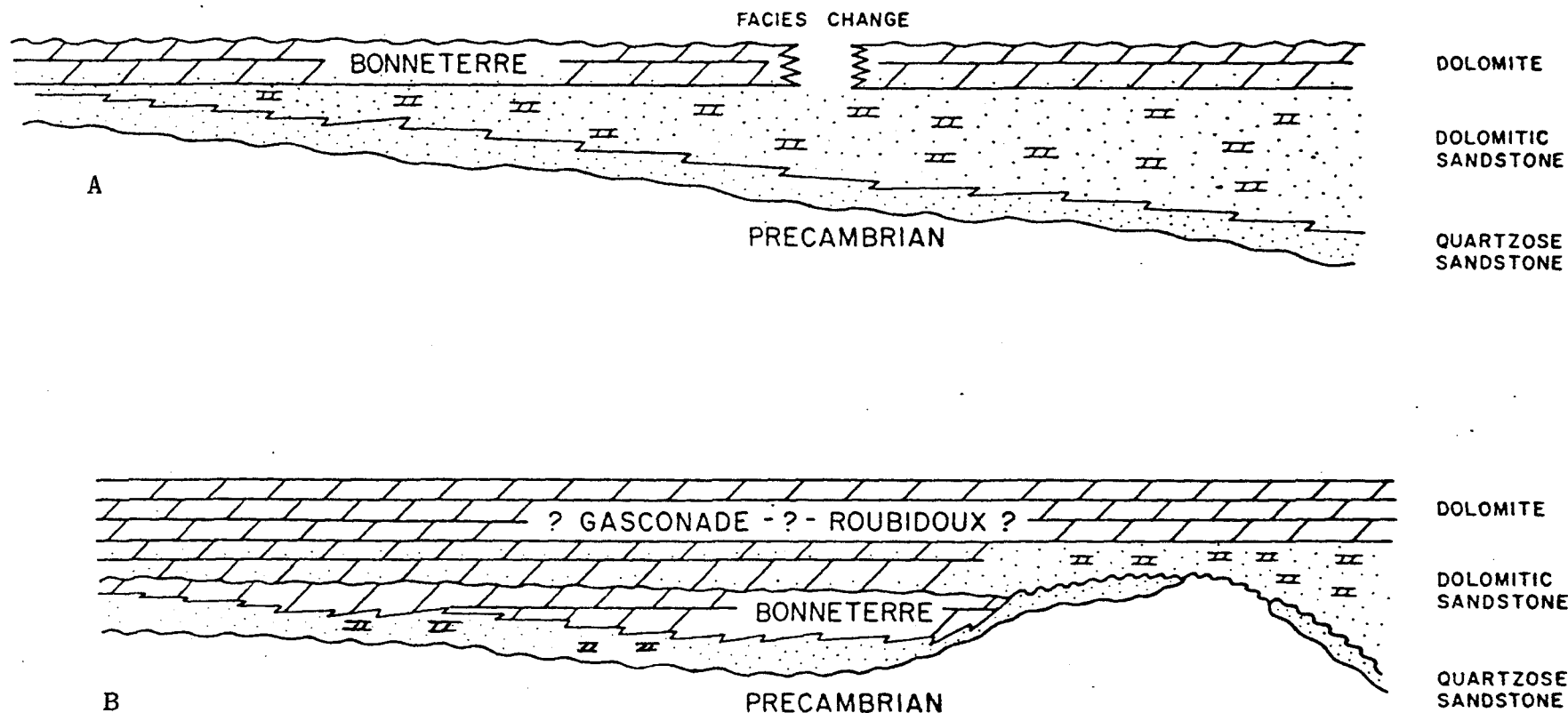


Figure 27 .-Diagrams showing proposed relationships between Cambrian and Ordovician rocks in central Kansas (not to scale). A, proposed relationship between the Reagan Sandstone and the Bonneterre Dolomite at the time of deposition. B, modification of A caused by uplift, erosion, and deposition of later Arbuckle units.

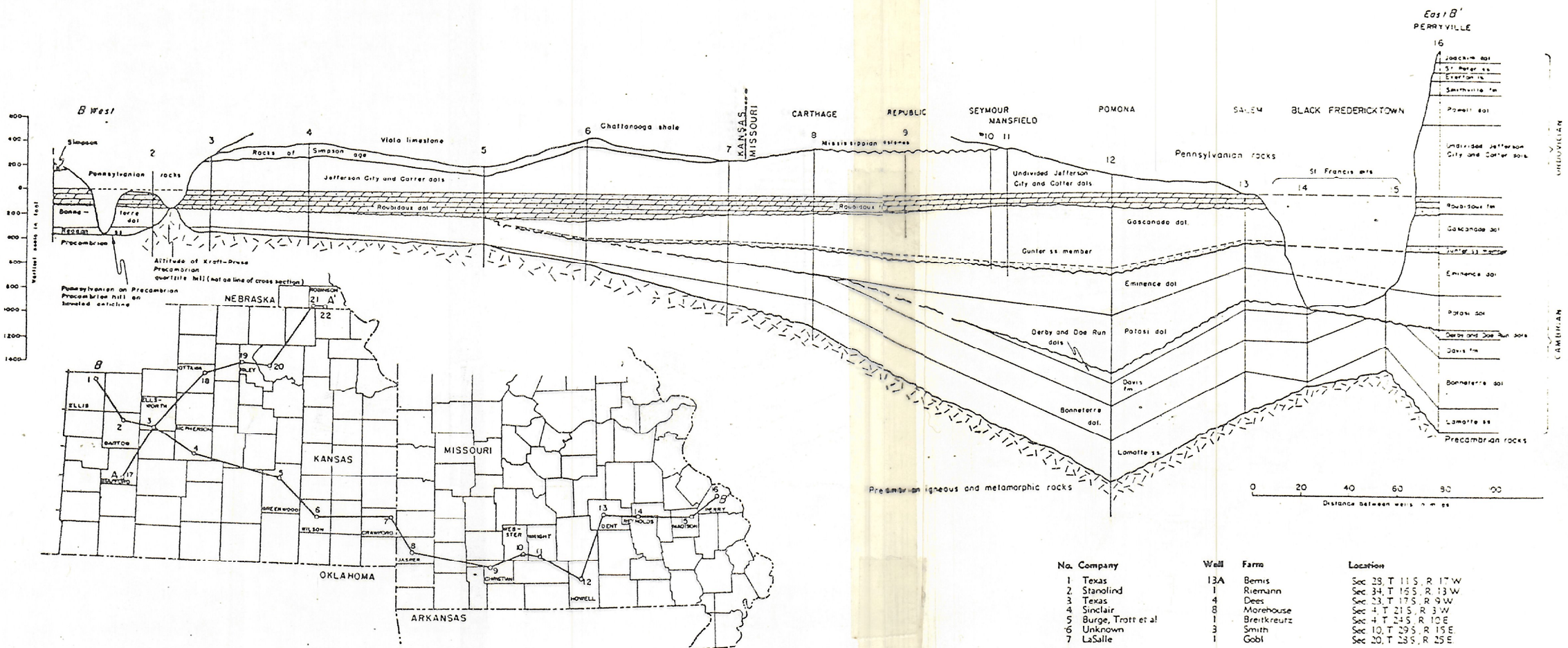


Figure 28.--Stratigraphic cross section showing relation of Roubidoux Formation to older rocks in southern Missouri and in southern Kansas (from Lee, 1956).

explained by the hypothesis illustrated in Figure 27. Diagram A illustrates conditions which are thought to have existed at the time of Reagan-Bonneterre deposition and the results of which can be found in low areas on the Central Kansas Uplift. The absence of glauconite and the change in the nature of dolomite in the Bonneterre between the Cambridge Arch and the Central Kansas Uplift may be interpreted as a slight facies change between the two areas. Diagram B illustrates a suggested modification of the original pattern due to uplift and erosion following the deposition of the Bonneterre Dolomite. The results of this condition are locally found on structurally high areas. Much of the dolomitic sandstone at the base of the Gasconade-Roubidoux is seemingly reworked and redeposited quartzose sandstone of the Reagan.

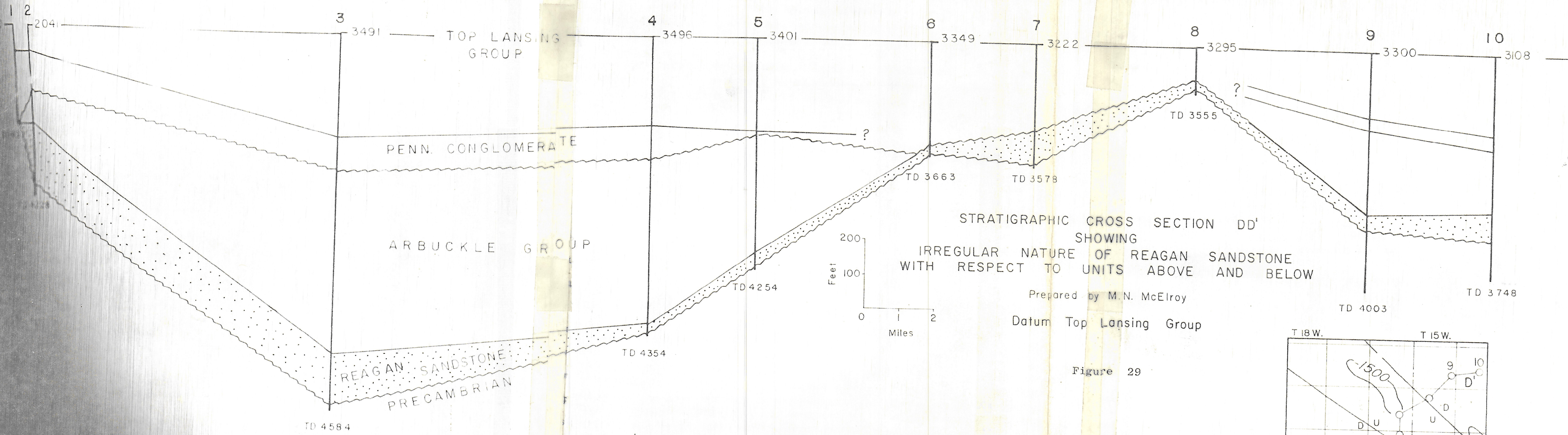
The dolomitic sandstone on the Central Kansas Uplift is thus interpreted as including sediments deposited during both Late Cambrian and Early Ordovician times.

Pennsylvanian System: Rocks of Pennsylvanian age are found in one place or another to be in contact with Precambrian crystalline rocks, the Reagan Sandstone, the Bonneterre Dolomite, the Roubidoux Dolomite and all other units below the Pennsylvanian. This relationship was developed through extensive uplift and erosion prior to Pennsylvanian deposition. The surface upon which these rocks were deposited was highly irregular during the early depositional periods as indicated by the variable lithologic nature and age of the

Pennsylvanian rocks. The Cherokee, Marmaton, Kansas City, and Lansing Groups are locally in contact with all pre-Pennsylvanian rocks.

The Pennsylvanian System includes sandstone, shale, limestone, and conglomerates. The conglomerate is usually found near the base of the System and in contact with pre-Pennsylvanian rocks.

Of primary importance to this study is the relationship between Pennsylvanian rocks and the Reagan Sandstone. On both the Central Kansas Uplift (Fig. 29) and the Cambridge Arch, areas were completely stripped of all pre-Pennsylvanian Paleozoic rocks and the Pennsylvanian is found in direct contact with partially reworked sub-Reagan arkose and crystalline Precambrian rocks, and on the truncated edges of the Reagan Sandstone and the Arbuckle Group (Plate III). The amount of reworking that accompanied this pre-Pennsylvanian erosion and deposition of the Pennsylvanian rocks is undeterminable. Undoubtedly material eroded from the Reagan was a source for many of the thin discontinuous sandstone bodies found in Lower Pennsylvanian rocks lying above Cambro-Ordovician rocks. The Reagan has been preserved in low areas and removed from the adjacent elevated areas. Irregular shale bodies in the upper part of the Reagan indicate reworking. Similar shale units are usually absent where Reagan is overlain by Arbuckle. Lithologic continuity when these wells are compared to nearby wells where the sandstone is overlain by Arbuckle indicates that the sandstone beneath the Pennsylvanian is actually Reagan and not a Pennsylvanian sandstone.

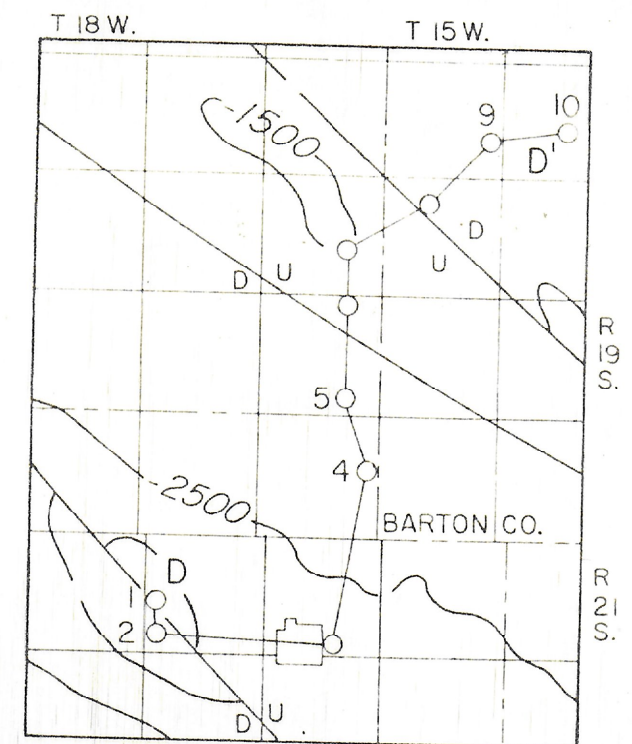


STRATIGRAPHIC CROSS SECTION DD'
 SHOWING
 IRREGULAR NATURE OF REAGAN SANDSTONE
 WITH RESPECT TO UNITS ABOVE AND BELOW

Prepared by M. N. McElroy
 Datum Top Lansing Group

Figure 29

INDEX MAP
 MAP FROM COLE (1962)
 CONTOUR LINES ON PRECAMBRIAN
 C.I. = 100 FEET D U FAULT



QUANTITATIVE ANALYSIS

The preceding part of this study has attempted to give the reader a general understanding of the nature of the Reagan Sandstone, its history and relation to other stratigraphic units in central and western Kansas. The irregularity of control in addition to complexity of the geology is obvious. Maps showing thickness, grain size, sorting, and elevation of the Reagan showed such a high degree of irregularity that meaningful maps were impossible to construct. It was for these reasons that various statistical analyses were employed in an effort to arrive at significant conclusions. Because the information is highly variable and, because the geology is understood only in a general way, it was felt that it would be interesting and valuable to evaluate the usefulness of several such techniques in studies of this type. Trend surface maps were constructed, and in addition, correlation matrices, factor analysis, and a method of clustering data, utilized in numerical taxonomy were all employed.

Trend Surface Maps

Eight trend surface maps were computed using data from 239 wells for control. Plate I shows the control and outline of area "surfaced". Linear, quadratic, and cubic surfaces and their respective residuals were computed on each of the following eight variables: elevation of the base of the

Reagan (also represents configuration of sub-Reagan rocks); thickness of the Reagan; elevation of the top of the Reagan (also represents base of Arbuckle Group); thickness of the Arbuckle Group; elevation of the top of the Arbuckle Group; mean grain size of the Reagan; sorting measure of the Reagan; and roundness index for the Reagan (Fig. 30,31,32, and 33).

A trend surface may be visualized as a smooth contour surface showing the systematic pattern of variation of a mapped variable. This is in contrast with local variations between control points which are present on the regional trend but can be regarded as non-systematic fluctuations. Several papers of importance dealing with this subject include those by Miller (1956), Krumbein (1959), Allen and Krumbein (1962), and Harbaugh (1964).

Lines, planes, and curved surfaces can be fitted to points such that the best fit is obtained. This is generally done by the method of least squares. A least-squares fit is unique because only one position of a line will yield the least possible sum of squared deviations. A surface is generated by this method and then contoured.

Figure 34 shows directions of slope derived from the linear trend surfaces. The amount of variation explained by the linear surfaces is small and averages less than 40 percent of the total variation; therefore, conclusions derived from these maps must be drawn with caution.

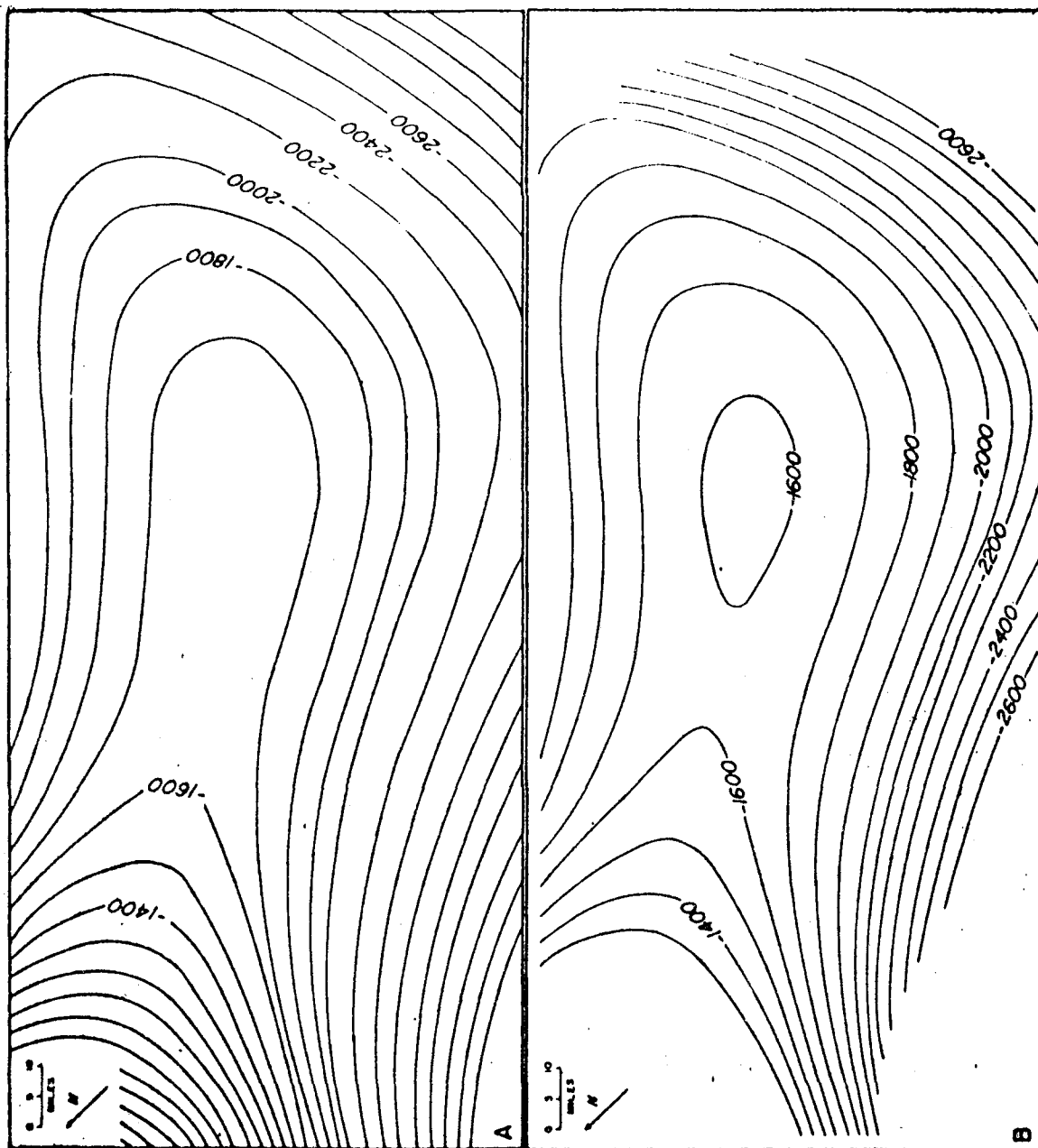


Figure 30.- A. Trend surface map of the structure of the base Reagan Sandstone. Contour interval 100 feet and changing to 200 feet on the -2000 foot contour line. B. Trend surface map of the structure of the top of the Reagan Sandstone. Contour interval 100 feet.

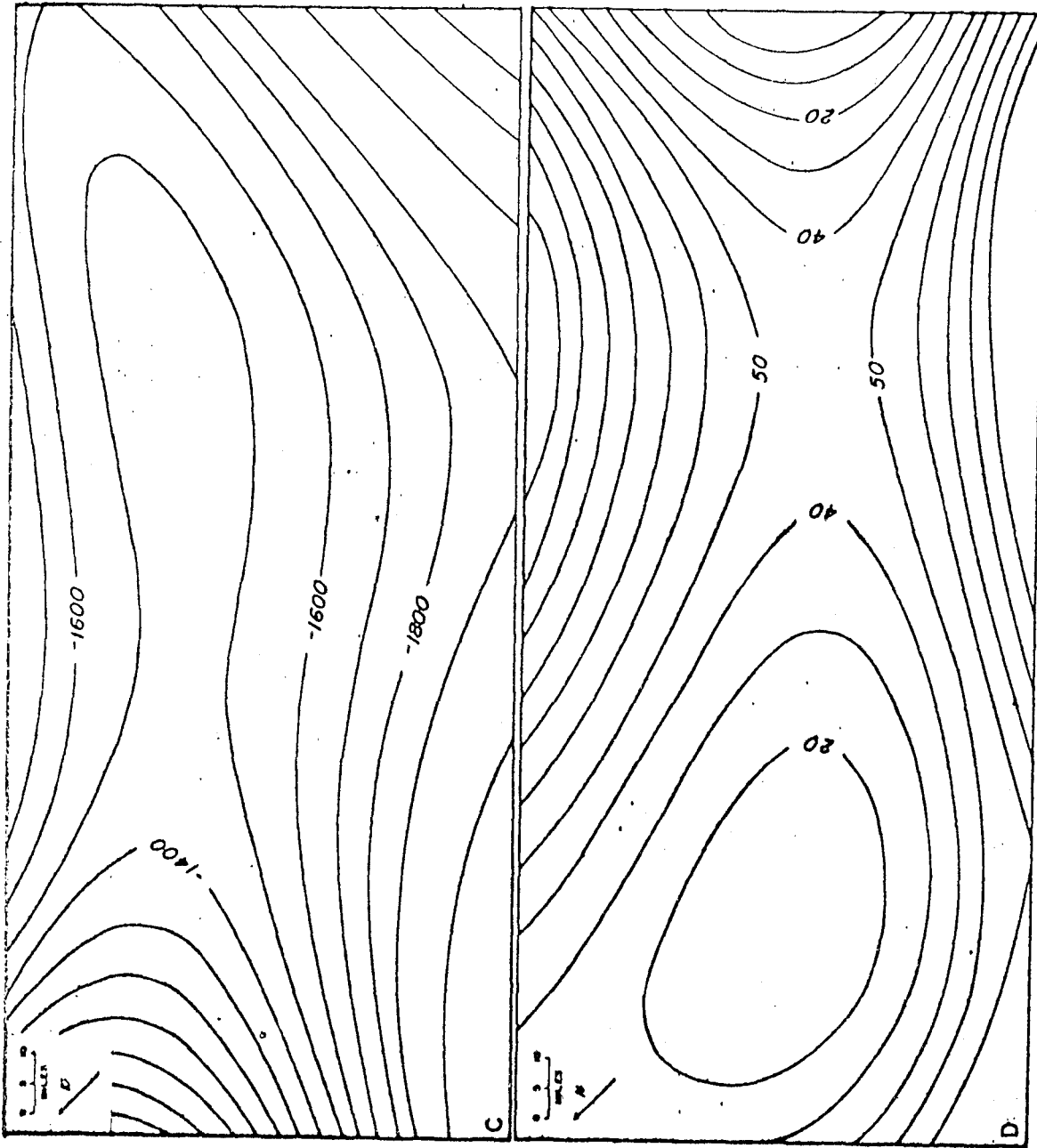


Figure 31 .- C. Trend surface map of the structure of the top of the Arbuckle Group. Contour interval 100 feet.
 D. Trend surface map of the Reagan thickness. Isopach interval 10 feet.

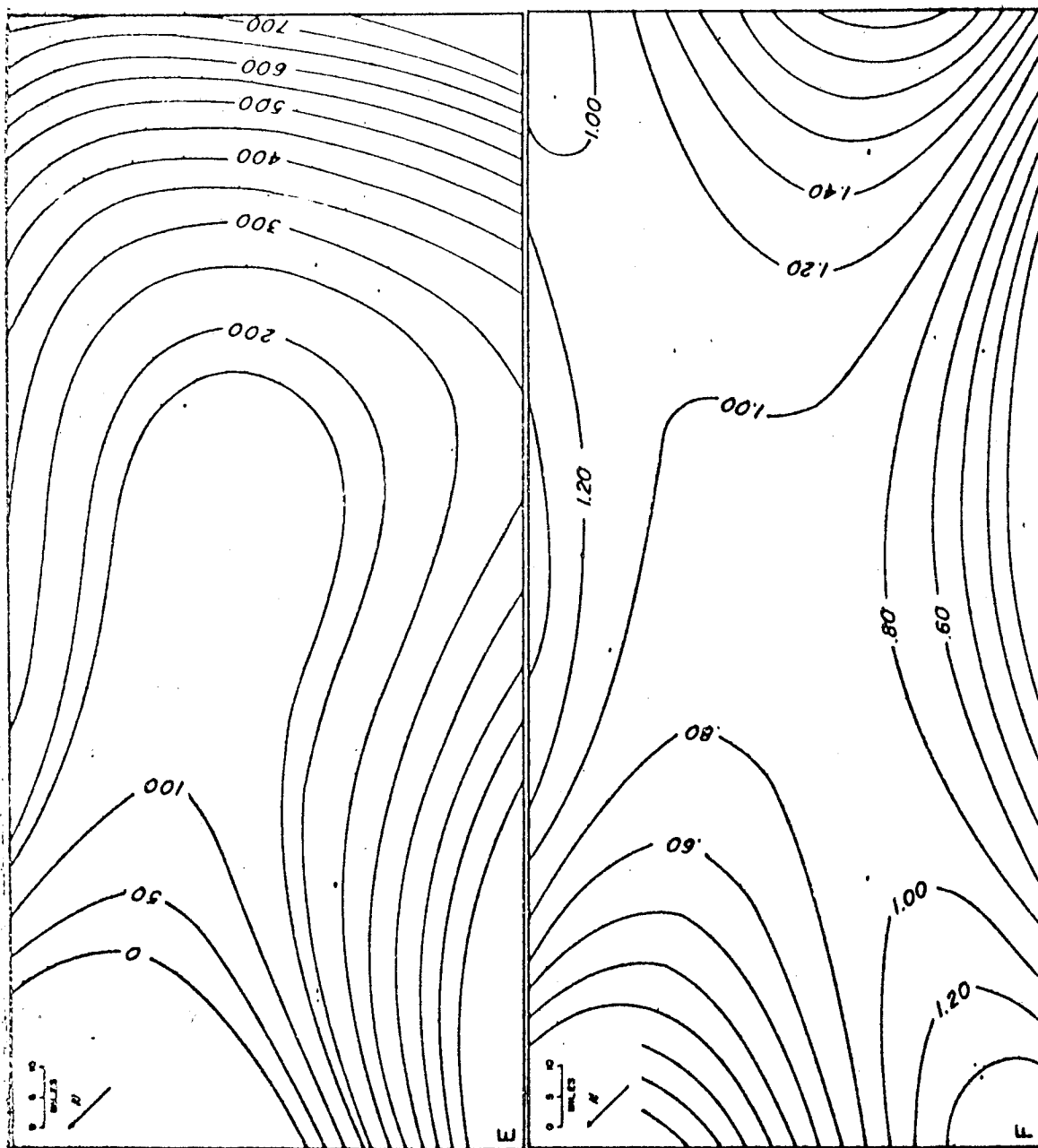


Figure 32 .- E. Trend surface map of the thickness of the Arbuckle Group. Isopach interval 50 feet. F. Trend surface map of the mean grain size of the Reagan. Contour interval 0.2 phi. Greater number indicates decrease in grain size.

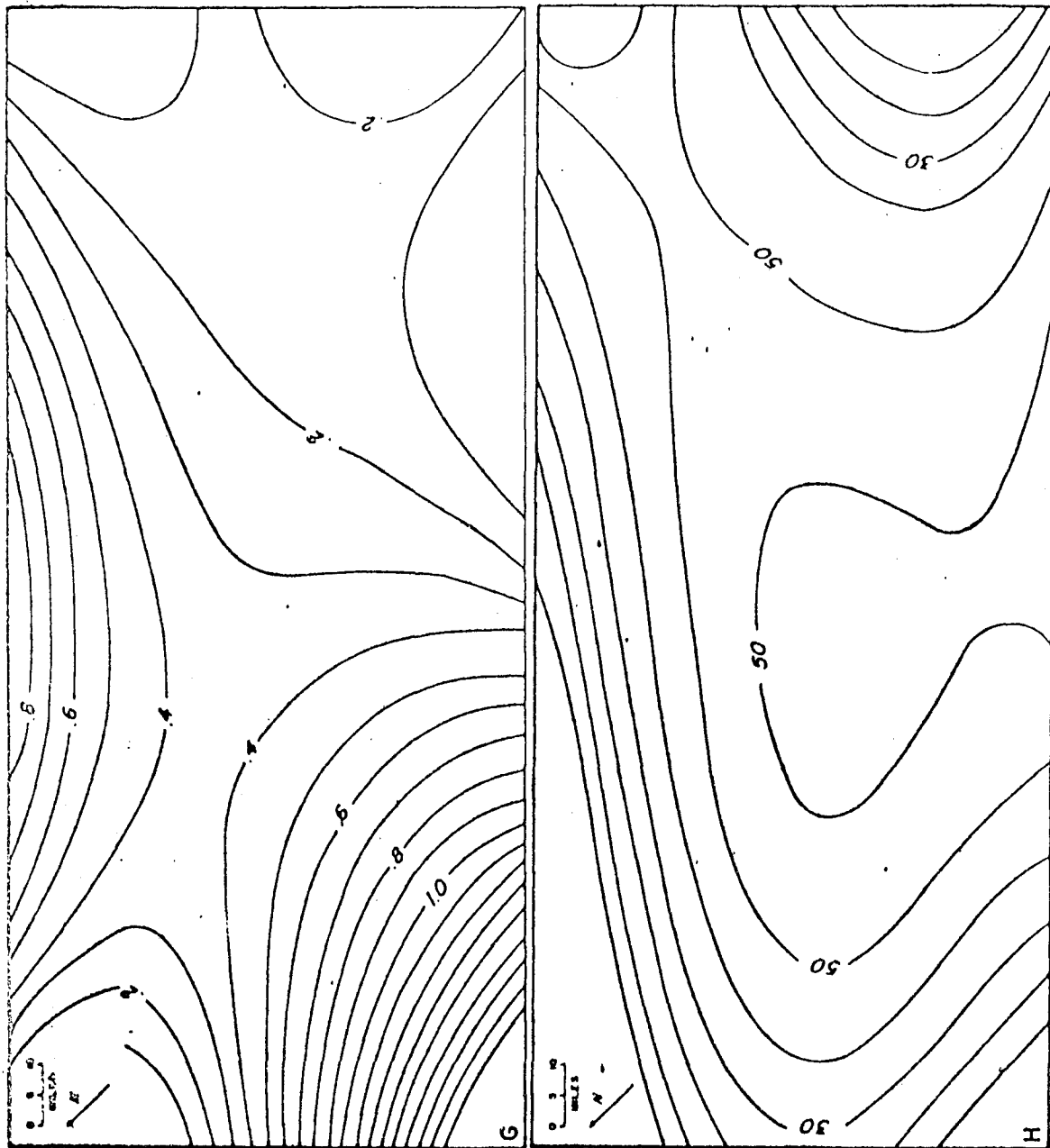
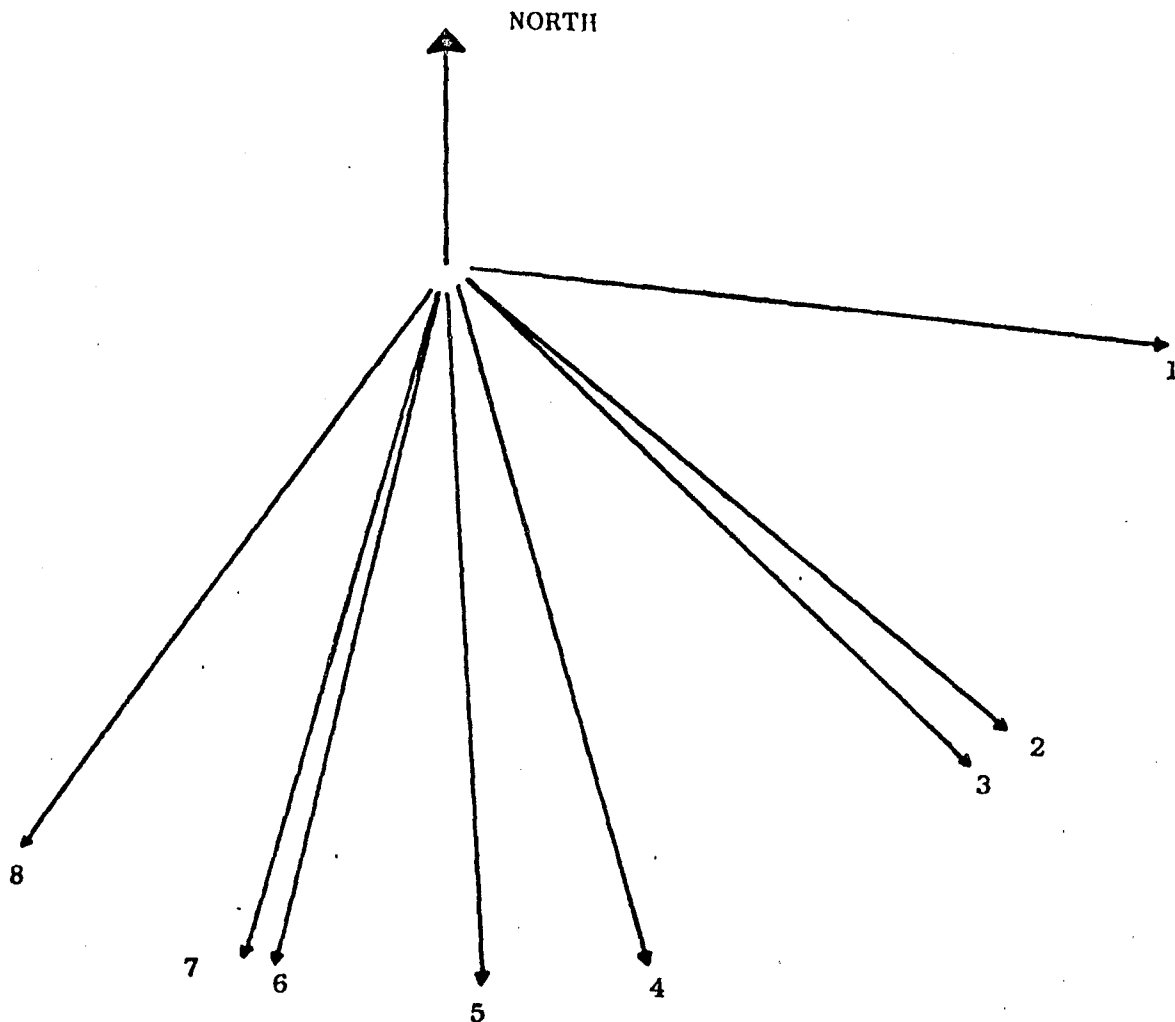


Figure 33 .- G. Trend surface map of roundness index of Reagan Sandstone. Contour interval 0.1. Greater number indicates greater roundness. H. Trend surface map of sorting measure of the Reagan Sandstone. Contour interval 10. Smaller number indicates better sorting.



- | | |
|---------------------|---------------------------|
| 1. Reagan Thickness | 5. Arbuckle Thickness |
| 2. Mean Grain Size | 6. Base Reagan Structure |
| 3. Sorting Measure | 7. Top Reagan Structure |
| 4. Roundness Index | 8. Top Arbuckle Structure |

Figure 34 .--Directions of linear trend surfaces for various factors related to the Reagan Sandstone.

Of special interest is the almost 90 degree angle at which the surface for the Reagan thickness meets the linear surface constructed on the top and bottom of the formation. The linear surfaces for the top and for the bottom of the Arbuckle Group also have general trends to the southwest. It is possible that the trend surfaces on the top of Arbuckle, base of Reagan, and thickness of Arbuckle are indicative of a direction of regional tilt following deposition. At first glance the trend of the Reagan thickness might indicate direction from which the sea advanced. This conclusion could in part be aided by the trend representative of mean grain size which shows a general decrease toward the southwest and might result from grain size decrease away from the source. It should also be noted that the degree of sorting becomes better in the same direction. Such interpretations fit the general pattern for the conditions during deposition.

With the exception of the maps of grain size, sorting, roundness, and thicknesses of Reagan and Arbuckle, the percent variation explained by the cubic surface averaged 78 percent, whereas the remaining maps averaged only 52 percent. This decrease indicates that a great amount of the variation that is not explained by the surface lies within the extreme irregularity of the original data. This includes natural variation, sampling error, and observational error. However, from what is known about variations in the Reagan thickness and

lithology, a great amount of the "unexplained" variation can be attributed to factors within the Reagan itself.

Maps A, B, and C can easily be interpreted, whereas D, E, F, G, H, require more detailed analysis. Map A, of the base of the Reagan is also representative of the present configuration of the Precambrian. Maps (A, B, C) display a high degree of similarity. Thus, where elevation of the Precambrian is high the units immediately above are likewise high. Local variations which have been "smoothed out" are readily apparent in the residual values and on maps showing units resting on the Precambrian. The outstanding feature shown by these maps is the general outline of the Central Kansas Uplift with the surfaces dipping toward the basin areas. A slight shift toward the east can be noted on the axis of the map on top of the Arbuckle. The Cambridge Arch is the highest feature indicated on the map. A comparison of these maps with the Configuration Map on the Precambrian by Cole (1962) and the Preliminary Structural Contour Map on the Arbuckle by Merriam and Smith (1961) indicated the gross oversimplification of the true pattern by the trend surface maps.

The trend surface map of the Reagan thickness (Fig. 31) shows the Reagan to be thin on the Cambridge Arch and along the southeast edge of the map. An increase in thickness is indicated to the southwest and northeast. Near the center of the Central Kansas Uplift uniform thickness is present.

Map E , a trend surface of the Arbuckle thickness, shows that the Arbuckle is absent in the general area of the Cambridge Arch. The thickness of the Arbuckle increases outward from the Central Kansas Uplift. The area of uniform Reagan thickness is at the approximate point where the Arbuckle begins to increase in thickness rather rapidly to the southeast.

Maps F, G, and H are trend surface maps on the mean grain size, roundness index, and sorting measure for the Reagan Sandstone. The mean grain size is in phi units and the greater positive number therefore indicates smaller size and the larger negative number indicates larger size. The roundness index is that employed by Dapples, Krumbein and Sloss (1953). The index of a sample is the ratio of the percentage of quartz whose roundness exceeds 0.5 to the percentage of those whose roundness is less than 0.5. The grain roundness classes are those defined in Pettijohn (1956, p. 59). The values ranged from 0.01 to 1.00 with the higher degree of roundness represented by the higher number. The sorting measure is the result of multiplying the range of phi sizes squared, times an estimate of the number of phi sizes represented in the modal 2/3 of the sample. Values ranged from 4 to 144 with the greater number representing the poorest sorting.

The trend surface map of mean grain size indicates decreasing size to the northwest, northeast, and southeast. An increase is shown towards the Cambridge Arch and to the

southwest. The increase to the southwest is anomalous in that it does not fit the observed data. It can perhaps be explained by the fact that the trend surface is computed only within the map boundaries and this increase is the result of the few wells near this margin with large mean grain sizes. Total variation in mean grain size is small throughout most of the area as indicated by the broad area over the Central Kansas Uplift.

The degree of roundness increases only toward the northeast, northwest, and a small area toward the south (Map G). The index shows extreme grain angularity on the Cambridge Arch and Central Kansas Uplift. A local area with little variation is seen in the saddle which separates the two structural provinces. Because this index is a ratio of percentages, the apparent trend toward increased roundness only indicates that the number of highly angular grains are less common than in areas with low value contours.

Map H is a trend surface map of sorting measure for the Reagan. Sorting of the sandstone becomes better toward the flanks of the uplifts. On the Cambridge Arch sorting is better than on the central and southeast part of the Central Kansas Uplift. On the Cambridge Arch fewer grain sizes are present whereas on the Central Kansas Uplift the very coarse grains are present in beds near the bottom of a well. The thick sequence of dolomitic sandstone with fine grains is also present.

From a study of the trend surface maps it is apparent that regional trends can be identified; but the evaluation of such trends rests heavily upon a knowledge of the geology. For instance, the linear trend surface directions for mean grain size, sorting measure, and Reagan thickness when analyzed in conjunction with the cubic surfaces, could lead to the conclusion that the regional paleoslope during Reagan deposition was to the southeast. In addition one might surmise that the source and shore line were present in the vicinity of the Cambridge Arch and deeper water conditions were present to the south, thereby accounting for the increased thickness of dolomitic sandstone. It has been shown earlier that this is not the most probable explanation.

Statistical Correlation Matrices

Correlation can be defined as a measure of the degree to which variables vary together or a measure of the intensity of association (Steel and Torie, 1960, p. 183). One of the values of the correlation coefficient (r) is that it is independent of the units of measurement. The absolute value of the coefficient varies from -1 to $+1$, indicating maximum or perfect correlation between the two variables.

The degree of association can be shown by means of scatter diagrams or matrices. The mechanics of constructing graphs prohibits their use when dealing with more than three or four variables; therefore, matrices were computed on 15 and 19

variables and 80 wells for use in factor analysis and the numerical taxon program. The first two matrices were to show the correlation between variables obtained from 50 and 80 wells respectively. The third shows the degree of association between 80 wells based on 19 variables. The variables include thickness, elevations, percentages of various minerals, and various sedimentary parameters. This method of assigning numbers to parameters was chosen in favor of verbal description so that statistical techniques such as this could be investigated. Only the 15x15 matrix, which was used in the factor analysis will be employed to illustrate this technique (Table 3). The 19x19 matrix was run on data obtained from wells other than those used in the 15x15 matrix as a check on the first matrix. The 80x80 matrix was used in the numerical taxon program. All data were processed on an IBM 7040 computer.

Most of the r values indicate little correlation between variables, and it should be kept in mind that no quantitative conclusions can be obtained by visual inspection. However, most values greater than $+0.2$ or -0.2 are statistically significant at the $.05$ alpha level. The primary value of the matrices lies in analysis by more sophisticated techniques such as factor analysis, but the relationships illustrated by the significant r values indicates interesting relationships between the variables. A great many of the conclusions arrived at may be quite obvious by simple observation, but it is those anomalous values which may be highly significant in a geological sense.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	x														
2	-0.1535	x													
3	-0.3575	-0.0065	x												
4	0.1736	-0.2187	-0.3610	x											
5	-0.0952	0.0122	0.0239	-0.0106	x										
6	-0.0022	-0.1695	-0.2164	0.0650	-0.0515	x									
7	0.1090	-0.1533	-0.1670	0.8605	-0.1173	-0.2663	x								
8	0.1170	0.2411	-0.2673	0.7626	0.0031	0.5429	0.4771	x							
9	0.9767	0.0611	-0.3625	0.1281	-0.0935	-0.0389	0.0770	0.0661	x						
10	-0.1439	0.2937	0.3690	-0.3018	0.1355	-0.3107	-0.1112	-0.3880	-0.0819	x					
11	-0.1323	0.3126	-0.0259	0.2421	-0.0010	-0.0491	-0.1370	-0.1910	-0.0660	0.3883	x				
12	0.1147	-0.1276	-0.4985	0.4322	-0.1013	0.1489	0.3597	0.3615	0.0883	-0.2730	0.2264	x			
13	0.1555	-0.1843	0.2440	0.2368	-0.1889	0.2764	0.0689	0.3077	0.1173	-0.8665	-0.5897	0.1225	x		
14	-0.1997	0.2888	0.3842	-0.3051	0.1457	-0.3062	-0.1127	-0.3875	-0.1393	0.9977	0.3965	-0.2693	-0.8700	x	
15	-0.1170	0.2078	0.3002	-0.3969	0.0299	-0.0477	-0.3688	-0.2037	-0.0732	0.0828	-0.2827	-0.4565	0.0887	0.0831	x

TABLE 3 Lower half of R-correlation matrix showing correlation coefficients among variables.

- | | |
|----------------------------------|---|
| 1. Quartzose sandstone thickness | 9. Quartzose sandstone thickness + Arkose thickness |
| 2. Arkose thickness | 10. Elevation of Reagan top |
| 3. Percent glauconite | 11. Absence of Arbuckle |
| 4. Mean grain size | 12. Percent quartz |
| 5. Roundness index | 13. Arbuckle thickness |
| 6. Sorting measure | 14. Elevation of Precambrian top |
| 7. Maximum grain size | 15. Relative distance from faults |
| 8. Minimum grain size | |

The following statements can be made with regard to the matrix shown in Table 3. No cause and effect relationships are implied by these statements.

1. Reagan thickness increases with structurally lower Precambrian elevation. The percent of glauconite decreases with increase in Reagan thickness.
2. As the arkose thickness increases, the Reagan grain size increases. Arkose has a greater thickness where Reagan and Precambrian elevations are higher, where Pennsylvanian rocks overlie Reagan, and where Arbuckle is thin.
3. The percentage of glauconite in the Reagan increases with increase in grain size, increase in sorting, decrease in percent quartz, increase in Reagan and Precambrian elevations, decrease in Reagan and Arbuckle thickness; and increases away from faults.
4. The mean grain size of the Reagan decreases with decrease in maximum grain size, minimum grain size, Reagan and Precambrian elevations, increase in Arbuckle thickness, and increase in percent quartz.
5. The degree of sorting decreases with an increase in maximum grain size and increase in minimum grain size, and also decreases with an increase in elevation of the Reagan and the Precambrian.
6. The maximum and minimum grain size becomes smaller with an increase in percent quartz and Arbuckle thickness, and increases with a decrease in Reagan and Precambrian elevation.

7. The elevation of the Reagan increases as percent quartz and Arbuckle thickness decrease, and increases as Precambrian elevation increases.
8. Arbuckle is absent when the elevation of the Reagan and Precambrian are high, and increases in thickness with a decrease in Precambrian elevation. The roundness index of the Reagan increases with decreasing Arbuckle thickness.

Most of these statements describe expected relationships, but serve to document the usefulness of such statistical methods.

Factor Analysis

Much of the following material on factor analysis as applied to the Reagan Sandstone was done in conjunction with Roger Kaesler, and full credit is hereby given for this help. Much of the following was taken from McElroy and Kaesler, (1965, p. 191). For more detailed discussion of factor analysis the reader is referred to papers by Cattell (1952), Fruchter (1954), Harman (1960), and Thurstone (1954).

From the numerous variables available, 15 were selected which were felt to be quantitatively the most reliable.

Following is a brief discussion of these variables.

1. "Quartzose sandstone thickness: This thickness includes only the quartzose sandstone occurring between the overlying Arbuckle Group and underlying

igneous, metamorphic, or arkosic rocks. Thickness of quartzose sandstone (Reagan) in the 50 wells ranged from 4 to 98 feet."

2. "Arkose thickness: This variable is the thickness of arkose below the quartzose sandstone and above Precambrian igneous and metamorphic rocks. Thickness ranged from 0 to 33 feet, but arkose was penetrated in only 3 of the wells used."
3. "Percent glauconite: Glauconite percentages vary considerably throughout the area and grain count estimates range from 0 to 15 percent of minerals present. A square root transformation was made on the percentages to approach a normal distribution."
4. "Mean grain size: This variable was determined by careful percentage examination of all phi sizes present in a given well sample. Mean phi size ranged from -2.0 to +2.0."
5. "Roundness index: This index is that employed by Dapples, Krumbein, and Sloss (1953), based upon the grain roundness classes defined by Russell and Taylor (1937, p. 239, 248), and placed in chart form by Pettijohn (1956, p. 59). The index of a sample is the ratio of the percentage of quartz grains whose roundness exceeds 0.5 to the percentage of those whose roundness is less than 0.5. Values ranged from .01 to 1.00."

6. "Sorting measure: In any measure of sorting both the range and spread must be considered. The measure used is the result of multiplying the range squared times an estimate of the number of phi sizes represented in the modal 2/3 of the sample. Values ranged between 4 and 98 with the greater number representing the poorest sorting."
7. "Maximum and minimum grain size respectively: These &
8. two variables were chosen as a check on mean grain size and sorting measure. Units of measure are ranked phi sizes."
9. "Quartzose sandstone plus arkose thickness: This variable is actually a combination of 1 and 2 and represents the distance that the quartzose sandstone top lies above the Precambrian igneous and metamorphic rocks at all locations. Values range from 7 to 98 feet."
10. "Subsea elevation of top of quartzose sandstone: Values range from -1062 to -3105 feet."
11. "Absence of Arbuckle: This measure was presence of either Arbuckle or Pennsylvanian formations. The number 1 was recorded for Pennsylvanian and a 0 for Arbuckle. Pennsylvanian rocks were present overlying the sandstone in 17 wells."
12. "Percent quartz: This variable is a measure of quartz content and is an average of all samples

measured in that well. Percentage values ranged from 83 to 98 percent. Values were subtracted from 100 and the negative square root of the remainder taken."

13. "Arbuckle thickness: Values ranged from 0 to 691 feet."
14. "Subsea elevation of top of Precambrian igneous and metamorphic rocks. Values ranged from -1118 to -3114 feet."
15. "Relative distance from nearest known faults: Measurements were in inches from faults indicated on the Configuration Map of Precambrian Basement Rocks in Kansas (Cole, 1962). Distances in inches range from 0.1 to 3.4 inches. Map scale is one inch equals 10 miles."

Fruchter (1954, p. 1) defines factor analysis "as a method of analyzing a set of observations from their inter-correlations to determine whether the variations represented can be accounted for adequately by a number of basic categories smaller than that with which the investigation was started." Once the variables are determined some method must be employed to compute the degree of association between all possible pairs of variables. Distance coefficients and correlation coefficients are the two most common methods. From this, computed matrix pairs of variables must be extracted by one of two methods referred to as the R and the Q technique. The

Q technique involves correlations of individuals based on measurements of several variables for each individual. The R technique uses correlations of the variables themselves based on the individuals from which the measurements were taken. Table 4 was used in the factor analysis and represents an R correlation matrix. Distribution of wells used is shown in Figure 35.

Three methods, principal components factor analysis, oblique rotation to simple structure, and transformation of simple structure to primary pattern were used to complete the objects of factor analysis (McElroy and Kaesler, 1965).

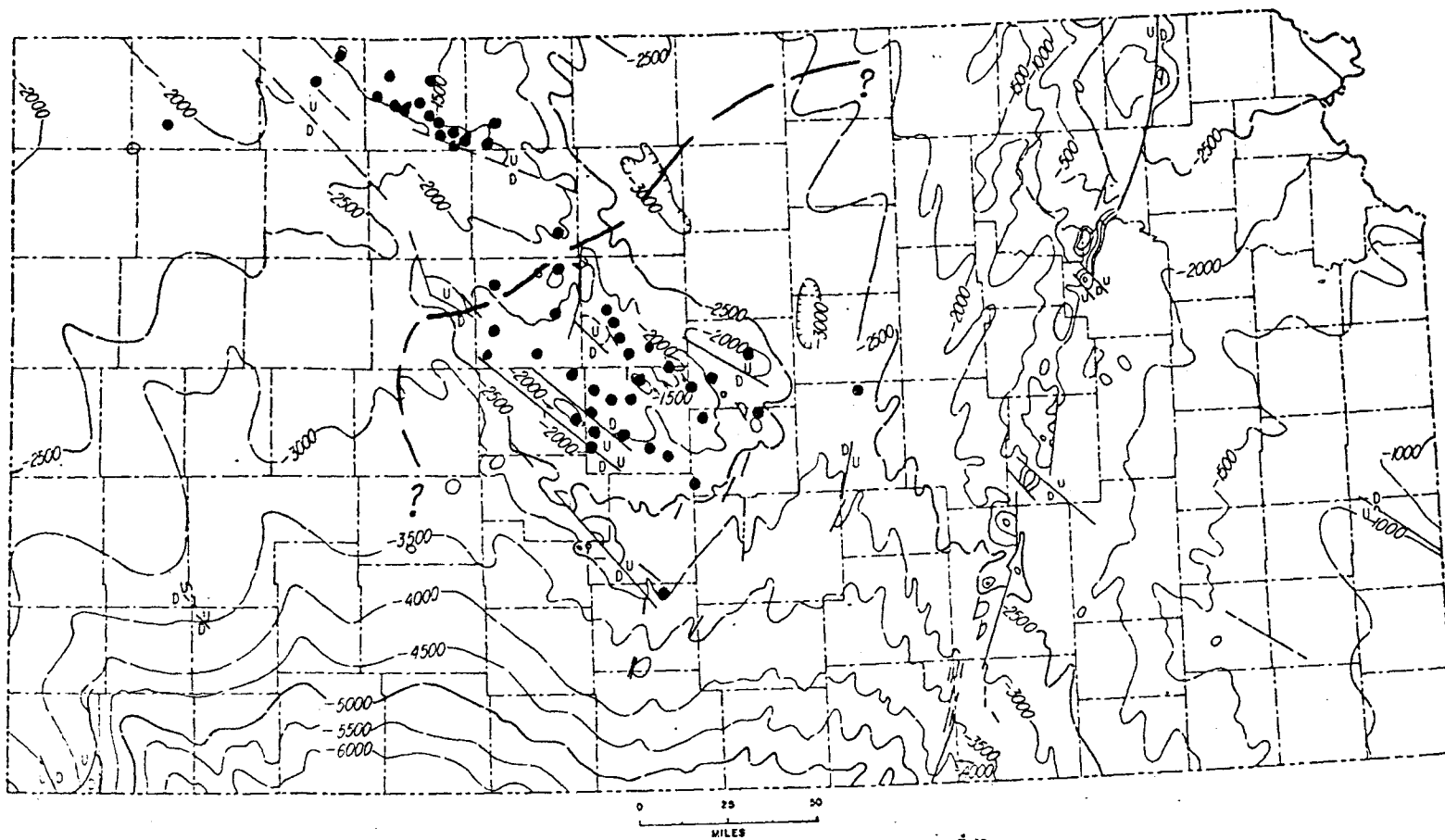
These methods produced four primary factors which were reified, or identified and named according to their effect on the variables in the study. Factor I is identified as subsidence during time of Reagan deposition, factor II is related to eastern distribution of the wells under consideration, factor III is related to conditions in the southern part of the area, and factor IV can be equated with Reagan and post-Reagan uplift or non-subsidence.

The following interpretation is quoted from McElroy and Kaesler (1965).

"Having found four primary factors, they must be reified if they are to be of any value in analyzing the Reagan Sandstone. To reify is to convert an abstract or mental construction into a supposed real thing; reifying factors involves identifying them and naming them according to their effect on the variables in the study. The variables of an R-correlation study may themselves be casual

VARIABLES		PRIMARY FACTORS			
		I	II	III	IV
Qtz ss + Arkose thick.	9	+++	.	.	.
Qtz. ss thickness	1	+++	.	.	.
Mean grain size	4	.	+++	o	.
Max. grain size	7	.	+++	o	.
Min. grain size	8	.	+	o	o
Percent quartz	12	.	-	+	.
Rel. dist. from fault	15	.	.	-	.
Percent glauconite	3	o	.	-	o
Absence of Arbuckle	11	.	.	-	-
Elev. of Reagan top	10	.	.	o	+++
Elev. Precambrian top	14	.	.	.	+++
Arbuckle thickness	13	.	.	.	++
Sorting measure	6	.	.	o	-
Arkose thickness	2	.	o	.	o
Roundness index	5
		/factor loading/		0.9 = +++	
		/factor loading/		0.9 - 0.8 = ++	
		/factor loading/		0.8 - 0.6 = +	
		/factor loading/		0.6 - 0.4 = -	
		/factor loading/		0.4 - 0.2 = o	
		/factor loading/		0.2 - 0.0 = .	

Table 4 . Relative primary pattern factor loadings.



in

Figure 35.-Map showing distribution of control used/factor analysis and limit of glauconite distribution in the Reagan (absent south of dashed line, modified from McElroy and Kaesler, 1965).

variables. According to the method of Cattell (1952) if several obviously related variables have very high loadings on one factor, such as variables 4, 7, and 8 (mean, maximum, and minimum grain size, respectively) have on factor II, it seems reasonable to identify that factor as a grain size factor; however, as mentioned above, we are looking for casual relationships. It is difficult to imagine how grain size could affect any of the other variables in the study. Similar difficulties are encountered in attempting to reify I as a quartzose sandstone thickness factor or IV as a pre-Arbuckle elevation factor. Instead these factors are highly correlated with and strongly affect grain size, quartzose sandstone thickness, and pre-Arbuckle elevation, respectively. They must be reified by examining all relationships both in the factor matrix and the original correlation matrix. See Table 3 .

Factor I might be identified as subsidence during time of Reagan deposition. Quartzose sandstone thickness would have a high positive regression on subsidence during Reagan deposition. The only other high regression is variable 9 which is equivalent to quartzose sandstone thickness because of the low regression of arkose thickness on factor I. All other variables have near zero loadings on I, except percent glauconite. Its low negative value indicates high glauconite formation during times of basin stability, i.e., low sediment influx.

Factor II appears to be related to eastern distribution of the wells under consideration. Mean grain size decreases toward the east, and percent quartz increases. Arkose thickness has a high negative loading, which agrees with the almost non-existence of arkose in the eastern part of the study area.

The magnitude and sign of the loadings on factor III supported by the original correlation matrix suggest that factor III may be a southern factor; however, geologically, a southern position is not so much a cause as a result of geological processes which differ in activity from south to north. Variables that have large values in the south have a high regression on III. For example, percent quartz, phi size, and sorting measures are higher in the southern part of the study area. Similarly

percent glauconite and elevation of tops, which are higher in the north, have substantial negative loadings on III.

Using similar reasoning factor IV can be equated with Reagan and post-Reagan uplift or non-subsidence. Thus elevation of top of Reagan and top of Precambrian have high positive regression on factor IV. Arbuckle thickness has a high negative regression on IV and can be explained by lack of Arbuckle deposition, or post-Arbuckle erosion when the underlying Reagan has a high elevation. A check on this is provided by variable II (absence of Arbuckle) with a positive loading.

Variables 3, 6, and 8 seem to have been affected by non-subsidence during time of Reagan deposition. Table 4 shows factor loadings of variable 3 on I and IV of nearly the same magnitude but with opposite sign. This is to be expected because the regression of 3 on I indicates low glauconite formation under conditions of subsidence and active sedimentation; whereas regression of 3 on IV indicates glauconite formation in a stable environment. Similarly with stable conditions we expect a higher degree of sorting as indicated by loading of variable 6 on factor IV (high sorting measure indicates poor sorting). It is obvious that the loadings of variables 7 and 8 also indicate increased sorting with non-subsidence."

From the above it can be seen that factor analysis can be usefully applied in stratigraphic studies. The problems associated with the Reagan are in many cases unclear and certainly unsolved; however, even with highly irregular control and variables this method concentrates the information such that useable deductions can be inferred.

Numerical Taxonomy

The principles of numerical taxonomy are well defined by Sneath and Sokal (1962) and Sokal and Sneath (1963).

Numerical taxonomy is defined (Sneath and Sokal, 1962) as "the numerical evaluation of the affinity or similarity between taxonomic units and the ordering of these units into taxa on the basis of their affinities."

Stratigraphers and sedimentologists are interested in the basic problems of taxonomic classification and the application of the taxonomists' methods of ordering units into "groups" on the basis of their affinities. To the best of my knowledge the technique described here has never been applied to stratigraphic and sedimentary data.

The term character will be used to refer to the variables such as sorting, roundness, thickness, etc., and in place of the term taxonomic unit, a well will be used to represent the "object" for which the characters were determined. The result will be wells grouped on their similarity with respect to the characters.

The first step is the determination of characters from each well which might be diagnostic in the estimation of "resemblance" between wells. The second step is the computation of resemblance by some coefficient of similarity. According to Sneath and Sokal (1962), these may be grouped into three major types. Of the many possible coefficients the most useable are coefficients of association, correlation coefficient, and distance coefficients. The last two are commonly used in factor analysis. The final computational step is the clustering of the wells by average linkage (Sokal

and Sneath, 1963, p. 182), into groups on the basis of the similarity coefficients. Data were not standardized, but the original correlation coefficients were converted to Z values.

Finally, the groups are interpreted as to meaning of association.

In this study 50 wells were used and 19 characters from each well. The present program limits the number of wells to 50. On an IBM 7040 computer correlation coefficients were computed for the coded characters giving a 50x50 matrix followed by the "taxon program" which clustered the wells and printed the dendogram.

The 19 characters include:

1. elevation of the top of the Reagan
2. elevation of the top of the Precambrian
3. Arbuckle thickness
4. Reagan thickness
5. arkose thickness
6. relative amounts of quartz in Precambrian rocks
7. relative amounts of biotite in Precambrian rocks
8. relative amounts of feldspar in Precambrian rocks
9. distance from fault
10. percent quartz in the Reagan
11. percent glauconite in the Reagan
12. percent dolomite in Reagan
13. mean grain size of the Reagan
14. roundness index of the Reagan
15. sorting increase of the Reagan

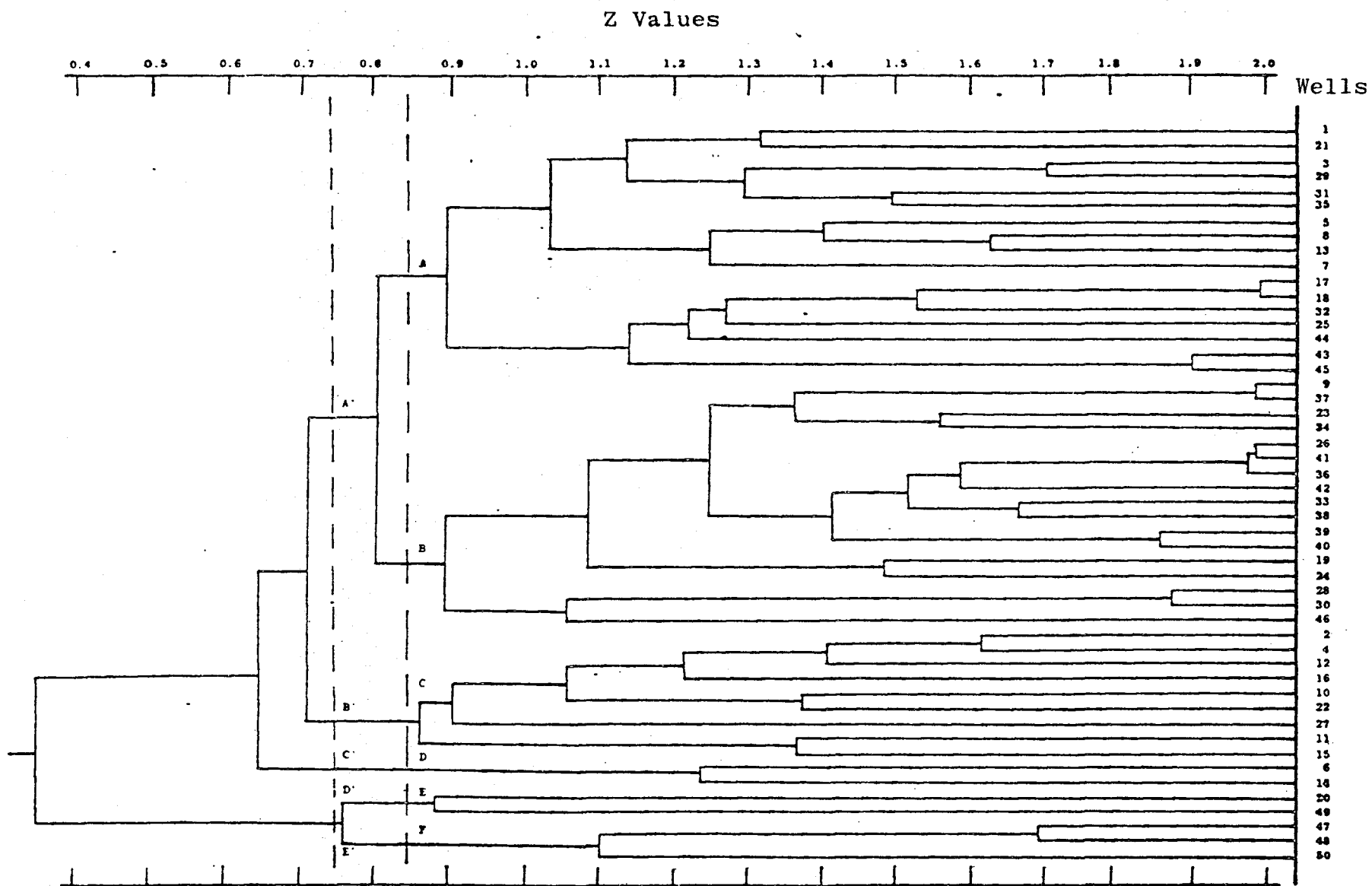


Figure 36.--Dendrogram prepared by the weighted pair group method based on R-matrix of correlation coefficients transformed to Z values computed from well data. Dashed lines and letters refer to clusters determined from 0.75 and 0.85 Z values and plotted on Figures and .

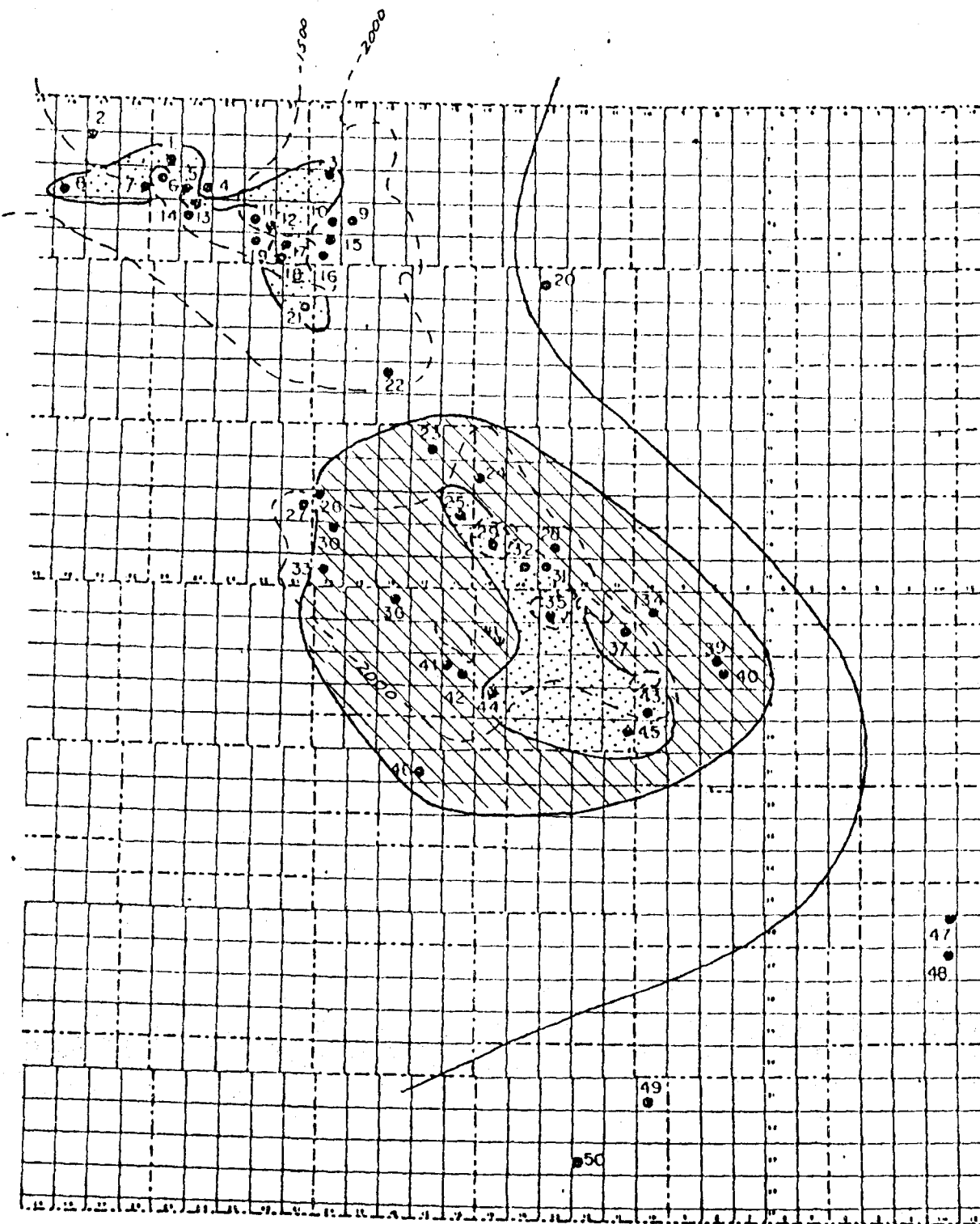


Figure 37.-Map showing distribution of clusters determined at the 0.85 Z value. Dashed lines are -1500 and -2000 foot contours on Precambrian surface. Stippled area is cluster A; lined area is cluster B; unmarked area surrounding clusters A and B and west of the line; cluster D is scattered; clusters E and F fall east and south of the line.

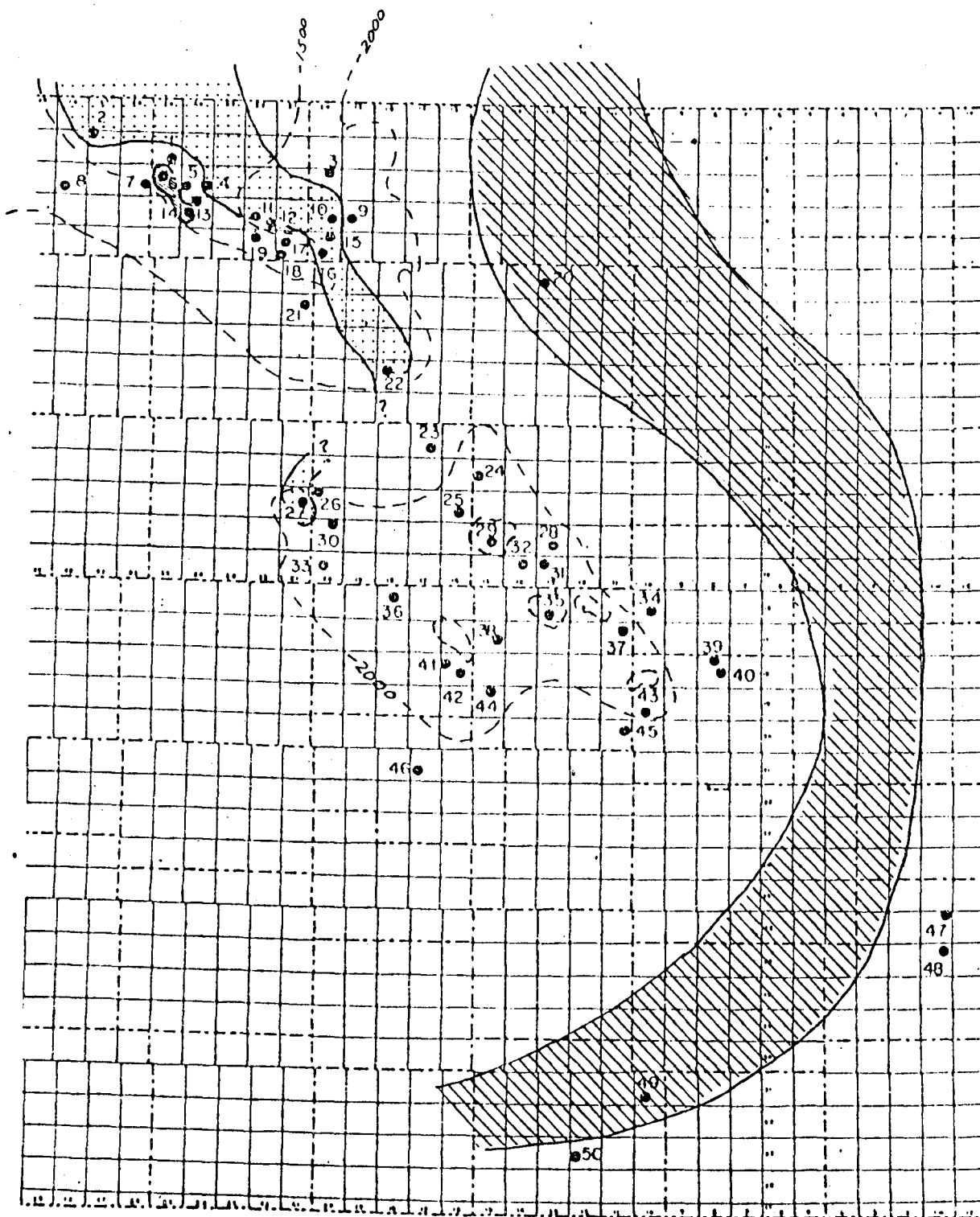


Figure 38.- Map showing distribution of clusters determined at the 0.75 Z value. Dashed lines are -5000 and -2000 foot contours on Precambrian surfaces; unmarked area in center represents cluster A'; stippled area is cluster B'; cluster C' encloses wells 6 and 13; cluster D' encloses both lined and unmarked area east. This cluster can be further subdivided by dropping level to 0.782 without affecting other contours, thus giving the division shown on the map.

16. percent feldspar in the Reagan
- 17, location with respect to upthrown or downthrown side
- 18 of faults
- 19: location with respect to Precambrian highs and lows.

Figure 36 is the dendrogram computed from the well data. The clusters determined from the 0.75 and 0.85 Z values are plotted in Figures 37 and 38. The area involved is essentially the same used in the factor analysis (Fig. 35), although different well control was used.

It is quite obvious that the major structural elements (Cambridge Arch and Central Kansas Uplift, and basin area to the east) exert control on the distribution; however, it is difficult at this time to interpret the amount of influence of any given character. All 19 characters vary throughout the area and as seen by the qualitative interpretation, trend surfaces, correlation matrices, and the factor analysis, these variations follow regional trends from northwest to southeast.

This application of taxonomic grouping to highly variable stratigraphic data is only the first step in a series of methods of examination. Before any definitive conclusions can be made, such techniques as factor analysis, other methods of clustering data, and determination of similarity coefficients by distance measurements, etc., should be evaluated.

GENESIS AND HISTORY OF THE REAGAN SANDSTONE

The Reagan Sandstone was originally deposited in a Late Cambrian transgressive sea upon the eroded and truncated edges of Precambrian igneous, metamorphic, and sedimentary rocks of questionable age. The Precambrian rocks had been a source of supply for the Rice Formation. The sub-Reagan surface was low and characterized by intermittent streams with low gradients. Throughout the area now occupied by the Central Kansas Uplift and Cambridge Arch, monadnocks of varying relief, determined in part by the composition of the underlying rocks, were common.

Transgression of the sea probably began in Kansas during the early part of the Dresbachian and deposited the Reagan on the Cambridge Arch during this period as indicated by Apsotreta sp. and the trilobites from the Crepicephalus zone.

The direction from which the sea advanced in this area is difficult to demonstrate. Based upon results of this study, the most logical direction of transgression are from the southeast, south, southwest and west as demonstrated by thickness increases and paleontological relationships between Kansas and Missouri and Texas.

The close relationship between the composition of the Reagan and the underlying Precambrian rocks indicates that they served as a major source of clastic material for the Reagan. The absence of clay throughout the sandstone and absence of detrital silt and clay sized particles presents a problem. Local depressions contain some shale, but for

the most part, except where overlain by Pennsylvanian rocks, shale is absent. It is possible that currents moved this material to zones of deeper water but these areas were either not preserved or are still unlocated. A more plausible explanation is the removal by wind. This hypothesis helps explain the muscovite in upper portions of sandstone and dolomite deposited far from the shore.

Texture of the Reagan indicates that deposition was rapid. Grains are poorly sorted, yet, there is a great abundance of uniform sized well-rounded grains possessing a high degree of sphericity. It is doubtful that near-shore processes rounded all of the grains, in light of the poor sorting and intermixed angular grains. Granted, some of the ovoid quartz in the Precambrian schists and sub-Reagan sediments may account for some of these grains, but not all of them. It seems highly reasonable that eolian processes rounded, sorted, and frosted these grains and they were subsequently incorporated by the transgressing sea as well as having been blown into deeper waters where carbonate deposition was occurring.

Climatic indicators are almost nonexistent. A general discussion of Cambrian climatic conditions is presented by Calvert (1964, p. 173). He states: "...because there was no vegetation capable of binding loose material, the movement of sediment by water must have been very great during rainy periods. During dry periods . . . eolian transportation surely replaced water transportation as the dominant force which

transported debris from the land areas to the sea." Calvert also states that the direction of prevailing winds was most likely from west to east and "wind currents were much stronger than today because of more rapid and intense heating and cooling of the land surface, due to the lack of soil cover."

Assuming these conditions were present in Kansas at this time, eolian processes might well account for some of the relationships seen such as well-rounded, frosted quartz grains and the presence of such grains in carbonate deposits presumably deposited far from the shoreline. I do not feel that the sand supply was large enough for formation of massive dunes, offshore bars, etc. The relative flat nature of the Precambrian surface and lack of rapid subsidence gave rise to blanket type deposits.

It is not necessary to call upon distance sources to supply quartz but the well rounded zircon and tourmaline grains suggest some additions of material from elsewhere. It has been postulated that such heavy minerals as zircon, tourmaline and rutile become highly rounded only by means of several extensive periods of abrasion. The nature of the heavy minerals in the Precambrian schists and sub-Reagan Rice Formation are unknown and the possibility of such a source of the well-rounded heavy minerals is problematical. Ojakangas (1960) made a very detailed study of all possible sources of rounded tourmaline in regions which could, in view of paleoslopes and age, supply heavy minerals to southeast Missouri. He concluded that the Jacobsville Sand-

stone, Bayfield Group, Hinckley Sandstone, Fond du Lac Sandstone, and Pokegama Quartzite supplied much detrital material to the Lamotte Formation. It is possible that some of these areas also supplied material to the Reagan of Kansas, but there is no good evidence. If Lyons (1959) and Muehlberger and others (1964) are correct in their correlation of the Rice Formation with sediments in the Keweenawan of the upper Mississippi Valley, the Rice Formation could contain similar minerals and have been a source not only for the Reagan in Kansas but also for the Lamotte of Missouri.

As the Late Cambrian shoreline transgressed the Central Kansas Uplift and Cambridge Arch, the associated depositional environments likewise moved. The near-shore zone left deposits of poorly sorted quartzose sandstone which was locally arkosic at the base. The concentration of a sub-Reagan arkose was controlled by the location of granite and gneiss, fluvial processes, and eolian processes.

In an offshore direction, possibly great distances because of the gentle slope of the topography in some areas and much less in others, calcium carbonate was deposited on top of the quartzose sandstone. The high concentration of quartz grains in the dolomitic sandstone and overlying sandy dolomite of the Arbuckle can be accounted for by wind action which may have blown them into this zone. The decrease in quartz percentage upward results from deposition increasingly farther from the shore and beyond the capability of the wind

except for infrequent gusts or storms, or submergence of the source. As the shoreline migrated, the near-shore environments were overlapped by the more off-shore environments both regionally and on local monadnocks.

Several periods of local and regional uplift or sea retreat have modified the original relationships. Sometime following the deposition of the Bonneterre (and possibly other pre-Roubidoux rocks), erosion removed the Bonneterre, and locally the Reagan, from the high areas on the Central Kansas Uplift. Following erosion, a transgressing sea reworked and incorporated some of the Reagan material and residual Bonneterre quartz, in a sequence of dolomitic sandstone.

The northern part of the Cambridge Arch, a large area in central Rush County, and smaller more local areas throughout the Central Kansas Uplift were stripped of all pre-Pennsylvanian Paleozoic sediments during post-Mississippian pre-Pennsylvanian erosion. The amount of removal of the Reagan is conjectural, but by the time erosion had proceeded far enough to affect the Reagan, gradients were probably low, and in many areas only the upper part was removed. Rocks of Medial and Late Pennsylvanian were deposited on the erosional surface, comprised of reworked upper layers of the exposed Reagan and younger pre-Pennsylvanian units. Only regional uplift and tilting have affected the Reagan Sandstone since Pennsylvanian time.

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APPENDIX A

Table 1 gives the mode, median, mean, standard deviation, skewness and kurtosis of selected Reagan core analysis. These parameters were derived from the plot of size analysis data on probability paper. The position of the line on the graph depends on average particle size, and shape depends on the sorting. A sediment with a normal distribution plots a straight line. All formulae used are discussed in detail by Folk (1959) and a summary is given below to aid in the interpretation of the table.

The mean was determined by the formula: $(\phi_{16} + \phi_{50} + \phi_{84})/3$. Standard deviation was determined by the inclusive graphic standard deviation formula: $\frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$. The following limits are suggested by Folk (1959, p. 45).

very well sorted	< .35
well sorted	.35 to .50
moderately sorted	.50 to .71
moderately poorly sorted	.71 to 1.00
poorly sorted	1.00 to 2.00
very poorly sorted	2.00 to 4.00

Inclusive graphic skewness was determined by the formula:

$$\frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$$

Positive skewness indicates excess fine material and negative skewness have excess coarse material. Degrees of skewness as suggested by Folk include:

Strongly fine-skewed	+1.00 to + .30
fine-skewed	+ .30 to + .10
near-symmetrical	+ .10 to - .10
coarse-skewed	- .10 to - .30
strongly coarse-skewed	- .30 to -1.00

Kurtosis was determined by the formula:

$$\frac{\phi_{95} - \phi_5}{2.44 (\phi_{75} - \phi_{25})}$$

The following limits were used:

very platykurtic	< .67
platykurtic	.67 to .90
mesokurtic	.90 to 1.11
leptokurtic	1.11 to 1.50
very leptokurtic	1.50 to 3.00
extremely leptokurtic	> 3.00

APPENDIX B

List of Wells Used in Cross Sections

Figure

Cross Section AA'

<u>Well</u>	<u>Company</u>	<u>Lease</u>	<u>Location*</u>			<u>Elev.</u>	<u>Total Depth</u>
			<u>Sec.</u>	<u>T.</u>	<u>R.</u>		
1.	The California Oil Co.	1 Mumm		1-3-48		4253	6524
2.	The Texas Co.	1 Walz		3-5-42		3547	5387
3.	Ben Brack	1 Judy		26-1-39		3122	5142
4.	Phillips	1 Wilkins		16-2-37		3378	5390
5.	K. & E.	1 Foche		16-2-34		3136	5091
6.	Musgrove	1 Mines		11-2-30		2775	4320
7.	Anderson Prichard	1 Pollnow		4-3-29		2713	4406
8.	Anderson Prichard	1 Brown		33-3-27		2592	4074
9.	Gore	1 Clark		30-3-24		2420	3830
10.	Derby	4 Schoen		35-3-24		2435	3800

*all townships are south
all ranges are west

Figure Well	Company	Lease	Cross Section BB'			Elev.	Total Depth
			Location *				
			Sec.	T.	R.		
1.	Jones & Shelburne	1 Conover	34	3	24	2427	3783
2.	Jones, Shelburne, & Farmer	1 Ankenman	29	3	24	2402	3811
3.	Gore	1 Clark	30	3	24	2420	3830
4.	Trans Era	1 Humphry	25	3	25	2340	3730
5.	Jones, Shelburne, & Farmer	1 Brunk	22	3	25	2397	3822
6.	Anderson Prichard	1 Brooks	17	3	25	2483	3895
7.	Empire & Shields	1 Brooks	24	3	26	2537	3956

Figure		Lease	Cross Section CC'			Elev.	Total Depth
			Location *				
			Sec.	T.	R.		
1.	Cities Service	1 Thompson	9	5	22	2112	3634
2.	B. & R.	1 Archer	8	5	21	2061	3575
3.	Powell	1 Voss	31	5	21	2278	3965
4.	Barnett	1 Nichol	7	6	20	2229	3761
5.	Murfin	1 Wessling	35	6	7	1446	4555

*all townships are south
all ranges are west

<u>Well</u>	<u>Company</u>	<u>Lease</u>	<u>Location*</u>			<u>Elev.</u>	<u>Total Depth</u>
			<u>Sec.</u>	<u>T.</u>	<u>R.</u>		
6.	Frankfort	1 Kuck		8-14-10		1803	4537
7.	Continental	3"A" Lewis		13-18-8		1745	4288

<u>Figure</u>		<u>Cross Section DD'</u>				
1.	Honaker	1 Jordan	19-21-17	2063	4043	
2.	Amerada	1 Welch	30-21-17	2041	4228	
3.	Gulf	1 Bell	34-21-16	1983	4584	
4.	Mid-Continent	4 Smith	13-20-16	2064	4354	
5.	Gulf	1 Tammen	35-19-16	1982	4254	
6.	Stanolind	1"A" Budde	2-19-16	2017	3663	
7.	Brunson - Spines	6 Schroeder	23-18-16	1930	3578	
8.	Hannum	1 Haberman	8-18-15	1985	3555	
9.	Phillips	1 Boyle	25-17-15	1979	4003	
10.	Phillips	4 Karst	21-17-14	1869	3748	

*all townships are south
all ranges are west

Figure

Cross Section EE'

<u>Well</u>	<u>Company</u>	<u>Lease</u>	<u>Location*</u>			<u>Elev.</u>	<u>Total Depth</u>
			<u>Sec.</u>	<u>T.</u>	<u>R.</u>		
1.	Solar Oil Co.	1 Luft	29	18	16	2079	3727
2.	Auto Ordinance	1 Luft	29	18	16	2021	3632
3.	Luft and Weber	3 Luft	29	18	16	2048	3680
4.	Clark Knight Drlg. Co.	3 Roth	20	18	16	1987	3617
5.	Skelly Oil Co.	6 Miller	21	18	16	1969	3631
6.	Solar Oil Co.	1 Hanhardt	21	18	16	1974	3603
7.	Skelly Oil Co.	4 Dyer	21	18	16	1936	3568
8.	Skelly Oil Co.	1 Dyer	21	18	16	1936	3523

*all townships are south
all ranges are west

APPENDIX C
List of wells used in photomicrographs

Figure 8

<u>Company</u>	<u>Lease</u>	<u>Location</u>	<u>County</u>	<u>Sample Depth</u>
A. Stanolind	No. 1 Steelsmith	Sec. 28, T4S, R24W	Norton	3930
B. Continental	No. 1 Chenoweth	Sec. 36, T4S, R27W	Decatur	3900
C. Leben & Amerada	No. 1 Peterson	Sec. 8, T1S, R33W	Rawlins	4680
D. Derby Oil Co.	No. 4 Schoen	Sec, 35, T3S, R24W	Norton	3782

Figure 16

<u>Company</u>	<u>Lease</u>	<u>Location</u>	<u>County</u>	<u>Sample Depth</u>
A. Magnolia	No. 1 "B" Holsman	Sec. 15, T7S, R19W	Rooks	3525
B. Magnolia	No. 1 "B" Holsman	Sec. 15, T7S, R19W	Rooks	3525
C. Phillips	No. 2 Nettie	Sec. 34, T9S, R17W	Rooks	4032
D. Solar	No. 1 Pechanec	Sec. 18, T18S, R16W	Rush	3565

Figure 17

<u>Company</u>	<u>Lease</u>	<u>Location</u>	<u>County</u>	<u>Sample Depth</u>
A. Stanolind	No. 1 "A" Budde	Sec. 2, T19S, R16W	Rush	3645
B. Stanolind	No. 1 "A" Budde	Sec. 2, T19S, R16W	Rush	3653
C. Sinclair Prairie	No. 6 Sellens	Sec. 15, T15S, R13W	Russell	3475
D. Skelly	No. 7 Rein	Sec. 8, T15S, R13W	Russell	3425

Figure 18

<u>Company</u>	<u>Lease</u>	<u>Location</u>	<u>County</u>	<u>Sample Depth</u>
A. Sinclair Prairie	No. 6 Sellens	Sec. 15, T15S, R13W	Russell	3748
B. Derby Oil Co.	No. 4 Schoen	Sec. 35, T3S , R24W	Norton	3768
C. Darby-Bothwell	No. 1 Ficken	Sec. 33, T17S, R17W	Rush	3585
D. Gore	No. 4 Lawson	Sec. 25, T3S, R24W	Norton	3690

APPENDIX D

List of wells used in the study

County	Company, well number, and lease	Location	Th.*	No.
Norton	Raymond No. 1 Sauer	31-1-23W C SW NW	8	1
Decatur	Sauvage No. 1 Lawson	11-1-26W C NE SW	12	5
Decatur	Sauvage No. 1 Mizell	25-1-26W SW SW NW	41	6
Decatur	Sauvage No. 1 Kilzer	16-1-27W SW SW SW	23	8
Decatur	Sauvage No. 1 McQuillan	23-1-27W W2 NW NE	3	9
Decatur	Empire No. 1 Katha	7-1-28W C SE NE	15	10
Decatur	Farmer & Appleman No. 1 Southwick	17-1-28W SE SE SE	9	11
Decatur	Rains & Williamson No. 1 Waldo	23-1-30W C SW SW	42	12
Rawlins	Skelly No. 1 Kompus	33-1-32W SW SW SW	58	13
Rawlins	Skelly No. 1 Horinek	21-1-34W SE NW NW	64	14
Norton	Empire No. 1 McMullen	19-2-23W NE NE NE	10	19
Norton	C. & G. No. 1 Sanders	25-2-23W SE SE SE	10	20

*Reagan thickness

Norton	Empire & Shields No. 1 "A" Meier	1-2-24W SE SE SE	9	22
Norton	Jones, Shelburne & Farmer No. 1 Sheldon	14-2-24W SE SE NE	10	23
Norton	Sinclair No. 1 Thiele	20-2-24W NE NW NE	24	24
Norton	Hansen No. 1 Duensing	20-2-24W NE NE SE	18	25
Norton	Cities Service No. 1 Curran	11-2-25W C NE NE	8	26
Norton	C & G and Shields No. 1 Rubendall	35-2-25W NE NE NW	38	30
Decatur	Murfin No. 1 Carter	21-2-26W C NE SW	3	31
Decatur	Jones, Shelburne & Farmer No. 1 Holben	30-2-26W NW NW NW	10	33
Decatur	Franco Central No. 1 Uehlin	6-2-27W NE SW NW	22	34
Decatur	Jones, Shelburne & Farmer No. 1 Fortin	17-2-27W NE NE NE	10	35
Decatur	Rock Island No. 1 Reeves	12-2-28W C SW NE	6	36
Decatur	Helmerich & Payne No. 1 Jorn	28-2-28W SE SE SW	7	37
Rawlins	K & E and Bradley No. 1 Focke	16-2-34W NW NW SE	23	39
Phillips	Sinclair Prairie No. 1 Cummings	2-3-20W SW NW NW	60	40
Norton	Keating No. 1 Wesley	4-3-23W NW NW NE	15	42
Norton	Jones, Shelburne & Farmer No. 1 Snead	21-3-23W SW SW SE	17	43
Norton	Jones, Shelburne & Farmer No. 1 Stewart	26-3-23W NE NE NE	5	44

Norton	Gore No. 2 Lawson	25-3-24W NE SE SE	13	54
Norton	Gore No. 4 Lawson	25-3-24W NE NE SE	10	55
Norton	Ferguson No. 1. Ankenman	29-3-24W C NE NW	22	57
Norton	Jones, Shelburne & Farmer No. 1 Ankenman	29-3-24W SW SW SE	74	59
Norton	Gore and Trans Era No. 1 Clark	30-3-24W SW SW NE	14	60
Norton	Jones, Shelburne & Farmer No. 1 Conover	34-3-24W SE NE SE	5	63
Norton	Gore No. 1 Henry	35-3-24W SE NE SW	7	64
Norton	Shields No. 1 Hicks	2-3-25W C SW NE	4	67
Norton	Union Texas No. 1 Wiltfong	15-3-25W NW NW SW	22	69
Norton	Cities Service No. 1 Mizell	15-3-25W NE NE SE	16	70
Norton	Anderson-Prichard No. 1 Brooks	17-3-25W SE SE SE	10	71
Norton	Jones, Shelburne & Farmer No. 1 Burnk	22-3-25W NW NW NW	17	72
Norton	Trans Era No. 1 Humphrey	25-3-25W N2 NE NE	25	73
Norton	Empire Drilling No. 1 Gray	27-3-25W SW SE SE	15	74
Norton	Jones, Shelburne & Farmer No. 1 Eckhart	33-3-25W NE NE NW	14	75
Decatur	Empire & Shields No. 1 Brooks	24-3-26W NE NE NE	15	76
Decatur	Farmer No. 1 Johnson	27-3-27W C NE NW	18	77

Decatur	Phillips (Westgate-Greenl'd) No. 1 Vernon	32-3-28W C NE NE	14	78
Decatur	Anderson-Prichard No. 1 Pollnow	4-3-29W NE NW SW	25	79
Phillips	Sohio No. 1 Krause	1-4-19W SE SE SE	8	80
Phillips	Helmerich & Payne No. 1 Baird	8-4-19W NE NE NE	32	81
Phillips	Helmerich & Payne No. 1 Kinter	20-4-19W SW NW NW	33	82
Phillips	Lario No. 1 Lynch Estate	24-4-20W S2 SE SW	68	83
Phillips	Rine No. 2 "A" Lynch	25-4-20W C NW NW	25	84
Norton	Continental No. 1 Hemphill	8-4-22W NE NE SW	36	85
Norton	Jones, Shelburne & Farmer No. 1 Wiles	16-4-22W SW SW NW	31	86
Norton	Jones, Shelburne & Farmer No. 1 Wiley	19-4-22W SW SW SW	35	87
Norton	Empire Drilling & Trans Era No. 1 Troube	20-4-22W SW SW SW	25	88
Norton	Colorado No. 1 Foss	32-4-22W NE NW NW	25	89
Norton	Gore No. 1 Walters	36-4-22W SW SW SE	32	90
Norton	Walters, Isern, and Sunray Mid-Continent, No. 1 Rife	1-4-23W SW SW SE	4	91
Norton	Sterling No. 1 Shewey	29-4-23W C SE SE	22	93
Norton	Hansen No. 1 Essert	3-4-24W NW NW SE	8	97
Norton	Continental No. 1 Wiltfong	9-4-24W NW NW NW	39	99

Norton	Aurora No. 1 Zimmerman	11-4-25W SW SW NE	11	100
Rawlins	Sinclair Prairie No. 1 Robbins	32-4-35W SW SW NE	56	101
Phillips	Phillips No. 1 McKinley	13-5-18W E2 SW SE	135	103
Phillips	Cities Service No. 1 Templeton	14-5-20W SW SE SW	50	104
Phillips	Cities Service No. 2 Griffin	27-5-20W SW SE NW	56	109
Phillips	Cities Service No. 1 Vehige	28-5-20W SW SW SW	47	114
Phillips	Cities Service No. 2 "D" Reese	29-5-20W SW SE NE	51	122
Phillips	Cities Service No. 3 Veeh	31-5-20W SW SW NW	37	130
Phillips	Cities Service No. 2 "B" Johnson	32-5-20W NE NW SW	32	132
Norton	Bennett & Roberts Drlg. No. 1 Archer	8-5-21W NW NE NW	48	144
Norton	Bridgeport No. 1 "A" Riemann	10-5-21W NE NE NE	20	145
Norton	C & G No. 1 Archer	17-5-21W NE NE NW	31	147
Norton	Walters No. 1 Patton	30-5-21W NE NE NW	30	157
Norton	Powell No. 1 Voss	31-5-21W SW SW SW	38	159
Norton	Cities Service No. 12 Kitzke	36-5-21W NE NE SW	6	163
Norton	Hansen & C & G No. 1 Walters	2-5-22W SE NE SW	22	164
Norton	Hansen No. 1 Schafer	3-5-22W SW SW NE	23	165

Norton	Hansen No. 1 Hemphill	4-5-22W NW NE NW	27 166
Norton	Cities Service No. 1 Fredde	8-5-22W NE NE NE	18 169
Norton	Cities Service No. 1 "D" Thompson	9-5-22W SE SE NW	28 170
Norton	Jones, Shelburne & Farmer No. 1 Weogard	12-5-22W SW SW NW	22 172
Norton	Shields No. 1 Hunter	22-5-22W SW SW NW	7 176
Decatur	Sterling No. 1 Randall	11-5-27W W2 NE SW	5 182
Mitchell	Murfin No. 1 Wessling	35-6-7W SE SE NE	100 184
Osborne	Mid-Kansas No. 1 Boyce	18-6-13W SE SE NW	30 185
Rooks	Cities Service No. 1 Johnston	5-6-19W SW SW NE	34 186
Rooks	Harbar No. 1 Brobst	7-6-19W NW NW NW	16 187
Rooks	L.R. Travis - Veeder No. 1 Cole	1-6-20W SW NW SW	24 188
Rooks	C & G No. 1 Witt	3-6-20W NE NE SW	19 189
Rooks	Westgate-Greenland No. 1 Johnston	24-6-20W SE SW SW	16 194
Graham	Gore and B & R No. 1 Thurlow	25-6-22W NE NE NE	57 195
Rooks	Sierra & Houston No. 1 Long	5-7-19W SE SE SW	21 198
Rooks	Magnolia No. 1 "B" Holsman	15-7-19W SE NE SE	22 199
Graham	Appleman No. 1 Hibbitts	12-7-21W SW SW SW	33 200

Graham	Imperial No. 1 "A" Holsman	12-7-21W C SE SW	48	201
Rooks	Deep Rock No. 9 Ondrasek	32-8-19W NW NE NW	44	202
Rooks	Phillips No. 2 Nettie	34-9-17W SW SW SE	40	205
Rooks	Harbar No. 4 Stahl	17-9-18W NE SW NW	72	206
Rooks	Prairie No. 1 Gick	22-9-19W C SE	90	210
Graham	Sohio No. 7 Benson	15-9-21W NE SE SW	14	216
Graham	Petro-Atlas No. 8 "B" Cooley	17-9-21W SW NE NW	16	218
Sherman	Musgrove No. 1 Van Douge	31-9-38W NW NW SE	102	223
Osborne	Anderson-Prichard No. 2 "B" Ruggles	23-10-15W NE SE SE	41	225
Ellis	Gulf No. 10 Mai	14-11-17W SE NW SE	45	246
Ellis	Sohio (Margay) No. 6 "B" Bemis	15-11-17W SW SE SW	39	248
Ellis	Cities Service No. 3 "B" Hall	26-11-17W NW SW NW	42	252
Russell	Mast No. 5 "C" Beller	15-12-15W SW NW NW	23	275
Russell	Sohio (Central) No. 1 "B" Deckert	30-12-15W CNL SE NW	48	282
Ellis	Central Commercial No. 1 Helms	2-12-20W SE SE NE	47	290
Trego	Mid-Kansas No. 1 Ridgeway	28-12-21W NE NE SW	25	292
Trego	Stanolind No. 2 Monroe	36-12-22W NW SE SE	18	294

Russell	Prairie No. 1 Hill	13-13-14W NW NW NE	86	295
Russell	Empire No. 3 Ehrlich	28-13-14W SE SE SE	90	299
Russell	Skelly No. 3 Boxberger	33-13-14W SW NW NE	64	301
Russell	Heathman No. 1 Mermis	32-13-15W SW SW NE	4	304
Ellis	Midwest No. 19 Reidel	27-13-16W NW SW SE	32	310
Ellis	Texas No. 3 "B" Dreiling	21-13-17W NE NW SE	26	312
Ellis	Sunray No. 4 "B" Bittel	6-13-20W W2 NE NE	23	315
Ellis	Stearns-Streeter No. 1 Leiker	26-13-20W SW SW NE	67	316
Trego	Lafayette (Stanolind) No. 1 Homburg	11-13-21W SE SW SW	14	321
Trego	Bridgeport No. 1 "A" Egger	12-13-21W NW NW NW	12	322
Wallace	Sinclair No. 1 Glad & Brock Trustees	19-13-42W SE NW NE	40	324
Ellsworth	Frankfort No. 1 Kuck	8-14-10W SE SW NE	150	326
Russell	Continental No. 8 Letsch	26-14-13W SE SW SW	128	330
Russell	Cities Service No. 1 Opdycke	29-14-13W CSL NE NW	4	333
Russell	Darby No. 1 Letsch	34-14-13W SE NE NW	103	335
Russell	Ash & Smith No. 1 "A" Brown	7-14-14W NE SE NE	14	342
Russell	Hartman No. 1 Hildebrand	12-14-14W NW NE SW	15	346

Russell	Westgate-Greenland No. 2 Rusch	29-14-14W W2 SE NE	26	352
Russell	Cities Service No. 15 Crawford	2-14-15W NE SE SW	88	360
Russell	Sunray No. 1 Furthmeyer	22-14-15W NE NE SE	100	363
Ellis	Transit No. 2 Heyl	26-14-16W SE NW SW	10	370
Ellis	Phillips No. 1 Brull	34-14-17W C NW	86	371
Ellis	Walters (Brunson) No. 1 Weber	28-14-19W NE NE SW	41	372
Ellis	Sunray No. 2 "A" Pfeifer	2-14-20W SW SW SE	129	374
Ellis	Helmerich & Payne No. 1 Kuhn	16-14-20W C NE	98	380
Ellis	Shields No. 1 "B" Solomon	22-14-20W SE SW NW		382
Trego	Lauck & Harra (Olson) No. 1 Lang	1-14-21W SE SE NW		385
Trego	Central Commercial No. 1 Locker	12-14-22W SW NE SW	8	386
Trego	Marathon No. 1 Kline	19-14-24W SW SW SE	55	388
Ellsworth	Lario-Elwell No. 1 State	29-15-8W SW SW SW	98	389
Russell	Stanolind No. 2 Zeman	9-15-12W N2 NE NE	130	395
Russell	Lauck No. 9 Klusener	28-15-12W W2 NE SW	18	400
Russell	Skelly No. 7 Rein	8-15-13W N2 NE SW	55	403
Russell	Sinclair Prairie No. 6 Sellens	15-15-13W S2 NE SW	85	404

Russell	CRA No. 16 "W" Sellens	19-15-13W NE NE NE	65	410
Russell	Gulf No. 16 Hoffman	31-15-13W SW NW SW	84	422
Russell	NCRA No. 5 "A" Flegler	10-15-14W SE NE NE	70	431
Russell	B & R No. 5 Tittle	13-15-14W SE NW NW	63	433
Ellis	Labette No. 1 Urban	19-15-16W NE NW NW	66	441
Ellis	NCRA No. 1 Leiker	30-15-17W NW NW SW	34	442
Ellis	Wood River No. 8 Dechant	14-15-18W NE SW NE	27	445
Ellis	Gulf (HH & B) No. 3 Engel	21-15-18W S2 NE SE	58	456
Ellis	Stickle No. 1 Penny	18-15-19W NE NE NW	14	461
Ellis	Lauck No. 1 Werth	19-15-19W SE SE SE	9	462
Ellis	Stanolind No. 1 Wann	12-15-20W NW SW SE	85	464
Ellis	Pratt No. 1 North	20-15-20W SE SW SW	7	465
Ellsworth	Wrightsman No. 1 Kunkle	3-16-8W C SW	61	468
Ellsworth	Independent No. 1 Gregory	24-16-9W C SW	120	470
Ellsworth	Gulf and Stanolind No. 1 Frevert	21-16-10W NE NE NE	95	472
Ellsworth	Magnolia No. 7 Schroeder	26-16-10W W2 W2 SW	75	474
Barton	Sinclair Prairie No. 2E. Oeser	17-16-11W SE SE SE	25	480

Barton	Black-Marshall No. 1 Redetzke	19-16-11W SE SW SE	11	483
Barton	Sinclair No. 7 Prusa	20-16-11W SE-SW SE	45	484
Barton	Palmer No. 3 Polzin	4-16-12W SW NE SE	71	491
Barton	Phil-Han No. 1 Schauf	10-16-12W SE SW NW	7	494
Barton	Shell No. 1 "B" Bitter	5-16-13W SE NW SW	156	507
Barton	Skelly No. 3 Susank	19-16-13W SE SW NE	51	509
Barton	Kaiser-Francis (Armer & Vernon) No. 4 Marquis-Johnson	32-16-13W S2 NE NW	39	511
Barton	Shell No. 10 "B" Schneider	1-16-14W NW SE NW	68	520
Barton	Midwest No. 34 Karst	11-16-15W SW SE SW	29	521
Rush	Leben and Aurora No. 1 Lippert	29-16-17W NE NE SW	4	527
Rush	Phillips No. 1 Legleiter	10-16-18W NE NW SE	72	529
Rush	Vickers No. 1 Herrman	12-16-18W SW SW NE	2	530
Rush	Messman-Rinehart No. 1 Bullock	11-16-20W SE SE NW	22	533
McPherson	Westgate-Greenland No. 2 Robinson	31-17-1W NW SW SE	40	534
McPherson	Auto-Ordnance No. 1 Melander	9-17-3W C SW NW	35	535
Ellsworth	Davis No. 3 Edwards	34-17-8W SE SW SE	34	539
Ellsworth	NCRA (Pryor & Lockhart) No. 4 Stratmann	1-17-10W CEL NW NW	40	546

Ellsworth	Transwestern No. 1 Stumps	33-17-10W SW SW SW	102	550
Barton	Phillips No. 1 Krautwurst	11-17-11W SE SW SW	18	552
Barton	National Refining No. 6 McLean	25-17-11W NE SE SE	33	562
Barton	Phillips No. 4 Karst	21-17-14W SW SW SE	69	571
Barton	Bridgeport No. 6 "A" Meitner	28-17-14W W2 NE NW	40	572
Barton	Phillips No. 1 Boyle	25-17-15W C SE	35	573
Rush	McPherson No. 1 Brack	24-17-16W C NW	60	575
Rush	Darby-Bothwell No. 1 Ficken	33-17-17W NE NE SE	12	579
Rush	Honaker No. 1 Becker	20-17-18W NW NW SW		581
Ice	Sinclair Prairie No. 6 Bolton	31-18-7W SE SW SW	80	587
Ice	Raymond No. 9 Dobrinski	3-18-8W NE NW SE	11	588
Ice	Continental No. 1 Fuller	12-18-8W SE SE NW	49	591
Ice	Continental No. 3 "A" Lewis	13-18-8W NE SW NW		592
Ice	Williams No. 4 Skiles	14-18-8W SW SW NE	48	593
Ice	Mid-Continent No. 4 Schlicht	6-18-10W CSL NW SE	55	601
Ice	Slick, Pryor & Lockhart No. 1 Schmidt	15-18-10W C NW NW		603
Barton	Coppinger No. 2 "C" Arnold	32-18-15W SE SW SE	25	614

Rush	Phillips No. 1 Pechanec	18-18-16W C SE SW	22	630
Rush	Morrison No. 1 Pechanec	18-18-16W SE SW ME	25	631
Rush	Wentz No. 1 Rodie	19-18-16W SW SW SW	20	633
Rush	Welch & Olsson No. 2 Schneider	22-18-16W NW SW SW	50	667
Rush	Brunson-Spines No. 6 Schroeder	23-18-16W C N2 SE	93	671
Rice	Bay No. 2 Grizzell	8-19-9W SW NE NW	17	707
Rice	McPherson No. 4 "D" Cramm	15-19-9W N2 S2 SW	15	708
Rice	Stanolind No. 3 Mitchell	32-19-10W SW NW SW	30	719
Rice	Hartman-Blair No. 2 "B" Schartz	33-19-10W SW NW SE	45	720
Barton	Continental No. 14 Risse	36-19-11W CNL NE SE	60	724
Barton	Mid-Continent No. 5 Schmidt	36-19-11W NW SE SW	47	725
Barton	Skelton No. 1 Ott	16-19-14W C SE SE	32	730
Barton	Vickers No. 3 Saylor	3-19-15W N2 NW NW	22	732
Barton	Coppinger No. 3 "B" Arnold	5-19-15W NE NE NW	51	736
Barton	Brach No. 1 Peterson	7-19-15W SW SW SW	33	742
Barton	Petroleum, Inc. No. 1 Lawrence	14-19-15W SW NW NE	40	747
Barton	Schermerhorn No. 1 Pendergast	27-19-15W SW SW NE	4	749

Rush	Stanolind No. 1 "A" Budde	2-19-16W SE SE NW	19	754
Barton	Gulf (Stanolind) No. 1 Tammen	35-19-16W NW SE SE	57	756
Rice	Bay No. 3 Keesling	3-20-9W S2 NE SW	30	758
Barton	Gulf No. 5 Nicholas	12-20-11W N2 S2 NW	30	770
Barton	Henderson No. 3 Scheufler	16-20-11W E2 E2 SW	25	771
Stafford	Cooper No. 1 Sifer	23-21-11W NW SW NE	59	777
Pawnee	Gulf No. 1 Bell	34-21-16W E2 NE NE	169	780
Pawnee	Amerada No. 1 Welch	30-21-17W C SE SE	175	781
Harvey	Continental No. 1 Westerman	5-22-1W NW NW NW	32	782
Harvey	Sinclair Prairie No. 2 "A" Neufeldt	18-22-3W CEL SE	49	783
Reno	Olson and Shell No. 7 Blake	23-23-4W NE NE SW	20	787
Reno	Olson and Shell No. 5 "A" Goering	26-23-4W NE NE SW	45	789
Reno	Republic Natural No. 4 Snowbarger	21-23-10W SW NW NE	14	791
Reno	Sinclair Prairie No. 1 Carmichael	15-24-4W C NE NW	9	793
Stafford	Sinclair No. 5 McComb	24-24-11W SW NW NW	31	794
Sedgwick	Wentz No. 1 Bright	1-26-1W SE NE NW	63	798
Sedgwick	Bu-Vi-Bar No. 1 Hudson	12-26-1W SE SW NE	49	802

Pratt	Mid-Continent No. 1 Hudson	25-26-13W SE SW NE	802
Pratt	Mid-Continent No. 3 Knop	25-26-13W SW SW NE	53 803
Pratt	Deep Rock No. 9 "C" Calbeck	33-26-13W C NE	55 804
Sedgwick	Lauck No. 1 McLean	1-27-1W SW SW SE	59 806
Kingman	Skelly No. 1 "A" Miles	30-27-10W NE NE NE	45 807
Barber	Shaw No. 1 McReynolds	29-31-10W NW NE SW	25 810
Barber	Barbara No. 1 Boggs	19-33-12W C SW NW	56 811

APPENDIX E

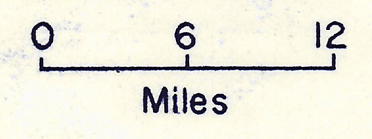
List of cores used in this study

County	Company, well number, and lease	Location	Nature of sample
Norton	British American No. 1 Ervin	13-1-25W C NE NE	Chips 3533-3553
Norton	Gore No. 2 Lawson	25-3-24W NE SE SE	Chips 3732-3745
Norton	Gore No. 4 Lawson	25-3-24W NE NE SE	Chips 3681-3691
Norton	Derby No. 4 Schoen	35-3-25W C SE	Core 3762-3800
Norton	Colorado Oil & Gas No. 1 Foss	32-4-22W NE NW NW	Chips 3687-3712
Norton	Cities Service No. 1 "D" Thompson	9-5-22W SE SW NW	Chips 3578-3595
Rooks	Magnolia No. 1 "B" Holsman	15-7-19W SE NE SE	Core 3510-3538
Trego	Stanolind No. 2 Monroe	36-12-22W NW SE SE	Chips 4110-4119
Ellis	Stanolind No. 1 Wann	12-15-20W NW SW SE	Core 3615-3700
Rush	Messman-Rinehart No. 1 Bullock	11-16-20W SE SE NW	Chips 3921-3943
Rush	Morrison No. 1 Pechanec	18-18-16W SE SW NE	Core 3542-3570
Rush	Carter Oil Co. No. 1 Schroeder	23-18-16W	Core



MAP SHOWING PALEOZOIC ROCKS ON
 PRECAMBRIAN ROCKS AND
 SUB-REAGAN ARKOSE IN
 CENTRAL KANSAS

Prepared by M.N. McElroy 1965






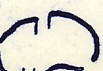
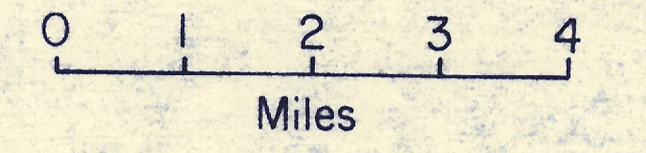
-  Pennsylvanian rocks
-  Arbuckle Group
-  Reagan Sandstone
-  Reagan more than 50 feet thick

PLATE III

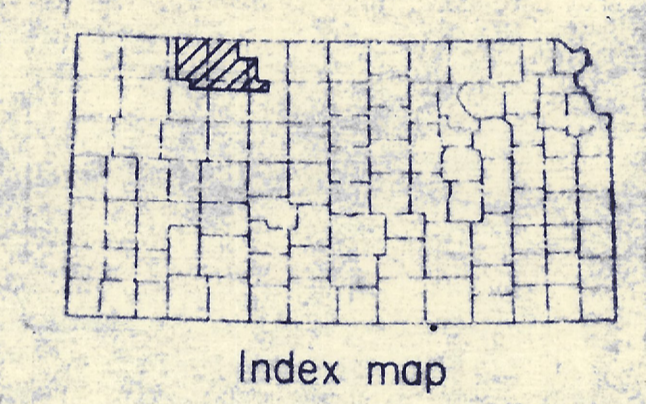
MAP SHOWING PALEOZOIC ROCKS ON
PRECAMBRIAN ROCKS AND
ARKOSE (SUB-REAGAN)

Prepared by M. N. McElroy, 1965



EXPLANATION

- Reagan overlain by Arbuckle
- Reagan overlain by Pennsylvanian
- Reagan
- ▨ Arbuckle
- ▩ Pennsylvanian



DECATUR CO.
SHERIDAN CO.

NORTON CO.
GRAHAM CO.

PHILLIPS CO.
ROOKS CO.

R28W

R26W

R24W

R22W

R20W

T 2 S

T 4 S

T 6 S

R 28 W

R 26 W

NEBRASKA
KANSAS

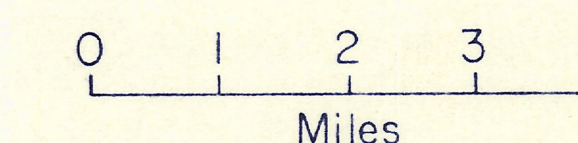
R 24 W

R 22 W

PLATE IV

ISOPACHOUS MAP OF PRECAMBRIAN-PALEOZOIC ARKOSE ON CAMBRIDGE ARCH, NORTHWESTERN KANSAS

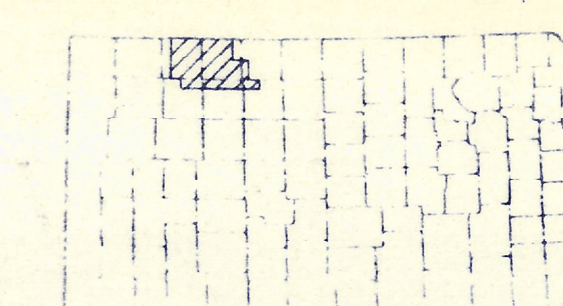
Prepared by M. N. McElroy, 1965



Isopach interval 20 feet

EXPLANATION

- Arkose
- Arkose absent
- Control point



Index map

R 20 W

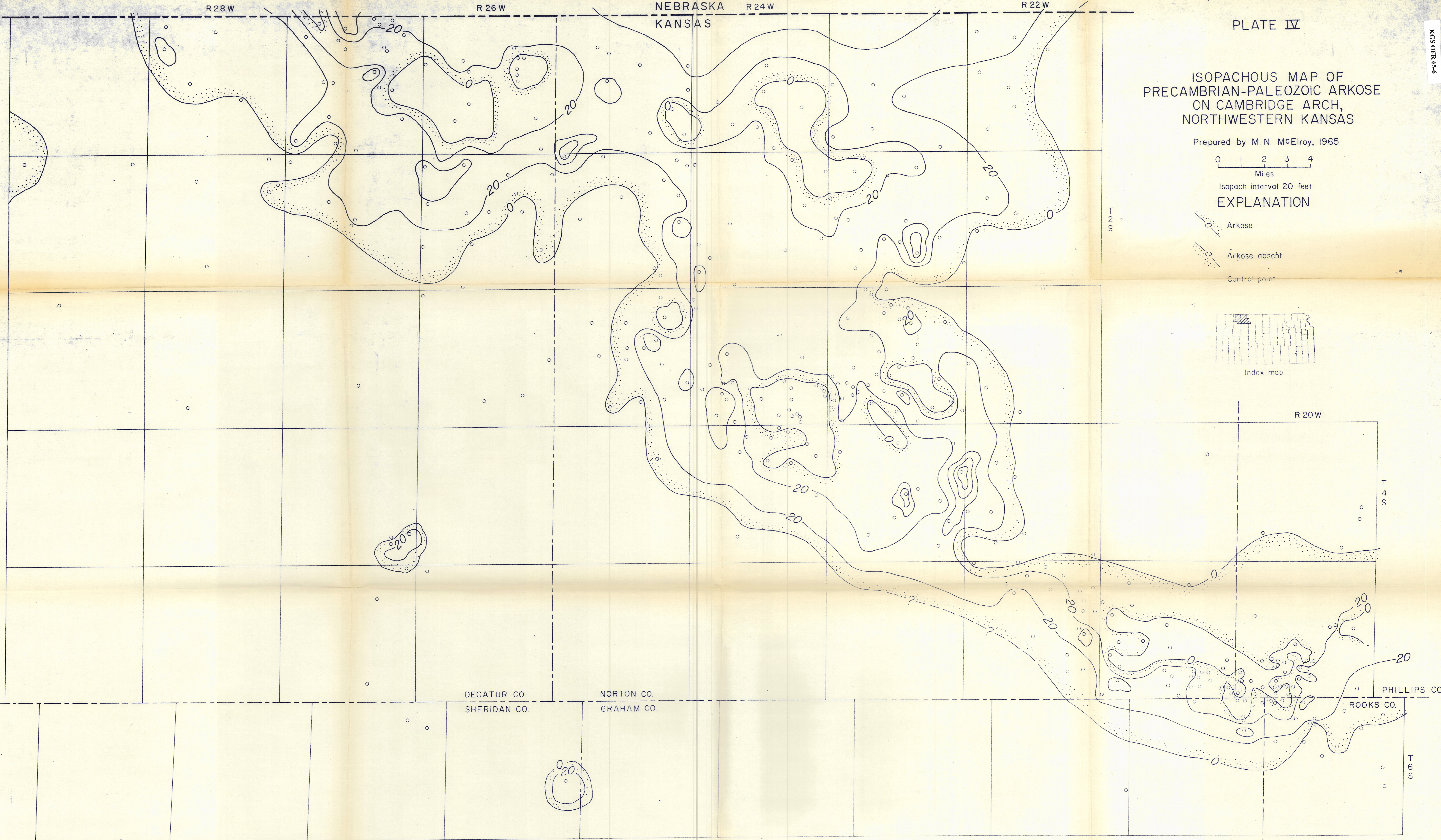
T 4 S

T 6 S

DECATUR CO.
SHERIDAN CO.

NORTON CO.
GRAHAM CO.

PHILLIPS CO.
ROOKS CO.

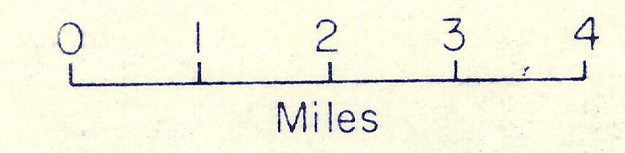


KGS ORR 65-6

PLATE V

CONTOUR MAP OF
PRECAMBRIAN IGNEOUS AND METAMORPHIC SURFACE

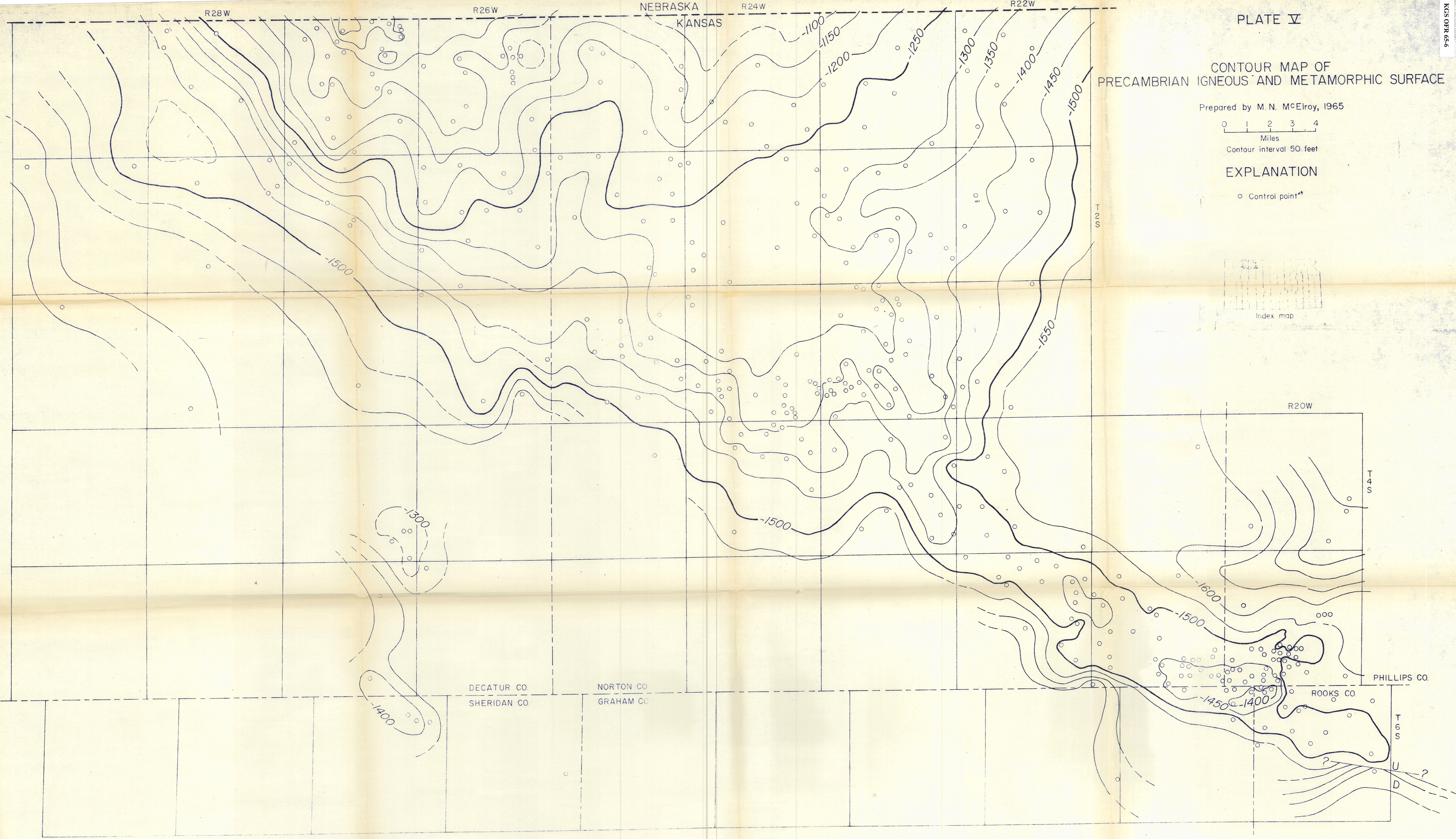
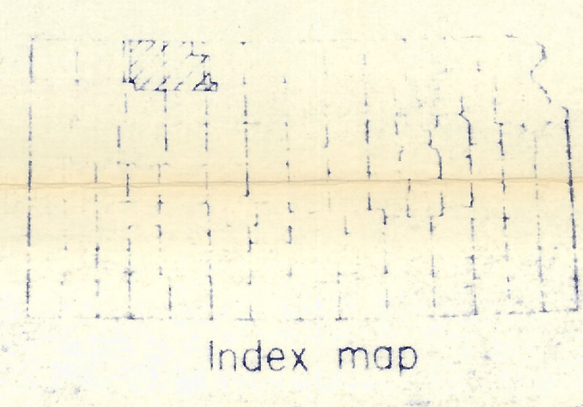
Prepared by M. N. McElroy, 1965



Contour interval 50 feet

EXPLANATION

○ Control point**



R 17
W 16
T-17S
T-18S

RUSH CO. R 16 W
BARTON CO. R 15 W

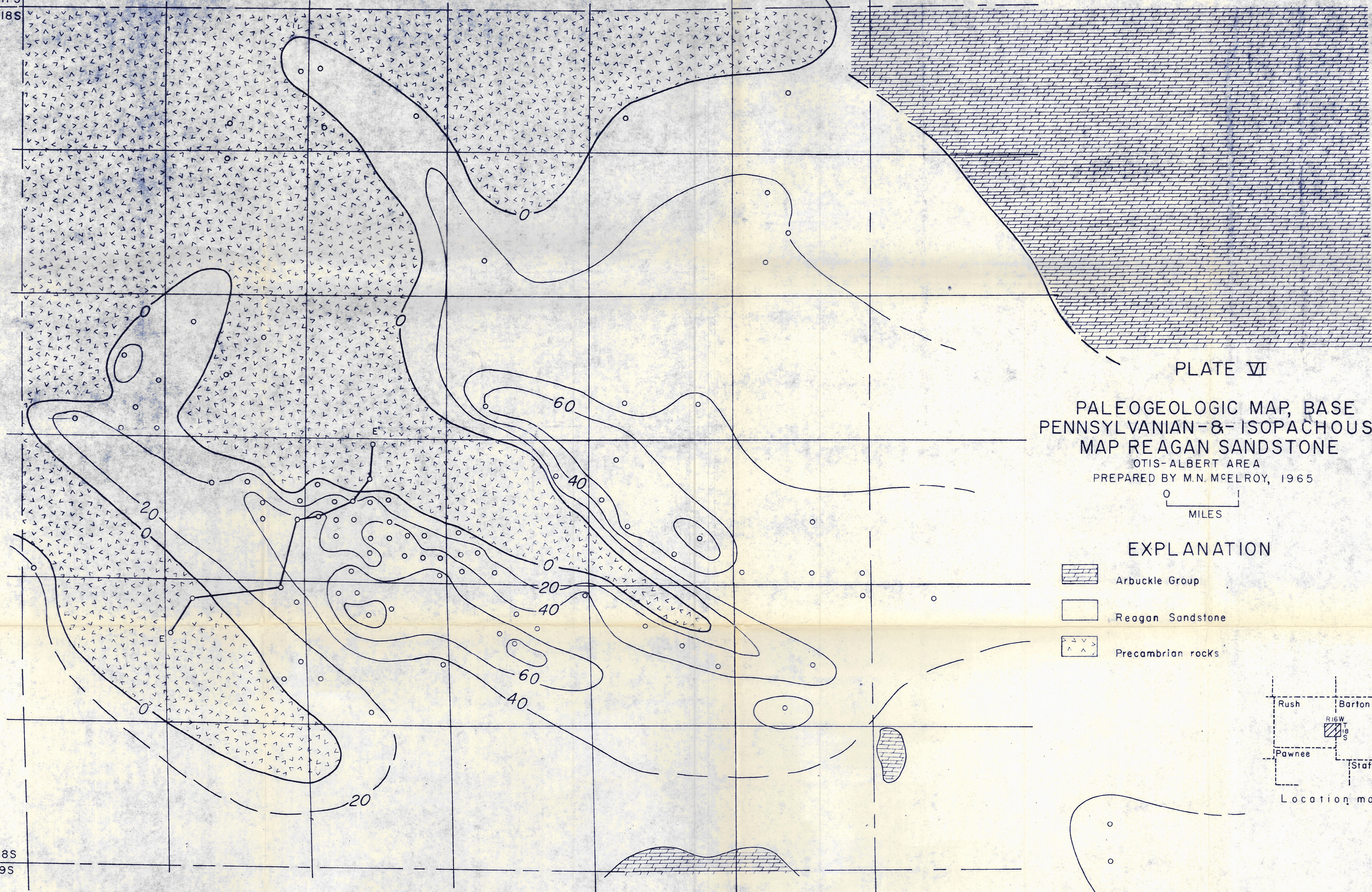
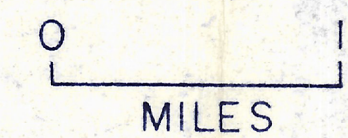


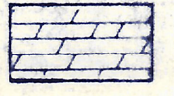
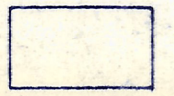
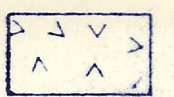
PLATE VI

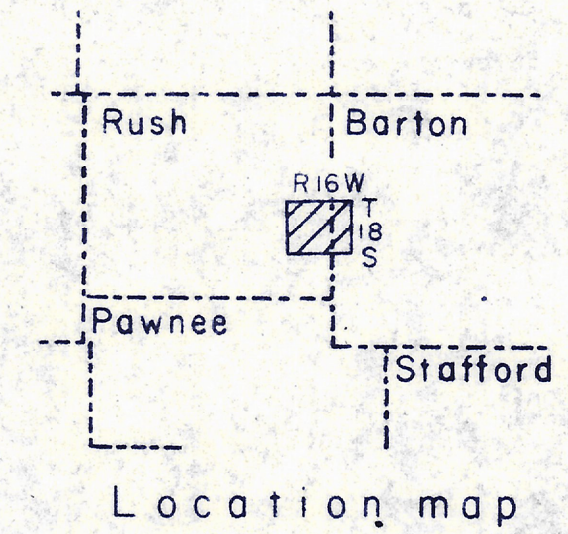
PALEO GEOLOGIC MAP, BASE
PENNSYLVANIAN - & - ISOPACHOUS
MAP REAGAN SANDSTONE

OTIS-ALBERT AREA
PREPARED BY M.N. McELROY, 1965

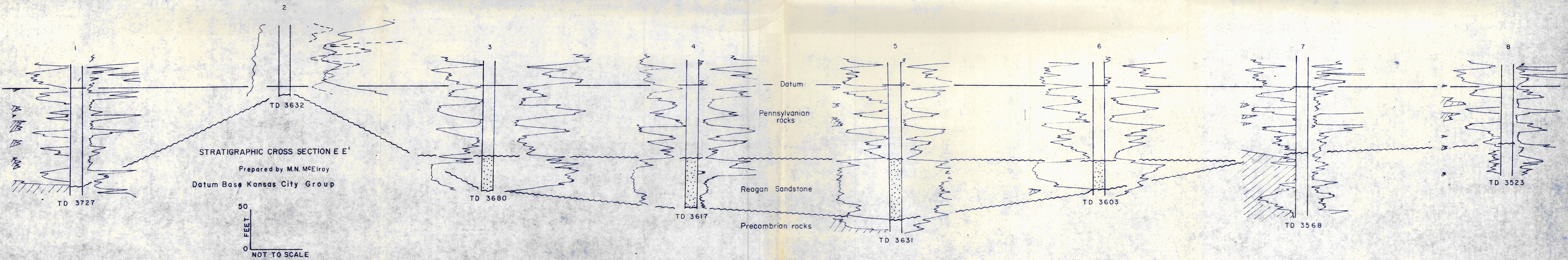


EXPLANATION

-  Arbuckle Group
-  Reagan Sandstone
-  Precambrian rocks



T-18S
T-19S



STRATIGRAPHIC CROSS SECTION E-E'
Prepared by M.N. McElroy
Datum Base Kansas City Group

50
FEET
0
NOT TO SCALE

KCS OPR 65-6