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STRUCTURAL GEOLOGY AND RECENT SEISMICITY OF SOUTHEASTERN RILEY, EASTERN GEARY, AND WESTERN WABAUNSEE COUNTIES, KANSAS

by

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INTRODUCTION

An area in eastern Kansas, along the Nemaha Anticline, is in an earthquake-risk belt in which "moderate damage" may occur, although Kansas is in the central stable region of the United States (Wilson, 1979). This belt is about 150 km wide and extends 725 km from southeast Nebraska to north-central Oklahoma (Fig. 1).

Earthquake intensity is measured by the Modified Mercalli Scale and earthquake magnitude by the Richter Scale. The Modified Mercalli Intensity Scale measures the effect of an earthquake on people and on structures. The scale ranges from I to XII. An earthquake with an intensity of I is not felt by people and one with an intensity of XII destroys all structures. Seismographs can measure the energy released by an earthquake. The scale used to measure the magnitude of this energy is the Richter Scale. In this scale, an earthquake with a magnitude of 3 releases 31 times more energy than an earthquake with a magnitude of 2, and a quake of magnitude 4 releases 31 times more energy than a quake of magnitude 3 (Steeples, 1979).

An earthquake of magnitude 5 on the Richter Scale would cause moderate damage at its epicenter, corresponding to about intensity VII on the Modified Mercalli Scale. Damage to man-made structures from an earthquake of this magnitude varies, depending on quality of construction. Locations, dates, and intensities of earthquakes and microearthquakes (magnitudes less than 3 on the Richter Scale) in Kansas that have occurred since 1867 are given in Figure 2. The microearthquakes located in Figure 2 have been recorded by microearthquake seismograph stations since December 1, 1977.

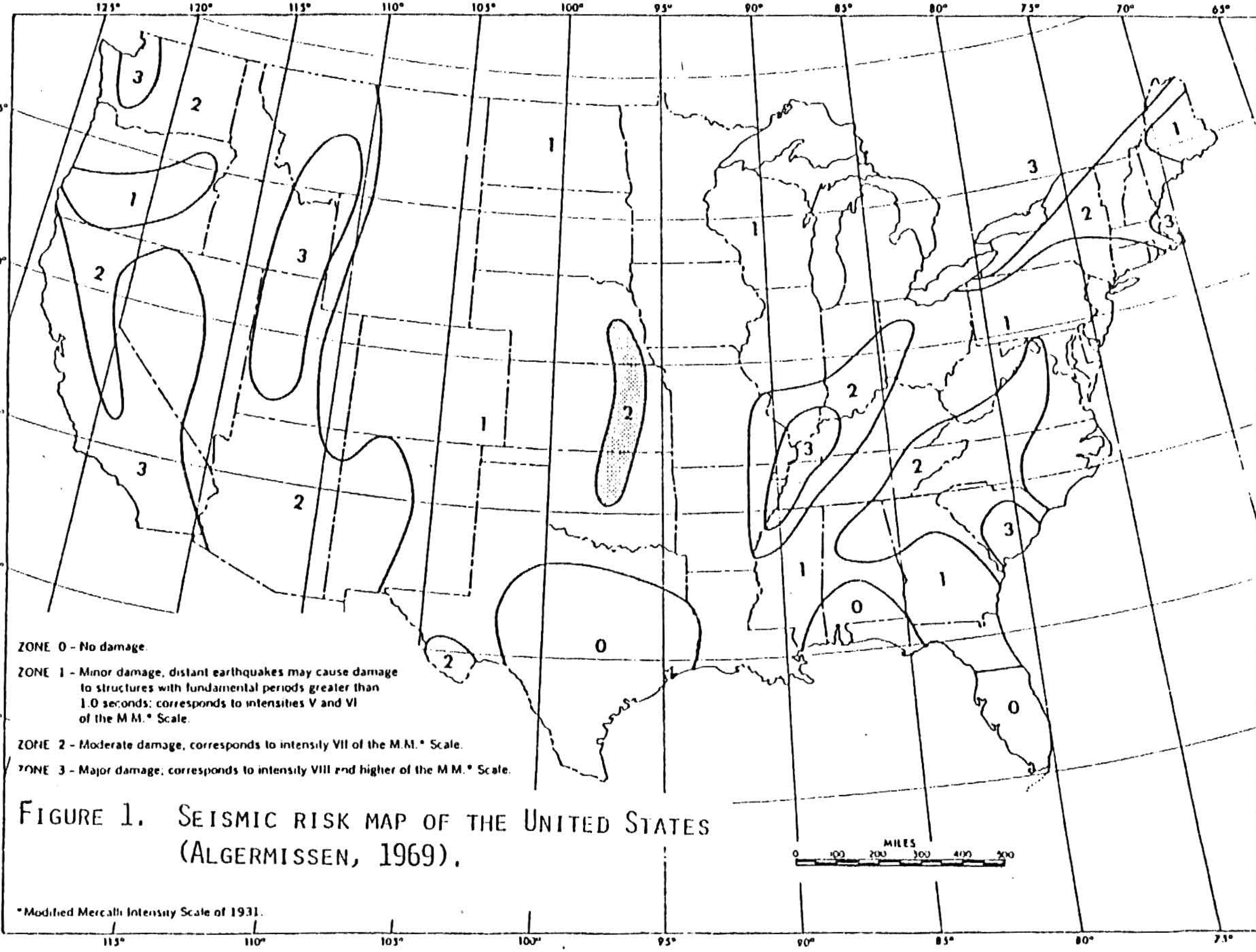
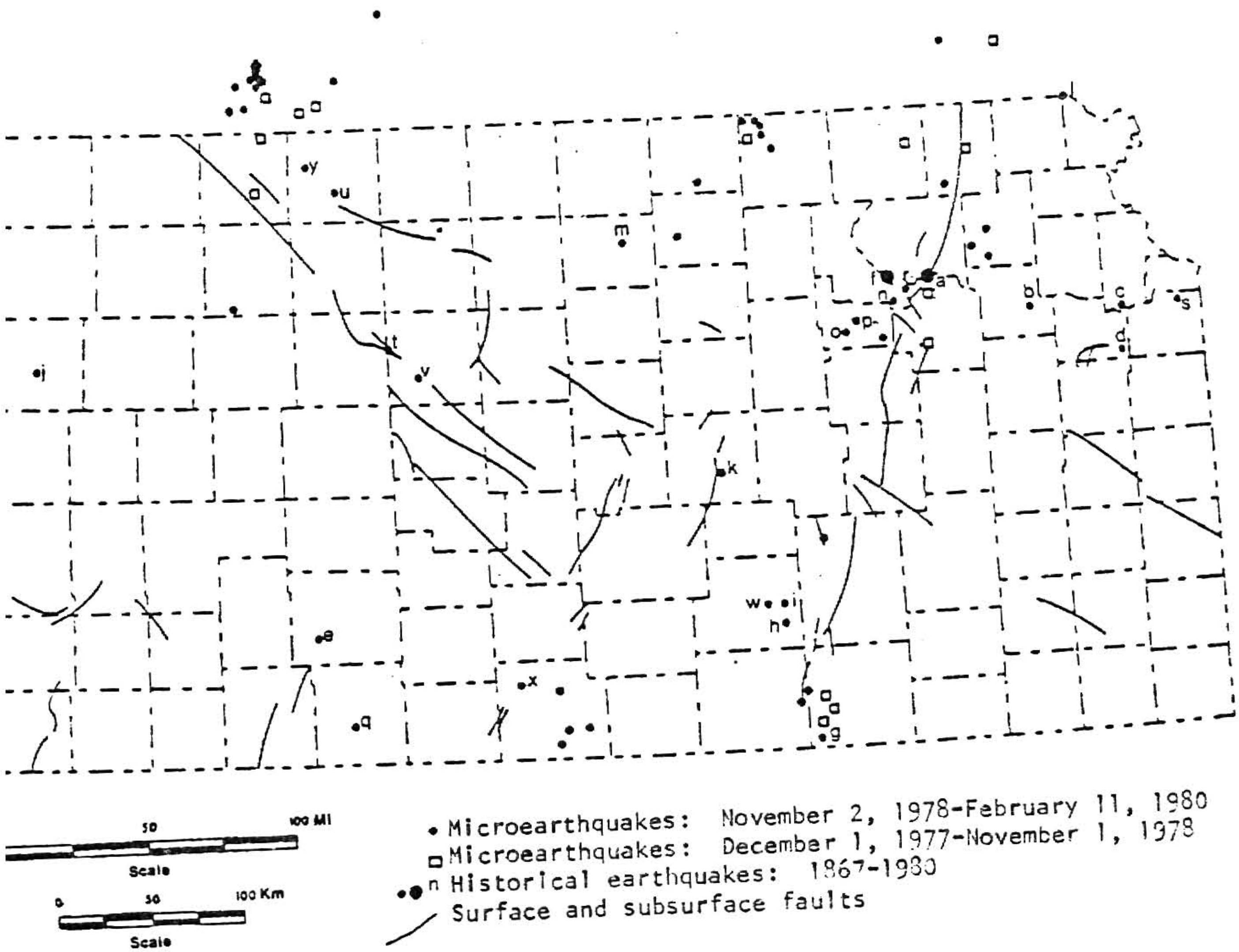


FIGURE 1. SEISMIC RISK MAP OF THE UNITED STATES (ALGERMISSEN, 1969).



Magnitude of Historic Earthquakes (Modified Mercalli Scale)

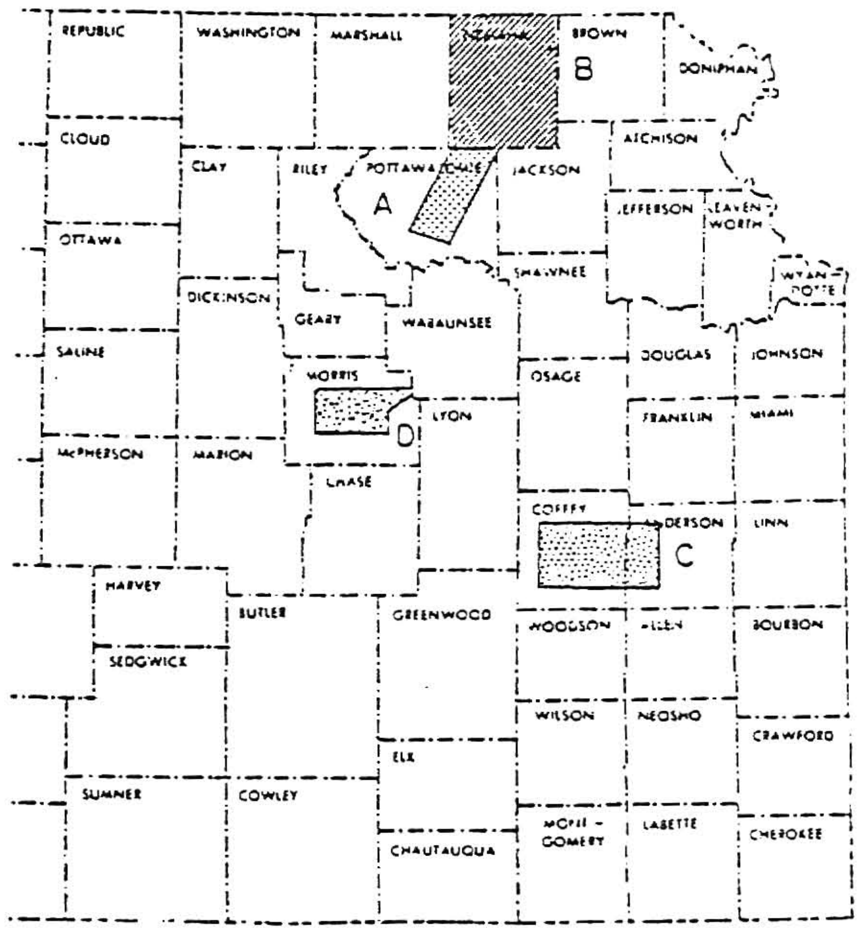
a	1867	VIII	f	1906	VII	k	1927	V	p	1929	V	u	1933	V
b	1875	V	g	1907	IV	l	1927	VI	q	1929	V	v	1942	IV
c	1881	III	h	1919	IV	m	1928	IV	r	1929	V	w	1948	IV
d	1903	II	i	1919	IV	n	1929	V	s	1931	VI	x	1956	VI
e	1904	IV	j	1926	?	o	1929	V	t	1932	VI	y	1961	V

Figure 2. Modified from Merriam (1963) and DuBois and Wilson (1978).

The Kansas Geological Survey, together with the Oklahoma, Nebraska, and Iowa state geological surveys, is conducting a five-year investigation of the geology and recent seismic activity along the Nemaha Anticline and other regional geologic structures in these states, to determine the frequency and intensities of earthquakes (Wilson, 1979). This investigation is jointly funded by the Division of Reactor Safety Research, U.S. Nuclear Regulatory Commission; the Kansas City District, U.S. Corps of Engineers; and the Kansas Geological Survey (Wilson, 1979).

The proposed construction of dams, nuclear power plants, and other earthquake sensitive structures in northeast Kansas has created a need for the evaluation of the risk of earthquake damage. Four detailed field investigations have been conducted by research assistants working for the Kansas Geological Survey prior to this investigation. Figure 3 shows the locations of these investigations.

In 1977, Seyrafian conducted surface and subsurface geologic investigations along the subsurface trace of the Humboldt Fault in Pottawatomie County, Kansas. The Humboldt Fault was named by Condra in 1927 for a surface fault north of Humboldt, Nebraska where a vertical displacement of 161 m (100 ft) has been measured (Nelson, 1952). Seyrafian concluded that subsurface faults did occur on the east flank of the Nemaha Anticline in Pottawatomie County, and although no surface faults were found, dips of 4^{o} to 5^{o} to the east-southeast were thought, by Seyrafian, to be caused by draping of beds over a fault on the east flank of the Nemaha Anticline. In 1978, DuBois investigated the geology of Nemaha County, Kansas, and conducted a detailed study of the Humboldt Fault Zone. She concluded that recent movement of glacial till adjacent to the Humboldt Fault had occurred and that recent activity is indicated



A. A. Seyrafian (1977)
B. S. M. DuBois (1978)
C. R. S. Woods (1978)
D. P. A. Macfarlane (in prep.)

Figure 3. Locations of detailed field investigations (Wilson, 1979).

by a microearthquake recorded on January 27, 1978 and by other older earthquakes recorded near the Humboldt Fault Zone. Woods (1978) conducted an investigation of magnetic and gravity anomalies in central Coffee and western Anderson counties, Kansas. Woods concluded that a north-south positive gravity trend that cuts across a subcircular positive magnetic anomaly is due to faulting in the Precambrian basement or to intrusions of igneous rocks. Macfarlane is currently doing detailed geomorphic analysis and geologic mapping of Morris County, Kansas. Surface faults were not found by Macfarlane, but she mapped a monoclinal flexure that correlates closely to the location of the Humboldt Fault.

Purpose of Investigation

The purpose of this investigation was to search for evidence of surface and subsurface faults in western Wabaunsee, southeastern Riley, and eastern Geary counties, Kansas and to determine the faults' relationship to each other and to sites of recent seismicity in the area.

Location

The area of investigation includes western Wabaunsee, southeastern Riley, and eastern Geary counties, Kansas (Fig. 4). Two areas of surface investigation were chosen for this report. These areas were suggested by Dr. Claude W. Shenkel Jr. and Frank W. Wilson and include western Wabaunsee and southeastern Riley counties. The area in western Wabaunsee County was selected because it included the site of the Schmitt No.1 well, drilled in sec. 21, T. 12 S., R. 9 E. in October, 1959. This well penetrated an anomalously thick section of the Cherokee Group. The Cherokee Group in this well is 405 m (1,329 ft) thick. Wells drilled

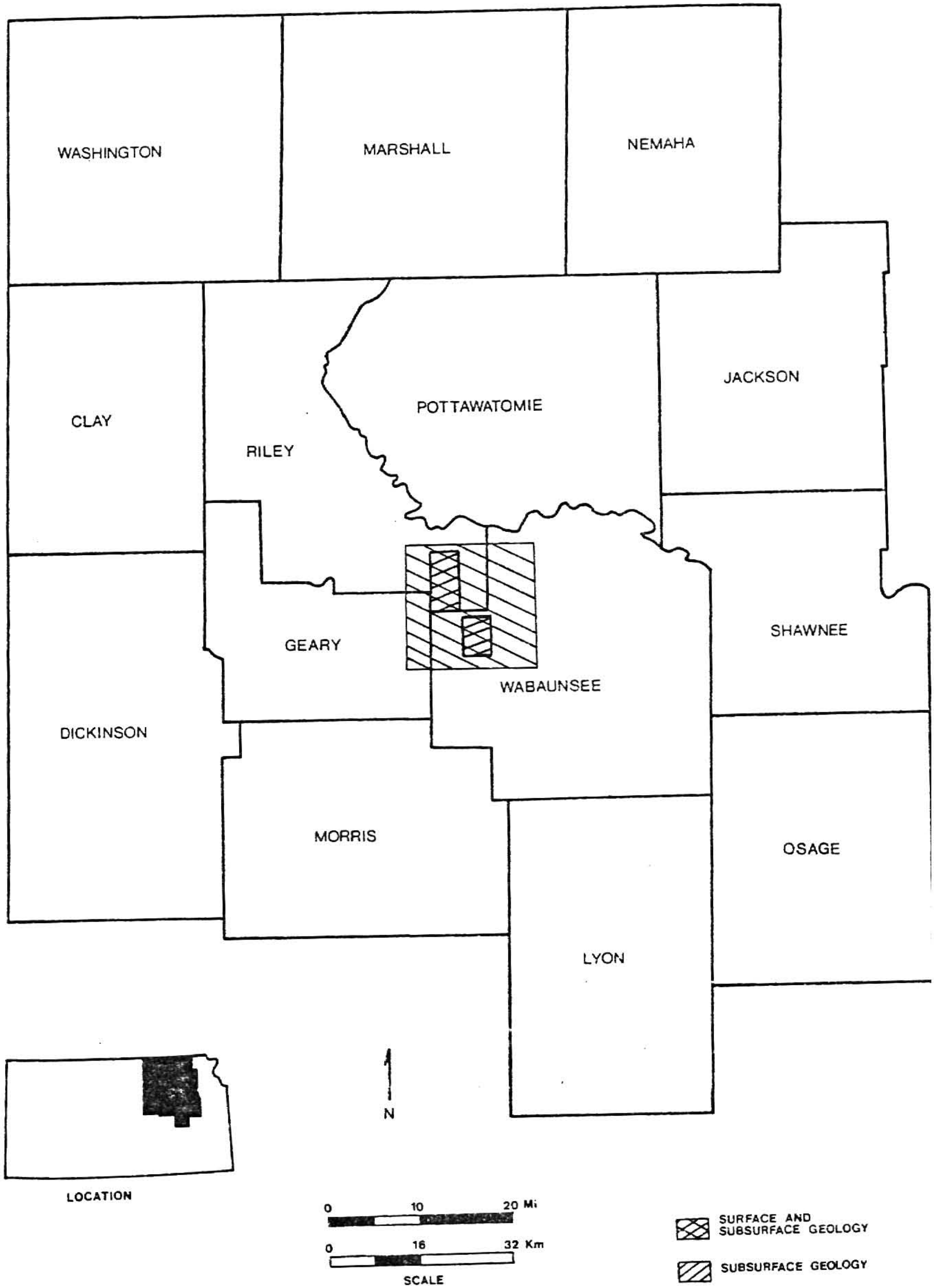


Figure 4. Locations of surface and subsurface investigations.

within a one and a half to two-mile radius of the Schmitt well reveal the thickness of the Cherokee Group to range from 30.5 m (100 ft) to 114.3 m (375 ft) on the crest of the Nemaha Anticline; the Cherokee Group is 185 m (607 ft) thick in a well on the west side of the Forest City Basin. The area in southeastern Riley County was chosen because seven normal faults have been mapped at the surface by Mudge and Beck (1949), Neff (1949), Nelson (1952), and Bruton (1958).

The area in western Wabaunsee County occupies approximately thirteen square miles and includes the central and south-central part of T. 12 S., R. 9 E., approximately 20 miles southeast of Manhattan, Kansas. The area in southeastern Riley County occupies fifteen square miles and includes the eastern part of T. 11 S., R. 8 E. and the eastern part of T. 11 S., R. 9 E., approximately 10 miles southeast of Manhattan (Fig. 4).

Subsurface investigations of this study included southeastern Riley, western Wabaunsee, and eastern Geary counties, Kansas. This area occupies approximately 324 square miles and includes T. 11 S., Ranges 8 E., 9 E., and 10 E.; T. 12 S., Ranges 8 E., 9 E., and 10 E.; and T. 12 S., Ranges 8 E., 9 E., and 10 E.

Physiography

The area selected for this report lies in the Flint Hills upland of the Osage Plains, which is a section of the Central Lowlands Physiographic Province (Fig. 5). The Flint Hills are characterized by east-facing scarps that developed on resistant limestone strata of the Lower Permian Series. The scarps form prominent terraces in the eastern part of the Flint Hills, whereas the western part of the Flint Hills consist of gentle west-directed dip slopes. Elevations range from 314 m (1,030 ft) above sea level in the northern part of the area to 463 m (1,520 ft) above sea level in the central part of the area. The area mapped in western Wabaunsee County has a maximum relief of 97.5 m (320 ft) and the mapped area in southeastern Riley County has a maximum relief of 143.3 m (470 ft). The area is drained by Deep Creek and its tributaries in southeastern Riley County and by Spring Creek and its tributaries in western Wabaunsee County. The Kansas River is 3.2 to 6.4 km (2-4 mi) from the northern border of the area.

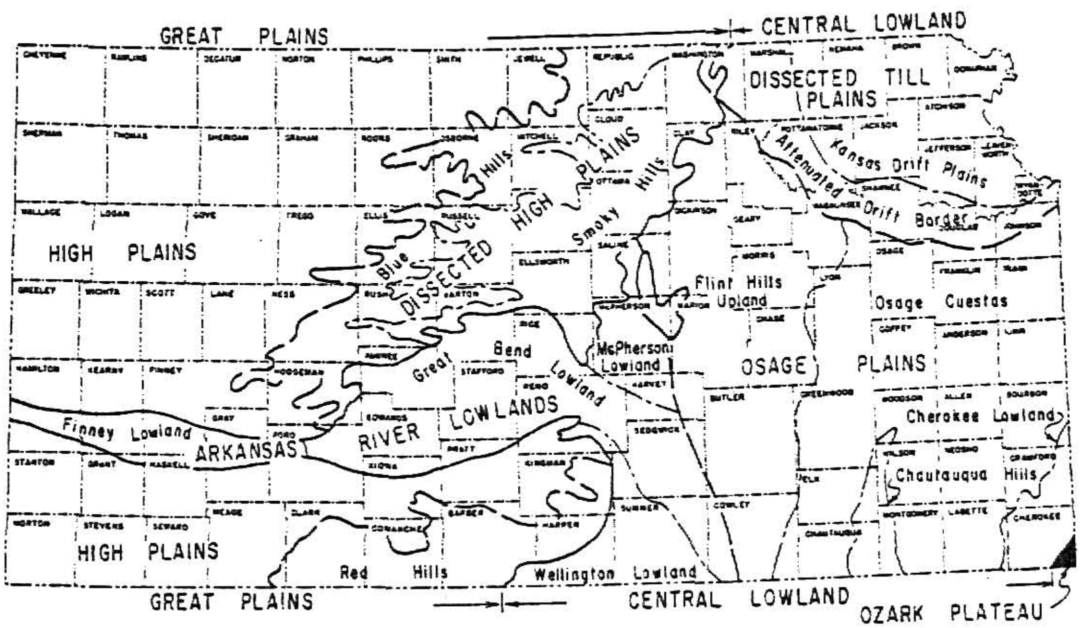


Figure 5. Physiographic provinces of Kansas (Merriam, 1963).

Previous Work

The geology of western Wabaunsee, southeastern Riley, and eastern Geary counties, Kansas is described in several unpublished masters theses and a few publications. Coombs (1948) mapped the Cottonwood Limestone in Riley County, Kansas. He concluded that the structure of the Cottonwood Limestone there has resulted from a combination of surface expression of buried hills, differential compaction across buried hills, and compaction of overlying sediments. Neff (1949) studied the fracture patterns of Riley County and noted that normal faults in Riley County strike essentially parallel to the strike of the northwest-trending joint set. Neff concluded that the joints were formed first and that vertical displacement occurred later along the joint planes. Mudge (1949) described the pre-Quaternary stratigraphy of Riley County and included a section on structural geology in which he compiled a list of geologic structures in the county. In 1952, Nelson investigated relationships between surface and subsurface structures. He wrote that the structural pattern in Riley and Marshall counties is controlled by a regional joint system in the basement complex. Bruton (1958) mapped fifteen square miles in southeastern Riley County that contains seven normal faults. The faults have a northwesterly strike, are 0.5 to 2.7 km (0.3-1.68 mi) long, and have a maximum displacement of 7.6 m (25 ft). He concluded that the combination of intermittent uplift, differential compaction, and rotation of a fractured basement complex could cause the en echelon-type faults at the surface in southeastern Riley County.

Rieb (1954), who described the surface and subsurface structural geology of the Nemaha Anticline, postulated subsurface faults along the east flank of the Nemaha Anticline in northwestern Wabaunsee County and along the southern flank of the Zeandale Dome in southeastern Riley County. He concluded that the east flank of the Nemaha Anticline is marked by a discontinuous, normal fault that extends across the state of Kansas and that the structure is the result of differential vertical uplift. Koons (1955) suggested that faulting was the origin of the Nemaha Anticline and that the fault system along the east flank of the Nemaha Anticline is present throughout the length of the anticline.

Baysinger (1963) conducted a magnetic investigation along the Nemaha

Anticline in Wabaunsee, Geary, and Riley counties to contradict or support evidence of faults in the subsurface along the east flank of the anticline. He proposed the existence of a subsurface fault striking northeast in T. 12 S., R. 9 E., but he did not map the fault through the entire length of Wabaunsee County. Swett (1959) described the surface expression of the Zeandale Dome in southeastern Riley and northwestern Wabaunsee counties. He concluded that the Zeandale Dome developed from differential compaction of sediments over an erosional hill on the Precambrian granite surface. Gasaway (1959) described the surface expression of the Nemaha Anticline and the Zeandale Dome in northwestern Wabaunsee and southeastern Riley counties. He noted a reversal and steepening of dip on the east flank of the Nemaha Anticline along a line that parallels the axis of the anticline, and he mapped 24.4 m (80 ft) of surface closure on the Zeandale Dome. He concluded that both structures were produced by differential compaction of sediments over the Precambrian basement.

Mudge and Burton (1959) published a detailed stratigraphic investigation of Wabaunsee County that included a geologic map of the county. Merriam (1963) described a subsurface structure in western Wabaunsee County as a graben. He suggested that the graben is on the northwesterly trend of the Chesapeake Fault Complex which extends from Missouri through southeast Kansas and into Nebraska.

The name Chesapeake Fault Zone, according to Merriam (1963), was previously applied to a fault zone in southwestern Missouri, where Branson (1944) described the fault zone as a major fault, extending 129 km (80 mi) from Stone County northwest to western Dade County, Missouri. The fault is parallel to the Ste. Genevieve and Cap au Gris fault zones to the northeast. Many minor faults are associated with the major fault and are at right angles to it. Although Branson described the fault zone, no reference was made to the name Chesapeake Fault Zone.

Literature relative to seismic activity near the area of investigation includes publications of Lee (1954), Merriam (1956), DuBois and Wilson (1978), and Wilson (1979). Lee (1954) discussed seismicity in relation to the Nemaha Anticline. He noted that areas reporting shocks from an earthquake occurring in 1952 coincided with the area of the Nemaha Anticline. He concluded that minor adjustments along the Nemaha Anticline are still taking place and probably have been intermittently since the Permian Period.

Merriam (1956) discussed the history of earthquakes in Kansas. In this report, Merriam placed the epicenters of the two largest (VII and VIII on the MM Scale) earthquakes recorded in Kansas near the Manhattan area in southeastern Riley County. The 1867 earthquake epicenter, with an intensity of VIII on the Modified Mercalli Scale, was placed about 35.7 km (22 mi) northwest of Manhattan in northeastern Riley County, and 1906 earthquake epicenter, with an intensity of VII, was placed 16.1 km (10 mi) north of Manhattan in Pottawatomie County. Merriam's work was revised by DuBois and Wilson in 1978. They relocated the epicenters of the 1867 and 1906 earthquakes using reports from old newspaper files and microfilm of old newspapers. DuBois and Wilson located the 1867 earthquake epicenter approximately 4.8 km (3 mi) south of Wamego in the Kansas River flood plain. The 1906 earthquake epicenter was in the Manhattan area.

Wilson (1979) compiled a list of microearthquake magnitudes, locations, and dates from December 1, 1977 to September 30, 1978 (Fig. 6 and Table 1). He noted that several of the microearthquakes occurred along the same trend

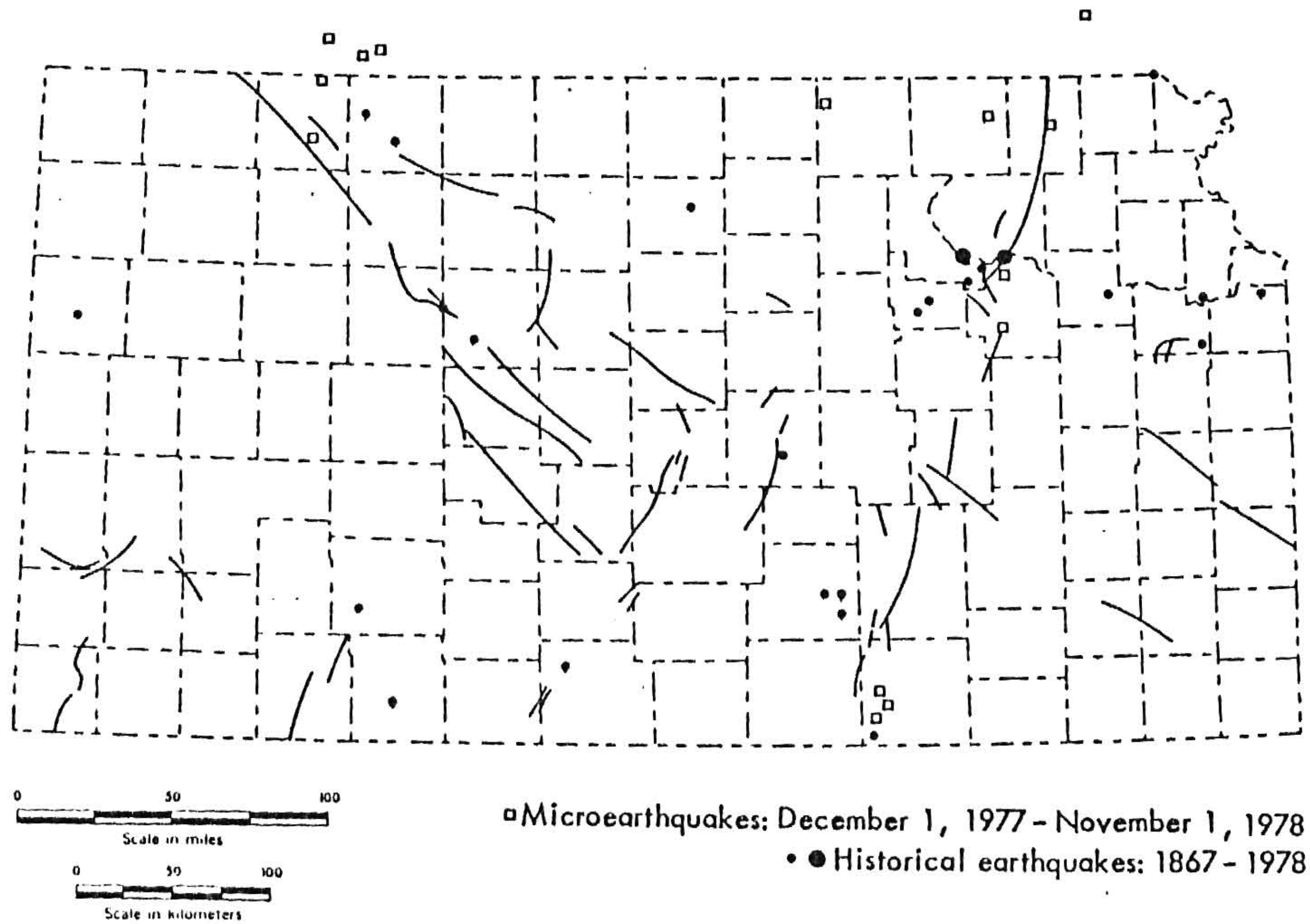


Figure 6. Locations of some principal faults in Kansas (After Merriam, 1963), and locations of microearthquakes and historic earthquakes in Kansas (Wilson, 1979).

TABLE 1

MICROEARTHQUAKES LOCATED BY KANSAS GEOLOGICAL SURVEY
1 DECEMBER 1977 TO 30 SEPTEMBER 1978
(Wilson, 1979)

Date		Origin Time (UTC)	Latitude	Longitude	Magnitude*	Remarks
18 Aug.	1977	10:34:25.2	41.416 ± 0.3N	98.468 ± 0.3W	$2.8M_{bLg}$	Central Nebraska
1 Dec.	1977	13:04:34.19	40.313N	100.366W	2.6 ± 0.2	NW of Norton, KS.
1 Dec.	1977	13:22:45.38	40.316N	100.297W	2.7 ± 0.2	NW of Norton, KS.
16 Dec.	1977	06:12:26.94	37.169N	97.031W	1.8 ± 0.2	Near Winfield, KS.
20 Dec.	1977	07:56:39.35	37.127N	97.031W	1.8 ± 0.2	Near Winfield, KS.
8 Jan.	1978	04:16:34.4	37.083N	97.070W	1.5 ± 0.2	Possible error in location, 30 km
11 Jan.	1978	21:32:03.88	38.868N	96.202W	1.2 ± 0.3	Near Alma, KS.
13 Jan.	1978	20:15:28.0	40.3N	95.8W	1.4 ± 0.3	Near Nemaha, Neb.
27 Jan.	1978	11:25:36.71	39.900N	96.006W	2.3 ± 0.3	Near Seneca, KS.
3 Feb.	1978	00:25:48.31	39.697N	100.381W	2.8 ± 0.2	NW of Norton, KS.
14 Apr.	1978	23:27:38.30	39.815N	96.395W	1.5 ± 0.2	SE of Beattie, KS.
20 May	1978	01:53:43.90	39.510N	100.390W	2.7 ± 0.2	SW of Norton, KS
22 May	1978	04:28:35.06	39.135N	96.292W	$1.9M_{bLg}$	SE of Wamego, KS.
14 Sept.	1978	08:06:19.92	40.722N	100.223W	2.6 ± 0.2	NW of Norton, KS.

*Magnitudes are estimated, pending final calibration of duration magnitude to M_{bLg} (M_{bLg} is the magnitude of the body wave through the granite, calculated from Love waves).

as the "Nemaha/Humboldt structure" and concluded that parts of this structure are still active today.

Procedures

Surface Mapping

Aerial photographs were used for surface geologic mapping in western Wabaunsee County. The numbers of the aerial photographs were ZF-IG 47-55 and 80-87. The scale of the photographs was 1:20,000, and they were provided by the Kansas Geological Survey. A geologic map of western Wabaunsee County was compiled by walking the entire area and pinholing the outcropping units on the aerial photographs. Each pinhole was given a number on the back of the photograph and a corresponding number was entered in a field notebook. Following the number in the notebook, the name of the rock unit was recorded together with other geologic information, such as dip and strike of strata, joint patterns, and descriptions of rock units. Using a stereoscope and the data collected in the field, geologic contacts were placed on the aerial photographs. Dip and strike of strata and of joints were measured using a Brunton compass and placed on the aerial photographs. When all the mapping on the photographs was complete, a sheet of acetate was placed over the photographs and the information was traced onto the acetate. The final copy of the map was traced from the acetate onto a sheet of vellum.

A geologic map of Riley County was compiled by Mudge and Beck in 1949. Seven northwest-striking normal faults were mapped in southeastern Riley County. A field check of these faults and the geology of southeastern Riley County was made. Additional geologic data (attitudes of strata and joint sets) were collected and placed on the map compiled by Mudge and Beck.

Subsurface Mapping

Subsurface isopachous and structure contour maps of the area were compiled. Herndon maps were used for subsurface control points. Two isopachous maps were made. Stratigraphic intervals used for these maps were: (1) the "Base" of the Kansas City Group to the Mississippian unconformity, and (2) the top of the Kansas City Group to the "Base" of the Kansas City Group.

Five structure-contour maps were made. The stratigraphic horizons used for these maps were the upper surfaces of (1) the Precambrian, (2) the Hunton Group, (3) the Mississippian, (4) the Lansing Group, and (5) the Heebner Shale.

Determination of Fault Displacement

In sections 15, 16, and 21 in T. 12 S., R. 9 E., a fault was mapped and the amount of vertical displacement along this fault was determined by measuring the elevations of the same rock units on either side of the fault with plane table and alidade. All measurements (thicknesses, distances, displacements, and so on) were calculated in feet or miles and converted to meters or kilometers respectively.

STRATIGRAPHY

Precambrian Rocks

Precambrian rocks are known only in the subsurface in Kansas, and were described by Farquhar (1957), Merriam and others (1961), and Muehlberger and others (1967). Farquhar (1957) described the Precambrian in central and northeast Kansas as igneous and metamorphic rocks. The igneous rocks intrude the metamorphic rocks. The Precambrian rocks on the crest of the Nemaha Anticline are mostly granite and granite wash. Granite wash is recognized on drillers' logs and consists of weathered granite. Precambrian rocks 4.8 to 6.4 km (3-4 mi) on either side of the anticline consist of schist, quartzite, and metasedimentary rocks underlain by granite.

The Precambrian rocks that underlie the area of investigation consist of granite and granite wash. These rocks range from 312.7 to 761.4 m (1,026-2,500 ft) below the surface on the Zeandale Dome in southeastern Riley County and from 1,049.4 to 1,103.3 m (3,443-3,620 ft) below the surface in the Forest City Basin.

Paleozoic Rocks

Paleozoic rocks in the area of investigation range in age from Late Cambrian to Early Permian. All Paleozoic systems are represented, but within the systems, some series are absent or partially absent. Major unconformities exist between the: (1) Precambrian and Upper Cambrian, (2) Chesteran and Desmoinesian, and (3) Devonian and Kinderhookian. Many minor unconformities exist throughout rocks of the Paleozoic Era. On the crest of the Nemaha Anticline, many of the Paleozoic rocks are absent because of post-Mississippian pre-Desmoinesian erosion, and rocks as young as Desmoinesian lie on rocks as old as Precambrian.

Pre-Pennsylvanian rocks consist mainly of limestone and dolomite with some sandstone and shale. The limestone and dolomite are commonly cherty. Pennsylvanian and Permian rocks consist mainly of alternating limestone and shale with some sandstone and coal. Only the uppermost Pennsylvanian and Lower Permian occur at the surface in this area. Tables 2 and 3 show detailed stratigraphy of Precambrian and Paleozoic rocks.

Thickness of Paleozoic rocks in the area ranges from 312.4 m (1,025 ft) on the crest of the Nemaha Anticline to 1,067 m (3,500 ft) in the Forest City Basin.

Cambrian-Ordovician Rocks

Cambrian-Ordovician rocks lie unconformably on Precambrian rocks. They consist mostly of cherty to non-cherty dolomite, but include some limestone, sandstone, and shale (Sternin, 1961). Four major subdivisions are recognized on drillers' logs, and they are, in ascending order: the Arbuckle Group, Simpson Group, Viola Limestone, and the Maquoketa Shale. Except on the Zeandale Dome, where Cambrian-Ordovician rocks are absent, the thickness of Cambrian-Ordovician rocks averages 116.1 m (381 ft).

Silurian-Devonian Rocks

Silurian-Devonian rocks lie unconformably on Ordovician rocks. They consist of vuggy, porous, and locally oolitic limestone and dolomite (Merriam, 1963). Silurian-Devonian rocks are collectively referred to as the Hunton Group and have an average thickness of 76.2 m (250 ft).

Devonian-Mississippian Rocks

The Chattanooga Shale, often included in the Kinderhookian Series,

Table 2. Stratigraphy, Precambrian to Permian, of southeastern Riley, western Wabaunsee, and eastern Geary counties. Units recognized on drillers' logs. *Units recognized by Sternin (Modified from Lee, 1943; Sternin, 1961; and Merriam, 1963).

STRATIGRAPHY

Precambrian to Permian

System	Series	Group	Formation	Thickness Meters (Feet)	Description
Pennsylvanian	Virgilian	Wabaunsee Group		121.9 (400)	Shale with interbedded thin limestone lenses and some sandstone lenses; fossiliferous
Pennsylvanian	Virgilian	Shawnee Group		91.4 (300)	Alternating limestones and sandy shales with small amounts of coal; fossiliferous
Pennsylvanian	Virgilian	Douglas-Pedee Groups		23.5-54.3 (77-178)	Shale, sandy shale, shaly sandstone, and oolitic limestone
Pennsylvanian	Missourian	Lansing Group		23.5-46.9 (77-154)	Alternating limestones and shales; limestones contain minor amounts of chert
Pennsylvanian	Missourian	Kansas City Group		61-97.5 (200-320)	Alternating marine limestones and non-marine shales; limestones are cher and fossiliferous; some sandstone
Pennsylvanian	Missourian	Pleasanton Group		7.6-28.7 (25-94)	Shale, with some sandstone, limestone and coal
Pennsylvanian	Desmoinesian	Marmaton Group		23.5-59.4 (77-195)	Alternating limestones and shales with some sandstone and coal; fossiliferous
Pennsylvanian	Desmoinesian	Cherokee Group		0-145.1 (0-476)	Sandstone and shale with minor amounts of coal and limestone
Pennsylvanian		Basal Pennsylvanian Deposits		0-15.5 (0-51)	Conglomerate, made up largely of reworked chert
Mississippian	Meramecian				Limestone and dolomite with abundant chert; fossiliferous
Mississippian	Osagian			0-169.2 (0-555)	Limestone, very cherty, dolomitic, and fossiliferous
Mississippian	Kinderhookian				Limestone, very cherty to non-cherty, and cherty dolomite; fossiliferous
Dev			Chattanooga Shale	0-83.5 (0-274)	Shale, gray to black, organic; plant spores abundant
Sil		Hunton Group		0-120.7 (0-396)	Limestone and dolomite, locally vuggy and oolitic; cherty near top
Ordovician			Maquoketa Shale	0-28.3 (0-93)	Dolomitic shale and very shaly dolomite
Ordovician			Viola Limestone	0-30.5 (0-100)	Dolomite, cherty to non-cherty and non-cherty limestone; chert is fossiliferous
Ordovician		Simpson Group		0-61.3 (0-201)	Sandstone, with shale near middle; minor amounts of limestone and dolomite
Ordovician		Arbuckle Group			Dolomite, chert throughout, and abundan in upper part
Cambrian			*Bonnterre Dolomite	0-33.5 (0-110)	Dolomite, with shale near top and sandy dolomite near base
Cambrian			*Lamotte Sandstone		Sandstone, rounded, coarse, and frosted grains
Precam					Granite and granite wash

Table 3. Permian Stratigraphy of southeastern Riley, western Wabaunsee, and eastern Geary counties. (Modified from Mudge, 1949; Mudge and Burton, 1959; and Jewett, 1941).

PERMIAN STRATIGRAPHY

Series	Group	Formation	Member	Thickness Meters (Feet)	Description
Lower Permian	Chase	Doyle Shale	Homesville Shale	7.6 (25)	Shale, varicolored, silty to clayey, calcareous, thin-bedded
Lower Permian	Chase	Barneston Limestone	Ft. Riley Limestone	7.6 (25)	Limestone, resistant, massive and thin-bedded; forms "rim rock"; fossiliferous
Lower Permian	Chase	Barneston Limestone	Oketo Shale	0.3-2.4 (1-8)	Shale, thin-bedded to blocky, gray, calcareous, silty; locally, calcite geodes; fossiliferous
Lower Permian	Chase	Barneston Limestone	Florence Limestone	10.7 (35)	Limestone, cherty, massive, gray to tan, shale partings; fossiliferous
Lower Permian	Chase	Matfield Shale	Blue Springs Shale	9.1 (30)	Shale, varicolored, argillaceous; limestone lenses present
Lower Permian	Chase	Matfield Shale	Kinney Limestone	1.2-2.7 (4-9)	Limestone, massive, gray; shale parting near middle
Lower Permian	Chase	Matfield Shale	Wymore Shale	8.2 (27)	Shale, varicolored, thin-bedded, silty, calcareous seams
Lower Permian	Chase	Wreford Limestone	Schroyer Limestone	4.3 (14)	Limestone, cherty, tan to brown, massive, upper non-cherty zone; fossiliferous
Lower Permian	Chase	Wreford Limestone	Havensville Shale	5.2 (17)	Shale, gray, thin-bedded, calcareous; limestone bed near top; limestone fossiliferous
Lower Permian	Chase	Wreford Limestone	Threemile Limestone	3.7 (12)	Limestone, cherty, light gray to white; non-cherty limestone near middle; shale near base; fossiliferous
Lower Permian	Council Grove	Speiser Shale		5.2 (17)	Shale, varicolored, silty; persistant limestone near top; fossiliferous
Lower Permian	Council Grove	Funston Limestone		3.0 (10)	Limestone, massive, gray, porous; shale parting near middle; biostrome locally; fossiliferous
Lower Permian	Council Grove	Blue Rapids Shale		6.1 (20)	Shale, varicolored, calcareous seams; fossiliferous
Lower Permian	Council Grove	Crouse Limestone		3.0 (10)	Limestone, lower massive zone and upper platy zone, with intervening shale; fossiliferous
Lower Permian	Council Grove	Easly Creek Shale		4.6 (15)	Shale, varicolored, interbedded thin limestones; locally, black and thinned
Lower Permian	Council Grove	Bader Limestone	Middleburg Limestone	1.8 (6)	Limestone, tan to gray, porous; thin shale parting; fossiliferous
Lower Permian	Council Grove	Bader Limestone	Hooser Shale	1.8-2.7 (6-9)	Shale, gray, reddish near middle, silty; contains thin limestone lenses; fossiliferous
Lower Permian	Council Grove	Bader Limestone	Eiss Limestone	2.1 (7)	Limestone, tan to gray, local conglomerate at base; top commonly silicified pelecypods; shale parting
Lower Permian	Council Grove	Stearns Shale		4.6-5.5 (15-18)	Shale, gray, thin-bedded, silty, calcareous seams; locally fossiliferous
Lower Permian	Council Grove	Beattie Limestone	Morrill Limestone	0.9-1.5 (3-5)	Limestone, tan to brown, chert nodules; shale parting near middle
Lower Permian	Council Grove	Beattie Limestone	Florena Shale	2.4 (8)	Shale, gray, silty, thin-bedded; lower part very fossiliferous

Permian Stratigraphy (continued from p. 22)

Series	Group	Formation	Member	Thickness Meters (Feet)	Description
Lower Permian	Council Grove	Beattie Limestone	Cottonwood Limestone	1.4-1.8 (4.5-6)	Limestone, massive, light gray to white, chert nodules; abundant fusulinids near top
		Eskridge Shale		10.7 (34)	Shale, varicolored, silty, calcareous; two or three limestone lenses, fossiliferous
		Grenola Limestone	Neva Limestone	4.3-5.2 (14-17)	Limestone, massive to platy, gray brown, shale partings; fossiliferous
			Salem Point Shale	2.4 (8)	Shale, gray, green, thin-bedded to blocky limestone bed near middle
			Burr Limestone	2.4 (8)	Limestone, gray brown to tan, shale parting; fossiliferous
			Legion Shale	0.47-2.7 (1.4-8.7)	Shale, fissle, gray to black, clayey or silty
			Sallyards Limestone	0.37 (1.2)	Limestone, thin, gray to tan gray, fossiliferous
		Roca Shale		7.6 (25)	Shale, varicolored, silty, thin limestone beds, locally fossiliferous
		Red Eagle Limestone	Howe Limestone	1.2 (4)	Limestone, gray to brown, slightly dolomi tic, argillaceous, massive, porous; abundant ostracods
			Bennett Shale	1.8-3.5 (6-11.5)	Shale, dark gray to black, thin-bedded to fissle, silty, calcareous; middle argillaceous limestone; fossilifero
			Glenrock Limestone	0.46 (1.5)	Limestone, tan gray, hard, massive, blocky; fusulinids abundant
		Johnson Shale		7.6 (25)	Shale, tan, gray, green, silty; thin argillaceous limestone
		Foraker Limestone	Long Creek Limestone	0.76-2.4 (2.5-8)	Limestone, massive, gray to gray orange dolomitic, granular, porous, shale lentils; fossiliferous
			Hughes Creek Shale	11.6 (38)	Shale, dark gray to black; series of shal separated by dark gray limestones; fossiliferous, fusulinids abundant
			Americus Limestone	1.1 (3.5)	Limestone, gray to dark gray, massive, shale parting; fossiliferous
	Admire	Janesville Shale	Hamlin Shale	10.7-13.7 (35-45)	Shale, silty to clayey, gray, green, maroon; some sandstone, siltstone, conglomerate, and limestone
			Five Point Limestone	1.2 (3.8)	Limestone, hard, massive to platy, gray, argillaceous; fossiliferous
			West Branch Shale	6.1 (20)	Shale, gray, gray green, silty to clayey; sandstone lense near middle, limesto lense near top; fossiliferous
		Falls City Limestone		3.7-5.2 (12-17)	Limestone, gray, hard, dense; shale, gray thin-bedded, clayey; very fossiliferous
		Onaga Shale	Hawxby Shale	1.8-5.2 (6-17)	Shale, gray to gray green, thin-bedded, calcareous to non-calcareous, clayey; interbedded limestones
			Aspinwall Limestone	0.34-0.52 (1.1-1.7)	Limestone, gray orange, slightly crystal-line, blocky, massive; fossiliferous
			Towle Shale	2.1-26.2 (7-86)	Shale, tan gray to blue gray, thin-bedded, clayey; some limestone, sandstone, ar siltstone; locally, channel sand

lies between the overlying Mississippian limestone and the underlying Hunton Group in a normal stratigraphic sequence. Lee (1943) described the Chattanooga Shale as a black to gray fissile shale. Part is Mississippian and part is Devonian. Sternin (1961) noted that in Geary and Morris counties, the Chattanooga Shale is absent on the crest of the Nemaha Anticline and is 83.5 m (274 ft) thick near the east flank of the anticline.

Mississippian Rocks

Where Mississippian rocks are present, they are separated from the overlying Pennsylvanian rocks by a major unconformity of post-Mississippian pre-Desmoinesian age. Mississippian rocks consist mainly of limestone that is silty, oolitic in places, very cherty, and dolomitic in part (Lee, 1943). Three series make up the Mississippian rocks, and they are, in ascending order: the Kinderhookian, Osagian, and Meramecian. Mississippian rocks in the area of investigation are absent in some areas along the crest of the Nemaha Anticline but are 169.2 m (555 ft) thick in west-central Wabaunsee County.

Pennsylvanian Rocks

The Pennsylvanian System is divided into five series in Kansas; they are, in ascending order: the Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian. The upper three series are present in the area of investigation. Atokan rocks are thought to be present in the deepest part of the Forest City Basin (Merriam, 1963).

Pennsylvanian rocks unconformably overlie Mississippian rocks where they are present, but where Mississippian rocks are absent, Pennsylvanian rocks may lie on rocks as old as Precambrian. The Pennsylvanian-Permian boundary is gradational, but local disconformities are present. The boundary is difficult to recognize in the subsurface.

Pennsylvanian rocks in the area of investigation consist mainly of marine limestone and shale alternating with non-marine clastic deposits (Merriam, 1963). Thicknesses of Pennsylvanian deposits range from 352.3 to 645.3 m (1,156-2,117 ft) (Table 2).

Pennsylvanian rocks occur only in the subsurface within the area of investigation, except for the upper part of the Wabaunsee Group (Virgilian). Pennsylvanian rocks do not crop out in the two areas of surface investigation.

Permian Rocks

The Permian System lies gradationally on Pennsylvanian rocks, but locally a disconformity separates Pennsylvanian and Permian rocks. According to Zeller (1968), the Permian System in Kansas contains the Lower Permian Series and the Upper Permian Series. The Lower Permian Series is divided into the Gearyan and Cimarronian stages and the Upper Permian Series contains the Custerian Stage. The Gearyan State is the only stage present in the area covered by this report. It is divided into three groups, and they are, in ascending order: the Admire, Council Grove, and Chase groups (Table 3) (Zeller, 1968).

Rock units of all three groups crop out in the area of investigation. The oldest formation cropping out in the areas of surface investigation is the Onaga Shale of the Admire Group, and the youngest formation cropping out in the areas of surface investigation is the Barneston Limestone of the Chase Group.

Permian rocks consist of alternating limestone and shale and a few sandstone lenses. Thickness of Permian rocks ranges from 145.4 to 197.2 m (477-647 ft). Descriptions of rock units cropping out in the areas of surface investigation are given in Table 3. Descriptions of units mapped by the author in Wabaunsee County are given in the appendix and in Table 3.

Quaternary System

The Quaternary System consists of non-marine deposits that are of glacial and fluvial origin. They consist of unconsolidated conglomerate and sandy and silty clay.

Quaternary deposits in the area of investigation include the Sanborn Formation, terrace deposits, and loess deposits. The Sanborn Formation was mapped by Mudge and Burton (1959) in Wabaunsee County and by Mudge and Beck (1949) in Riley County. It consists of loess with sand and gravel at the base. The loess is red-brown silty clay, and the gravel consists of subangular fragments of chert intermixed with cobbles of limestone and smaller quartzite erratics. The thickness of the Sanborn Formation averages 2.4 m (8 ft) (Mudge and Burton, 1959).

Terrace deposits include high terrace deposits (15-18 m above stream bed) and low terrace deposits (2-18 m above stream bed). High terrace deposits which occur along the Kansas River, contain Illinoian and Wisconsin sediments that consist of angular to subangular fragments of limestone, shale and chert (1-10 cm in diameter) interbedded with sandy and silty clay. The low terrace deposits are recent deposits and are described by Mudge and Burton (1959) as mainly silt and clay with some chert and limestone gravel lenses near the base.

A loess deposit, mapped in the SW¼ sec. 22, T. 12 S., R. 9 E., overlies the Quaternary terrace deposit and consists of reddish-brown to brown clayey silt. The loess is approximately 4.6 m (15 ft) thick and is probably Wisconsin in age.

REGIONAL STRUCTURAL GEOLOGY

Major tectonic features include the Salina Basin, Nemaha Anticline, and Forest City Basin, and local structures include the Abilene Anticline, Irving Syncline, Zeandale Dome, Brownville Syncline, and Alma Anticline. All of these structures are interpreted as tectonic except the Zeandale Dome, which may be erosional, tectonic, or both. Figure 7 shows the locations of these structures.

Major Tectonic Features

Salin Basin

The Salina Basin is the second largest basin in Kansas, covering 12,700 square miles. It is bounded on the east by the Nemaha Anticline and on the west by the Cambridge Arch and central Kansas Uplift. The Salina Basin is a post-Mississippian pre-Desmoinesian syncline whose axis plunges northwest. Maximum structural relief on Precambrian rocks is approximately 488 m (1,600 ft). Cretaceous rocks crop out at the surface in the western part of the basin and Permian rocks crop out at the surface in the eastern part of the basin. Sedimentary rocks within the Salina Basin represent all systems of the Paleozoic plus the Cretaceous System. These rocks attain a maximum thickness of 1,372 m (4,500 ft) (Merriam, 1963).

Nemaha Anticline

The Nemaha Anticline is a post-Mississippian pre-Desmoinesian structure that extends through Kansas from Nemaha County in the north, to Sumner County in the south, and into Nebraska and Oklahoma. It is bounded on the west by the Salina Basin and on the east by the Forest City Basin.

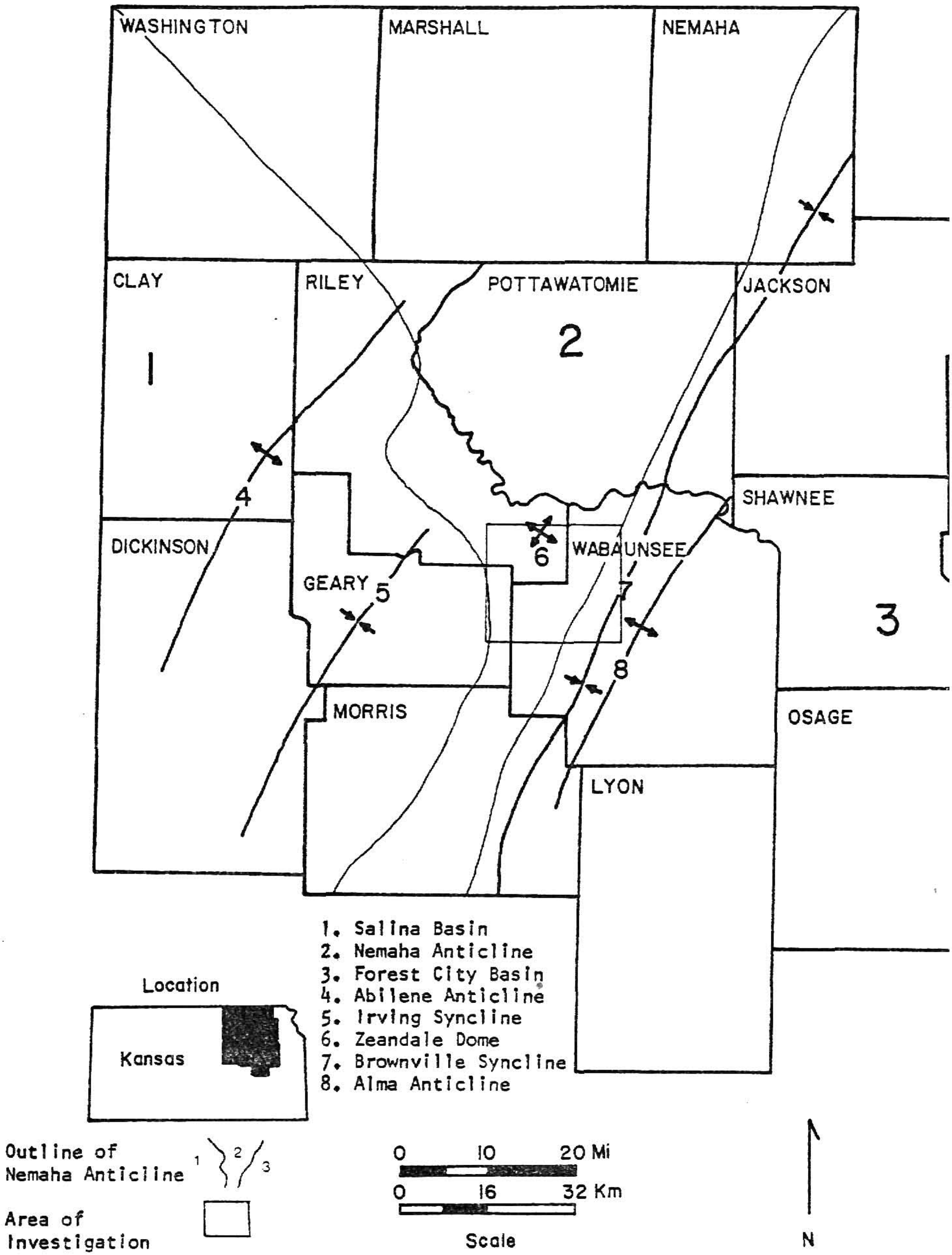


Figure 7. Structures in northeast Kansas (Modified after Merriam, 1963).

Surface expression of the Nemaha Anticline can be identified but is more pronounced in the subsurface. Along the east flank of the Nemaha Anticline, dips as much as 5^{o} to the east (opposite of the regional dip) are not uncommon at the surface. Faults occur along much of the anticline's east flank in the subsurface, and surface faults with vertical displacements of 30 m and 19.8 m (100 and 65 ft) on the east flank of the anticline occur in Nemaha (Merriam, 1963) and Wabaunsee counties respectively. Maximum structural relief on Precambrian rocks from the Nemaha Anticline to the Forest City Basin is approximately 1,097 m (3,600 ft).

Precambrian basement rocks on the Nemaha Anticline consist of granite. The granite is 183 m (600 ft) from the surface in Nemaha County and plunges to 1,219 m (4,000 ft) below the surface at the Oklahoma border. The Precambrian surface is an erosional surface characterized by a series of knobs and saddles along the crest of the anticline. Lower Paleozoic rocks are upturned, truncated, and overstepped by Pennsylvanian deposits. Pennsylvanian rocks lie on rocks as old as Precambrian along the crest of the Nemaha Anticline (Merriam, 1963).

Forest City Basin

The Kansas part of the Forest City Basin makes it the third largest basin in the state, covering more than 9,500 square miles. It is bounded on the west by the Nemaha Anticline and on the southwest by the Bourbon Arch, which extends southeast from Chase County, Kansas through Bourbon County, Kansas. The axis of the Forest City Basin trends a few degrees east of north, and parallels the axis of the Nemaha Anticline. The basin's axis is on the west side of the basin, producing an asymmetrical profile. Maximum structural relief on Precambrian rocks in the basin is approximately

518 m (1,700 ft).

Sedimentary rocks within the basin include units of Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian age. These rocks obtain a maximum thickness of 1,219 m (4,000 ft) in the western part of the Forest City Basin. On the west side of the basin (east flank of the Nemaha Anticline), lower Paleozoic rocks have been upturned, truncated, and overstepped by Pennsylvanian rocks (Merriam, 1963). Precambrain rocks in the Forest City Basin include granite and metamorphic rocks.

Local Structures

Abilene Anticline

The Abilene Anticline lies within the Salina Basin to the west of the Nemaha Anticline. It extends from Marshall to Dickinson counties, Kansas. The Abilene Anticline formed contemporaneously with the Nemaha Anticline and is parallel to it (Bruton, 1958). It plunges to the southwest and has a maximum structural relief, on the Precambrian rocks, of 671 m (2,200 ft).

Irving Syncline

The Irving Syncline lies between the Abilene Anticline to the west, and the Nemaha Anticline to the east. Its axis parallels the Nemaha and Abilene anticlines. It plunges northeast and has a maximum structural relief, on Precambrian rocks, of 244 m (800 ft).

Zeandale Dome

The Zeandale Dome is in southeastern Riley County; its apex is a few miles southeast of Zeandale, Kansas. The Zeandale Dome lies on the crest of the Nemaha Anticline and was described by Farquhar (1957) as one of many erosional knobs and saddles that mark the Precambrian surface of the anticline. Koons (1955) mapped 183 m (600 ft) of closure in the subsurface, and Gasaway (1959) mapped 24.4 m (80 ft) of closure on the Americus Limestone Member at the surface.

Brownville Syncline

The Brownville Syncline lies between the Nemaha Anticline to the west and the Forest City Basin to the east, and was described by Sternin (1961) as the deepest part of the Forest City Basin. The Brownville Syncline extends from Nebraska, southward to Morris County, Kansas. It parallels the axis of the Nemaha Anticline, plunges northeast, and has a maximum relief on the Precambrian surface of 366 m (1,200 ft).

Alma Anticline

The Alma Anticline is within the Forest City Basin in Wabaunsee, Pottawatomie, and Morris counties, Kansas. It is essentially parallel to the Nemaha Anticline and formed contemporaneously with it. The anticline is faulted on its east side and, like the Nemaha, is strongly asymmetrical (Sternin, 1969). Maximum vertical displacement on the fault is 38.1 m (125 ft). Closure on the Precambrian surface on the Alma Anticline is approximately 213.4 m (700 ft) (Koons, 1955).

The John Creek Anticline and the Davis Ranch Anticline are structural highs on the Alma Anticline in Morris and Wabaunsee counties respectively (Sternin, 1961).

SURFACE STRUCTURE

Western Wabaunsee County

A geologic map of western Wabaunsee County was compiled by walking every outcrop visible on the aerial photographs and by walking every stream valley where outcrops were concealed, on the photographs, by trees (Fig. 8). Only one publication could be found that deals with the surface geology of the area in western Wabaunsee County covered by this investigation. Mudge and Burton (1959) conducted a detailed stratigraphic investigation of Wabaunsee County that produced a geologic map of the county that contained two faults. Four additional faults were mapped in the area of this investigation. Five formations and one member were mapped in the northwest corner of sec. 28 and the eastern half of sec. 29, T. 12 S., R. 9 E. that were not previously mapped. These rock units crop out on an upthrown fault block, and include, in ascending order: Neva Limestone Member of the Grenola Limestone, Eskridge Shale, Beattie Limestone, Stearns Shale, Bader Limestone, and Easly Creek Shale.

Two of the faults mapped in western Wabaunsee County have a northeast strike, whereas the other two faults have a northwest strike. All of these faults were difficult to recognize on aerial photographs. The largest fault, 2 km (1.25 mi) long, in sec. 12, 16, and 21, creates a faint line on the aerial photographs, but this line was identified by the writer only after recognition of the fault in the field. Melton (1974) compiled an anomaly-lineament map of southeastern Nebraska, southwestern Iowa, northwestern Missouri, and northeastern Kansas that includes prominent anomalies and lineaments, less prominent anomalies and lineaments, and drainage anomalies and lineaments. The lineaments and anomalies were superimposed by

EXPLANATION

Unconsolidated Sediments

Pleistocene and Recent	Ql	Loess Deposit	QUATERNARY
Pleistocene and Recent	Qt	Terrace Deposit	QUATERNARY

Sedimentary Rocks

		Formation	Member	
Chase Group	Pbf	Barneston Limestone	Florence Limestone	PERMIAN
Chase Group	Pm	Matfield Shale	Blue Springs Shale; Kinney Limestone; Wymore Shale	PERMIAN
Chase Group	Pw	Wreford Limestone	Schroyer Limestone; Havensville Shale; Threemile Limestone	PERMIAN
Council Grove Group	Pfc	Speiser Shale; Funston Limestone; Blue Rapids Shale; Crouse Limestone		PERMIAN
Council Grove Group	Peb	Easly Creek Shale; Bader Limestone	Middleburg Limestone; Hooser Shale; Eiss Limestone	PERMIAN
Council Grove Group	Psb	Stearns Shale; Beattie Limestone	Morrill Limestone; Florena Limestone; Cottonwood Limestone	PERMIAN
Council Grove Group	Pne	Eskridge Shale; Grenola Limestone	Neva Limestone	PERMIAN

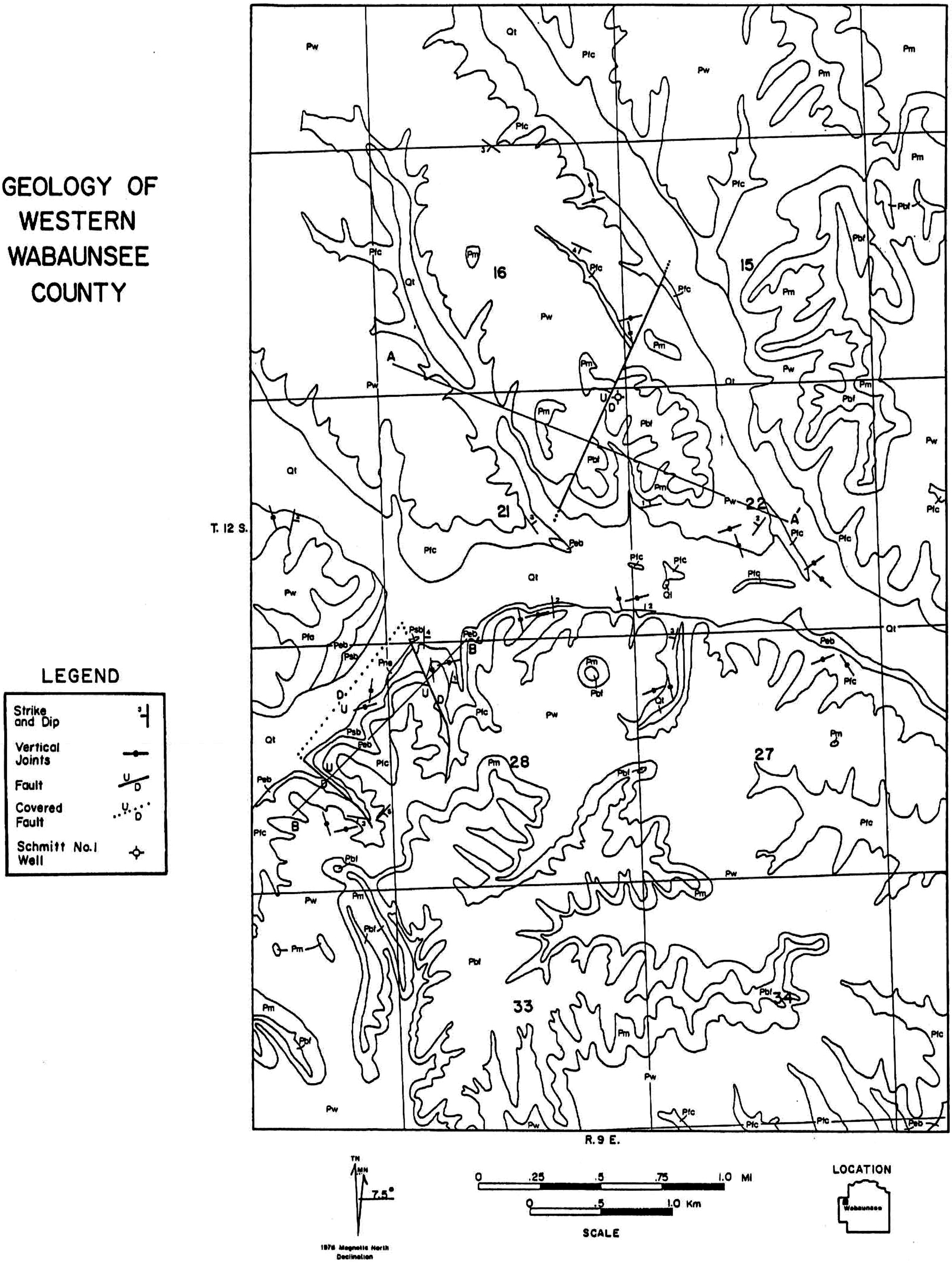

GEOLOGY OF WESTERN WABAUNSEE COUNTY
LEGEND
Strike and Dip
Vertical Joints
Fault
U D
Covered Fault
Schmitt No.1 Well
T. 12 S.
R. 9 E.
15
16
21
22
27
28
33
34
A
A'
B
Pw
Pfc
Pm
Pbf
Peb
Psb
Qt
0 .25 .5 .75 1.0 MI
0 .5 1.0 Km
SCALE
TN
MN
7.5°
1978 Magnetic North Declination
LOCATION
Wabaunsee

Figure 8

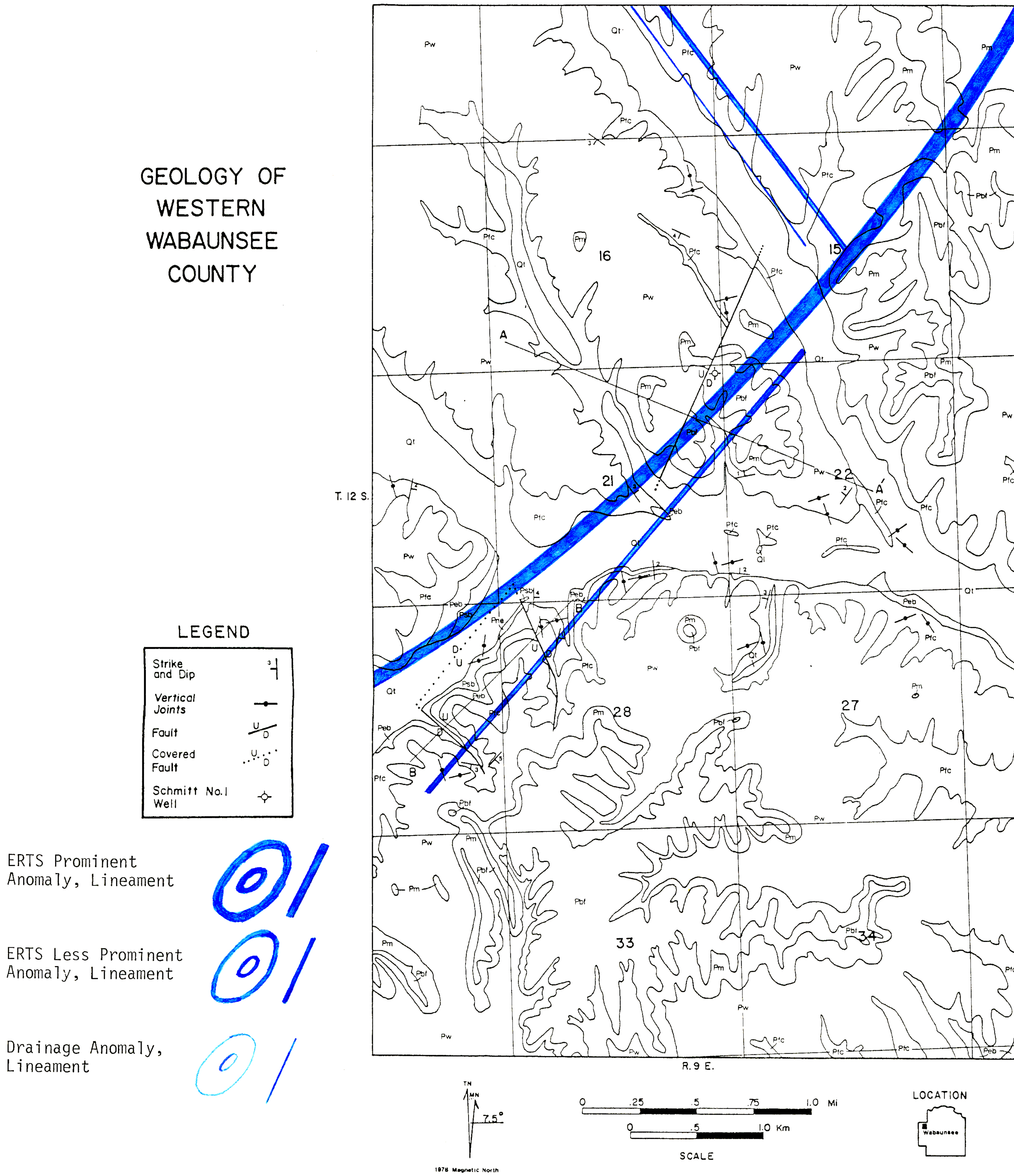


Figure 9. (Modified from Melton, 1974).

the writer on the map of western Wabaunsee County (Fig. 9). Part of a large prominent anomaly and a less prominent lineament coincide with the fault in sec. 15, 16, and 21, and the fault in sec. 21 and 29. The anomaly and lineament that coincide with the surface faults may reflect an impression made by the surface and subsurface faults in this area.

The oldest outcrop cut by the faults in western Wabaunsee County is the Neva Limestone Member of the Grenola Limestone. The youngest unit cut by these faults is the Florence Limestone Member of the Barneston Limestone. Each fault can be traced laterally to Quaternary deposits where the faults disappear. The faults in western Wabaunsee County are post-Upper Permian; they may be as young as Quaternary. Although no displacement of Quaternary sediments was seen, much of these deposits are Recent and may have concealed any evidence of earlier Quaternary movement.

Faults

Four faults were mapped in western Wabaunsee County (Fig. 8). The largest fault is in the NE¼ sec. 21 and the southeast corner of sec. 16 and the SW¼ sec. 15. This fault is 2 km (1.25 mi) long, strikes N 24° E, has a vertical displacement of 18.3 to 21.3 m (60-70 ft) near the center of the fault, and is upthrown to the northwest. A vertical displacement of 10.7 m (35 ft) was measured with a plane table and alidade near the southwest end of the fault. The fault plane cannot be seen but is believed by the writer to be vertical, because a fault was mapped by the writer in the subsurface, directly below this surface fault, and the fault makes a straight line outcrop over a hill.

Strata near this fault generally dip toward the fault. Dips of 3-4° NE and SW were recorded on the northwest side of the fault, and dips of 1-2°

NW were recorded on the southeast side of the fault. Two hills on the northwest side of the fault in the NE¼ sec. 21 and the SE corner of sec. 16 have northeast slopes of 3°, inclined toward the fault. These slopes are probably dip slopes. The Funston Limestone has a dip of 3° NE near the center of sec. 21.

Location of this fault was based on three criteria: (1) the abrupt termination of the 3° dip slopes to a nearly horizontal bench produced by weathering of the Florence Limestone Member, (2) the abrupt termination of the Threemile Limestone Member in the SW¼ sec. 15, and (3) the faint lineament that can be seen on the aerial photographs. Cross section A-A' on the geologic map of western Wabaunsee County shows the interpretation of the structure and stratigraphy across the fault (Fig. 10).

Three faults in the E½ sec. 29, the NW¼ sec. 28, and the southwest corner of sec. 21 border a small horst. The fault in sec. 29 and 21 is covered by Quaternary deposits and is therefore an inferred fault. Dips recorded in this area make it difficult to explain a 7.6 to 10.7 m (25-35 ft) difference in elevation of rock units from one side of the stream to the other by folding, and this difference is best explained by a fault. The other two faults that make up the horst are hinge faults, with the greatest vertical displacements to the northwest.

The inferred fault in sec. 29, T. 12 S., R. 9 E., is 1.2 km (0.75 mi) long, strikes N 40° E, has a vertical displacement of 7.6 to 10.7 m (25-35 ft), and its upthrown side is to the southeast. Strata to the northwest of the fault dip 1° to 2° SE. Strata directly southeast of the fault on the upthrown block are nearly horizontal, with a slight dip to the southeast.

The fault in the SW corner of sec. 21 and W½ of sec. 28 is approximately 1.2 km (0.75 mi) long, strikes N 21° W (but curves to a north-south

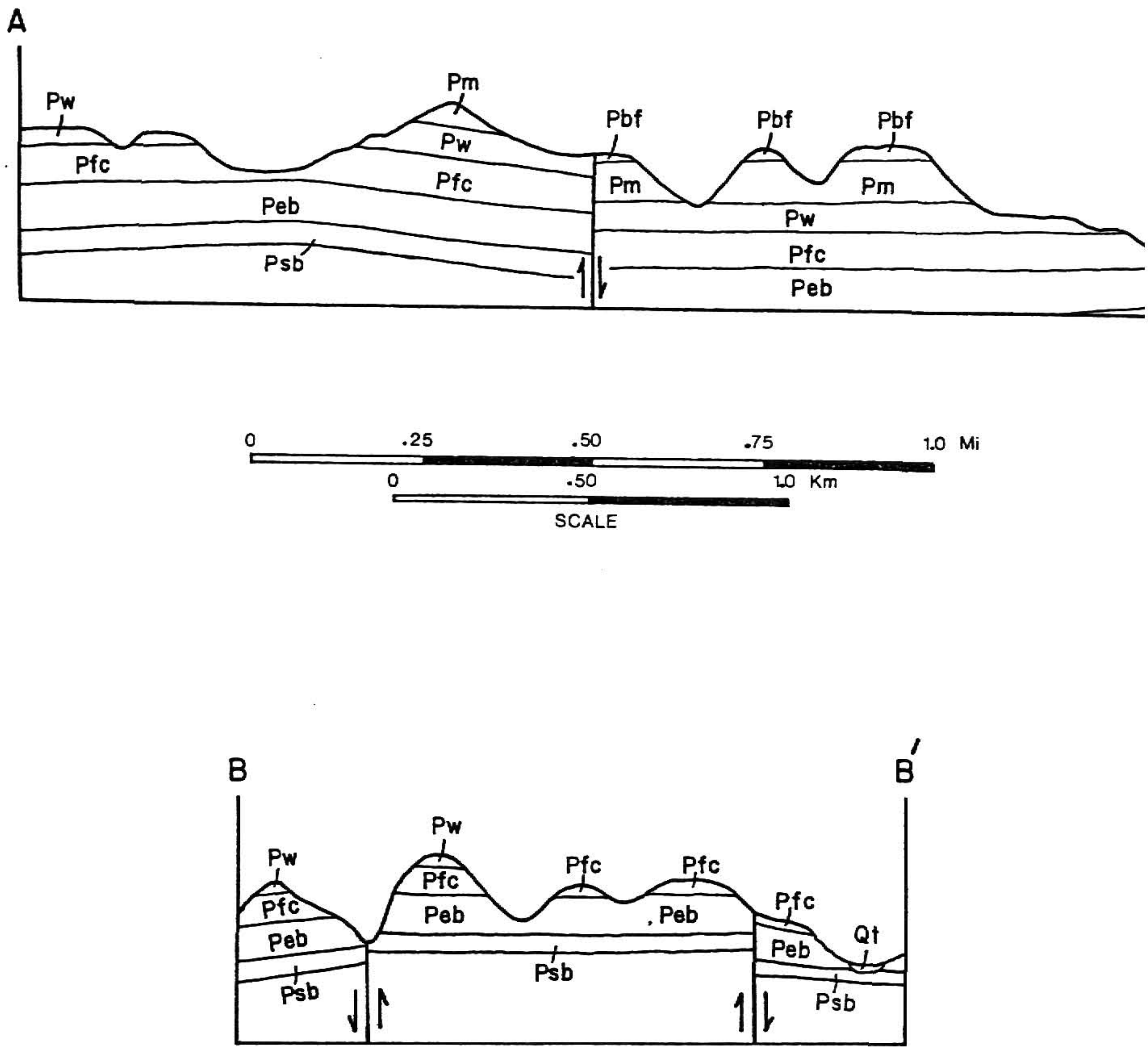


Figure 10. Schematic-geologic cross section A-A' and B-B' on geologic map of Wabaunsee County (Fig. 8).

trend at the southeast end of the fault), has a maximum vertical displacement of 9.1 m (30 ft), and its upthrown side is to the southwest. Vertical displacement on this fault was determined by noting that the top of the Eiss Limestone Member was at the same elevation as the middle of the Cottonwood Limestone Member. Thickness of the strata between these two members was then added to obtain a vertical displacement of about 9 m.

The fault plane is vertical and can be seen between two outcrops of the Cottonwood Limestone on the border of sec. 21 and 28. Strata to the northeast of the fault dip to the southeast and strata on the upthrown block are nearly horizontal, and have a dip of less than one degree to the southeast. A dip of 4° SE in the southwest corner of sec. 21 was recorded and is probably related to the fault in sec. 21. Dips of 4 or 5° are relatively large for Kansas, and in western Wabaunsee County, dips of 4 or 5° occur only near faults. When faulting occurred in sec. 21, rocks near the fault were affected by the fault movement and assumed their present dip. The monoclinal fold on the northwest side of the fault (Fig. 10) may be due to a combination of drag folding and differential compaction over the subsurface structure (Fig. 13).

The fault in the middle part of the E½ sec. 29 is approximately 0.75 km (0.5 mi) long, strikes N 46° W but curves slightly to the southeast near the southeast end of the fault, has a maximum vertical displacement of 9.1 m (30 ft), and is upthrown to the northeast. Vertical displacement was calculated by measuring vertical distance from a common point in the draw to the Funston Limestone Member on either side of the draw. The difference in these two measurements is a vertical displacement of about 9 m, matching that of the fault bordering the horst on the northeast.

The plane of this fault cannot be seen but is believed by the writer to be vertical, or nearly so, because it occupies a narrow draw. Strata on the upthrown block to the northeast of the fault are nearly horizontal, with a dip of less than one degree to the southeast. At the southeast end of the fault a dip of 3° SW was measured on the southwest side of the fault and a dip of 5° SE (largest dip measured in the area) was measured on the northeast side of the fault. The magnitudes of these dips are local and were probably caused by drag along the fault plane. Cross section B-B' on the map of western Wabaunsee County, shows the structure and stratigraphy across two of the faults that make up the horst in sec. 28 and 29 (Fig. 10).

Joints

Joints in western Wabaunsee County occur in two major sets. The joints are vertical, or deviate only a few degrees from vertical. The strike of one of the major sets ranges from N 5° W to N 46° W. Of fourteen measurements, however, 86 percent have a strike that ranges from N 5° W to N 16° W; the average is N 12° W. The strike of the other joint set ranges from N 55° E to N 81° E, but 86 percent of these strike from N 70° E to N 81° E and average N 76° E.

The fault in the NW¼ sec. 28 and the southwest corner of sec. 21 is subparallel to one of the joint sets to the northeast of the fault. The strikes of the other faults mapped in western Wabaunsee County do not show any correlation with the strikes of the joint sets. Surface faults in western Wabaunsee County closely parallel basement fracture patterns.

Southeastern Riley County

A reconnaissance of southeastern Riley County was conducted to field check the geology and faults mapped by Mudge and Beck (1949), and to try to determine age of faulting. Additions to Mudge's and Beck's map included strike and dip symbols, joint pattern symbols, and upthrown and downthrown symbols of faults. Two geologic contacts were omitted from Mudge's and Beck's map (Fig. 11) to make the map easier to read.

Faults

Seven faults were mapped by Mudge and Beck (1949) in southeastern Riley County. These faults were described later by Neff (1949), Nelson (1952), and Bruton (1958). The faults have a northwest strike, are 0.5 to 2.0 km (0.3-1.7 mi) long, and have a maximum displacement of 7.6 m (25 ft). Five of the faults are upthrown to the northeast, one is downthrown to the northeast, and one is a scissors fault with the upthrown side to the southwest on the northwest end of the fault, and the upthrown side to the northeast on the southeast end of the fault. Six of the faults are within 2.2 km (1.4 mi) of each other. These six faults are parallel to subparallel and strike from N 18° W to N 24° W. The seventh fault is southwest of the six faults, in sec. 26, 35, and 36, T. 11 S., R. 8 E., and strikes N 40° W. All the faults in southeastern Riley County are vertical or nearly so. Cross section A-A' on the map of southeastern Riley County shows the structure and stratigraphy across six of the faults (Fig. 12).

The oldest outcropping unit cut by the faults in southeastern Riley County is the Red Eagle Limestone. The youngest deposits cut by the faults are glacio-fluvial deposits, which are of Kansan age (Dr. Henry V. Beck, personal communication). Not all the faults in southeastern Riley County displace Quaternary deposits, but if one assumes the faults are contemporaneous, then all the faults are post-Kansan.

EXPLANATION

Unconsolidated Sediments

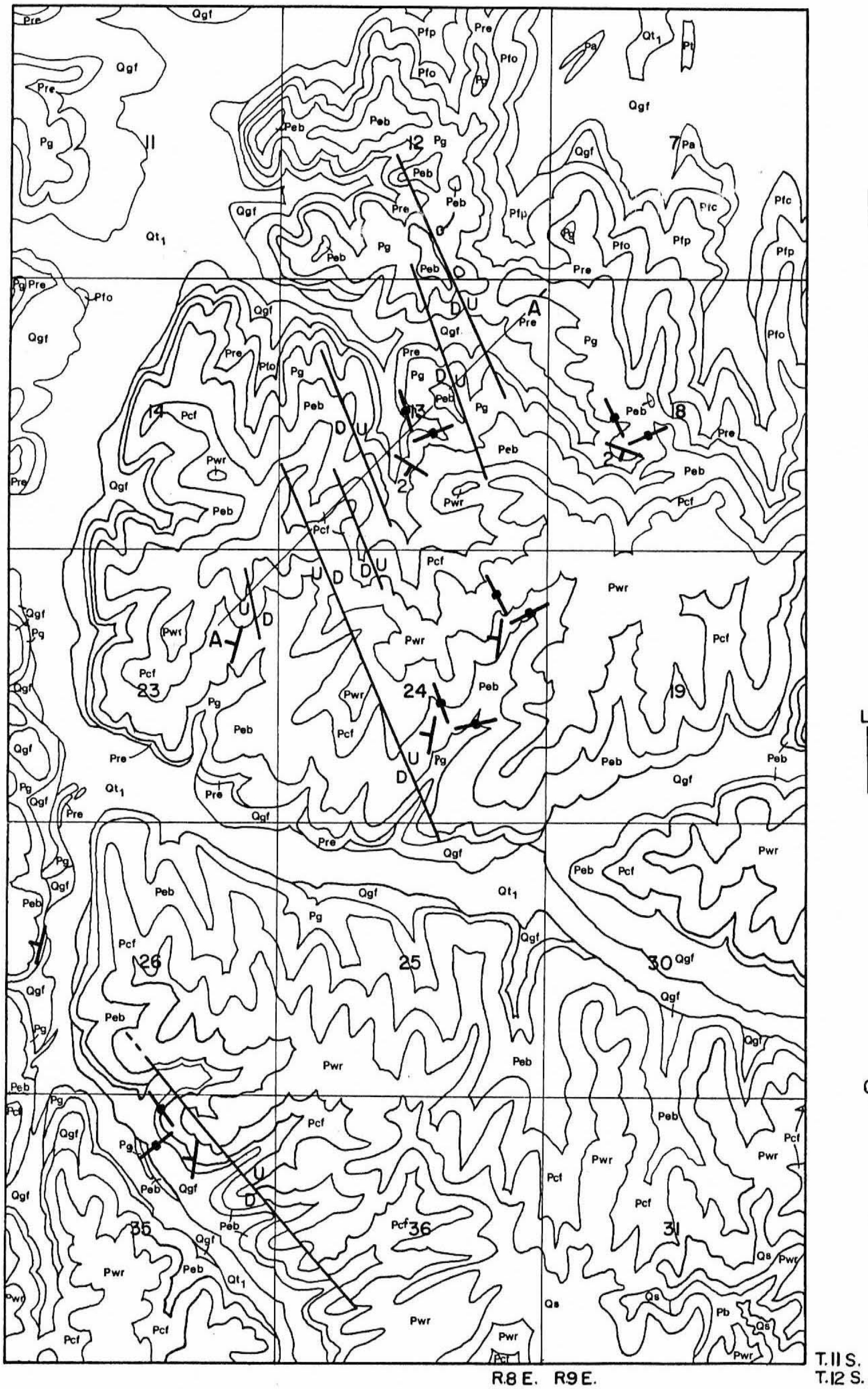
Qt_1	High Terrace Deposit	QUATERNARY
Qs	Sanborn Formation	QUATERNARY
Qgf	Glacio-fluvial Deposit	QUATERNARY

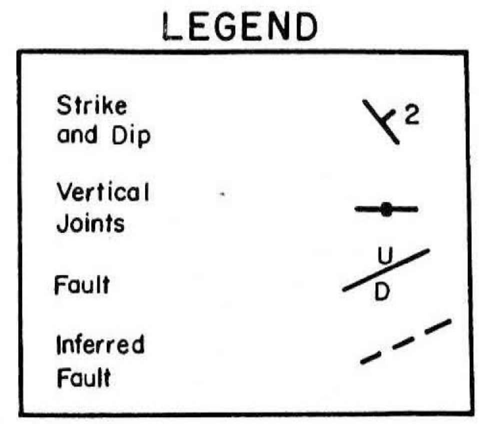
Sedimentary Rocks

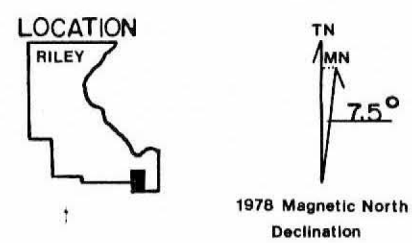
Pb	Barneston Limestone	PERMIAN
Pwr	Matfield Shale Wreford Limestone	PERMIAN
Pcf	Speiser Shale Funston Limestone Blue Rapids Shale Crouse Limestone	PERMIAN
Peb	Easly Creek Shale Bader Limestone Stearns Shale Beattie Limestone	PERMIAN

Council Grove Group	Pg	Eskridge Shale Grenola Limestone	PERMIAN
Council Grove Group	Pre	Roca Shale Red Eagle Limestone	PERMIAN
Council Grove Group	Pfo	Johnson Shale Foraker Limestone	PERMIAN
Admire Group	Pfp	Hamlin Shale Five Point Limestone	PERMIAN
Admire Group	Pfc	West Branch Shale Falls City Limestone	PERMIAN
Admire Group	Pa	Hawxby Shale Aspinwall Limestone	PERMIAN
Admire Group	Pt	Towle Shale	PERMIAN

GEOLOGY OF SOUTHEAST RILEY COUNTY







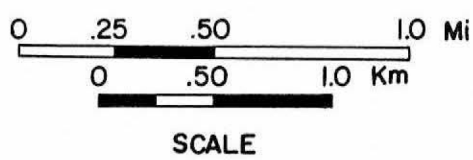


Figure 11. (Modified from Mudge and Beck, 1949).

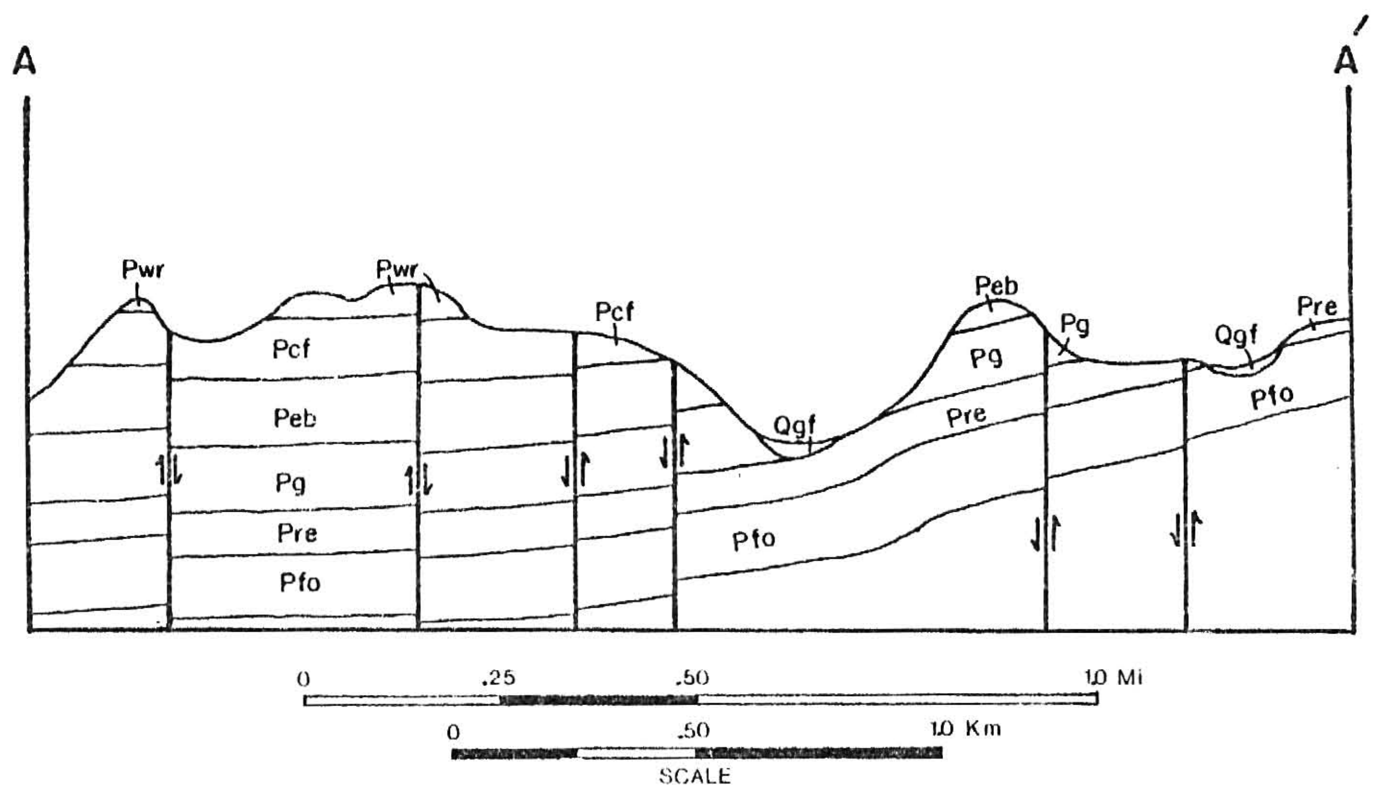


Figure 12. Schematic-geologic cross section A-A' on geologic map of southeastern Riley County (Fig.11)

Joints

Two major joint sets occur in southeastern Riley County. The joints are vertical or nearly so. The strike of the northwest-trending set ranges from N 18° W to N 39° W. The N 39° W reading was made in the southwest corner of the area. The strike of the northwest joint set in the rest of southeastern Riley County averages N 21° W. The strike of the northeast-trending joint set ranges from N 50° E to N 77° E; the average is N 65° E.

Unlike the faults in western Wabaunsee County, the faults in southeastern Riley County closely parallel the northwest-trending set of joints. In sec. 35, the strike of the northwest-trending joint set deviates 18° from the average and so does the fault in sec. 26, 35, and 36. The striking parallelism of the faults and joints probably indicates that the joint pattern in southeastern Riley County controls the strike of the faults. Bruton (1958) and Neff (1949) concluded that the joint system probably developed first, and faulting occurred along the already developed joints, which had established lines of weakness.

SUBSURFACE STRUCTURE

The subsurface geology in the area covered by this report has been described by Lee (1943, 1956), Nelson (1952), Rieb (1954), Koons (1955), Farquhar (1957), Sternin (1961), and Baysinger (1963). In the center of the area of investigation in western Wabaunsee County, sec. 21, T. 12 S., R. 9 E., is the Schmitt No.1 well (Fig. 8), drilled in 1959. In this well, the Cherokee Group is 405 m (1,329 ft) thick, whereas in surrounding wells, the thickness of the Cherokee Group ranges from 30.5 m (100 ft) to 185 m (607 ft). In the Schmitt No.1 well, the top of the Mississippian limestone was logged at 686 m (2,251 ft) below sea level. In surrounding wells, the Mississippian was logged at 166 to 246 m (543-806 ft) below sea level on the crest of the Nemaha Anticline, and 278 to 366 m (912-1,200 ft) below sea level in the Forest City Basin. Elsewhere, on the crest of the Nemaha Anticline, the Mississippian limestone is absent because of post-Mississippian pre-Desmoinesian erosion.

Two questions need to be answered before interpreting the subsurface structure near the Schmitt No.1 well: (1) Are the well-log data correct? (2) If the well-log data are correct, what type of structure or stratigraphic anomaly is responsible for the abnormal thickness of the Cherokee Group and the anomalous elevation of the Mississippian?

According to well-log data, 51.2 m (168 ft) of Mississippian limestone was penetrated at the bottom of the Schmitt No.1 well. If a mistake was made in identifying the Mississippian, the only other limestone of sufficient thickness to be penetrated 51.2 m is the Hunton Group. If the unit logged as Mississippian is actually the Hunton Group, then the Mississippian is absent in this well, and the Cherokee Group is lying unconformably on the

Hunton Group. In the Forest City Basin, Mississippian rocks are present throughout and are overlain unconformably by the Cherokee Group. The contact between the Mississippian and Cherokee rocks ranges from 305 to 366 m (1,000-1,200 ft) below sea level. Where Mississippian rocks are preserved, they are deeper than 122 m (400 ft) below sea level. Generally, above this elevation, Mississippian rocks have been removed by erosion. Therefore, if the base of the Cherokee Group is 686 m (2,251 ft) below sea level, the Mississippian should be present, and has probably been logged correctly in the Schmitt No.1 well.

Another question concerning the well-log data is: Is the thickness of the Cherokee Group correct? Merriam (1963) described the Cherokee Group as all Pennsylvanian beds between the Fort Scott and the top of the "Mississippian lime", except where Atokan rocks are present. The Cherokee consists of shale, sandy shale, sandstone, coal, and minor amounts of limestone. This type of sequence is identified on the sample and electric logs of the Schmitt No.1 well over a vertical distance of 405 m (1,329 ft). If all the rocks logged as Cherokee are not Cherokee, they must be Morrowan or Atokan, inasmuch as they are underlain by Mississippian rocks. The writer believes, therefore, that the well-log data are correct.

Type of Structure

The structure that is responsible for the anomalous thickness and elevations in the Schmitt No.1 well may be one of two things: (1) a large sinkhole, or (2) a fault system.

Subsurface sinkholes in northeast Kansas are most commonly developed in Arbuckle and Mississippian rocks. According to Herndon maps, the Simpson Group is abnormally thick in two wells in sec. 5, T. 11 S., R. 10 E., where thicknesses of 51.8 and 61.3 m (170-201 ft) were logged. The Arbuckle in these two wells is abnormally thin (9.1 and 11.3 m (30 and 37 ft)). The abnormal thicknesses may be due to sinkholes developed in the Arbuckle.

A sinkhole in Mississippian rocks was proposed by Smith and Anders (1951) in the Davis Ranch oil pool in Wabaunsee County, where they reported an abnormal thickness of 128 m (420 ft) of the Cherokee Group. A fault is present in Mississippian and older rocks on the Davis Ranch oil pool. On the upthrown side of the fault the Cherokee Group averages 115.8 m (380 ft) thick, and on the downthrown side of the fault the Cherokee Group is 121.9 to 144.8 m (400-475 ft) thick. A thickness of 128 m of Cherokee rocks does not seem abnormal, and may be due to a thicker sequence of the Cherokee Group on the downthrown side of the fault, rather than a sinkhole.

The largest known sinkholes in Kansas are 48.8 to 82.3 m (160-270 ft) deep and are developed in the Arbuckle Group. In the Bemis pool, Ellis County, Kansas, a sinkhole in the Arbuckle is 82.3 m deep. Of 37 known sinkholes developed in Arbuckle rocks, in Barton County, Kansas, the largest is 49.7 m (163 ft) deep and is filled with Lower Pennsylvanian deposits. The Trapp pool in Russell and Barton counties, Kansas, has 12 known depressions in Arbuckle rocks. The largest of these is 51.2 m (168 ft) deep (Merriam, 1963).

The Cherokee Group in the Schmitt No.1 well is 405 m (1,329 ft) thick. The nearest well, on the east side of the Nemaha Anticline, reveals a thickness of 95.1 m (312 ft) for the Cherokee Group. If the structure near the Schmitt No.1 well is a sinkhole, then a depression 309.9 m (1,017 ft) was developed in the rocks below. The average thickness from Mississippian rocks to the Precambrain, in this area, is approximately 335.3 m (1,100 ft). All of the rocks from the Mississippian to the Precambrian would have to have been removed to produce a sinkhole of this magnitude, which is highly unlikely

Proof that a depression is a sinkhole is provided by the occurrence of untransported residual weathered products from the dolomite. These products include chert fragments, clay, sand, silt, quartz crystals, and shale (Walters, 1946). Occurrence of residual products was not logged in the Schmitt No.1 well, and if 335.3 m (1,100 ft) of rock were dissolved to produce a sinkhole of this magnitude, one would expect to find an abundance of residual material.

The Mississippian was logged at 686 m (2,251 ft) below sea level in the Schmitt No.1 well. The Mississippian is 354 m (1,163 ft) below sea level in a well in sec. 16, T. 12 S., R. 9 E. A sinkhole does not explain the difference in elevation. Therefore, because of the magnitude of the structure, the lack of residual material due to solution removal of dolomite and limestone, and a 331.7 m (1,088 ft) difference, from the Schmitt No.1 well to a nearby well, in the elevation of the Mississippian, the writer concludes that the structure in this area is not a sinkhole.

The structure near the Schmitt No.1 well has been interpreted by Cole (1976), Merriam (1963), and Watney (1978) to be a graben. These authors have all mapped two faults striking approximately N 40° W, and the Schmitt No.1 well is in the middle of the downdropped block. The faults explain the difference in elevation of the Mississippian from the Schmitt well to adjacent wells.

Faults can also explain the abnormal thickness of the Cherokee Group in the Schmitt No.1 well. A large depression could have developed on the downthrown side of a fault near the Schmitt well, and then the depression was filled with sediments producing an abnormally thick sequence. Growth faulting may also have occurred, producing an abnormally thick sequence on the downthrown side of the fault. According to Chapman (1973), growth faulting is common. "Growth faults occur in many--perhaps most, possibly all--sedimentary basins of the world, and in rocks of all ages."

A surface fault was mapped just to the west of the Schmitt No.1 well. The well is on the downthrown side of the fault at the surface and in the subsurface. The surface fault supports the theory that the structure in the subsurface was produced by faulting, the explanation that the writer favors to explain the structure near the Schmitt No.1 well.

Description of Subsurface Structure

Five structure-contour maps were compiled to determine the extent of the fault or faults responsible for the anomalies in the Schmitt No.1 well. Stratigraphic horizons used for these maps were the upper surfaces of the Precambrian, the Hunton Group, the Mississippian limestone, the Lansing Group, and the Heebner Shale. The Precambrian and the Mississippian maps were contoured on erosional surfaces, and show a combination of structure and topography.

Precambrian Structure Map

The Precambrian structure map was compiled from limited data (Fig. 13). Except on the Zeandale Dome, in the north-central part of the area, few wells reached the Precambrian. Wells that did not reach the Precambrian were extrapolated to the Precambrian by adding the average thickness of strata between the Precambrian and the deepest unit logged for the well. On the Precambrian structure map, wells to the Precambrian are marked by dots and wells extrapolated to the Precambrian are marked by x's.

Four faults were mapped on the Precambrian surface (Fig. 13). The

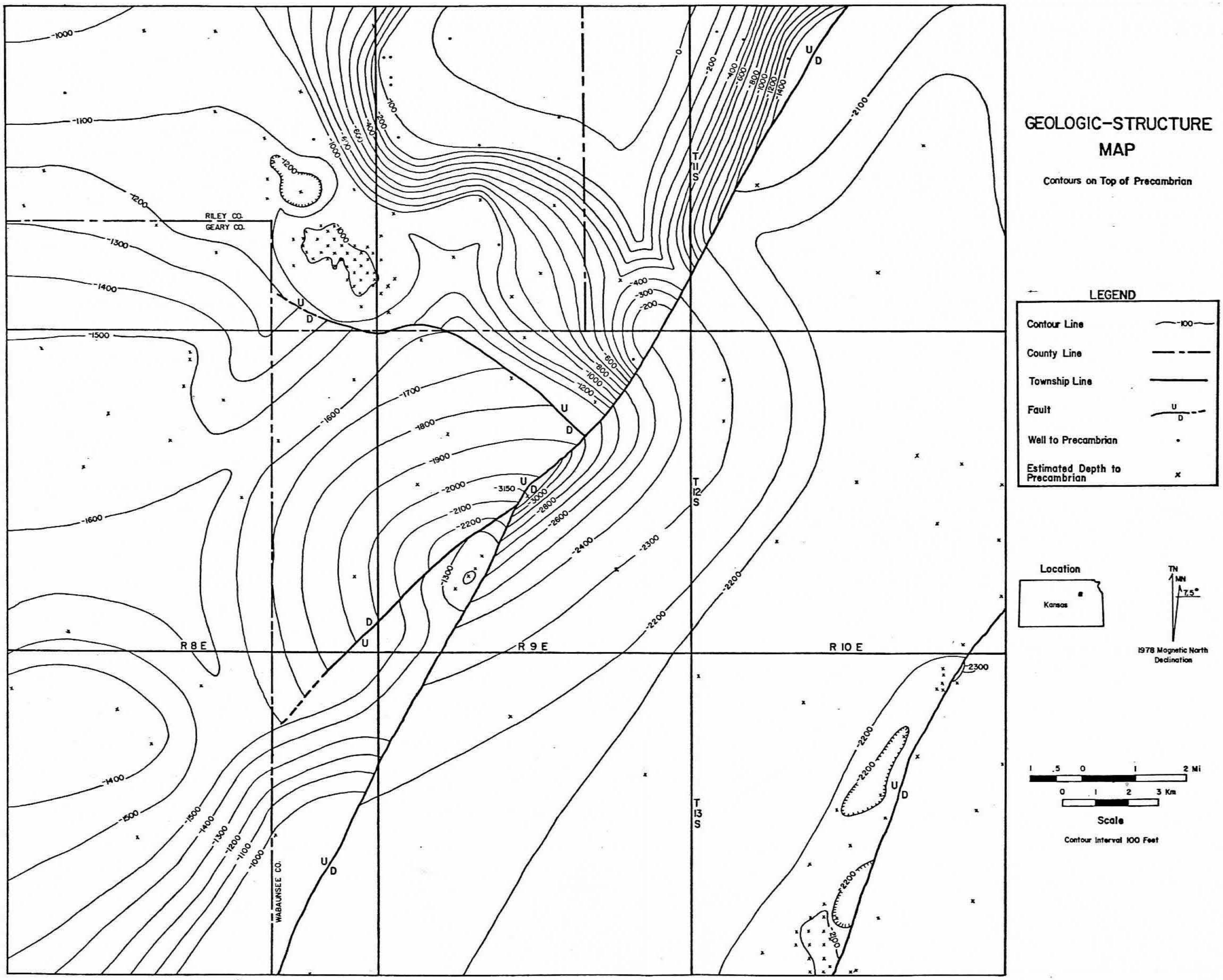

GEOLOGIC-STRUCTURE MAP
Contours on Top of Precambrian
LEGEND
Contour Line
County Line
Township Line
Fault
Well to Precambrian
Estimated Depth to Precambrian
Location
Kansas
1978 Magnetic North Declination
Scale
Contour Interval 100 Feet
RILEY CO.
GEARY CO.
WABAUNSEE CO.
R 8 E
R 9 E
R 10 E
T 11 S
T 12 S
T 13 S

Figure 13

principal (longest) fault extends through the entire area from the southeast corner of T. 13 S., R. 8 E. northeastward through the western half of T. 11 S., R. 10 E. The fault strikes N 25° E to N 30° E (roughly parallel to the axis of the Nemaha Anticline) and is upthrown to the northwest. The maximum vertical displacement along this fault occurs in the northeast corner of T. 12 S., R. 9 E., where a displacement of more than 671 m (2,200 ft) was mapped. The Precambrian in the Schmitt No.1 well, sec. 21, T. 12 S., R. 9 E., was extrapolated to be 960 m (3,150 ft) and is not greater, as one might expect, because the upthrown side is downthrown relative to two other fault blocks that will be described later. The main fault is probably vertical, or nearly so, because a fault mapped at the surface, directly above the subsurface fault, is probably a continuation of the subsurface fault.

Two smaller faults branch off the main fault. One is approximately 11.3 km (7 ft) long, extends from sec. 10, T. 12 S., R. 9 E. northwestward into the southeast corner of T. 11 S., R. 8 E., and has its upthrown side to the northeast. This fault strikes N 50° W to N 65° W. Maximum displacement of 183 m (600 ft) occurs along the fault at the southeast end where it is truncated by the main northeasterly-trending fault.

The other fault branching off the main fault is subparallel to it. The fault is approximately 9.7 km (6 mi) long, strikes N 40° E to N 50° E, and extends from the middle of T. 12 S., R. 9 E. southwestward through the southeast corner of T. 12 S., R. 8 E. and into the northeast corner of T. 13 S R. 8 E. Maximum displacement along this fault is 289.6 m (950 ft) near the northeast end of the fault where it is truncated by the main fault.

The structure on the southeast side of the main fault, near the Schmitt No.1 well, is a basin that is truncated on the northwest side by the main fault. This basin is probably related to the fault and may be a result of the fault. The two smaller faults that branch off the main fault form a graben that is truncated by the main fault on the southeast side. The basin moved down relative to the graben. Dips on the northwest side of the main fault are to the southeast, and dips on the southeast side of the fault are to the northwest. The geologic map of western Wabaunsee County (Fig. 8) shows a similar relationship. Dips on the northwest side of the fault mapped in sections 15, 16, and 21 are toward the fault, and dips on the southeast side of the fault are to the northwest.

Another fault was mapped in the eastern half of T. 13 S., R. 10 E., and the southeast corner of T. 12 S., R. 10 E. This fault cuts the east flank of the Alma Anticline and was previously mapped by Smith and Anders (1951), Merriam (1963), and Sternin (1961). This fault strikes N 20° E to N 25° E, is upthrown to the northwest, and has a maximum vertical displacement (on the Precambrian surface) of 38.1 m (125 ft).

The most prominent high (probably both structural and erosional) is the Zeandale Dome in the north-central part of the map. The Precambrian on the crest of the dome is within less than 305 m (1,000 ft) of the surface. Closure on the Zeandale Dome is approximately 183 m (600 ft) (Koons, 1955).

Hunton Structure Map

The structure map of the Hunton Group is similar to the Precambrian structure map (Fig. 14). The elevation of the Hunton Group in the Schmitt No.1 well was interpolated the same way as much of the Precambrian. Maximum displacement along the main fault is 366 m (1,200 ft). Near the Schmitt No.1 well, the displacement on the main fault is 335 m (1,100 ft), the same as mapped on the Precambrian.

The northwest-trending fault branching off the main fault has a maxi-

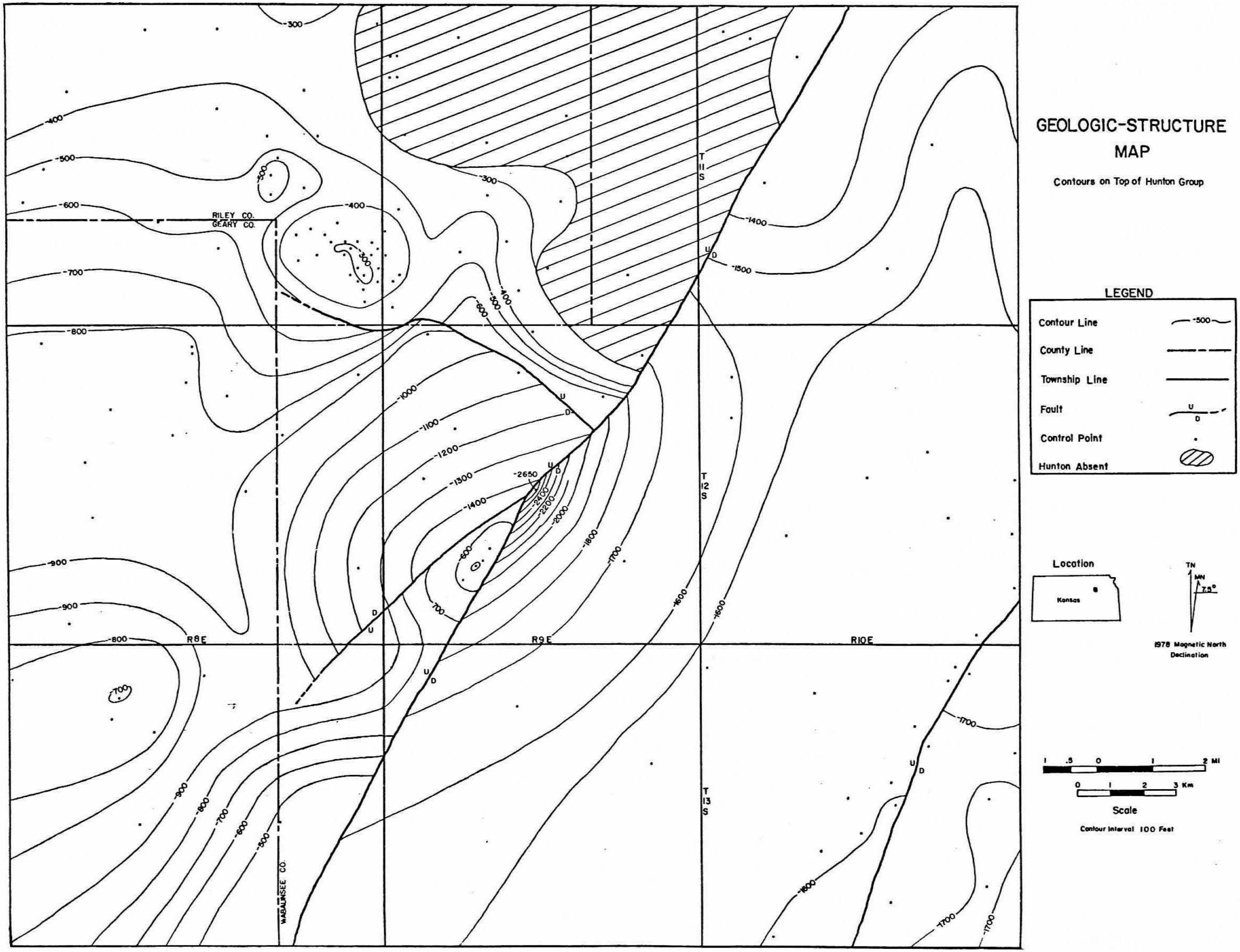

GEOLOGIC-STRUCTURE MAP
Contours on Top of Hunton Group
LEGEND
Contour Line
County Line
Township Line
Fault
Control Point
Hunton Absent
Location
Kansas
TN
MN
7.5°
1978 Magnetic North Declination
Scale
Contour Interval 100 Feet
RILEY CO.
GEARY CO.
WABAUNSEE CO.
R8E
R9E
R10E
T 11 S
T 12 S
T 13 S

Figure 14

mum displacement of 183 m (600 ft) near the southeast end of the fault. The southwest-trending fault branching off the main fault has a maximum displacement of 213 m (700 ft) near the northeast end of the fault. The fault that cuts the Alma Anticline in T. 12 S., R. 10 E., has a displacement of 15.2 m to 22.9 m (50-75 ft).

Much of the Hunton Group on the Zeandale Dome was removed by erosion in post-Mississippian pre-Desmoinesian time. The Hunton Group is absent against the fault, in part of T. 11 S., ranges 8, 9, and 10 east, and T. 12 S. R. 9 E. (Fig. 14). The writer believes that the upthrown side of the fault raised Hunton rocks to a height sufficient for them to have been eroded. Generally, above 91.4 m (300 ft) below sea level, Hunton rocks have been removed by erosion.

Mississippian Structure Map

The structure map on the top of the Mississippian still shows the faults mapped on the Hunton and the Precambrian surfaces (Fig. 15). On this map, however, maximum displacement along the main fault occurs near the Schmitt No.1 well, and is approximately 366 m (1,200 ft). Displacements on the smaller faults that branch off the main fault are smaller than on the Hunton and Precambrian surfaces. The northwest-trending fault has a maximum displacement of 91 m (300 ft), and the southwest-trending fault has a maximum displacement of 137 m (450 ft). The fault in T. 12 S., R. 10 E. and T. 13 S., R. 10 E. can be identified in two places along the fault trace where displacements of 15 to 23 m (50-75 ft) occur. Elsewhere along the strike of the fault trace, differences in elevations on the Mississippian are so small as to make the presence of a fault there uncertain. Therefore, a dashed line is drawn for this portion of the fault trace.

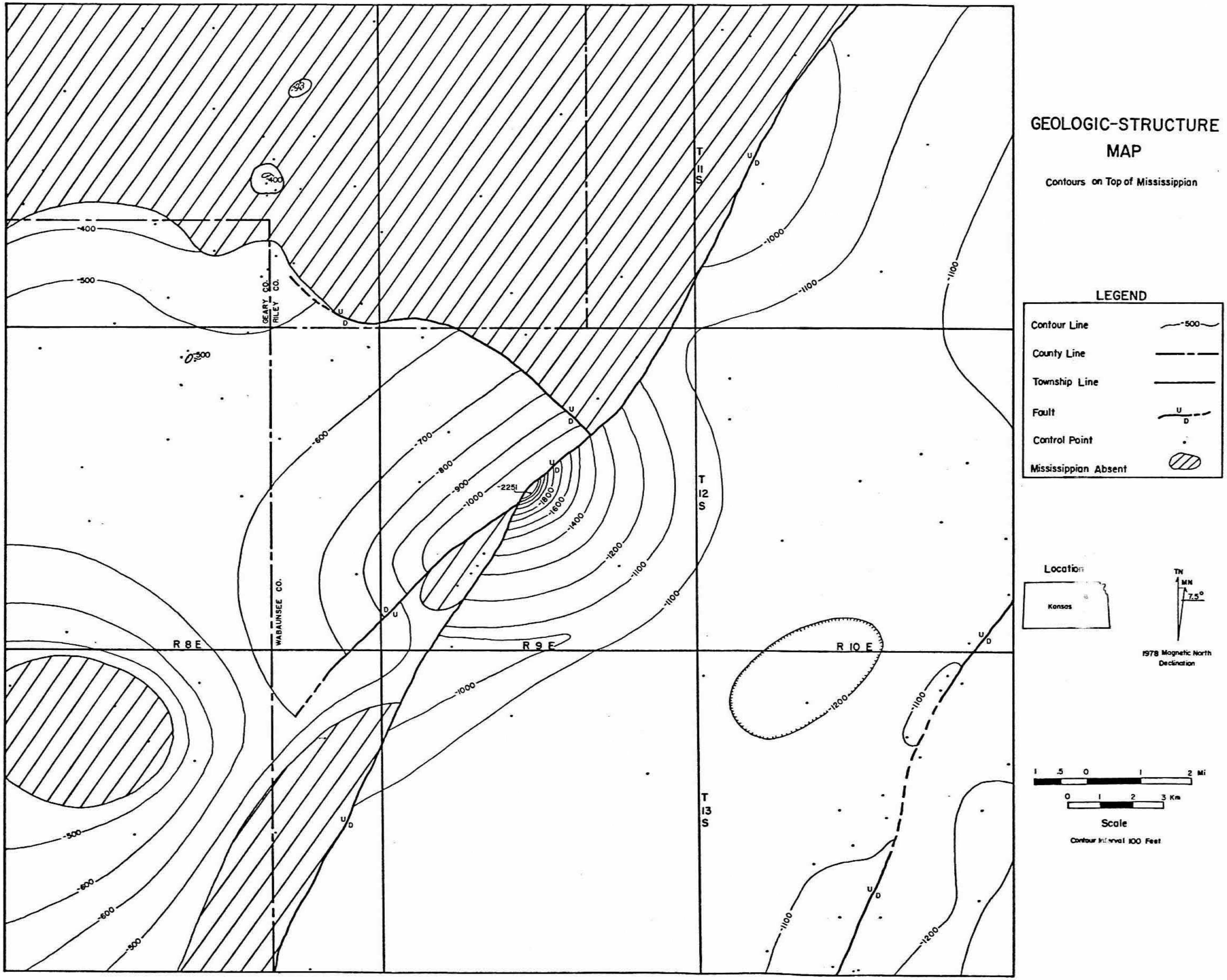

GEOLOGIC-STRUCTURE
MAP
Contours on Top of Mississippian
LEGEND
Contour Line
County Line
Township Line
Fault
Control Point
Mississippian Absent
Kansas
1978 Magnetic North Declination
Scale
Contour Interval 100 Feet
GEARY CO.
RILEY CO.
WABAUNSEE CO.
R 8 E
R 9 E
R 10 E
T 11 S
T 12 S
T 13 S

Figure 15

The nature of the structure on the east flank of the Nemaha Anticline has long been a subject of debate (Lee, 1943). Lee compiled an isopachous map of Mississippian limestone that included a fault along the east flank of the Nemaha Anticline from the Nebraska-Kansas border, in Nemaha County, Kansas, to Chase County, Kansas. Thirteen years later, Lee (1956) constructed a cross section from T. 11 S., R 8 E. to T. 11 S., R. 10 E. This time, Lee did not place a fault along the east flank of the Nemaha Anticline and wrote that the impulse to assume faulting on the east limb of the anticline is checked by redrawing the cross section with equal vertical and horizontal scales.

Thomas (1927), Lee (1943), Koons (1955), Gasaway (1959), and Muehlberger and others (1967) postulated a fault extending through Wabaunsee County. Farquhar (1957) compiled a structure map of the Precambrian in Kansas that contained no fault.

In 1960, Merriam compiled a structure map on the Mississippian surface in Kansas (Fig. 16). Sternin (1961) compiled a structure map on the Mississippian surface in Geary and Morris counties, Kansas, and Baysinger (1963) compiled a structure map on the Mississippian surface in Riley, Geary, and Wabaunsee counties, Kansas. None of the structure maps included a fault along the east flank of the Nemaha Anticline. Baysinger did map a local fault near the Schmitt No.1 well in T. 12 S., R. 9 E. All of these maps show areas where Mississippian rocks are absent, including, on the east side, an area where Mississippian rocks are absent at elevations as low as 274 to 366 m (900-1,200 ft) below sea level. On the west side of the area in Morris, Geary, and Riley counties, Mississippian rocks are absent at elevations above 152 m (500 ft) below sea level, for the most part. Some Mississippian rocks were logged as high as -99 m (-325 ft).

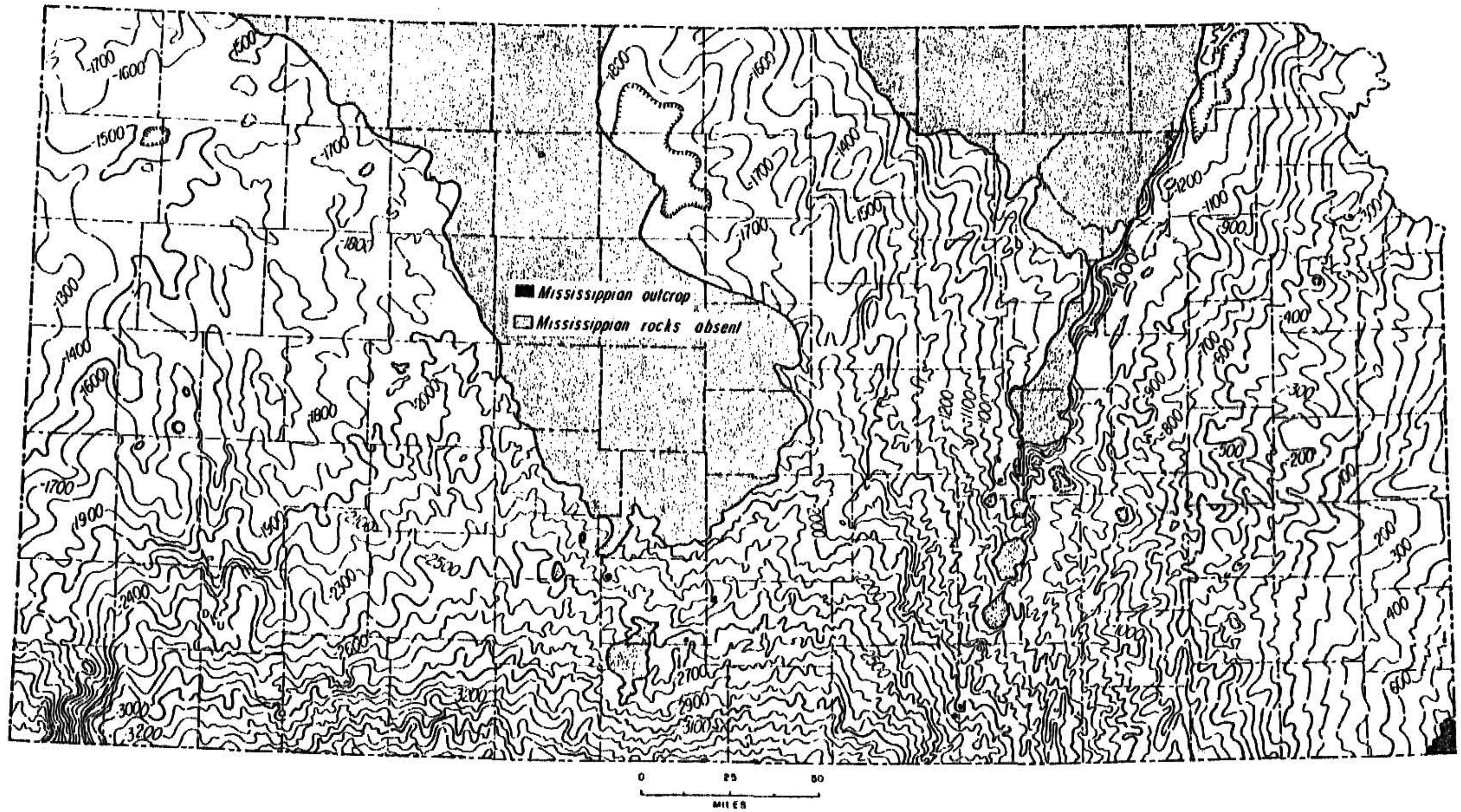


Figure 16. Geologic structure map on the Mississippian surface. Contour interval 100 ft (Merriam, 1963)

Why would Mississippian rocks be removed by erosion at -366 m and be preserved at -99 m? This can be explained by the faults shown in Figure 15. These faults were first mapped by elevation differences alone; later, the Mississippian structure map was compiled. On this map, a structural high, an upthrown side of a fault, or both, are present where Mississippian rocks are absent. Where Mississippian rocks are preserved, they are at elevations lower than 122 m (400 ft) below sea level. Generally, above this elevation, Mississippian rocks have been removed by erosion. Therefore, areas where Mississippian rocks are absent do not extend to elevations of -274 to -366 m, but are on the upthrown side of a fault or on structural highs at elevations of -122 m (-400 ft) or higher.

The preceding argument gives much support to the idea that faulting has occurred at least from the Nebraska-Kansas border, in Nemaha County, Kansas, through western Wabaunsee County, Kansas.

Lansing Structure Map

The structure map on the surface of the Lansing Group shows the same structure near the Schmitt No.1 well as the Mississippian, Hunton, and Precambrian structure maps (Fig. 17). Examination of the Lansing structure map reveals a vertical displacement of 99 m (325 ft) along the main fault, which is much less than the vertical displacement in Mississippian and older rocks. The three faults are shown dashed along much of their length because their presence is questionable at this horizon. The fault near the Schmitt No.1 well is not dashed and is thought to be present because a fault with the same trend was mapped at the surface near the Schmitt well. The underlying fault does not appear to cut this horizon on the Alma Anticline in T. 13 S., R. 10 E.

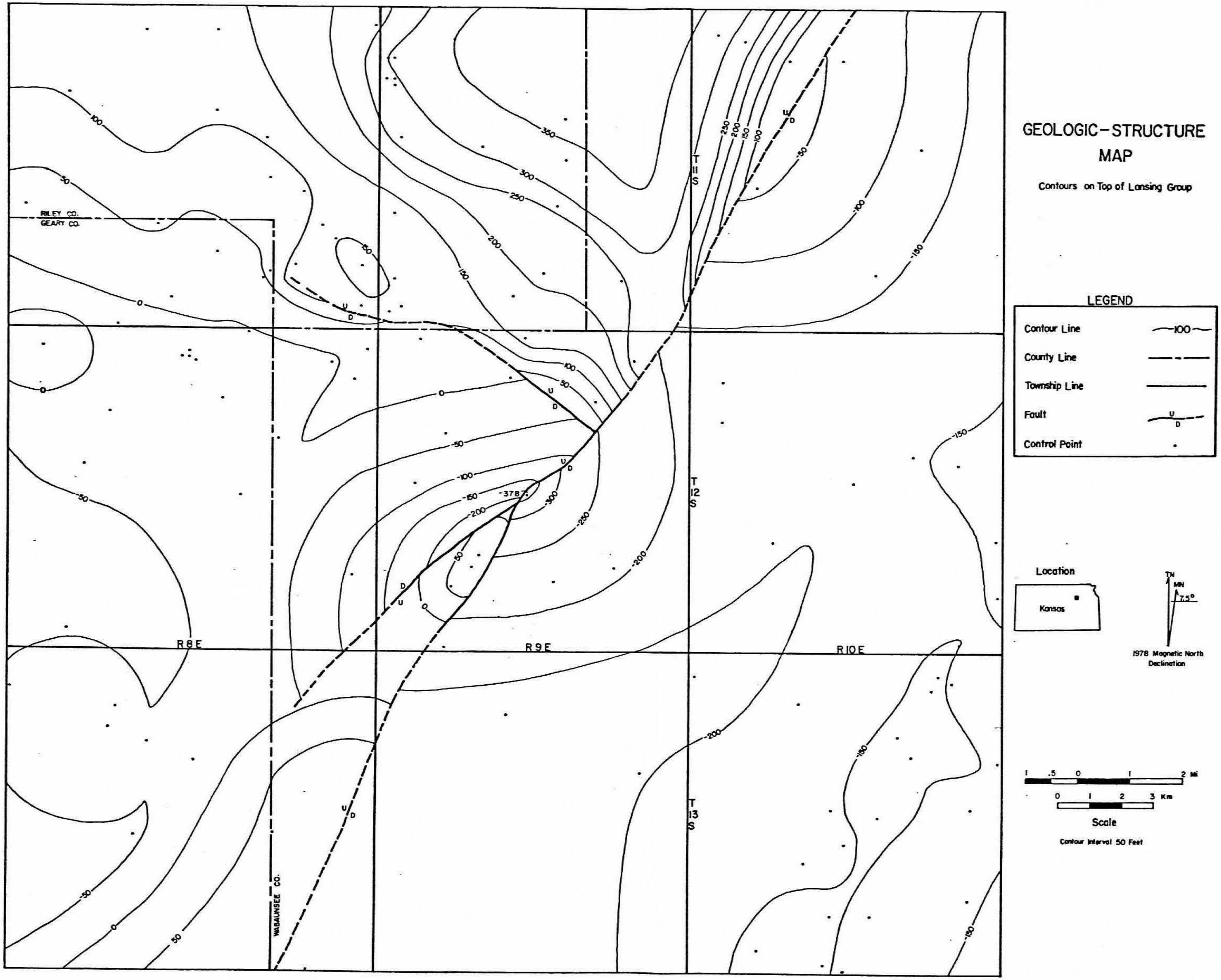

GEOLOGIC-STRUCTURE MAP
Contours on Top of Lansing Group
LEGEND
Contour Line
County Line
Township Line
Fault
Control Point
Location
Kansas
1978 Magnetic North Declination
Scale
Contour Interval 50 Feet
RILEY CO.
GEARY CO.
WABAUNSEE CO.
R8E
R9E
R10E
T 11 S
T 12 S
T 13 S
-3787

Figure 17

Heebner Structure Map

The Heebner structure map is similar to the Lansing structure map (Fig. 18). Again, the faults are shown dashed over much of their length because their presence is questionable. The fault near the Schmitt No.1 well is not dashed because of the surface fault mapped near the Schmitt well. Maximum displacement along the main fault is 76 m (250 ft). Figure 19 is a cross section compiled from well log data, showing structural and stratigraphic relationships across two of the faults from the Precambrian to the Heebner Shale.

Time of Faulting

Two isopachous maps were compiled to help determine time of faulting. The stratigraphic intervals used were: (1) the "Base of the Kansas City Group to the Mississippian unconformity, and (2) the top of the Kansas City Group to the "Base" of the Kansas City Group.

Isopachous Maps

The isopachous map from the "Base" of the Kansas City Group to the Mississippian unconformity suggests that thickness of this interval was controlled by faulting (Fig. 20). Thickness of this interval is greater on the downthrown sides of the faults than on the upthrown sides. In the Schmitt No.1 well, this interval is 457 m (1,498 ft) thick, much greater than anywhere else in the area. Therefore, faulting occurred before or during deposition of this interval.

The isopachous map from the top of the Kansas City Group to the "Base" of the Kansas City Group shows no relationship of thickness to faults (Fig. 21). Thicknesses of strata are relatively uniform in thickness

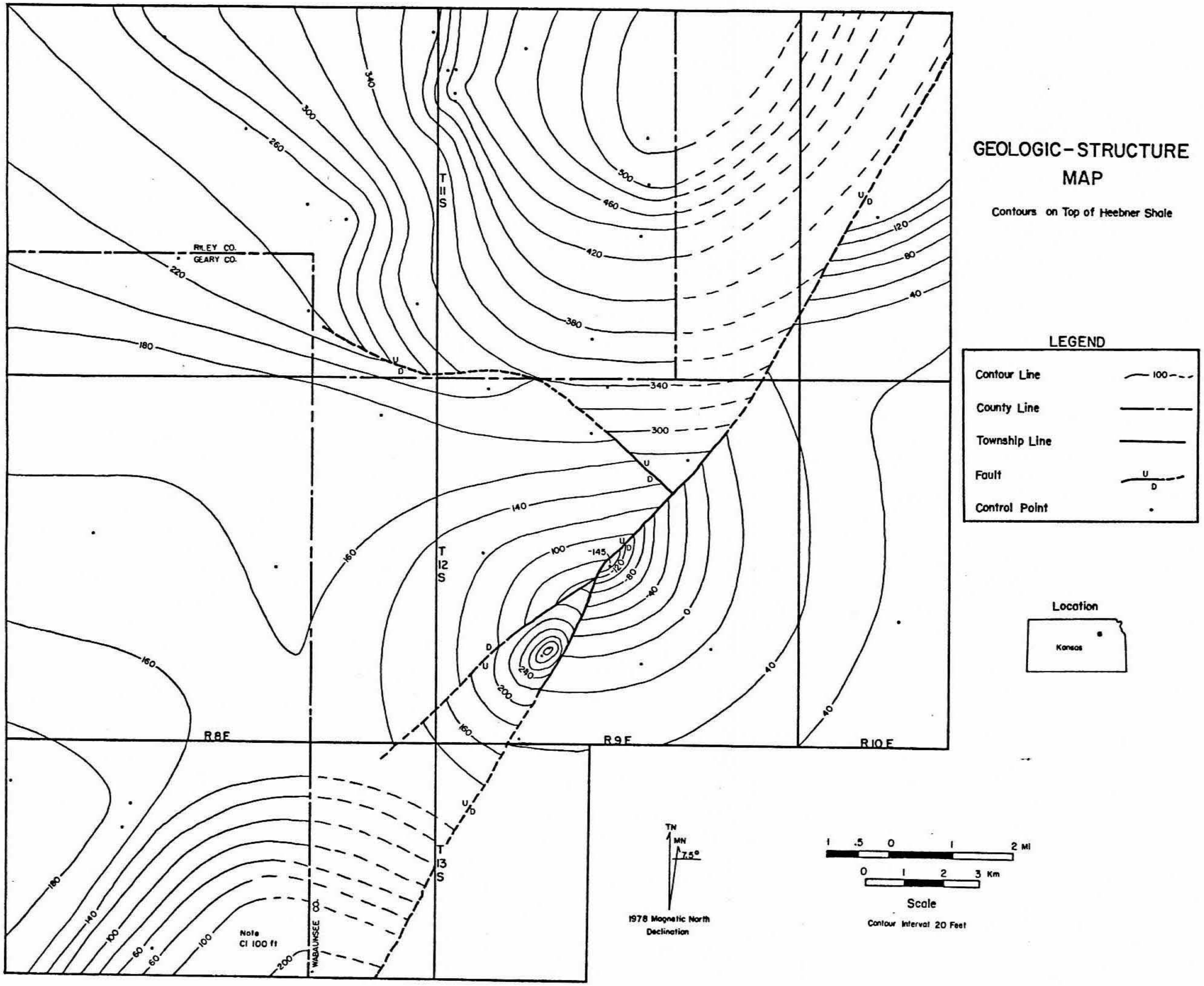

GEOLOGIC-STRUCTURE MAP
Contours on Top of Heebner Shale
LEGEND
Contour Line
County Line
Township Line
Fault
Control Point
Location
Kansas
RILEY CO.
GEARY CO.
WABAUNSEE
T 11 S
T 12 S
T 13 S
R8E
R9E
R10E
Note CI 100 ft
1978 Magnetic North Declination
Scale
Contour Interval 20 Feet

Figure 18

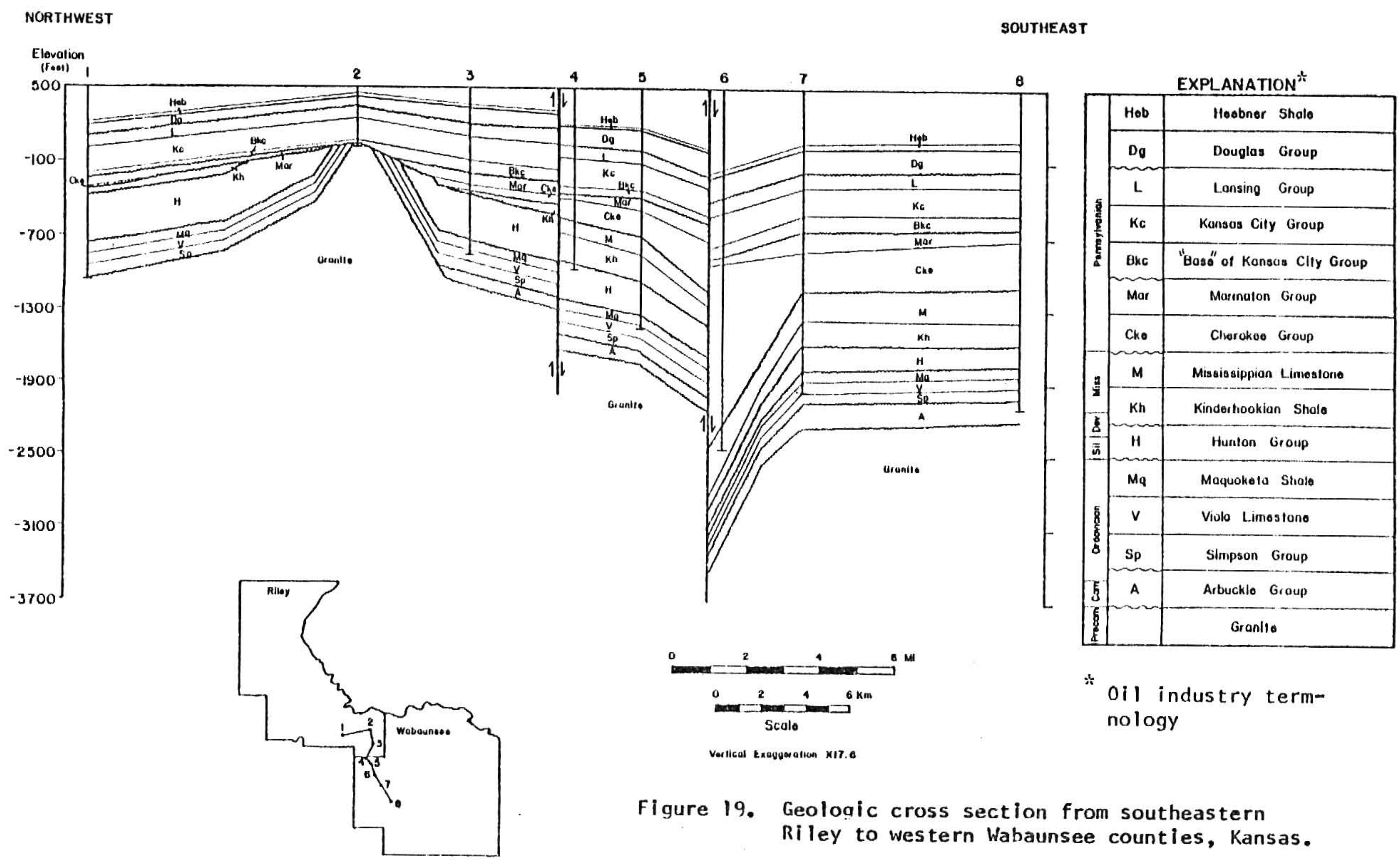


Figure 19. Geologic cross section from southeastern Riley to western Wabaunsee counties, Kansas.


ISOPACHOUS MAP
Thickness from the Base of the Kansas City Group to the Mississippian Unconformity
LEGEND
Contour Line
200
County Line
Township Line
Fault
U
D
Control Point
Location
Kansas
TN
MN
7.5°
1978 Magnetic North Declination
1 .5 0 1 2 Mi
0 1 2 3 Km
Scale
Contour Interval 50 Feet
Riley Co.
Geary Co.
Wabaunsee Co.
R8E
R9E
R10E
T 11 S
T 12 S
T 13 S

Figure 20

across the faults. Because the faults are present, but do not affect the thickness of the Kansas City Group, deposition of the Kansas City Group must have occurred during an inactive period in the history of the fault. Younger rock units show the same relationship between thickness and faults.

From the structure and isopachous maps, it can be determined that most of the faulting occurred prior or during deposition of the interval from the "Base" of the Kansas City Group to the Mississippian unconformity. Structure maps show maximum vertical displacements on the main fault to be 671 m (2,200 ft) and 366 m (1,200 ft) on the Precambrian and Mississippian surfaces respectively. Younger strata (Lansing Group and Heebner Shale) have maximum vertical displacements along the main fault of 99 m (325 ft) or less. Younger strata are relatively uniform in thickness across the fault, suggesting deposition of the strata occurred between episodes of active faulting

Advance of the Pennsylvanian sea into Oklahoma and Kansas was investigated by Weirich (1953). Figure 22 shows the shoreline of the sea during the time of deposition of the lower Cherokee and the middle Cherokee. The lower Cherokee shoreline is restricted to southeast Kansas. During deposition of the middle Cherokee, the shoreline extended to the east side of the Nemaha Anticline, which was probably a fault scarp over much of its length.

Structural development of the Nemaha Anticline occurred mainly in post-Mississippian pre-Desmoinesian time with minor amounts of deformation continuing to the present (Merriam, 1963; Lee, 1943, 1956). Because most of the deformation along the Nemaha Anticline, in the area covered in this investigaiton, occurred before the advancement of the sea that deposited the middle Cherokee in this area, one of two things can explain the abnormal thickness of the Cherokee Group in the Schmitt No.1 well: (1) Faulting later than Mississippian and earlier than deposition of the middle Cherokee

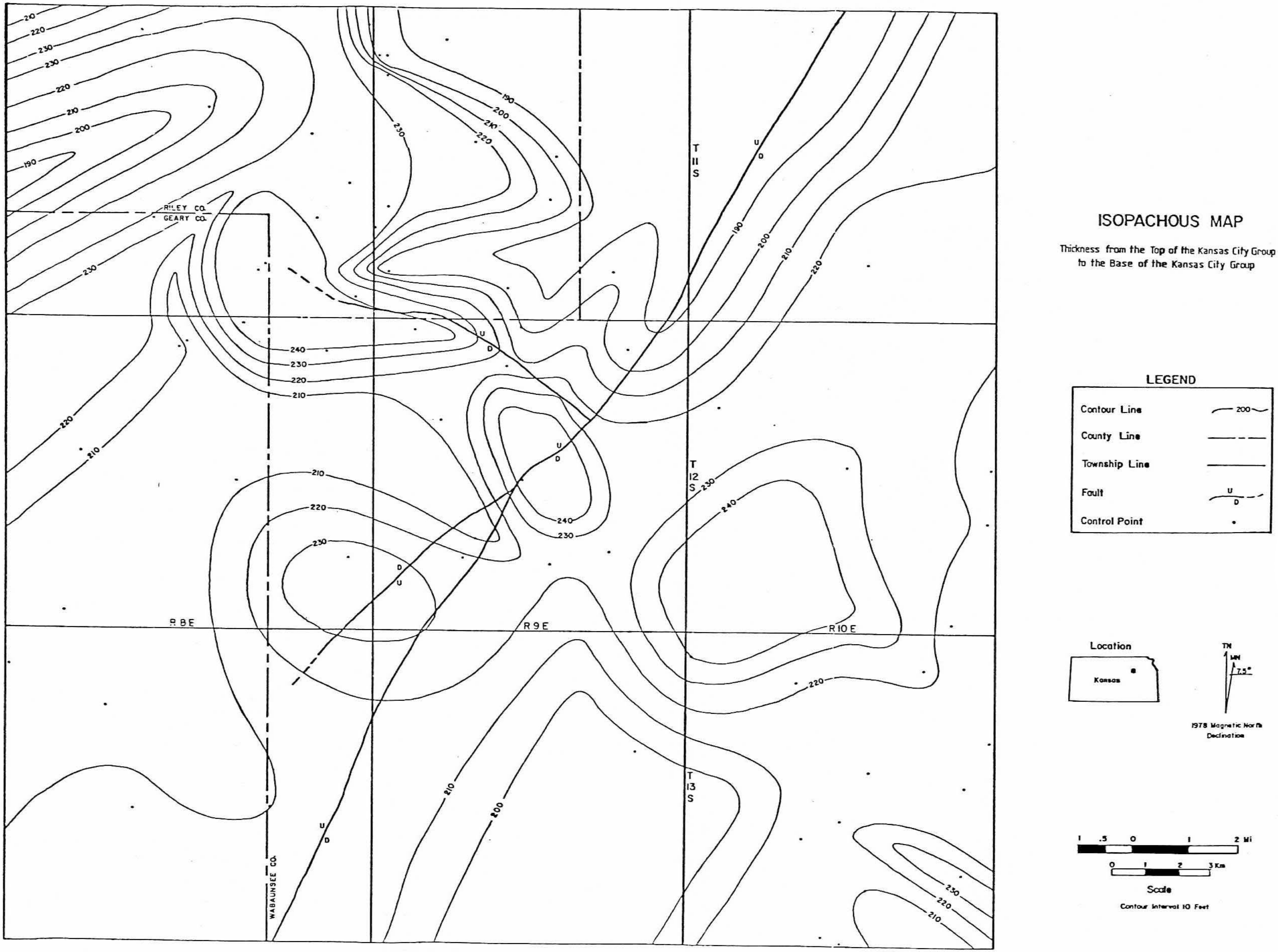

ISOPACHOUS MAP
Thickness from the Top of the Kansas City Group to the Base of the Kansas City Group
LEGEND
Contour Line
200
County Line
Township Line
Fault
U
D
Control Point
Location
Kansas
TN
MN
7.5°
1978 Magnetic North Declination
1 .5 0 1 2 Mi
0 1 2 3 Km
Scale
Contour Interval 10 Feet
RILEY CO.
GEARY CO.
WABAUNSEE CO.
T 11 S
T 12 S
T 13 S
R 8 E
R 9 E
R 10 E
190
200
210
220
230
240

Figure 21

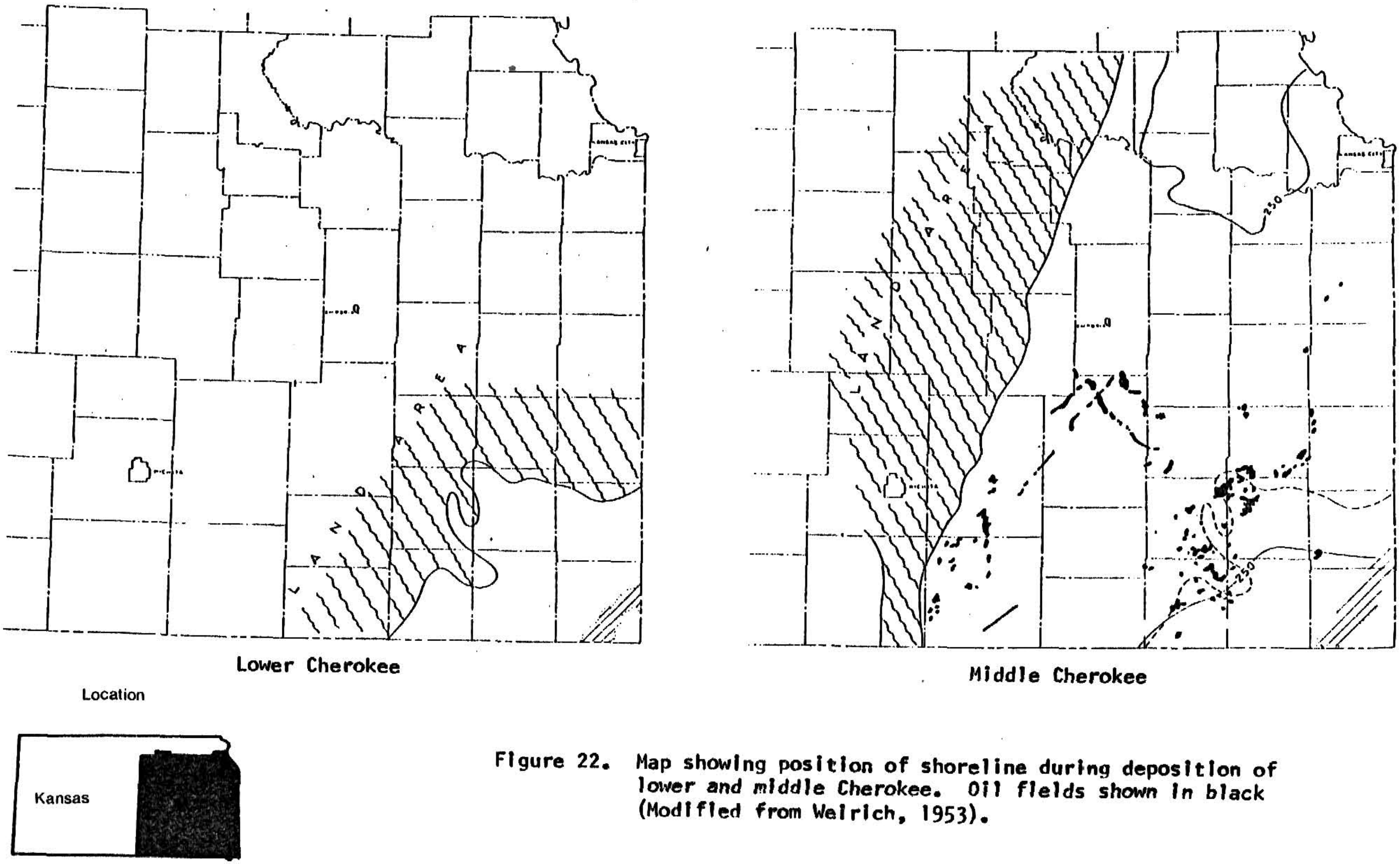


Figure 22. Map showing position of shoreline during deposition of lower and middle Cherokee. Oil fields shown in black (Modified from Weirich, 1953).

produced a large depression that was filled with little or no sediment until the advancement of the sea that deposited the middle Cherokee. (2) Faulting during this same period of time was accompanied by deposition of sediments from the adjacent Nemaha Anticline on the downthrown side of the fault (growth faulting).

Extensive erosion of Mississippian and older rocks occurred on the Nemaha Anticline in post-Mississippian pre-late Cherokee time. It seems highly unlikely that a large closed depression adjacent to the anticline would not receive much sediment from the anticline. A better explanation would be that faulting occurred in post-Mississippian pre-middle Cherokee time, not as one diastrophic movement, but in smaller increments over much of this time. Mississippian and older rocks were eroded from the Nemaha Anticline and deposited on the downthrown side of the fault simultaneously with the faulting, producing a thick sequence of pre-middle Cherokee sediments, that are overlain by middle and upper Cherokee sediments.

Time of faulting near the Schmitt No.1 well may be narrowed down by examination of the interval from the top of the "Base" of the Kansas City Group to the Mississippian unconformity. Gamma-ray logs of the upper part of the Cherokee Group in the Schmitt No.1 well, sec. 21, T. 12 S., R. 9 E., and the Humphries No.1 well, sec. 32, T. 12 S., R. 9 E., show a good correlation of rock units (Fig. 23). The upper part of the Cherokee in the Schmitt well, however, is thicker than the upper part of the Cherokee in the Humphries well. The greater thickness can be explained by growth faulting, that is, faulting was occurring during deposition of the upper Cherokee, producing a thicker sequence on the downthrown side of the fault.

Little difference is noted in the thickness of the interval from the "Base" of the Kansas City Group to the Cherokee Group in the two wells

(Fig. 23), indicating that faulting ceased during deposition of this interval. Faults do cut the "Base" of the Kansas City Group, but faulting must have occurred after deposition.

A post-Mississippian pre-Kansas City sequence of events near the Schmitt No.1 well may have been as follows:

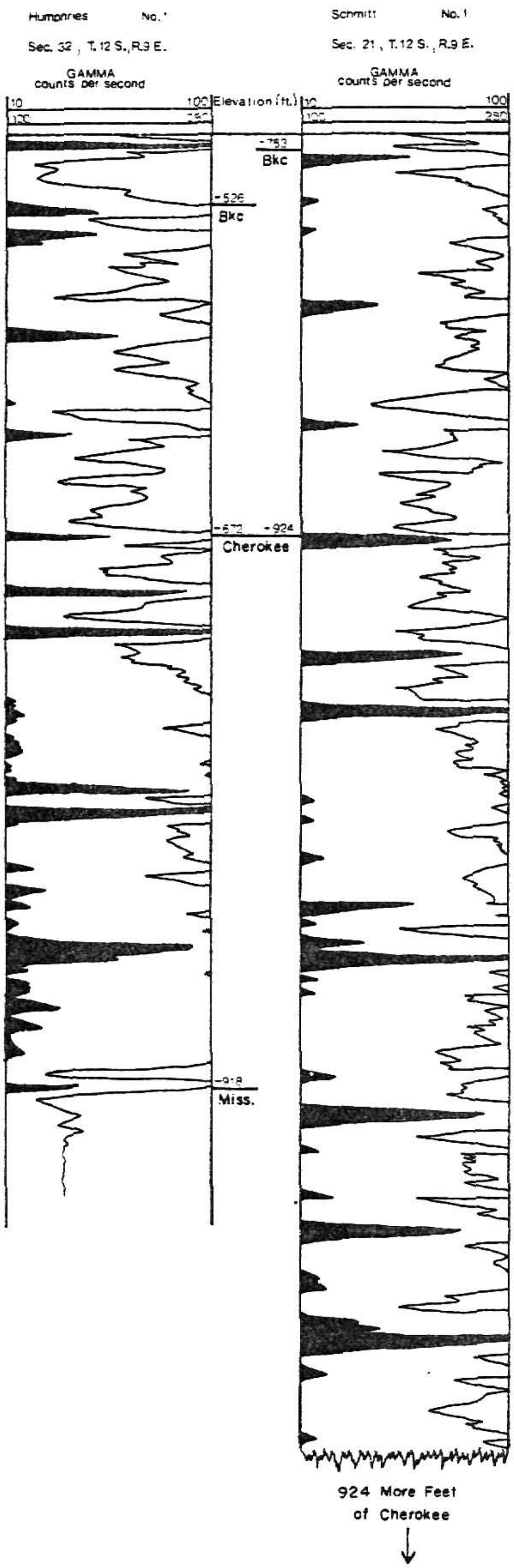
1. Post-Mississippian pre-middle Cherokee faulting occurred simultaneously with deposition of pre-middle Cherokee sediments, eroded from the Nemaha Anticline, on the down thrown side of the fault.

2. In middle Cherokee time, the Pennsylvanian sea abutted against the Nemaha Anticline (Fig. 22). Middle Cherokee sediments were deposited on pre-middle Cherokee sediments on the downthrown side of the fault. Minor faulting was probably still occurring at this time.

3. In late Cherokee time, the Pennsylvanian sea covered much of the Nemaha Anticline. Comparison of upper Cherokee rocks from the Schmitt No.1 well to the Humphries No.1 well indicate that growth faulting was still occurring (Fig. 23).

4. Comparison of these same two wells indicates that growth faulting has ceased near the time of deposition of the uppermost part of the Cherokee Group.

5. Deposition of the interval from the "Base" of the Kansas City Group to the Cherokee Group occurred, followed by faulting.



GAMMA - RAY
CURVES

Figure 23. Gamma-ray logs showing correlation of the Cherokee Group and the "Base" of the Kansas City Group in the Schmitt No.1 and Humphries No.1 wells.

RELATIONSHIP BETWEEN SURFACE AND SUBSURFACE FAULTS

Only one surface fault can be directly related to a fault in the subsurface. The fault in sec. 15, 16, and 21 T. 12 S., R. 9 E. (Fig. 8) is the surface expression of the main fault mapped in the subsurface. Both faults have a similar strike and their downthrown side to the southeast. The surface fault is directly above the subsurface fault near the Schmitt No.1 well.

The other three surface faults in western Wabaunsee County may, or may not, be directly related to the subsurface faults. The northeast-trending fault in sec. 29, R. 12 S., R. 9 E. has a similar trend and location as the smaller northeast-trending subsurface fault. Both surface and subsurface faults in this area produce an upthrown block bounded by at least two faults. A major difference exists between the three surface faults and the subsurface faults directly below. Two of the surface faults strike nearly perpendicularly to the subsurface faults and match the subsurface regional trend. All of the faults in western Wabaunsee County are at angles to the joint sets. This suggests that the strike of the faults are controlled not by the joints, but by something else, possibly the subsurface trends, including joints or faults in the basement.

The surface faults in southeastern Riley County are parallel to the northwest-trending joint set and are post-Kansan in age. This suggests that these faults are controlled by the joint pattern and may not have a direct relationship with the subsurface faults.

RELATIONSHIP BETWEEN FAULTS AND SEISMICITY

Figure 2 shows the locations of epicenters of historical earthquakes, and epicenters of microearthquakes that have occurred from December 1, 1977 to February 11, 1980. Many of the earthquakes in Figure 2 are along the Nemaha Anticline. Two microearthquakes have occurred in Wabaunsee County since November 2, 1978, and one microearthquake occurred in southeastern Geary County on August 2, 1979.

The epicenter of the microearthquake that occurred in northwest Wabaunsee County is just northeast of the area covered by this report, along the trend of the main subsurface fault. The microearthquake that occurred in southwest Wabaunsee County is along the trend of the fault that cuts the east flank of the Alma Anticline. A fault was mapped by Cole (1976) on the Precambrian 8.5 km (5.3 mi) southeast of the microearthquake epicenter in southeastern Geary County. In January, 1978, a well was drilled in sec. 35, T. 13 S., R. 8 E. that encountered Precambrian wash at an elevation of -626 m (-2,055 ft). Because of this new information, the main fault on the subsurface maps was shifted 3.5 km (2.2 mi) northwest, closer to the earthquake epicenter.

No recent microearthquakes have been recorded near any of the surface faults mapped in the area of investigation. However, three historical earthquake epicenters (Fig. 2) are in southeast Riley County. Although the surface faults in southeast Riley County are post-Kansan, there is no evidence at the surface of modern movement.

The three microearthquakes mentioned above are on, or near, known subsurface faults, and together with other microearthquakes and historical earthquakes that have occurred along the Nemaha Anticline, suggest that the area of investigation along the Nemaha is still active today.

CONCLUSIONS

A subsurface fault is mapped along the east flank of the Nemaha Anticline extending northeast-southwest through the entire area covered by this report. The geologic structure map on the Mississippian surface strongly supports the existence of a fault on the east flank of the Nemaha Anticline instead of an area of steep dip. Where Mississippian rocks are preserved, they are at elevations lower than 122 m (400 ft) below sea level. Generally, above this elevation, Mississippian rocks have been removed by erosion.

The anomalous elevation of -686 m (-2,251 ft) on the Mississippian surface and the abnormal thickness of the Cherokee Group in the Schmitt No.1 well is best explained by growth faults. Growth faulting occurred from post-Mississippian through the time of deposition of the Cherokee Group. The fault near the Schmitt well was mapped all the way to the surface, but relatively uniform thicknesses of Paleozoic units younger than the Cherokee Group indicate that most of the faulting occurred before and after their deposition.

The surface fault near the Schmitt No.1 well is directly related to the main subsurface fault, and extends from the Precambrian to the surface. The other three surface faults mapped in Wabaunsee County may be related to the subsurface faults. One of the three surface faults has a strike similar to the subsurface faults. The three surface faults produce a structure similar to the structure produced by two faults directly below in the subsurface. All the surface faults in Wabaunsee County strike at angles to the joint pattern, indicating little or no control of the faults' trends by the joints. The surface faults in southeast Riley County parallel the northwest-trending joint set. The strikes of these faults are controlled by the joints and probably not controlled by subsurface faults.

Three microearthquakes have occurred in, or near, the area investigated in this report since November 2, 1977. Locations of historical earthquake and recent microearthquake epicenters indicate that the area covered by this investigation is still active today.

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REFERENCES CITED

Algermissen, S.T., 1969, Seismic risk studies in the United States; Proceedings of the Fourth World Conference on Earthquake Engineering, v. 1, p. 14-27, Santiago, Chile-NOAA reprint.

Baysinger, B.L., 1963, A magnetic investigation of the Nemaha Anticline in Wabaunsee, Geary, and Riley counties, Kansas: Unpub. M.S. thesis, Kansas State Univ., 47p.

Branson, E.B., 1944, The geology of Missouri: The University of Missouri Studies, V. 19, no. 3, 535p.

Bruton, R.L., 1958, The geology of a fault area in southeast Riley County, Kansas: Unpub. M.S. thesis, Kansas State Univ., 44p.

Chapman, R.E., 1973, Petroleum geology; a concise study: New York, Elsevier Scientific Publishing Company, 304p.

Cole, V.B., 1976, Configuration of the top of Precambrian rocks in Kansas: Kansas Geol. Survey Map no. M-7, scale 1:500,000.

Coombs, V.B., 1948, The structural geology of the Cottonwood Limestone in Riley County, Kansas: Unpub. M.S. thesis, Kansas State Univ., 26p.

DuBois, S.M., 1978, The origin of surface lineaments in Nemaha County, Kansas: USNRC report NUREG/CR-0321. Available from National Technical Information Service, Springfield, Virginia 22161, 36p.

DuBois, S.M., and Wilson, F.W., 1978, A revised and augmented list of earthquake intensities for Kansas, 1867-1977: Environmental Geology Series 2, Kansas Geol. Survey and USNRC report, NUREG/CR-0294, 56p.

Farquhar, O.C., 1957. The Precambrian rocks of Kansas: Kansas Geol. Survey Bull. 127 pt. 3, p. 53-122.

Gasaway, M.A., III, 1959, Surface expression of the Nemaha Anticline in southeastern Riley County and northwestern Wabaunsee County, Kansas: Unpub. M.S. thesis, Kansas State Univ., 74p.

Jewett, J.M., 1941, The geology of Riley and Geary counties, Kansas: Kansas Geol. Survey Bull. 39, 164p.

Koons, D.L., 1955, Faulting as a possible origin for the formation of the Nemaha Anticline: Unpub. M.S. thesis, Kansas State Univ., 33p.

Lee, W., 1943, The stratigraphy and structural development of the Forest City Basin in Kansas: Kansas Geol. Survey Bull. 51, 142p.

_______, 1954, Earthquakes and the Nemaha Anticline: Am. Assoc. Pet. Geol. Bull., V. 38, no. 2, p. 338-340.

_______, 1956, Stratigraphy and structural development of the Salina Basin area: Kansas Geol. Survey Bull. 121, 167p.

Melton, F.A., 1974, Unpub. map of circular anomalies and lineaments, identified on ERTS images, of Nemaha Arch-Forest City Basin area: scale 1:250,000, prepared for John E. Brewer, petroleum consultant.

Merriam, D.F., 1956, History of earthquakes in Kansas: Bulletin Seismological Society of America, v. 46, no. 2, p. 87-96.

____________, 1960, Preliminary regional structural contour map on top of Mississippian rocks in Kansas: Kansas Geol. Survey, Oil Gas Invest., map no. 22, scale 1:633,600.

____________, 1963, The geologic history of Kansas: Kansas Geol. Survey Bull. 162, 317p.

Merriam, D.F., Cole, V.B., and Hambleton, W.W., 1961, Distribution of Precambrian basement rock types in Kansas: Am. Assoc. Pet. Geol. Bull., v. 45, no. 12, p. 2018-2024.

Mudge, M.R., 1949, The pre-Quaternary stratigraphy of Riley County, Kansas: Unpub. M.S. thesis, Kansas State Univ., 247p.

Mudge, M.R., and Beck, H.V., 1949, Map of Riley County showing construction material and geology: U.S. Geol. Survey Open File Report.

Mudge, M.R., and Burton, R.H., 1959, Geology of Wabaunsee County, Kansas: U.S. Geol. Survey Bull. 1068, 210p.

Muehlberger, W.R., Denison, R.E., and Lidiak, E.G., 1967, Basement rocks in continental interior of United States: Am. Assoc. Pet. Geol. Bull., v. 51, no. 12, p. 2351-2380.

Neff, A.W., 1949, A study of the fracture patterns of Riley County, Kansas: Unpub. M.S. thesis, Kansas State Univ., 44p.

Nelson, P.D., 1952, The reflection of the basement complex in the surface structures of the Marshall-Riley County area of Kansas: Unpub. M.S. thesis, Kansas State Univ., 73p.

Rieb, S.L., 1954, Structural geology of the Nemaha Ridge in Kansas: Unpub. M.S. thesis, Kansas State Univ., 36p.

Seyrafian, A., 1977, The Humboldt Fault, Pottawatomie County, Kansas: Unpub. M.S. thesis, University of Kansas, 44p.

Smith, R.K., and Anders, E.L., Jr., 1951, The geology of the Davis Ranch oil pool, Wabaunsee County, Kansas: Kansas Geol. Survey Bull. 90, pt. 2, p. 13-52.

Steeples, D.W., 1979, Earthquakes: Kansas Geol. Survey pamphlet, 7p.

Sternin, J.E., 1961, Subsurface geology of Geary and Morris counties, Kansas: Unpub. M.S. thesis, Kansas State Univ., 62p.

Swett, E.R., Jr., 1959, The surface expression of the Zeandale Dome: Unpub. M.S. thesis, Kansas State Univ., 59p.

Thomas, C.R., 1927, Flank production of the Nemaha Mountains (granite ridge), Kansas: Am. Assoc. Petr. Geol. Bull., v. 11, no. 9, p 919-931.

Walters, R.F., 1946, Buried Precambrian hills in northeastern Barton County, central Kansas: Am. Assoc. Petr. Geol. Bull., v. 30 no. 5, p. 660-710.

Watney, W.L., 1978, Structure contour map: Base of Kansas City Group (Upper Pennsylvanian) eastern Kansas: Kansas Geol. Survey map M-10, scale 1:500,000.

Weirich, T.E., 1953, Shelf principle of oil origin, migration, and accumulation: Am. Assoc. Petr. Geol. Bull., v. 37, no. 8, p. 2027-2045.

Wilson, F.W., 1979, A study of the regional tectonics and seismicity of eastern Kansas-summary of project activities and results to the end of the second year, or September 30, 1978: Kansas Geol. Survey and USNRC report, NUREG/Cr-0666, 70p.

Woods, R.S., 1978, A correlation of gravity and magnetic anomalies in central Coffey County and western Anderson County, Kansas: Unpub. M.S. thesis, Wichita State Univ., 51p.

Zeller, D.E., 1968, The stratigraphic succession in Kansas: Kansas Geol. Survey Bull. 189, 81p.

APPENDIX

Descriptions of outcropping rock units in western Wabaunsee County (modified from Mudge and Burton, 1959, and Jewett, 1941).

QUATERNARY

Pleistocene

Illinoisan and Wisconsin States

Loess - Thickness: 0-4.6 m (0-15 ft) Reddish-brown to brown clayey silt. Probably the Peoria Loess of Wisconsin age.

Terrace Deposits - Thickness: 0-6.1 m (0-20 ft) Angular to subangular fragments of limestone, chert, and shale 1-10 cm in diameter, interbedded with brown sandy and silty clay.

PERMIAN

Lower Permian Series

Chase Group:

Barneston Limestone:

Florence Limestone Member - Thickness: 10.7 m (35 ft) Limestone with shale partings and bedded chert and chert nodules throughout. Limestones are gray to tan and massive*. Shales are thin, thin-bedded, gray, and silty. The Florence Limestone is fossiliferous and forms a prominent terrace, often covered with chert fragments weathered out of the less resistant limestone.

* Massive refers to beds over 100 mm thick that are free of minor joints and laminations.

Matfield Shale:

Blue Springs Shale Member - Thickness: 9.1 m (30 ft) Varicolored shale with some thin limestone lenses. Shales are gray, green, maroon, and purple in lower part and gray and green in upper part. Limestone lenses are argillaceous.

Kinney Limestone Member - Thickness: 1.2-2.7 m (4-9 ft) Two beds of limestone separated by a thin shale. Limestones are gray to tan-gray, massive, and weather into irregular blocks. Shale is thin-bedded, gray, and calcareous. Fossiliferous throughout. Often produces a small ledge that breaks the steep slope formed by the Matfield and Blue Springs shales.

Wymore Shale Member - Thickness: 8.2 m (27 ft) Varicolored shale with calcareous beds. Upper shale is gray to gray-green, thin-bedded, silty, and calcareous. Maroon shale near base and middle.

Wreford Limestone:

Schroyer Limestone Member - Thickness: 4.3 m (14 ft) Limestone with lenses and nodules of chert. Limestone is tan to brown, massive, fossiliferous, hard, and weathers gray. Non-cherty zone near top is porous, weathers tan to brown, and small crinoid columnals protrude from the weathered surface. Forms the most extensive hillside terrace in the area. Distinguished from Threemile Limestone by lack of shale parting and position of non-cherty limestone.

Havensville Shale Member - Thickness: 5.2 m (17 ft) Gray, thin-bedded, calcareous shale with thin bed of gray to tan, fossiliferous, argillaceous limestone near top.

Threemile Limestone Member - Thickness: 3.7 m (12 ft) Limestone with persistant shale near base. Limestone is light gray to white and contains zones and nodules of chert. Weathered chert is often iron stained. Massive non-cherty limestone one meter thick occurs near middle. Shale is thin-bedded, gray, calcareous, and fossiliferous. Forms prominent hillside terrace. Distinguished from Schroyer Limestone by shale parting and middle non-cherty zone.

Council Grove Group:

Speiser Shale - Thickness: 5.2 m (17 ft) Varicolored shale with thin persistant limestone near top. Upper shale is gray, and calcareous, and fossiliferous. Lower shale is gray, green, purple, maroon, and silty. Limestone is light gray, fossiliferous, and weathers gray.

Funston Limestone - Thickness: 3.0 m (10 ft) Massive limestone with shale parting near middle. Limestone is light gray, porous and weathers into dark gray, large, irregular blocks. Shale is thin, gray and silty. Algae of the Spongiostroma division occur locally. Identified in field by algae and large weathered blocks.

Blue Rapids Shale - Thickness: 6.1 m (20 ft) Varicolored shale with some calcareous beds. Upper part is gray to tan-gray and lower part is gray, gray-green, and maroon.

Crouse Limestone - Thickness: 3.0 m (10 ft) Lower massive limestone and upper platy limestone with thin intervening shale. Lower limestone is gray and weathers tan. Upper limestone is gray, platy, and weathers into thin, brown, irregular plates. Shale is thin-bedded, gray, and tan-gray. Limestones are fossiliferous. Recognized in the field by upper platy limestone.

Easly Creek Shale - Thickness: 4.6 m (15 ft) Varicolored shale with interbedded thin limestones. Shale is thin-bedded to blocky, red and maroon near the base, and gray near the top. Limestones are gray and argillaceous. In the SE¼ sec. 21, T. 12 S., R. 9 E., the Easly Creek Shale thins to 1.1 m (3.5 ft) and consists of thin-bedded black shale.

Bader Limestone:

Middleburg Limestone Member - Thickness: 1.8 m (6 ft) Two limestone beds separated by thin shale. Lower limestone is gray and fossiliferous. Shale parting is gray, calcareous, and clayey. Upper limestone is tan to tan-gray, porous, and weathers into small irregular plates.

Hooser Shale Member - Thickness: 1.8-2.7 m (6-9 ft) Gray Shale with a reddish-purple shale near the middle. Shale is silty and contains thin limestone lenses. Limestone is tan to gray, dense, and fossiliferous.

Eiss Limestone Member - Thickness: 2.1 m (7 ft) Two limestone beds with intervening shale. Lower limestone is tan to gray and weathers blocky. In the SE¼ sec. 29, T. 12 S., R. 9 E., the lower bed is a limestone conglomerate of gray and green fragments of shale and white to light brown fragments of limestone in a crystalline, gray, limestone matrix. Limestone and shale fragments are 5 mm to 3 cm in diameter. Intervening shale is gray, silty, thin-bedded, and calcareous. Upper limestone is gray, dense, siliceous, and weathers porous. In the NW¼ sec. 28, T. 12 S., R. 9 E., the top 15 cm of the Eiss Limestone consists of silicified pelecypods in a silica matrix. Pelecypods are white and stand out in a light gray, brown, and dark-gray matrix.

Stearns Shale - Thickness: 4.6-5.5 m (15-18 ft) Thin-bedded, gray to gray-green, silty shale with some calcareous seams near the middle. Locally fossiliferous.

Beattie Limestone:

Morrill Limestone Member - Thickness: 0.9-1.1 m (3-5 ft) Two thin limestone beds separated by a shale parting. Limestones are medium hard, tan to brown, and exhibit cavernous weathering. Lower limestone contains chert nodules. Shale is gray, calcareous, silty, and thin-bedded to blocky.

Florena Shale Member - Thickness: 2.4 m (8 ft) Lower shale is gray, silty, thin-bedded and very fossiliferous. Upper shale is gray and clayey.

Cottonwood Limestone Member - Thickness: 1.8 m (6 ft) Massive bed of limestone that is hard, light-gray to white, and fine grained. Chert nodules are present throughout and often protrude from the limestone on a weathered surface. Fusulinids very abundant.

Eskridge Shale - Thickness: 5.2 m (17 ft) In the area of surface investigation in western Wabaunsee County, the Eskridge Shale crops out only in sec. 28 and 29, T. 12 S., R. 9 E. Here, the Eskridge Shale is abnormally thin compared to its average thickness of 10.7 m (34 ft). It consists of varicolored, silty, and calcareous shale with two or three limestone beds. Shales are gray, gray-green, green, maroon, and purple. Limestones are thin, gray, hard, dense, and fossiliferous.

Grenola Limestone:

Neva Limestone Member - Thickness: 4.6 m (15 ft) Limestone beds separated by shale. Limestones are massive to platy, gray-brown to tan-gray, dense, and porous. Middle limestone bed weathers into large irregular blocks. Shales are gray, tan gray, black, thin-bedded, silty, and calcareous. The Neva Limestone is fossiliferous.

STRUCTURAL GEOLOGY AND RECENT SEISMICITY OF SOUTHEASTERN RILEY, EASTERN GEARY, AND WESTERN WABAUNSEE COUNTIES, KANSAS

by

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B.S., Eastern Illinois University, 1978

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

ABSTRACT

Surface and subsurface geologic mapping in western Wabaunsee, southeastern Riley, and eastern Geary counties, Kansas has revealed evidence of surface and subsurface faults. The purpose of this investigation was to determine the faults' relationship to each other and to sites of recent seismicity in the area. Aerial photographs were used to compile two geologic maps of western Wabaunsee and southeastern Riley counties. Geologic structure maps, isopachous maps, and surface and subsurface cross sections were constructed. Earthquake data were obtained from the Kansas Geological Survey.

Precambrian to Quaternary rocks occur in the area, but only rocks of Pennsylvanian, Permian, and Quaternary systems crop out. Precambrian rocks consist of granite, granite wash (weathered granite), schist, quartzite, and metasedimentary rocks. All systems of the Paleozoic are represented, but some series are absent or partially absent. Pre-Pennsylvanian rocks consist of limestone, dolomite, and minor amounts of sandstone and shale. Pennsylvanian and Permian rocks consist of alternating limestone and shale, and some sandstone and coal. Quaternary rocks are of glacial and fluvial origin and consist of unconsolidated conglomerate and sandy and silty clay.

Major tectonic features in the region include the Salina Basin, Nemaha Anticline, and Forest City Basin. Smaller structures include the Abilene Anticline, Irving Syncline, Zeandale Dome, Brownville Syncline, and Alma Anticline.

Four previously unmapped surface faults were recognized in western Wabaunsee County. The faults strike at angles to the two major joint sets. The largest fault visible at the surface in sec. 15, 16, and 21, T. 12 S.,

R. 9 E., has a maximum vertical displacement of 21.3 m and extends downward to the Precambrian. The other surface faults in western Wabaunsee County may, or may not, be related to faults mapped in the subsurface.

Seven northwest-striking surface faults occur in southeastern Riley County. The faults have a maximum vertical displacement of 7.6 m and parallel the northwest-trending joint set, which probably controlled the orientation of the faults.

Four subsurface faults were mapped. Maximum vertical displacement appears to occur in Precambrian rocks and decreases progressively upward. The Mississippian geologic structure map strongly supports the existence of a fault along the east flank of the Nemaha Anticline.

Growth faulting resulted in an anomalous elevation on the Mississippian surface and abnormal thickness of the Cherokee Group in the Schmitt No.1 well in sec. 21, T. 12 S., R. 9 E. The greater thickness of the Cherokee Group indicates that growth faulting occurred after deposition of Mississippian units and throughout deposition of the Cherokee Group. Faults cut post-Cherokee units, but relatively uniform thicknesses of these units across the faults indicate that the fault became inactive for some time during the Late Paleozoic.

Three microearthquakes have occurred in or near the area of investigation since November 2, 1977. Locations of historical earthquake and recent microearthquake epicenters indicate that the area is still seismically active.