GEOLOGY OF THE WELCH-BORNHOLDT POOLS AREA, RICE AND MCPHERSON COUNTIES, KANSAS

by

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B. S., Kansas State College
of Agriculture and Applied Science, 1958

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE UNIVERSITY
OF AGRICULTURE AND APPLIED SCIENCE

1960

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INTRODUCTION

The Prairie Oil and Gas Company and the Meridian Oil and Gas Company completed the discovery well of the Welch pool in the SE $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 34, T. 20 S., R. 6 W., Rice County, Kansas, in April 1924. Initial production was 115 barrels of 33.5 degrees Bau me' oil per day from 3,370 - 3,416 feet in the Mississippian "chat". Production decreased to 25 barrels per day by April 1926 which was subsequently increased to 230 barrels per day by deepening the well to 3,490 feet. Originally the oil pool was called both the Hutchinson field and the Rice County field, but the term Welch pool became accepted usage. Discovery of the Welch pool in western Kansas was second only to the Fairport pool of Russell County, Kansas. The Bradley Brothers Drilling Company completed the discovery well of the Bornholdt pool, named after the Bornholdt farm, in Sec. 30, T. 20 S., R. 5 W., McPherson County, Kansas, in 1937. The well had a daily potential of 131 barrels of oil per day in the Mississippian "chat" from 3,292 - 3,335 feet. In 1938 the Bornholdt discovery well was deepened to 3,392 feet. The reworked well only made 40 barrels per day with two per cent water so it was recompleted to produce the original potential of 131 barrels of oil per day.

Drilling activity from 1924 to the end of 1957 is shown by Plate 13, Fig. 1. Thirty-five wells were drilled within three years after the discovery well of the Welch pool. Eight of these wells were dry and abandoned. Few wells were drilled in the 1930's because of the economic depression. The sharp rise in drilling activity in 1940 represents development of the Bornholdt pool. The sharp rise of drilling activity in 1942 is represented by exploitation of the Smyres pool. The effects of World War II and post-World War II oil demands are shown by the drilling activity to the end of 1957. At the end of 1957, 424 wells were still producing in the Welch-Bornholdt Pools Area and estimated cumulative production was 29,473,180 barrels.

The Welch pool discovery well site was drilled because of "doodle-bug" advice (Clark, 1948). A core drilled high of small closure in the Permian rocks was used to locate the discovery well of the Bornholdt pool (Clark, 1948). Early in the development of the Welch-Bornholdt pool the trap was believed to be anticlinal (Ver Wiebe, 1938), however subsequent drilling has proved that the accumulation of petroleum is controlled primarily by stratigraphic factors.

Geographic Location

This investigation includes pools officially designated as the Welch-Bornholdt pool, Welch North pool, Smyres North pool, Green pool, and the Rellim pool, all of which the author has designated collectively as the Welch-Bornholdt Pools Area. The Welch-Bornholdt pool was originally, at various periods in its development, seven different pools. As exploitation proceeded and drilling brought the pool limits together, the Kansas Nomenclature Committee consolidated the pools into the Welch-Bornholdt pool. Plate 1, Fig. 2 shows the individual pools in the area of mapping that produce from the Mississippian "chat" and/or Pennsylvanian basal conglomerate. The Welch-Bornholdt pool has been subdivided into four principal sectors.

The Welch-Bornholdt Pools Area lies within T. 19 S., R. 5 W. and R. 6 W., T. 20 S., R. 5 W. and R. 6 W., and T. 21 S., R. 6 W. of Rice and McPherson Counties, Kansas (Plate 1, Fig. 2). The Welch-Bornholdt Pools Area covers 12,200 productive acres in the two counties.

The townsite of Windom lies in the north part of the Welch-Bornholdt pool. Lyons is approximately 13 miles west, McPherson about 13 miles east, and Sterling about 11 miles southwest of the Welch-Bornholdt Pools Area.

Topography

The Welch-Bornholdt Pools Area is located in the Plains Border portion of the Great Plains Province (Plate 2). The Plains Border in central Kansas is subdivided into the Smoky Hills and the Great Bend Prairie. The area of investigation lies in these two areas. Cretaceous rocks form an erosional hilly topography, the Smoky Hills, in the north part of the Welch-Bornholdt Pools Area (Plate 3, Fig. 1). The Great Bend Prairie in the south part has a nearly level surface because of the relatively flat undissected Tertiary cover (Plate 3, Fig. 2). The south part of the Welch sector has a sand dune topography (Plate 4, Figs. 1 and 2).

The main drainage streams in the area of study are the Smoky Hill River and tributaries to the north and the Arkansas

EXPLANATION OF PLATE 1

Fig. 1. Index map of Kansas showing area of investigation.

Fig. 2. Area investigated, showing distribution of pools producing petroleum from the Mississippian "chat" and/or Pennsylvanian Basal Conglomerate.

Explanation

Index No.	Pool Name	Year of Discovery	Producing Horizon
1	Welch-Bornholdt	1924	
1a	Welch sector	1924	Miss. "chat"
1b	Bornholdt sector	1937	Miss. "chat"
1c	Smyres sector	1942	Miss. "chat" and Penn. Basal Congl.
1d	Windom sector	1953	Miss. "chat" and Penn. Basal Congl.
2	Welch North	1937	Miss. "chat"
3	Smyres North	1942	Miss. "chat"
4	Green	1953	Miss. "chat"
5	Rellim	1957	Miss. "chat"
6	Wherry	1933	Penn. Basal Congl.
7	Engelland	1949	Penn. Basal Congl.
8	Ponce	1936	Penn. Basal Congl.
9	Dymond	1955	Miss. "chat"

PLATE 1

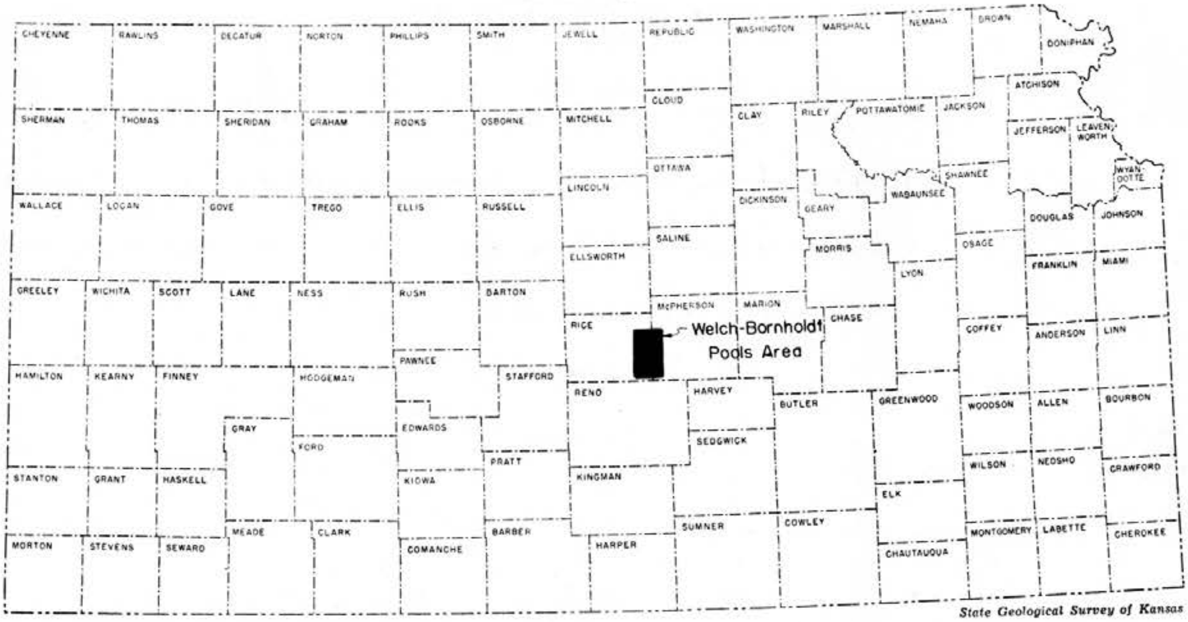


Fig. 1

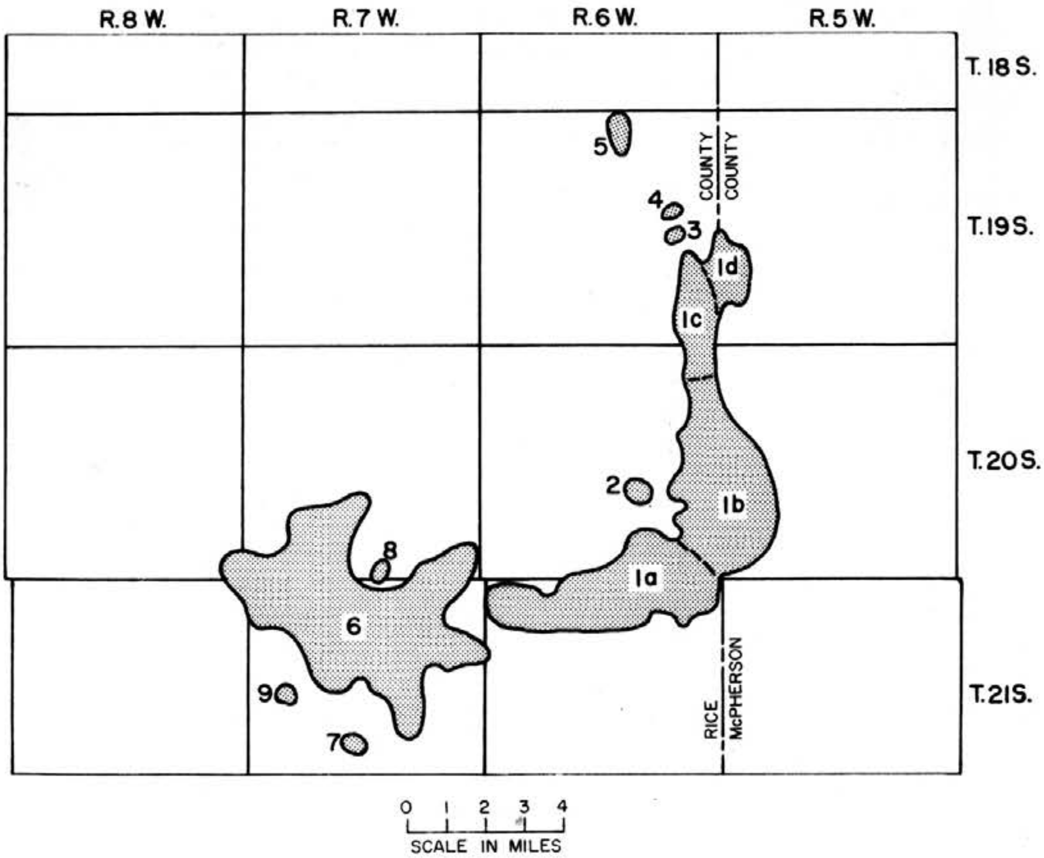
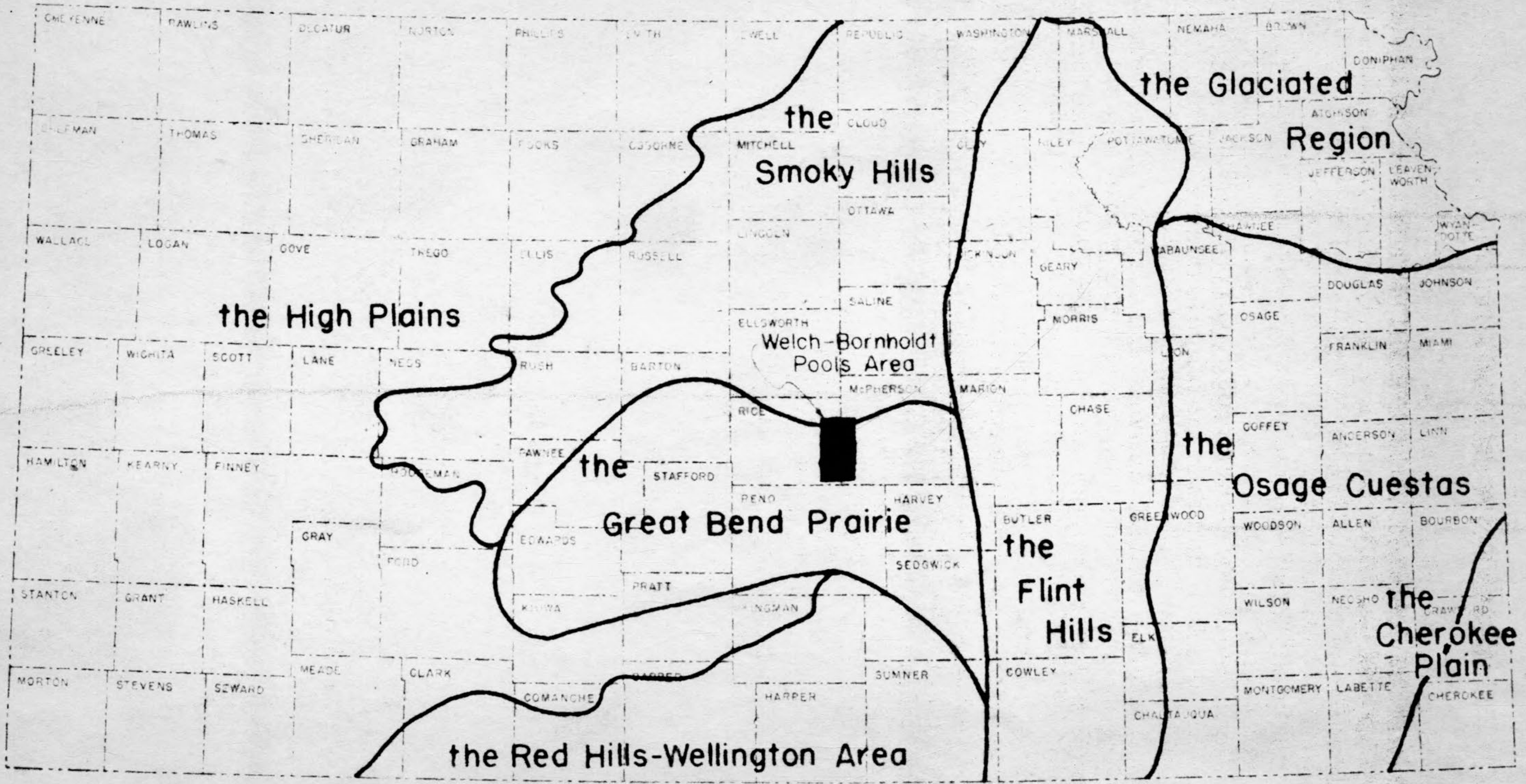


Fig. 2

EXPLANATION OF PLATE 2

Physiographic units of Kansas in relation to area of investigation (adapted from Muilenburg, 1953).



State Geological Survey of Kansas

PLATE 2

EXPLANATION OF PLATE 3

Fig. 1. Photograph of southern part of Smoky Hills in which Smyres sector is situated. Sec. 1, T. 20 S., R. 6 W. Note gently rolling hills.

Fig. 2. Photograph of Great Bend Prairie in which Bornholdt sector is situated. Sec. 30, T. 20 S., R. 5 W. Note flat undissected topography.

PLATE 3

Fig. 1

Fig. 2

EXPLANATION OF PLATE 4

Figs. 1 and 2. Photographs of Great Bend Prairie in which Welch sector is situated. Sec. 4, T. 21 S., R. 6 W. Note sand dune topography.

PLATE 4

Fig. 1

Fig. 2

River and tributaries to the south. Outcropping rocks range from Permian red bed rocks to Quaternary river alluvium.

Previous Investigations

Kesler (1928) reported the discovery well of the Welch pool, Rice County, Kansas. Folger (1933), Hall (1933), Koester (1934), Ver Wiebe (1938-47), Ver Wiebe and others (1948-55), and Goebel and others (1956-57) have subsequently reported the geology, production, and drilling information of the Welch-Bornholdt Pools Area.

Bramlette (1925) constructed a subsurface stratigraphic cross section from Marion County to Russell County. A part of the line of this cross section is two miles north of the Welch-Bornholdt pool and shows geologic conditions similar to those in the Welch-Bornholdt Pools Area. Moore (1926) named the producing zone of the discovery well in the Welch pool the Welch chert. He also described the lithology, discussed genesis, and assigned a geologic age to the rock unit. Ley (1926), Barwick (1928), Rich (1928), and Denison (1926) further discussed the geology of the producing zone.

Jewett (1951) has summarized and discussed geologic structures in Kansas. Barwick (1928), Koester (1935), Lee (1939-40-56), Walters (1946), Fent (1950), Lee and Merriam (1954), and Farquhar (1957) have contributed general and detailed knowledge of the structure and stratigraphy of central Kansas. Taylor (1946-47), Keroher and Kirby (1948), and Moore and others (1951) have described stratigraphy of central Kansas. Fenneman (1931) and Muilenburg (1953) have described the physiography of Kansas.

McNeil (1941) discussed the geology of the Wherry pool, Rice County, Kansas, in detail. Clark and others (1948) discussed the geology of the Geneseo Uplift and the oil fields associated with the Uplift. Koester (1952) described Mississippian "chat" production of the Lost Springs pool; Shenkel (1955) discussed the geology and production of the Lost Springs Pools Area.

Purpose of Investigation

The purpose of this investigation is to determine the geology of the Welch-Bornholdt Pools Area, stratigraphic trap pools which produce from a zone of porosity and permeability in the Mississippian "chat" at the southeastern extremity of the Geneseo Uplift, generally downdip from the truncated Mississippian chert beds. An analysis of the geologic data should disclose conditions that will account for petroleum accumulation in the area of investigation, the results of which may lead to the discovery of similar traps in adjacent localities.

Procedure

Two structure contour maps, a thickness map, and two stratigraphic cross sections were constructed in the course of this investigation. A structure contour map on the top of the Mississippian "chat" (Plate 22) and an isopachous map of the combined thickness of the Mississippian "chat" and unweathered limestone (Plate 23) were drawn to see if any relation existed between petroleum accumulation and structure. A structure contour map on the top of the Chattanooga shale (Plate 24) was drawn to supplement the other two maps in interpretation of structure and geologic history of the Welch-Bornholdt Pools Area. Plate 25, Fig. 1, a semi-regional stratigraphic cross section, shows stratigraphic and structural conditions from the west flank of the Voshell Anticline to the Central Kansas Uplift. Plate 25, Fig. 2, a local stratigraphic cross section, was drawn to show that the Windom sector is a structural and not a topographic "high".

A structure contour map on the top of the Pennsylvanian basal conglomerate was constructed but was not included in this thesis. In the area of study the map was very similar to the Mississippian "chat" structure contour map. This is interpreted to indicate that: (1) the Mississippian "chat" surface must have been relatively level preceding Pennsylvanian basal conglomerate sedimentation, (2) the Pennsylvanian basal conglomerate is of uniform thickness in the Welch-Bornholdt Pools Area, and (3) the Pennsylvanian basal conglomerate surface was probably level before Cherokee and Marmaton deposition.

Formation tops were obtained from Herndon maps, scout cards, various types of electronic logs, driller logs, and sample logs of the Kansas Sample Log Service. Most of the sources used for obtaining formation tops listed a conglomerate top and a Mississippian top. The conglomerate top was interpreted as the top of the Pennsylvanian basal conglomerate and the Mississippian top as the top of the Mississippian "chat". This interpretation is based upon microscopic examination of well cuttings and personal communication with geologists familiar with the area of investigation. The chief lithologic difference between the two sediments is the varicolored shales and the varicolored cherts of the Pennsylvanian basal conglomerate as contrasted to the white opaque chert of the Mississippian "chat". The Pennsylvanian basal conglomerate can be distinguished from the Mississippian "chat" by radioactive logs. Sometimes the unweathered Mississippian limestone can be differentiated from the residual chert or "chat" by some electronic logs (Miller, 1959).

The stratigraphy, other than that of the producing zone and outcrops in the Welch-Bornholdt Pools Area, was taken from references listed in Literature Cited. Plate 5 shows the generalized stratigraphic sequence of rocks in the Welch-Bornholdt Pools Area. Four wells that the author examined well cuttings from were: (1) Phillips Petroleum Company No. 1 Welch, SW $\frac{1}{4}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 35, T. 20 S., R. 6 W., (2) Sterling Drilling Company No. 2 Miller, NE $\frac{1}{4}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 3, T. 21 S., R. 6 W., (3) Alladin No. 1 Lackey, CW $\frac{1}{2}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 1, T. 21 S., R. 6 W., and (4) Trans Era Petroleum, Inc. No. 1 Neal, NE $\frac{1}{4}$ SW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 30, T. 19 S., R. 6 W. Much structural and geologic history, other than that gained from analysis of the attached maps and cross sections, was obtained from Wallace Lee's (1956) geological studies in which he employed thickness maps and cross sections to describe the geology of the Salina Basin Area.

STRATIGRAPHY

Precambrian Rocks

Precambrian rocks of Kansas consist of an igneous and metamorphic complex. Regional metamorphism occurred about 1,500 million years ago and was moderately intense as shown by the presence of garnet and sillimanite (Farquhar, 1957). The regional metamorphism subsequently metamorphosed the sedimentary rocks into quartzite, granulite, schist, phyllite, gneiss, and marble. A "later" Precambrian granite intruded the metamorphic complex approximately 830 million years after the regional metamorphism (Farquhar, 1957). The intrusive rocks were dominately granite, but grabbro and syenite have been found which may represent either a phase of the main granitic magma or a separate magma. Dikes, sills, veins, pegmatites, and probably lava flows were associated with the "later" igneous activity. The Precambrian surface, especially in the northern half of Kansas, consists of Precambrian rocks weathered in situ.

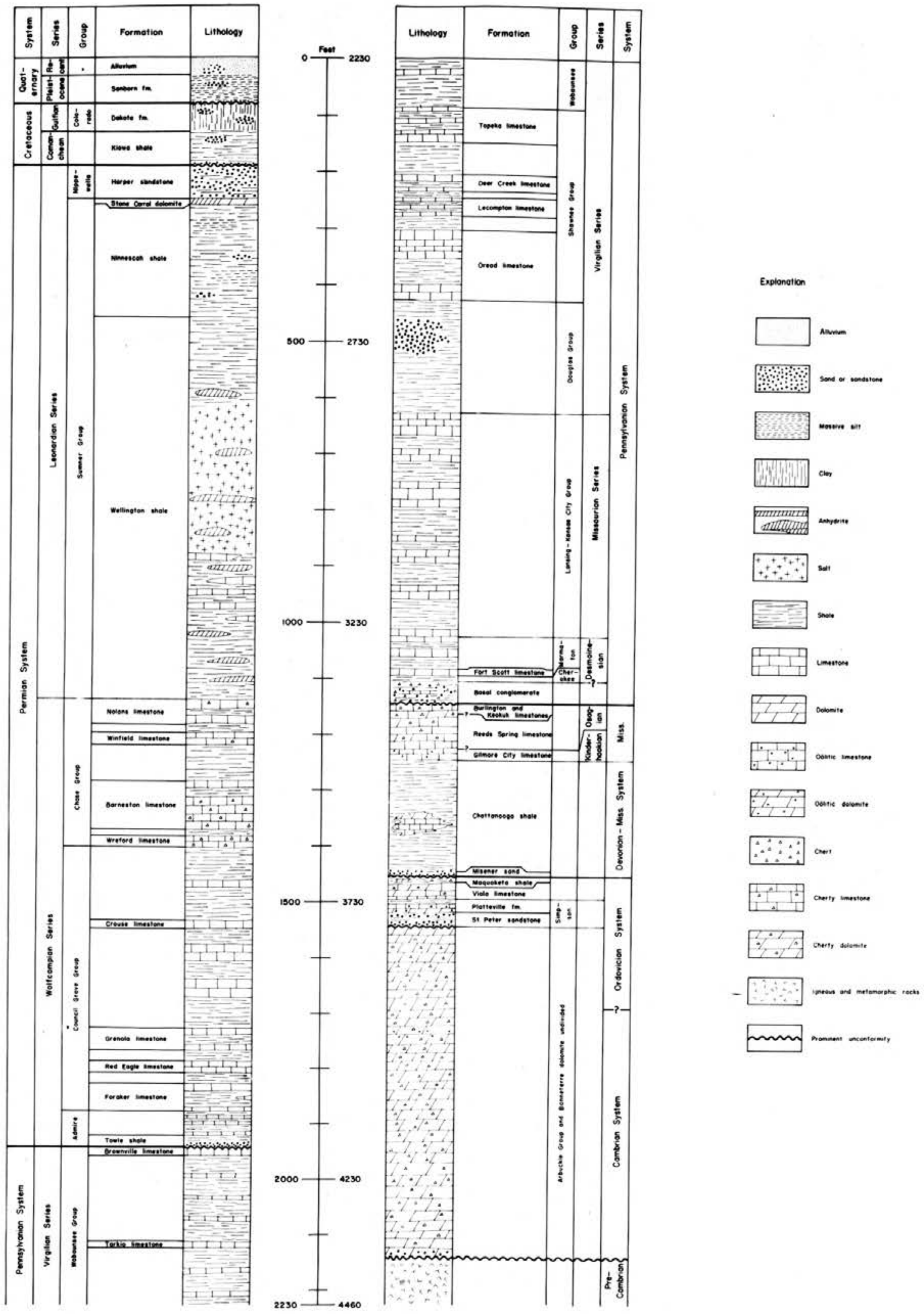
Upper Cambrian Rocks

Lamotte Sandstone. The Precambrian terrain provided the source material for the Lamotte sandstone. The lower part of the Lamotte sandstone is generally arkosic and grades upward through an angular and subangular sandstone into sandy dolomite. The Bonneterre dolomite conformably overlies the Lamotte sandstone, the division between the two formations is arbitrarily assigned where dolomite predominates over sand.

EXPLANATION OF PLATE 5

Generalized stratigraphic sequence of rocks in the Welch-Bornholdt Pools Area.

PLATE 5


System
Series
Group
Formation
Lithology
Quaternary
Pleistocene
Recent
Cretaceous
Comanchean
Gulfian
Colorado
Alluvium
Sanborn fm.
Dakota fm.
Kiowa shale
Nippewalla
Harper sandstone
Stone Corral dolomite
Ninnescah shale
Leonardian Series
Sumner Group
Wellington shale
Permian System
Nolans limestone
Winfield limestone
Chase Group
Barneston limestone
Wreford limestone
Wolfcampian Series
Council Grove Group
Crouse limestone
Grenola limestone
Red Eagle limestone
Foraker limestone
Admire
Towle shale
Brownville limestone
Pennsylvanian System
Virgilian Series
Wabaunsee Group
Tarkio limestone
Feet
0
2230
500
2730
1000
3230
1500
3730
2000
4230
2230
4460
Wabaunsee
Topeka limestone
Deer Creek limestone
Lecompton limestone
Shawnee Group
Oread limestone
Virgilian Series
Douglas Group
Lansing - Kansas City Group
Missourian Series
Pennsylvanian System
Marmaton
Cherokee
Desmoinesian
Fort Scott limestone
Basal conglomerate
Burlington and Keokuk limestones
Osagian
Reeds Spring limestone
Kinderhookian
Miss.
Gilmore City limestone
Chattanooga shale
Devonian - Miss. System
Misener sand
Maquoketa shale
Viola limestone
Platteville fm.
Simpson
St Peter sandstone
Ordovician System
Arbuckle Group and Bonneterre dolomite undivided
Cambrian System
Pre-Cambrian
Explanation
Alluvium
Sand or sandstone
Massive silt
Clay
Anhydrite
Salt
Shale
Limestone
Dolomite
Oölitic limestone
Oölitic dolomite
Chert
Cherty limestone
Cherty dolomite
Igneous and metamorphic rocks
Prominent unconformity

Upper Cambrian - Lower Ordovician Rocks

Arbuckle Group. The Arbuckle group of rocks consists predominately of dolomites of late Cambrian and early Ordovician age. The late Cambrian dolomites are the Bonneterre and Eminence dolomites. The remainder of the Arbuckle group, early Ordovician in age, are the Gasconade, Roubidioux, and Jefferson City-Cotter dolomites. The Arbuckle group is about 600 feet thick in the Welch-Bornholdt Pools Area.

The Bonneterre dolomite covers a more widespread area than the Lamotte sandstone, and overlaps upon the topographic "high" of central Kansas which the Lamotte sandstone did not (Keroher and Kirby, 1948). The Bonneterre still is absent over much of central Kansas. A pre-Roubidioux syncline in southern McPherson County contains 170-183 feet of Bonneterre dolomite which becomes truncated to the west where the Welch-Bornholdt Pools Area is situated. The Bonneterre is generally a buff to white, noncherty, arenaceous, slightly glauconitic, coarse, crystalline dolomite.

The Eminence dolomite, like the Bonneterre dolomite, is absent over much of central Kansas but is present in the pre-Roubidioux syncline of southern McPherson County where it is about 35 feet thick. Westward the Eminence wedges to zero near the Welch-Bornholdt Pools Area. The Eminence is a light buff, medium and coarse crystalline dolomite. Some green shale and pyrite are also present in varying amounts. The Eminence is unconformable with the underlying Bonneterre and the overlying

Gasconade.

The only occurrence of the Gasconade dolomite in the Salina Basin is in the pre-Roubidioux syncline of southern McPherson County. The Gasconade ranges from an arenaceous dolomite at its base upward to a cherty, white and light gray, coarse, crystalline dolomite.

After Gasconade deposition pre-Roubidioux erosion truncated the older rocks west and east of the syncline in southern McPherson County. Pre-Roubidioux erosion was widespread. After pre-Roubidioux erosion a basal sand was deposited on the erosional surface. The Roubidioux basal sand grades upward to an arenaceous, cherty, white, coarse, crystalline dolomite with brown oolitic chert present in the dolomite at the top.

The Jefferson City-Cotter dolomites are essentially conformable above the Roubidioux (Lee, 1956). The Jefferson City-Cotter dolomites are variable in lithologic character laterally and vertically. Generally the rock is characterized by white to gray, dense, somewhat argillaceous, soft dolomite. Smooth tan finely oolitic chert commonly occurs at the base of the Jefferson City dolomite. The Roubidioux and Jefferson City-Cotter dolomites were deposited uniformly over much of Kansas. After Jefferson City-Cotter deposition a major period of uplift, erosion, and peneplanation occurred in which the state was tilted southward along a line parallel to the northern margin of Kansas. The Roubidioux and Jefferson City-Cotter dolomites are truncated along an east-west line and thicken southward.

Ordovician Rocks

Simpson Group. The Simpson group includes the St. Peter sandstone and the Platteville shale. The formations are separated by an obscure but important unconformity, the contact being placed at the base of a bed of dolomite in the Platteville shale. The St. Peter sandstone was deposited on the relatively level Arbuckle erosional surface. In northeastern Kansas the St. Peter sandstone has a three-fold division. The upper and lower sandstone members consist of white well-rounded and frosted sand grains and the middle member, varying in lithology, is composed predominantly of arenaceous green shale. Toward the southwest the St. Peter's lithology varies from the three-fold division. The lower member is sometimes missing, probably due to non-deposition on topographic and structural "highs"; and the upper member is absent at places probably due to post-St. Peter erosion. The St. Peter sandstone in the Welch-Bornholdt Pools Area is an arenaceous limestone or dolomite locally interstratified with sandstone and shale (Lee, 1956).

Lee (1956) describes the Platteville formation of northeastern Kansas as,

> . . . green clay shale, dolomite, sandstone, earthy to granular limestone, and sublithographic limestone, locally interbedded with dolomite. The basal member of the formation is a persistent and widespread bed of sucrose or granular dolomite which is interstratified in some wells with thin earthy limestone and in others with interbedded green shale.

The Platteville shale in the Welch-Bornholdt Pools Area, on the southwest flank of the North Kansas Basin (Plate 8), is five to ten feet of brown, densely crystalline basal dolomite with embedded rounded sand grains.

Viola Limestone and Dolomite. The Viola is separated from the underlying Simpson rocks and the overlying Maquoketa shale by unconformities. The wide distribution of the basal limestone member of the Viola in the Salina Basin indicates absence of erosional relief of the Simpson rocks (Lee, 1956). Pre-Maquoketa erosion reduced the thickness of the Viola, so that sometimes only the basal coarse crystalline limestone of the Viola remained.

The Viola averages 50 feet in thickness in the Welch-Bornholdt Pools Area. The Viola formation in the Welch-Bornholdt Pools Area and surrounding area consists of interstratified coarse to medium crystalline limestone and calcareous dolomite. North and northeast of the Welch-Bornholdt Pools Area the Viola is composed almost entirely of dolomite, while to the south and southwest it is nearly all limestone. The dolomite varies from densely crystalline to vuggy and granular in character. Chief distinguishing characteristics of the Viola are the absence of argillaceous components and presence of non-traceable buff, brown or gray chert beds. Lee (1956) states the following about the chert beds,

> The lack of continuity in the presence and position of cherty dolomite suggests intraformational disconformities, but no definite interruption of the sequence is determinable. The changes from dolomite to limestone and from limestone to dolomite and the dissimilarities in the chert content at apparently the same horizon in wells only a few miles apart are regarded as the result of facies variations. . .

> The chert and some of the limestone and dolomite enclose sparsely disseminated or crowded particles of spicules and disintegrated graptolites in the form of black flakes, tubes, flecks, and dust. . . .

Maquoketa Shale. The Maquoketa shale is composed on one or more of the following rocks: argillaceous shale, dolomitic shale, silty shale, argillaceous dolomite, cherty and siliceous dolomite, and minor amounts of limestone (Lee, 1956). The shale ranges from gray to green in color. The dolomite is gray to dark gray, composed of fine crystals set in an argillaceous or silty matrix. The chert is similar to chert in the Viola formation. The Maquoketa shale is zero to fifty feet thick in the Welch-Bornholdt Pools Area.

Silurian - Devonian Rocks

"Hunton Limestone". Silurian-Devonian rocks, called the "Hunton limestone" by petroleum geologists, is separated from the underlying Maquoketa shale by a slight unconformity and from the overlying Chattanooga shale by an important unconformity. Deposition of the "Hunton limestone" was interrupted between the Silurian and Devonian periods which resulted in an unconformity. The "Hunton limestone" is not present in the Welch-Bornholdt Pools Area because of pre-Chattanooga erosion, but is present nearby.

Devonian - Mississippian Rocks

Chattanooga Shale. The Chattanooga shale, called "Kinderhook shale" by petroleum geologists, is as much as 250 feet thick in the Welch-Bornholdt Pools Area. Plate 6 shows the thickness of the Chattanooga shale in the area of investigation. The great thicknesses of Chattanooga shale in this area as contrasted with the Salina Basin area must be due to shale accumulation in pre-Chattanooga erosional valleys. The Welch-Bornholdt Pools Area is situated near a tributary of one of these erosional valleys that enters the east-west McPherson Valley.

The Chattanooga shale is composed of gray to black fissile shale, slightly silty and finely micaceous, and contains small amounts of pyrite. The spore Sporangites huronensis occurs sparsely or in great quantities near the base of the shale.

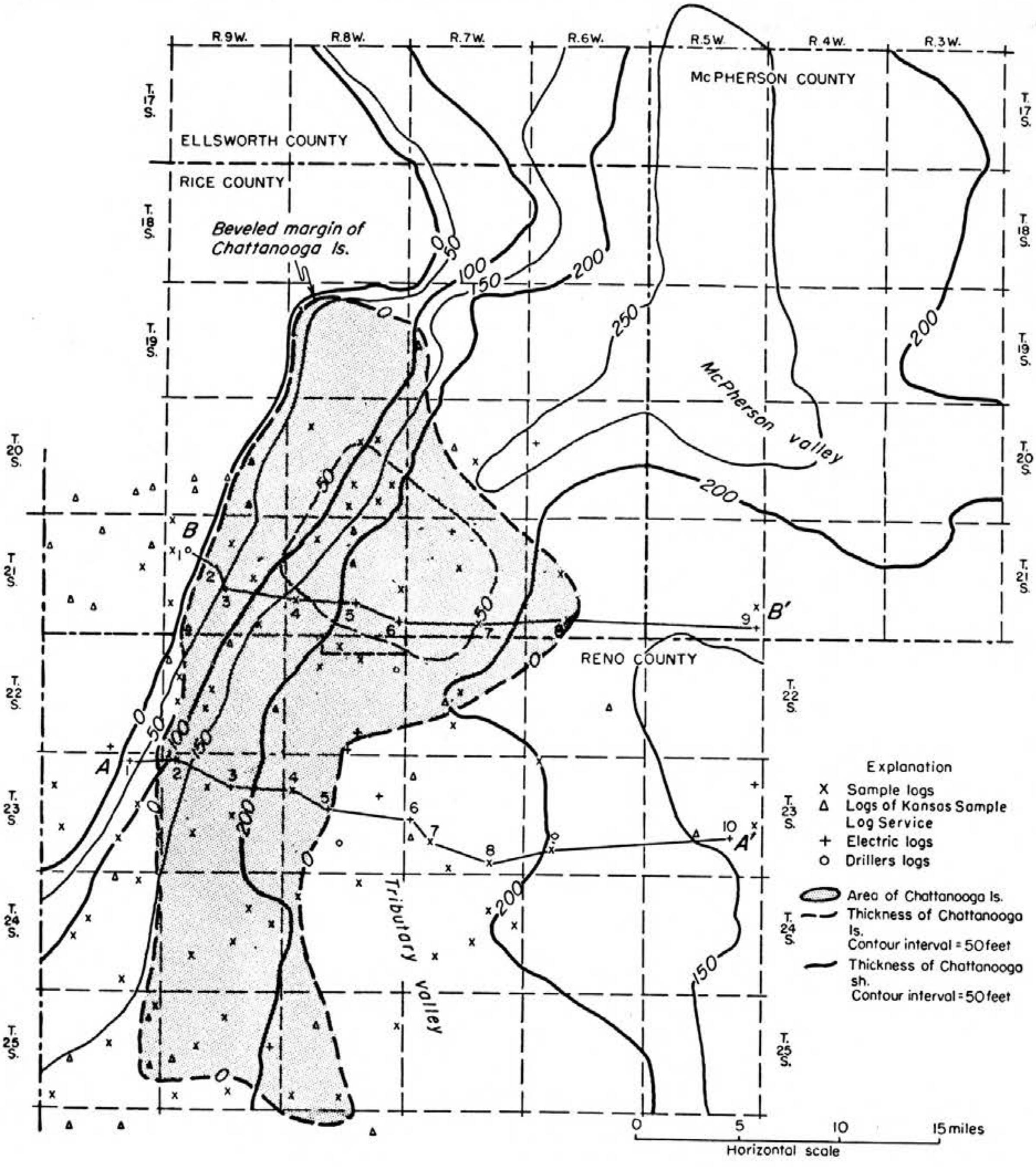
The Misener sand represents the basal deposit of the Chattanooga shale and consists of rounded sand grains that comprise definite sand bodies or that are present disseminated throughout the basal part of the shale. Distribution of the Misener sand seems to have a relation to the proximity of pre-Chattanooga outcrops of Simpson sand on the Central Kansas Uplift and to pre-Chattanooga outcrops of the basal sandy beds of Devonian rocks, which probably represent the sources of the Misener sand (Lee, 1956). The Misener sand varies from zero to thirty-five feet in thickness in the Welch-Bornholdt Pools Area.

A Chattanooga limestone lentil, zero to 110 feet thick, is present in the Chattanooga shale (Plate 6). The limestone is gray and mostly mealy or chalky and slightly argillaceous. Lee (1956) explains the presence of the limestone lentil in the Chattanooga shale as, ". . . the result of temporary shielding of the limestone area from clastic sediments by the building up

EXPLANATION OF PLATE 6

Isopachous map of the Chattanooga shale in area of investigation (adapted from Lee, 1956).

PLATE 6


R.9W.
R.8W.
R.7W.
R.6W.
R.5W.
R.4W.
R.3W.
T. 17 S.
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
T. 22 S.
T. 23 S.
T. 24 S.
T. 25 S.
ELLSWORTH COUNTY
RICE COUNTY
McPHERSON COUNTY
RENO COUNTY
Beveled margin of Chattanooga ls.
McPherson valley
Tributary valley
B
B′
A
A′
Explanation
X Sample logs
Δ Logs of Kansas Sample Log Service
+ Electric logs
o Drillers logs
Area of Chattanooga ls.
Thickness of Chattanooga ls. Contour interval = 50 feet
Thickness of Chattanooga sh. Contour interval = 50 feet
0 5 10 15 miles
Horizontal scale

of a shale delta at the mouth of the tributary to the McPherson Valley as the valleys were being filled."

Mississippian Rocks

Sedalia Limestone. The upper member of the Sedalia limestone, a widespread dolomite, represents the first Mississippian deposit to be laid down over the relatively level Chattanooga-Boice shale erosional surface in the Salina Basin. The southern limit of the Sedalia dolomite is southern Saline County, but thin outliers occur to the south. One such outlier is located in western McPherson County, in the vicinity of the Conway Syncline. The Sedalia dolomite present in the Salina Basin generally consists of noncherty, buff to brown, locally gray, sucrose dolomite. The outlier in McPherson County is a buff sucrose dolomite less than five feet thick.

Gilmore City Limestone. The center of the Gilmore City, and probably late Sedalia, sedimentary basin was in central Iowa with the axis of the basin aligned in a southwesterly direction (Lee, 1940). The Gilmore City limestone in the Salina Basin was deposited as a relatively pure noncherty or slightly cherty granular limestone composed of worn fragments of finely broken fossils, with or without oolites, embedded in a cryptocrystalline matrix (Lee, 1956). The noncherty Gilmore City limestone is present in the Windom sector of the Welch-Bornholdt Pools Area (Smith, 1959) and possibly in other sectors.

St. Joe Limestone. After Gilmore City deposition the Mississippian sedimentary tectonic framework changed in Kansas so that the younger Mississippian beds were deposited in a sedimentary basin that deepened to the south. The successive Mississippian limestone beds progressively overlapped northward into Kansas. South of the Welch-Bornholdt Pools Area, in Sedgwick County, the St. Joe limestone consists of interlayered beds of noncherty, semigranular limestone, argillaceous limestone, and calcareous shale (Lee, 1956). Northward the St. Joe becomes more argillaceous and thins from 75 to 100 feet in thickness in Sedgwick County to zero in McPherson County. The presence of the St. Joe limestone in the Welch-Bornholdt Pools Area is questionable. McNeil (1941) suggests that the red shale beneath the Mississippian "chat" in the Wherry pool may be the St. Joe formation or the shale may be a deposit left by percolating ground waters from solution of the overlying limestones.

Reeds Spring Limestone. The Reeds Spring limestone in the Salina Basin consists mainly of semigranular limestone. Included in the Reeds Spring limestone are interbedded dolomite and some slightly argillaceous limestone. Chert is usually conspicuous but is sparse near the base of the formation. Reeds Spring chert is translucent and semitranslucent with blue to bluish gray the dominate color. Chert well cuttings are predominately smooth splinters and blocky fragments with sharp flinty edges.

Burlington-Keokuk Limestones. Lee (1956) subdivided the Burlington-Keokuk rocks into lower and upper zones. Both zones are composed of cherty limestone and dolomite which are differentiated by the chert. The lower zone is characterized by white, opaque, dense chert which appears in well cuttings as blocky fragments with somewhat tabular surfaces. The upper zone contains white, rough, and pitted chert that breaks into subangular fragments.

The Burlington-Keokuk limestones are not present as such in the Welch-Bornholdt Pools Area, but are present as the Mississippian "chat". During the post-Mississippian - pre-Marmaton the soluble constituents of the Osagian rocks were removed by solution action and the relatively unsoluble chert remained in situ. Evidently the tectonic movements were of a gentle epeirogenic nature with little topographic relief created so as to cause little, if any, mechanical transportation of the residual chert. The Mississippian "chat" is discussed in more detail under Producing Zone.

"Warsaw" Limestone. The "Warsaw" in the Salina Basin is composed of semigranular limestone. Some sucrose dolomite occurs as matrix cementing crystalline fragments of broken fossils.

Spergen Limestone. The Spergen in the Salina Basin consists of noncherty yellowish granular limestone with a slightly waxy luster. The "Warsaw" and Spergen limestones are preserved in the center of the Salina Basin and in other synclinal areas (Conway Syncline) (Lee, 1956). These limestones and younger Meramecian rocks probably were deposited throughout much of Kansas but were removed from anticlinal areas by post-Mississippian deformation.

Pennsylvanian Rocks

Pennsylvanian Basal Conglomerate. Koester (1935) describes the genesis and lithology of the Pennsylvanian basal conglomerate as,

> . . . a transgressive deposit, overlying rocks from pre-Cambrian to Mississippian in age, and underlying beds ranging in age from Cherokee in central Kansas to possible Permian in northwestern Kansas. In its most common development it is a coarse, cherty, partly sandy conglomerate, commonly cemented with red shale. In many samples the red shale composes most of the material. The chert is commonly white, yellow, red, brown, gray, or black, partly oolitic and doloclastic, rarely sandy, but everywhere weathered and reworked. Dolomite, green shale, gray shale, and other types of pre-Pennsylvanian and Pennsylvanian material are intermixed. Sand grains are fine to very coarse, etched, pitted, and frosted. The conglomerate is clearly derived from whatever type of sediments were at hand for reworking and redepositing as the first Pennsylvanian sea advanced upon the uplift. It represents the first deposit of a transgressive sea. Locally it contains several sand zones, within the coarser cherty material. Naturally the thickest sections of it are found in structural or topographic depressions.

Cherokee Group. After post-Mississippian folding and erosion the Cherokee sea advanced into Kansas from the Cherokee basin of Oklahoma. The still tectonically active Nemaha Anticline rose differentially as the Cherokee and Forest City Basins to the east subsided. Early Cherokee sedimentation occurred in these basins east of the topographically high Nemaha Anticline, but in late Cherokee time the sea advanced over the southern and central part of the Nemaha Anticline in Kansas and deposition occurred in the Salina Basin. Cherokee sediments in the Salina Basin consist of clastic gray, silty shales interstratified with red shale. The Cherokee rocks in well samples are somewhat difficult to separate from rocks of the Marmaton group because of lithologic similarities. The saddle separating the Salina Basin from the Sedgwick Basin has varying amounts of Cherokee sediments present. In T. 18 S., R. 4 W. Cherokee rocks are 105 to 115 feet thick (Lee, 1956). Westward, in the Windom sector, Cherokee sediments are also present above the Pennsylvanian basal conglomerate (Smith, 1959). The Cherokee sediments range from zero to fifty feet thick in the Welch-Bornholdt Pools Area with the zero line traversing approximately through the Welch-Bornholdt Pools Area (Lehman, 1959).

Marmaton Group. The Marmaton group consists of limestone and shale. The shale formations include some sandstone, and locally thin limestone beds. The lenticular sandstone bodies are oil and gas reservoirs in the Cherokee and Forest City Basins, but in the Salina Basin the sandstone bodies are not present.

Pleasanton Group. The Pleasanton group is absent in the area of investigation.

Kansas City-Lansing Groups. The Kansas City-Lansing groups comprise a group of alternating limestones and shales with some interbedded sandstone. During cyclic deposition of these rocks and other Pennsylvanian rocks intercyclic erosion occurred which is responsible for variations in thickness of formations and for absence of formations. The predominance of limestone over shale characterizes the Kansas City-Lansing groups of central Kansas as contrasted to the outcrops in eastern Kansas. The limestone members appear to thicken in the sub-surface of central Kansas probably because the calcareous shales are like dense argillaceous limestone. Presence of fusulinids, oolites, chert, and varicolored shale in limestone members help in the identification of limestone formations. Oil shows in the Kansas City-Lansing group in the Welch-Bornholdt Pools Area have been found but the oil is not present in commercial quantities (Lane, 1959). The oil, if ever present in commercial quantities, probably migrated westward to the crest of the Geneseo Uplift.

Pedee Group. Sediments of the Pedee group are probably absent throughout the Salina Basin (Lee, 1956) and the Welch-Bornholdt Pools Area.

Douglas Group. The Douglas group in the Welch-Bornholdt Pools Area consists of the Stranger formation and the Lawrence formation. The Stranger formation is mostly gray shale and sandstone with several limestone members. The Lawrence formation is composed predominately of the Ireland sandstone in McPherson County (Lee, 1956) which probably extends west to the Welch-Bornholdt Pools Area. Above the Ireland sandstone is a gray shale which includes a widespread red shale bed at the top.

Shawnee Group. The Shawnee group consists of alternating limestone and shale formations. Within the limestone formations are thin shales. Within the shale formations are lenticular sandstone bodies. The limestones do not present any definite lithologic characteristic for identification.

Wabaunsee Group. The Wabaunsee group is composed of alternating limestones and shales. The limestone of the Wabaunsee group, including shale members, comprises about 20 per cent of the total of the group. Sandstone and coal occur in the shale.

Permian Rocks

Admire Group. The Admire group is separated from the underlying Pennsylvanian sediments by a low angular unconformity. The unconformity in the subsurface is a slightly dissected surface. Above the Indian Cave sandstone (basal Permian sediment), the Admire group is composed predominately of slightly arenaceous shales interbedded with widespread limestone beds.

Council Grove Group. The Council Grove group consists of alternating shales and limestones. The slightly calcareous shales are usually gray, but some shale formations display a red color. The argillaceous limestones are well-defined with paleontology as one criteria used in their identification.

Chase Group. The Chase group consists of alternating beds of thick limestone and shale formations. The percentage of limestone to shale is about equal, as in the Council Grove group. The cherty limestones are excellent marker beds at the outcrop and in the subsurface. Fusulinids are found in several of the limestone formations. The calcareous shale is variegated with red predominating.

Sumner Group. The Sumner group represents the oldest outcropping rocks in the Welch-Bornholdt Pools Area. The Stone Corral dolomite and Ninnescah shale are the outcropping formations. The Wellington shale occurs only in the subsurface. The gray Stone Corral dolomite is composed of dolomite, anhydrite, and gypsum interstratified at places with thin shale members. The lithologic compositions varies in areal extent and ranges in thickness from zero to thirty feet.

The Ninnescah shale predominantly consists of red shale, minor amounts of gray shale, and thin beds of limestone and siltstone. The shale ranges from 200 to 300 feet thick in the Welch-Bornholdt Pools Area.

The Wellington formation, as divided by Lee (1956) consists of three members. The lower member is "anhydrite beds" interbedded with gray shale at the bottom. The middle member is the Hutchinson salt member or "salt beds" which is an evaporite zone consisting of salt interstratified with beds and laminae of anhydrite. The unnamed upper member is composed of "middle gray beds" (mainly gray shale interbedded with some anhydrite), "red beds" (red shale with little or no anhydrite), and "upper gray beds" (gray clay and blue shale with some interstratified anhydrite).

Nippewalla Group. The Harper sandstone is composed of red sandstone and siltstone divided by thin beds of red shale and represents the only rock of the Nippewalla group in the Welch-Bornholdt Pools Area. The Harper sandstone varies from zero to 200 feet in thickness in the area of study (Fent, 1950). Unconformably above the Harper sandstone are Cretaceous rocks, as the younger Permian sediments were eroded during the post-Permian - pre-Cretaceous hiatus.

Triassic and Jurassic Rocks

Presence of Triassic and Jurassic sediments in the Welch-Bornholdt Pools Area is unknown. The rocks, if ever present, were removed during the hiatus preceding Cretaceous deposition.

Cretaceous Rocks

Two formations of Cretaceous age are found in the Welch-Bornholdt Pools Area. The Kiowa shale, a brown, fine-grained sandstone in the upper part and a gray to black, fissile shale in the lower part, is found in the Smoky Hills erosional area. Above the Kiowa shale is the Dakota formation. It is predominantly varicolored clays with numerous but discontinuous, coarse-grained, brown sandstone bodies.

Tertiary and Quaternary Rocks

Tertiary and Quaternary rocks in the Welch-Bornholdt Pools Area consist of gravel, sand, silt, clay deposits, river alluvium, and sand dunes. Sand dunes occur in the Welch sector (Plate 4, Figs. 1 and 2); river alluvium is in the Little Arkansas River, and alluvial deposits of gravel, sand, silt, and clay cover the remainder of the area of investigation except where Cretaceous rocks outcrop.

STRUCTURE

Regional Structure

The Welch-Bornholdt Pools Area is situated on the southeastern flank of the Geneseo Uplift, eastermost lobe of the Central Kansas Uplift (Clark and others, 1948). The complex regional structure of the area of study is related to geologic history. The pre-Mississippian rocks have an easterly dip; the upper Pennsylvanian and Permian rocks have a westerly dip; and the Cretaceous rocks have a northerly dip (Clark, 1948). The regional dip of all the sedimentary rocks has been the result of basement movements which have tilted all or parts of Kansas at various intervals from the Paleozoic through the Cenozoic.

Structure Within the Welch-Bornholdt Pools Area

Plate 22 shows structure contours on top of the Mississippian "chat"; Plate 23 shows isopachous contours of the combined Mississippian "chat" and unweathered limestone; Plate 24 shows structure contours on top of the Chattanooga shale. The Mississippian "chat" and Chattanooga shale represent former erosional surfaces but Plates 22 and 24 show a surprisingly close correlation. The erosional surfaces must have been nearly level before subsequent sedimentation. Plate 23 respectively correlates well with the two structure contour maps.

The Chattanooga shale zero line was adapted from Lee (1956) and slightly modified. Plate 24 shows the Central Kansas Uplift plunging eastward from T. 19 S., R. 9 W. but the eastward dip is interrupted by the Geneseo Uplift. The syncline, between the two uplifts, is well illustrated on Plate 24 and is probably faulted in part on its east flank. A displacement of 143 feet exists between wells CSL SE $\frac{1}{4}$ Sec. 26, T. 19 S., R. 8 W. and NW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 25, T. 19 S., R. 8 W. on the southwest side of the Geneseo Uplift. When the area was contoured without a fault an anomalous appearance was created in relation to the rest of the map. Therefore a fault was placed between the two wells.

The Mississippian zero line was adapted from Nicholas (1954) and slightly modified. The Mississippian zero line probably followed structure prior to Pennsylvanian sedimentation. During Pennsylvanian basal conglomerate deposition the Mississippian zero line was modified and left erractically distributed in respect to structure. Plate 22 shows the zero line of the Mississippian rocks extending westward to the Lyons gas field, southern most extension of the Geneseo Uplift. Plates 22 and 24 show monoclinal dip of the rocks to the east and southeast from the Lyons gas field.

Plates 22 and 24 show an anticlinal structure trending north-south in S $\frac{1}{2}$ T. 19 S., R. 7 W. and T. 20 S., R. 7 W. Plate 23 shows a corresponding thinning of the Mississippian rocks where the "high" is located.

Plates 22 and 24 show that the Wherry pool, in S $\frac{1}{2}$ T. 20 S., R. 7 W. and T. 21 S., R. 7 W., is located on a southeast trending structural nose. On each side of the nose are synclinal structures trending parallel to the structural nose. Plate 24 shows that the synclinal structure on the northeast side of the nose is a more definite structure as the synclinal structure continues westward until it turns northward and becomes a part of the syncline between the Central Kansas Uplift and the Geneseo Uplift. Plate 23 illustrates the Wherry pool structural nose and the synclinal structures on each side of the nose. The Mississippian rocks over the nose thin but the Mississippian rocks thicken in the structural "lows". The synclinal structures continue southward to become parts of the Conway Syncline.

The Conway Syncline in Plate 24 traverses north-south through T. 21 S., R. 5 W., T. 20 S., R. 5 W., and on the edge of T. 19 S., R. 4-5 W. In T. 19 S., R. 5 W. a tributary is observed that trends northwesterly. Plate 22 shows the main axis of the Conway Syncline traversing in a meandering north-south direction through T. 21 S., R. 5 W., T. 20 S., R. 5 W., S ½ T. 19 S., R. 5 W. and E ½ T. 19 S., R. 6 W. On the Mississippian "chat" surface the main axis of the Conway Syncline follows the northwesterly tributary in T. 19 S., R. 5 W. of Plate 24. Plate 23 shows a thickening of the Mississippian rocks along the tributary. Evidently the Mississippian limestones were deposited and the "chat" formed such that the axis of the Conway Syncline on the Mississippian surface followed the structural northwesterly tributary in T. 19 S., R. 5 W. of Plate 24 instead of the main axis of the Syncline.

East of the Conway Syncline the dip of the rocks reverses as the west flank of the Voshell Anticline is approached. Plate 23 shows that the Conway Syncline is a post-Mississippian structure. If the Syncline had been a Mississippian structure an abnormal thickness of sediments, which is not apparent, would be present along the axis of the Conway Syncline. The 300 foot contour on the east edge of Plate 23 represents the thickest section of Mississippian rocks in the area of investigation. Eastward the Mississippian rocks thin as the Voshell Anticline is approached.

The increased number of points on Plate 22 gave the author more control to contour the Mississippian "chat" surface. Small structures and topographic features are observable. The Windom sector in Plate 22 appears as an anticlinal structure. Plate 25, Fig. 2 also illustrates that the Windom sector is a structural rather than a topographic "high". There is not enough control on Plate 24 to show the Windom sector structure.

The Syncline on Plate 22 that separates the Windom and Smyres sectors has a subsidiary synclinal axis that trends westward from Sec. 31, T. 19 S., R. 5 W. through Sec. 36, T. 19 S., R. 6 W., then turns northwesterly and continues to the Mississippian zero line. This subsidiary fold axis shown on Plate 22 is only slightly evident on Plate 24. Plate 23 illustrates a definite thickening of Mississippian rocks along the synclinal tributary. Evidently the tributary represents a slight structural feature amplified by topographic relief.

The Welch-Bornholdt Pools Area is situated on a structural nose at the southeast extremity of the Geneseo Uplift. In the central and north parts of the Welch-Bornholdt Pools Area the structure contours trend north-south; in the south part of the Welch-Bornholdt Pools Area the structure contours trend southeastward. The thickness of the combined Mississippian "chat" and unweathered limestone ranges from 120 feet in the Welch sector to 60 feet in the Rellim pool.

Plate 25, Fig. 1 shows the regional relation of the Welch-Bornholdt Pools Area to the Voshell Anticline, Conway Syncline, Geneseo Uplift, and Central Kansas Uplift. The Welch-Bornholdt Pools Area lies between wells 5 and 6.

GEOLOGIC HISTORY

The Precambrian history of Kansas is not completely known. An interpretation of wells drilled through the sedimentary strata and penetrating the Precambrian have suggested that the depositional basins of Kansas have metasedimentary basement rocks as their chief constituent whereas areas of regional uplift have granitic material. Farquhar (1957) does not believe from the available information any correlation exists between structural configuration and lithology of the basement. An inferred Precambrian history concludes that igneous batholiths intruded the former complex of rocks to produce a varied basement of igneous and metamorphic rocks. Koester (1935) believes the ancestral Central Kansas Uplift probably originated in Precambrian time, but Lee (1956) does not find any expression of the Uplift on his Arbuckle group isopachous map.

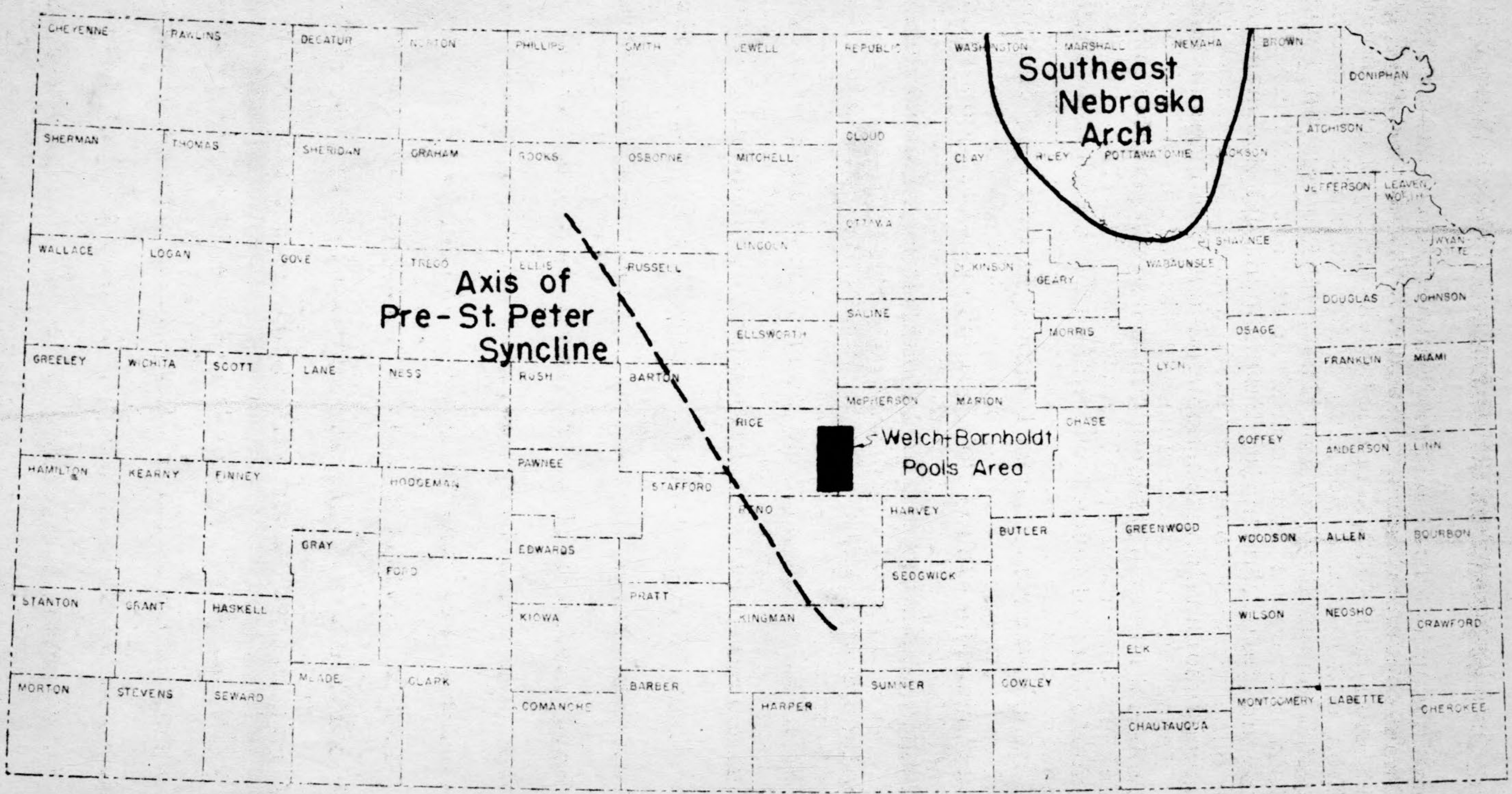
A partially-peneplaned Precambrian terrain of granite, metamorphic rocks, and "granite wash" existed when the Upper Cambrian sea extended into Kansas. Precambrian "granite wash" is the detritus from granite and metamorphic rocks that filled in the irregularities of the basement topography. Deposition of the arkosic and quartzitic Lamotte sandstone on the eroded surface of the basement rocks produced a relatively level surface. Northwest of the Welch-Bornholdt Pools Area, resistant Precambrian quartzite monadnocks rose 225 feet above the plain (Walters, 1946).

Lamotte deposition gave way to an advancing deep sea from which was deposited the Arbuckle group of rocks. The Bonneterre dolomite conformably overlies the Lamotte sandstone and overlaps on Precambrian hills where the Lamotte is absent. The following interval of Arbuckle deposition was marked by intermittent movements as shown by the distribution and thickness of formations and the unconformities between formations of the Arbuckle group. After Jefferson City-Cotter deposition a major deformation occurred in Kansas in which the Arbuckle and older rocks were subsequently partially-peneplaned. Structures in Kansas during Arbuckle deposition were the Southeast Nebraska Arch and a northwesterly trending syncline situated on the southwest side of the Arch (Plate 7). Elsewhere in the state, the sedimentary rocks were tilted southward toward the Anadarko Basin of Oklahoma.

An encroaching, fluctuating Ordovician sea from Oklahoma deposited clastic sediments in Kansas in late Simpson time. After the Simpson group, the St. Peter and Platteville formations, was deposited on the eroded Arbuckle surface, the Viola, Maquoketa, "Hunton", Chattanooga, and Boice rocks were deposited over much of Kansas. Erosion not only occurred after deposition of each of the formations, but some intraformational erosion occurred. The topographic relief created by the intermittent periods of erosion in central and northeastern Kansas was less than structural subsidence (Lee, 1956). Lee's (1956) thickness maps and cross sections of Arbuckle through Chattanooga rocks shows the Kansas sedimentary tectonic framework during this interval of deposition. The maps and cross sections reveal truncated Arbuckle and St. Peter rocks flanking the Southeast Nebraska

EXPLANATION OF PLATE 7

Pre-Simpson structural features of Kansas (adapted from Lee, 1956).



State Geological Survey of Kansas

PLATE 7

Arch and thickening of the Platteville formation in the same geographic location. During the hiatus between St. Peter - Platteville sedimentation the Southeast Nebraska Arch subsided to form the broader North Kansas Basin. Other structural features that developed in Simpson - Chattanooga time include arching of the Chautauqua Arch and the ancestral Central Kansas Uplift. The Welch-Bornholdt Pools Area in this period of sedimentation and deformation was situated on the eastern flank of the ancestral Central Kansas Uplift with the North Kansas Basin to the east and northeast (Plate 8).

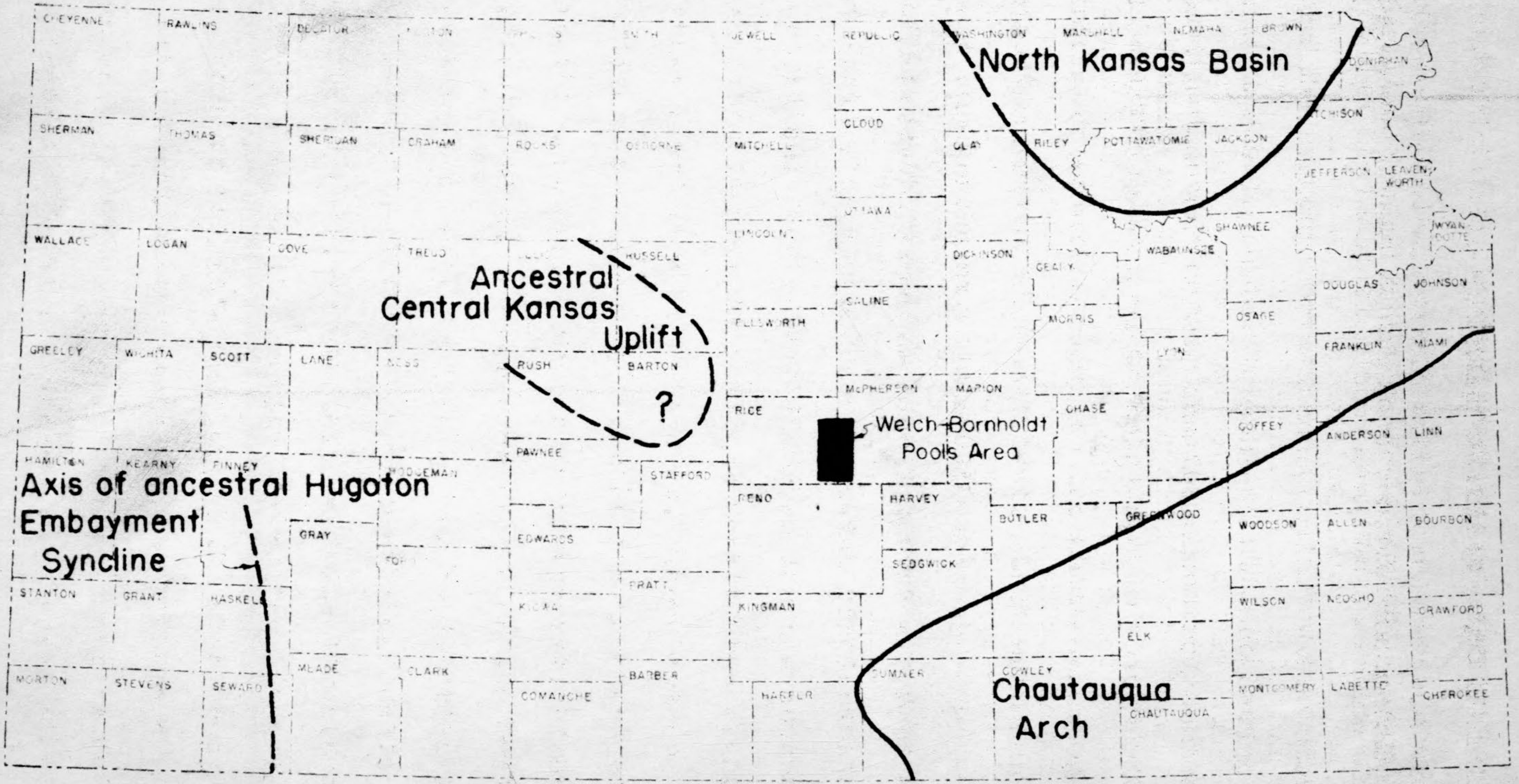
The post-Chattanooga-Boice interval of erosion presented an exceptionally level surface upon which Mississippian limestones were deposited. The early Kinderhookian sea covered eastern Kansas. The Kinderhookian limestones thicken toward central Iowa where subsidence was greatest. The Chouteau limestone and correlatives are found only east of the Nemaha Anticline. The area to the west must have been a structural "high" in early Kinderhookian time. Submergence of the Salina Basin and the area west of the Basin in late Kinderhookian time is indicated by the presence of the upper member of the Sedalia limestone, a widespread dolomite, and the Gilmore City limestone.

At the end of Gilmore City deposition, the Kinderhookian limestones were uplifted and beveled. Subsequent subsidence in the southern part of the state and in Oklahoma created a sedimentary basin for Osagian and Meramecian Series deposition. These Mississippian limestones show progressive overlap of successive formations to the north. Incipient movements of the

EXPLANATION OF PLATE 8

Simpson - Chattanooga structural features of Kansas (adapted from Lee, 1956).

PLATE 8



State Geological Survey of Kansas

Nemaha Anticline in early Osage time are indicated by the reentrant distribution of the St. Joe and Reeds Spring limestones on each side of the Nemaha Anticline where Mississippian strata is absent. The Burlington-Keokuk limestones represent the only Osagian formations that extended across the Central Kansas Uplift and rising Nemaha Anticline. Erosion followed Burlington-Keokuk deposition, after which the "Warsaw", Spergen, St. Louis, and St. Genevieve limestones of the Meramecian Series were deposited in the sedimentary basins and across anticlinal areas.

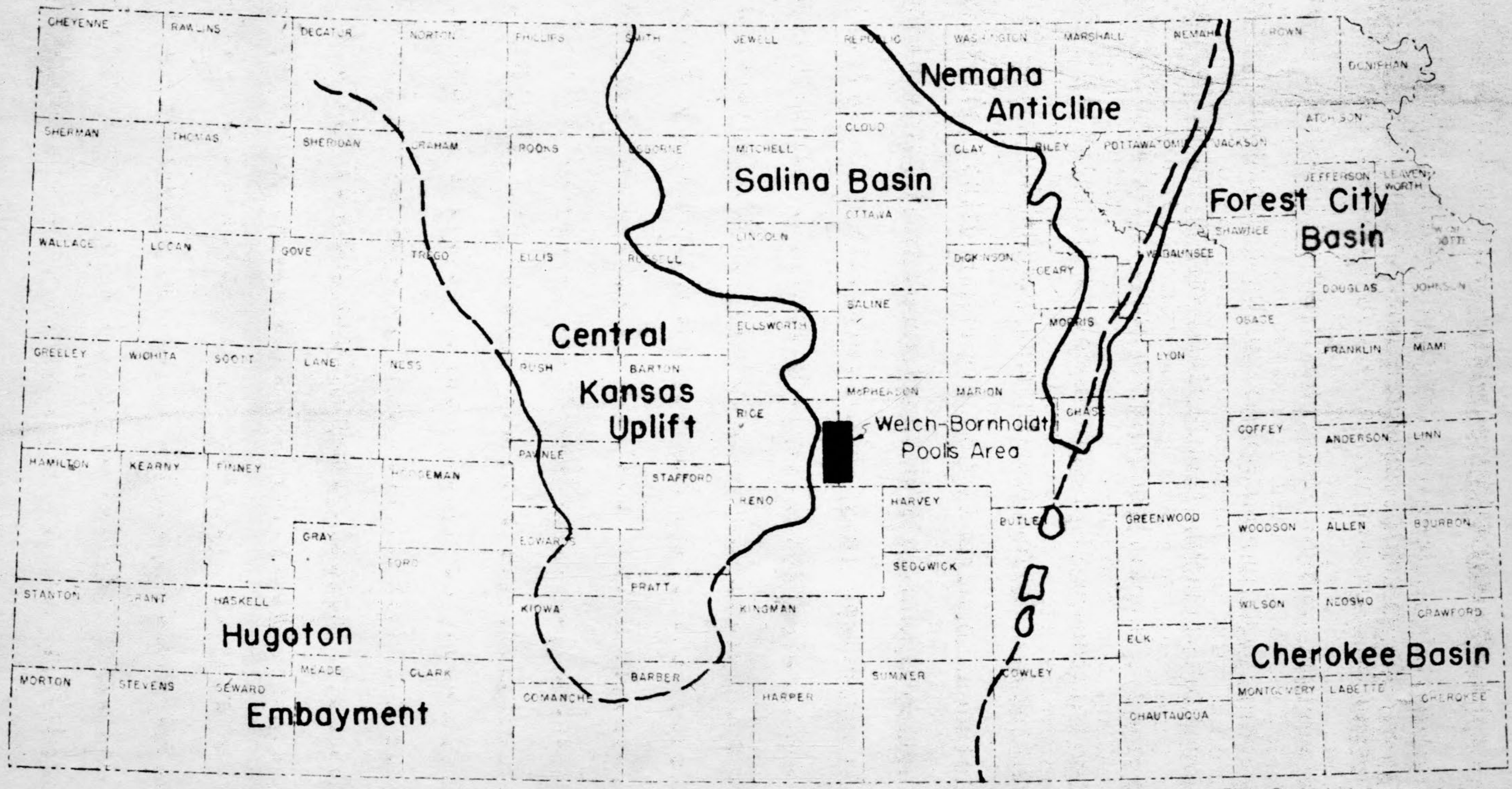
The Mississippian period of limestone deposition ended with a long interval of intermittent uplift and erosion which modified pre-existing structural features, destroyed older structures, and created new structures (Plate 9). The ancestral Central Kansas Uplift was arched so that most of the Mississippian limestones and older rocks present above the Arbuckle dolomites were removed and in places the Precambrian exposed. The Simpson and younger sedimentary rocks are found truncated on the flanks of the Uplift. The broad, northwesterly trending ancestral Central Kansas Uplift that existed prior to post-Mississippian deformation had associated, parallel, similar folds. Some of these folds were rejuvenated during post-Mississippian deformation.

The narrow, linear Nemaha Anticline was contemporaneously arched with the Central Kansas Uplift, but must have been of different structural grain. The northeasterly trending, long, narrow Nemaha Anticline contrasts strongly with the broad, northwesterly trending Central Kansas Uplift. The Nemaha Anticline is present in Nebraska and traverses southwesterly through

EXPLANATION OF PLATE 9

Mississippian - middle Permian structural features of Kansas (adapted from Lee, 1956).

PLATE 9



State Geological Survey of Kansas

Kansas into Oklahoma and fades out in the Anadarko Basin. Where the Nemaha Anticline traverses Nebraska and northeastern Kansas, it divided the former North Kansas Basin into the Forest City Basin to the east and the Salina Basin to the west. Southward the Nemaha Anticline crosses the west end of the structureless pre-Mississippian Chautauqua Arch. The Sedgwick Basin lies south of the Salina Basin, separated from the Salina Basin by an east-west saddle from the Central Kansas Uplift to the Nemaha Anticline. The tectonic forces responsible for the formation of the Nemaha Anticline also produced similar parallel folds. One prominent sharp fold with associated faulting, the Voshell Anticline, lies just east of the Welch-Bornholdt Pools Area.

Peneplanation followed post-Mississippian warpings which consisted of gentle positive movements that produced land areas only slightly above sea level. This is shown by the large amount of residuum (an untransported aggregate of the insoluble constituents of rocks) present on top of the unweathered limestones. The Mississippian residuum in the Welch-Bornholdt Pools Area probably represents chert and other detritus from the Burlington-Keokuk limestones and younger limestones (Clark, 1948). The soluble constituents of the limestone were removed by solution action during peneplanation.

After peneplanation but before the Pennsylvanian seas extended into Kansas the folded, truncated Mississippian and older rocks were subjected to renewed folding. The rejuvenated arching amplified most previous post-Mississippian folds, but some structural features were not revived and some new structural features were introduced. In general, the sharp northeasterly folds were more active than the broad northwesterly folds. This interval of folding and erosion did not last as long as the previous post-Mississippian interval of uplift, erosion, and peneplanation. The residuum that had formed and accumulated in situ was slightly redistributed, if any, so as to level the topographic irregularities created by this later folding.

A varied lithologic outcrop pattern existed in Kansas before Pennsylvanian sedimentation. A few Precambrian monadnocks were present on the Central Kansas Uplift with the Arbuckle dolomite being the most prominent outcrop (Walters, 1946). The Nemaha Anticline had a relatively narrow outcrop of Precambrian along its crest in central and northern Kansas and the Mississippian and older rocks were upturned and truncated on the flanks of the Anticline. In the central part of the Salina Basin and in other synclinal areas (Conway Syncline), only the "Warsaw" and Spergen limestones of the Meramecian Series remained. Collapsed caverns formed in places on the erosional surface where solution action was especially active.

The Pennsylvanian basal conglomerate, which varies in thickness and lithology, was deposited on Mississippian residuum in the Welch-Bornholdt Pools Area. The Cherokee sea of northeastern Oklahoma extended into Kansas in late Cherokee time. The gentle topographic relief of the Nemaha Anticline kept the Upper Cherokee sea from advancing any farther west until later. The Cherokee shale, sandstone, and coal section of southeastern Kansas is not present, as such, in the Salina Basin. When present, the rocks consist mainly of clastic gray silty shale interstratified with red shale. Intermittent folding and uplift of the Nemaha Anticline and Central Kansas Uplift affected the distribution, thickness, and lithology of these sediments west of the Nemaha Anticline. Subsequent cyclic and semi-cyclic deposition of Pennsylvanian and Permian rocks filled in the subsiding basins and progressively overlapped upon the regional positive areas.

Lee's (1956) thickness maps show the post-Mississippian structural features continued intermittent movements with diminishing intensity until middle Permian time. During deposition of salt beds in Wellington time, the Central Kansas Uplift and Salina Basin areas were tilted to the southwest toward the Hugoton embayment (Lee and Merriam, 1954). The erosion during the hiatus between the Permian and Cretaceous removed, if ever present, Triassic and Jurassic sediments and roughly truncated the westerly inclined Permian rocks. Cretaceous seas advanced from the Gulf of Mexico through Texas, Oklahoma, Colorado, and northward. Cretaceous deposition extended eastward to central Kansas and probably farther. A structural contour map on top of the Dakota group, of Cretaceous age, shows a northward tilting of most of Kansas toward basins in Nebraska (Lee and Merriam, 1954). This tilting is a composite of all tectonic movements that have occurred since Dakota deposition. Tertiary and Quaternary deposits occur throughout in central Kansas. Recent erosion is cutting the Cretaceous escarpment westward and is incising the present drainage valleys.

PRODUCING ZONE

Bramlette (1925) published a cross section from Marion County to Russell County, Kansas, in which a part of the line of the cross section traverses about two miles north of the Welch-Bornholdt Pools Area in which similar stratigraphic and structural conditions persist. Bramlette interpreted the chert beds as Mississippian in age.

Moore (1926) assigned the name Welch chert to the producing zone of the Welch pool. He believed the Welch chert was early Pennsylvanian in geologic age because of paleontological evidence from similar chert in the adjacent "Sheridan well", Ellsworth County, Kansas. Moore (1926) described the Welch chert from well samples in Reno, Rice, and Ellsworth Counties as,

> . . . a zone consisting mostly of white chert, and ranging in thickness to nearly 200 feet, a part of the chert is much weathered, rotten, and is deeply stained by iron oxide; there are rounded and unevenly pitted surfaces that contrast strongly with fresh broken surfaces made by the drill. Very much of the chert has been broken up by the drill and is correspondingly sharp angled and splintery; it consists in large part of very dense "butcher knife" chert, and much of it is not unlike the "chat" so widely used as road metal in the Joplin country and elsewhere. In some cases the cuttings consist of almost nothing but this chert for scores of feet, and the horizon is naturally very distinctive. Some of the samples show more or less admixed red clay, and not uncommonly there are a few fairly large, very well-rounded, and often frosted grains of transparent quartz. Irregular fragments of fine sandstone or in some cases more or less siliceous and dolomitic limestone occur also. Fragmentary, worn, silicified fossils, some of them apparently derived from the Mississippian, appear to be secondarily deposited in this formation . . .

The red material associated with the chert occurs below it, above it, or intermingled with it. Microscopic

> examination shows that the red rock is mostly a very deep oxidized, ferruginous, clayey material like the residual strongly ferruginous clay that is seen in most limestone regions. A part of the red material is a typical geest with abundant scattered sand grains and other foreign material in a matrix of red clay. Indeed, the entire deposit suggests strongly the residual chert and red clayey materials which are so common in the Mississippian areas of southwest Missouri and other parts of the country.

Moore (1926) believed the Nemaha Anticline was the dominant structure in the formation of the Welch chert.

Denison (1926) more correctly interpreted the structural genesis of the Welch chert. Denison believed the Barton Arch (Central Kansas Uplift) was the responsible structure for the formation of the chert beds.

Ley (1926) believed that Mississippi "lime" was present to some extent west of the Nemaha Anticline, and that the Welch chert as defined by Moore (1926) was correlative with the Fort Scott (Oswego Lime) limestone at the outcrop to the east. Ley drew his conclusion from "well-logs".

Barwick (1928) did an excellent job of explaining the origin of the Welch chert and the Pennsylvanian basal conglomerate from well samples he studied. Barwick stated,

> The uplift of the granite ridge and Barton arch in the interval between Mississippian and Pennsylvanian deposition also resulted in the "Mississippian lime" in the lowest part of the Salina basin being raised above the level of the surface of the "Mississippian lime" east of the ridge. Erosion followed, which very nearly base-leveled the area, but which left it with a southeastward slope. Pennsylvanian deposition began in southeastern Kansas, and the seas gradually advanced northwestward. During early Cherokee deposition in eastern Kansas, the area of the Salina basin was beyond the limits of the sea, but so nearly base-leveled that mechanical erosion and transportation were almost impossible. Conditions were then ideal for the action of

> ground water on the cherty limes exposed in the basin. The soluble carbonates in the limestone were dissolved and replaced by silica in the form of chert. This process had its greatest effect on the "Mississippian limes" on the flanks of the basin, where the entire thickness of the "Mississippian lime" was altered and residual cherts as much as 150 feet in thickness were formed. The northwestward advancing seas covered the Salina basin in late Cherokee and early Marmaton time. Their initial deposit was a basal conglomerate, which, like the floor over which they were advancing, consisted largely of chert, but contained also considerable quartz sand, and granitic material. Above it were deposited the varicolored shales and thin limes of the Marmaton.

Barwick (1928) described the Welch chert as, " . . . chert of remarkable purity and constancy in stratigraphic position, ranging gradually in thickness from a few feet to 150 feet and resting either directly on the "Mississippian lime" or on top of the Skelton shales (Chattanooga shale)."

McNeil (1941) described the Mississippian "chat" beneath the Pennsylvanian basal conglomerate in the Wherry pool as, " . . . residual chert, very probably the insoluble residue from the solution of Burlington-Keokuk beds. The chert is commonly white opaque to translucent and insoluble to slightly soluble in hydrochloric acid."

Walters (1946) described the conditions under which an Ordovician residuum of probable Mississippian age and an early Pennsylvanian conglomerate were formed in the Kraft-Purusa district. Similar conditions probably existed in the Welch-Bornholdt Pools Area. Walters (1946) stated,

> When the lithology of these non-carbonate sediments (Ordovician residuum) in cores or excellent cable-tool samples is plotted in detail, exactly the same material is present in the lower part of these non-carbonate sediments as is present in laboratory prepared acid

> insoluble residues made from fresh Cambro-Ordovician dolomite in well cuttings from a near-by test, and in exactly the same lithologic sequence. It is therefore now recognized that these non-carbonate sediments include a considerable amount of untransported residuum of Cambro-Ordovician. Instead of being a clastic "conglomerate" associated with orogenic movements, the sediments associated with the early Pennsylvanian land surface include three types of material of varied origin, all associated with gentle epeirogenic movements. These are . . . (1) untransported leached residuum of Cambro-Ordovician, (2) Pennsylvanian nonmarine conglomerate, and (3) Pennsylvanian marine conglomerate.

The Mississippian "chat" as observed by the author in microscopic examination of well cuttings consisted of both fresh and weathered chert grains. The fresh chert appeared as gray to white dense grains with sharp conchoidal faces. Some fresh chert grains showed cementation of grains with chalky weathered seams both through the grains and along cementation contacts. Evidently fracturing occurred, irrespective of grain contacts, with subsequent weathering along the fractures. One fresh chert grain studied had a clear crystalline quartz seam within a chalky seam, which illustrates that some diagenetic changes have occurred. Numerous quartz crystals were seen on the sides of fresh chert grains. This appearance of quartz probably represented geode development as illustrated by Plate 10 or where the "drill" broke across a recrystallized quartz seam. Some clear, transparent quartz grains were also present. These grains were usually small, well-rounded to angular in outline. The source of these individual quartz grains probably is the same as the quartz on the sides of the fresh chert grains. The weathered chert appeared as white, opaque, porous grains. The weathered porous chert was not always completely weathered through the fresh chert. Where the "drill" broke many of the weathered chert grains various stages of weathering were observable. These grains showed a weathered porous outside cover. The center of the chert grains were unweathered fresh dense chert. Some pyrite and celestite also were present in the samples. Green, gray, and red shale appeared in the samples.

Plates 10, 11, and 12 are cores of the Mississippian "chat" from Barber County, Kansas. Although the cores are not from the Welch-Bornholdt Pools Area, they illustrate well the lithology which probably exists in the Welch-Bornholdt Pools Area.

Porosity and permeability of the Mississippian "chat" are determined by the amount of silica cementation, shale, and lime present. Clark and others (1948) attributed the origin of porosity and permeability in the area of study to, "The fact that sufficient porosity to permit accumulation does not occur along the wedge edge suggests that the phenomenon may have been controlled by the ground water levels prevailing during the Mississippian-Pennsylvanian hiatus." No quantitative values for permeability were available except in the Smyres sector where electric and radioactive logs had been taken. The well logs showed widely varying porosities in the Smyres sector. The logs indicated high filtrate loss of fluid to the formation which was indicative of rather high permeabilities and low reservoir pressure. Continental Oil Company's petroleum engineers estimated permeability at several hundred millidarcys in the most permeable parts of the Smyres sector.

EXPLANATION OF PLATE 10

A core of the Mississippian "chat" from Barber County, Kansas. The diagenetic change, recrystallization, produced a geode lined with quartz crystals. (Courtesy of Continental Oil Company).

PLATE 10

EXPLANATION OF PLATE 11

A core of the Mississippian "chat" from Barber County, Kansas. This core illustrates fractured fresh chert with early Pennsylvanian shale penetration of the fracture planes. (Courtesy of Continental Oil Company.)

PLATE 11

EXPLANATION OF PLATE 12

A core of the Mississippian "chat", illustrating the general character of the producing "chat" in the Welch-Bornholdt Pools Area. The chert was greatly weathered so that only a white, opaque, porous chert remained which is an excellent reservoir rock. (Courtesy of Continental Oil Company.)

PLATE 12

As in many other pools, especially Mississippian "chat" or Pennsylvanian basal conglomerate producing pools, a small percentage of the wells produce the majority of the oil. Greatest production in the Welch-Bornholdt Pools Area has been from parts of the Welch and Bornholdt sectors.

Mississippian "chat" petroleum production in the Welch-Bornholdt Pools Area has been somewhat erratic, but not as erratic as production from the Pennsylvanian basal conglomerate. Oil is found after about two to eight feet of low-porosity-permeability "chat" has been penetrated. The first occurrence of oil is in a dense saturated "chat" that requires sand fracturing before satisfactorily commercial production can be obtained. Beneath the saturated dense "chat" is a porous saturated "chat" which has been the profic reservoir horizon from which most of the oil has been obtained. A modified water drive in the lower porous producing horizon has produced a slight water flooding effect.

The only locality within the Welch-Bornholdt Pools Area that has produced from the Pennsylvanian basal conglomerate has been the Windom sector (Smith, 1959) and perhaps the northern part of the Smyres sector. The Wherry pool, west of the Welch-Bornholdt pool, and the Lost Springs pool, in Marion and Dickinson Counties on the east flank of the Salina Basin, have produced from the Pennsylvanian basal conglomerate. Petroleum production has been very erratic. Initial production has been in great or small quantities with cumulative production varied according to length of well producing life. The variable production of these pools has been due to the sedimentation in the post-Mississippian - pre-Marmaton that produced the conglomeratic nature of the reservoir rock.

Barwick (1928) described the Pennsylvanian basal conglomerate above the Welch chert as,

> . . . heterogeneous material consisting largely of chert, but with considerable rounded-to-angular quartz sand, some granitic material, and much admixed shale, ranging in short distances from almost nothing to as much as 15 to 20 feet in thickness and resting on the pre-Pennsylvanian erosional surface.

McNeil (1941) described the Pennsylvanian basal conglomerate of the Wherry pool as,

> . . . a mass of unconsolidated rounded chert pebbles and boulders. These are much weathered and cuttings appear as red, brown, yellow, pink, tan, and white translucent to dull opaque chert. As a general rule, the chert appears more unaltered and compact with depth. The size of the fragments ranges from small pebbles to boulders several pounds in weight.
>
> Medium-rounded sand grains may be present with the chert. These sand grains may or may not be found in a matrix of pale green or red soft soapy shale. In certain parts of the pool a section of fine-to-medium consolidated calcareous sand up to ten or more feet in thickness may immediately overlay the chert or may be separated from it by a thin bed of green or red shale. This sandy phase is best developed in the central and southern part of the pool . . .
>
> The conglomerate becomes shaly at the east end of the pool. There may be one or more beds of red shale below the top of the chert . . .

Rich (1928) described the Pennsylvanian basal conglomerate of the Lost Springs pool as,

> . . . the so-called "chat" of the drillers (presumable the local representative of the Welch chert) seems clearly to lie on or to be the eroded top of the "Mississippian lime". Part of it, at the top, is

> certainly more or less reworked, as is evidenced by the pebbly character of some of the material and the presence of chert pebbles in the shale immediately above. Below the re-worked material appears to be a gradation through residual chert, as described by Barwick, to unaltered cherty limestone, or "Mississippian lime".

Shenkel (1955) described the "chat" and Pennsylvanian basal conglomerate as synonamous in the Lost Springs Pools Area. Shenkel's description of the Pennsylvanian basal conglomerate was,

> . . . grains of tripolitic chert, chert, quartz, and chalcedony imbedded in varicolored clay and shale. Buff, finely crystalline dolomite occurs irregularly in the conglomerate in the northern and western parts of the Lost Springs Pools Area. In places, the varicolored clays and shales are absent and the weathered chert particles may be unconsolidated, or loosely cemented by iron oxide or silica.

Tectonic movement along the western flank of the Nemaha Anticline evidently caused the Mississippian residuum that formed and accumulated during the post-Mississippian - pre-Marmaton to be completely reworked and assimilated by the early Pennsylvanian seas. The resulting Pennsylvanian basal conglomerate was deposited directly on the unweathered Mississippian limestone.

DRILLING METHODS

From 1924, when the discovery of the Welch pool was drilled, to the early 1940's most wells were drilled with cable tool equipment. Since the early 1940's wells have been drilled with rotary equipment.

Several techniques of drilling wells are employed by operators in the Welch-Bornholdt Pools Area. Some companies drill with rotary equipment to the top of the Mississippian "chat", or several feet into the upper dense "chat" and set pipe. Rotary equipment is moved off location and cable tool equipment is moved in to "drill in" the well. When the first porous zone in the "chat" is reached, drilling is stopped. Another technique of drilling wells is to drill completely through the "chat" into the unweathered limestone or Chattanooga shale and set pipe. Then the pipe is perforated where desired. In the Windom sector, oil is obtained from both the Pennsylvanian basal conglomerate and the Mississippian "chat" and the wells are perforated at the two producing zones.

Recent wells drilled in the Welch-Bornholdt Pools Area have been sand fractured upon well completion and older wells have been sand fractured to increase production. Acidization of the producing zone is not considered a necessary completion technique. Some wells have been squeeze-cemented to decrease salt water production.

The oil occupies the spaces between impermeable chert grains (Lee, 1939). Care must be taken in the evaluation of sample study at the well site because washed samples may not show evidence of oil.

PETROLEUM PRODUCTION

Plate 13, Fig. 2 shows petroleum production by years in the Welch-Bornholdt Pools Area from 1924 to the end of 1957. Estimated cumulative production to the end of 1957 was 29, 473, 180 barrels of oil with 424 wells still producing. Maximum production occurred in 1943, after the rapid exploitation of the Bornholdt and Smyres sectors.

A correlation exists between drilling activity (Plate 13, Fig. 1) and petroleum production (Plate 13, Fig. 2). After initial development of the Welch sector between 1924-27, drilling activity ceased because much of the pool had been developed and because of the economic depression. Accordingly Plate 13, Fig. 2 shows a rapid rise in petroleum production corresponding to development of the Welch sector with a gradual decline in production in the late 1920's and 1930's because of no drilling activity. Production soared upward in 1940 as a result of exploitation of the Bornholdt sector. Drilling activity since 1940 continued somewhat erratically because of the effects of World War II and post-World War II oil demands. Continuous drilling activity, complimented by recent developments in well completions and workovers, has been responsible for keeping production from declining at a too rapid rate.

Oil wells have been drilled on 10, 20, and 40 acre spacing. The Welch sector was developed on 10 acre spacing, the Bornholdt sector on 20 acre spacing, and the Smyres sector on 40 acre spacing. Subsequent drilling has reduced the 20 and 40 acre spacing to 10 and 20 acre spacing.

Crude oil of the Welch-Bornholdt Pools Area averages 35 degrees Baume, ranges from 100 to 110 degrees F., and is a black paraffin type base of crude oil. The paraffin oil involves production problems which requires periodic attention. Pumping

EXPLANATION OF PLATE 13

Fig. 1. Drilling activity by years in Welch-Bornholdt Pools Area (adapted from files of Kansas Geological Survey).

Fig. 2. Petroleum production by years in Welch-Bornholdt Pools Area (adapted from files of Kansas Geological Survey).

PLATE 13

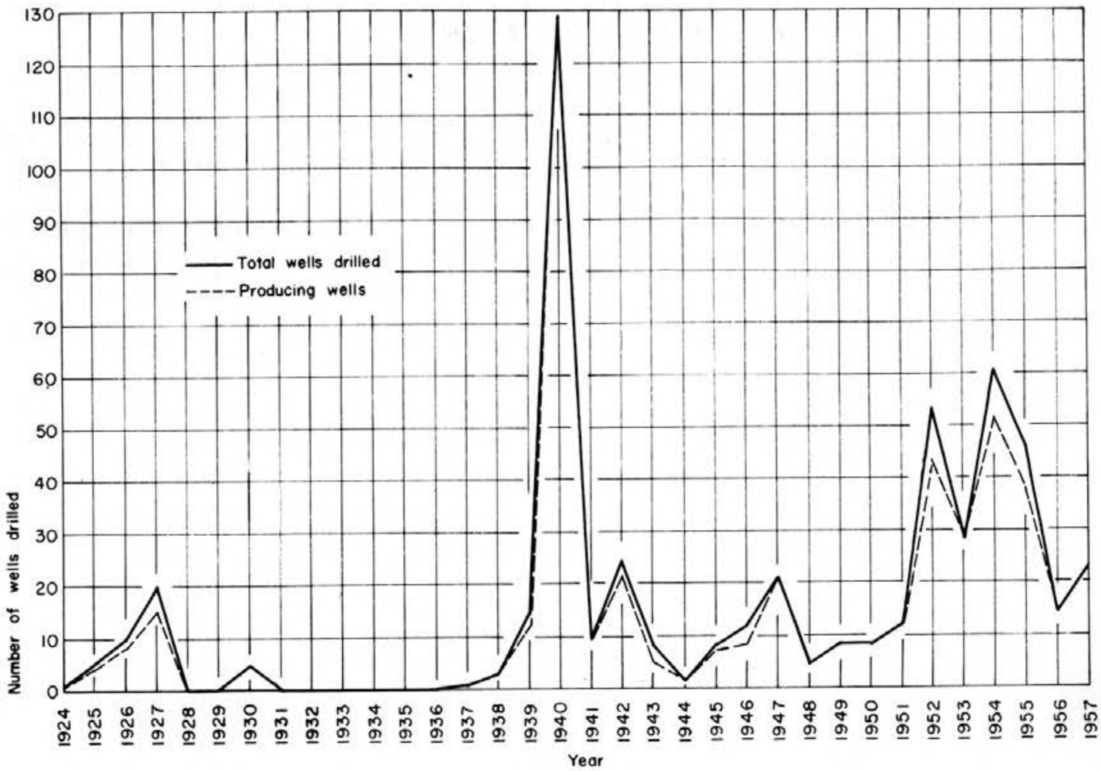


Fig. 1

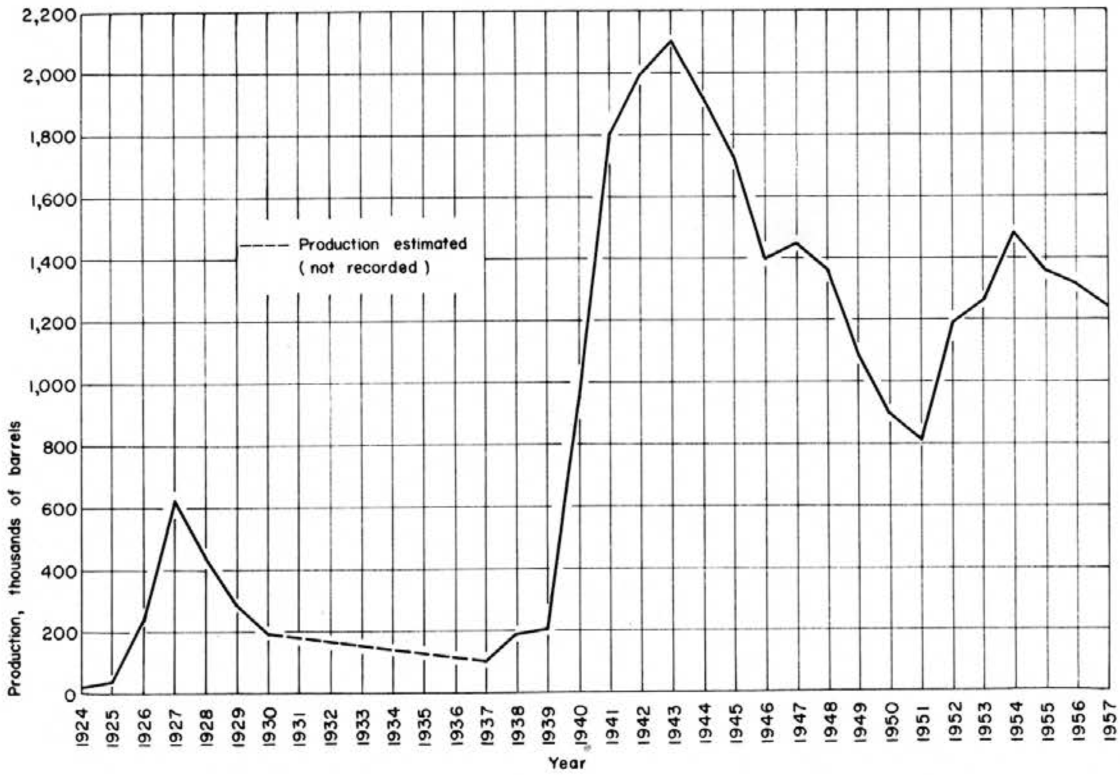


Fig. 2

equipment is maintained in condition by injection of hot water down the anular space between the tubing and casing. The hot water returns to the surface inside the tubing, thus removing the troublesome paraffin. This procedure must be repeated every four to six weeks. After the crude oil is pumped from the well to the tank battery, the paraffin settles to the bottom of the storage tanks. The storage tanks must be cleaned periodically to keep the paraffin content low so the pipe line will not become troubled.

Originally the oil-water contact was -1845 foot on the downdip edge of production in the Bornholdt sector. Initially only downdip marginal wells produced water with oil; the updip wells only had traces of water with produced oil. Subsequent production has differentially raised the water level, at least 40 feet, and now all wells produce water with oil. At present, wells in the Welch-Bornholdt Pools Area produce from 25 to 99 per cent water with oil. The present oil-water contact is not known. The water level has never been uniform probably due to the variations in porosity and permeability. An example is the -1845 foot original oil-water contact in the Bornholdt sector. In the Windom sector the original oil-water contact was -1805 foot, and in the Rellim pool the oil-water contact was about -1705 foot. During early development of the area of study, salt water produced with oil was undoubtedly disposed of by shallow evaporation ponds, but presently all salt water is disposed of by disposal wells in the Arbuckle rocks or the Mississippian "chat". A chemical is added periodically into the oil and salt water as it is pumped from the well to the tank battery. Separation of the oil and salt water occurs in the gun barrel, assisted by a chemical, whereupon the oil flows into the storage tanks and the salt water into disposal wells. Constant attention must be paid to equipment to watch for salt water leaks. Salt water is very destructive to equipment because of its corrosional activity.

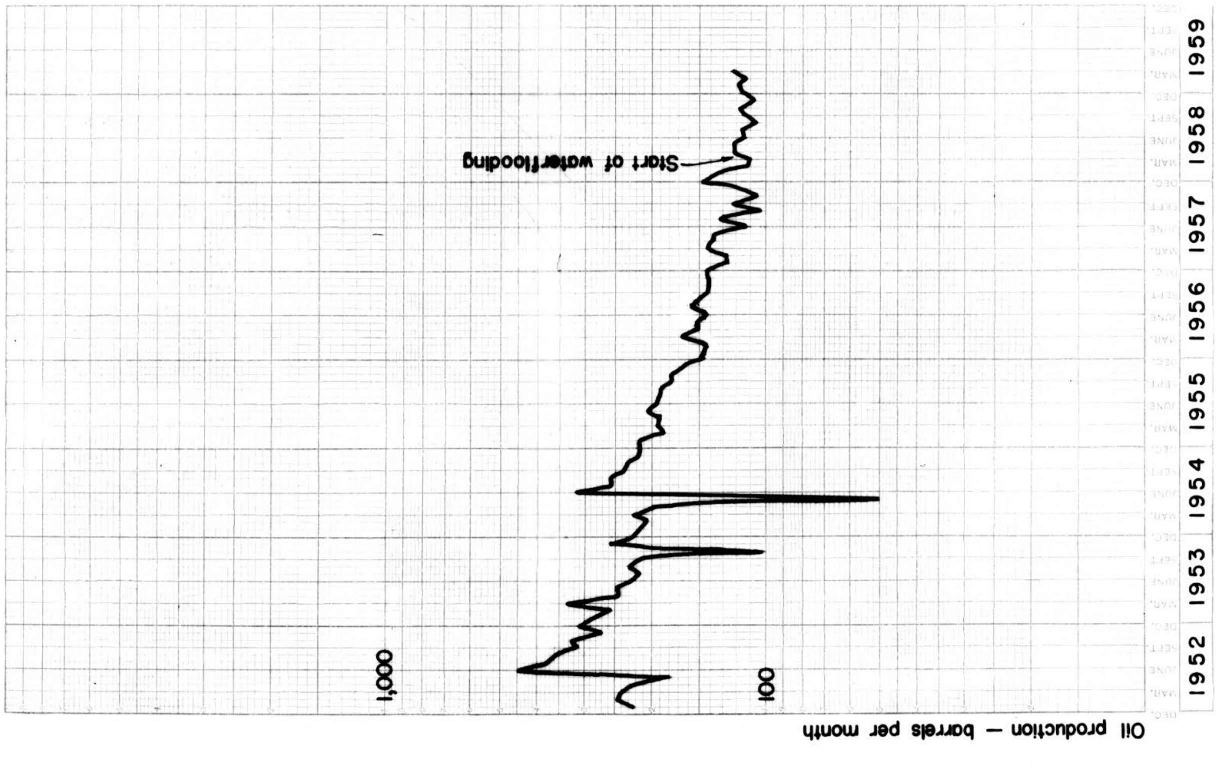
The pools in the Welch-Bornholdt Pools Area have a gas-solution modified water drive. The author does not know of a past or present definite gas cap in any of the pools, but many producing wells still have a slight gas-solution drive. Initial wells in the area of study, primarily in the Welch and Bornholdt sectors, had a high gas-oil ratio (332 cubic feet of gas per barrel of oil), a moderate water drive, and an approximate reservoir pressure of 1200 psi. These initial wells flowed naturally from one to two years before being put on standard pumping equipment. The present reservoir pressure is unknown but as the Mississippian "chat" disposal wells take salt water by gravity, very low pressure is indicated. All oil is pumped in the Welch-Bornholdt Pools Area at the present time. Oil wells in the area of study are all electrified except in parts of the Welch and Bornholdt sectors. These wells are powered by natural gas, all or part of which is produced with the oil.

Plate 14 shows the petroleum production decline curve of Sterling Drilling Company's Miller lease (4-215-6W) from 1952-59. Plate 15 shows the history of the wells on the Miller

EXPLANATION OF PLATE 14

Petroleum production decline curve of Miller lease in Welch-Bornholdt Pools Area. Producing horizon, Mississippian "chat". (adapted from files of Sterling Drilling Company.)

PLATE 14


Oil production — barrels per month
1,000
100
Start of waterflooding
1952
1953
1954
1955
1956
1957
1958
1959

EXPLANATION OF PLATE 15

History of wells on Sterling Drilling Company's Miller lease (adapted from files of Sterling Drilling Company).

PLATE 15

Miller #1 - Injection well.

Miller #2 - Completed September 1947 as open hole. Never fractured. Later drilled deeper and well flooded with salt water. Plugged back to original depth for production of 5 bbl oil/day.

Miller #3 - Completed October 1947 as open hole. Sand fractured in June 1951 with 1400 lb. sand. Before treatment well produced 5 bbl oil/day no water, after fracturing well produced 25 bbl oil/day 20 per cent water.

Miller #4 - Completed November 1947 as open hole. Produced 50 bbl oil/day no water, by 1956 production had declined to 4 bbl oil/day and 40 bbl water/day. In May 1956, well was sand fractured and presently produces 6 bbl oil/day and 294 bbl water/day.

Miller #5 - Completed December 1947 as open hole. Sand fractured in 1954, presently produces 8 bbl oil/day and 119 bbl water/day.

Miller #6 - Completed February 1948 as open hole. Fractured in January 1952, presently produces 4 bbl oil/day and 62 bbl water/day.

Miller #7 - Completed September 1948 as open hole. Previous to sand fracture in July 1951, well produced 4 bbl oil/day and 1 bbl water/day. After treatment well produced 16 bbl oil/day and 313 bbl water/day. Present production is 3 bbl oil/day and 430 bbl water/day.

Miller #8 - Completed May 1952 as fractured open hole. Initial production was 25 bbl oil/day no water, present production 7 bbl oil/day and 77 bbl water/day.

lease. The Miller No. 1, structural lowest well on the lease, was used as a disposal well in the Mississippian "chat" starting April 5, 1958. Initial injection was 530 barrels of salt water per day. Present water injection rate is 1100 bbls/day. Total water to date injected into the Miller No. 1 is 380,066 barrels. The water is slightly treated at the injection well. Prior to water flooding the Miller lease produced 33 to 35 barrels of oil per day. Average production since water flooding is 40 barrels of oil per day. Water flooding has leveled the production decline curve. Plate 14 shows the effects of water flooding which somewhat illustrates the amount of residual oil present and the permeability of the "chat"; but conclusions are not definite because water flooding has been in progress only a short time. The decline curve indicates that water flooding may be a feasible economic method of secondary recovery for the rest of the pools in the Welch-Bornholdt Pools Area. As a relatively inexpensive production technique water flooding holds future promise for the Welch-Bornholdt Pools Area.

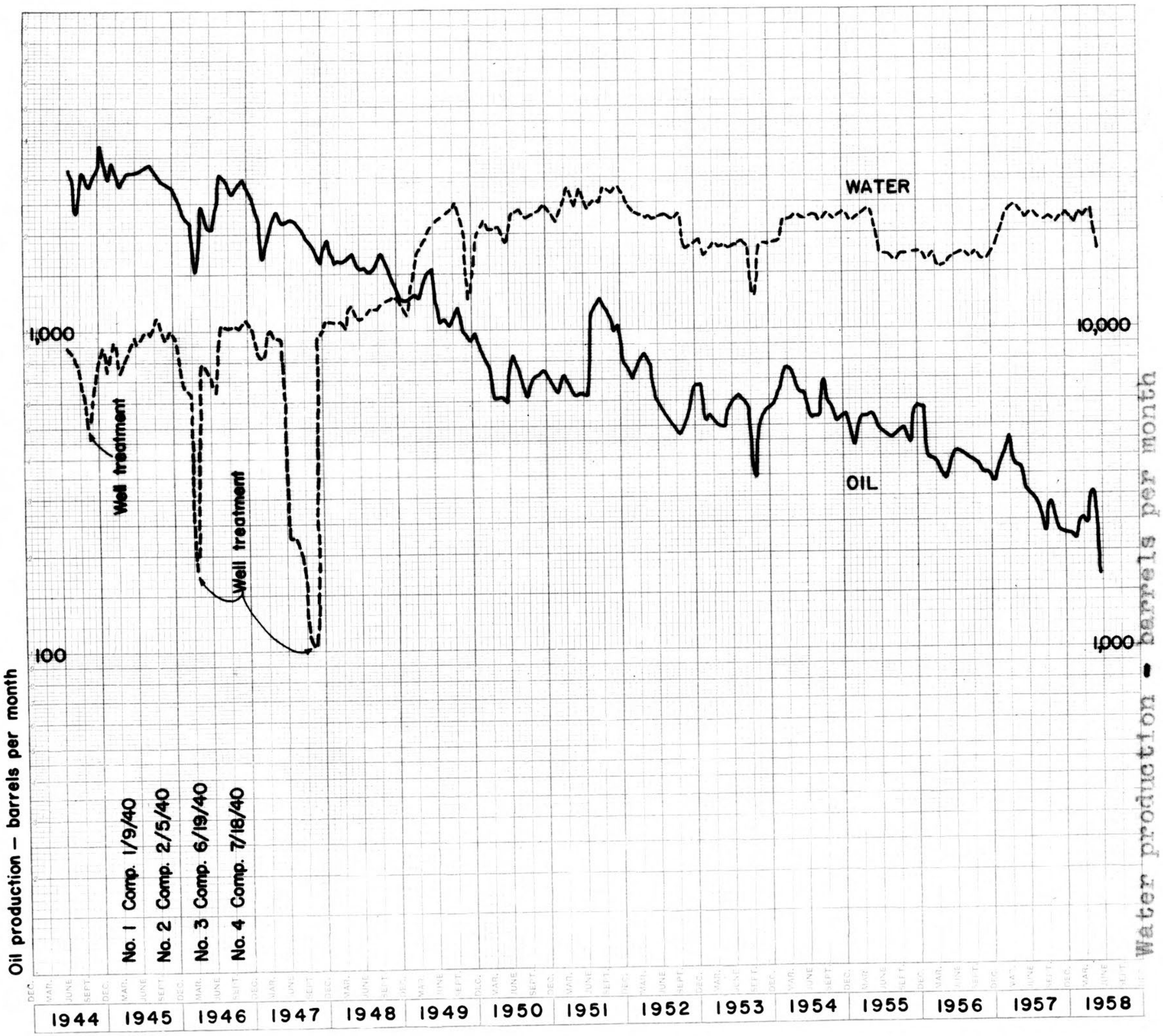
The Bornholdt sector is on the downdip edge of production. After production had differentially raised the original water level from -1845 feet to an unknown present elevation, all wells produced water with the oil. Continental Oil Company's leases in the Bornholdt sector by 1944-45 produced more salt water than could be economically produced and disposed. Continental Oil Company subsequently reworked six wells to reduce water production. The procedure employed was to "squeeze cement" the entire open hole section with 75 sacks of cement to

2,000 psi, drill out approximately 20 feet, and shoot the lower 10 feet of section with nitroglycerin. Plate 16, a decline curve of Continental Oil Company's Bornholdt lease (E $\frac{1}{2}$, SE $\frac{1}{4}$, Sec. 30, T. 20 S., R. 5 W.) shows the effects of the well treatment. November 1944, April 1946, and November 1947 represent temporary decreases in salt water production due to the well treatment. The effects of the well treatment only lasted about one month. Oil production steadily decreased with an increase in salt water production until 1949, which has remained fairly constant to the present day.

Continental Oil Company sand fractured 13 wells between 1953-56 to decrease the rapid oil production decline on their leases in the Bornholdt sector. Two fractured wells were subsequently re-sand fractured successfully. Only two out of 15 fracture treatments were unsuccessful. The average fracturing treatment for these wells consisted of 7,200 lbs of sand and 6,500 gallons of oil. The average increase in production was 23 barrels of oil per day. Plates 17 and 18 summarize the production history from 1944-58 of two Continental Oil Company leases. Plate 17 shows the production history of the Knackstedt lease (E $\frac{1}{2}$, NW $\frac{1}{4}$, Sec. 30, T. 20 S., R. 5 W.). In February 1953, one well was sand fractured. The decline curve shows a corresponding temporary increase in oil production with a slight increase in salt water production. In May 1956, two other wells on the Knackstedt lease were fractured. Again a substantial temporary increase in oil production is shown on the decline curve with essentially the same salt water production. The

EXPLANATION OF PLATE 16

Petroleum production decline curve of Bornholdt lease, E. $\frac{1}{2}$, SE Sec. 30, 20 S., 5 W., in Welch-Bornholdt Pools Area. Producing horizon, Mississippian "chat". (Adapted from files of Continental Oil Company.)

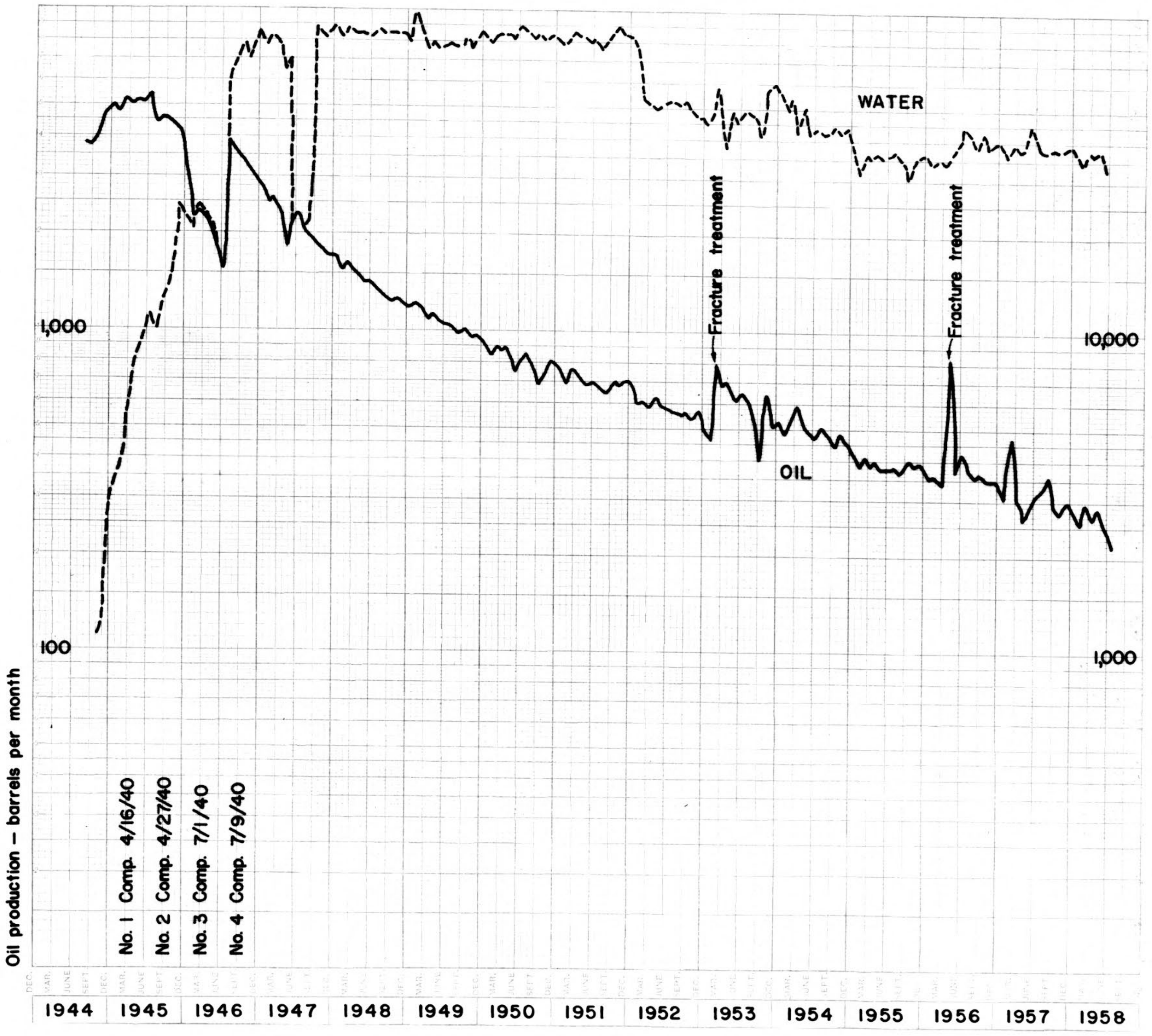


Oil production — barrels per month
Water production - barrels per month
WATER
OIL
1,000
100
10,000
1,000
Well treatment
Well treatment
No. 1 Comp. 1/9/40
No. 2 Comp. 2/5/40
No. 3 Comp. 6/19/40
No. 4 Comp. 7/18/40
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958

PLATE 16

EXPLANATION OF PLATE 17

Petroleum production decline curve of Knackstedt lease, E. ½, NW Sec. 30, T. 20 S., R. 5 W., in Welch-Bornholdt Pools Area. Producing horizon, Mississippian "chat". (Adapted from files of Continental Oil Company.)



Water production - barrels per month

PLATE 17

EXPLANATION OF PLATE 18

Petroleum production decline curve of Carlson lease, Sec. 35, T. 20 S., R. 6 W., in Welch-Bornholdt Pools Area. Producing horizon, Mississippian "chat". (Adapted from files of Continental Oil Company.)

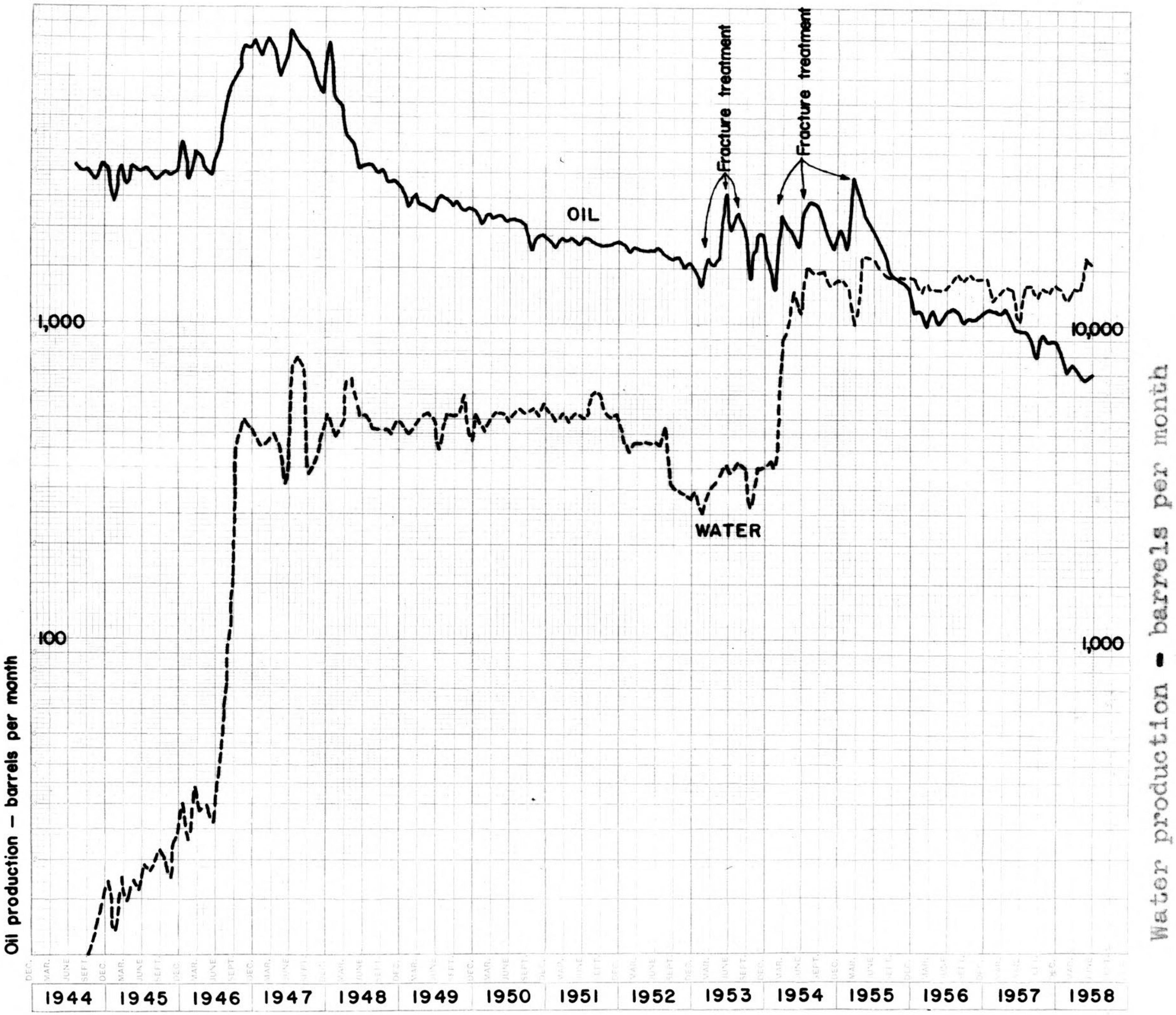

Fracture treatment
Fracture treatment
OIL
WATER
1,000
100
10,000
1,000
Oil production – barrels per month
Water production - barrels per month
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958

PLATE 18

overall effect of the fracture treatments to wells on the Knackstedt lease is shown as a very slight "flattening" on the decline curve with no significant change in salt water production.

Plate 18 shows the petroleum and salt water production history of the Carlson lease (Sec. 35, T. 20 S., R. 6 W.) from 1944-58. Three wells on the Carlson lease were fractured in February, May, and July of 1953. The decline curve shows corresponding increases in oil and salt water production following well treatment. Well fractures in February and June 1954, and February 1955, also increased oil and salt water production after well treatment. The overall effect of fracture treatment to wells on the Carlson lease increased oil production for about a year or less, with a resumption to its previous decline. The Carlson lease is about average in the Welch-Bornholdt Pools Area for sand fractured wells. The lease showed a substantial increase in salt water production that remained high. Oil production temporarily increased and then returned to its normal decline.

The Windom sector and the northern half of the Smyres sector produce from both the Mississippian "chat" and the Pennsylvanian basal conglomerate. Most production is obtained from the Mississippian "chat". The oil from both producing zones is similar. In the Windom sector the Pennsylvanian basal conglomerate produces less salt water than the Mississippian "chat". The Windom sector, an anticlinal structure, has salt water present completely surrounding it which produces a modified water drive.

The Rellim pool has a good gas-solution drive and a poor water drive (Frensley, 1959).

RELATIONSHIP OF PETROLEUM ACCUMULATION TO STRUCTURE AND STRATIGRAPHY

Plate 22 shows the relationship between the petroleum reservoir rock, the Mississippian "chat", and the structure. Plate 24, similar to Plate 22 in structure, shows the general structure of the Welch-Bornholdt Pools Area as a structural nose at the southeast extremity of the Geneseo Uplift. Plate 22 shows that petroleum accumulation is not associated with anticlinal structure, but is controlled by stratigraphic factors. Production generally occurs in a porous zone of the "chat" downdip from the truncated Mississippian chert beds. An exception is the Rellim pool which is adjacent to the Mississippian zero line. Clark and others (1948) believed porosity and permeability was formed in the Welch-Bornholdt Pools Area by solution action during the post-Mississippian - pre-Marmaton. A correlation probably does not exist between petroleum accumulation and the Mississippian zero line. Porosity and permeability probably formed somewhat uniformly around the east and southeast flank of the Geneseo Uplift prior to Pennsylvanian sedimentation. As the Pennsylvanian basal conglomerate was deposited, the Mississippian zero line was modified so production occurred adjacent or downdip from the Mississippian zero line. A guide for development was to follow apparent porosity and permeability trends.

Greatest production (over 100,000 barrels of oil per well) has been concentrated in the Welch and Bornholdt sectors where the structural nose changes direction. One explanation is that better porosity and permeability were developed in these sectors. Another explanation is that where the structural nose changes direction, greater fracturing probably occurred enabling oil to be removed easier and in greater quantities. The Welch and Bornholdt sectors not only have had the greatest cumulative petroleum production but were the principal areas in which initial wells naturally flowed from one to two years.

Plate 23 shows that petroleum accumulation is not necessarily restricted to a zone of particular thickness of the Mississippian beds. Lee (1939) states Mississippian petroleum production in central and eastern Kansas is obtained wherever porosity and permeability are present, irrespective of stratigraphic position in the Mississippian stratigraphic section. In the Welch-Bornholdt Pools Area petroleum has accumulated in the Rellim pool where the Osageian residuum is 60 feet thick and in Mississippian beds up to 120 feet thick in the Bornholdt sector.

A rough correlation does exist between greatest petroleum production in the Welch and Bornholdt sectors and in the Lost Springs pool. Greatest production from both pools has been from 80 to 120 foot thicknesses of the producing horizon, although the Lost Springs pool's production is from the Pennsylvanian basal conglomerate. The correlation is also true in the two areas in that neither pool has had prolific production outside of the 80-120 thicknesses. A correlation probably exists between petroleum accumulation and dolomitization in the Lost Springs Pools Area (Shenkel, 1959). This correlation probably does not exist in the Welch-Bornholdt Pools Area.

Source and migration of oil is largely speculative. Possibly the Chattanooga shale could have been the source bed for oil in the Welch-Bornholdt Pools Area. Shenkel (1955) suggests that the Chattanooga shale could be the source bed for oil in the Lost Springs Pools Area. The oil could have migrated vertically upward through fractures into the producing horizon becoming emplaced where porosity, permeability, and perhaps fractures were most favorable for accumulation. Plate 6 shows thickness of the organically rich Chattanooga shale in the Welch-Bornholdt Pools Area. The area of investigation is situated near a pre-Chattanooga northward flowing tributary that drained into the McPherson Valley. The Chattanooga shale is up to 250 feet thick in the Welch-Bornholdt Pools Area and along the McPherson Valley.

The Wherry pool, Pennsylvanian basal conglomerate the producing zone, appears to be a southwest extension of the Welch sector. Oil from the Wherry pool is similar to oil in the Welch-Bornholdt Pools Area. Outside of the area of mapping the Crawford, Crawford NW, and Crawford SE pools, Pennsylvanian basal conglomerate the producing zone, appear to be in line with the northern trend of the Welch-Bornholdt Pools Area. Two interpretations of this alignment of petroleum accumulation on the flanks of the Geneseo Uplift are: (1) oil migration into the producing zones after Pennsylvanian basal conglomerate sedimentation, or (2) oil accumulation in place. Some migration of oil is evident in the Welch-Bornholdt Pools Area. The oil from the Pennsylvanian basal conglomerate and the Mississippian "chat" of the Windom sector is the same type of crude oil. More water is produced from the Mississippian "chat" than the Pennsylvanian basal conglomerate. The author believes that migration of oil has been from the Mississippian "chat" into the Pennsylvanian basal conglomerate.

Lee (1956) stated that greatest petroleum production in the Salina Basin Area is situated in the constricted area between the Central Kansas Uplift and the Nemaha Anticline. The Welch-Bornholdt Pools Area is situated in this area. McPherson Valley, a pre-Chattanooga erosional valley, approximately traverses between the Central Kansas Uplift and the Nemaha Anticline. The Griffith pool, Mississippian beds the reservoir rock, is situated on the west flank of the Nemaha Anticline. Prior to post-Mississippian deformation a thick Chattanooga shale section, at least 250 feet thick, was present near the Griffith pool as part of the McPherson Valley that drained into the former North Kansas Basin.

FUTURE POSSIBILITIES

Petroleum production in the Welch-Bornholdt Pools Area appears to be on a steady decline with salt water production remaining high and oil production declining. It is believed that future production will involve workovers of many wells and the employment of water flooding if pools in the area of study are to remain economically productive.

Future possibilities of finding additional petroleum in the Welch-Bornholdt Pools Area is poor. East of the pools the oil-water contact has been reached and to the west the Mississippian "chat" loses permeability. The only place where future drilling activity could take place is north of the Rellim pool and between the Rellim pool and the Smyres sector. The Smyres North and Green pools, one well pools, are situated between the Rellim pool and the Smyres sector. These pools have been disappointing in relation to petroleum production. Evidently porosity and permeability were not developed as well in the north part of the Welch-Bornholdt Pools Area as in the Welch and Bornholdt sectors. As there are several dry holes between the Rellim pool and the Smyres sector, the area does appear favorable for additional exploration. Future Mississippian "chat" petroleum production on the flanks of the Geneseo Uplift would be restricted to the northeast flank because Mississippian beds are absent to the west. Pennsylvanian basal conglomerate production might be found on the north and west flanks of the Geneseo Uplift.

It is believed that the flanks of the Voshell Anticline are favorable localities for future Mississippian "chat" and/or Pennsylvanian basal conglomerate production even though Mississippian production is obtained along the crest of the Anticline. At one place on the Voshell Anticline the Mississippian beds thin to zero thickness (Lee, 1939). Mississippian strata were uplifted on the Voshell Anticline during the post-Mississippian - pre-Marmaton, similar to the deformation of the Mississippian beds on the Geneseo Uplift. Conditions for developing porosity and permeability in Mississippian rocks would be as favorable on the flanks of the Voshell Anticline as conditions were for developing these physical properties on the flanks of the Geneseo Uplift.

Future possibilities for discovering oil traps similar to the Welch-Bornholdt Pools Area in adjacent localities are excellent. Similar areas existed in Kansas where positive "highs" and their flanks were leached and solution action occurred to create a reservoir rock. One such locality is the Lost Springs pool on the west flank of the Nemaha Anticline. In discussing future possibilities of Pennsylvanian basal conglomerate pools similar to the Lost Springs pool, Shenkel (1955) stated,

> Stratigraphic and structural conditions similar to those in the Lost Springs Pools Area occur north and south of the Lost Springs Pools Area along the west flank of the Nemaha Anticline.
>
> The entire west flank of the Nemaha Anticline extending north from the Lost Springs Pools Area into Nebraska offers possibility for the discovery of oil in the Pennsylvanian basal conglomerate and in anticlines and stratigraphic traps buried beneath Pennsylvanian rocks.

Discovery of the Griffith pool 1957, Mississippian beds the reservoir horizon, has proven Shenkel's (1955) statement concerning future petroleum production north of the Lost Springs Pools Area on the west flank of the Nemaha Anticline. The author believes similar stratigraphic and structural conditions probably exist on both the east and west flanks of the Salina Basin where future petroleum reserves will be discovered.

SUMMARY OF FINDINGS

The accumulation of petroleum in the Welch-Bornholdt Pools Area is associated with the following stratigraphic and structural features: (1) a broad structural nose plunging east and southeastward from the southeast flank of the Geneseo Uplift, (2) a zone of porosity and permeability in the Mississippian "chat" that was formed along the southeastern flank of the Geneseo Uplift in the post-Mississippian - pre-Marmaton irrespective of stratigraphic position or thickness of the Mississippian beds, and (3) greatest petroleum production, probably due to a greater number of fractures, has been from the zone of porosity and permeability where the structural nose changes direction.

ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Dr. Claude W. Shenkel, Jr., Professor of Geology at Kansas State University, for his advice while preparing this thesis and for criticisms and suggestions while editing the manuscript.

The Herndon Map Service and Kansas Geological Survey supplied much information upon which this thesis is based. Special thanks are due to Continental Oil Company, Phillips Petroleum Company, Sierra Petroleum Company, Shell Oil Company, Sterling Drilling Company, and Messman-Reinhardt Oil Company for their time in discussing the geology of the area of study. The author is also indebted to Milliard Smith and Robert Frensley, consulting geologists, for their time in discussing the geology of the Welch-Bornholdt Pools Area.

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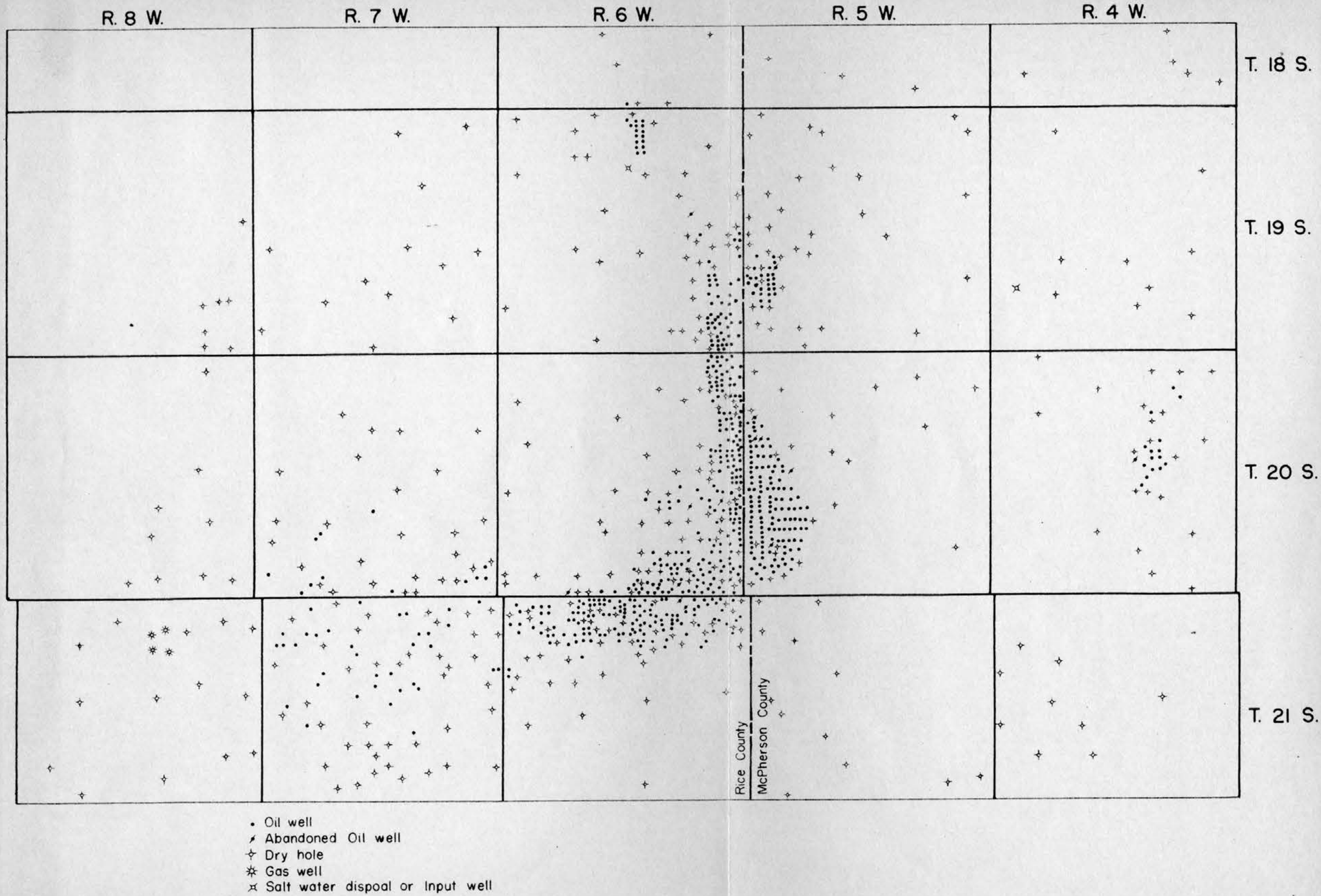
APPENDIX

EXPLANATION OF PLATE 19

Map showing location of wells used to construct the Mississippian "chat" structure contour map, Welch-Bornholdt Pools Area, Rice and McPherson Counties, Kansas.

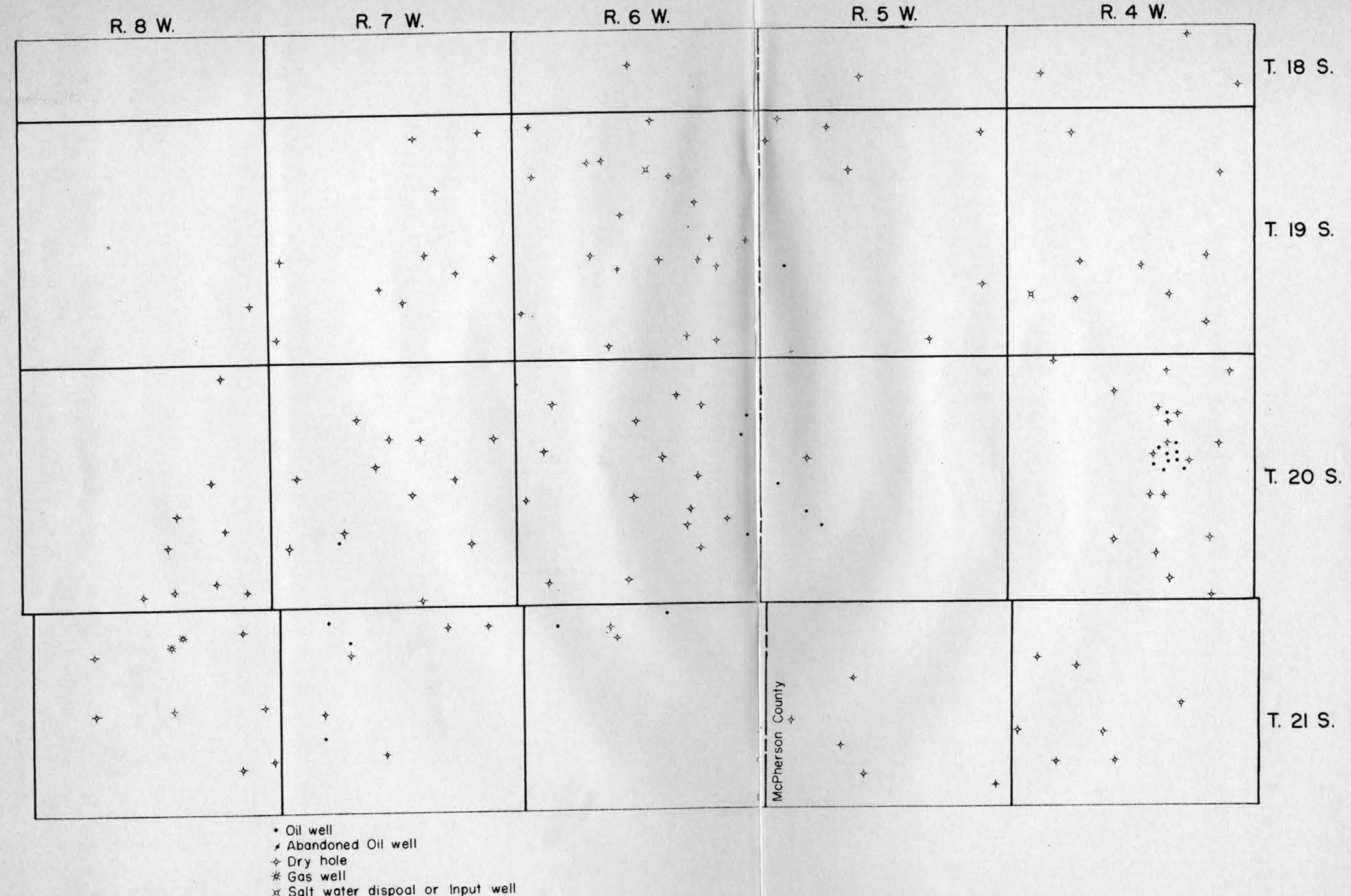
PLATE 19


R. 8 W.
R. 7 W.
R. 6 W.
R. 5 W.
R. 4 W.
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
Rice County
McPherson County
• Oil well
Abandoned Oil well
Dry hole
Gas well
Salt water dispoal or Input well

EXPLANATION OF PLATE 20

Map showing location of wells used to construct the combined Mississippian "chat" and unweathered limestone isopach map, Welch-Bornholdt Pools Area, Rice and McPherson Counties, Kansas.

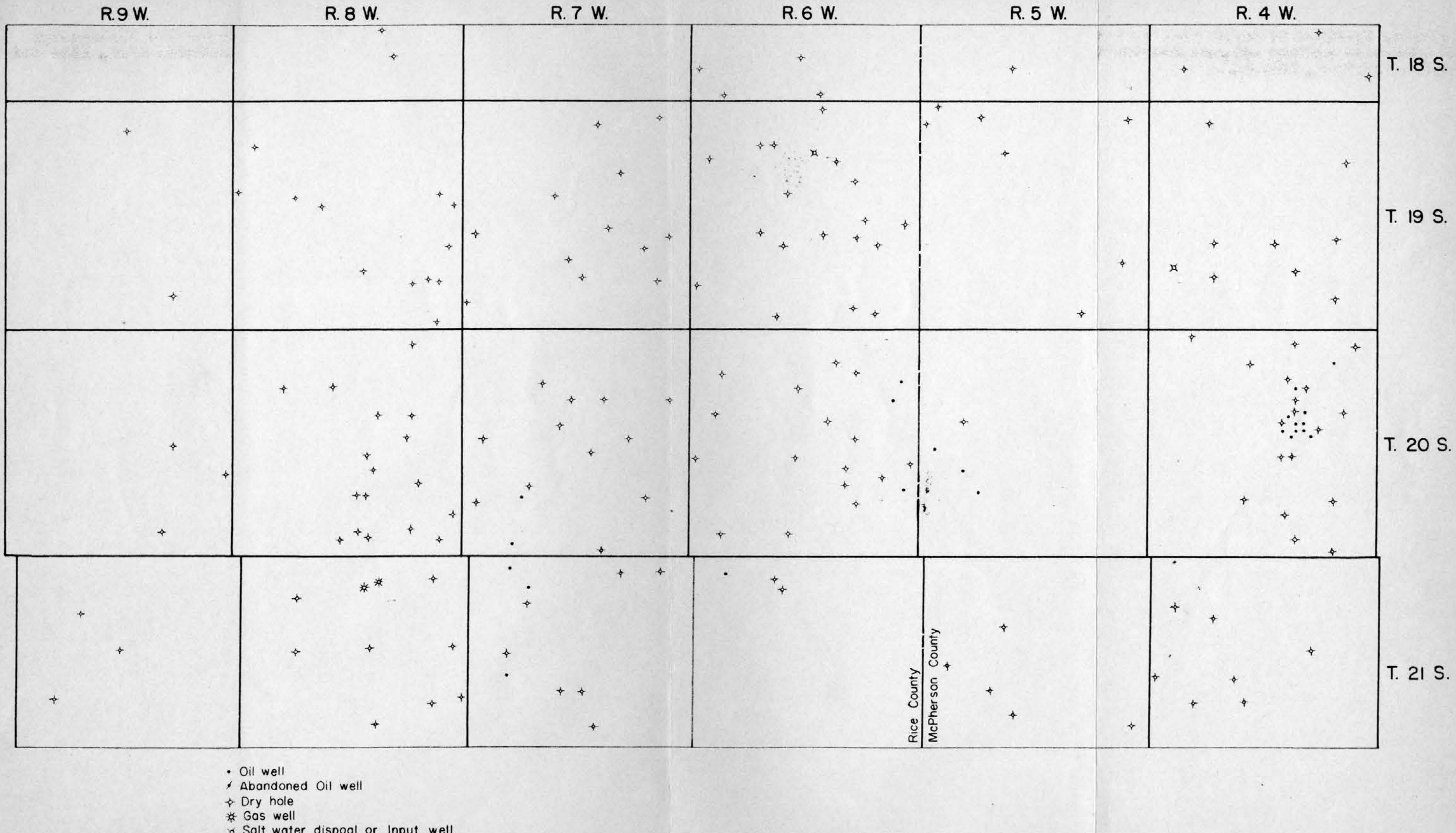
PLATE 20


R. 8 W.
R. 7 W.
R. 6 W.
R. 5 W.
R. 4 W.
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
McPherson County
• Oil well
Abandoned Oil well
Dry hole
Gas well
Salt water dispoal or Input well

EXPLANATION OF PLATE 21

Map showing location of wells used to construct the Chattanooga Shale structure contour map, Welch-Bornholdt Pools Area, Rice and McPherson Counties, Kansas.

PLATE 21


R. 9 W.
R. 8 W.
R. 7 W.
R. 6 W.
R. 5 W.
R. 4 W.
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
Rice County
McPherson County
• Oil well
Abandoned Oil well
Dry hole
Gas well
Salt water dispoal or Input well

PLATES 22 TO 25 INCLUSIVE

(in accompanying plate box)


R. 8 W.
R. 7 W.
R. 6 W.
R. 5 W.
R. 4 W.
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
PLATE 22
Structure contours on top of the Mississippian "chat"
Welch–Bornholdt Pools Area
Rice and McPherson Counties, Kansas
Explanation
0
1/2
1
2
Scale in miles
North
Area that is producing oil or has produced oil from the Mississippian "chat" and/or Pennsylvanian basal conglomerate
Contour interval = 20 feet
Sea level datum
Contour line
County line
Township line
Section line
1960
Gary K. Hylton
Rice County
McPherson County
-1600
-1620
-1640
-1660
-1680
-1700
-1720
-1740
-1760
-1780
-1800
-1820


R. 8 W.
R. 7 W.
R. 6 W.
R. 5 W.
R. 4 W.
PLATE 23
Isopachous contours of the combined thickness of the Mississippian "chat" and unweathered limestone
Welch–Bornholdt Pools Area
Rice and McPherson Counties, Kansas
Explanation
0 1/2 1 2
Scale in miles
North
Area that is producing oil or has produced oil from the Mississippian "chat" and/or Pennsylvanian basal conglomerate
Contour interval = 20 feet
Sea level datum
Contour line
County line
Township line
Section line
1960
Gary K. Hylton
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
0 – Mississippian
Rice County
McPherson County

R. 9 W.
R. 8 W.
R. 7 W.
R. 6 W.
R. 5 W.
R. 4 W.
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
Rice County
McPherson County
PLATE 24
Structure contours on top of the Chattanooga Shale
Welch–Bornholdt Pools Area
Rice and McPherson Counties, Kansas
Explanation
0 1/2 1 2
Scale in miles
North
Area that is producing oil or has produced oil from the Mississippian "chat" and/or Pennsylvanian basal conglomerate
Contour interval = 20 feet
Sea level datum
Fault
Contour line
County line
Township line
Section line
Chattanooga Shale absent structure contours inferred
1960
Gary K. Hylton

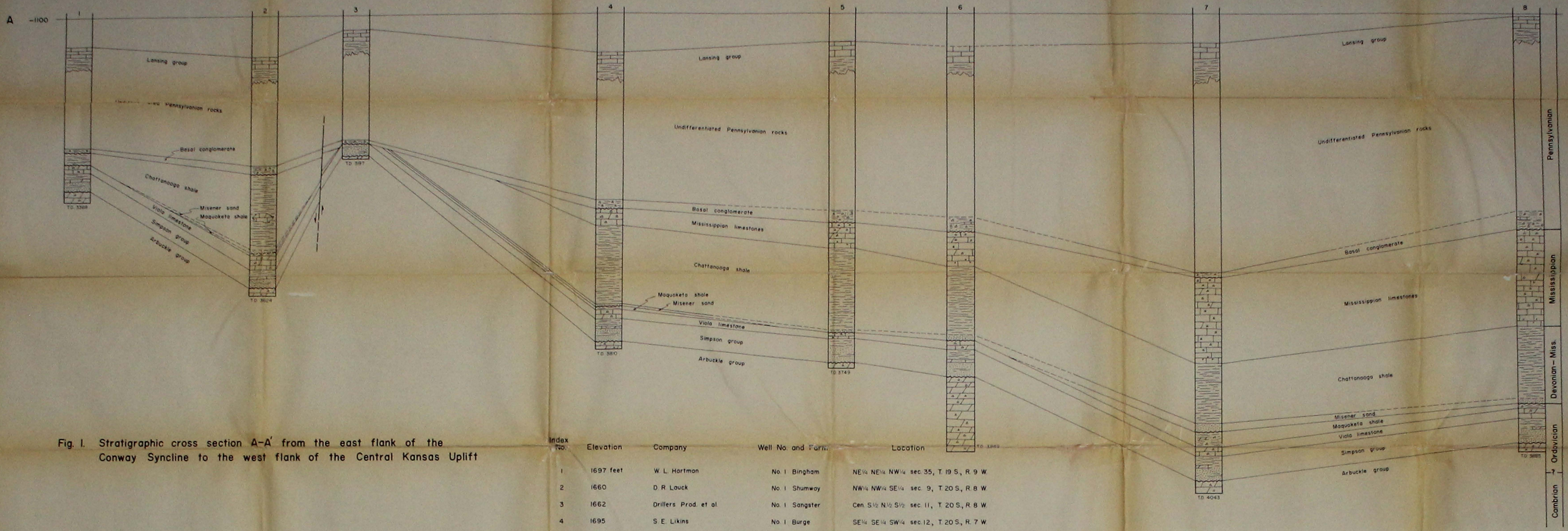
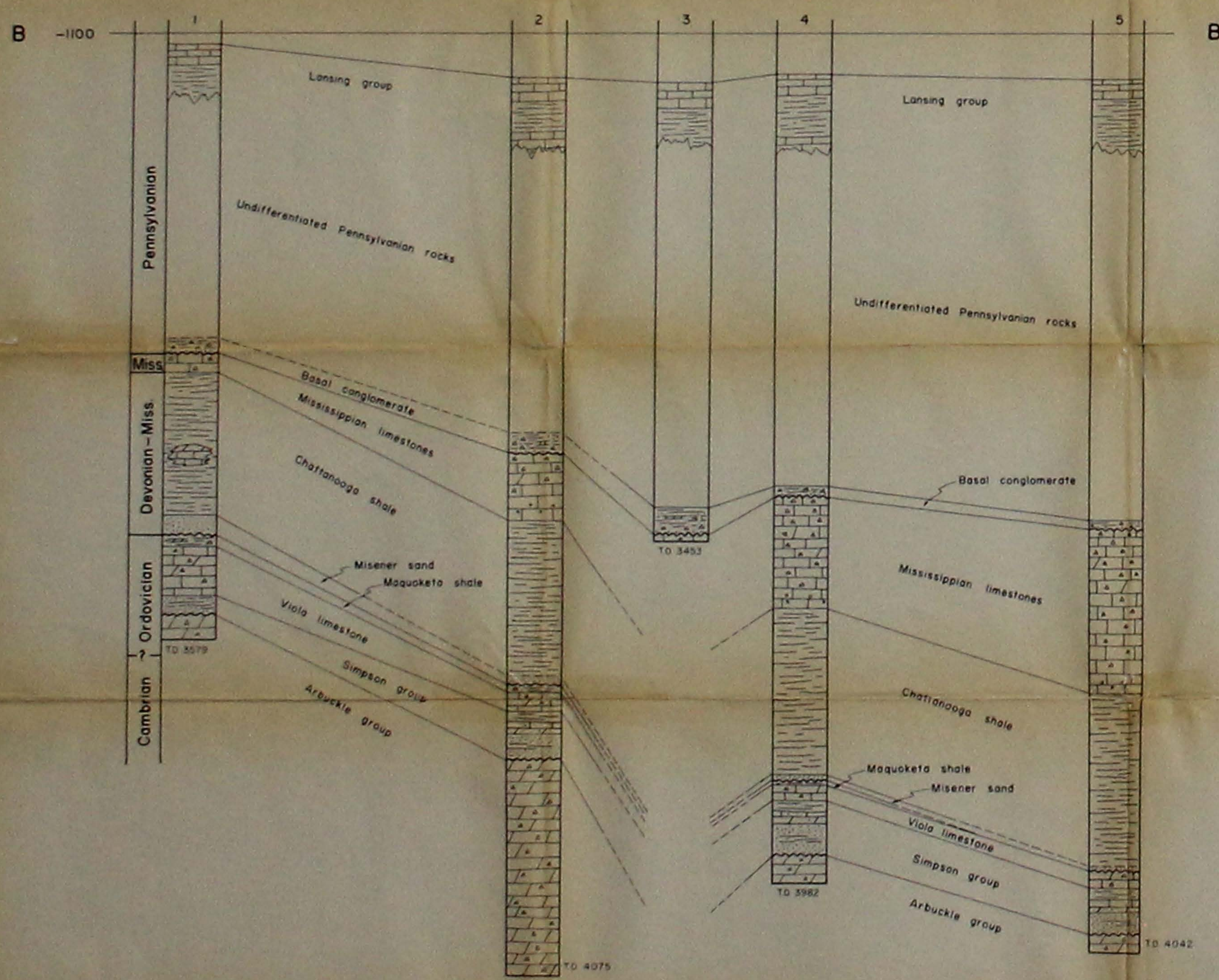
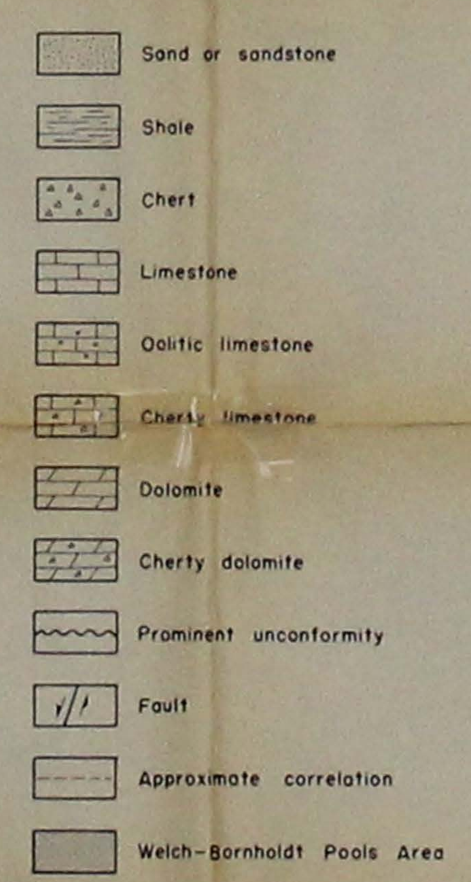
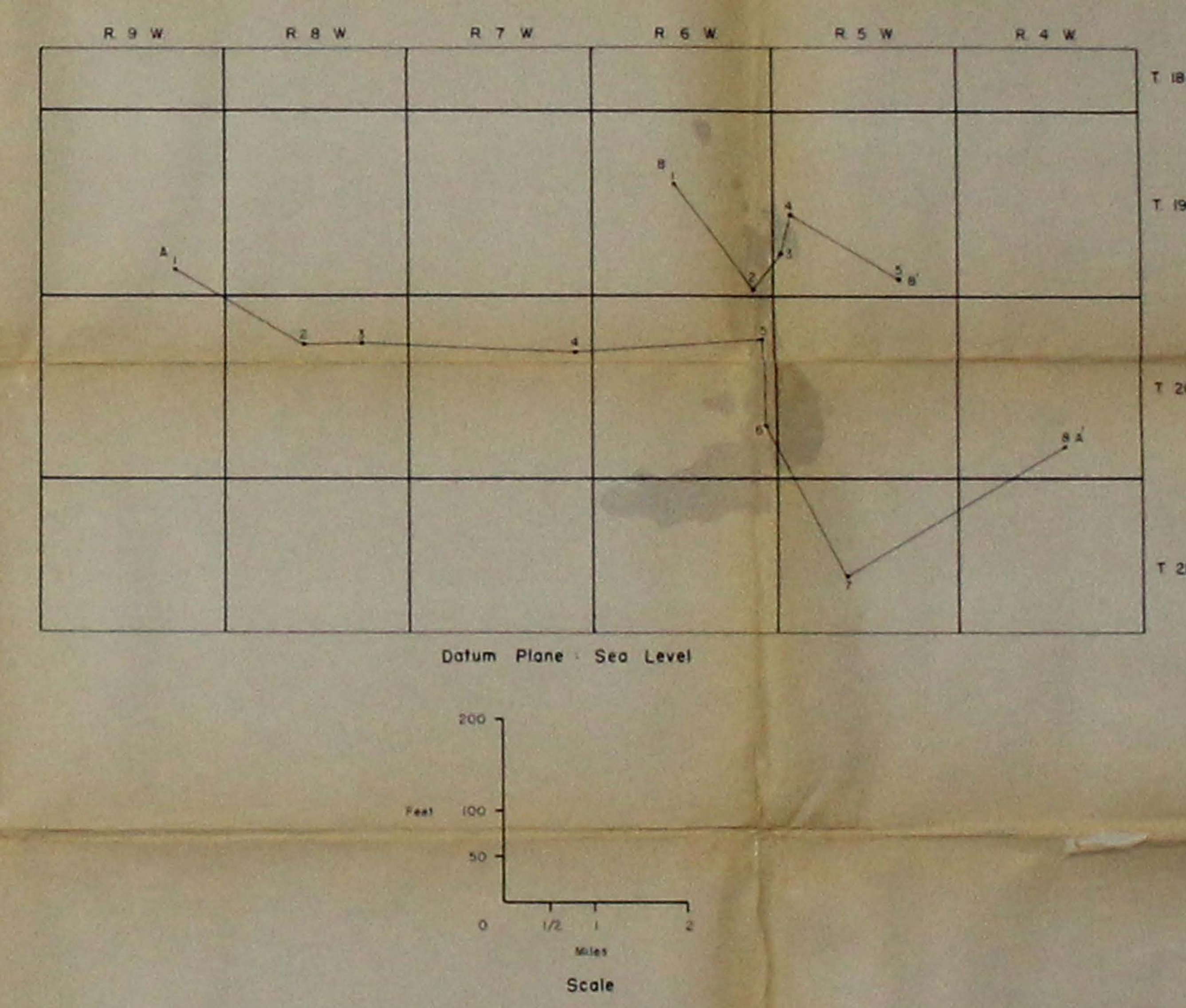


Fig. 1. Stratigraphic cross section A-A' from the east flank of the Conway Syncline to the west flank of the Central Kansas Uplift

Index No.	Elevation	Company	Well No. and Farm	Location
1	1697 feet	W. L. Hartman	No. 1 Bingham	NE¼ NE¼ NW¼ sec. 35, T. 19 S., R. 9 W.
2	1660	D. R. Lauck	No. 1 Shumway	NW¼ NW¼ SE¼ sec. 9, T. 20 S., R. 8 W.
3	1662	Drillers Prod. et al.	No. 1 Sangster	Cen. S½ N½ S½ sec. 11, T. 20 S., R. 8 W.
4	1695	S. E. Likins	No. 1 Burge	SE¼ SE¼ SW¼ sec. 12, T. 20 S., R. 7 W.
5	1579	El Dorado Refining et al.	No. 1 Wernet	SW¼ SW¼ NE¼ sec. 12, T. 20 S., R. 6 W.
6	1527	Westgate-Greenland	No. 2 Hodge	Cen. S NW¼ NE¼ sec. 25, T. 20 S., R. 6 W.
7	1501	Phillips Petroleum	No. 1 Abe	NE cor. NW¼ sec. 28, T. 21 S., R. 5 W.
8	1465	Anschutz and Pack	No. 1 Mitchell	SW¼ SW¼ SE¼ sec. 27, T. 20 S., R. 4 W.







1960

Gary K. Hylton

Fig. 2. Stratigraphic cross section B-B' of the Windom and Smyres sectors of the Welch-Bornholdt Pools Area

Index No.	Elevation	Company	Well No. and Farm	Location
1	1589 feet	L. B. Jackson	No. 1 Alton	SW¼ SW¼ NE¼ sec. 16, T. 19 S., R. 6 W.
2	1596	Westgate-Greenland	No. 3 Smyres	Cen. W½ SE¼ SW¼ sec. 36, T. 19 S., R. 6 W.
3	1613	Natl. Coop. Refining et al.	No. 2 Mattson	Cen. N½ S½ SW¼ sec. 30, T. 19 S., R. 5 W.
4	1641	S. J. Carter et al.	No. 1 Myers	SW¼ SW¼ NE¼ sec. 19, T. 19 S., R. 5 W.
5	1604	J. B. Allison	No. 1 Allison	NW¼ NW¼ SW¼ sec. 35, T. 19 S., R. 5 W.

GEOLOGY OF THE WELCH-BORNHOLDT POOLS AREA,
RICE AND MCPHERSON COUNTIES, KANSAS

by

GARY K. HYLTON

B. S., Kansas State College
of Agriculture and Applied Science, 1958

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE UNIVERSITY
OF AGRICULTURE AND APPLIED SCIENCE

1960

The discovery well of the Welch-Bornholdt Pools Area, Rice and McPherson Counties, Kansas, was drilled in March 1924. Discovery of the Welch pool in western Kansas was second only to the Fairport pool of Russell County, Kansas. At the end of 1957 424 wells were still producing oil and estimated cumulative petroleum production was 29,473,180 barrels. Early in the development of the Welch-Bornholdt Pools Area the trap was believed to be anticlinal but subsequent drilling proved that petroleum accumulation was due primarily to stratigraphic factors.

The purpose of this investigation was to determine the geology of the Welch-Bornholdt Pools Area. A study of the data disclosed the probable structural and stratigraphic features responsible for accumulation of petroleum in the Welch-Bornholdt Pools Area. These geologic factors might lead to the discovery of future similar oil traps in adjacent localities.

Two structure contour maps, an isopach map, and two stratigraphic cross sections were constructed in the course of this investigation. One structure contour map was drawn on top of the producing zone, the Mississippian "chat"; the other structure contour map was drawn on top of the Chattanooga shale. The structure contour maps plus an isopachous map of the combined thickness of the Mississippian "chat" and unweathered limestone were used in an interpretation of geologic history and structure in the Welch-Bornholdt Pools Area.

Pre-Chattanooga erosion reduced the thickness of the "Hunton limestone" over much of central Kansas and entirely removed it from the Welch-Bornholdt Pools Area. Vast thicknesses of Chattanooga shale, up to 250 feet or greater, accumulated in the erosional valleys. The Welch-Bornholdt Pools Area is situated near a junction of a pre-Chattanooga tributary that flowed into McPherson Valley. The deformation that followed Mississippian deposition removed all Mississippi strata from the crest of the Geneseo Uplift so that the Mississippian zero line was left distributed only on the uplift's east flank. During post-Mississippian - pre-Marmaton uplift and erosion great thicknesses of Mississippian residuum accumulated in the Welch-Bornholdt Pools Area. A zone of porosity and permeability in the residual chert beds, the reservoir rock, probably was developed by ground water levels during this interval of time. The Pennsylvanian basal conglomerate and younger rocks were deposited on top of the Mississippian and older rocks.

The accumulation of petroleum in the Welch-Bornholdt Pools Area is associated with the following stratigraphic and structural features: (1) a broad structural nose plunging east and southeastward from the southeast flank of the Geneseo Uplift, (2) a zone of porosity and permeability in the Mississippian "chat" that was formed along the southeastern flank of the Geneseo Uplift in the post-Mississippian - pre-Marmaton irrespective of stratigraphic position or thickness of the Mississippian beds, and (3) greatest petroleum production, probably due to a greater number of fractures, has been from the zone of porosity and permeability where the structural nose changes direction.