

A SUBSURFACE GEOLOGICAL STUDY OF THE  
REDFIELD GAS STORAGE AREA

by

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A SUBSURFACE GEOLOGICAL STUDY OF THE  
REDFIELD GAS STORAGE AREA

INTRODUCTION

Purpose and Scope

This paper has a two-fold purpose. Primarily, it establishes criteria for correlation of the formations within the stratigraphic section of the Redfield Gas Storage Area by the use of geophysical logs. Secondly, by information derived from the logs, an interpretation of the anticlinal structure was determined.

There are few wells in Iowa for which geophysical data are available. Consequently, there have been no standards established for correlation purposes. The complete logging which was done in this area provides an exceptionally good source for correlation purposes. The geologic section is relatively complete and some characteristics have been noted which should prove useful in future correlations by electronic methods in Iowa.

Acknowledgments

Well records, samples, geophysical logs and other data used in this report were released by Northern Natural Gas Company through the Iowa Geological Survey. Without these

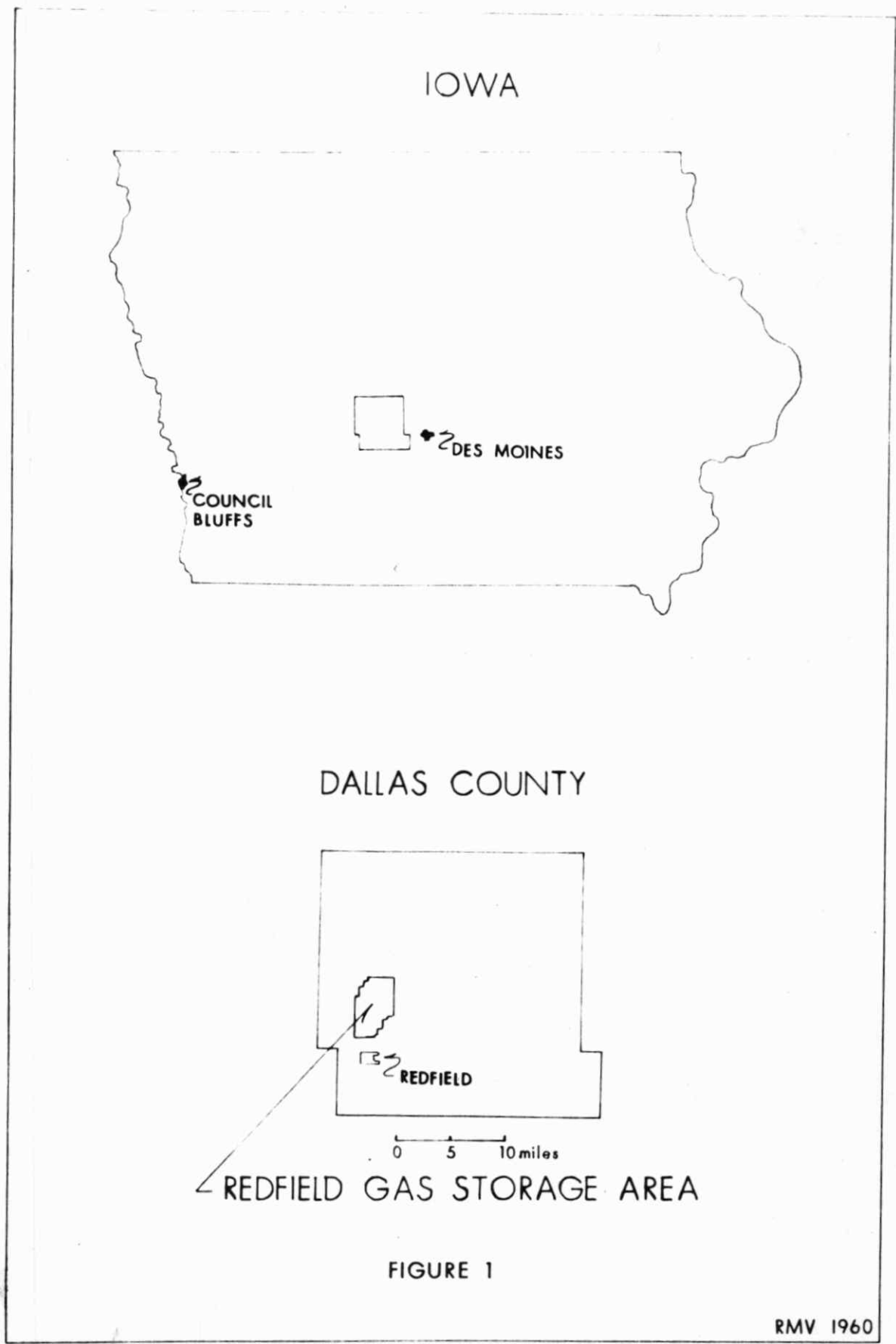


FIGURE 1

facts and the approval by Dr. H. Garland Hershey, State Geologist, this report could not have been written.

The writer takes this opportunity to express his appreciation to Professor Allen C. Tester for the helpful supervision and invaluable criticism during the preparation and revision of this report. The personnel of the Iowa Geological Survey were extremely helpful and their cooperation is appreciated. In particular, I am thankful to Dr. C. N. Brown, Assistant State Geologist, who provided a considerable amount of information and assistance to the writer, and also to Russell Campbell, Fred Dorheim, Richard Northup, and Mary Parker who were always willing to provide assistance and suggestions throughout the preparation of this report.

#### Location and Extent of the Area

The Redfield Gas Storage Area is located in the west-central portion of Dallas County, Iowa (fig. 1). It lies immediately north of Redfield, Iowa, whence it derives its name. The area encompassed by the lease held by Northern Natural Gas Company contains some sixteen square miles and is aligned in a general north-south direction.

The anticlinal structure is located within twenty miles of the pipeline used by Northern Natural Gas Company in its transportation of natural gas from Texas, Oklahoma, and Kansas gas fields to customers in the upper Mississippi

Valley states. The structure is well situated geographically to store gas in periods of less demand, and hence, to provide an adequate supply in close proximity to users in times of great demand.

The Redfield Gas Storage Area lies in the northern part of the regional structure called the Forest City Basin.

For purposes of brevity, the term Redfield Area will be used hereafter as a synonym for the proper name Redfield Gas Storage Area.

#### Previous Investigations

The earliest recorded geologic work was done in this area in 1867 by O. H. St. John as a reconnaissance of Dallas and surrounding counties. A preliminary report by St. John (1868, p. 84-87) mentioned the presence of a coal seam at Redfield as well as a thick bed of sandstone.

A more complete report of the geology of the county was published by St. John in 1870 (p. 13-46), and with reference to the "Lower Coal Formation", he reported,

"This formation occupies the larger portion of the northern half of the county, and a slight anticlinal fold or undulation brings its upper beds to view in the valley of the South Raccoon, in the southwestern corner of the county, near Redfield, where it outcrops over a limited area, partially hemmed in by the succeeding strata of the Middle coal-measures. This area may possibly prove to be an arm running southward along the crest of a gentle anticlinal undulation from the main area of

the formation, forming a bay-like recess corresponding to similar recessions in the border outcrops of the Middle coal-measures in the counties to the southeastward."

St. John reiterated his belief in the anticlinal structure when referring to the Panora coal in the southeast quarter of Section 31, Township 80 North, Range 29 West, Dallas County, when he stated,

". . . . The elevation of the coal at this locality, above the Middle Raccoon, corresponds very nearly to the level it occupies at Parker's mine, near the mouth of Mosquito Creek, and also in the valley-side on the south side of the South Raccoon, two miles south of Redfield, which apparently indicates that the exposure at this locality lies upon the western flank, and but little below the crest of a low, anticlinal undulation which has a nearly north-south trend" (St. John, 1870, p. 35).

Keyes (1894, p. 253-267) referred to several coal exposures and coal mines in the vicinity of Redfield but made no mention of any structure in the area.

In 1898, Leonard (p. 90-91) also noted the presence of the Redfield anticlinal structure in his report on Dallas County. He stated,

"The strata of the county have been for the most part but little disturbed from the nearly horizontal position which they occupied when deposited. They have a gentle dip to the southwest, but this is so slight that it is scarcely noticeable in any single outcrop. The only marked deformation noted is in the southwestern corner of the county, in the vicinity of Redfield. The beds have here been forced into an anticline, whose axis appears to have a direction approximately north and south, though this could not be definitely determined."

Keyes (1916, p. 103-112) suggested parallel breaks in the strata of western Iowa at 25-mile intervals. He gave the name "Red Oak fault" to a fault which he considered extended from Hebron, Nebraska, northeastward beyond Des Moines, Iowa. Tilton (1919, p. 383-390) used the term "Thurman-Wilson fault" to describe this same feature and stated that the deformation, faulting and associated folding, extended from the Earlham, Iowa, locality southwestward into Nebraska. Condra and Reed (1938, p. 15-16) preferred the use of the term "Redfield anticline" for this extensive structure for they believed this was an extension of the structure noted by Leonard (and also previously by St. John) in his Dallas County report. They further considered the allusion to the "anticline at Redfield" sufficient basis for priority of the name, "Redfield anticline."

A structure map of southwestern Iowa based on the Ardmore limestone (Cherokee Group, Des Moines Series) was prepared by L. M. Cline and Edward Heuer in the 1940's for the Iowa Geological Survey. This unpublished map provided more accurate data on the structure which had been noted by previous workers.

The folding indicated by the Ardmore structure map appeared promising to Northern Natural and in 1953, a test drilling and coring program was started. Most of these

wells were limited to Mississippian rocks as the purpose was to verify the existence and size of the structure. The only wells that had been drilled through the Mississippian strata to that time were Hunt Number 1 oil prospect of 1943 (the Moncelle Number 1 used in this report) and two water wells, the Kipping Number 1 of this report, and a well drilled on the Joe Messamer property (unpublished well records, Iowa Geological Survey). This latter well is located on the northeast flank of the anticline but was not used by Northern Natural Gas Company. This coring program eventually covered some forty square miles (Northern Natural Gas Company, unpublished report, Erickson and Svoboda, 1956, p. 7).

In January 1954, the first deep well, Nelson Number 1, was started to determine accurate data on reservoir conditions. The drilling program was completed in the fall of 1959. Included in this drilling program was the drilling and logging of approximately 100 wells which penetrated Mississippian and older strata.

A seismological survey of the Redfield Area was conducted by National Geophysical Incorporated. In general, the seismic survey produced very little useful information other than to confirm the presence of a structural high (Northern Natural Gas Company, unpublished report, Erickson and Svoboda, 1956, p. 7-8).

Northern Natural Gas Company is now storing natural gas in the structure in the sands of the St. Peter formation and the Mt. Simon member of the Dresbach formation and the operation has exceeded expectations (oral communication, Dr. C. N. Brown, Iowa Geological Survey).

Leonard (1898, p. 78-83) noted several locations along the Raccoon River south and southeast of Redfield where Des Moines and Missouri Series formations crop out. However, in the immediate area with which this report is concerned, the surface material is restricted to the Pleistocene, Wisconsin drift (Leonard, 1898, p. 88). This study is restricted to the subsurface geology and the writer did no field work on the surface geology.

#### Methods of Investigation

Rotary well cuttings, electric logs, radioactivity logs, micrologs, and drilling time logs had been supplied regularly to the Iowa Geological Survey by Northern Natural Gas Company. In the summer and fall of 1959 washed samples from six wells were examined and the lithologies were plotted to scale by the writer. Three wells, Maher Number 1, Walker Number 1, and Moncelle Number 1, are located on the north, west, and south limbs of the structure; and three wells, Davis Number 1, Hummell Number 1, and Nelson Number 1, are

at locations near the top of the structure.

Characteristics of the formations were determined from the detailed lithology of the well cuttings, and contacts of the several formations were identified. The criteria were then applied to the geophysical logs available for the area. The spontaneous potential and the short normal resistivity curves were the logs most frequently employed for correlation purposes.

The resistivity of a formation depends largely upon the chemical nature and amount of water within the pores. Since various rock units have different porosities and contain water with different chemical natures, the various adjacent lithologies are represented by different configurations on the logs.

The spontaneous potential log is a record of spontaneously occurring potentials, measured in the fluid at different depths in the bore-hole. The base line of the SP log is located at the right side of the log and generally corresponds with impermeable horizons. Deflections from this base line generally indicate permeable beds, although there is no direct correlation between the magnitude of the SP deflection and the permeability or porosity of the bed.

Radioactivity logs were used primarily for supporting information. The gamma ray log is a measure of the variation

of natural radioactivity of the formations. Most of the deflections toward the right (increasing values) indicate increasing shale content while portions with lower values correspond generally to "clean" or non-shale horizons. In this general sense then, the variations of the gamma ray curve often correspond to the variations of the spontaneous potential curve.

The neutron logs are a measure of the gamma rays emitted by atoms of chlorine, sodium, silicon, and particularly hydrogen when these atoms are excited by the capture of neutrons emitted from a special source in the sonde. The major variations in the neutron curve are caused by changes in the hydrogen concentration within the formations. Since a relation exists between the hydrogen concentration and the liquid-filled pore space, any formation condition which alters the porosity, the hydrogen content or both, will affect the neutron response. Generally then, the neutron curve will have a low response to shale and a higher response to sand and porous carbonates.

The microlog is an electric log recorded with the electrodes mounted at a short distance from one another. Because of the short spacing, the resolving power is very small and lithologic boundaries can be determined very accurately. Unfortunately, micrologs were available for only a small number of wells. The vertical scale on which the micrologs

were produced did not agree with the vertical scale of the electric and radioactivity logs; consequently, the micrologs were not reproduced for this study as were the other logs.

Drilling time logs were used and proved helpful when used to corroborate changes in lithology. The principle utilized in interpreting drilling time logs is that a change in drilling rate indicates a change in the type of rock penetrated by the bit.

The writer examined geophysical logs from 74 wells which are on file with the Iowa Geological Survey. However, duplicates of these logs are not available to incorporate in this report. Figures 2 through 8 show the major geophysical reactions of the individual formations as expressed by wells 11 and 46 which are typical for the area.

The sea level datum elevation of the kelly bushing of the drilling rig was determined by Northern Natural Gas Company for each well. The rig setting placed the bushing from five to ten feet above the original ground elevation with the majority of the settings between eight and ten feet above ground. The depth to the top of each formation below the bushing has been converted to datum elevation values for each formation contact in all wells. These elevations provide the control for the structural contour maps and the isopach maps constructed for this report.

A qualitative determination was used to differentiate limestone and dolomite. Cold dilute hydrochloric acid in proportions of 1:10, one part acid to ten parts water, was placed in an acid dish, chips of the rock were added, and a determination was based on the reaction. The differentiation was based on the following scale (From Low, 1958, Examination of well cuttings, p. 31):

**Limestone:** Violent effervescence; frothy audible reaction; specimen bobs about and tends to float to the surface.

**Dolomitic limestone:** Brisk, quiet effervescence; specimen skids about on the bottom of the container, rises slightly off bottom; continuous but slow flow of CO<sub>2</sub> beads through the acid.

**Calcitic dolomite:** Mild emission of CO<sub>2</sub> beads; specimen may rock up and down, but tends to remain in one place.

**Dolomite:** No effervescence; no immediate reaction; slow formation of CO<sub>2</sub> beads on the surface of the rock; reaction slowly accelerates until a thin stream of fine beads rises to the surface.

The relative permeability of the rocks was determined by placing a drop of water on a dry chip and observing under the microscope how quickly the water was absorbed. Relative porosity was determined by direct observation of the area of voids in a unit area of rock surface and by repeated

addition of water drops which permeate the rock to saturation.

### Well Numbering System

The wells used in this report have been arranged in alphabetical order and assigned consecutive numbers (Table 1). The same numbers are used on all maps and figures accompanying this report. Included in the listing is the location and the well name as used by Northern Natural Gas Company and where applicable, the number as recorded by the Iowa Geological Survey.

Table 1

## TABULATION OF LOCATION OF WELLS USED IN THIS REPORT

Well No.	Northern Natural Name	Reservoir Formation Tested*	Location: Sec., T. - N., R. - W.	Iowa Geol. Survey Well No.
1	Blackburn No. 1	SP	SE-SE-SE-SW 18-79-28	W-7198
2	Book No. 1	SP	SW-SW-SE-SW 8-79-28	W-6930
3	Book No. 2	SP	SW-SW-SE-SE 7-79-28	W-7230
4	Broderick No. 2	SP	NW-NW-SW-SW 7-79-28	W-7231
5	Broderick No. 3	MS	SE-SW-SW-SW 7-79-28	
6	Broderick No. 4	MS	SE-SW-SE-SW 7-79-28	
7	Broderick No. 5	MS	SW-SW-NW-SW 7-79-28	
8	Broderick No. 6	MS	SW-SW-NE-SW 7-79-28	
9	Burriss No. 1	SP	NW-SE-SE-SE 15-79-29	
10	Clark No. 1	SP	NW-NE-NE-SW 13-79-29	W-6994
11	Davis No. 1	MS	NE-NW-NE-SW 12-79-29	W-6686

\*Legend:

SP = St. Peter

MS = Mt. Simon

Well No.	Northern Natural Name	Reservoir Formation Tested	Location: Sec., T. - N., R. - W.	Iowa Geol. Survey Well No.
12	Davis No. 4	MS	SE-SE-NE-SW 12-79-29	
13	Davis No. 6	SP	NE-NE-NW-NW 12-79-29	
14	Davis No. 7	SP	SW-SW-NW-NW 12-79-29	
15	Davis No. 8	MS	NW-NW-NE-NW 12-79-29	
16	Davis No. 9	MS	NW-NW-SE-NW 12-79-29	
17	Davis No. 10	MS	NW-NW-NW-NW 12-79-29	
18	Dickey No. 1	SP	SE-SE-SE-NE 23-79-29	
19	Dickey No. 2	MS	SE-SE-SE-NW 23-79-29	
20	Dickey No. 3	MS	NE-NE-NE-NE 23-79-29	
21	Fitch No. 1	MS	SE-NW-NE-NE 11-79-29	
22	Garret No. 1	MS	SE-SE-SE-NE 2-79-29	
23	Hagerman No. 1	SP	NE-NE-SW-NW 12-79-29	
24	Hagerman No. 2	SP	NW-NW-NW-SW 12-79-29	
25	Hagerman No. 4	MS	SW-SW-NW-SW 12-79-29	
26	Hagerman No. 6	SP	SE-SE-SE-SW 6-79-28	
27	Henning No. 1	SP	SE-SE-SW-SE 14-79-29	W-7197

Well No.	Northern Natural Name	Reservoir Formation Tested	Location: Sec., T. - N., R. - W.	Iowa Geol. Survey Well No.
28	Hummel No. 1	MS	NE-NE-NW-NW 18-79-28	W-6903
29	Hummel No. 2	SP	NE-NE-NE-NW 18-79-28	W-7195
30	Hummel No. 4	SP	SW-SW-NW-NW 18-79-28	W-7204
31	Hummel No. 5	SP	SE-SE-NW-NW 18-79-28	W-7363
32	Hummel No. 9	MS	SE-SE-NW-NW 18-79-28	
33	Hummel No. 10	SP	SE-SE-SE-NW 18-79-28	
34	Kern No. 1	SP	SE-SE-SE-NE 12-79-29	W-7661
35	Kern No. 2	SP	SE-SE-SW-NE 12-79-29	W-7660
36	Kern No. 5	MS	NW-NW-SW-NE 12-79-29	
37	Kern No. 6	MS	SE-SE-SE-NE 12-79-29	
38	Kipping No. 1	SP	NW-NW-NE-SE 14-79-29	
39	Kipping No. 2	SP	NW-NW-NE-NW 24-79-29	
40	Kipping No. 3	MS	NE-NW-NE-SW 13-79-29	
41	Kipping No. 4	MS	NW-NW-NE-SE 14-79-29	
42	Madren No. 1	SP	NE-NE-NE-NE 14-79-29	
43	Madren No. 2	SP	SW-SW-NE-NE 14-79-29	

Well No.	Northern Natural Name	Reservoir Formation Tested	Location: Sec., T. - N., R. - W.	Iowa Geol. Survey Well No.
44.	Madren No. 3	MS	NW-SW-NE-NE 14-79-29	
45	A. Madren No. 1	MS	NE-SW-NW-SW 23-79-29	
46	Maheer No. 1	MS	SE-SE-SE-NE 1-79-29	W-6579
47	Maheer No. 2	SP	NW-NE-NW-NE 12-79-29	
48	Maheer No. 3	SP	SE-SE-NW-NE 12-79-29	
49	McCarthy No. 1	SP	NW-NW-NW-NE 36-80-29	W-7194
50	Moncelle No. 1	MS	NE-NW-SW-SE 26-79-29	W-7203
51	Nelson No. 1	MS	NW-NW-SE-SW 12-79-29	W-6365
52	Nelson No. 2	SP	NE-NE-NE-NE 13-79-29	W-7199
53	Nelson No. 3	SP	SE-SE-NE-SE 12-79-29	W-7206
54	Nelson No. 4	SP	NE-NE-NW-NE 13-79-29	W-7337
55	Nelson No. 9	MS	NW-NW-NW-NE 13-79-29	
56	Nelson No. 10	MS	NW-NW-NE-NE 13-79-29	
57	Nelson No. 11	MS	SE-SE-NW-SE 12-79-29	
58	Pitsenbarger No. 1	SP	NE-NE-NE-NW 13-79-29	
59	Pitsenbarger No. 2	SP	NE-NE-NW-NW 13-79-29	
60	Pitsenbarger No. 3	SP	NW-NW-SW-SW 12-79-29	

Well No.	Northern Natural Name	Reservoir Formation Tested	Location: Sec., T. - N., R. - W.	Iowa Geol. Survey Well No.
61	Pitsenbarger No. 4	SP	NW-NW-SW-NW 13-79-29	
62	Pitsenbarger No. 5	MS	NW-NW-NE-NW 13-79-29	
63	Pitsenbarger No. 6	MS	NW-NE-SE-NE 13-79-29	
64	Pitsenbarger No. 7	MS	NW-NW-SW-NE 13-79-29	
65	Pitsenbarger No. 8	SP	NW-NW-NE-SE 10-79-29	
66	Pitsenbarger No. 9	MS	NE-NW-SW-NW 13-79-29	
67	Price No. 1	SP	E cen SE-SW 36-80-29	W-6876
68	Price No. 3	MS	NE-SE-SE-SW 36-80-29	
69	Russell No. 1	SP	SW-SW-SW-NE 2-79-29	W-6992
70	Russell No. 2	MS	SW-SW-SW-NE 2-79-29	
71	Wagoner No. 1	SP	SE-SW-SW-SE 7-79-28	W-7343
72	Walker No. 1	MS	NE-NE-SW-SW 11-79-29	W-6804
73	York No. 1	SP	NE-NE-NE-SE 7-79-28	W-7196
74	York No. 2	MS	NE-NE-NE-SE 7-79-28	

## GEOLOGY

### GENERAL STRATIGRAPHY

All major geologic units from Precambrian through lower Pennsylvanian are present in the Redfield Area. Pleistocene deposits overly the Pennsylvanian Desmoinesian Series (Chart 1). The Cambrian, Ordovician, Silurian, and Devonian Systems and the Mississippian System through the Osagian Series will be covered in this report. The majority of the logs which were available to this writer did not include that portion of the section above the Mississippian Osagian Series.

A detailed composite graphic and descriptive columnar section (Chart 2) is included in the report. A full description of the lithology of all units is shown on this chart and can be used to supplement the text which contains only a generalized statement for members or formation.

The formational nomenclature as used in this study is that which is recognized by the Iowa Geological Survey.

### PRECAMBRIAN ROCKS

The basement complex in the Redfield Area consists of a dark-green igneous or metamorphic rock which has a schistose appearance. The rock contains large feldspars, hornblende,

CHART 1

CHART SHOWING STRATIGRAPHIC RELATIONSHIPS REDFIELD GAS STORAGE AREA				
SYSTEM	SERIES	FORMATION	MEMBER	TH'KN'S
QUATERNARY	PLEISTOCENE	UNDIFFERENTIATED		50-175
PENNSYLVANIAN	DESMOINESIAN	UNDIFFERENTIATED		75-325
MISSISSIPPIAN	MERAMECIAN	ST. LOUIS WARSAW		38-127
	OSAGIAN	KEOKUK		158-
		BURLINGTON		182
	KINDERHOOKIAN	GILMORE CITY		161-
		HAMPTON		183
DEVONIAN	UPPER DEVONIAN	LIME CREEK		109-132
	MIDDLE DEVONIAN	CEDAR VALLEY		312-424
		WAPSIPINICON		37-96
SILURIAN	NIAGARA	GOWER		41-53
ORDOVICIAN	CINCINNATIAN	MAQUOKETA	BRAINARD	276-
			FT. ATKINSON	
			ELGIN	309
	MOHAWKIAN	GALENA		154-
			DECORAH- PLATTEVILLE	168
	CHAZYAN	ST. PETER		54-63
	BEEKMANTOWNIAN	PRAIRIE DU CHIEN	WILLOW RIVER	354-
ROOT VALLEY				
ONEOTA			403	
CAMBRIAN	ST. CROIXIAN	JORDAN		108-
		ST. LAWRENCE		122
		FRANCONIA		170-183
		DRESBACH	EAU CLAIRE	316-
			MT. SIMON	339
?	?	?	RED CLASTICS	
PRECAMBRIAN				

and quartz and the green color appears to have been derived from the weathering of chlorite-like material. In the lower portions of the wells, the rock has a more granite-like appearance. In the key logs used in this report, there was a maximum penetration into the Precambrian of approximately 14 feet.

### PRECAMBRIAN (?) ROCKS

The age of the Red Clastics is problematical and may be either Keweenawan or early Cambrian. It is very difficult to draw a boundary between the Mt. Simon member and the Red Clastics on the basis of well cuttings and nearly impossible by electric logs. These conditions indicate a greater intimacy of the Red Clastics with the overlying Mt. Simon member than a Precambrian designation would infer. However, stratigraphic relations of the Red Clastics in other areas suggest a Precambrian age. There is a possibility that the beds in the Redfield Area are not true Red Clastics and may actually be a facies of St. Croixian deposition or of earlier Middle Cambrian age.

#### Lithology

The unit which presumably is the Red Clastics is a conglomeratic sandstone with the grains ranging from fine-grained to pebble size with a gradual decrease of size-grade

range toward the top. Color is derived from the iron oxide cement which produces tones of red, pink, and yellow. The grains are well abraded being curvilinear to sub-rounded. Grains of feldspar are common, particularly in the lower one-half of the unit. A grayish-red shale is present 10 to 15 feet above the bottom of the section and overlying a zone of conglomeratic sandstone. The porosity and permeability of the entire unit is relatively high. The average thickness of the Red Clastics is 85 feet.

Summary of Geophysical Characteristics (See Figure 2)

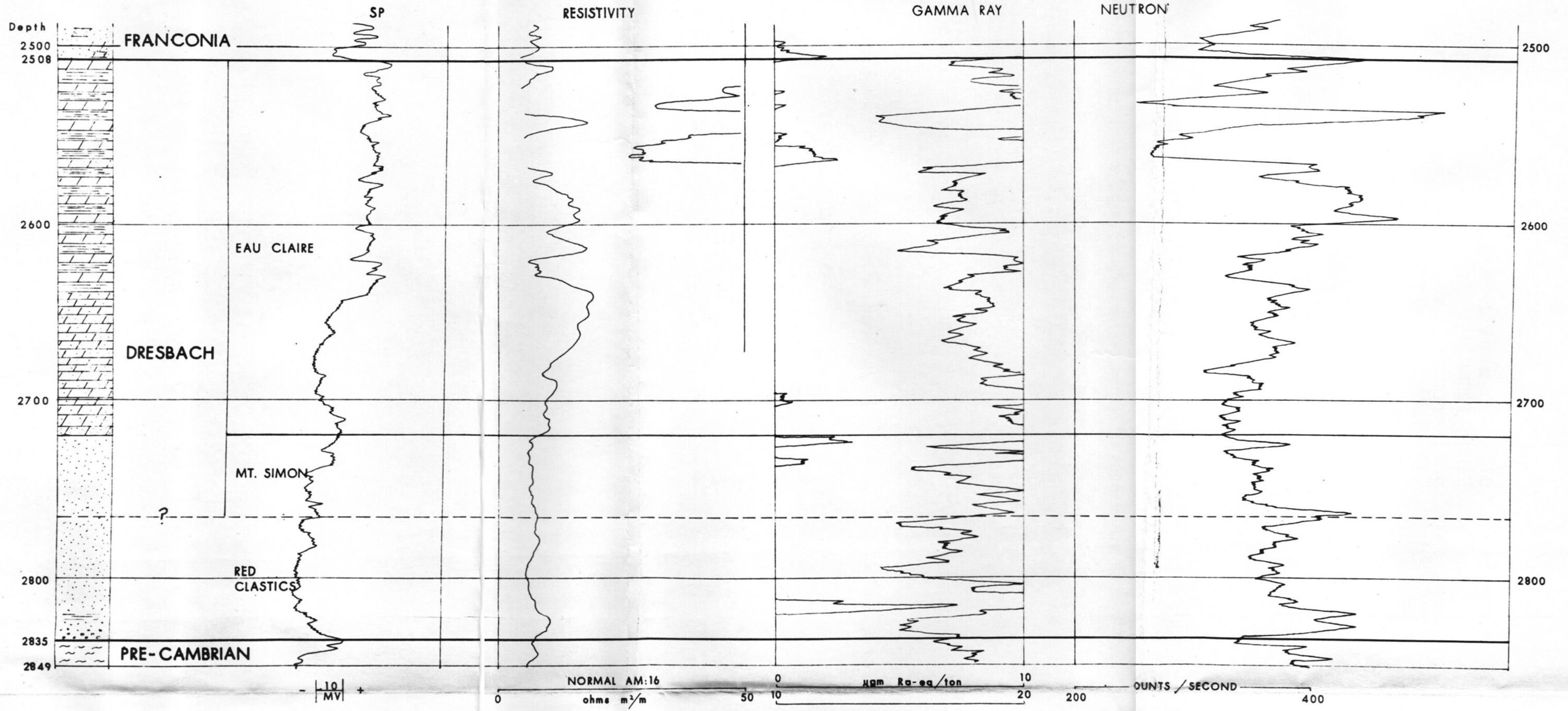
Spontaneous Potential: Relatively low potential values, except increase in the lower 15 feet. Slight differentiation at contact of overlying Mt. Simon.

Resistivity: Low, uniform resistivity values; essentially the same as overlying Mt. Simon.

Gamma Ray: Contact with Mt. Simon marked by sharp decrease in Red Clastics sandstone but with a marked increase in the red shale zone above the conglomerate. This is the highest gamma ray value in the entire section.

Neutron: Distinct increase at contact with Mt. Simon, and decrease at base. Configuration of curve in Red Clastics generally higher than Mt. Simon.

EXAMPLE OF GEOPHYSICAL DATA DERIVED FROM WELL 11  
Showing Properties of  
DRESBACH FORMATION



VERTICAL SCALE 1" = 50'

FIGURE 2

CAMBRIAN SYSTEMST. CROIXIAN SERIES

Four Cambrian formations are present in the Redfield Area; in ascending order they are the Dresbach, the Franco-  
nia, the St. Lawrence, and the Jordan. The United States Geological Survey includes the St. Lawrence and Jordan in the Trempeleau formation, but the Iowa Geological Survey assigns formational rank to these two units.

Dresbach Formation

## Mt. Simon Member

Lithology

The Mt. Simon is a sandstone, light-gray in color and fine-grained. The grains are frosted and curvilinear to round. A compact, laminated, light- to dark-green shale within the top fifteen feet of the section was observed in several wells. The Mt. Simon has a carbonate cement. Porosity and permeability is high. The average thickness of the member is 38 feet.

Summary of Geophysical Characteristics (See Figure 2)

Spontaneous Potential: Moderately uniform values with slight increase in upper 20 feet. No distinct change at top contact.

Resistivity: Values are low and very uniform, with small but distinct increase at top.

Gamma Ray: High to very high values with a pronounced increase at the top contact.

Neutron: Moderately uniform but with noticeable increase five feet below top.

#### Eau Clair Member

##### Lithology

The lower third of the unit is a dolomite, light-gray to light-grayish brown, medium- to fine-grained, and is very silty. Some wells have a shale associated with the dolomite within the bottom 20 feet of the section. The shale is green and reddish-brown, and laminated. The upper two-thirds of the member is an interbedded light-brownish-gray, medium-grained, dense dolomite and a dark-green and brown, laminated, compact shale. The average thickness of the member is 205 feet.

##### Summary of Geophysical Characteristics (See Figure 2)

Spontaneous Potential: The upper part with interbedded shale has consistently higher potential values than the overlying Franconia but no distinct change of values at the contact. Little difference between the basal dolomite and the underlying Mt. Simon.

Resistivity: A slight change in resistivity marks the Franconia-Dresbach contact. The upper half of the member shows some very low values.

Gamma Ray: The values are generally in the same range as the Franconia but with more rapid changes in the shale interbedded zone. A small but sharp decrease at Franconia-Dresbach contact. Increasing values approaching the base.

Neutron: Very pronounced and sharp changes of values in top 100 feet with a distinct increase at contact with Franconia. Bottom 100 feet, gradual decrease by moderate changes, some parts relatively uniform, lowest values at base.

## Franconia Formation

### Lithology

The Franconia formation consists of a sandstone, light-gray in color, fine-grained, sub-angular to sub-rounded, and the grains show minor frosting. The rock has dolomitic cement and large quantities of light-green glauconite characterize the formation. Green shale partings are also present in the bottom forty feet of the section. Mica is present but is relatively more abundant in the upper part of the formation. Porosity and permeability are high. The thickness of the Franconia ranges from 170 to 183 feet.

### Summary of Geophysical Characteristics (See Figure 3)

**Spontaneous Potential:** An increase in values toward base where an abrupt small decrease occurs, otherwise very uniform without distinct change from overlying St. Lawrence. The curve indicates a decrease of permeability in the lower 40 feet.

**Resistivity:** Resistivity is uniformly low. The top contact is marked by a pronounced decrease in values as compared to the overlying dolomite. The values are comparable to the deeper Mt. Simon and Red Clastics members.

**Gamma Ray:** Generally higher than St. Lawrence with distinct increase noted at contact. Increasing values towards the base.

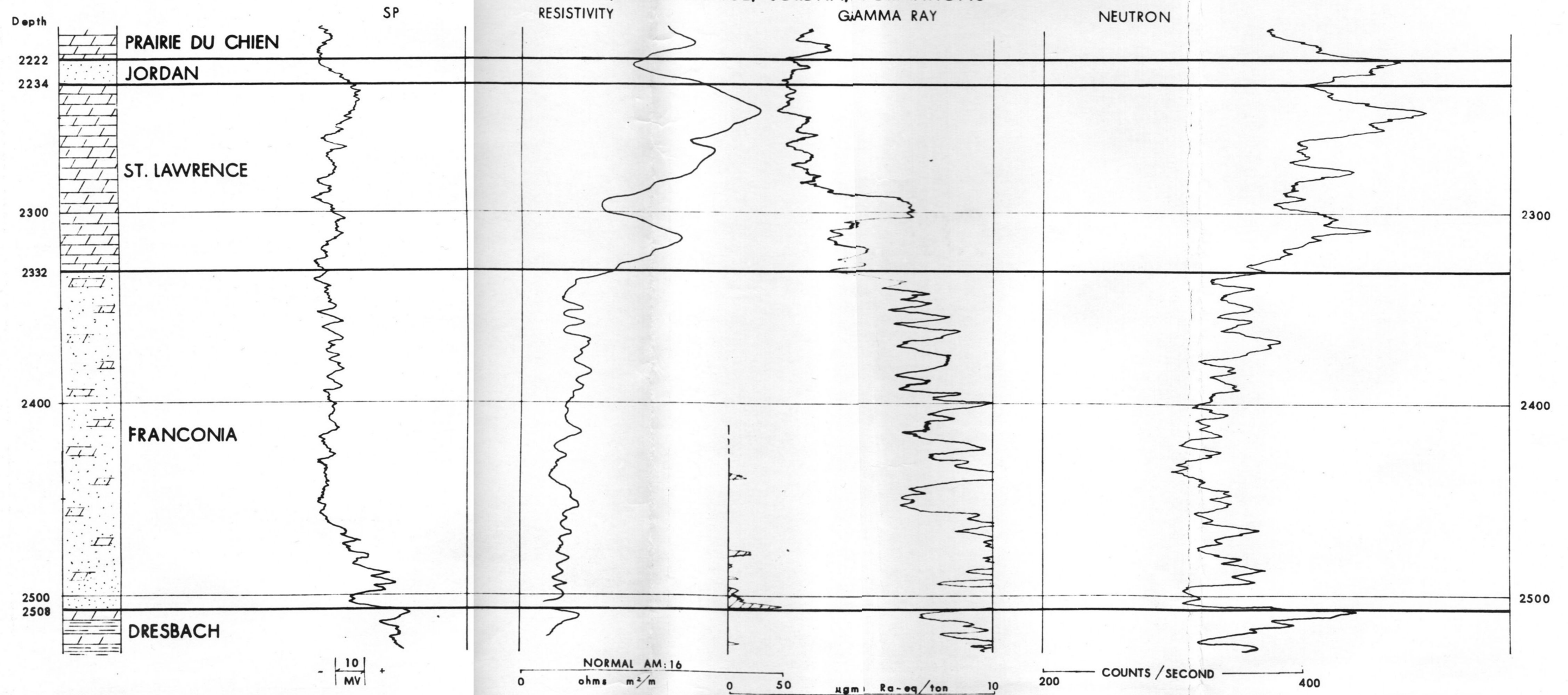
**Neutron:** Drop in values from overlying St. Lawrence with pronounced drop at contact. Values relatively uniform but marked decrease 10 feet above base.

### St. Lawrence Formation

#### Lithology

The St. Lawrence consists of a homogeneous dolomite which is light-gray to light-brown, medium- to fine-grained, and contains many small pores. Light-green glauconite is present in the lower half of the section. Porosity and permeability are relatively high.

EXAMPLE OF GEOPHYSICAL DATA DERIVED FROM WELL 11  
Showing Properties of  
FRANCONIA, ST. LAWRENCE, JORDAN, FORMATIONS



VERTICAL SCALE 1" = 50'

FIGURE 3

### Summary of Geophysical Characteristics (See Figure 3)

**Spontaneous Potential:** The top 30 feet shows a small increase in value which may indicate lower permeability than the overlying Jordan.

**Resistivity:** Abrupt changes are noted at both top and bottom of the St. Lawrence. The resistivity decreases downward to the Franconia with marked deviation about 30 feet above the base and then a resumption of decrease to the Franconia contact. The resistivity is markedly higher than in the overlying Jordan.

**Gamma Ray:** The values at the top are similar to the Jordan with a small increase downward. At 55 feet below the top a marked increase occurs for 15 feet at the same zone as the marked deviation of resistivity.

**Neutron:** This curve resembles the resistivity curve except at the top where a decrease occurs at the contact with the Jordan. However, the general decrease of neutron activity downward in the St. Lawrence is marked by swings of the curve that are several times greater than the total decrease in values.

### Jordan Formation

#### Lithology

The Jordan formation is a sandstone, light-gray, fine- to medium-grained, curvilinear to sub-rounded, and has a

dolomitic cement.

Summary of Geophysical Characteristics (See Figure 3)

Spontaneous Potential: Little initial change from overlying Prairie du Chien. Gradual increase in values towards lower contact.

Resistivity: Drop in resistivity at upper contact. Gradual increase in resistivity from five feet below upper contact.

Gamma Ray: Small drop in values from overlying Prairie du Chien. Little variation in values through formation.

Neutron: Sharp increase in values at upper contact but values drop sharply from this contact to the base.

Thickness of Jordan-St. Lawrence formations

The combined thickness of the Jordan and St. Lawrence formations ranges from 108 to 122 feet. Inasmuch as the Jordan is only 10-20 feet thick in the Redfield Area, the combined thickness is given here and the dual interval is used on the structure maps.

ORDOVICIAN SYSTEMBEEKMANTOWNIAN SERIESPrairie du Chien Formation

## Oneota Member

Lithology

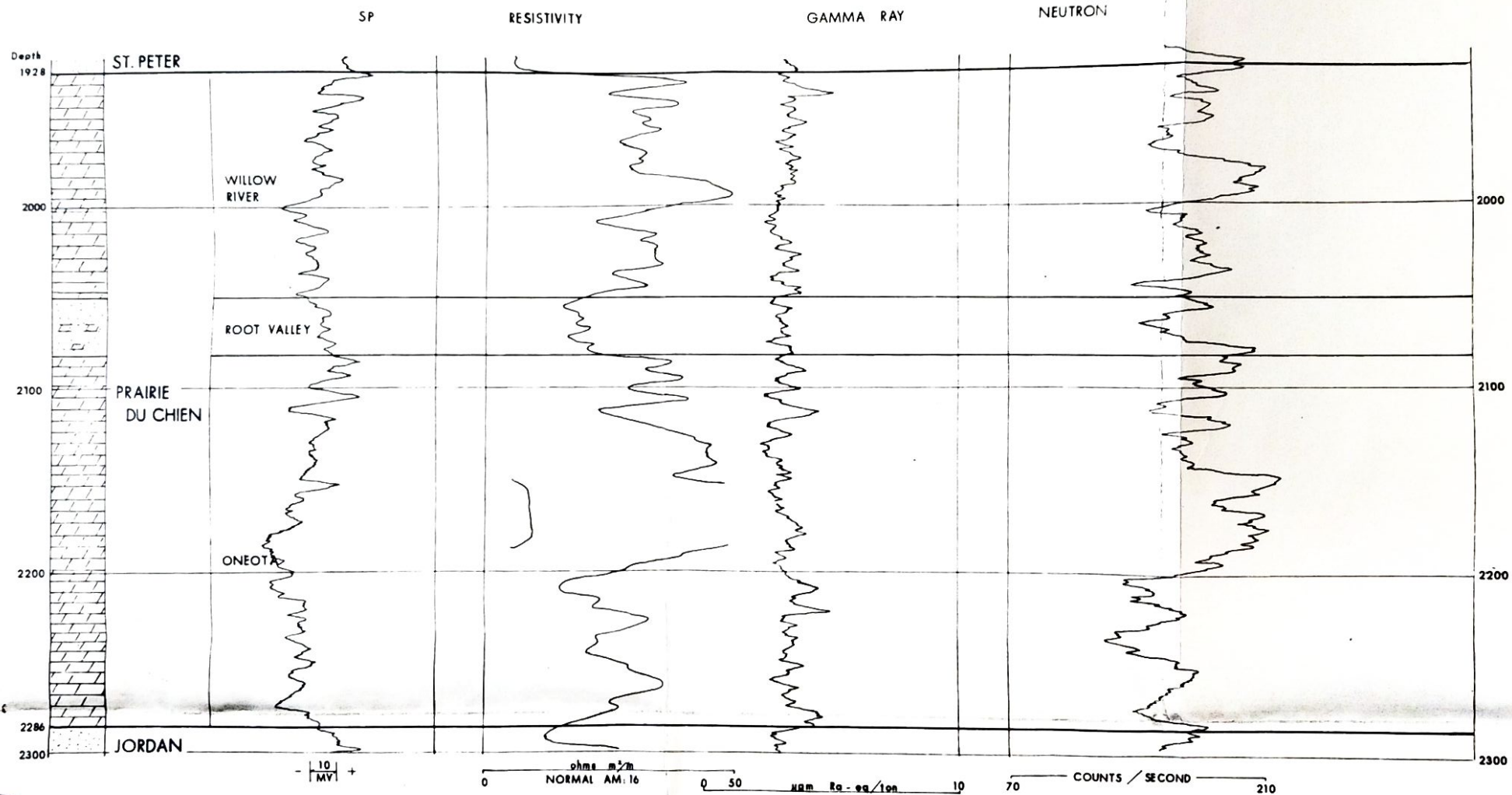
The Oneota is dolomite, light-gray to light-yellowish brown at the top to light or dark-brown at the bottom. It is fine-grained and a few open pores are present in the lower half of the section. A small amount of light-gray chert was present near the middle of the section. The dolomite contains a light-gray sand throughout. The thickness of the Oneota is approximately 220 feet.

Summary of Geophysical Characteristics (See Figure 4)

The logs used in preparation of the figures were selected on the basis of presenting that log which was most typical for the area. The logs from Well Number 46 were used to illustrate the geophysical characteristics of the Prairie du Chien formation. Therefore there is a scale difference for the neutron log and the curves of the other logs do not coincide precisely at the contacts with adjacent formations.

Spontaneous Potential: Pronounced increase in potential at the upper contact. From this initial high, the values decrease for approximately 100 feet and then a

EXAMPLE OF GEOPHYSICAL DATA DERIVED FROM WELL 46  
Showing Properties of  
PRAIRIE DU CHIEN FORMATION



VERTICAL SCALE 1" = 50'  
FIGURE 4

gradual increase in the potential is noted. Abrupt deflections are present in the upper 20 feet.

Resistivity: Sharp increase in resistivity present at upper contact. Relatively high values throughout but particularly from approximately 70 to 110 feet below the top.

Gamma Ray: Low but uniform values throughout the Prairie du Chien formation. The uniformity and small deviations of the curve provides a distinct contrast to any other part of the stratigraphic section below the Silurian.

Neutron: Gradual decrease in values in upper 25 feet from the relatively high value at the base of the Root Valley. Moderate fluctuations throughout the upper 115 feet with values comparable to the overlying members. The basal 90 feet has lower overall values.

Root Valley Member

#### Lithology

The Root Valley is a fine-grained, light-gray sandstone. The grains are angular to sub-angular and are cemented by dolomite which may assume the dominant lithology. The carbonate-rich portions of the section are light-grayish-brown. The thickness of the Root Valley is approximately 35 feet.

#### Summary of Geophysical Characteristics (See Figure 4)

Spontaneous Potential: Small increase in potential at the upper contact of the Root Valley. Values throughout the

member do not vary greatly from the overlying Willow River member.

**Resistivity:** The resistivity curve defines the Root Valley member to a greater extent than the other geophysical logs. There is a sharp drop in resistivity from the overlying member and overall the resistivity of the Root Valley is less than the overlying member.

**Gamma Ray:** This member is not distinct from the overlying Willow River nor the underlying Oneota.

**Neutron:** Contains deviations of the same order and range as the overlying Willow River.

#### Willow River Member

##### Lithology

The Willow River is a dolomite, light-brown at the top but grading to a light-grayish-brown with depth to a light-gray at the base. It is fine-to medium-grained and contains many pores and dolomite rhombs. Disseminated pyrite is present in the upper 20 feet and "floating" sand grains are present throughout. The thickness of the Willow River is approximately 120 feet.

##### Summary of Geophysical Characteristics (See Figure 4)

**Spontaneous Potential:** Slight initial increase in potential at contact with St. Peter but thereafter, gradual decrease in values with moderate deflections in the curve.

Resistivity: Abrupt increase in resistivity present at the upper contact. This deflection is distinctive throughout the Redfield Area. Values are high throughout the member relative to adjacent units.

Gamma Ray: Overall values are low and the curve is not distinct from adjacent units.

Neutron: An abrupt increase in value present at upper contact. Values are higher than the overlying St. Peter.

#### Thickness of the Prairie du Chien

The thickness of the Prairie du Chien formation ranges from 354 to 403 feet.

### CHAZYAN SERIES

#### St. Peter Formation

##### Lithology

The St. Peter sandstone is very light-gray in color. The well-abraded grains range from fine-to coarse but are moderately well-sorted in any horizon. The cementing is weak and the sand is quite friable. The formation is very porous and permeable. A zone of breccia containing sandstone, dolomite, and clay is present in some wells at the base of the formation. The thickness of the St. Peter ranges from 27 to 34 feet.

### Summary of Geophysical Characteristics (See Figure 5)

**Spontaneous Potential:** The abrupt decrease in potential from the overlying Decorah-Platteville and the relatively low values provides a good marker and suggests a wide variance in permeability.

**Resistivity:** The resistivity curve of the St. Peter formation is a good marker for correlation purposes as the resistivity values are low and uniform relative to formations above and below.

**Gamma Ray:** Upper contact well-defined by abrupt decrease from the very high values of the Glenwood member of the Platteville formation to the relatively low values of the St. Peter formation.

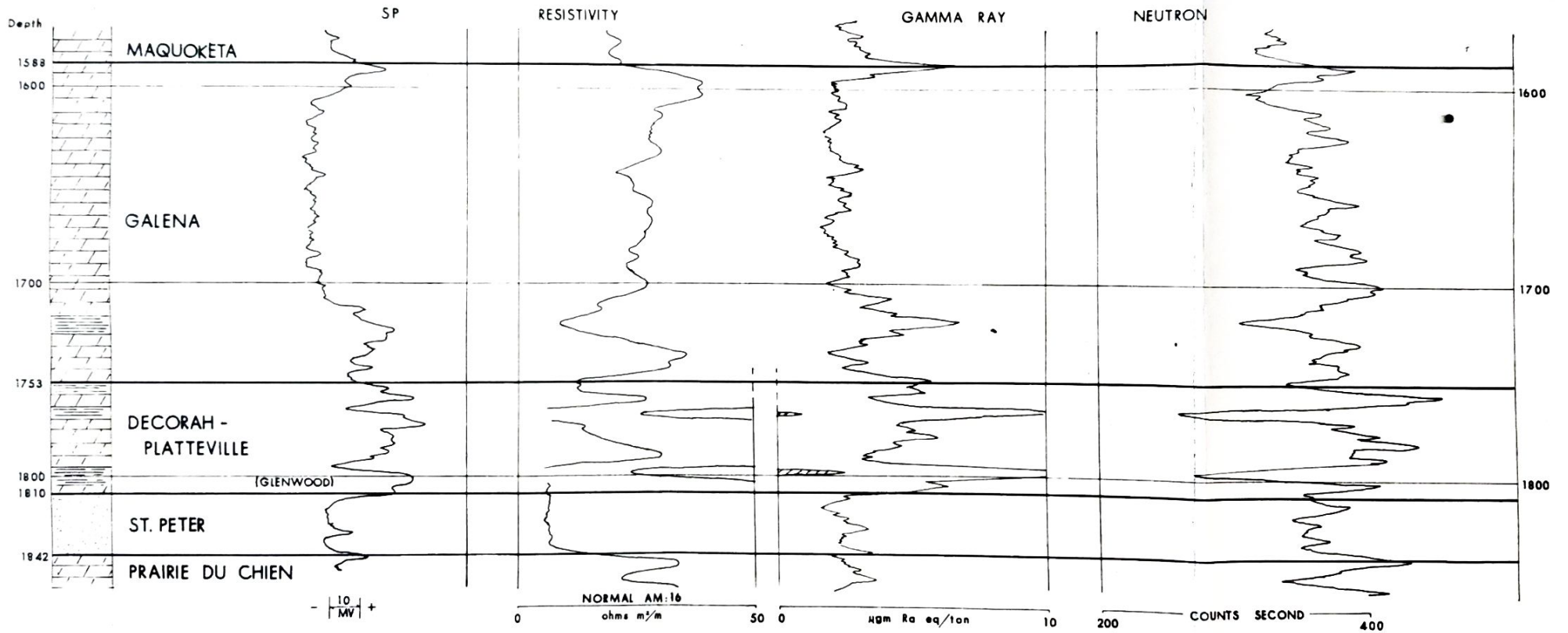
**Neutron:** A small increase in values present in the upper five feet of the St. Peter but overall values lower than adjacent formations.

### MOHAWKIAN SERIES

#### Decorah-Platteville Formations

The Decorah and Platteville formations are considered together in this report due to the difficulty in separating the formations on the basis of lithology or geophysical log characteristics. An exception to the above is the basal lithologic unit which is, in all probability, the Glenwood shale member of the Platteville formation.

EXAMPLE OF GEOPHYSICAL DATA DERIVED FROM WELL 11  
 Showing Properties of  
 ST. PETER, DECORAH-PLATTEVILLE, GALENA, FORMATIONS



VERTICAL SCALE 1"=50'

FIGURE 5

### Lithology

The basal five to ten feet of this formation group is a distinctive shale, dark-gray and light-dark-green, laminated, and compact. Dolomite may also be present in this interval. Overlying the shale in some wells is a sandstone, light-gray, medium-grained, and curvilinear to sub-rounded. This sand was probably derived from the St. Peter but it is unlikely that it is the Mooar sandstone of eastern Iowa as it is not persistent even in this limited area. The primary lithology of the Decorah-Platteville formations is a dolomite, light-brown to brown, fine-grained, dense and argillaceous. Two other shale units are present, one a three to five foot zone is at the top of the unit and a second five to ten foot zone is present 15 to 20 feet below the top. Both shales are green, laminated, and compact. A light-brown, sub-lithographic, limestone is present beneath the upper shale in some wells. The thickness of the Decorah-Platteville ranges from 54 to 63 feet.

### Summary of Geophysical Characteristics (See Figure 5)

Spontaneous Potential: Wide fluctuations present.

Shale portions have high potentials indicating low permeability. The overall values are higher than the overlying Galena and a sharp increase is noted at the contact.

Resistivity: Abrupt drop in resistivity at the contact with the Galena. The configuration of the deflection (the drop in resistivity, a narrow zone of uniform values, and an increase in resistivity) is persistent throughout the Redfield Area and is an excellent marker. Low values also present in the other shale horizons.

Gamma Ray: Increase in values at upper contact. The shale portions of this unit provide characteristic deflections in the curve.

Neutron: As with the gamma ray log, the shale horizons cause large fluctuations in the values. These narrow deflections on the radioactivity log provide a good marker for correlation purposes.

#### Notations

The shales of this formation group are particularly important in the Redfield Area for it is their relatively impervious character which provides a tight seal and makes the St. Peter formation an ideal reservoir for gas storage.

### Galena Formation

#### Lithology

The Galena formation is dolomite, light-yellowish-red to light-grayish-brown. It is fine- to medium-grained and it contains many pores. A prominent feature of the Galena is the "cinnamon specks" which are present in the upper one-

quarter of the formation. These specks appear to be an iron mineral which weathers to give a limonitic stain. Light-gray chert is persistent in the lower two-thirds of the Galena. A five- to eight-foot zone of green, laminated, shale is present within 40 feet of the base. The Galena ranges from 154 to 168 feet in thickness.

Summary of Geophysical Characteristics (See Figure 5)

**Spontaneous Potential:** Sharp increase in potential at upper contact but values revert to the same range as overlying Elgin within 20 feet of the top. There is another increase in potential in the lower one-third of the formation corresponding to the shale zone.

**Resistivity:** The resistivity increases to a high 10 feet below the upper contact. From this point, the resistivity drops, erratically but persistently, to a point including the shale zone. Another sharp deflection with higher values is present between the shale zone and the lower contact.

**Gamma Ray:** Initial high at upper contact. The shale horizon also gives a distinctive break in the curve. The balance of the formation has values corresponding with the overlying Elgin.

**Neutron:** High values at upper contact relative to overlying Elgin. Values moderate but erratic in rest of

unit with the exception of the low values corresponding to the shale break.

## CINCINNATIAN SERIES

### Maquoketa Formation

#### Elgin Member

##### Lithology

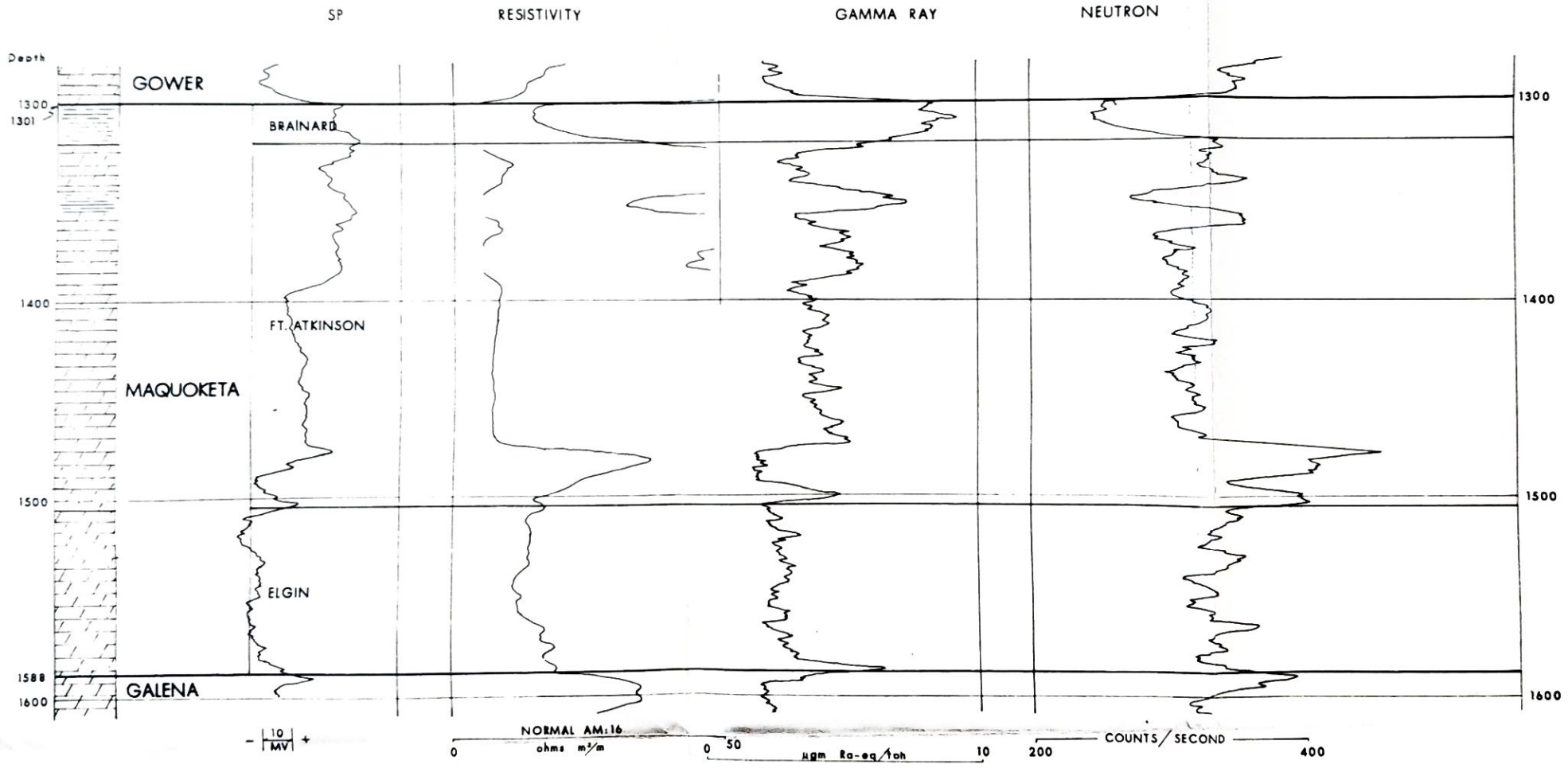
The Elgin member is chiefly a dolomite but there is a large amount of chert present throughout the section. The dolomite is light-grayish-brown near the top of the section but the bottom three-fourths of the unit is light-gray. The dolomite is fine- to medium-grained. The chert is mottled light and dark-gray, has a dull luster and the fracture may produce either smooth or irregular surfaces. The Elgin may also contain thin shale partings which are mottled green and red. The thickness of the Elgin is approximately 85 feet.

##### Summary of Geophysical Characteristics (See Figure 6)

**Spontaneous Potential:** Upper contact marked by decrease in potential. The values of the member are quite uniform and overall they are lower than those of the Ft. Atkinson.

**Resistivity:** Few fluctuations present. The upper contact is picked at the large drop in resistivity from the Ft. Atkinson.

EXAMPLE OF GEOPHYSICAL DATA DERIVED FROM WELL 11  
Showing Properties of  
MAQUOKETA FORMATION



VERTICAL SCALE 1" = 50'

FIGURE 6

Gamma Ray: Fluctuations in curve are small and upper contact picked at drop in values from overlying member.

Neutron: The upper contact picked on drop in values from overlying unit. As with the other logs, the amorphism of the curve in respect to adjacent units is distinctive.

#### Ft. Atkinson Member

##### Lithology

The basal 20 to 30 feet of the Ft. Atkinson is a dolomite, very light-gray, medium- to coarse-grained with many pores. The upper portion of the formation is a dolomite, light-gray, fine-grained, argillaceous and densely compacted. A light-gray, interstitial chert which has both smooth and irregular fractures is present in the upper 10 feet and also from 50 feet below the top down to the basal 30 feet which is chert-free. Like the Elgin, the Ft. Atkinson may have numerous layers of green and reddish shale. The thickness of the Ft. Atkinson is approximately 175 feet.

##### Summary of Geophysical Characteristics (See Figure 6)

Spontaneous Potential: Small drop in potential from overlying shale which would agree with variations in permeability. There is a step-like reduction in potential from the upper contact to the lower contact.

Resistivity: Upper contact well marked by very large increase in resistivity from the overlying shale. An upper

zone of 60 to 70 feet has low to very low fluctuating values, the underlying 80 feet has a uniformly low curve with no fluctuations and the basal 20 to 25 feet are characterized by a very prominent deflection in which the values rise rapidly and drop to the lower contact. This whole interval is very distinct and the configuration of the curve is persistent throughout the Redfield Area.

**Gamma Ray:** The upper contact is marked by the overlying shale deflection. Two prominent fluctuations are prominent within the unit; one, a shale deflection near the top and the second, a drop in values near the base.

**Neutron:** Similar fluctuations as in the gamma log except the basal deflection is an increase in values.

#### Brainard Member

##### Lithology

The Brainard shale is a mottled green and red color. It is waxy, thin laminated, and contains scattered phosphatic nodules. The thickness of the Brainard is approximately 21 feet.

##### Summary of Geophysical Characteristics (See Figure 6)

The Brainard shale is one of the most distinctive units in the stratigraphic section in regards the geophysical logs.

**Spontaneous Potential:** Upper contact well marked by large increase in potential relative to the Gower.

**Resistivity:** The resistivity of the Brainard is very low, much less than the low values of the adjacent units.

**Gamma Ray:** Distinct shale fluctuation in the curve and higher values than adjacent units.

**Neutron:** Shows the distinctive shale horizon with values lower than adjacent units.

#### Thickness of the Maquoketa Formation

The thickness of the Maquoketa formation ranges from 276 to 309 feet.

### SILURIAN SYSTEM

#### NIAGARA SERIES

##### Gower Formation

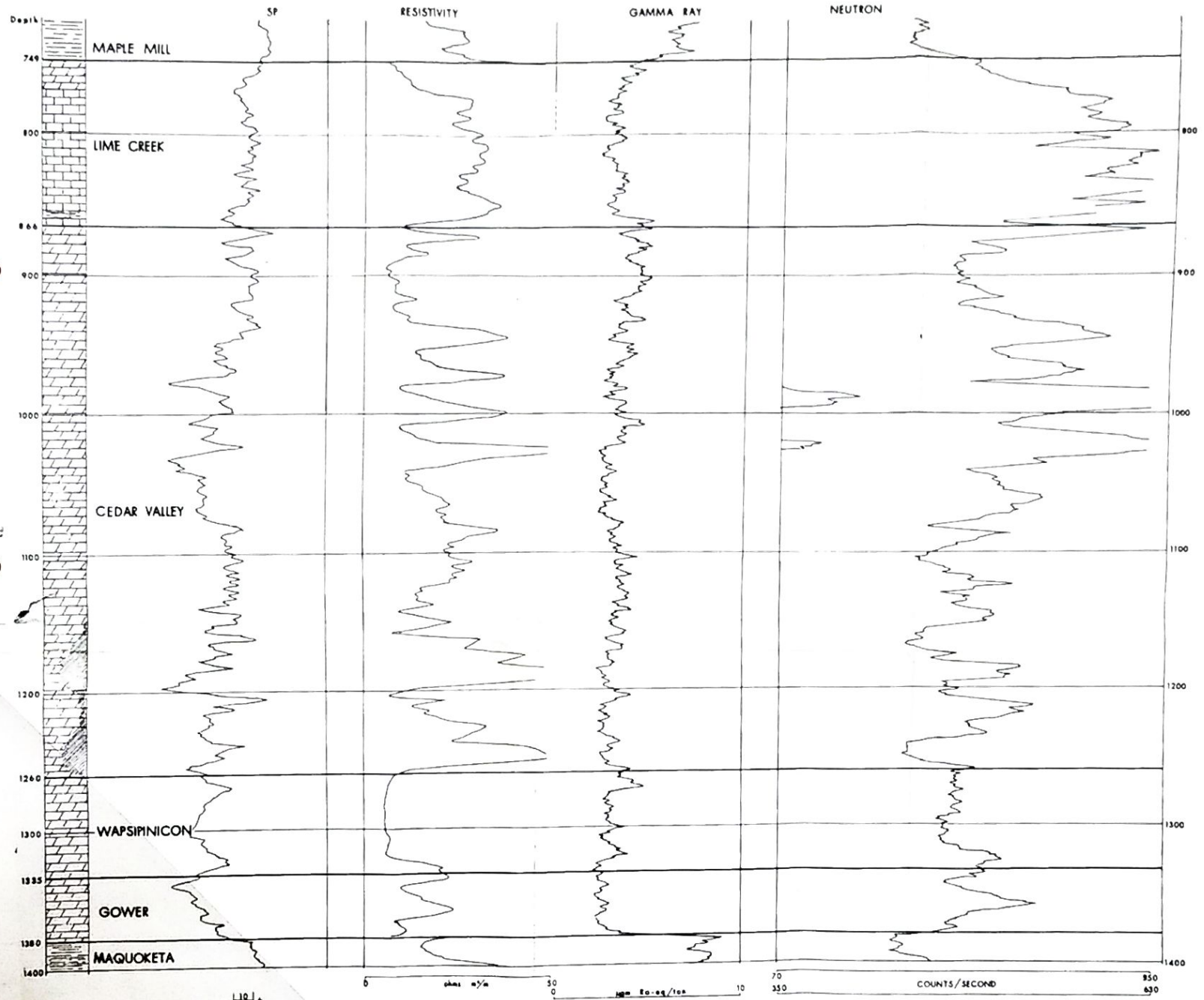
##### Lithology

The Gower formation is a homogeneous unit composed of dolomite, light- to dark-gray at the top and becomes darker brown toward the base. It is medium-grained and contains many pores which give the formation high porosity. The Gower ranges in thickness from 41 to 53 feet.

##### Summary of Geophysical Characteristics (See Figure 7)

Well 46 was used for Figure 7 primarily to show the geophysical response to the gypsum section in the Cedar Valley which was not present on Well 11. For this reason the curves of the logs above and below do not correspond precisely.

EXAMPLE OF GEOPHYSICAL DATA DERIVED FROM WELL 46  
 Showing Properties of  
 GOWER, WAPSIPINICON, CEDAR VALLEY, LIME CREEK, FORMATIONS



VERTICAL SCALE 1"=50'  
 FIGURE 7

Spontaneous Potential: Initial drop in potential at upper contact but values increase to lower contact. The SP log contains the most persistent marker for determining the upper contact.

Resistivity: Resistivity fluctuates widely and not consistent in logs throughout area. In general, values are higher than overlying Wapsipinicon.

Gamma Ray: Low consistent values throughout the Gower and this amorphism continues through the overlying Devonian formations.

Neutron: Initial drop in values at upper contact. A large fluctuation in middle portion of the formation.

## DEVONIAN SYSTEM

### MIDDLE DEVONIAN SERIES

#### Wapsipinicon Formation

##### Lithology

The Wapsipinicon is a dolomite, light-gray to light-brown in color, fine-grained, sandy, argillaceous, and slightly porous. The thickness of the Wapsipinicon ranges from 37 to 96 feet.

##### Summary of Geophysical Characteristics (See Figure 7)

Spontaneous Potential: Initial increase in values at upper contact. The values of the Wapsipinicon are within

the range of values of the Cedar Valley and therefore, this log in itself is not distinctive.

Resistivity: The upper contact displays an abrupt drop in values from the Cedar Valley. Resistivity is low and uniform relative to adjacent formations.

Gamma Ray: Not distinct from the overlying Cedar Valley nor underlying Gower.

Neutron: Sharp increase in values at upper contact. Values generally are uniform within the formation with a possible increase in values near the base.

### Cedar Valley Formation

#### Lithology

The Cedar Valley is primarily a dolomite, light-yellowish-red to light-grayish-brown with some mottling of darker values of the same colors. It is fine- to medium-grained and dolomite rhombs and pyrite are disseminated throughout. The basal 150 feet of the section contains gypsum, primarily in one or two zones, which is very light-gray in color. The maximum thickness of the gypsiferous unit is present on the periphery of the structure but it decreases in thickness to a minimum of 10 feet on the top of the structure. A light-gray, fine-grained, limestone is present at the base of the Cedar Valley in some wells. The thickness of the Cedar Valley ranges from 312 to 424 feet.

Summary of Geophysical Characteristics (See Figure 7)

Spontaneous Potential: Increase in potential from the overlying Lime Creek. As a whole, the log is erratic with many fluctuations and the values are lower than the Lime Creek.

Resistivity: The upper contact is an abrupt, narrow, deflection with lower values than the Lime Creek. This is a persistent deflection throughout the area and the configuration of the change in values makes it a good marker. The values of the formation are variable ranging from low to high. In areas where a full section of gypsum is present, two deflections of high values are present within 100 to 150 feet of the base. The gypsum is variable in its presence and only one or no deflections may be present which can be related to the gypsum.

Gamma Ray: Not distinct from the overlying Lime Creek or underlying Wapsipinicon formations.

Neutron: A sharp increase in values present at upper contact. The values are high but are not as high nor as consistent as the overlying Lime Creek.

UPPER DEVONIAN SERIES

Lime Creek Formation

Lithology

The Lime Creek has two distinct lithologic units present.

The upper 10 to 20 feet is a dolomite, light-gray, fine-grained, and calcitic. This unit is distinct from the underlying limestone which is light-grayish-brown to brown, fine-grained to sub-lithographic, and contains numerous pores. Some thin bands of light-green, laminated, shale are present in the limestone.

The thickness of the Lime Creek formation ranges from 102 feet to 132 feet. These are the extreme figures, however, and most of the wells recorded a thickness of from 110 to 120 feet. The wells which contain the thicker sections are on the flanks of the structure.

Summary of Geophysical Characteristics (See Figure 7)

**Spontaneous Potential:** Small but perceptible decrease in potential from the overlying Maple Mill. Values have small fluctuations and the interval is quite uniform.

**Resistivity:** Upper contact is well marked by abrupt increase in resistivity from overlying shale. Gradual increase in values in upper 20 feet. Remaining portion of the unit has high, consistent values relative to adjacent formations.

**Gamma Ray:** Abrupt drop in values from shale contrasts with uniform low values of the Lime Creek.

**Neutron:** Low values of the overlying Maple Mill contrasts with the very high values of the Lime Creek.

MISSISSIPPIAN SYSTEMKINDERHOOKIAN SERIESMaple Mill FormationLithology

The Maple Mill is a green or grayish-green shale. It is laminated and becomes dolomitic near the base of the formation. The thickness of the Maple Mill ranges from 36 to 44 feet.

Summary of Geophysical Characteristics (See Figure 8)

**Spontaneous Potential:** Large increase in potential from Hampton. This suggests a sharp reduction in permeability.

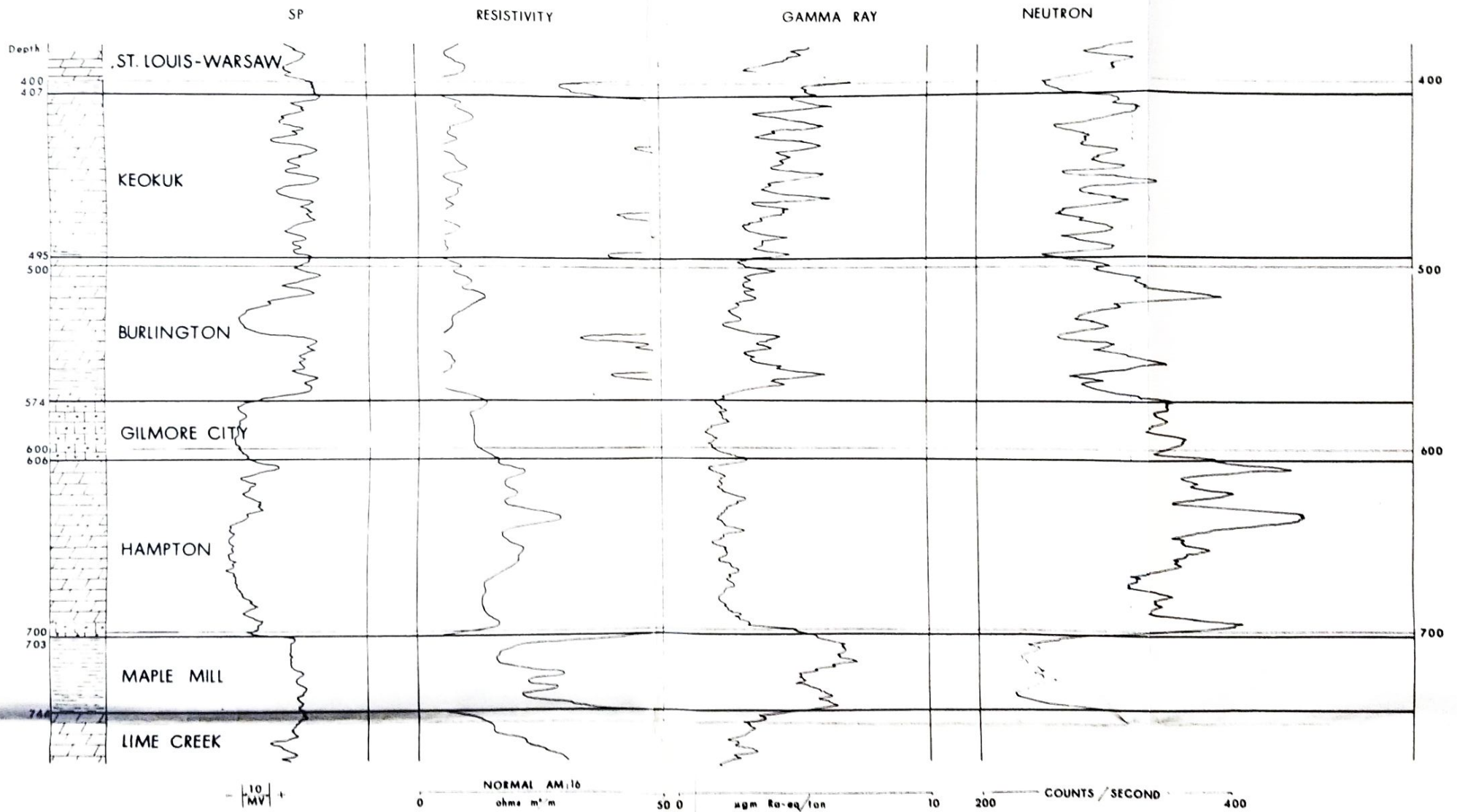
**Resistivity:** Extremely low resistivity relative to adjacent formations.

**Gamma Ray:** Abrupt increase in values from overlying Hampton.

**Neutron:** Decrease in values giving a distinctive shale break.

The general configuration of the curves on all logs makes this the most distinctive horizon in the stratigraphic section and thus provides an excellent correlation check point.

EXAMPLE OF GEOPHYSICAL DATA DERIVED FROM WELL 11  
 Showing Properties of  
 MAPLE MILL, HAMPTON, GILMORE CITY, BURLINGTON, KEOKUK, FORMATIONS



VERTICAL SCALE 1" = 50'

FIGURE 8

## Hampton Formation

### Lithology

The Hampton formation may be divided into four lithologic units. Within the basal 20 feet of the formation is a light-brown oolitic limestone which has moderate porosity. The overlying 45 to 65 foot unit is a light-gray to light-brown dolomite which is fine-grained, tight, calcitic, and contains a small amount of light-gray chert. The following ten feet, plus or minus, is a limestone, light-gray to light-brown, fine-grained, and containing dolomite rhombs. The upper 10 to 25 foot unit is dolomite, light-grayish-brown, fine-grained, tightly compacted, calcitic, and argillaceous. The thickness of the Hampton formation ranges from 80 to 100 feet in thickness.

### Summary of Geophysical Characteristics (See Figure 8)

**Spontaneous Potential:** Upper contact has an increase in potential from the overlying Gilmore City. However, this is not a trend which can be detected throughout the area and this contact is not particularly evident.

**Resistivity:** Increase in resistivity at the upper contact. Resistivity values for this formation are high relative to adjacent formations.

**Gamma Ray:** Upper contact on this log marked only by a small deflection and the values are essentially the same as the overlying formation.

Neutron: This log expresses the Hampton in a more distinctive manner. The upper contact is marked by an abrupt rise in values. Many fluctuations but overall the values are higher than adjacent units.

### Gilmore City Formation

#### Lithology

The Gilmore City is very distinctive within the Redfield Area. The upper portion is an oolitic limestone, light-brown, medium- to coarse-grained, and is moderately porous. The oolites are smaller toward the base and there is a transition to a clastic limestone which is light-brown and fine-grained. The thickness of the Gilmore City ranges from 30 to 40 feet.

#### Summary of Geophysical Characteristics (See Figure 8)

Spontaneous Potential: Large decrease in potential values from overlying Burlington. Few fluctuations in the curve.

Resistivity: Sharp rise in values from the Burlington at the contact and overall higher values than the Burlington.

Gamma Ray: Large decrease in values at the upper contact. Curve has very small fluctuation and lower values than overlying formation.

Neutron: Increase in values at upper contact. Relatively few fluctuations and higher values than the Burlington.

OSAGIAN SERIESBurlington FormationLithology

The Burlington formation is a cherty dolomite. The dolomite is light-gray to light-brown in color and fine-grained. The chert is light-gray; it has a dull luster and the fracture is irregular. Light-green glauconite is present in the upper 50 feet of the section and is used as a lithologic determinant for the top of the formation. Thin zones of light-gray, medium-grained, clastic limestone are present in the middle portion of the section. Shale, grayish-green, laminated, is present in some wells near the base. The thickness of the Burlington formation ranges from 75 to 95 feet.

Summary of Geophysical Characteristics (See Figure 8)

Spontaneous Potential: No distinctive features at the upper contact. Generally very high values with a large drop in potential in the middle of the section.

Resistivity: Upper contact marked by a persistent rise in values.

Gamma Ray: Not distinct from overlying Keokuk although overall the values are lower.

Neutron: Rise in values at upper contact. Little variation from Keokuk.

## Keokuk Formation

### Lithology

The Keokuk formation resembles the Burlington in that both formations are cherty dolomites. However, there is also some gray and brown shale present in the Keokuk, particularly in the upper half of the formation. The dolomite is brown to light-grayish-brown, fine-grained and slightly porous. The chert is dominantly light-gray to brown, and, to a lesser extent, mottled blue color. The Keokuk-Burlington contact is based largely on the change of chert color and the abundance of glauconite in the Burlington. The thickness of the Keokuk is approximately 80 feet.

### Summary of Geophysical Characteristics (See Figure 8)

**Spontaneous Potential:** General drop in values from the high potential of overlying shale. However, values are quite high and uniform.

**Resistivity:** Upper contact marked by sharp increase in values from the very low values of the overlying shale. Values generally low and uniform.

**Gamma Ray:** Upper contact based on the shale break of the overlying Warsaw.

**Neutron:** Increase in values over the low values of the overlying shale.

MERAMECIAN SERIESWarsaw FormationLithology

The Warsaw formation is a dolomite which is brown or mottled light and dark brown. Thin beds of sandy and silty material alternate with the dolomite. There are gray and brown shale partings two or three feet thick, and five foot (plus or minus), thin-bedded, micaceous shale unit is present at the base of the formation. A grayish-brown chert is also present in minor amounts. The thickness of the Warsaw is approximately 20 feet.

Geophysical Information

The geophysical logs available to this writer normally did not include any of the interval above the Osagian Series so the geophysical data for the post-Osagian section is not included in this report.

St. Louis FormationLithology

The St. Louis has two lithologies. The top one-third to one-half of the formation is limestone and the lower portion is a dolomite. The dolomite in turn is divided into two zones, the lower half, a sandy and cherty zone and the upper half which is generally lacking in arenaceous material. The dolomite is light-gray to light-yellow or grayish-brown

with occasional light-dark shale partings. The upper portion of the dolomite is very fine-grained. The limestone is light-yellowish-brown, fine-grained, and contains disseminated oolites. The thickness of the St. Louis formation ranges from 20 to 120 feet.

### STRUCTURE

#### The Redfield Anticline

Leonard (1898, p. 90-91) noted the presence of the anticlinal structure in Dallas County and listed it in his table of contents as the Redfield anticline. In the text on page 91 he again used the term in a general description of the structure. Condra and Reed (1938, p. 15-16) proposed that the term "Redfield anticline" be substituted for the regional structural feature which Tilton (1919, p. 383-390) had named the "Thurman-Wilson fault."

The Iowa Geological Survey in a publication now in press (Iowa State Highway Commission H. R. No. 11, 1960) introduced the term "Thurman-Redfield Structural Zone" to include the faulting and folding of the regional structural condition with which Condra and Reed and Tilton were concerned.

This writer proposes that the structure of the gas storage area which is located near Redfield, Iowa, be known as the Redfield anticline inasmuch as this name has priority

and because the form of the structure is anticlinal in nature.

### Structural History

Lee (1946) included the Redfield Area in the Forest City Basin and suggested that this latter structural feature was the controlling factor in the development of many smaller structures during the late part of the Paleozoic.

The isopach map of the Cambrian formations (Plate V) shows a thickening of 20 feet plus between the west flank and the crest of the anticline. This is essentially the same value as the increase of structural closure as is indicated by the elevations at the base and top of the Cambrian formations. The closure on the Precambrian-Cambrian surface (Plate I) is 155 feet, on the Dresbach-Franconia surface (Plate II) 172 feet, on the Franconia-St. Lawrence surface (Plate III) 167 feet, and on the Jordan-Prairie du Chien surface (Plate IV) 173 feet. From the above figures, it is seen that the main variations in thickness occur in the Dresbach.

The closure, as noted for the Cambrian formations above, was derived from well 5 on the top of the structure and well 68 on the northern end of the structure. In some cases, the contours show more or less closure but the use of these two wells established a convenient standard for comparison.

The isopach map of the Prairie du Chien formation (Plate VII) shows a slight thinning over the present crest of the anticline. It is possible that this variation in thickness can be related to the general thickening of the Cambrian over much of this same area as the thicker parts of the Cambrian formations nearly coincide with the thin areas of the Prairie du Chien formation (Plates V and VII). Lee (1946) and others have described a large unconformity at the base of the St. Peter and the breccia and clay noted at the base of the St. Peter in the Redfield Area suggests agreement with this hypothesis. If the thinning of the Prairie du Chien is attributed to erosion, the pattern described by the isopach contours suggests a small uplift prior to deposition of the St. Peter. The closure of the Prairie du Chien as shown on Plate VI is 152 feet and the lessening of closure from the Cambrian can be attributed to the thinning as noted above.

The thickness of the St. Peter formation ranges but a few feet and no pattern could be described on an isopach map. This is also true of the Decorah-Platteville and the Galena formations. Therefore, these formations were included with the Maquoketa formation on an isopach map (Plate XII). Most of the variance in the thicknesses expressed on this map can be traced to the Brainard member of the Maquoketa

formation. There is approximately a 20 foot increase in thickness of the Brainard from Well 4 on the top of the anticline to Well 71 which is on the relatively steeply dipping east flank. The pattern indicated by the thickening suggests a small uplift which was a forerunner of the uplift in the Cedar Valley. But if the thickening to the northeast was caused by an uplift, it was a very small feature.

The presence of only a thin Silurian section relative to areas in eastern Iowa and further southwest in the Forest City Basin suggests one or more of the following conditions occurred during the Silurian:

1. The Redfield Area was a structural high during the latter part of the Silurian and received no deposition;
2. The area was one in which there was failure of deposit;
3. Sediments were deposited but were subjected to erosion after deposition.

The relative homogeneity in thickness of the Gower formation does not suggest local uplift in the Redfield Area before deposition of the overlying Wapsipinicon. However, the thin section does suggest that this area was, during most of the Silurian, an area of non-deposition.

The isopach map of the Devonian formation (Plate XVII) shows the first definite indication of movement of the

Redfield anticline. A regular thinning of the Devonian occurred which is centered in section 12, T. 79 N., R. 29 W. This center of uplift is located approximately one mile northwest of the crest of the existing structure. The alignment of the uplift was a general northwest-southeast direction. Correlation of the available logs indicates that the portion within the basal 150 feet of the Cedar Valley formation which contains the gypsum is the missing section. This is verified by the lithologic logs composed of the several wells examined by the writer. The gypsum ranges in thickness from 10 feet in Davis Number 1 to 150 feet (plus or minus) in Moncelle Number 1. The closure at the Wapsipinicon-Cedar Valley contact is 148 feet (Plate XIV); at the Cedar Valley-Lime Creek contact the closure is 113 feet (Plate XV) and at the Lime Creek-Maple Mill contact, the closure is 107 feet (Plate XVI) (based on wells 28 and 67). This abrupt and sizable decrease in amount of closure between the Wapsipinicon-Cedar Valley and Cedar Valley-Lime Creek contact is further evidence for uplift during Cedar Valley time.

The isopach map of the interval between the top of the Keokuk and the top of the Lime Creek formation (Plate XX) does not suggest further uplift in that interval. The closure at the Kinderhook-Osage contact is 101 feet (Plate XVIII) and at the Osage-Meramec contact, the closure is 94 feet (Plate XIX).

The 100 foot (plus) uplift which occurred in the Devonian does not account for the 170 feet of closure at the top of the Cambrian. It must be concluded that there was another period of uplift which was post-Osagian. Lee (1946) stated that the primary movement in the Forest City Basin in northeastern Kansas and southeastern Nebraska occurred prior to the deposition of the Hertha limestone (lower portion of the Kansas City Group, lower Missouri Series, Pennsylvanian) and another phase of uplift occurred in post-Hertha time. This would account for the large unconformity on the top of the Mississippian below the Desmoinesian Series as noted by Erickson and Svoboda (1956, p. 11) and also provide the additional uplift needed to explain the closure in the Cambrian.

#### Structural Form and Orientation

The anticline can be divided into three general areas. The northern third of the structure has an alignment which is approximately N. 10° E. The angle of plunge is one degree northeast and this end of the structure is sharp or pointed relative to the gently rounded southern end of the structure. The southern two-thirds of the structure is oriented north-south and the angle of plunge is about one-half degree which is less than the northern portion. The protruding nose on the east flank of the anticline is the highest part of the structure.

The orientation of the existing structure as described above does not coincide with the structure which was present after the uplift in the Devonian. The orientation of the structure has shifted from northwest-southeast to north-south or a little bit northeast-southwest. Also, the center of the uplift has shifted approximately one mile to the east-southeast.

The dip on the west flank of the existing structure does not exceed two degrees while the dip on the east flank may be as much as eight degrees. Because of the unequal dips, the axial plane is inclined to the west.

It is probable that the change in location of the center of uplift and the shift in orientation of the structure was the primary factor which controlled the formation of the nose on the east side and the unequal dips on the flanks.

## CONCLUSIONS

### Electric and Radioactivity Log Correlations

Correlations based upon the electric logs proved very satisfactory. Determinable correlation check points are found at nearly every formational contact except the Gower-Wapsipinicon contact. The radioactivity logs were less helpful and were used primarily to corroborate information derived from the electric logs. Micrologs, when available, proved invaluable for determining precise contacts. However, they are not a tool in themselves and were used in conjunction with the electric and radioactivity logs.

The following intervals were particularly helpful in establishing correlation points when using spontaneous potential and resistivity logs:

1. Both contacts of the Maple Mill shale.
2. Both contacts of the Brainard shale.
3. Both contacts of the St. Peter sandstone.
4. The large change in the resistivity near the base of the Ft. Atkinson.
5. The top of the Franconia formation.
6. The top of the Kinderhook Series.

Similarly, the following list includes those distinctive points on the gamma ray and neutron logs which were persistent on the logs throughout the area:

1. Both contacts of the Maple Mill shale.
2. Both contacts of the Brainard shale.
3. Both contacts of the Decorah-Platteville interval.
4. The upper contact of the Dresbach formation.

Most of the units and the lithologies of the units listed above are generally persistent throughout much of the Upper Mississippi Valley. Although it is realized that successive steps would be needed to bridge long distant correlations, the same general features should remain relatively constant and future correlative work in this area will undoubtedly utilize these same distinctive markers.

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