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SUBSURFACE GEOLOGY OF THE BEREA SANDSTONE, BARLOW AND
WARREN TOWNSHIPS, WASHINGTON CO., SE OHIO.

A thesis submitted to the
Division of Graduate Studies and Research
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

in the Department of Geology
of the College of Arts and Sciences

1995

by

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ABSTRACT

The lower Mississippian Berea Sandstone is a thin but well-defined sandstone that occurs in the subsurface throughout the Appalachian basin. It has been recognized as an important producer of oil and gas in eastern Ohio, eastern Kentucky, western Pennsylvania, and western West Virginia. This study includes Barlow and Warren Townships east in Washington County, Ohio. It covers an area of approximately 120 square miles. Although many gas and oil wells have been drilled to and through the Berea Sandstone in this county, no studies have been made to show the detailed variations in the thickness of this sand, its depositional environment, and the relation of these two factors to the accumulation of oil and gas. This is the purpose of this study.

The Berea Sandstone and the genetically related Bedford Shale lie between two shales, the Sunbury Black Shale and the Chagrin member of the Ohio Shale. Regional studies have shown that the paleogeography of the Berea Sandstone and Bedford Shale was influenced by small uplifts of the land and oscillations in the sea level. For this reason, in this project, the Berea Sandstone is studied as a gas reservoir and also as the upper part of a genetic depositional sequence with the underlying Bedford Shale and Chagrin/Ohio Shale.

Detailed correlation of three hundred geophysical logs, as well as information taken from more than three hundred completion logs, were the basis for tracing the lower Mississippian Sunbury Shale, Berea Sandstone and the Berea - Bedford facies sequence in the subsurface. Due to its high radioactive signature, the bottom of the Sunbury Shale

was taken as a horizontal datum to correlate these formations. In the subsurface, the top of the Berea Sandstone is easily recognized from radioactivity logs because of its low radioactivity geophysical log configuration and also because it underlies the highly radioactive Sunbury Shale. The Berea Sandstone becomes finer-grained downward showing an increase in radioactivity because of the presence of shaley siltstones. These siltstones grade into the lithologically similar siltstones of the underlying Bedford Shale and they form a lithogenetic sequence of marine shelf and deltaic origins that grades downward into the basinal Chagrin member of the Ohio Shale.

Interpretation of well log signatures, mapping of the thickness of these formations and information on previous work permitted the identification of a regressive deltaic distributary mouth bar depositional environment for the Berea Sandstone. A regional structural map on the bottom of the Sunbury Shale and top of the Berea Sandstone was needed to identify structures on the Berea Sandstone and hydrocarbons traps.

The correlation of various parameters to the initial production (IP) yielded unexpected results. Structure and thickness of the Berea Sandstone were expected to display strong correlation to initial production, but instead only displayed slight correlation. The most significant production of gas and oil only occurred in the Berea Sandstone with thickness between 4 and 8 feet. The greatest initial production usually occurred at 6 feet in thickness. On the other hand, the depositional environment showed a much stronger correlation to IP (initial production). Specific log signatures, Type II and III, coincided with large initial production.

Calculation of mean, maximum and minimum expected IP values showed that the highest average IP is expected in wells with 7 feet on Berea Sandstone thickness and in Type III log signatures.

The IP is likely related to various other parameters such as rock properties (porosity and permeability), pressure of the reservoir, and productivity conditions (natural productivity or fracturing). These other parameters could not be fully investigated due to the lack of appropriate data.

Results from the nearby outcrop showed that the Berea Sandstone is a coarsening upward, fine-grained sandstone as first described by Newberry (1870). Bedding characteristics, trace fossil contents and ripple marks were found on the Berea Sandstone showing the relation with a shallow marine depositional environment. It was very helpful relating this outcrop with the gamma ray signatures to understand the lithology and vertical grain size trends in these formations.

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I would like to thank everyone who contributed to the development of this project. First and foremost I want to thank Dr. Wayne A. Pryor for his academic counsel, for helping me develop the idea for my thesis, for working with me on it, and for being a good friend. I want to thank Dr. Barry Maynard for believing in me from the beginning, and for always giving me his honest advise. I want to thank Dr. Bill Slack for being a member of my committee and for reminding me of the petroleum engineering perspective.

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INTRODUCTION

Purpose of this study

The lower Mississippian Berea Sandstone is a thin but well-defined sandstone that occurs in the subsurface throughout the Appalachian basin. It has been recognized as an important producer of oil and gas in eastern Ohio, eastern Kentucky, western Pennsylvania, and western West Virginia. This study includes Barlow and Warren Townships, Washington County, eastern Ohio.

The Berea Sandstone is easily recognized in the subsurface by radioactivity logs because it is overlain by the high radioactive Sunbury Shale, and it is underlain by the shaley siltstones of the Bedford Shale. Pepper and DeWitt (1954) carefully noted the relationship of the Berea sediments and the Bedford sediments based on reported thickness and color characteristics from driller logs and petrographic characteristics from cuttings. These sediments were represented as a distinct depositional cycle between two black shales. Integrating the Berea and Bedford as a depositional sequence helped to solve problems associated with the geometrical - geographical distribution and facies environments in this basin.

The main purpose of this project is to provide a further understanding to the depositional framework, environmental facies relations and reservoir geology of the Berea Sandstone located in Barlow and Warren Townships in Washington County, southeastern Ohio. It is essentially an outgrowth of previous studies that deal with the depositional environment of the Berea Sandstone by focusing on an integrated interpretation of gamma

ray logs, completion logs and cross section configurations. Although numerous wells have been drilled in this area, few studies has been done to relate the depositional environment with initial productivity. This research is a detailed stratigraphic study of a small area as opposed to the previous general studies made on the Appalachian basin.

Interpretation of the depositional environment of the Berea Sandstone, the relationship in thickness, lithology, and character of the sand from place to place are related to the production and accumulation of oil and gas.

The different types of log signatures were related with the outcrop to better understand the relationship of the exposed units to subsurface log configuration.

This project also offers an excellent opportunity to examine the resolution of exploration techniques by integrating geophysical log correlation and interpretation, isopach and structure mapping interpretation and cross section configurations.

Study area.

The area of study of the Berea Sandstone includes Barlow and Warren townships in Washington County, southeastern Ohio (Figure 1). It covers an area of approximately 78 square miles.

The Berea Sandstone can be traced throughout this area by geophysical logs. The Berea Sandstone is by far the most important gas and oil reservoir of the shallow gas sands in Washington county and is productive in almost every county in eastern and southern Ohio. There have been many regional studies done in the Appalachian basin

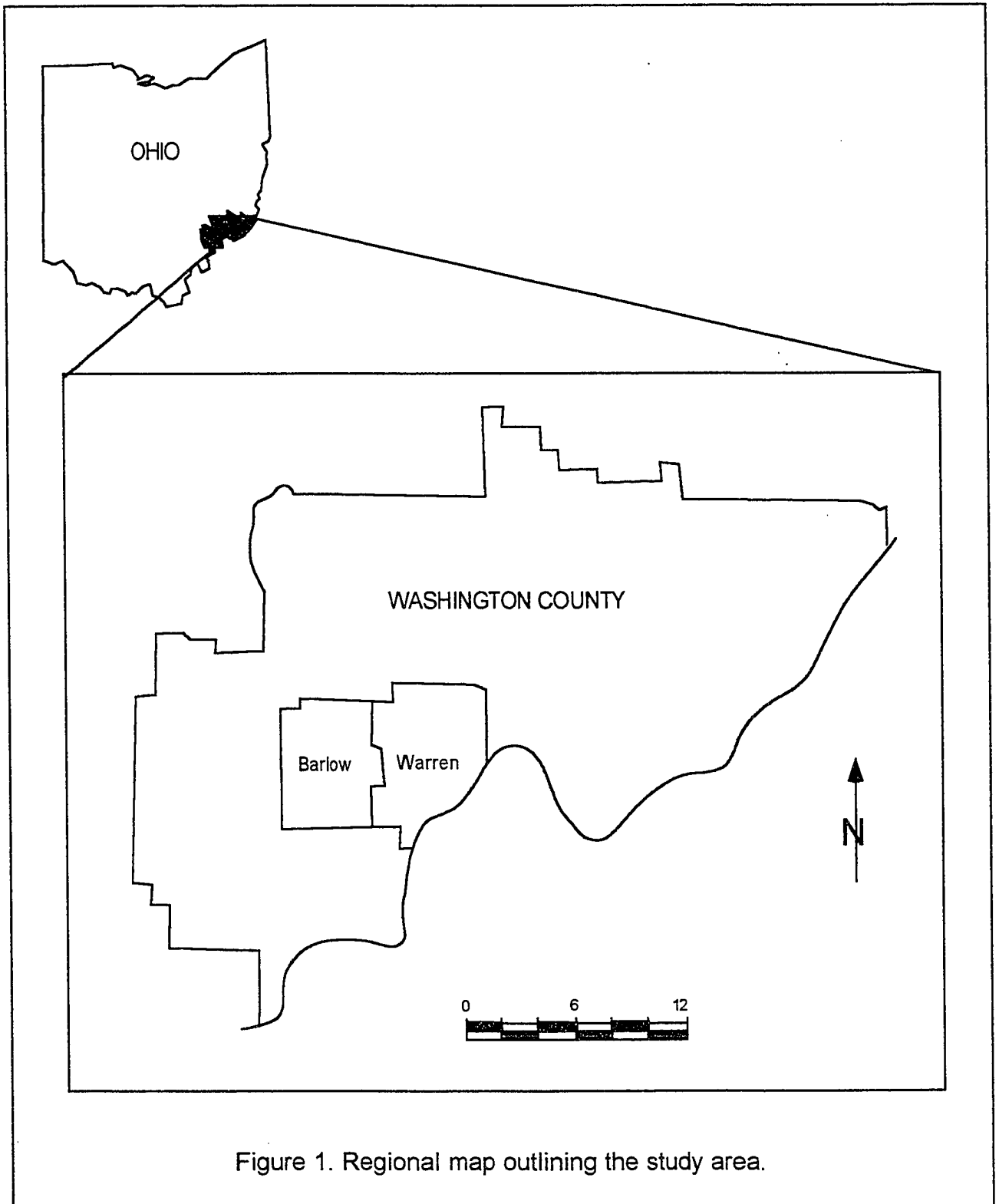


Figure 1. Regional map outlining the study area.

about the Berea Sandstone, the overlying Sunbury Shale and the underlying Bedford formation (see references). These studies include general surface and subsurface information and have given excellent information about the lower Mississippian. However, few studies have been made to correlate subsurface data and to understand the depositional environment of the Berea Sandstone in these two townships.

Many small companies operate in this area and depend on the production of gas and oil found in productive sands such as the Berea Sandstone. Therefore, a subsurface study of the Berea Sandstone, an interpretation of the depositional environment of the Berea Sandstone and the relationship of these factors with oil and gas accumulation can lead to understanding of the deposition of the Berea Sandstone and the characteristics that make it a good reservoir.

Previous Studies

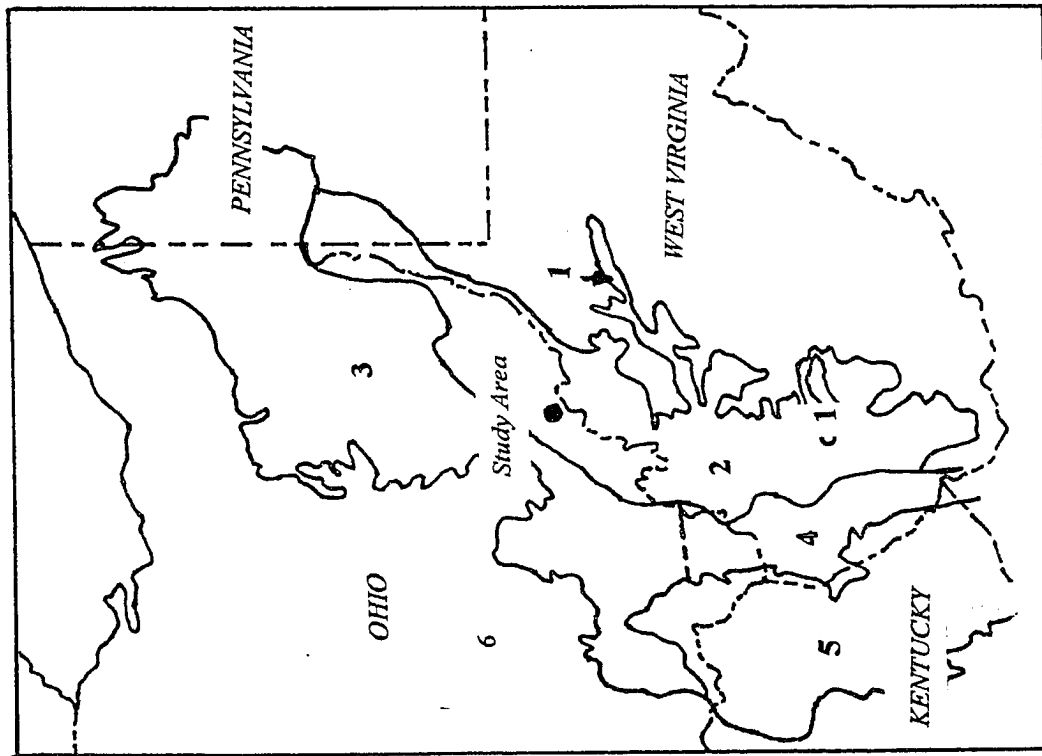
The names Berea and Bedford were first given by Newberry in 1870 in the Report of Progress of the Geological Survey of Ohio from outcrops in the north part of the Ohio State. The Berea was known as "grit" by the drillers of northern Ohio and early geologist such as Orton (1888) who applied the name Berea Grit throughout the outcrop belt and to its continuation underground as the search for oil progressed in Ohio. The black Sunbury Shale was not noted by Newberry. Rather, in 1879, when Hinks gave the name Sunbury Shale to this black bed.

The Berea Sandstone of the Appalachian Basin has been a prolific gas and oil producer since the early 1900's. It was studied and mapped in detail in a regional study by Pepper, DeWitt in 1954. This research of the Berea Sandstone included:

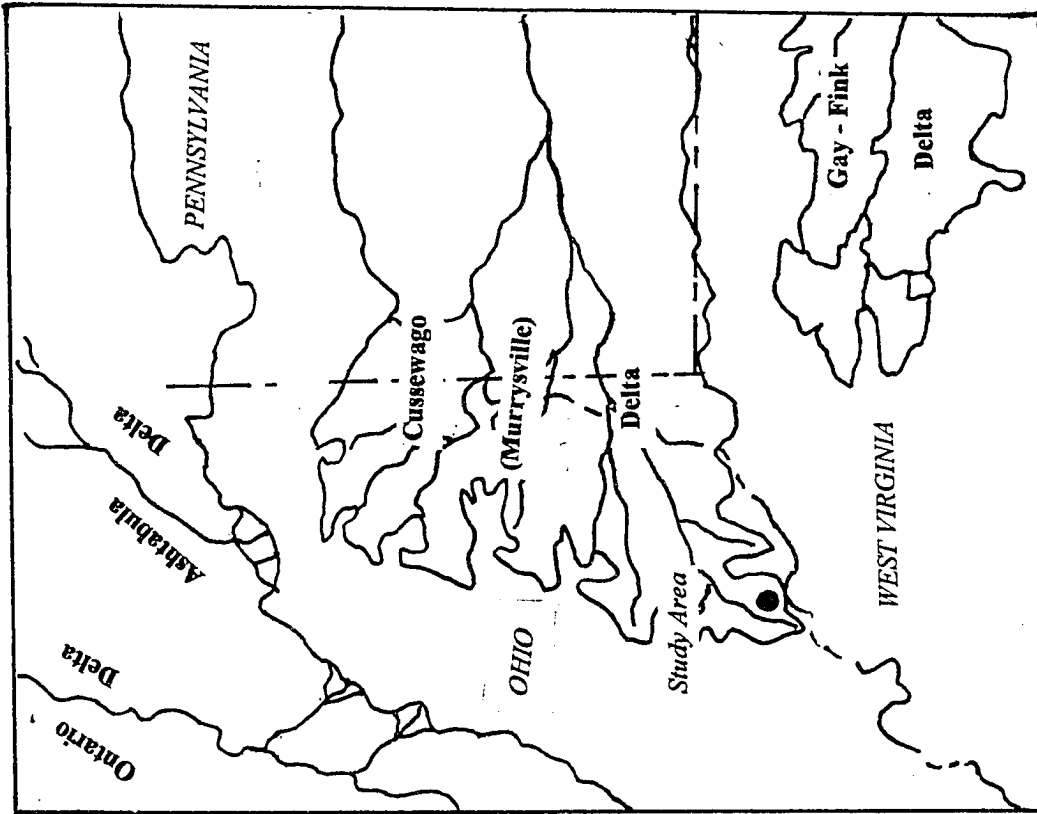
1. Mapping of the surface outcrops of a part of the Berea Sandstone of Ohio and also some of the rocks above and below the Berea.
2. Subsurface studies of many drillers logs of wells drilled into and through the Berea Sandstone and sample logs that were available, for the purpose of correlation and determination of thickness of the sand.
3. Petrographic studies of samples of sand to determine the sources of the sand; direction of the movement of the sand into the Appalachian Basin; and the variations in texture of the sand in the relation to the pools producing oil and gas.

Pepper (1954) produced a lithofacies map of the Bedford Shale and the Berea Sandstone that distinguished the kinds of facies present in south central Ohio (Figure 2a). He also produced a paleographic map illustrating the possible deltas systems that brought the sediments into the basin (Figure 2b). The facies map distinguished:

1. The fluvial facies of the Berea Sandstone in the Gay Fink channel and the Cabin Creek channel in West Virginia.
2. Sandstone and siltstone of marine shelf and coastal origin.
3. An area of thick marine sand and silt accumulation.
4. An area of thin marine sand and silt accumulation.
5. An area of thick fine-grained marine sand and silt accumulation.



a. Lithofacies Map of the Berea Sandstone (Modified from Pepper 1954)



b. Paleogeographic Map at the early Berea Time (Modified from Pepper 1954)

Figure 2.

6. A sheet of medium to fine grained, cross bedded sandstone overlying medium grained sandstone of a channel system.

A later study by Larese (1974) was focused on the petrology, stratigraphy and environmental analyses of the Berea Sandstone of the Cabin Creek and Gay - Finks trends in West Virginia. He identified two kinds of depositional environments, one fluvial system in the eastern part of the study area and a marine environment for the western part of his study. Larese (1974) identified discrete barrier island and distributary mouth bar environments within the mapped sheet sandstone facies of West Virginia based on geometry, gamma ray signatures, vertical grain size trends and sedimentary characteristics described by outcrops and cores. Larese noted the generally upward coarsening of the Berea Sandstone of the sheet sandstone facies suggesting a deposition of fine sandstone and siltstones during regressive marine conditions.

A subsequent study by Potter, DeReamer, Jackson and Maynard (1983) contains a review of the different kinds of depositional environments that are likely to occur in the Berea which included meandering, anastomosing, braided alluvial deposits; lower delta plain deposits; deltas; and coastal and shelf deposits. It also illustrated the distinct sedimentary structures of the Berea Sandstone that can be found in the outcrop as well as in cores. Description of vertical profiles of grain size and composition of the sandstone were made for each outcrop. Interpretation of the complex depositional system of the Berea Sandstone was based on subsurface mapping.

DeWitt and others (1993) showed the regional geology relation between the Devonian and Mississippian Black Shales with the production of hydrocarbons

throughout the Appalachian Basin. They distinguished that the Cleveland and Huron members of the Ohio Black Shale are overlain by the clastic strata of the Bedford Shale and the coarser grained Berea Sandstone on the Appalachian Basin. They also distinguished the Chagrin member of the Ohio Black Shale to be present eastern Ohio and to represent the distal part of a great eastward thickening wedge of gray marine shale and turbiditic siltstones that intertongue the basinal black shales (Cleveland and Huron members). Therefore, in eastern Ohio the Bedford Shale overlaps the Cleveland Shale, bringing both the Bedford Shale and the Berea Sandstone upon the Chagrin Gray Shale (Figure 3). Other studies consisting of theses and dissertations on the Berea Sandstone in eastern Ohio, northern Kentucky, western Pennsylvania and western West Virginia are shown on Table 1.

Age of the Berea Sandstone

The age of the Berea Sandstone, the overlying Sunbury Shale and the underlying Bedford Shale in the Appalachian Basin was described by Wallace DeWitt Jr. (1970 Geological Survey). His conclusions were based on a detailed palynologic analysis of data (mainly spores).

DeWitt found that the Hymenozonotriletes lepidophytus or also called Endosporites lacunosus could not be used to differentiate between the Mississippian - Devonian Boundary because this kind of spore occurs from the Cleveland member of the Ohio Shale to the Sunbury Shale.

DeWitt also found that the Sunbury Shale, the basal member of the Orangeville

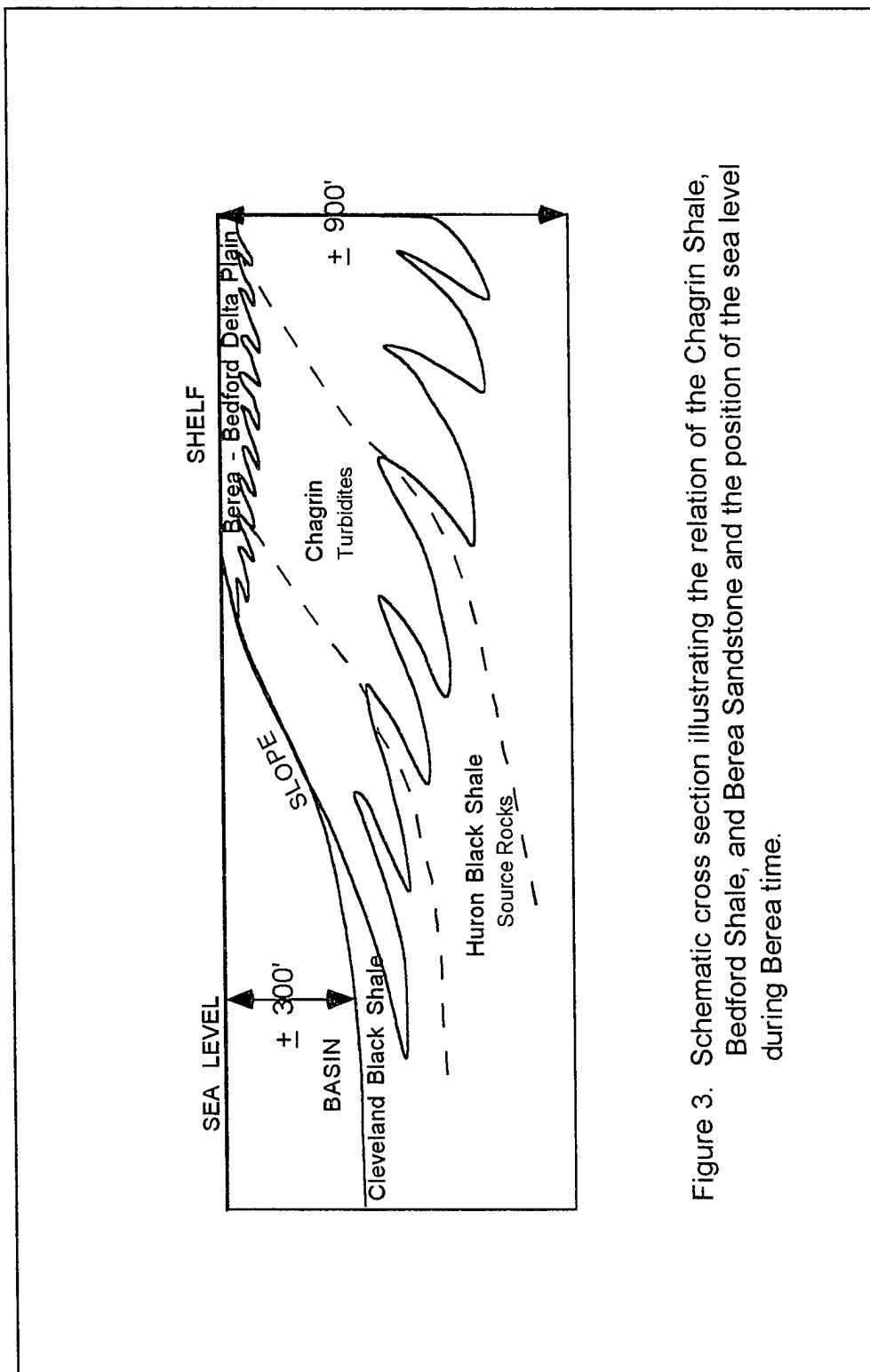


Figure 3. Schematic cross section illustrating the relation of the Chagrin Shale, Bedford Shale, and Berea Sandstone and the position of the sea level during Berea time.

Theses

- Attuna, S., 1979, The relationships of gas production from the Berea Sandstone to the Geology of Mc Dowell and Wyoming Counties. MS Thesis, Department of Geology and Geography, West Virginia University.
- Eames, L. E., 1974, Palynology of the Berea and Cuyanoha Group of north eastern Ohio: Ph.D. Dissertation, Department of Geology, Michigan State University.
- Elam, T. D., 1981, Stratigraphy and paleoenvironmental aspects of the Bedford - Berea sequence and the Sunbury Shale in eastern and south-central Kentucky: M.S. Thesis, Department of Geology, University of Kentucky.
- Henry, E. M., 1982, Gravity survey over the Berea Sand channels in Ashland County, Ohio: M.S. Thesis, Department of Geology, Bowling Green University.
- Huber, W., 1975, Petrology of the Berea Sandstone in western West Virginia: M.S. Thesis Department of Geology and Geography, West Virginia University.
- Jackson, D., 1985, The Petrology, Porosity, and Permeability of the Berea Sandstone (Mississippian) Perry township, Ashland County, Ohio: M.S. Thesis, Department of Geology, University of Cincinnati.
- Larese, R., 1975, Petrology and Stratigraphy of the Berea Sandstone in the Cabin Creek and Gay Fink trends, West Virginia: Ph.D. Dissertation, Department of Geology and Geography, West Virginia University.
- Mele, T., 1981, The occurrence of hydrocarbons in the Berea Sandstone in southeastern Ohio: M.S. Thesis, Department of Geology, Ohio University.
- VanBeuren, V., 1980, Stratigraphy of the Sunbury Shale (Lower Mississippian) of the central Appalachia Basin: M.S. Thesis, Department of Geology, University of Cincinnati.
- Warrner, C., 1978, Subsurface Stratigraphy of the Berea and Cussewago Sandstones in eastern Ohio: M.S. Thesis, Department of Geology, Kentucky State University.

Table 1. Theses written on the Berea Sandstone.

Shale in some parts of northern Ohio contains abundant Siphonodella fauna that is proper of the Early Mississippian age (Kinderhook series). Subsequently, he discovered that the basal few feet of the Bedford Shale in north central Ohio contains invertebrate fossils which were similar to the fauna of the Louisiana Limestone of the Mississippian Valley. These invertebrate fossils are conodont Spathognathodus anteposicornis that were present in both the basal fossil zone of the Bedford Shale and the Louisiana Limestone. As Gutshick and Moreman (1967) determined the Devonian Mississippian Boundary at the base of the Louisiana Limestone, DeWitt determined this boundary at the base of the Bedford Shale. Furthermore, It was stated by Huddle (1969) that Spathognathodus anteposicornis occurs above Siphonodella faunas in England. This correlation was used by DeWitt to relate the Bedford Shale to the Kinderhook series.

Finally, DeWitt related the Berea Sandstone with the Cussewago Sandstone in Northeast Pennsylvania to determine the Berea Sandstone age. The Cussewago Sandstone contained Adiantites flora of the early Mississippian age and was present in the Kinderhook Series of the Lower Mississippian rocks of the Appalachian Basin. He noted that in northwest Pennsylvania and northeastern Ohio the Cussewago Sandstone is overlapped by the Bedford Shale and the Berea Sandstone. These data indicated that except for the basal fossil zone, most of the Bedford Shale and younger Berea Sandstone are younger than the Mississippian Cussewago Sandstone. Therefore, because the Berea Sandstone and Bedford shale are underlain by the Cussewago Sandstone and overlain by the Sunbury Shale DeWitt concluded that they must be of the Kinderhook Series and Mississippian age (Table 2).

GEOLOGIC TIME (million years before present)	TIME STRATIGRAPHIC UNITS			ROCK UNITS	
	System	Series	Group	FORMATIONS Units found in the subsurface	DRILLERS' NAMES
320	MISSISSIPPIAN	Kinderhookian		Sunbury Shale	Coffee Shale
				Berea Sandstone	First Berea
				Bedford Shale	Second Berea
360	DEVONIAN	Chautaquan		Ohio Shale	Gordon
					Big Cinnamon

Table 2. Generalized Stratigraphic Column of the Bedrock units in Washington County, Eastern Ohio.
(Modified from Ohio Geological Survey)

PROCEDURES

The Berea Sandstone was correlated and traced throughout the entire area of study. This procedure was based on information taken from geophysical well logs, especially radioactivity logs. Three hundred gamma ray logs were correlated throughout Barlow and Warren townships Figure 4 (Base Map). Tracing of the Berea Sandstone was made in both west-east and south-north directions, covering the entire area (Figure 5) with a correlation network. Subsurface techniques such as cross section interpretation, mapping thickness of the formations and relationships between the depositional framework and productivity data were mainly used to develop this project.

Subsurface Procedures.

Due to the lack of surface exposure of the Berea Sandstone in this area, the lack of cores and the lack of cuttings, this study was based primarily on geophysical well logs and completion cards data.

Two general types of geophysical well logs were available in this area, gamma ray logs, and compensated density logs. Compensated neutron density logs use a radioactive source to measure properties of the rocks. Neutron logs respond primarily to the amount of hydrogen in the formations. They are used principally to determine porosity values in prospective formations and to relate signatures with gamma ray signatures to find boundaries between formations. Density logs measure radioactivity properties of the rocks as a bulk density of the formation. When they are combined in a compensated

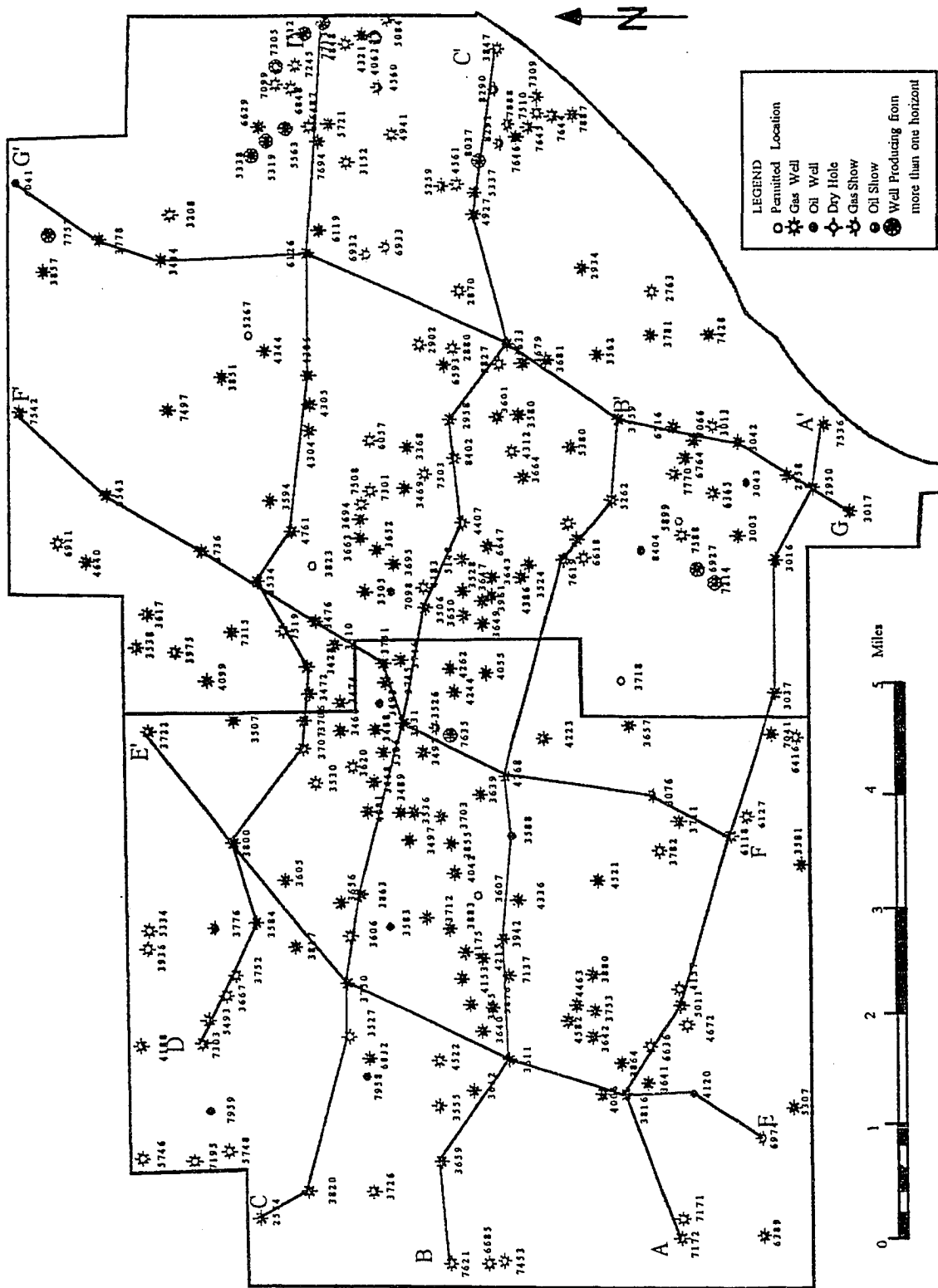


Figure 5. Map illustrating orientation of dip and strike cross sections.

density log, it can be used for porosity determinations, water saturation estimates, lithology determinations, and recognition of gas-bearing formations. The general response of gamma ray, neutron and density log signatures for the Berea Sandstone are shown on Figure 6. Few neutron and density logs were found in this area and proved to be unreliable. Therefore, no conclusions concerning porosity could be made. Gamma ray logs measure natural radioactivity of the rocks principally from clay minerals, feldspar and kerogen. From these well logs, gamma ray logs were used as the major source of data. Geophysical logs were obtained from the Ohio Geological Survey (Columbus, Ohio) and Hawell Oil Company operating in Marietta, close to the study area.

In the Appalachian Basin, completion cards (drillers logs), keep a daily record of the rock that has been drilled. The records include a generalized description of the kind, color, and hardness of the rock being drilled. Furthermore, depths, thickness, pay zones, IP values and the manner in which the drill bit cut the rocks are also recorded. Important information was taken from these completion cards. For this project, information about initial productivity of the Berea Sandstone in the wells and values of thickness of the Sunbury Shale, and the Berea Sandstone were compared with the readings obtained from the geophysical well logs. Completion cards were obtained from files of the Ohio Geological Survey (Columbus, Ohio).

Geophysical Logs.

The gamma ray log is a measurement of natural radioactivity of the formations. This log detects the presence of K, Th, and U in the formations. In sedimentary rocks, it

GENERAL LOG AND STRATIGRAPHIC COLUMN FOR THE BEREA SANDSTONE

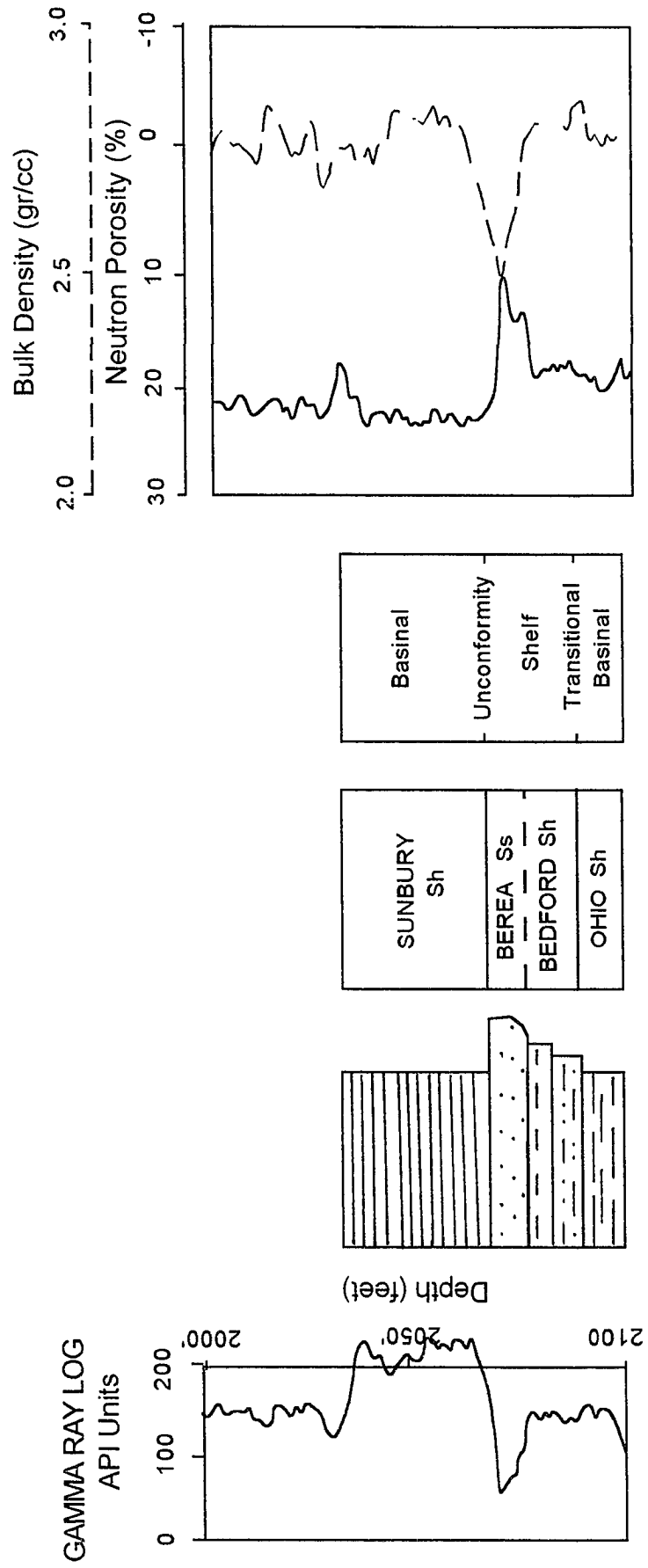


Figure 6. General log signature and stratigraphic column for the Berea Sandstone and adjacent units.

normally reflects the clay mineral, feldspar, and kerogen content of the formations because the radioactive elements tend to be concentrated in clay minerals, feldspar, and kerogen. Clean, well sorted sand, and carbonate formations usually have a very low radioactivity level. Gamma ray logs allow the close delineation of boundaries between formations because of sensitive response to changes in lithology. Gamma ray logs are the most common geophysical log run in the Appalachian basin well according to Harper (1979). Nearly three hundred well logs were utilized in this study. Well locations are shown on a base map (Figure 4). This map served to locate the resulting geological data such as thickness of the formations, elevations of the tops, initial productivity values, etc. Gamma ray logs were correlated from well to well to find the formation boundaries between the Sunbury Shale, the Berea Sandstone and the Bedford Shale (see Figure 5).

The formations were analyzed according to their gamma ray response configuration. A 100% sand base line was chosen at the lowest radioactive signature of the gamma ray on the Berea Sandstone. The position of this line varies from well to well. A 100% shale base line was also chosen. The location of this line was subjective and assumed to represent the non-organic shale. The shale base line was chosen correlating the signatures above the Sunbury Shale and the signatures for the silty shales of the Bedford Shale. A 50% sand cut off was chosen. In almost all the cases it represented the midway point between the maximum and minimum deflections on the gamma ray signatures. Between 20 to 30 API units above the 100% shale base line was considered to be the black Sunbury Shale as suggested by VanBeuren, 1980. These procedures were used to determine the tops and bottoms of the Berea Sandstone from well to well.

Pepper and De Witt (1954) carefully noted the relationship of the Berea Sandstone sediments and the Bedford sediments based on reported thickness, ripples marks and color characteristics from driller logs and petrographic characteristics from cutting. These sediments were represented as a distinct depositional cycle between two black shales (Cleveland and Sunbury Shales). Because the Berea Sandstone and the Bedford formations form a same cycle of deposition and are genetically related, they were also analyzed as a facies sequence. The Berea - Bedford facies sequence shows a finer downward gamma ray signal seen in almost all of the well logs. The bottom of this sequence was selected where this fining downward gamma ray signature ended. These assumptions were not arbitrary. They were directed by the study of the gamma ray responses to the vertical sequence, its lateral changes and typical log responses for the units.

Geophysical Well Log Cross Sections

After locating the available well log information, correlation cross section network was constructed through these two townships using geophysical well logs. Four cross sections were drawn from the east part of Barlow township to the west part of Warren township following the structural dip. In addition, three cross sections were drawn from south to north following the structural strike of the Berea Sandstone. Locations of this seven cross section network is shown in Figure 5.

To make these cross section, the geophysical logs were first transformed to a uniform vertical scale. The geophysical logs for each cross sections were then hung next

to each other on the wall to be correlated. The Sunbury Shale signature on the gamma ray was very noticeable in all of the well logs. Therefore, the bottom of this formation was used as a horizontal datum. That is, all the well logs were hung on the bottom of the Sunbury Shale. At this point, all of the cross sections were ready for the correlation and interpretation. The Berea Sandstone, as well as the Sunbury Shale and the Bedford Shale were marked with different colors on the logs. After identifying the specific signature for each of the formations, the tops and bottoms of the formations were correlated with straight strings from well to well.

After the seven main cross sections were loop correlated, lines were drawn connecting the other wells to this cross sections network. Then these wells were also related and marked in the same manner as the main cross sections. These cross sections were very useful to correlate the logs and pick the bottom and tops of the formations. General geophysical log patterns were chosen analyzing the log signatures in each well.

Structural Maps

Subsequently, the top of the Berea Sandstone or bottom of the Sunbury Shale was determined from all the well logs. The gamma ray logs showed the depth in feet of the formations in each well. These depths are shown in Table 13, Appendix II. The ground level elevation was acquired either from the information on the geophysical log or from the completion cards. These values were subtracted from the depth values to obtain the actual elevations of the Berea Sandstone below sea level. These subsea elevations of the Berea Sandstone were placed on the base map. Then, contour lines were drawn

having a contour interval of 20 feet. This map helped to select the logical orientation and amount of the structural dip, the direction of the structural strike and the differences in elevations of any two points on the map. In addition, the interpretation of the structural map showed the present structure of the Berea Sandstone in this area, and possible faults and folds as well as possible hydrocarbons traps were identified.

Isopach Maps

The top and bottom depths measured from the well logs of the Berea Sandstone were subtracted to obtain the thickness of this formation. The thickness readings of the formation from the gamma ray logs were compared with the information given on the completion cards. The drillers usually gave colloquial names to rock units that they recognized and usually reported them with these names on the completion cards (Table 2). On these completion cards, the Sunbury Shale is consistently called "brown shale", "black shale", or very commonly "coffee shale". The Berea Sandstone is called "Berea grit". The Bedford Shale is noted as slate (gray, green, or black shale) or "slate and shells" (interbedded, gray shale and siltstone). Those drillers logs showing obvious inconsistencies were discarded. Then, the thickness of the Berea Sandstone were plotted on the base map, and equal thickness contour lines were drawn. The same procedure was done for the Sunbury Shale and Berea - Bedford facies sequence.

Isopach maps were constructed to define these units. They were very important in the determination of the regional pattern of sedimentation of the Berea - Bedford unit. In addition, they were used to find both the stratigraphic dip and the stratigraphic strike of

the formations. They also helped to select logical orientations for the stratigraphic cross sections on the Berea Sandstone.

Finally, north- south and west - east cross sections were drawn on the Berea Sandstone isopach map. The purpose of these cross sections is to illustrate the lateral geometry of the Berea Sandstone. Once again, the Sunbury Shale was taken as a horizontal datum.

Type Log Map

The environmental interpretation and mapping of gamma ray signatures provides an additional insight to basin configuration. Gamma ray logs display a variety of characteristics throughout the study area. In almost all the well logs, the contact between the Sunbury Shale and the Berea Sandstone was a sharp contact. On the other hand, the contact between the Berea Sandstone and the Bedford Shale was variable and displayed a gradational basal contact.

Four distinct gamma ray signatures were identified in this area (Figures 8, 9 , 10, 11). The log signatures were put on a base map and also a contour map. The shape of the signatures can be related to sedimentation cycles, grain size distribution and shoreline processes that are responsible for the deposition of sediments.

Productivity data.

Thickness of clean sand, shale and total thickness of the Berea - Bedford facies sequence were obtained from the gamma ray well logs. Then, the percentage of clean

sand as well as the percentage of the silty shales were calculated. These data were placed on two base maps, one showing sand percentages and the other shale percentages. The maps show the correlation of these percentages with the depositional pattern of the Berea Sandstone on each map. Contours were drawn at points of equal percentages (sand and shale). The contour interval for these maps is 10%.

Although, hydrocarbon production from the Berea Sandstone is primarily in the form of natural gas, gas and oil productivity data were used in this study. Gas and oil initial productivity data from the Berea Sandstone were acquired from the completion card for each well. This data were also placed and contoured on a base map. The gas and oil initial productivity maps were compared with the Berea Sandstone isopach map to see if there is any relationship between these parameters.

Gas and oil initial productivity data were also plotted versus thickness, type log signatures and elevation on XY graphs. The initial production average was calculated for both each thickness and each type log signature. In addition, the standard deviations, maximum predicted initial productivity values and minimum predicted initial productivity values were calculated for each thickness and each type log signature.

Moreover, production data from 1881 to 1992 for wells in Barlow and Warren township were obtained from the Ohio Geological Survey. Production decline curves were made with these data.

Surface Procedures

In south-central Ohio, Lower Mississippian rocks and upper Devonian rocks outcrop along a north - south trend shown in Figure 31 . In these outcrops the Sunbury Shale, the Berea Sandstone, the Bedford Shale and the Ohio Shale are well exposed in valleys, and road cuts.

For the purpose of this study, one outcrop was visited. Sunbury Shale, Berea Sandstone and parts of the Bedford Shale are exposed in Tener Mountain. Tener Mountain is located on the north side of Ohio State Route 32, the Appalachia Highway, in Pike County. This outcrop was also sampled and compared with published section descriptions in state geologic reports Potter, DeReamer, Jackson and Maynard (1983). Close attention was given to variations in lithology, bedding characteristics, color, ripples marks and the occurrence of trace fossils. This was an opportunity to compare the outcrop with the gamma ray well log signatures obtained from the wells.

RESULTS AND DISCUSSION OF SUBSURFACE DATA

Cross Sections

The location of 4 dip cross sections (A-A', B-B', C-C', D-D') and 3 strike cross sections (E-E', F-F', G-G') is illustrated in Figure 5. The cross sections are illustrated on Figures 36 to 42. A list of the well logs with their permit numbers is presented in Appendix I. Although originally only the Berea Sandstone was planned to be correlated, it was evident that in order to understand the depositional relationship of the Berea Sandstone to adjacent units, the Sunbury Shale and Berea - Bedford facies sequence were also correlated.

The distinct Sunbury Shale provided a good datum through the study area. As stated by VanBeuren (1980) the log configuration of the Sunbury Shale appears either as a bifurcated or single-prong log configuration in all the cross sections. The contact between the Sunbury Shale and the Berea Sandstone is a sharp contact shown by the differences in radioactivity between the organic black shale and the sand. The contact between the Berea Sandstone and the Bedford shale is gradational. The Berea sandstone, in the basal part, becomes more silty until it grades into the Bedford shale that is mainly interbedded siltstones and shales. The Bedford Shale becomes more shaley in the basal part until it grades into the Chagrin Member of the Ohio Shale. The presence of the Chagrin Shale (gray shale), member of the Ohio Shale, made difficult to pick the bottom of the Bedford Shale because of its similarity on the gamma ray signature log and because both are gray shales.

The Sunbury Shale in the study area shows a thickening pattern from the west to the east. The Berea Sandstone shows a thickening pattern from the west to the east on the dip cross sections as well as from south to north in the strike cross sections. This change in thickness was greater from west to east. The Berea - Bedford facies sequence show a uniform pattern because the bottom of the facies sequence was consistently selected at the same point in the signatures.

Berea - Bedford Facies Sequence.

Studies of the Berea Sandstone has shown the intimate genetic relation of this sandstone with the underlying Bedford Shale. Pepper's (1954) study of southern Ohio concluded that the rocks of the Bedford Shale and Berea Sandstone form a gradational cycle of deposition beginning at the close of the deposition of the Ohio Shale and ending with the beginning of the deposition of the Sunbury Shale. The Berea - Bedford cycle of deposition shows a gradually increasing amount of coarser clastic material upward (Pepper 1954).

Hyde (1953) concluded that in southern Ohio the Berea Sandstone is only a phase of the Bedford Shale. Hyde stated that the Berea Sandstone and the Bedford Shale consist of the same kind of sediments, with the same ripple-marked structure. The only distinguishing features he noted is that the sandstone beds are relatively thicker and the shales beds are relatively thinner in the Berea Sandstone and some, not all of the sandstones of the Bedford are slightly calcareous. Therefore, Hyde noted the similarity of the Berea Sandstones and Bedford Shale according to the kind of sediments, the

composition of the sands and shales, the amount of sandstones and shales and the direction of ripple marks found in both the Berea and the upper surface of the Bedford shale.

In this study, the gamma ray log signatures of the Berea Sandstone and the Bedford shale also display a relation. The contact between them is gradational, changing from clean sand on the Berea Sandstone with low radioactivity to siltstones and shales on the Bedford Shale with higher radioactivity. Therefore, the Berea Sandstone and the Bedford Shale are considered as a facies sequence. The Berea - Bedford facies sequence exhibits a coarsening upward grain size distribution. The contact between the Bedford Shale and the Chagrin - Ohio Shale was taken at the end of the fining downward sequence.

Structural Map of the Berea

The structural contour map for the Berea Sandstone is shown in Figure 7. This map coincides with the general orientation of the Berea Sandstone through the Appalachian Basin. The contour interval is 20 feet. The Berea Sandstone has a regional dip of 20ft/mi. (0.2 degrees) to the southeast. The elevation below sea level of the Berea Sandstone ranges from 1000 feet in west Barlow Township to 1220 feet in east Warren Township. Because, log data was available for many wells a more uniform dip of the formations was obtained as well as the identification of scattered isolated highs and lows.

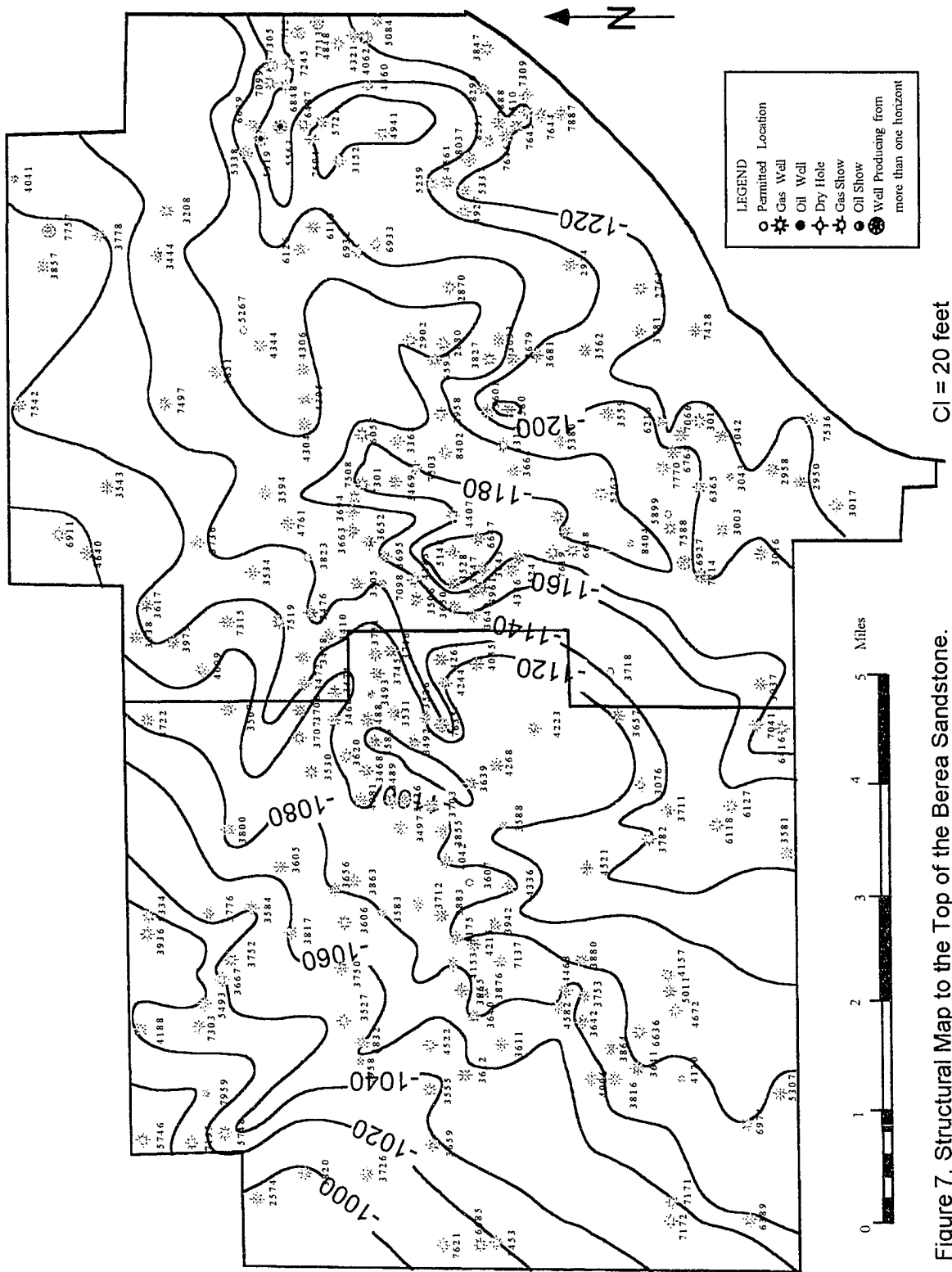


Figure 7. Structural Map to the Top of the Berea Sandstone.

The major structures noticed on the Berea Sandstone structural map are noses (anticlines, synclines), scattered highs (domes) and lows (depressions). See Figure 7. The maximum closure of the highs is 30 feet and is located in Warren Township. The other highs, lows and noses are less than 30 feet. The structural relief on the Berea structural map is 220 feet.

The structural highs and lows could be explained as a differential compaction of the Bedford shale under and around the Berea Sandstone. The shale should compact more beneath the thicker parts of the Berea Sandstone than it does under areas of thin sandstones. If this occurred there should be a correlation between the thickest areas of the Berea Sandstone in the isopach map and the Berea Sandstone structural map. However, there is not any correlation between these two maps.

Some of these highs or dome structures can act as structural traps for gas and oil in this area (Figures 7, 17, 18). However, stratigraphic traps seem to be the main mechanism for trapping the gas and oil in the Berea sandstone. The Berea Sandstone is lying in this area between two shales that provided source rocks and excellent reservoir seals for the accumulation of hydrocarbons.

A structural sag is present in western Barlow township. This linear depression has an alignment from northwest to southeast. It is a syncline that may be related to a fault in the Cambrian (Maynard, personal communication). There is a considerable displacement on the basement structure Cambrian contact and because of differential compaction those structures are transmitted upward through the Paleozoic cover.

It is unclear and is beyond the scope of this thesis to define exactly how and when the structural deformations occurred. I will however, attempt to correlate these structures with the initial production of gas and oil.

Type Log Description - Facies Interpretation

Self potential, resistivity, and gamma ray logs provide a mechanism to interpret depositional environments and physical characteristics of sand bodies. Gamma ray logs are normally preferred over self potential and resistivity logs because they are not affected by the formation fluid content and can be run in either open or cased holes. Gamma ray logs are used to define clay content, as well as, to infer grain size, and determine a coarsening or fining upwards sequence.

The main factors that should be considered in the interpretation of sandstone environments from log signatures are the vertical size variation and the kind of sand-shale boundaries. Pirson (1970) suggested these possibilities using both the self potential log and the resistivity log. Pirson stated that sedimentary cycles may be recognized by their curve shapes and contacts on the gamma ray and spontaneous potential log. In this project, these techniques were used in the interpretation of the gamma ray signatures. Pirson found that self potential and resistivity logs can be used to qualitatively recognize and quantitatively characterize the following sand depositional environments: regressive sands, transgressive sands, offshore bars, channel fill sand bars, turbidites and delta depositional environments. Quantifying the intensity of regression and transgression cycles derives a mapping parameter that may be contoured for deriving lateral sand

projections. He classifies two types of contacts between sands and shales as abrupt and gradational contacts. The gradational contact is further subdivided to rapid, linear and slow gradational contacts. The contact displayed on the gamma ray log signatures depend upon whether a rapid or slow regression or transgression of the shoreline occurred during the deposition of the sediments. The gamma ray curve shapes can be distinguished as either smooth or serrated depending on deposition environment of the sediments. Some examples of these curves shapes are barrier bars (smooth shape) and delta marine fringes (serrated shape). The contacts and curves shapes that are present on the gamma ray logs are summarized on Table 3.

Pirson (1970) also defines the general appearance of various log signatures according to the rapidity of the regressive sand deposition as follows:

1. A linear regression means a constant progradational rate and appears as a sloping straight line.
2. A decelerated or slow regression means a constant decreasing progradational rate and appears as a upward curve cusp.
3. An accelerated or rapid regression means a constant increasing progradational rate and appears as a downward curve cusp. See Table 4.

Vertical sequences and SP or GR log shapes have been related to sedimentary deposits by different authors, such as Klein (1985), Larese (1974), and DeReamer (1984). Consistent with these previous work, this relation was used in this thesis.

Four distinct Berea Sandstone gamma ray log signatures are defined in the study area (Figures 8, 9, 10, 11), and discussed below. In general, all of the patterns show









	Abrupt	Gradational		
		Rapid	Linear	Slow
Transgressive shore line				
Regressive shore line				

Table 3. Classification of log contacts, (modified from Pirson, 1970)



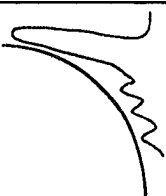
R E G R E S S I O N	Upward cusp, slow or retarded regression.	Linear regression.	Downward cusp, accelerated or rapid regression.
			

Table 4. Sedimentary patterns recognized from gamma ray curve shapes (modified from Pirson, 1970)

progradational regressive shorelines. Most of the gamma ray patterns show a decrease in radioactivity upwards within the unit producing a “inverted Christmas tree” pattern (Figure 9, 10). This kind of pattern was best recognized in gamma ray logs where the Berea Sandstone had a thickness greater than five feet. For intervals less than 4 feet the gamma ray pattern was normally “spike “ shaped (Figure 8).

Type I log shows a “spike” shape gamma ray signature (Figure 8). The Type I log is distributed on the west part of Barlow township. This type of log shows a sharp contact with the overlain Sunbury shale. The contact of the Berea Sandstone with the underlying Bedford Shale seems to be a rapid gradational contact. Type I log has thin, symmetric sandstones and is associated with an accelerated progradational regressive shoreline followed by a transgressive shoreline (Sunbury time). It can also be associated with the destructional phase of a transgressive sand or the reworking of the sediments after their deposition.

Type II log shows a “inverted Christmas tree” pattern (Figure 9). This gamma ray signature shows a sharp contact with the Sunbury Shale. Usually, the contact between the Berea Sandstone and Bedford Shales is linear gradational. Type II log has a serrated log signature that represents a linear regressive pattern. This type of log coarsens upward from a gradational base and may represent offshore bars, or distributary mouth bars.

Type III log also shows an “inverted Christmas tree” pattern (Figure 10). Type III log can represent a transitional phase from Type II log to Type IV log. It has a sharp contact with the Sunbury Shale and a gradational contact with the subjacent Bedford Shale. Similar to the Type II log, it has a coarsen upward sequence that could represent

TYPE I LOG

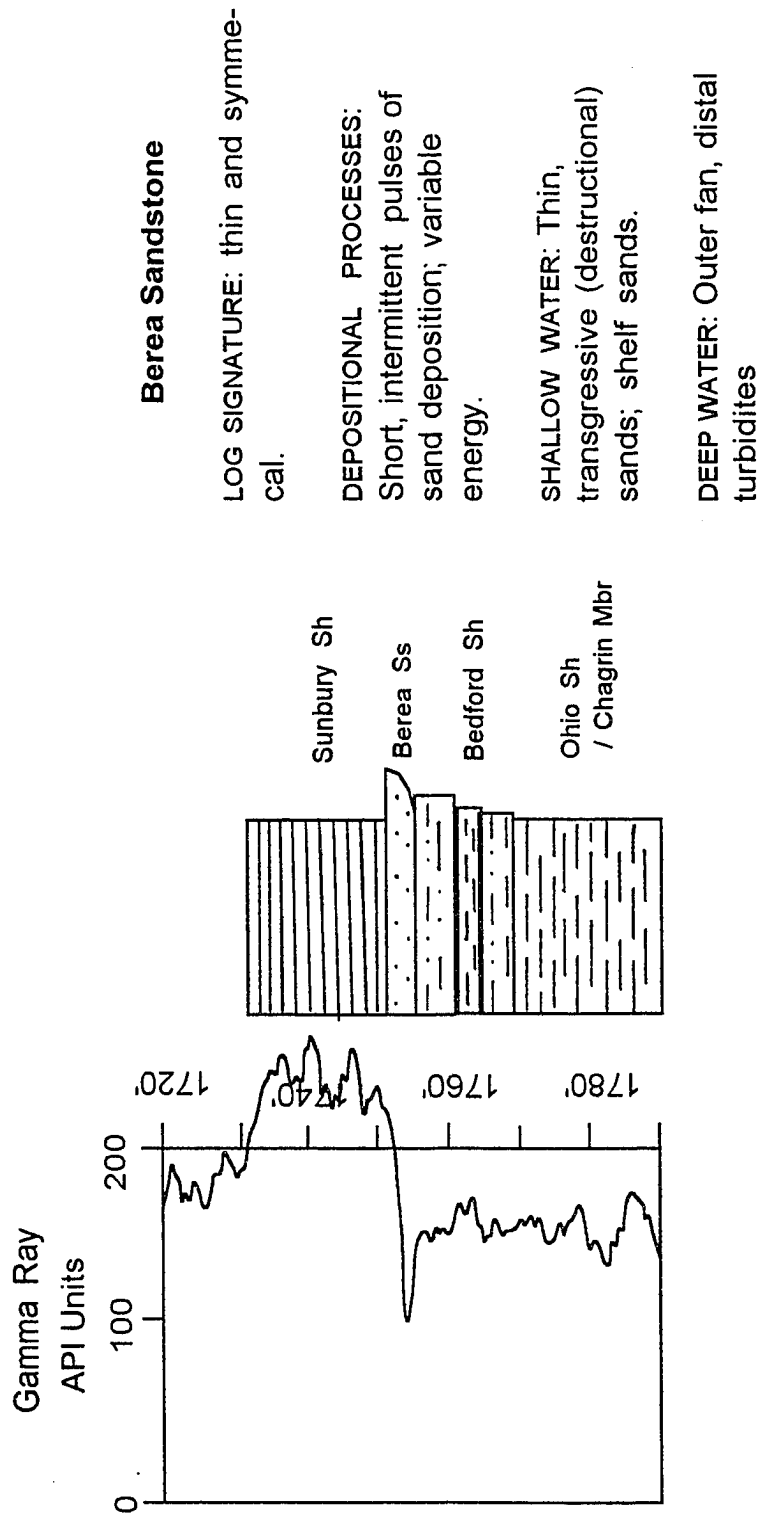


Figure 8. Gamma-ray log signature and depositional environments for the Berea Sandstone. modified from Potter and Others (1983)

TYPE II LOG

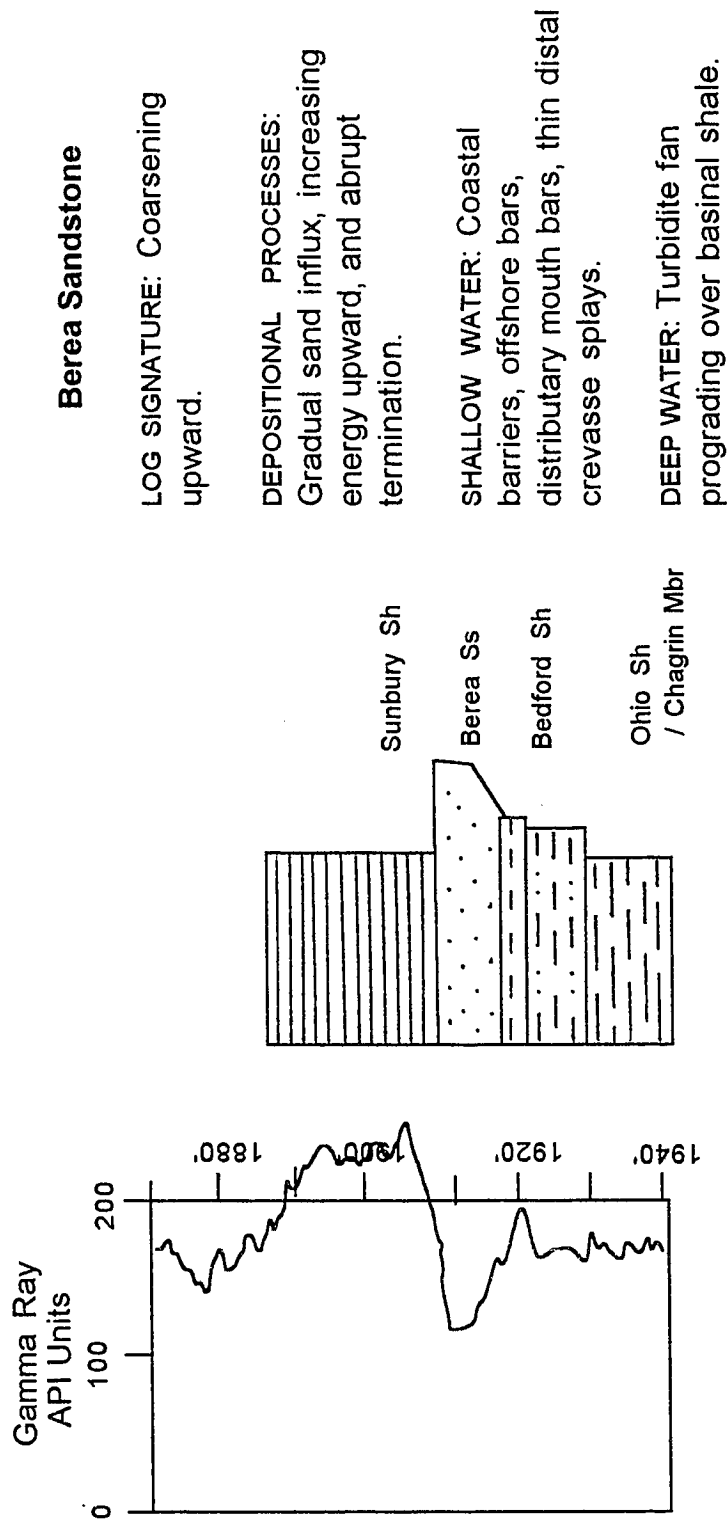


Figure 9. Gamma-ray log signature and depositional environments for the Berea Sandstone. Modified from Potter and Others (1983)

TYPE III LOG

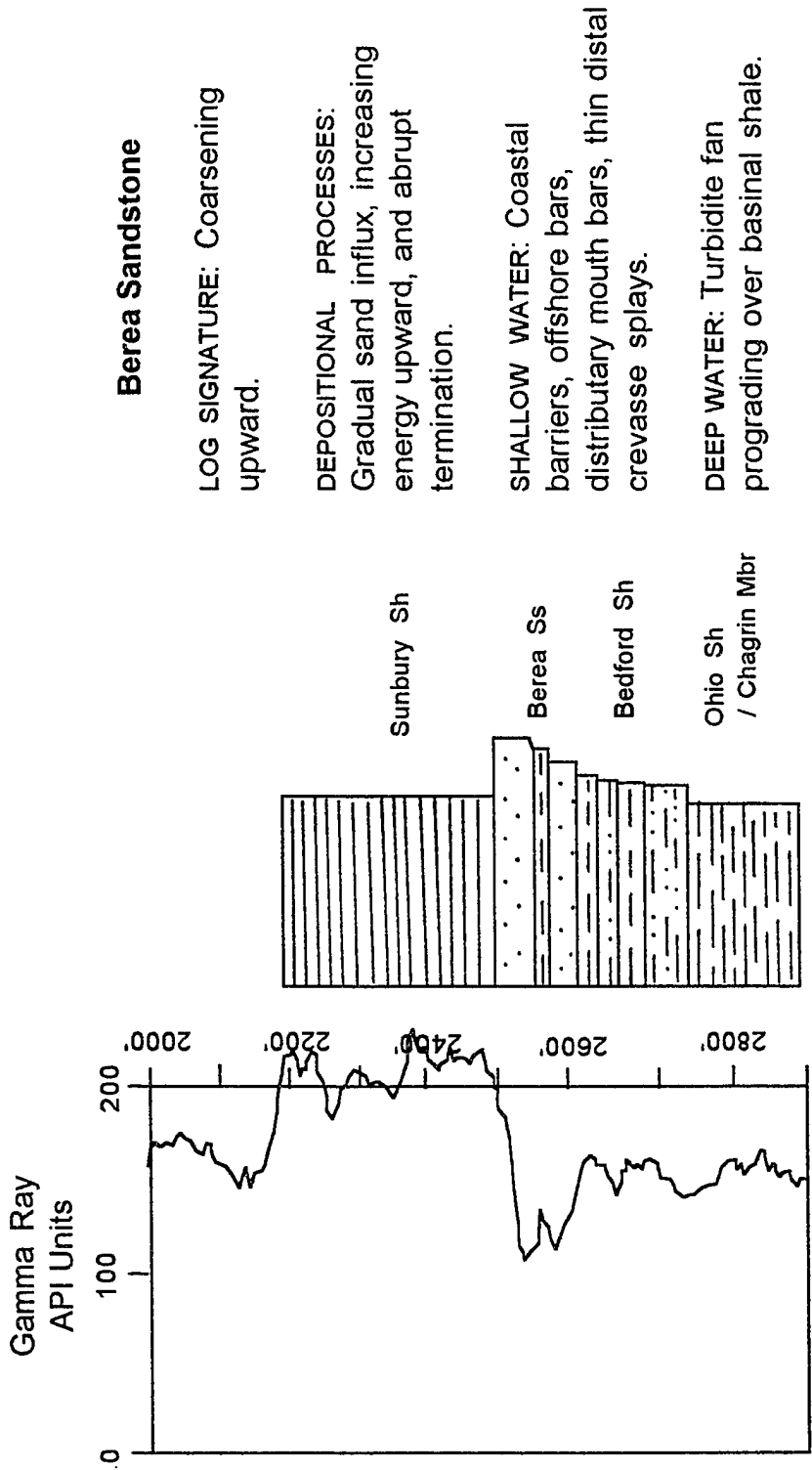


Figure 10. Gamma-ray log signature and depositional environments for the Berea Sandstone. Modified from Potter and Others (1983)

offshore bars or distributary mouth bars.

Type IV log shows a “inverted Christmas tree” pattern (Figure 11). It has a serrated log signature and represents a very slow regressive shoreline. The contact between the Berea Sandstone and the Sunbury Shale is abrupt. This pattern can also be considered as a blocky signature that exhibits greater thickness and very slow gradational base. It may represent a large distributary channel or a distributary mouth bar. Laresse (1974) identified the log forms I, II, II, IV in his study of the Berea Sandstone in West Virginia and assigned all to delta facies.

Because the same log signatures can be associated with different environments (Potter and others 1983), such as Type I log can be associated with thin transgressive sands or outer fan distal turbidites (Figure 8), the log types were mapped for a better interpretation of the sandstone environment (Figure 12). The resulting facies map shows a change from Type I log to Type IV log from the southwest to the northeast. The facies map coincides with the general pattern of the Berea Sandstone isopach map showing southwest oriented digitate pattern. This suggests the possibility of a deltaic environment for the Berea Sandstone in the study area.

Isopach Maps

Correlating and tracing the Sunbury Shale, the Berea Sandstone and the Berea - Bedford facies sequence from the gamma ray logs throughout Barlow and Warren townships, gives the variations in thickness shown on Table 5.

The isopach of the Sunbury Shale (Figure 13) shows an increase in thickness from

TYPE IV LOG

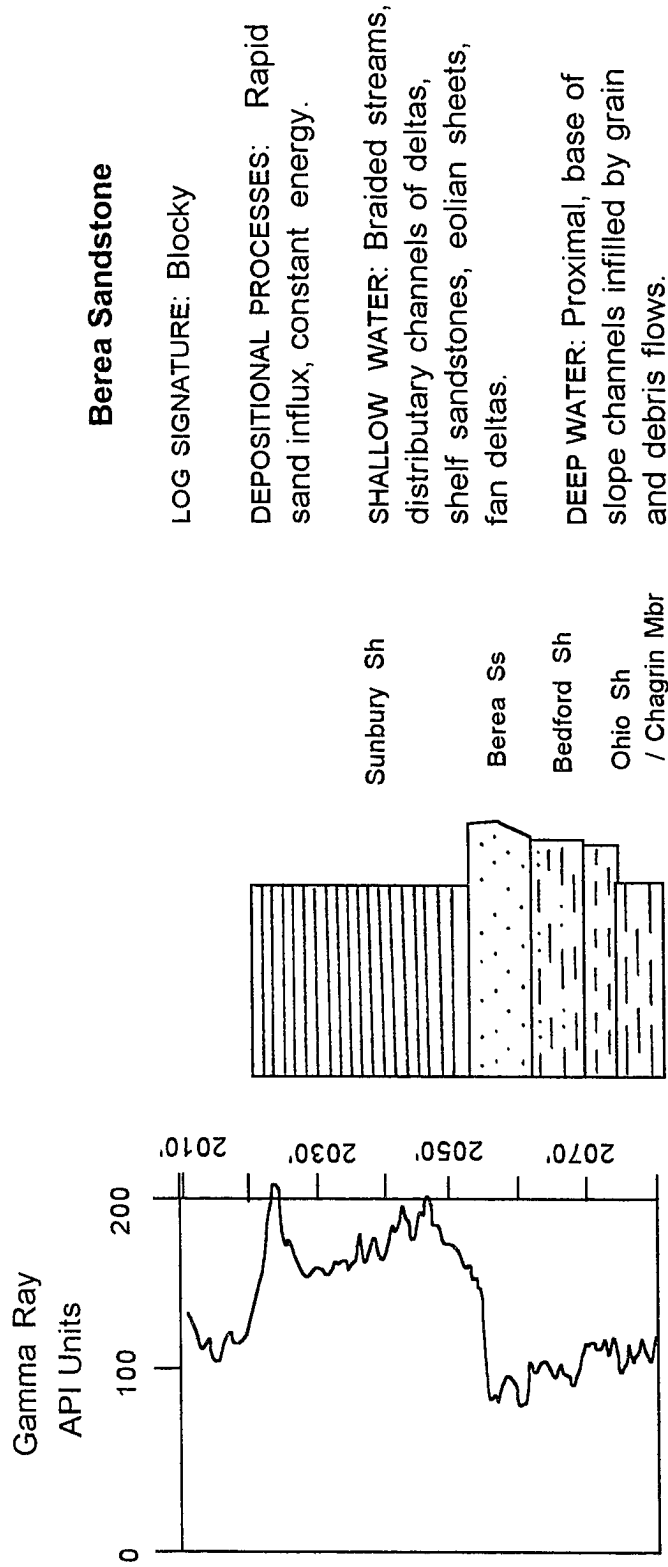


Figure 11. Gamma-ray log signature and depositional environments for the Berea Sandstone. Modified from Potter and Others (1983)

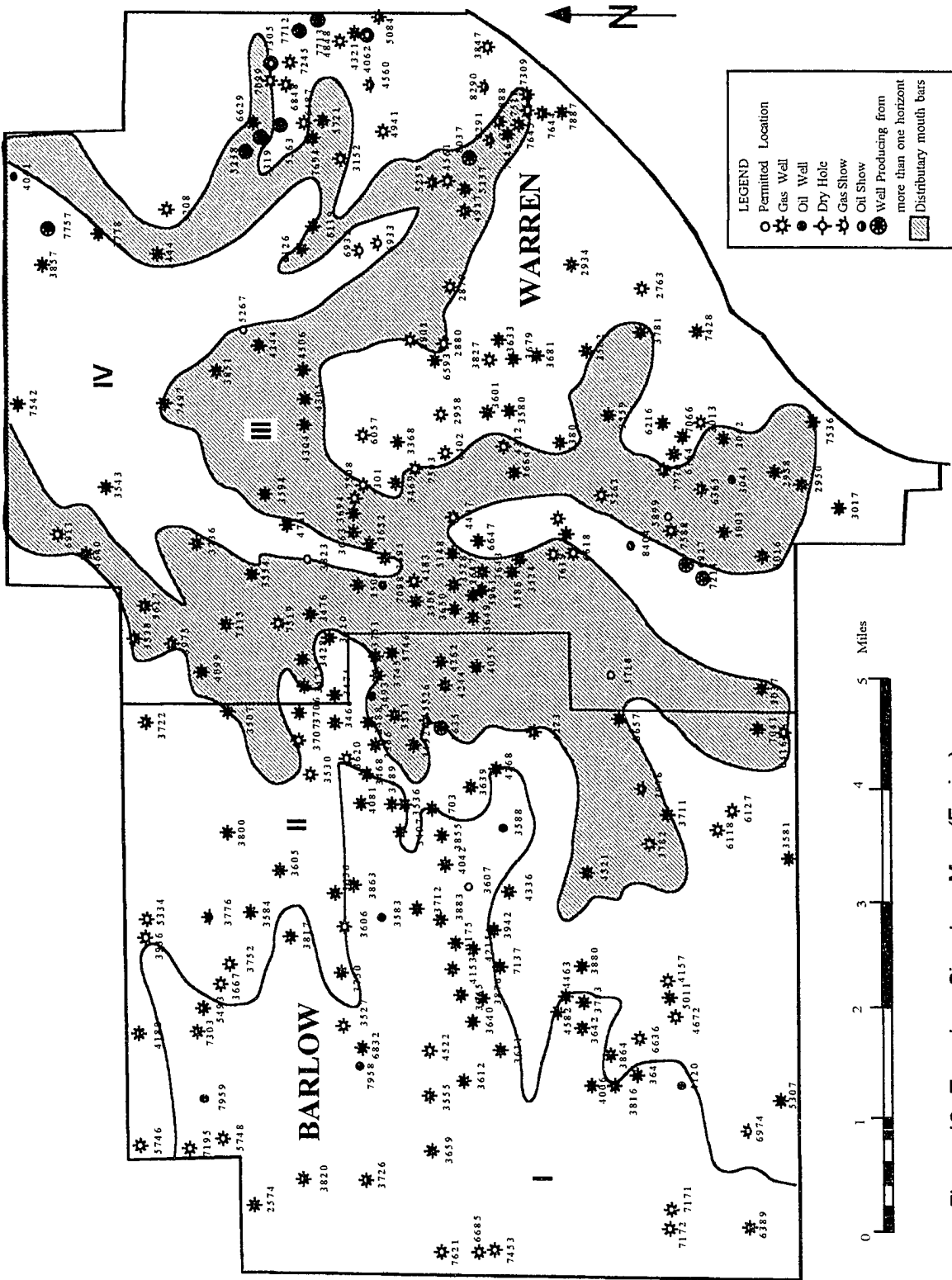


Figure 12. Type Log Signature Map (Facies)

west to east. It has a northeast - southwest depositional strike that suggests that in this part of the Appalachian basin the deposition of the Sunbury Shale was influenced by an eastern source. This also implies a possible northeast- southwest orientation of the shoreline. The Sunbury Shale is interpreted to represent a transgressive basinal deposit and this has been recognized by different investigators, Stockdale 1939, Pepper and other (1954), Wall, 1973, VanBeuren (1980).

Formation	Minimum thickness	Maximum thickness
Sunbury Shale	18 feet	40 feet
Berea Sandstone	2 feet	10 feet
Berea -Bedford Sequence	18 feet	22 feet

Table 5. Thickness of the Sunbury Shale, Berea Sandstone and Berea - Bedford Facies Sequence.

The isopach map of the Berea Sandstone in the study area shows little variation in thickness. The Berea Sandstone ranges over this area from 2 feet in thickness to 10 feet. The Berea Sandstone is thicker to the northeast (Figure 14). Digitate patterns of thicker sandstone, are interpreted to be distributary mouth bars that prograded in an arc from southeast to southwest, and the triangular shape of this distributary system implies a deltaic system was present in this area. As inferred from the log signatures and map patterns discussion, distributary mouth bars are present in this area. These are close distributary mouth bars with a deltaic geometry. These distributary mouth bars have been differentiated by the gamma ray signatures (see discussion above). The Gamma ray logs show a sharp response at the top of the unit which becomes more gradational at the

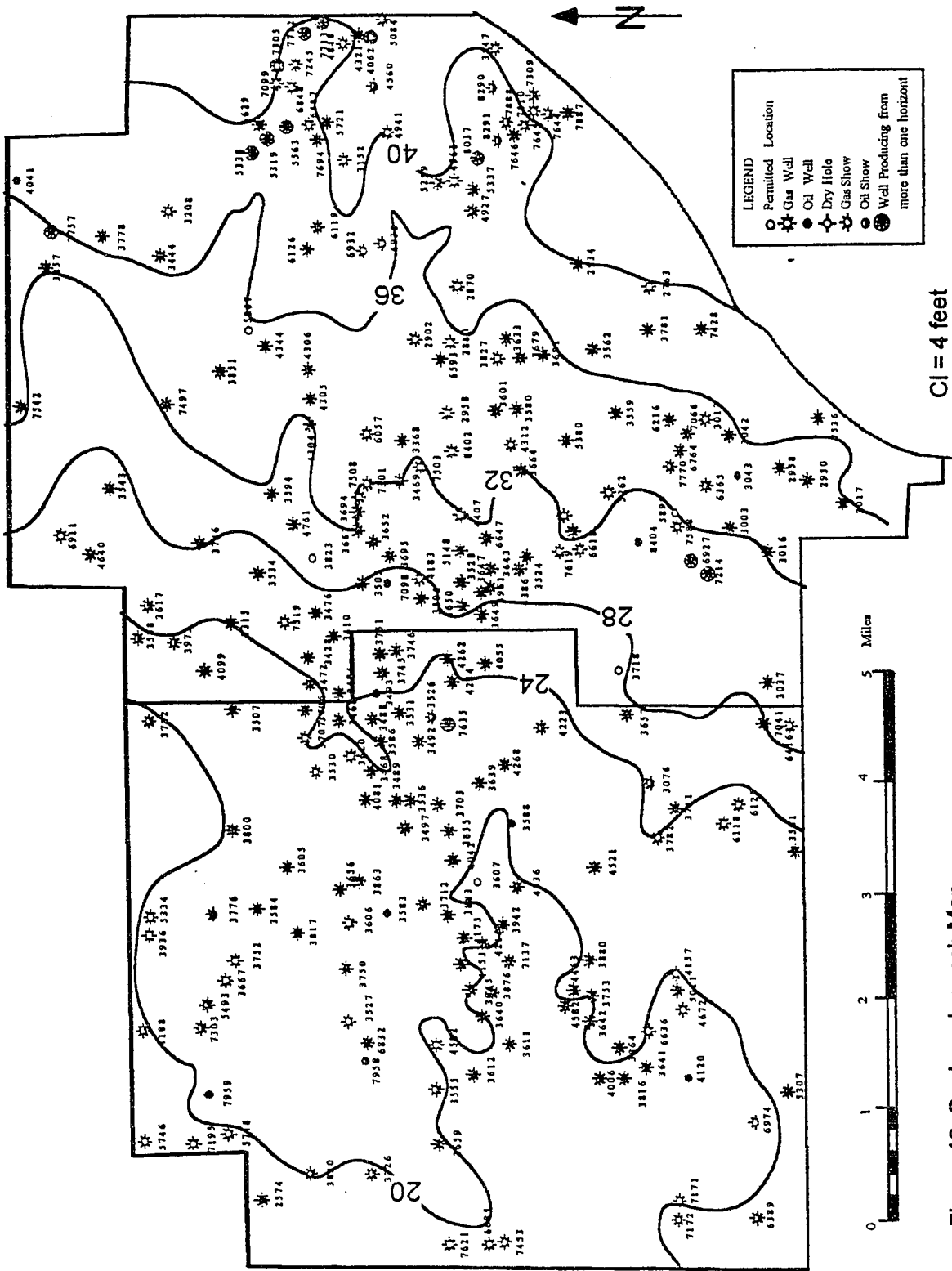


Figure 13. Sunbury Isopach Map.

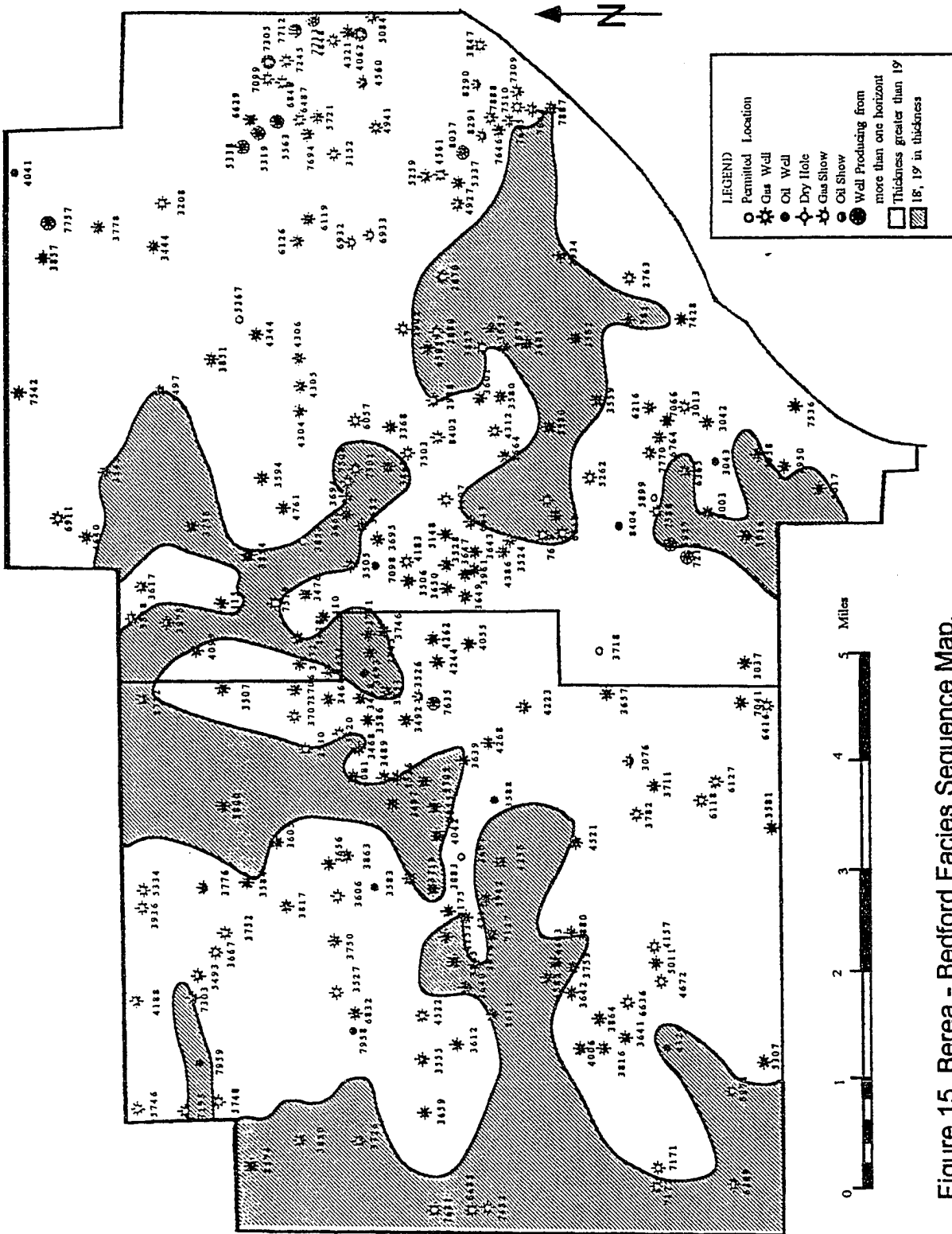


Figure 15. Berea - Bedford Facies Sequence Map.

bottom. This is representative of a coarsen upwards sequence found in shallow marine environments. The clean sand at the top gives a strong gamma ray signature. As the sand becomes silty and shaley towards the bottom of the unit the gamma ray units increase to the shale.

The source of sediments for the Berea Sandstone appears to be to the northeast. The evidence for the northeastern orientation includes the orientation of the distributaries northeast to southwest, the thickening of the distributaries to the north per my study and the decreasing of the grain size of the Berea to the south (Pepper 1954). The Berea Sandstone is gradually pinching out to the southwest. The Berea - Bedford facies sequence isopach show a uniform variation due to the selection of the bottom of the sequence. The thickness ranges from 18 feet to 22 feet (Figure 15).

Cross sections drawn north - south and west - east show the lateral geometry of the Berea Sandstone (Figure 16a, 16b). Taking the Sunbury Shale as an horizontal datum permitted the identification of sand channels on the distributary mouth bars.

Depositional Environment

Three different environments are associated with the deposition of sand bodies. These are continental (alluvial), transitional (deltaic) and marine environments. Different kinds of depositional environments have been suggested for the deposition of the Berea Sandstone. Potter and others (1983) made a review of the major depositional environments that occurred in the Berea Sandstone. Alluvial environments such as meandering, anastomosing and braided streams were recognized to be present on the

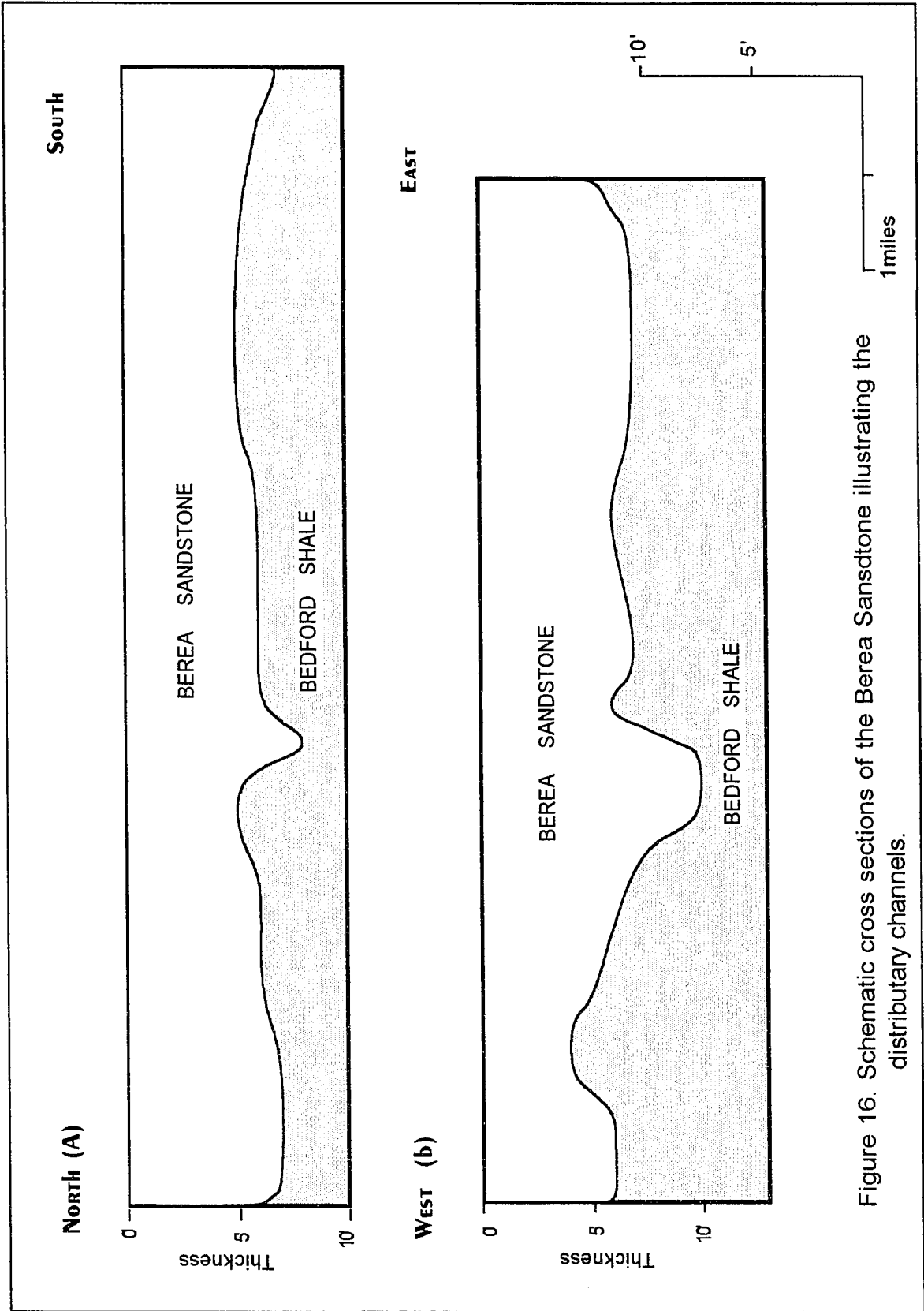


Figure 16. Schematic cross sections of the Berea Sandstone illustrating the distributary channels.

Berea Sandstone. Transitional environments such as lower delta plain deposits, delta and marine environments such as coastal and shelf deposits were also included in their study.

The Berea sandstone, in the study area, was deposited as an integral part of a complex deltaic system. The deposition of the sands was in a regressive shallow marine shelf environment. The Berea Sandstone deltaic system is best illustrated in the isopach map. There is not enough evidence to conclusively determine the kind of delta system. A particular subenvironment noted in these facies is distributary mouth bars. Through the extent of the study area, the gamma ray log displays a consistent “inverted Christmas tree” pattern.

Pepper (1954) stated that the sand sediments deposited along eastern Ohio and western West Virginia were derived at least from two sources. The Berea sediments along the eastern part of Ohio apparently came from a north or northwest source. He postulated that a great quantity of Berea sediments deposited in east Ohio were carried to the basin by the Ontario and Ashtabula rivers. On the other hand, the Berea sediments deposited west of West Virginia appears to have been derived mainly from a east source. The Gay Fink Channel and the Cussewago Delta apparently provided a good course for transportation of the eastern sediments, according to Pepper (1954). It is recognized in this project that the source of Berea sediments for the study area is a northeast source. This source can be probably a prograded delta lobe of either the Cussewago (more likely) or the Gay Fink delta. The delta front line is in the northeast of Warren Township (Figure 14). The configuration of these sand bodies from the delta front is lobate and becomes elongated to the south.

Berea Production Maps

Washington County has figured prominent since the early days of the petroleum industry in Ohio. Oil and gas were first encountered in the drilling of brine wells in the vicinity of Washington County as early as 1819. In 1860, a producing well was drilled in Aurelius township, Washington County. The discovery of the Col. Drake's famous well in Pennsylvania, marked the real beginning of the oil and gas industry in Washington County. Production of hydrocarbons in Washington County is divided almost equally between rocks of Pennsylvanian and Mississippian ages, with some occurrences in the Devonian Shale. The Berea Sandstone, Lower Mississippian, is by far the most important gas bearing zone of the shallow gas sands and is productive in almost every county of eastern and southern Ohio, (Collins and others 1977).

The Berea Sandstone IP (initial productivity) data were taken from the completion cards. Reported oil IP rates ranged from 0.25 to 75 barrels of oil per day. Gas IP was reported to range from 5 to 3000 thousands cubic feet (mcf) of gas per day. These data confirm that the Berea Sandstone has more production of gas than oil in the study area. The gas and oil initial productivity data were mapped and shown in Figures 17, and 18.

Correlation between the Berea Sandstone structural map and the Berea Sandstone initial productivity map shows little relation. Thus, the Berea production is slightly dependent upon structural setting. However, some areas of high gas initial productivity can be associated with positive structural closures. Comparison of these two maps shows

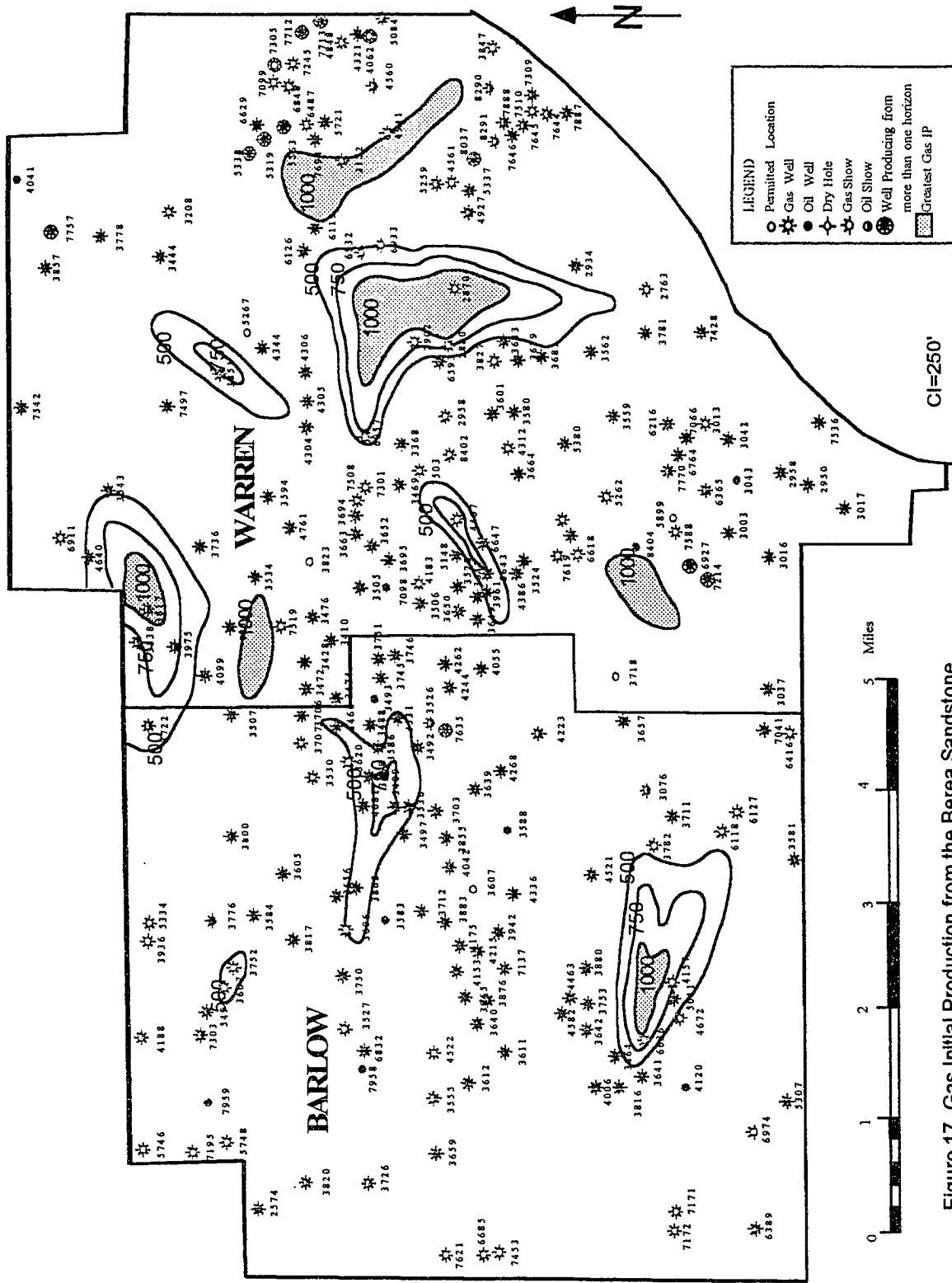


Figure 17. Gas Initial Production from the Berea Sandstone.

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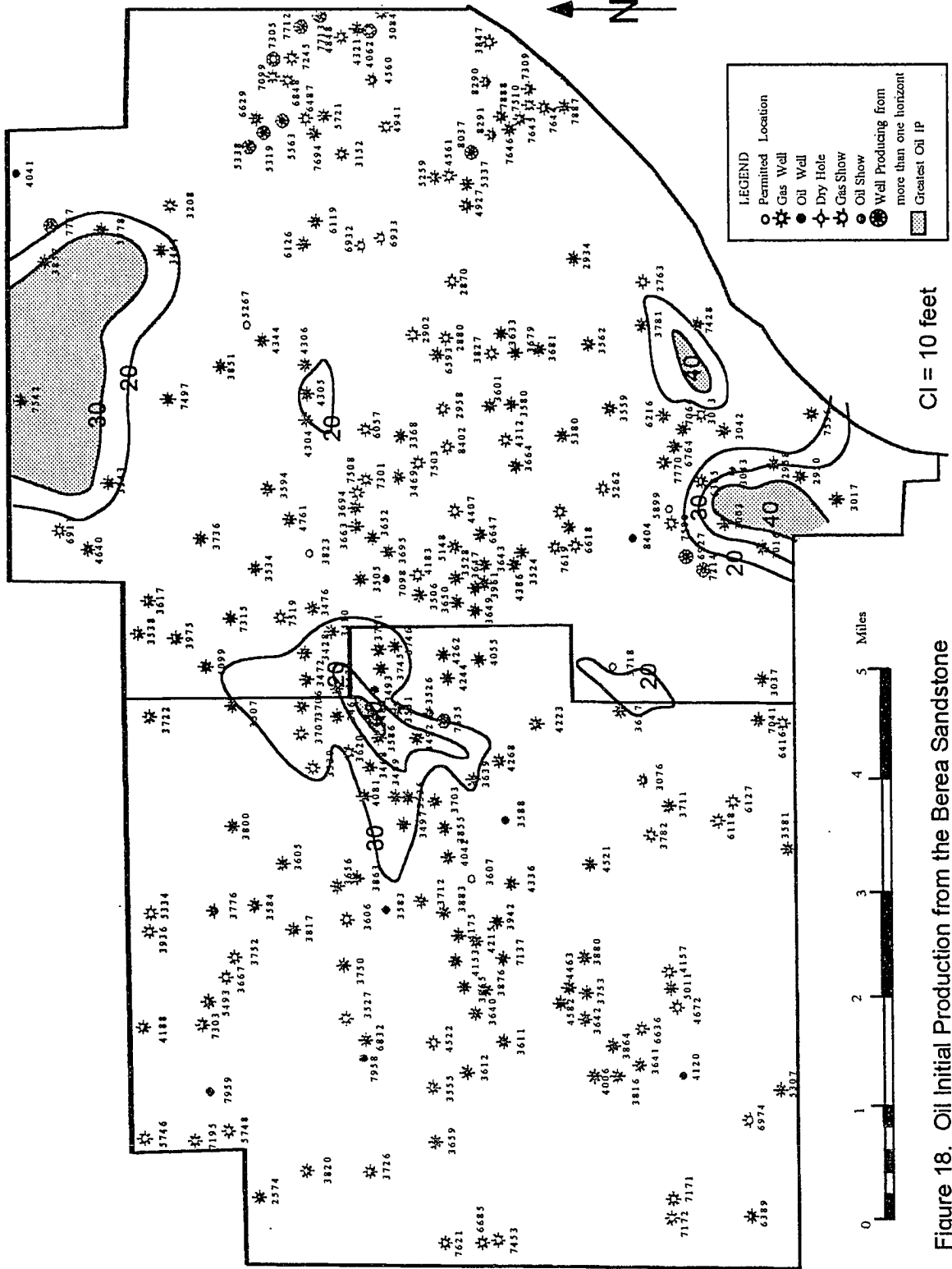


Figure 18. Oil Initial Production from the Berea Sandstone

that the Berea Sandstone only has a minor structural component in the accumulation of gas and oil.

Correlation between the Berea Isopach Map and the Berea initial productivity maps suggest that the trapping mechanism and the depositional environment of these sandstones seem to be the best parameter in the accumulation of hydrocarbons. It can be seen that most of the hydrocarbon traps in the Berea Sandstone in the study area are stratigraphic. The stratigraphic seal (sandstones enclosed by impermeable shales) makes the Berea Sandstone a good reservoir for the accumulation of hydrocarbons.

The facies map, as well as the isopach map, show the importance of the depositional environment in the accumulation of oil and gas. Distributary mouth bars thin to the west and gas production seem to be higher at the upper part of these distributary mouth bars. This condition can be explained by the distribution of the distributary bars and the property of hydrocarbons to migrate up dip as a consequence of both buoyancy and density properties between the fluids and gases.

Sand and shale percentage maps are shown on Figures 19, and 20. The percentage of sand map as well as the percentage of shale map show the same deltaic configuration as the Berea Sandstone isopach map. The percentage of shale is mainly decreasing from southwest to northeast in the study area. However, the percentage of sand is increasing in this direction. This inversely proportional relation is due to the selection of the bottom of the Berea - Bedford facies sequence.

Thickness, facies, elevation and oil and gas initial productivity data were also plotted to understand the main parameters controlling the accumulation and production of

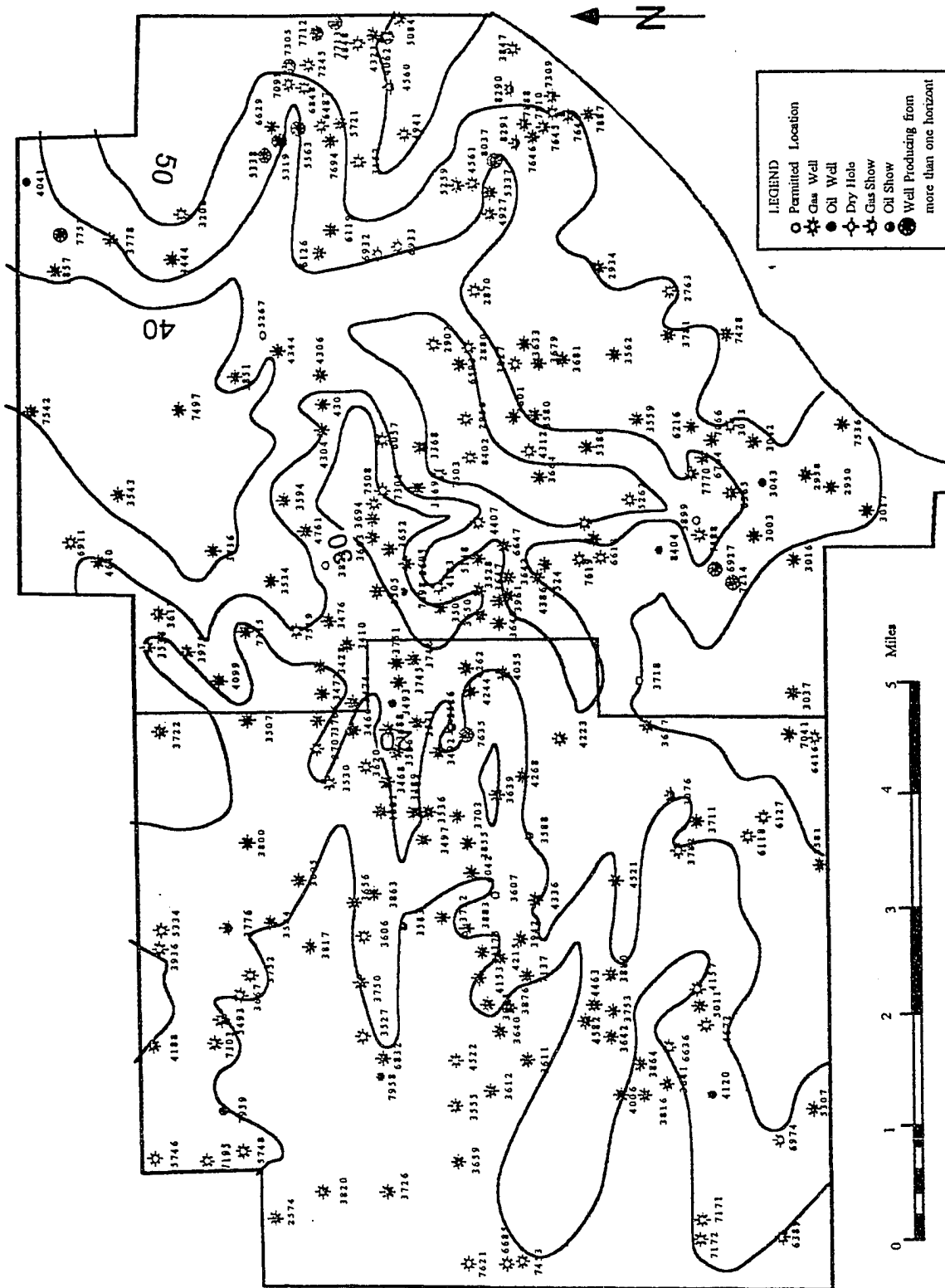


Figure 19. Percentage of sand on the Berea - Bedford Sequence. CI= 10 feet

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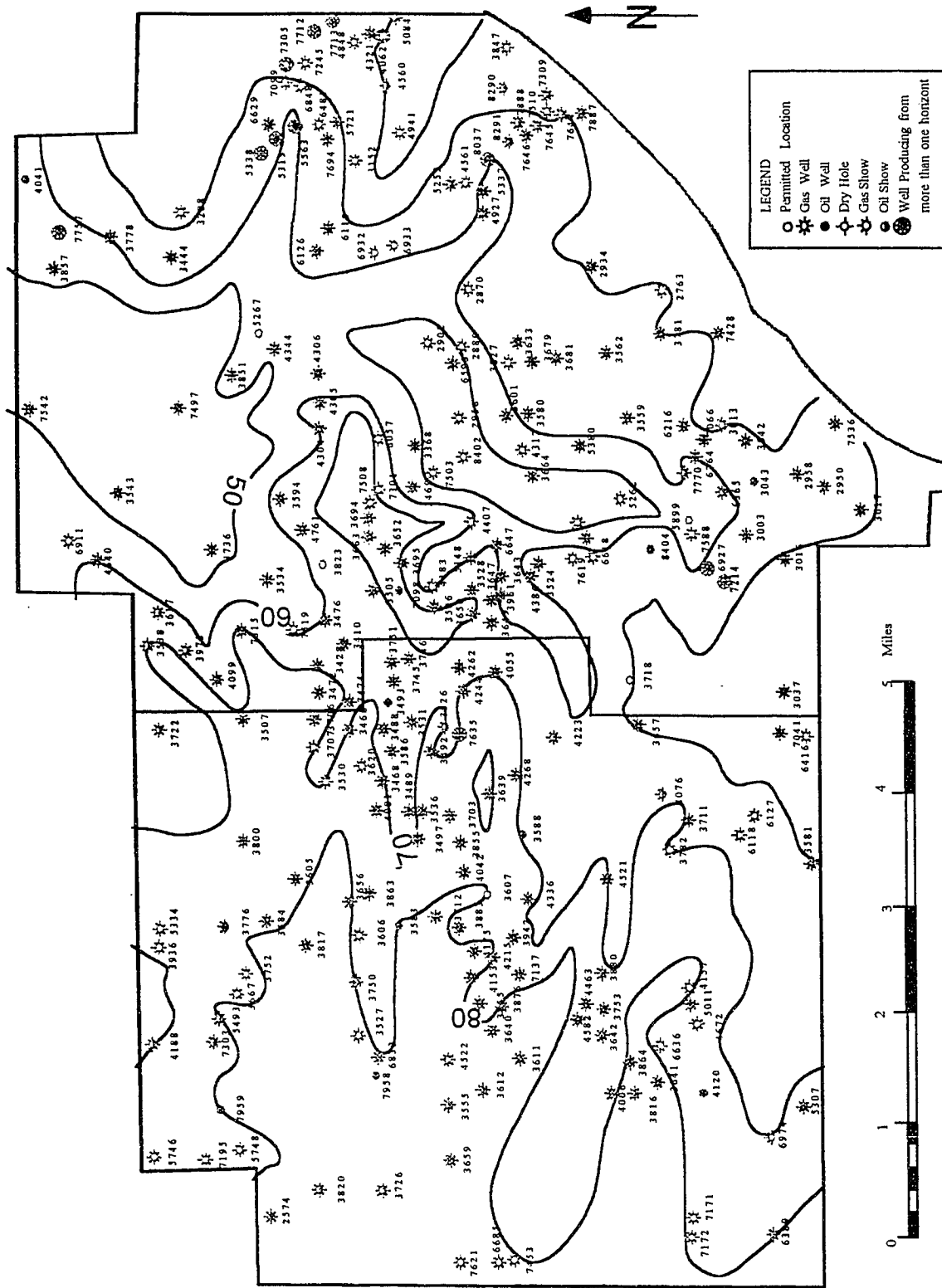


Figure 20. Percentage of Shale on the Berea - Bedford Facies Sequence CI = 20 feet

hydrocarbons. The gas IP vs. Thickness plot (Figure 21) shows that in order to obtain a productivity higher than 500 MCF, the thickness of the Berea Sandstone should range from 4 feet to 8 feet. The highest productivity was obtained from wells that have a Berea Sandstone thickness of 6 feet. Although, some production occurred from wells that have a thickness less than 4 feet, it is not recommended to produce such sandstones because the expected production is not great. Furthermore, it seems that production from wells with thickness greater than 8 feet will not produce a lot of hydrocarbons. The oil IP Vs Thickness (Figure 22) plot displays the same relation as the gas IP vs. Thickness plot. More than 40 barrels of oil per day can be produced from wells with thickness ranges from 4 feet to 8 feet. Similar to the gas production, the best thickness to produce oil is 6 feet.

The gas and oil IP vs. Facies plots (Figures 23, 24) display a relation with the Berea Sandstone production. It can be inferred that log type signatures II and III are best related with the production of hydrocarbon in this area. More than 1000 mcf and 40 BO was produced from these log types. These signatures show a linear regressive shoreline. These plots also suggest that the depositional environment of the sand plays an important role in the accumulation and production of hydrocarbons as was previously mentioned.

The gas IP vs. Elevation as well as the oil IP vs. Elevation (Figures 25, 26) show little relation between structure and productivity. This information confirmed the results obtained from the correlation of the structural map and IP maps. Therefore, structure has a minor control in the production and accumulation of hydrocarbons in the study area.

Gas IP vs Thickness

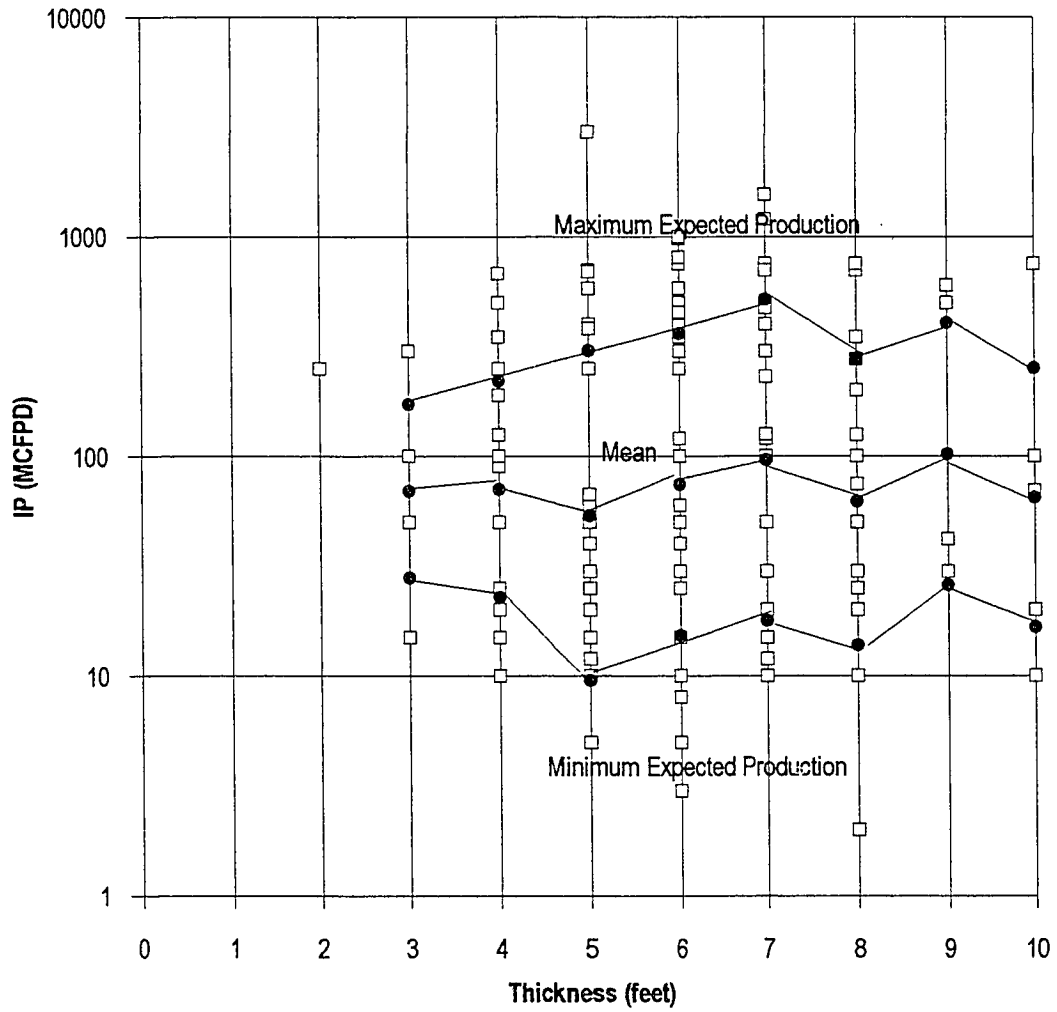


Figure 21. Gas Initial Production vs Thickness of the Berea Sandstone

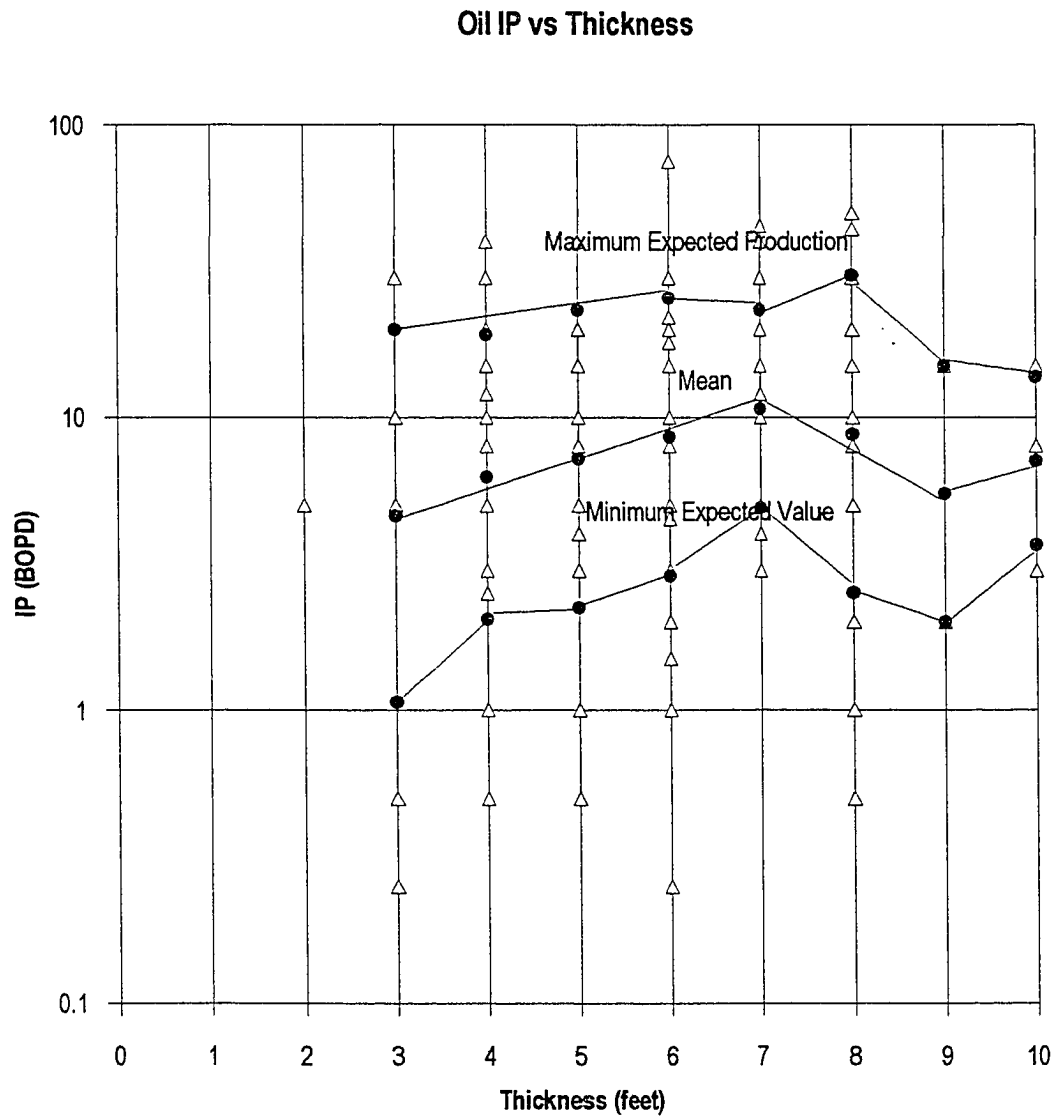


Figure 22. Oil Initial Production vs Thickness of the Berea Sandstone

Gas IP vs Log Signatures (Facies)

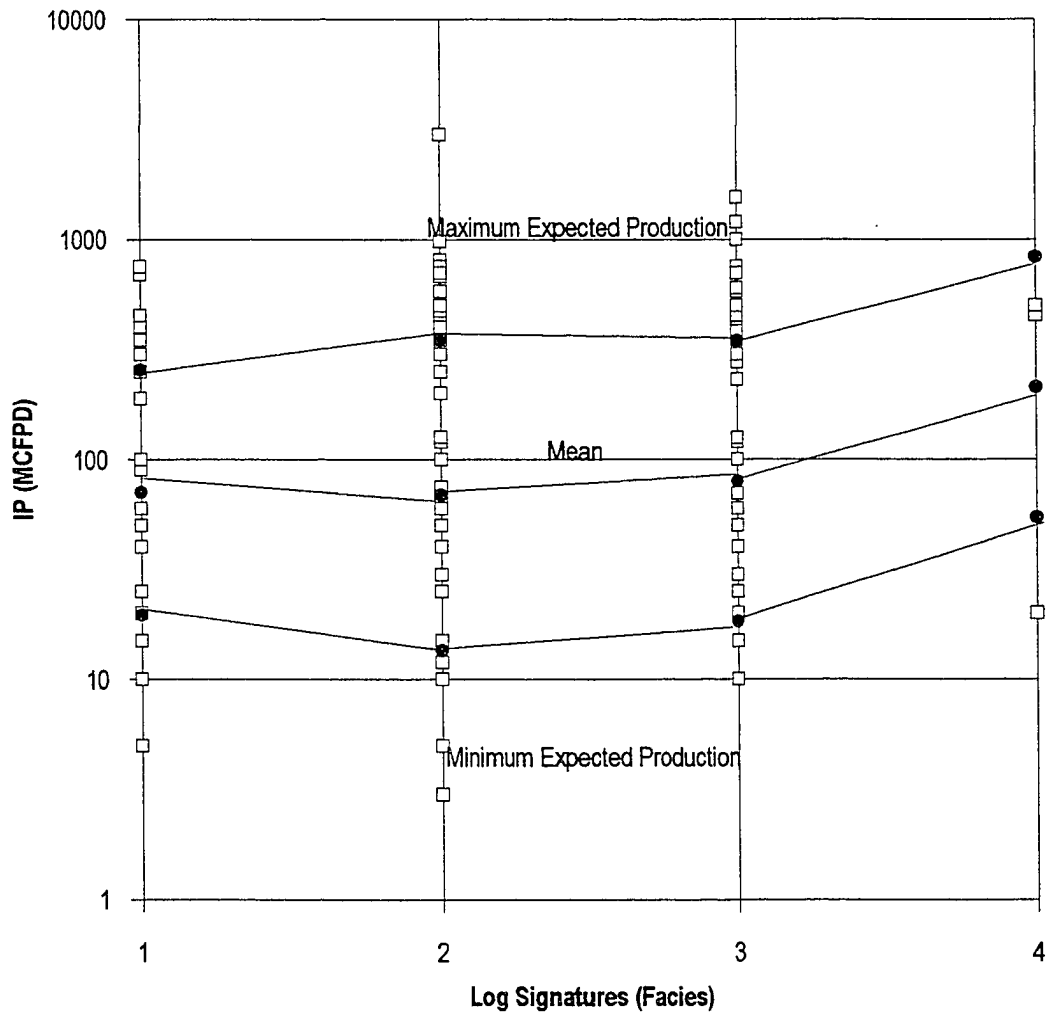


Figure 23. Gas Initial Production vs different Type Log Signatures present on the Berea Sandstone.

Oil IP vs Log Signatures (Facies)

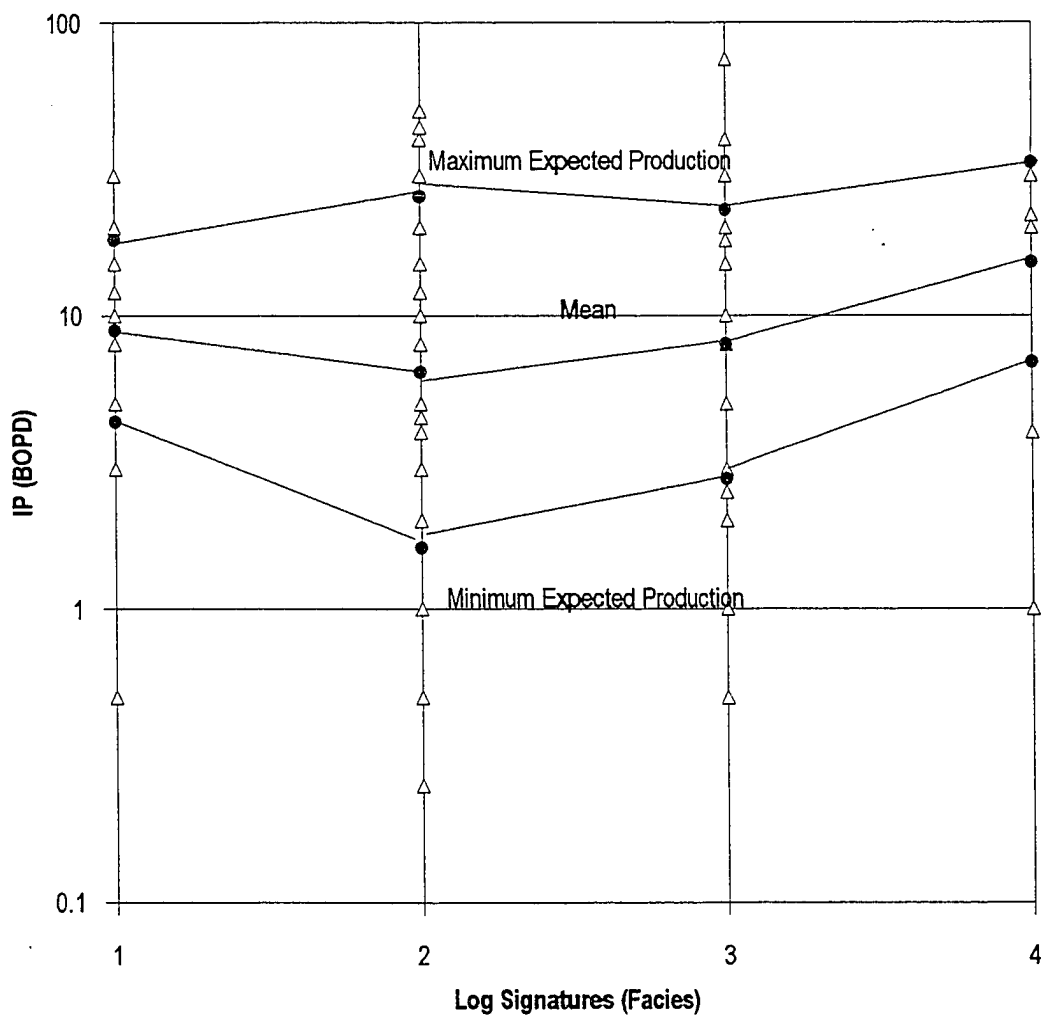


Figure 24. Oil Initial Production vs Different Type of Log Signatures present on the Berea Sandstone

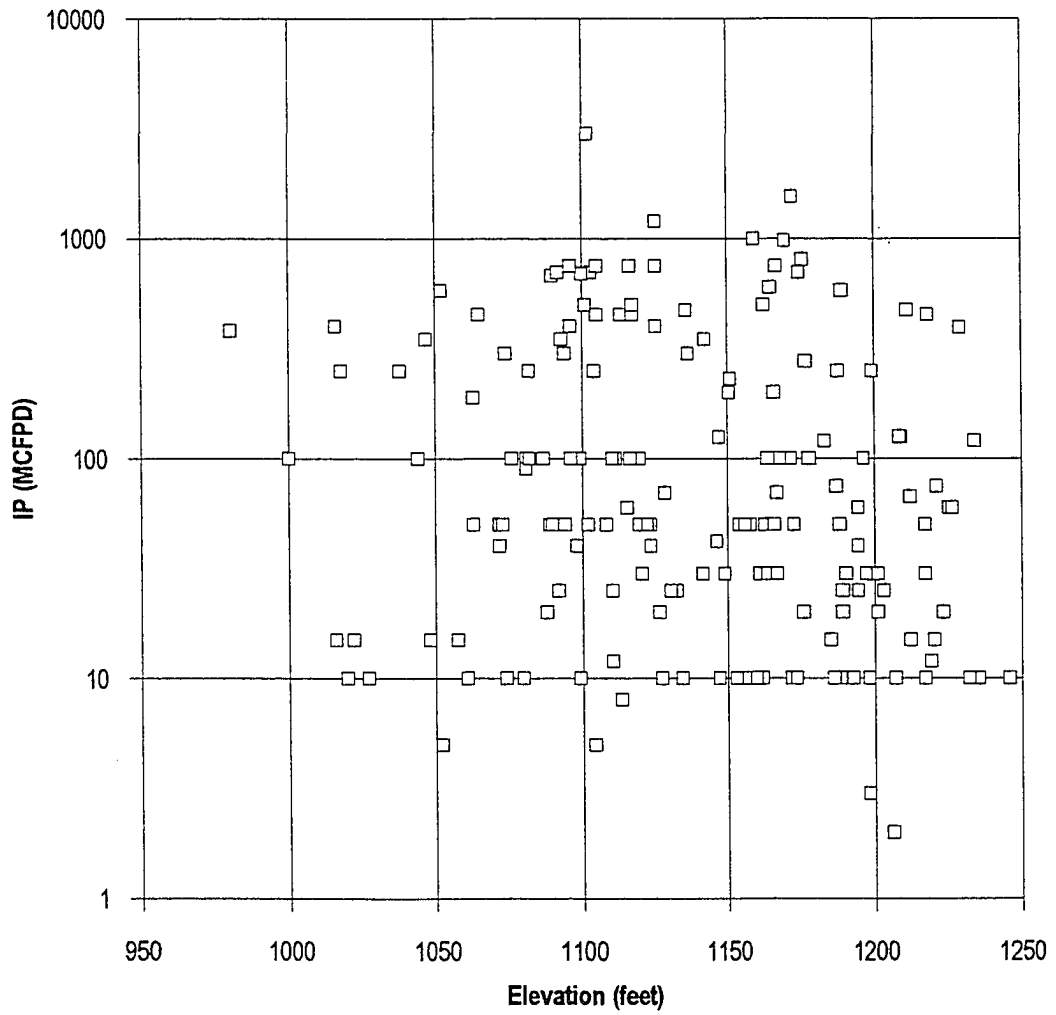
Gas IP vs Elevation

Figure 25. Gas Initial Production vs. Subsea elevations to the Top of the Berea Sandstone.

Oil IP vs Elevation

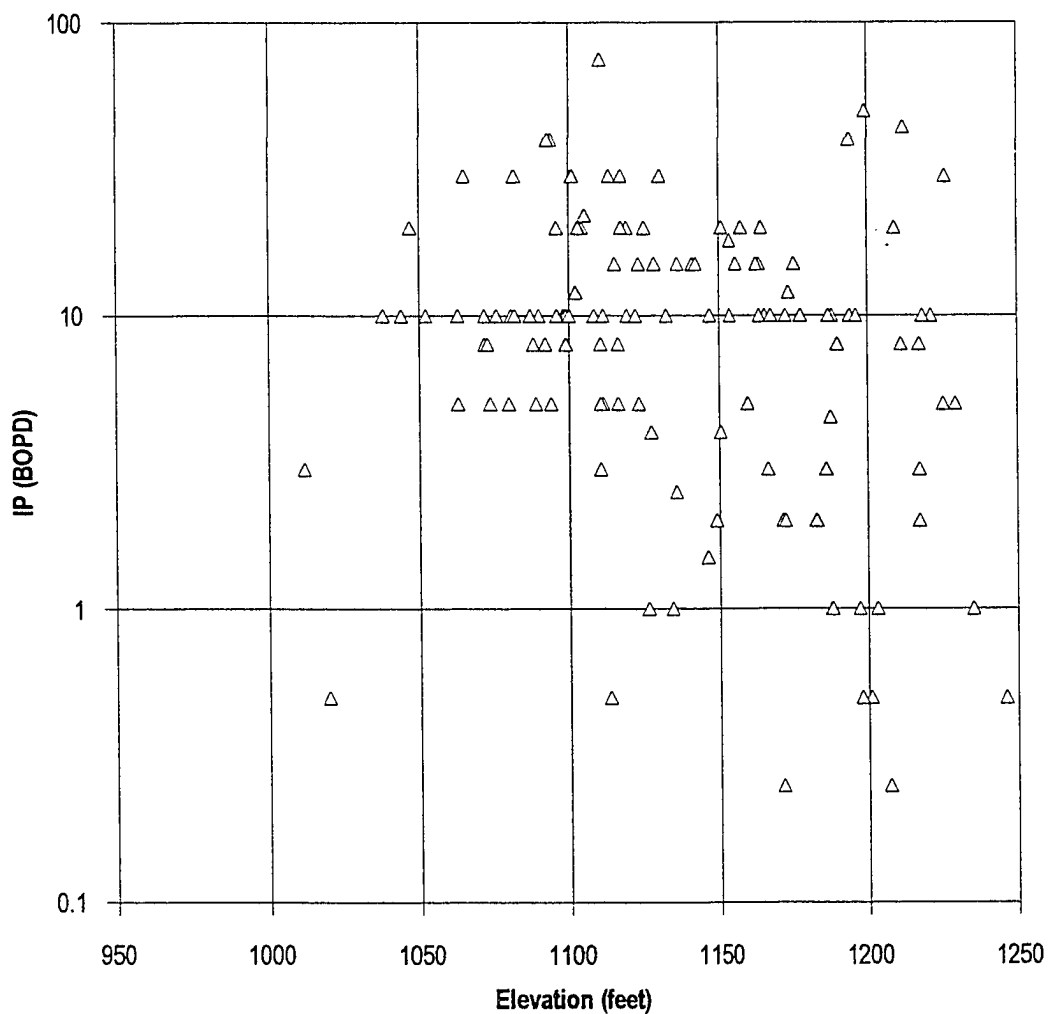


Figure 26. Oil Initial Production vs. Subsea elevations to the Top of the Berea Sandstone

Tables 6, 7, 8, and 9 show the calculated data for average gas IP, average oil IP, maximum expected gas and oil IP and minimum expected gas and oil IP. From these data the following can be inferred:

1. Seven feet in thickness for the Berea Sandstone shows the highest average gas IP.
2. Eight feet in thickness for the Berea Sandstone displays the highest average oil IP.
3. Type III log signature displays the highest average gas IP.
4. Type III log signature displays the highest average oil IP.
5. Type IV log signature in both gas and oil production expected values, as well as the nine feet thickness values, were disregarded due to limited and extreme variances of the data.

Berea Sandstone Thickness (feet)	Maximum Expected Gas IP (MCF)	Average Gas IP (MCF)	Minimum Expected Gas IP (MCF)
3	173	69	28
4	220	71	23
5	302	54	10
6	361	74	15
7	517	96	18
8	279	62	14
9	405	102	26
10	252	65	17

Table 6. Average, Maximum Expected and Minimum expected Gas IP values for different Berea Sandstone thickness.

Berea Sandstone Thickness (feet)	Maximum Expected Oil IP (BO)	Average Oil IP (BO)	Minimum Expected Oil IP (BO)
3	20	5	1
4	19	6	2
5	23	7	2
6	26	8	3
7	23	11	5
8	30	9	3
9	15	5	2
10	14	7	4

Table 7. Average, Maximum expected and Minimum Expected Oil IP values for different Berea Sandstone thickness.

Berea Sandstone Type Log Signature	Maximum Expected Gas IP (MCF)	Average Gas IP (MCF)	Minimum Expected Gas IP (MCF)
I	255	71	20
II	351	67	13
III	347	80	18
IV	830	212	54

Table 8. Average, Maximum Expected and Minimum Expected Gas IP values for different Berea Sandstone Type log signatures.

Berea Sandstone Type Log Signature	Maximum Expected Oil IP (BO)	Average Oil IP (BO)	Minimum Expected Oil IP (BO)
I	18	9	4
II	25	6	2
III	23	8	3
IV	33	15	7

Table 9. Average, Maximum Expected and Minimum Expected Oil IP values for different Berea Sandstone Type log signatures.

These interpretations are subjected to the information taken from old completion cards and the fact that production practices, sand pressures, porosity and permeability play an important role in the production of hydrocarbons.

Production declination curves are shown in Figures 27 to 33. Production data from 1983 to 1992 were plotted. The life of the Berea wells is commonly accepted to be from 4 to 6 years with a very steep decline curve. Figures 27 to 33 display a slow decline curve over a 9 year period. Natural occurring formation fractures most probably play a role in the productivity of the Berea Sandstone. It is very possible that the Ohio black shale may contribute to the prolonged production of gas and oil in this sand. The Huron Member of the Ohio Shale is considered an economically important gas shale (Wallace DeWitt and Others, 1993). It produced gas in shallow, low - pressure shale gas fields along the Lake Erie and in small fields in central southern Ohio. It has also produced high gravity oil in southern Ohio and contiguous West Virginia. Thus, the Huron Black Shale might probably contribute to the production of gas and oil from the Berea Sandstone. On the Other hand, the Berea Sandstone is overlain by Sunbury Shale which has displayed some porosity development. Although the Sunbury Shale is thin in comparison to the Huron Shale, it has also produced gas in southern Ohio. Elsewhere, fracture identification logs have verified the presence of fractures in this formation. If present here also, they would contribute to the Berea reservoir and enhance the productivity of the zone. In addition, from these decline curves also can be inferred that the Berea Sandstone is mainly a gas reservoir and the gas decline curve is slower for gas than for oil.

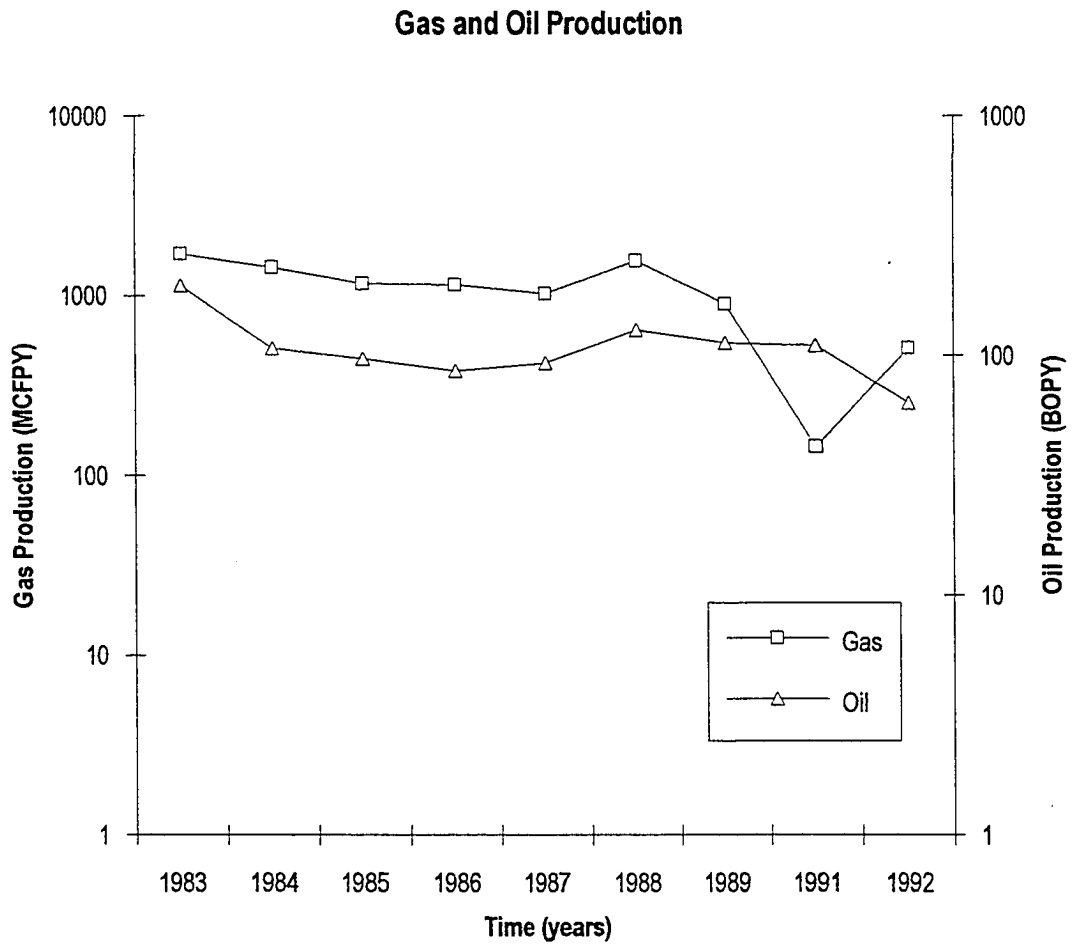


Figure 27. Decline Curve, Well Permit No. 3703. Gas IP =60 MCFPD, Oil IP =15 BOPD, Completion Date 1977.

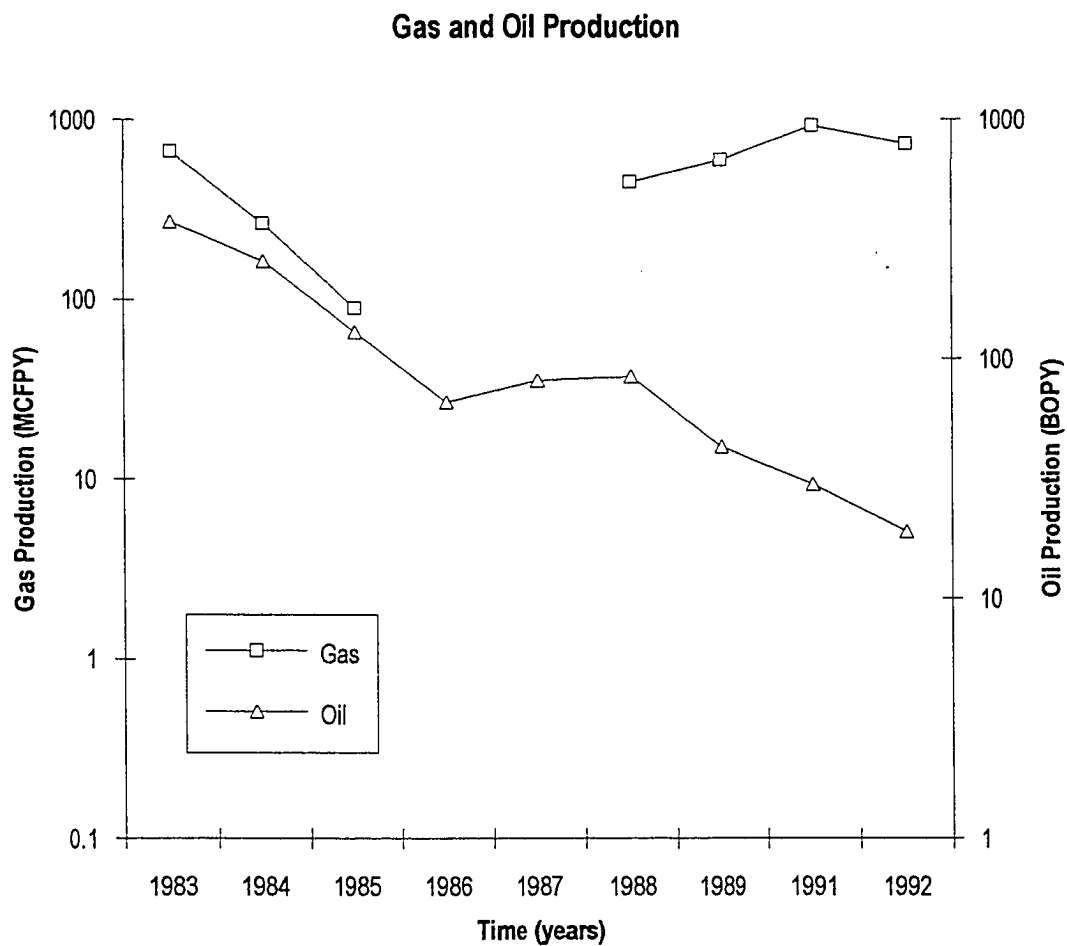


Figure 28. Decline Curve, Well Permit No. 4042. Gas IP = 50 MCFPD, Oil IP = 10 BOPD, Completion Date, 1977

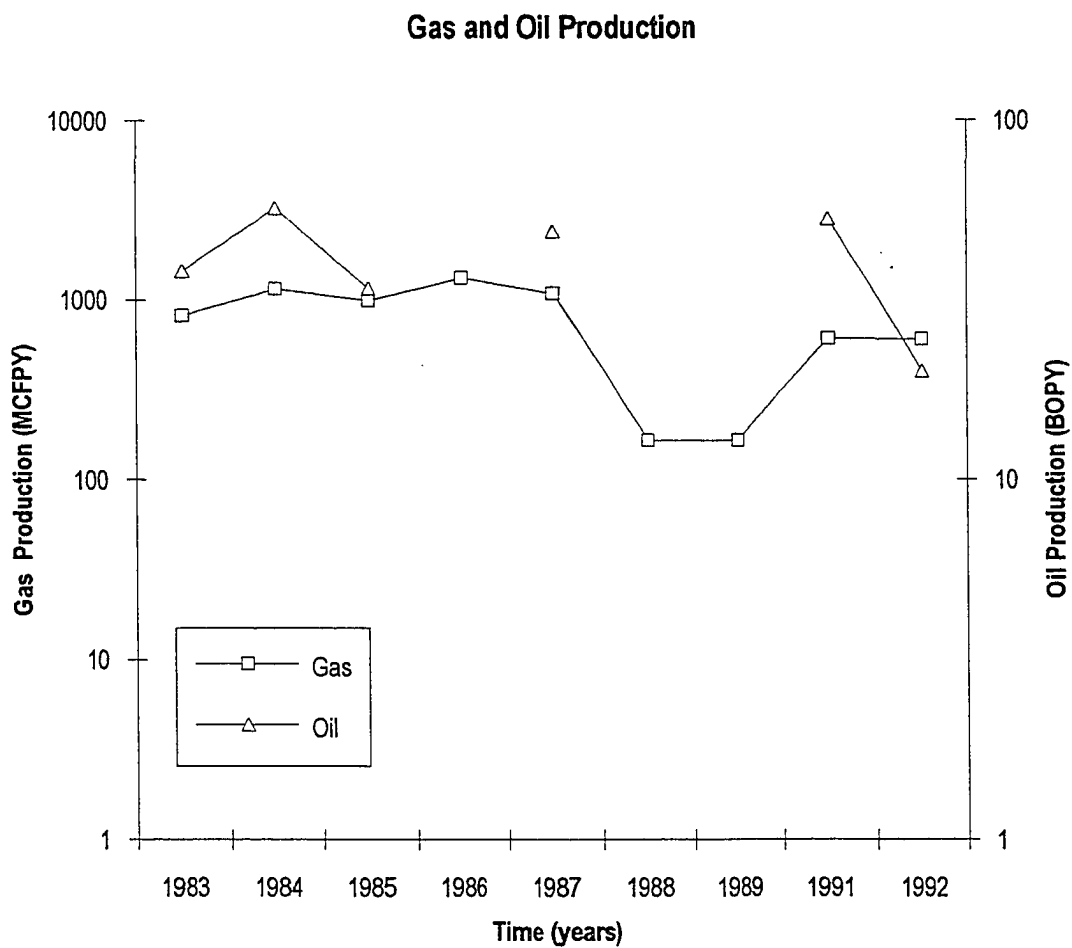


Figure 29. Decline Curve, Well Permit No. 3606. Gas IP =692 MCF, Oil IP = 10 BO, Completion Date 1976.

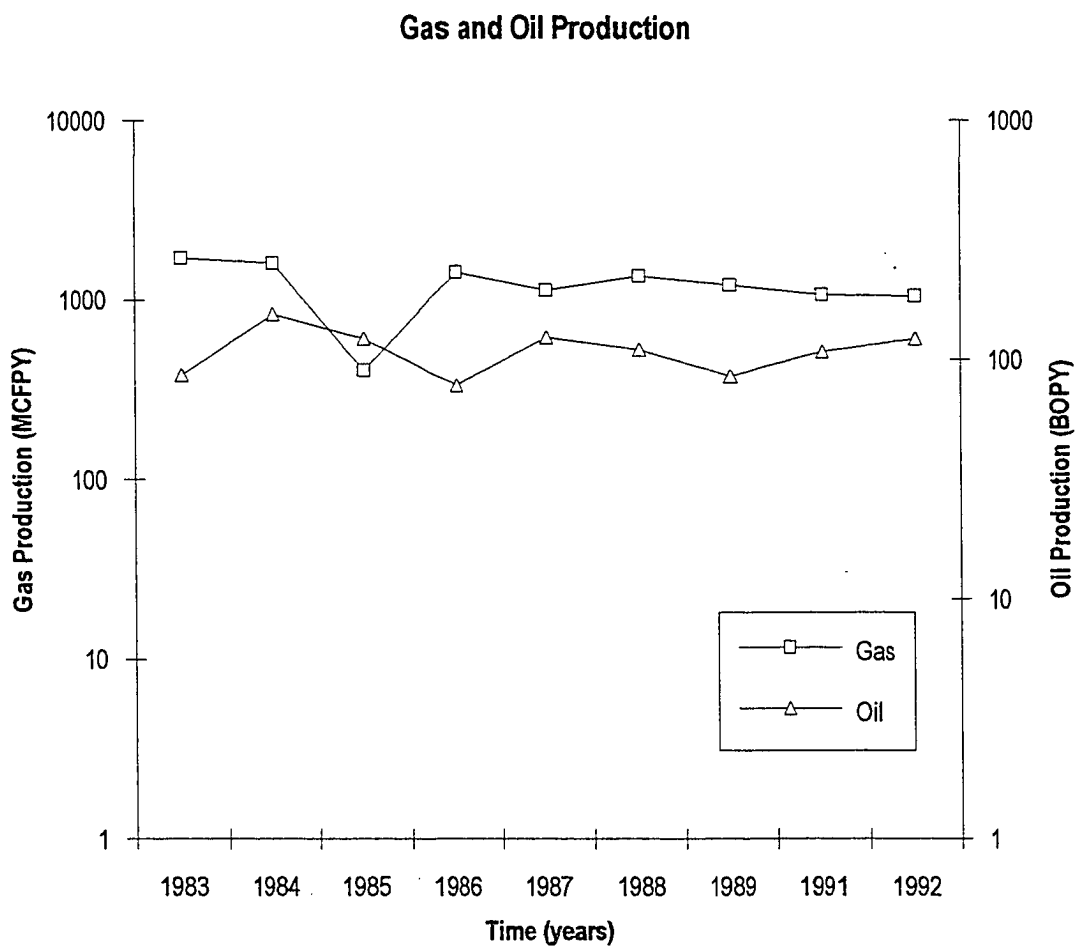


Figure 30. Decline Curve, Well Permit No. 3444. Gas IP = 230 MCFPD, Oil IP = 20 BOPD, Completion Date 1976

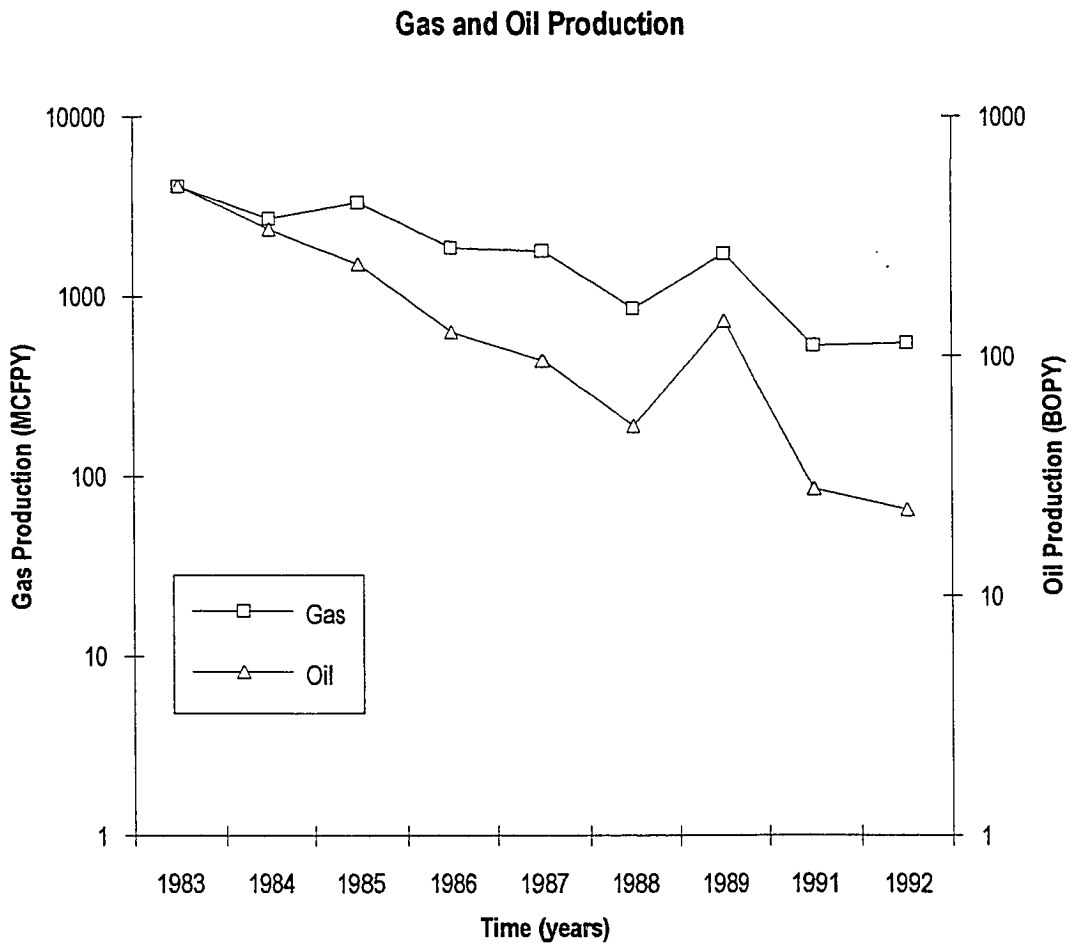


Figure 31. Decline Curve, Well Permit No. 7066. Gas IP = 20 MCFPD, Oil IP = 4 BOPD, Completion Date 1977.

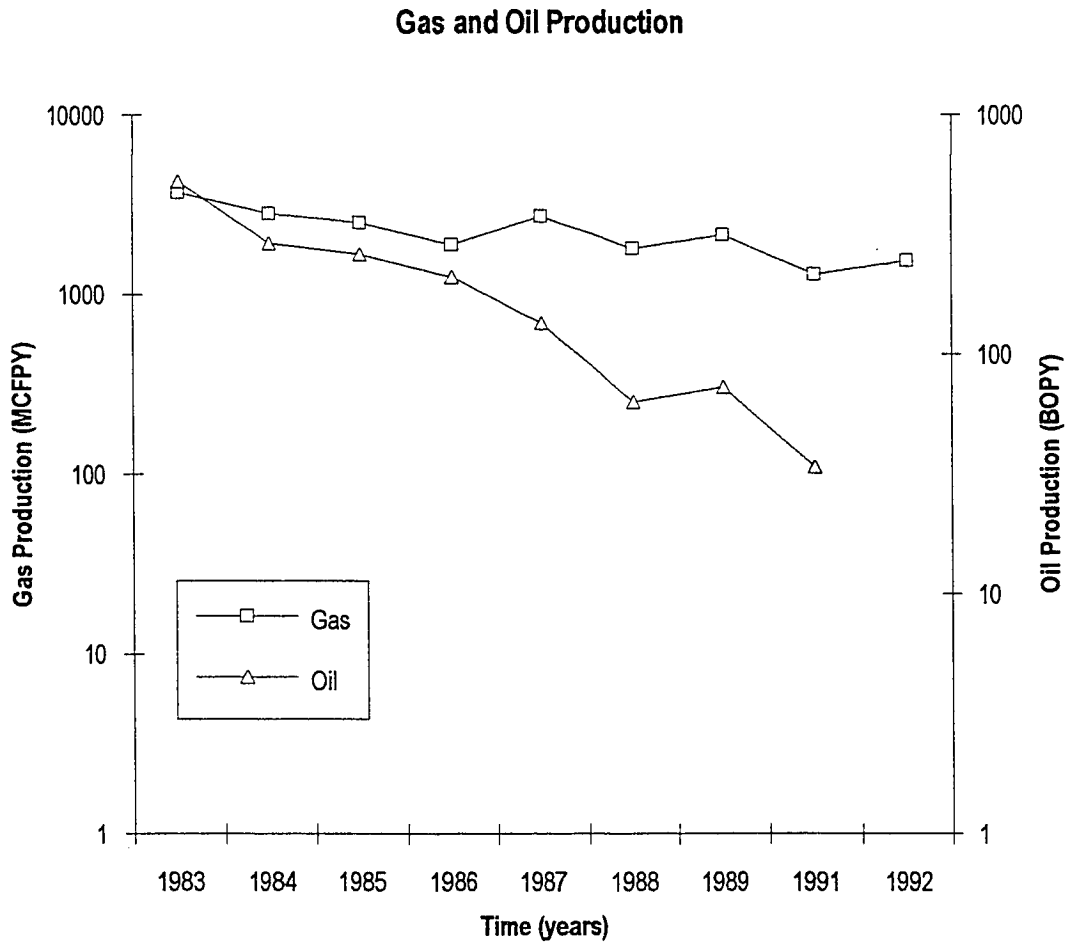


Figure 32. Decline Curve, Well Permit No. 6216. Gas IP = 100 MCFPD, Oil IP = 20 BOPD, Completion Date 1976

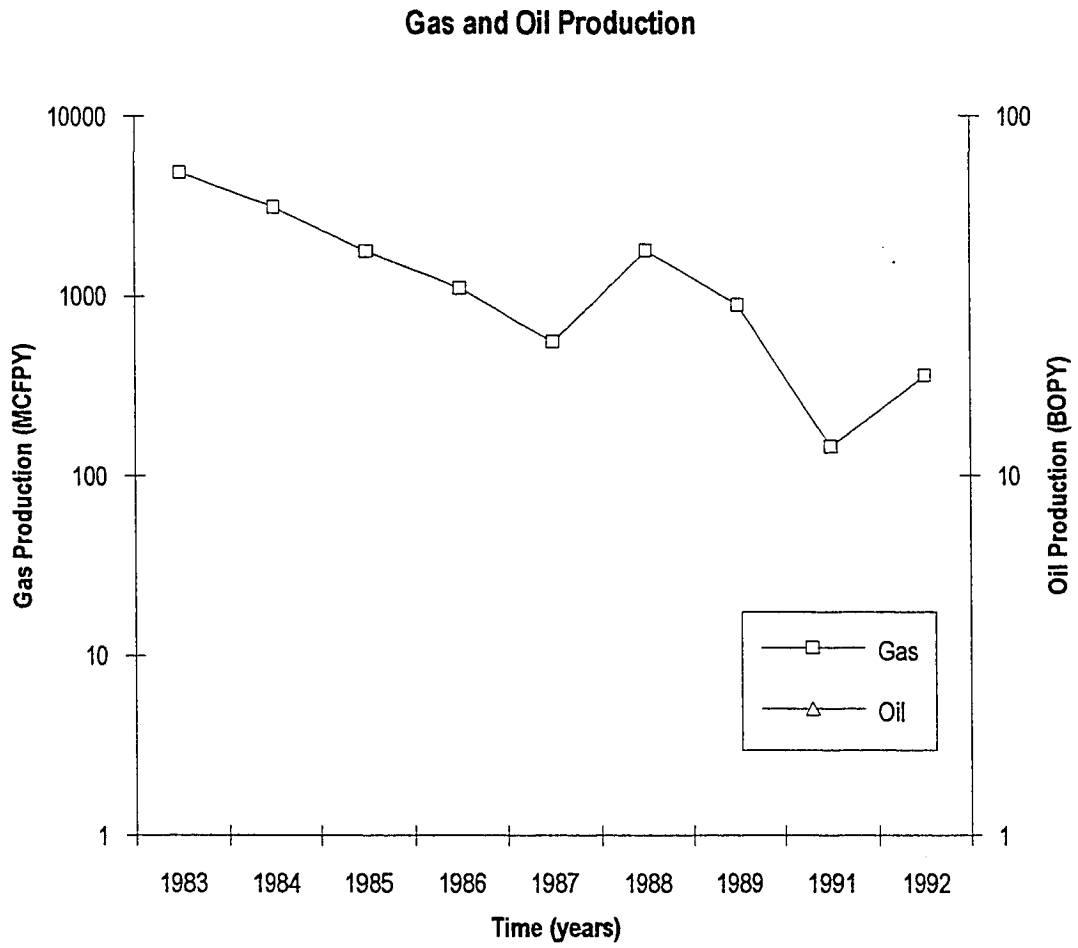


Figure 33. Decline Curve, Well Permit No. 5746. Gas IP = 100 MCFPD, Oil IP = 0 BOPD, Completion Date 1977.

The quality and composition of gas produced from one well in Barlow township, Washington County is shown in Table 10. It is primarily methane (74.41%) ethane (12.74%) and propane (7.24%) with traces of other gases.

Composition	Percentage
Methane	74.41
Nitrogen	1.77
Ethane	12.74
Propane	7.24
C6 plus	0.52
I-Butane	0.60
N-Butane	2.09
I - Pentane	0.31
N - Pentane	0.28
BTU Content	1284

Table 10. Gas Analysis from one well in Barlow Township, Washington County.

Surface Interpretation

Berea Sandstone outcrops are located throughout central and southern Ohio and Kentucky (Figure 34). A nearly complete section of the Sunbury shale, Berea Sandstone, Bedford shale and the Ohio shale are well exposed on Tener Mountain (Figure 35). Tener Mountain is located on the north side of Ohio State route 32, the Appalachian highway, between Ohio route 73 and route 772 in Pike County. This was a

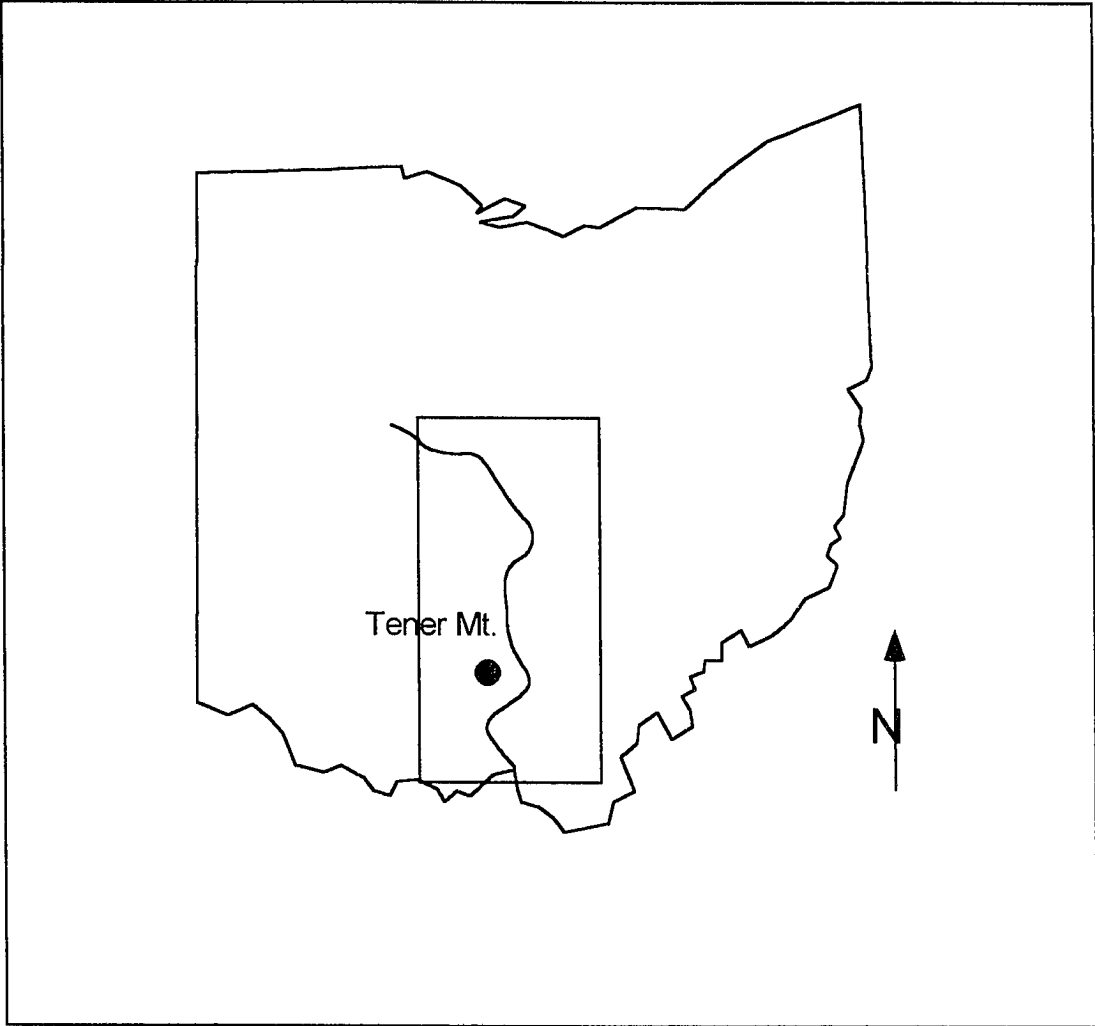


Figure 34. Location of the studied Outcrop. Tener Mountain

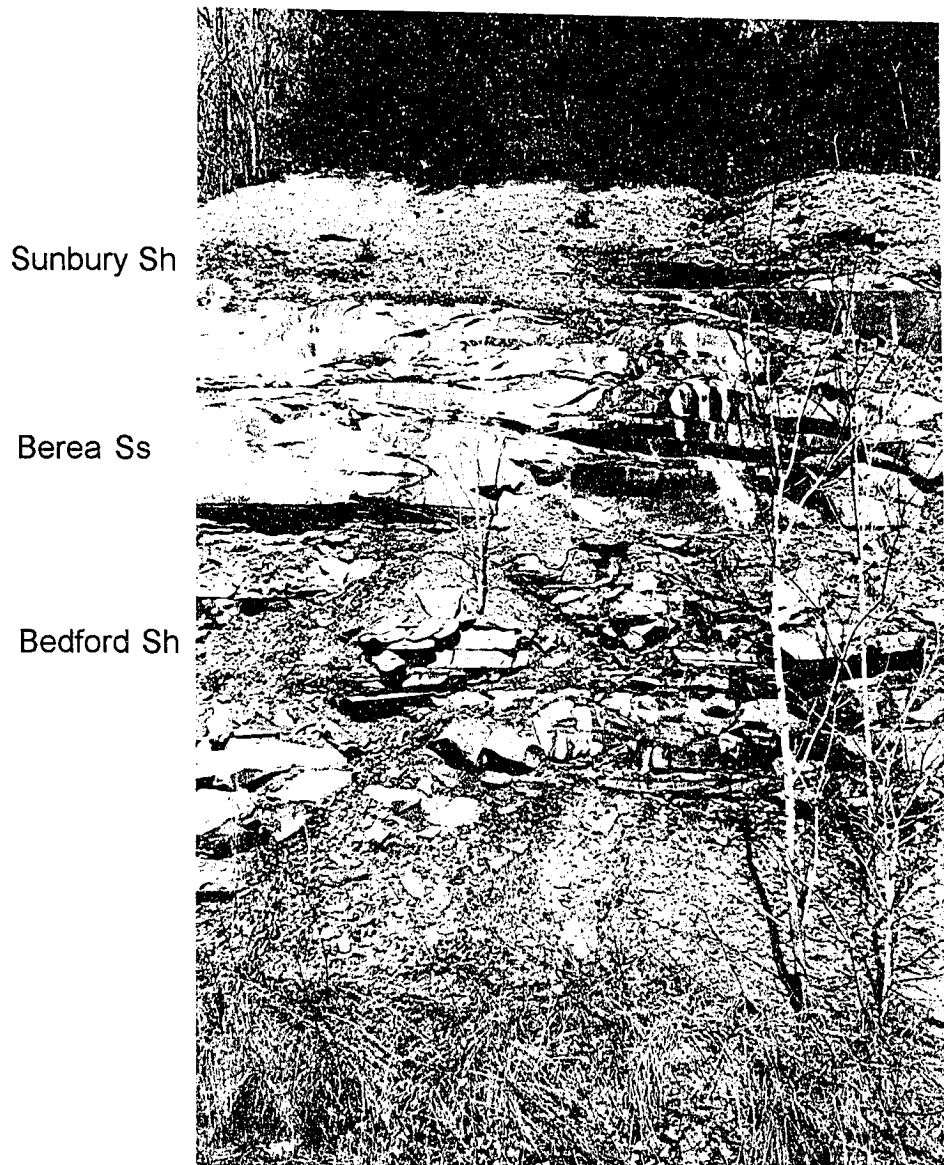


Figure 35. Overview of the outcrop of the Sunbury Shale, Berea Sandstone and Bedford Shale. Tener Mountain.

good opportunity to correlate the gamma ray signatures with the outcrop. It also provided a good view of the marine facies of the Berea Sandstone. The contact between the Sunbury Shale and the Berea Sandstone was a sharp contact. In addition, the interbedded nature of the gradational contact between the Berea Sandstone and the Bedford Shale was also observed.

The Sunbury Shale is a black highly carbonaceous shale. Weathering has changed the surface color to blackish red or moderate reddish orange. The rock is very fissile. This fissility appears to be related to the high organic carbon content of the shale.

This outcrop displays a system of massive beds of fine grained sandstone, Berea Sandstone, that grade to intercalated siltstone and shale partings. Sand beds are generally laminated. Ripples marks, weak hummocky cross bedding, and trace fossils were some of the sedimentary characteristics seen in this outcrop. Grain size and bedding thickness was noticed to slightly coarsen upwards.

Trace fossils are scarce in the Berea sandstone. The Berea Sandstone presents broad, shallow scour channels and some hummocky cross - stratified bed interbedded with massive sands and ripples marks. The Bedford Shale is characterized by a heterogeneous lithology of interbedded thin, rippled, bioturbated siltstones and gray shales. Trace fossils were abundant in the Bedford Shale. The description of this outcrop is summarized on Table 7.

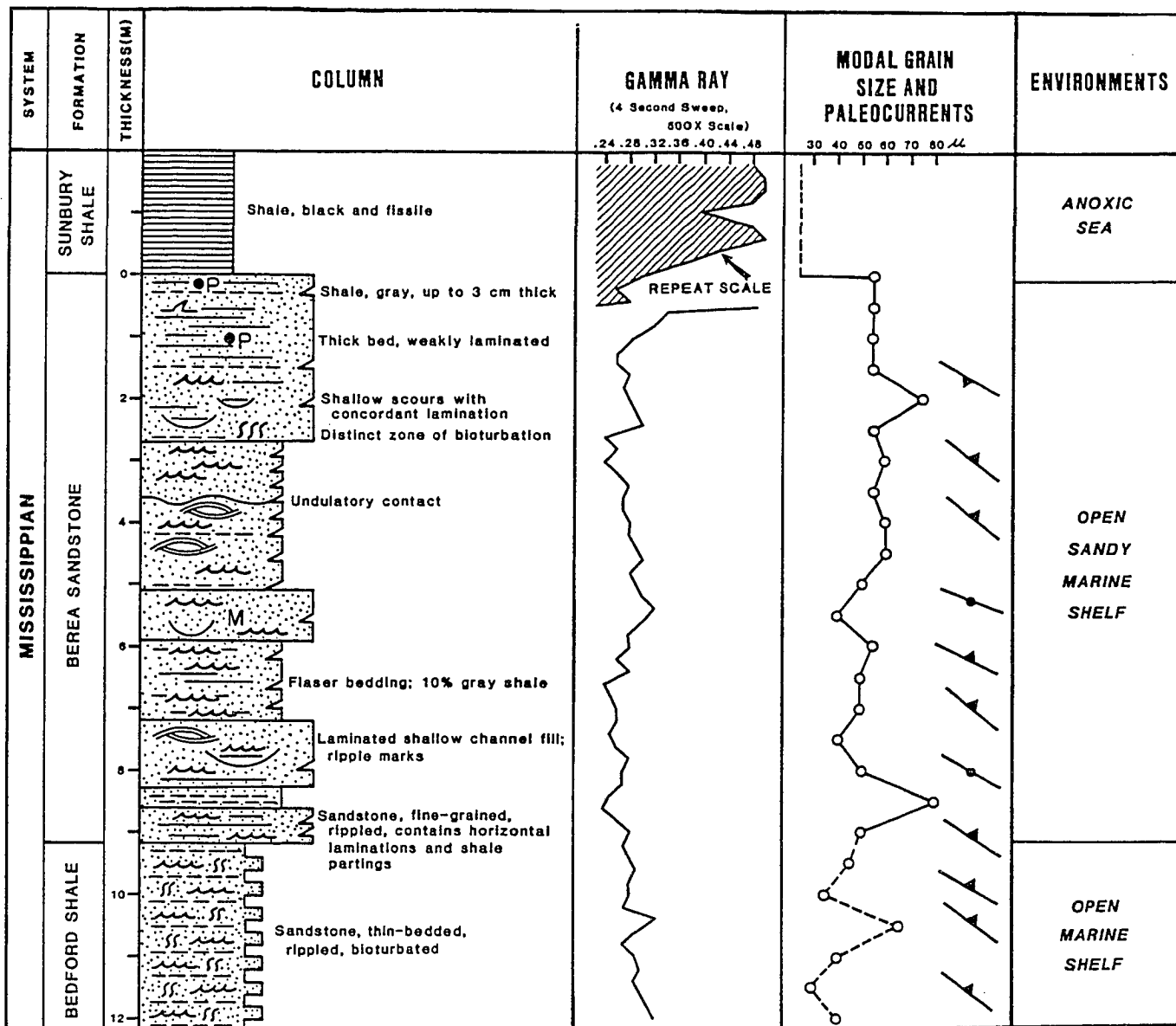
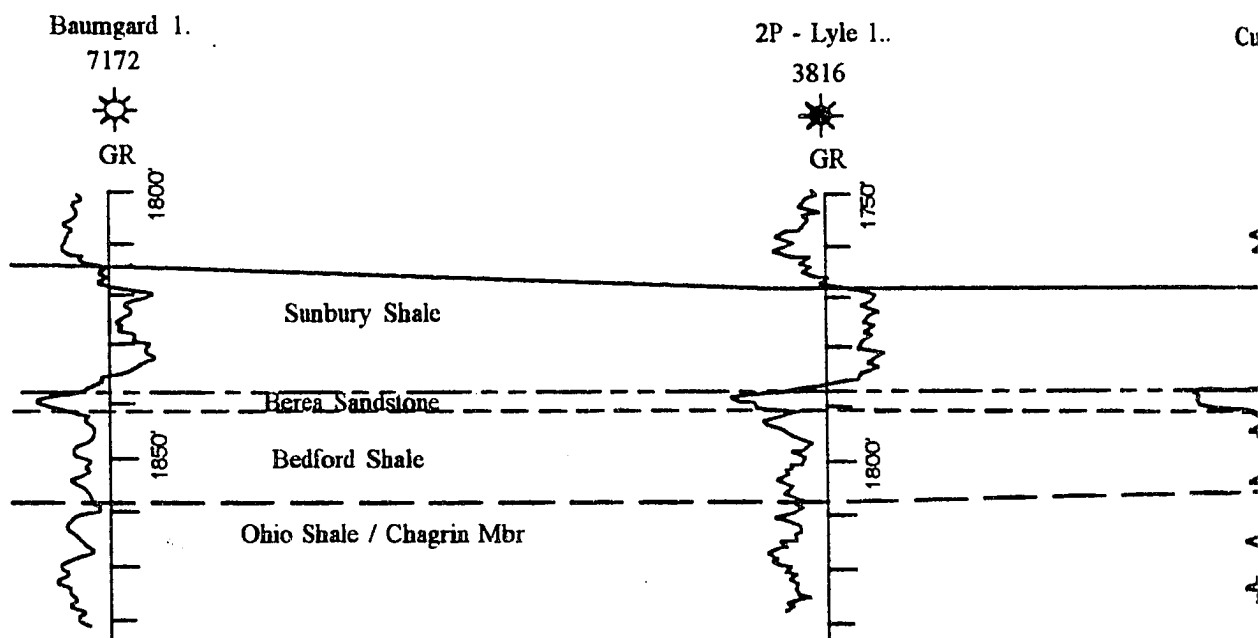


Table 7. Description of the outcrop. Tener Mountain. Potter and Others (1983).

SOUTHWEST

A



LEGEND

- | | | | |
|-------|--------------------|-------|------------------|
| —— | Formation Boundary | —— -- | Unconformity |
| - - - | Facies Boundary | —— — | Fair Correlation |

DIP LOG CROSS SECTION A - A'

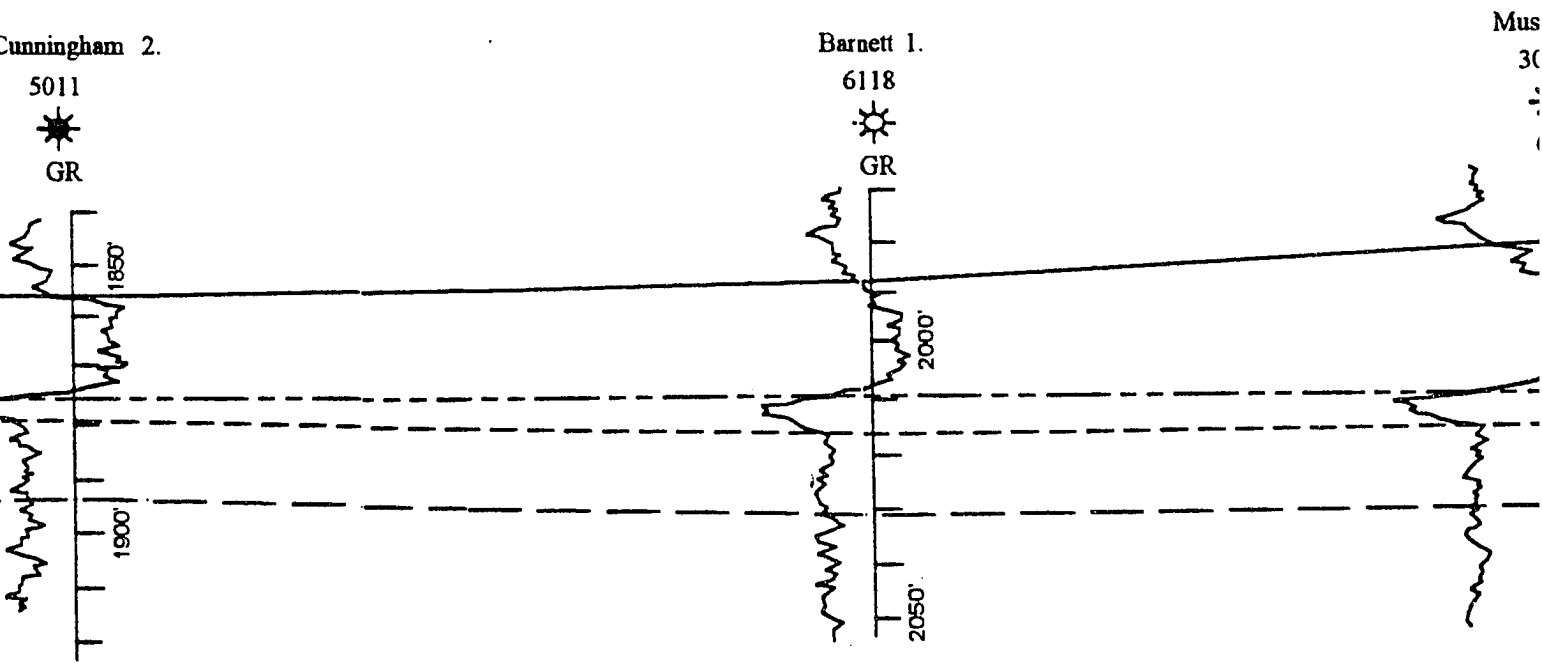
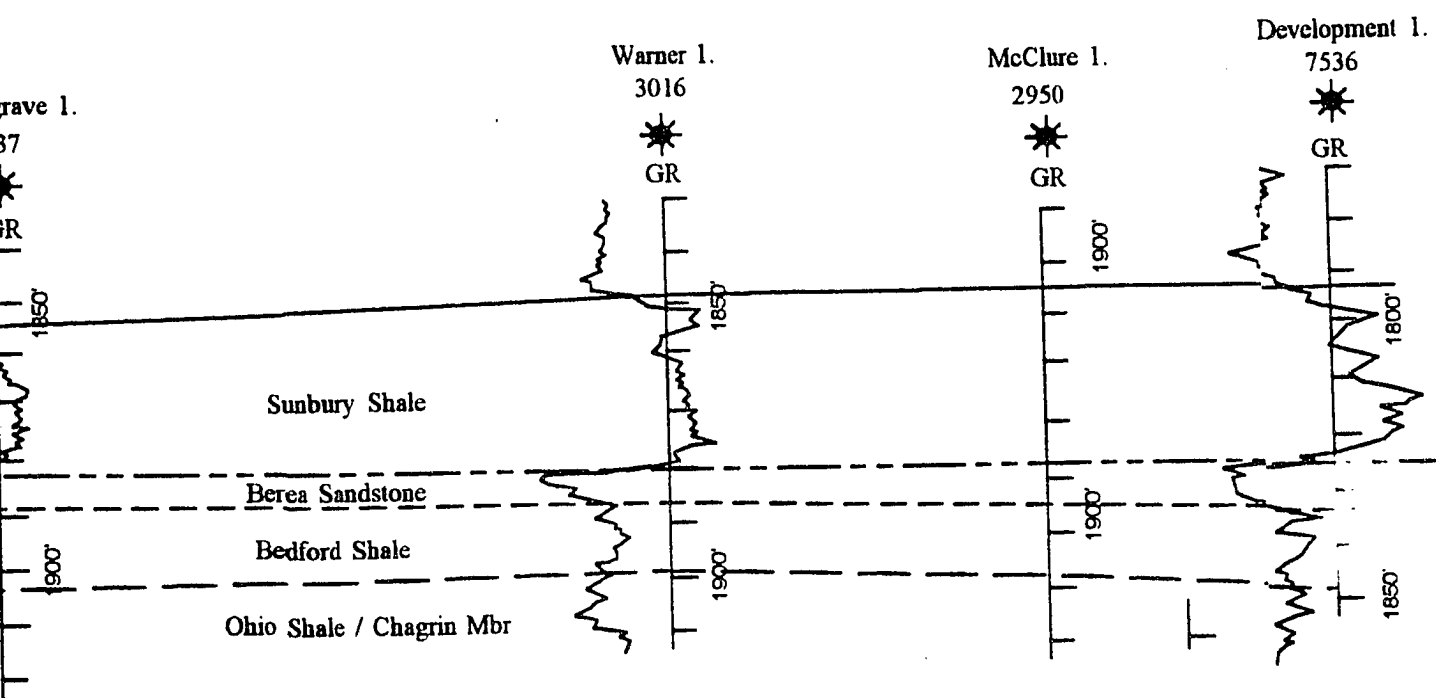


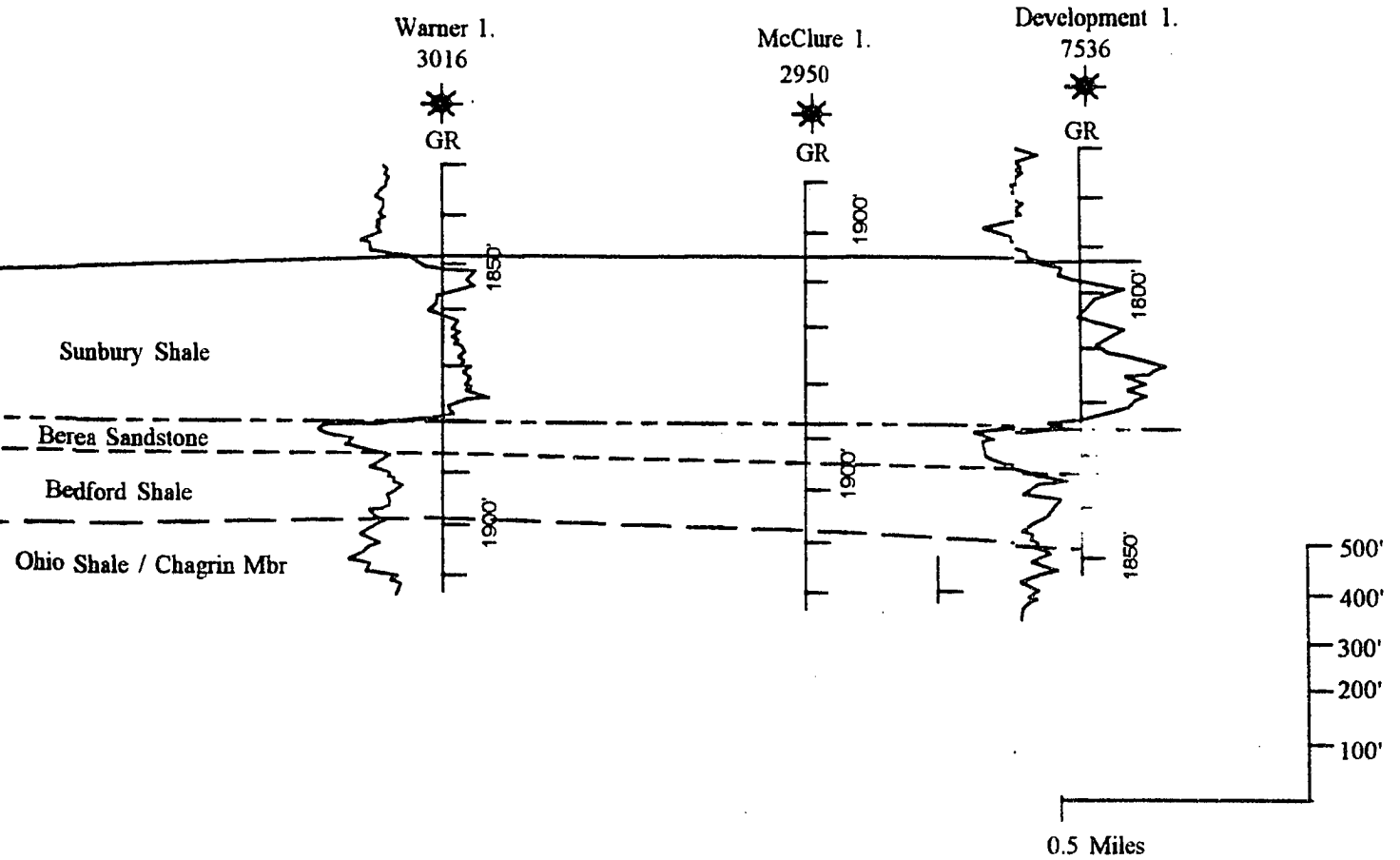
Figure 36.

SOUTHEAS
A'



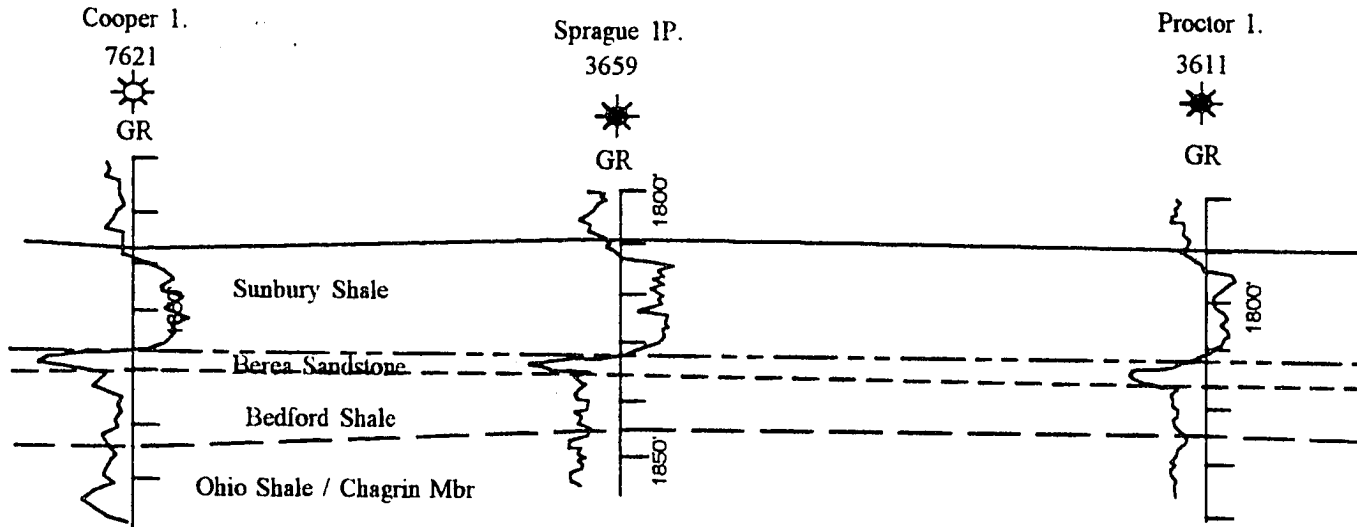
0.5 Miles

SOUTHEAST
A'



NORTHWEST

B



LEGEND

- Formation Boundary
- - - Unconformity
- - - Facies Boundary
- — Fair Correlation

DIP LOG CROSS SECTION B - B'

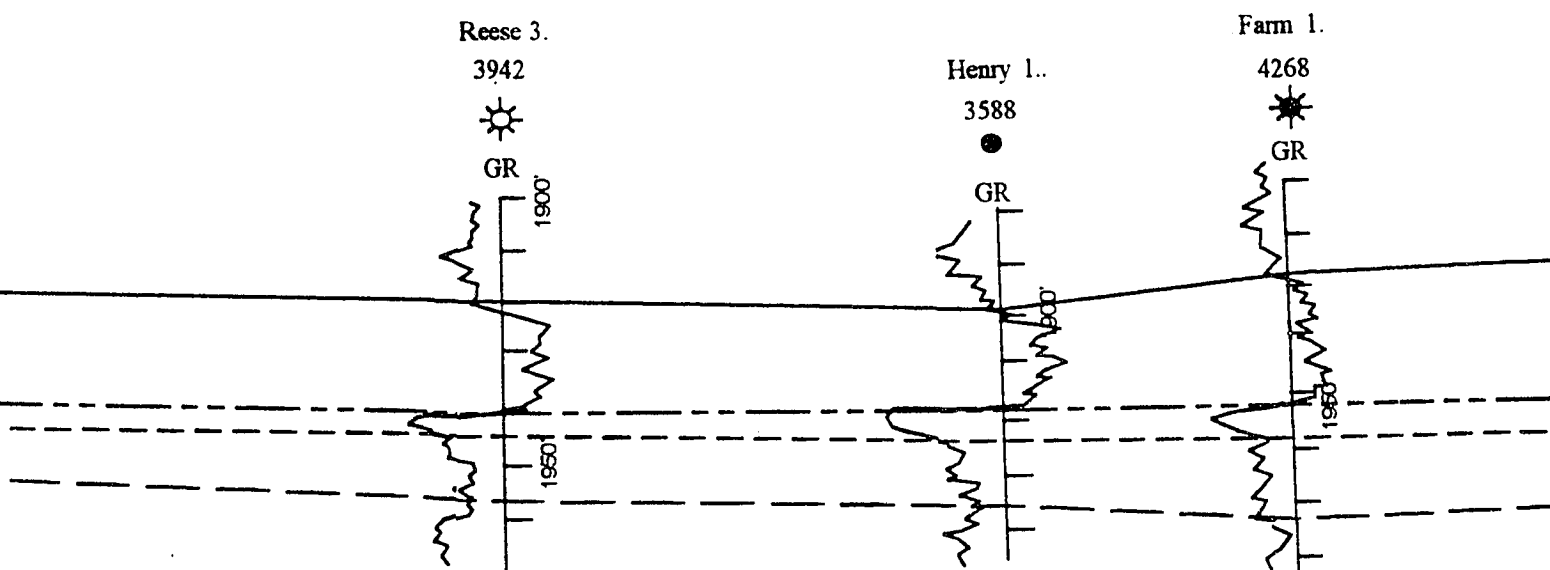
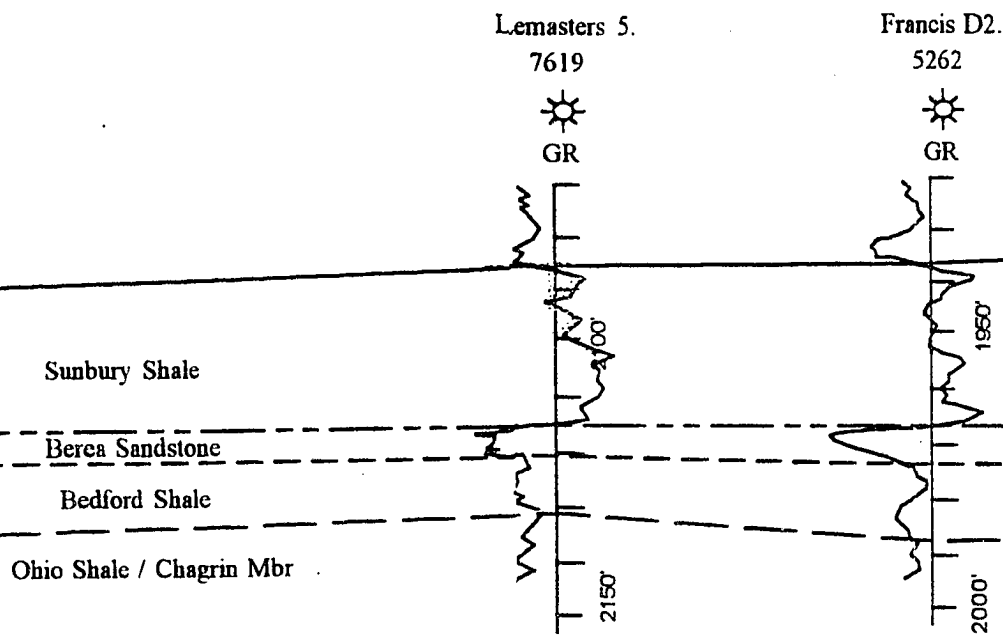


Figure37.

B - B'



SOUTHEAST
B'

Lemasters 5.
7619

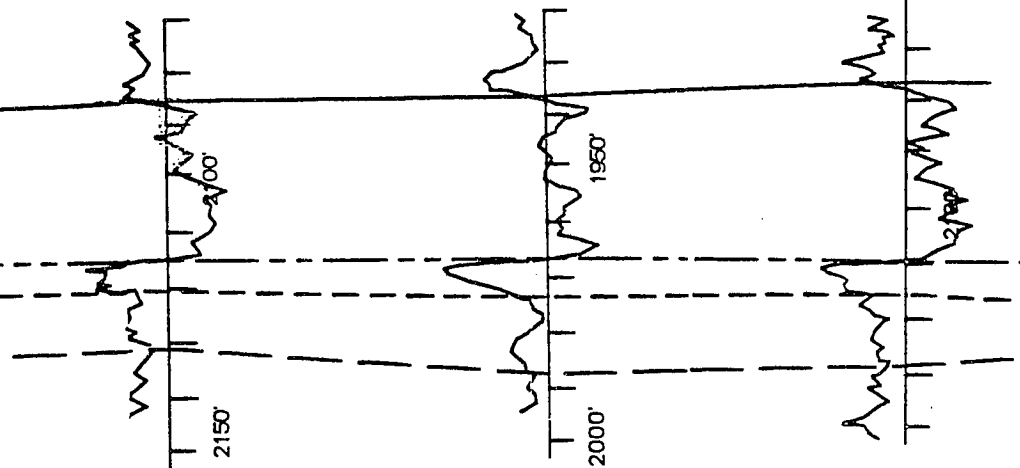
GR

Francis D2.
5262

GR

Gustke 3.
3559

GR



0.5 Miles

NORTHWEST

©

Buchanan 1.

2574



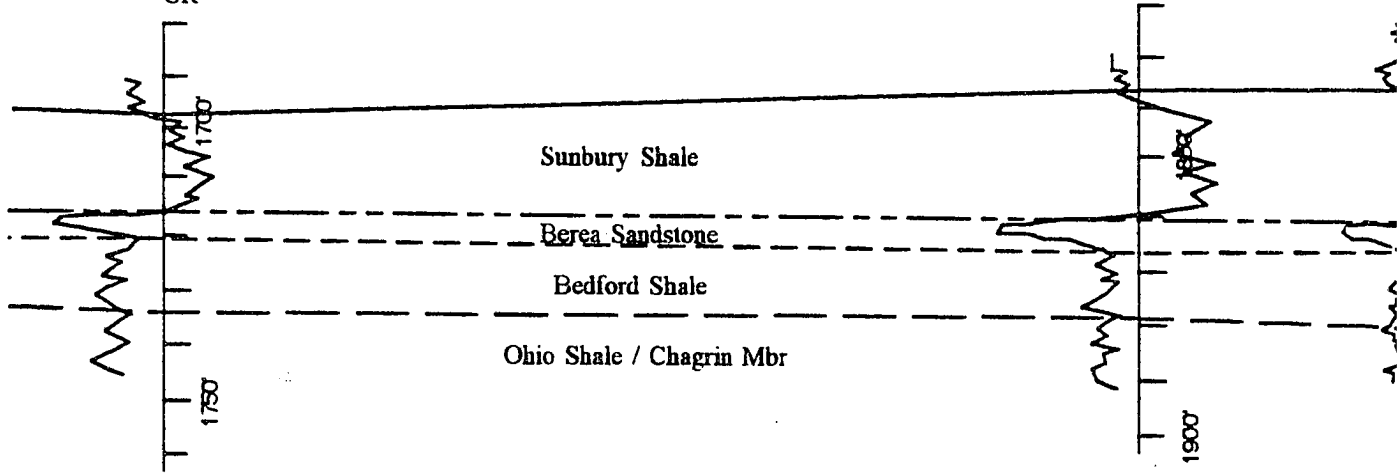
GR

Foreman 1.

3527

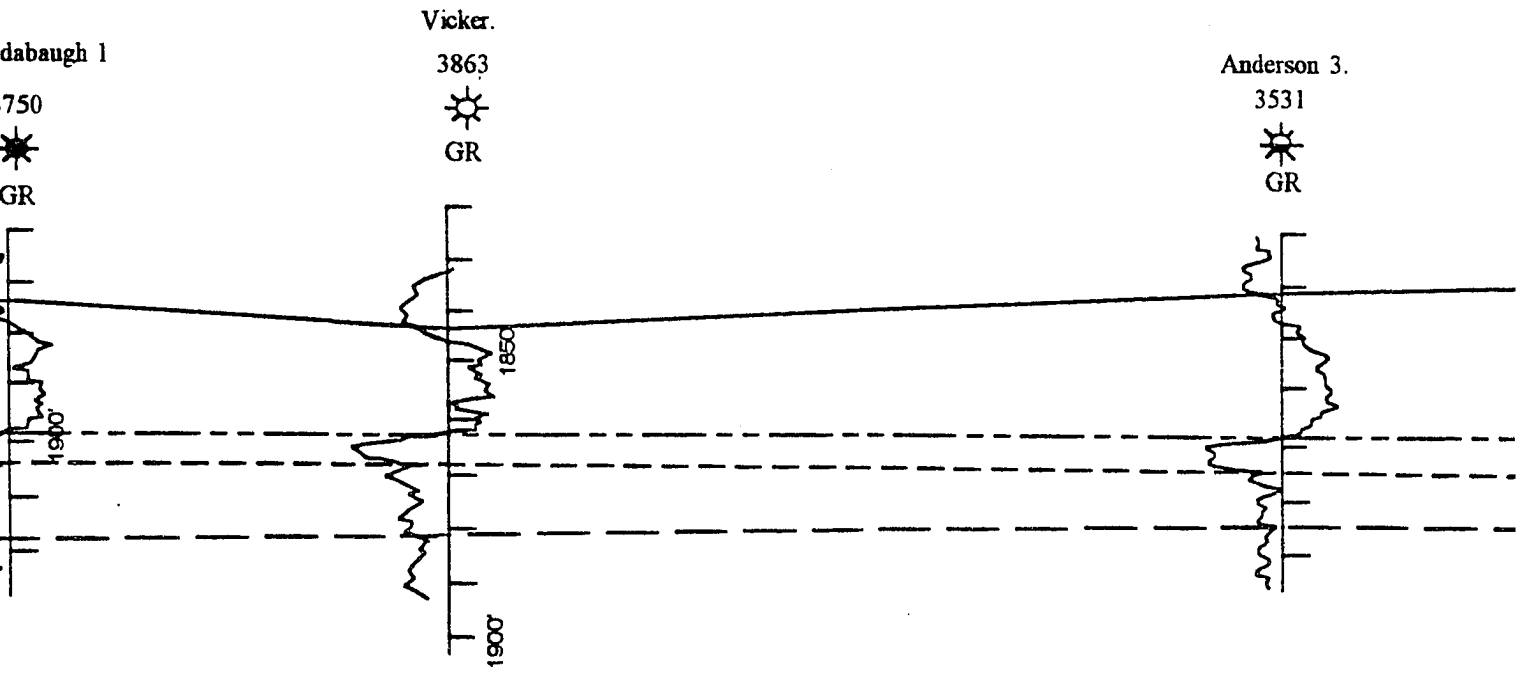


GR



LEGEND

- Formation Boundary
- Unconformity
- - - Facies Boundary
- - - Fair Correlation



n

DIP LOG CROSS SECTION C - C'

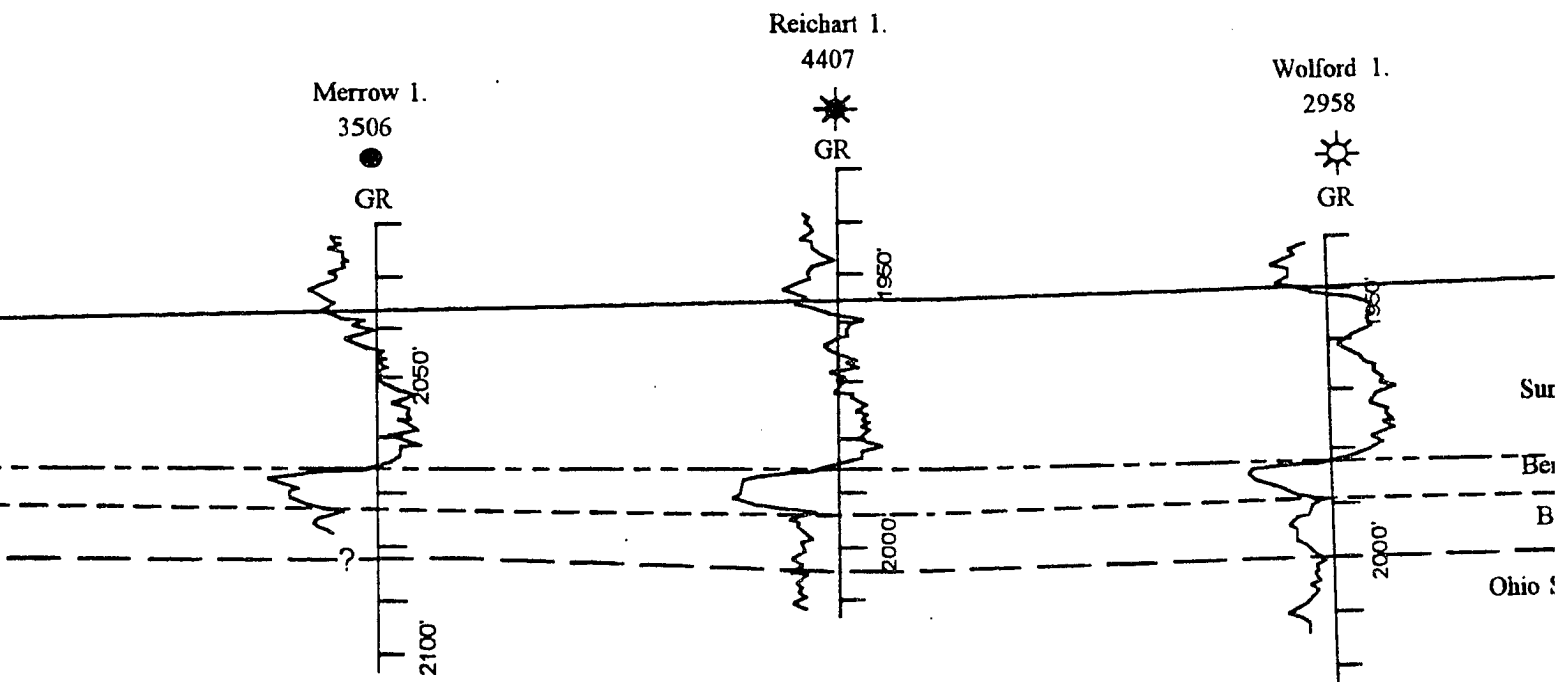


Figure 38.

SOUTHEAST
C'

Hanna 5.

3633



GR

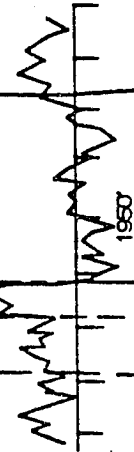


Lemaster 1.

4927



GR



bury Shale

ea Sandstone

dford Shale

hale / Chagrin Mbr

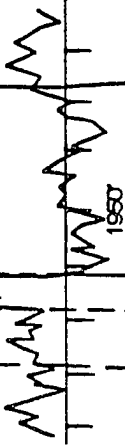
SOUTHEAST

C'

Lemaster 1.
4927



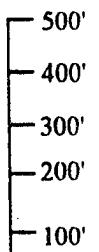
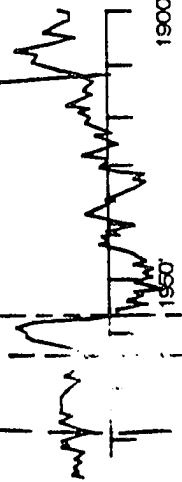
GR



Grovers 2.
3847



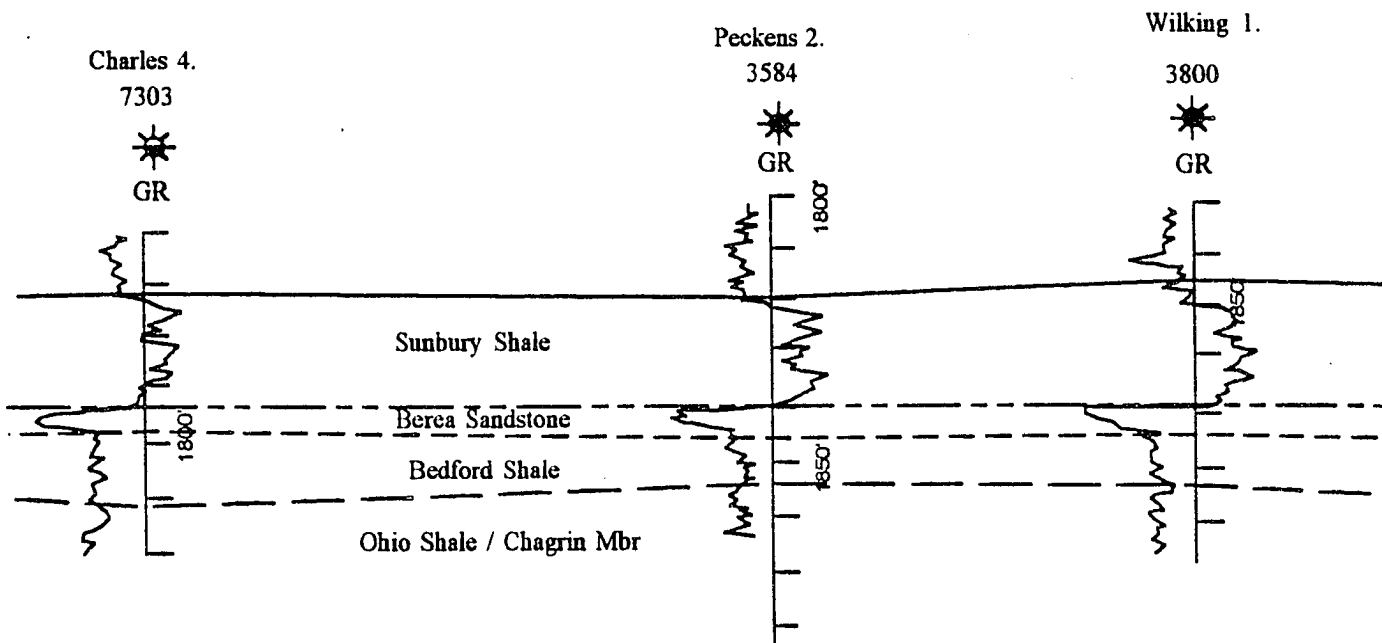
GR



0.5 Miles

NORTHWEST

D



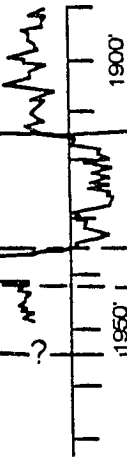
LEGEND

- Formation Boundary
- Unconformity
- - Facies Boundary
- - Fair Correlation

DIP LOG CROSS SECTION D - D'

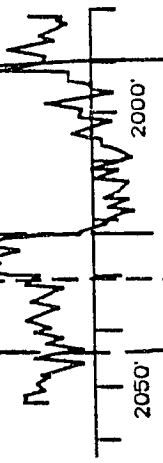
Earl 7.
3707

GR



Greenless 1-29.
4761

GR



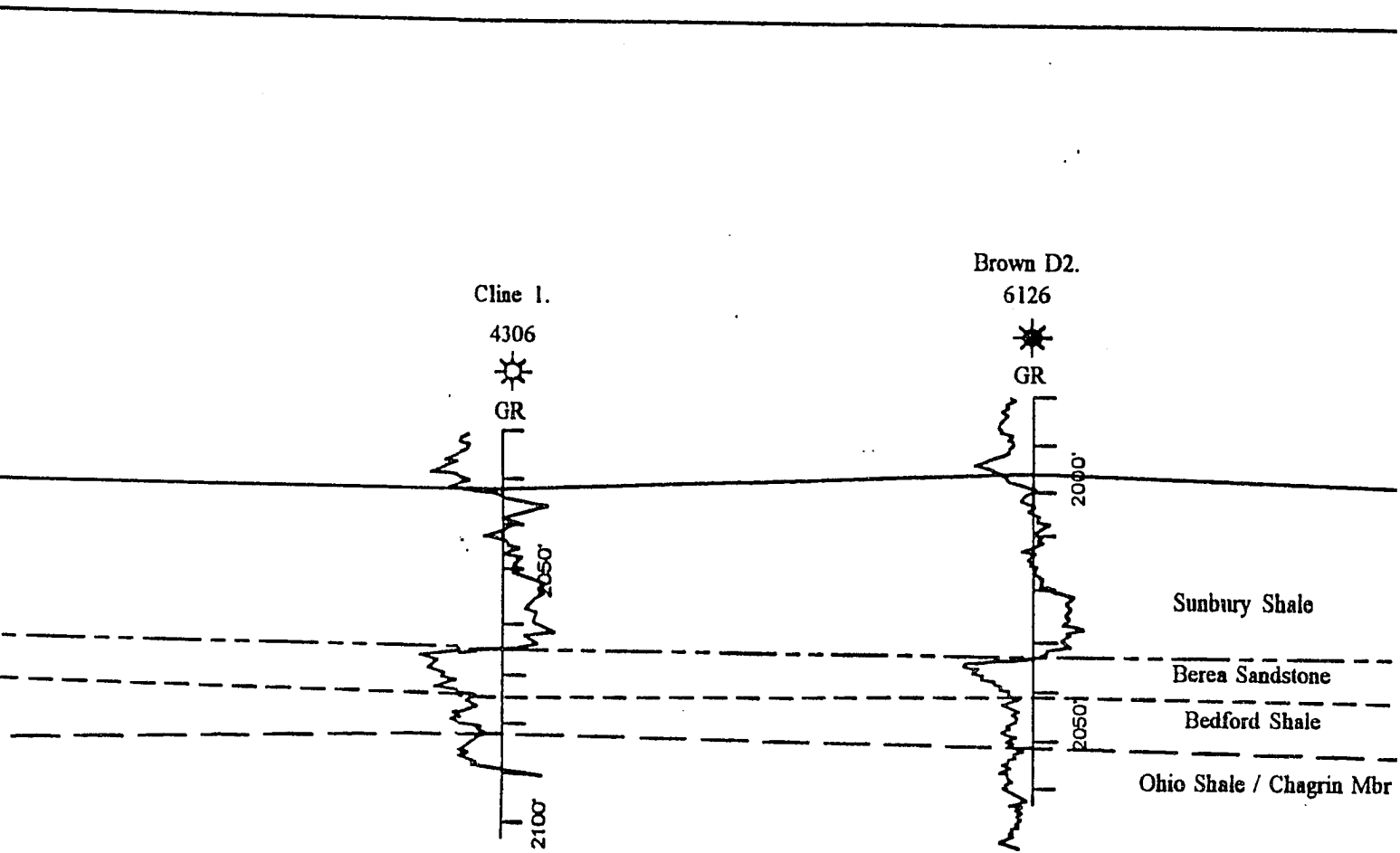


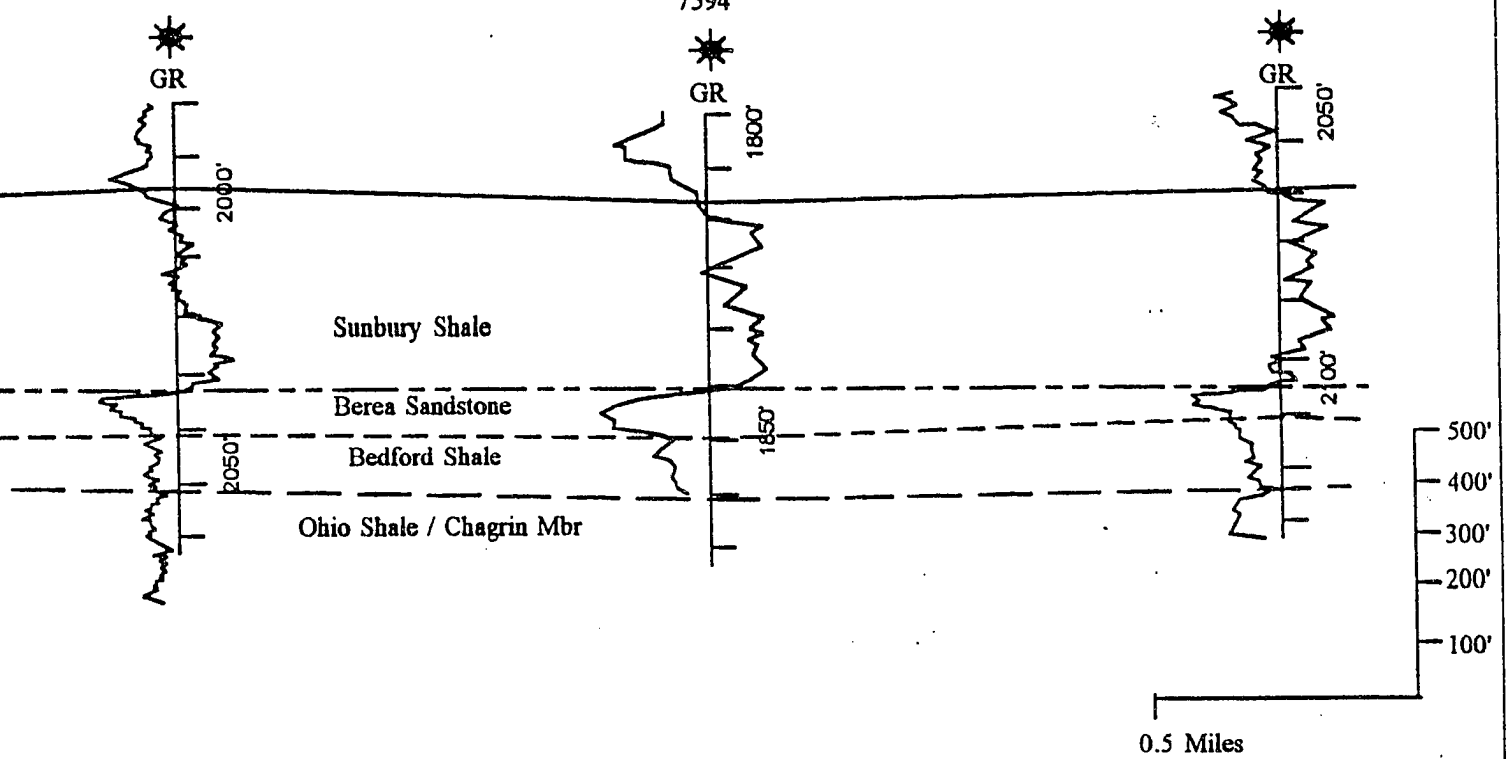
Figure 39.

SOUTHEAST
D'

Brown D2.
6126

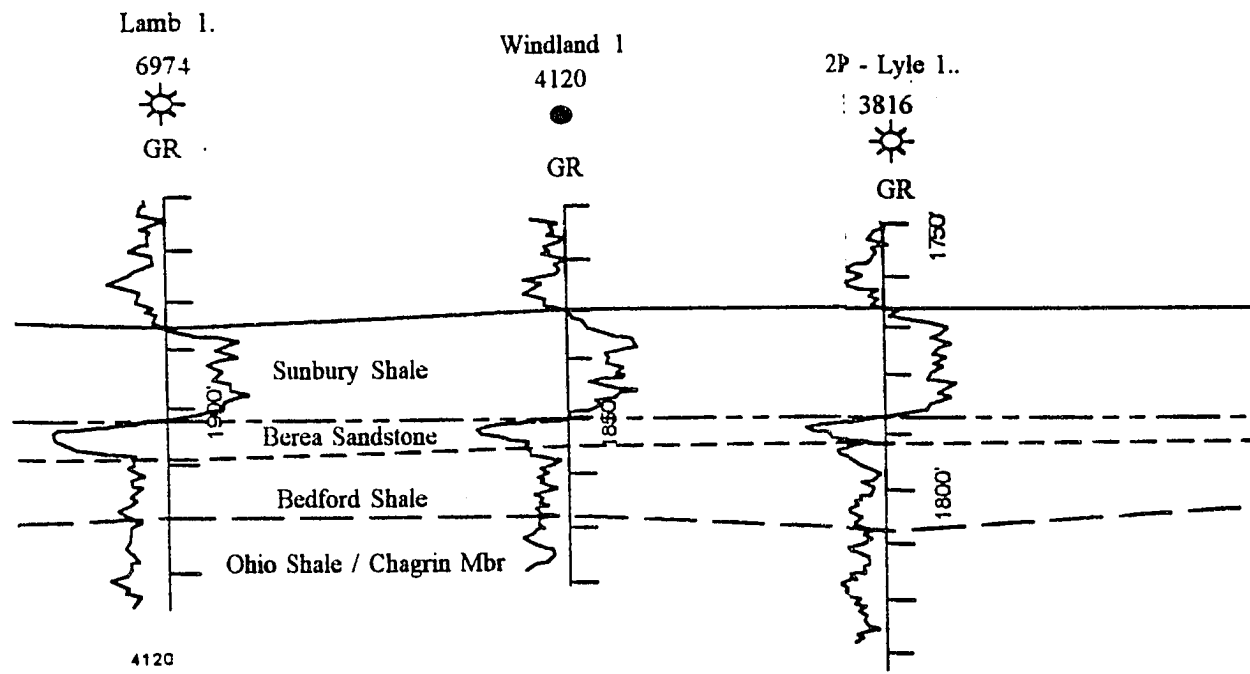
Baumgard 1.
7594

Anderson.
7713



SOUTHWEST

E



LEGEND

- Formation Boundary
- Unconformity
- - - Facies Boundary
- - - Fair Correlation

STRIKE LOG CROSS SECTION E - E'

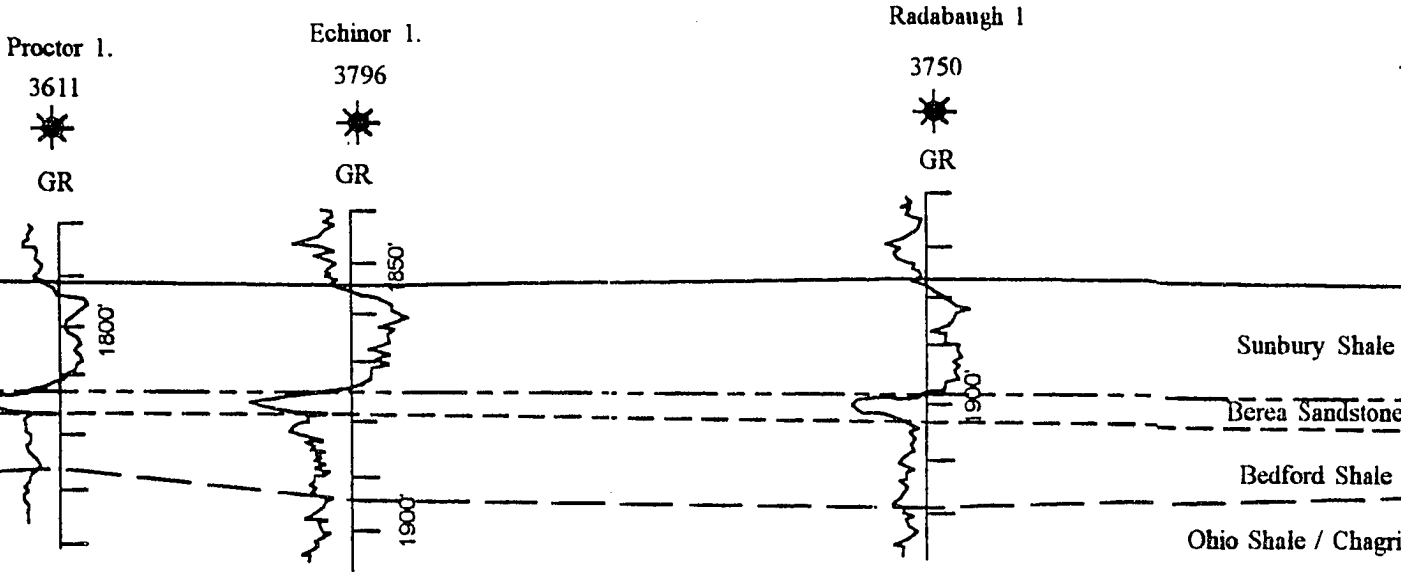


Figure 40.

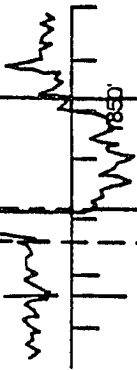
NORTHEAST
E'

Wilking 1.

3800



GR

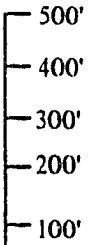
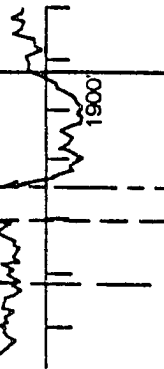


Morgan 1.

3722



GR

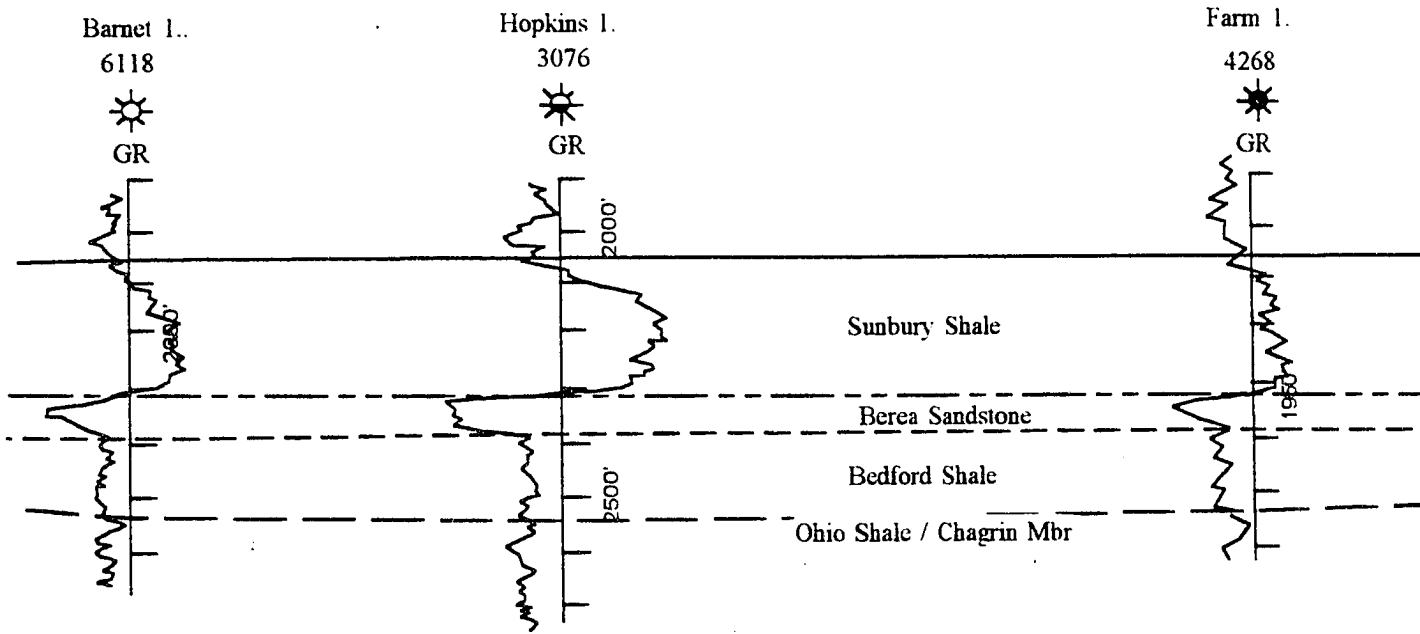


0.5 Miles

n Mbr

SOUTHWEST

F



LEGEND

- | | | | |
|-------|--------------------|---------|------------------|
| —— | Formation Boundary | —— — — | Unconformity |
| - - - | Facies Boundary | - - - - | Fair Correlation |

STRIKE LOG CROSS SECTION F - F'

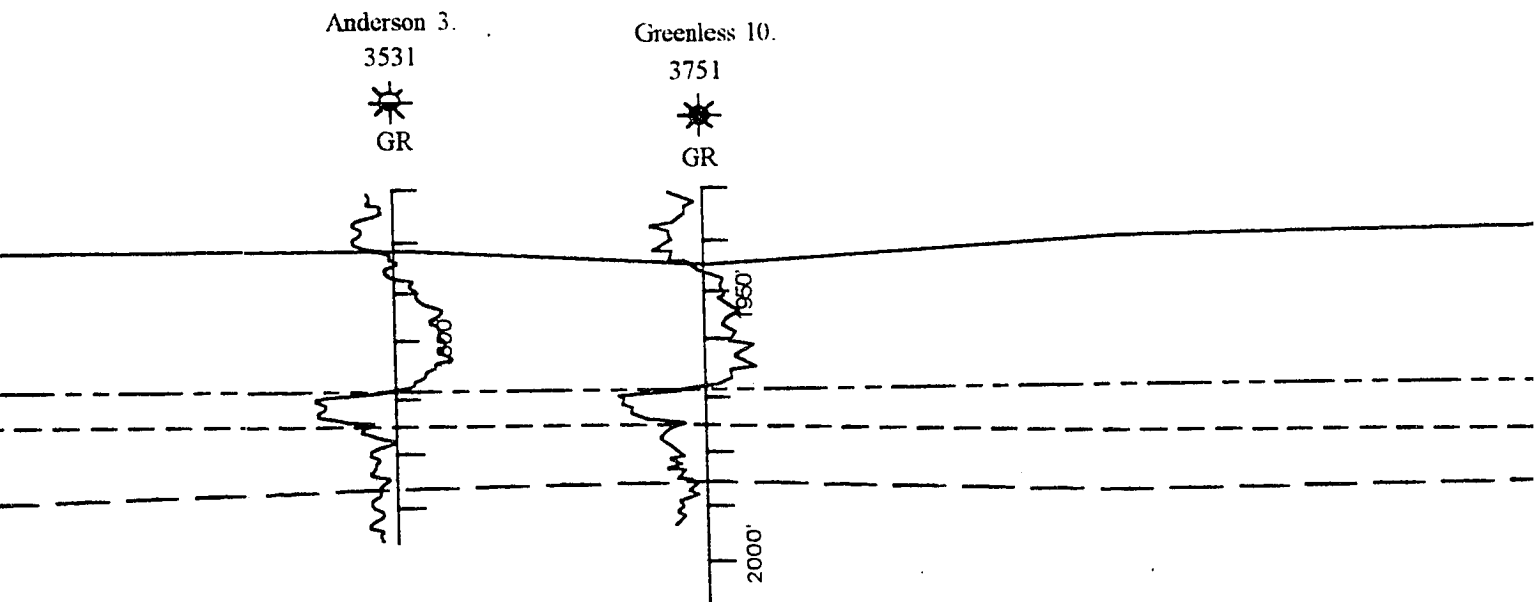
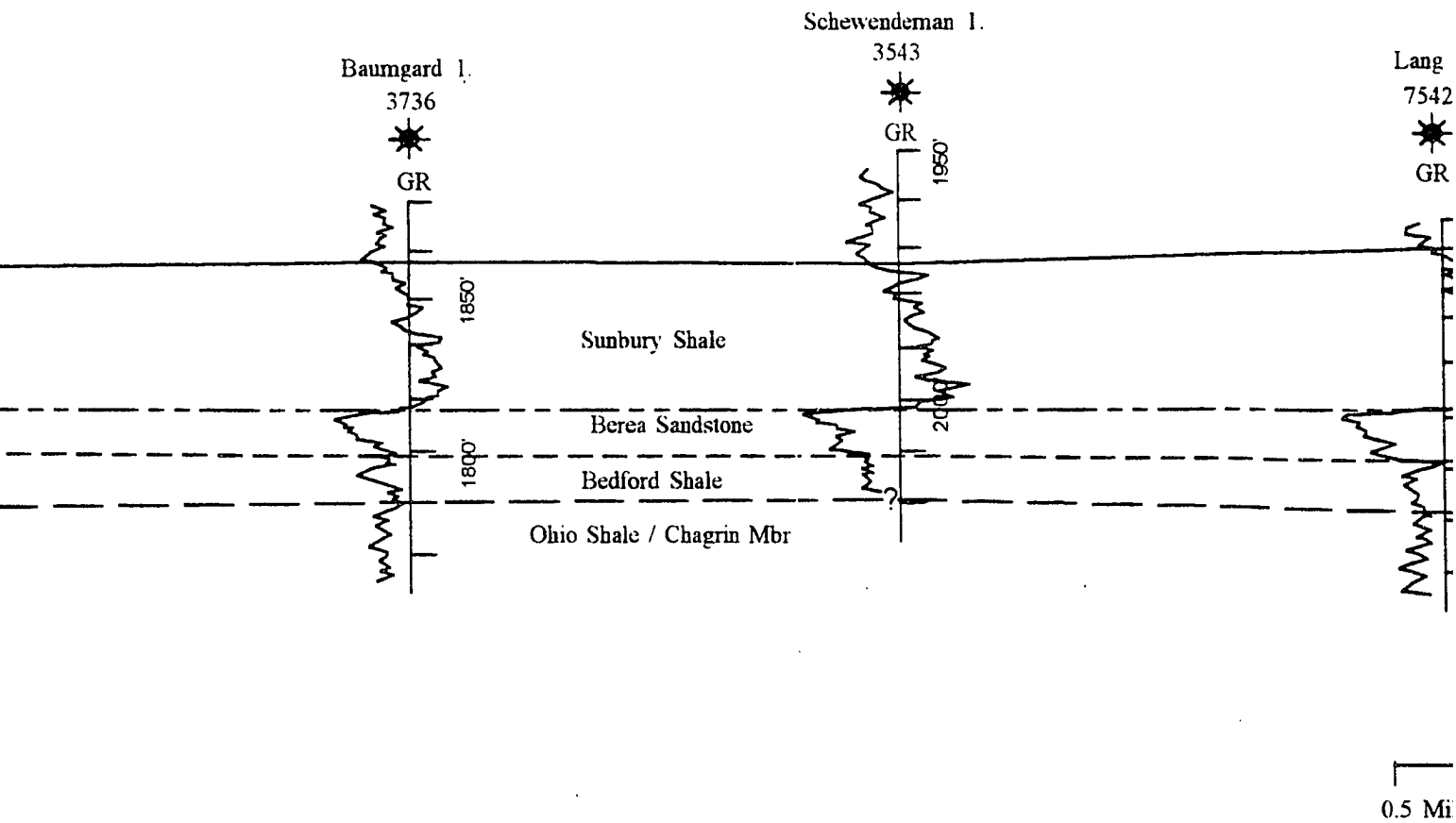


Figure 41.

N F - F'

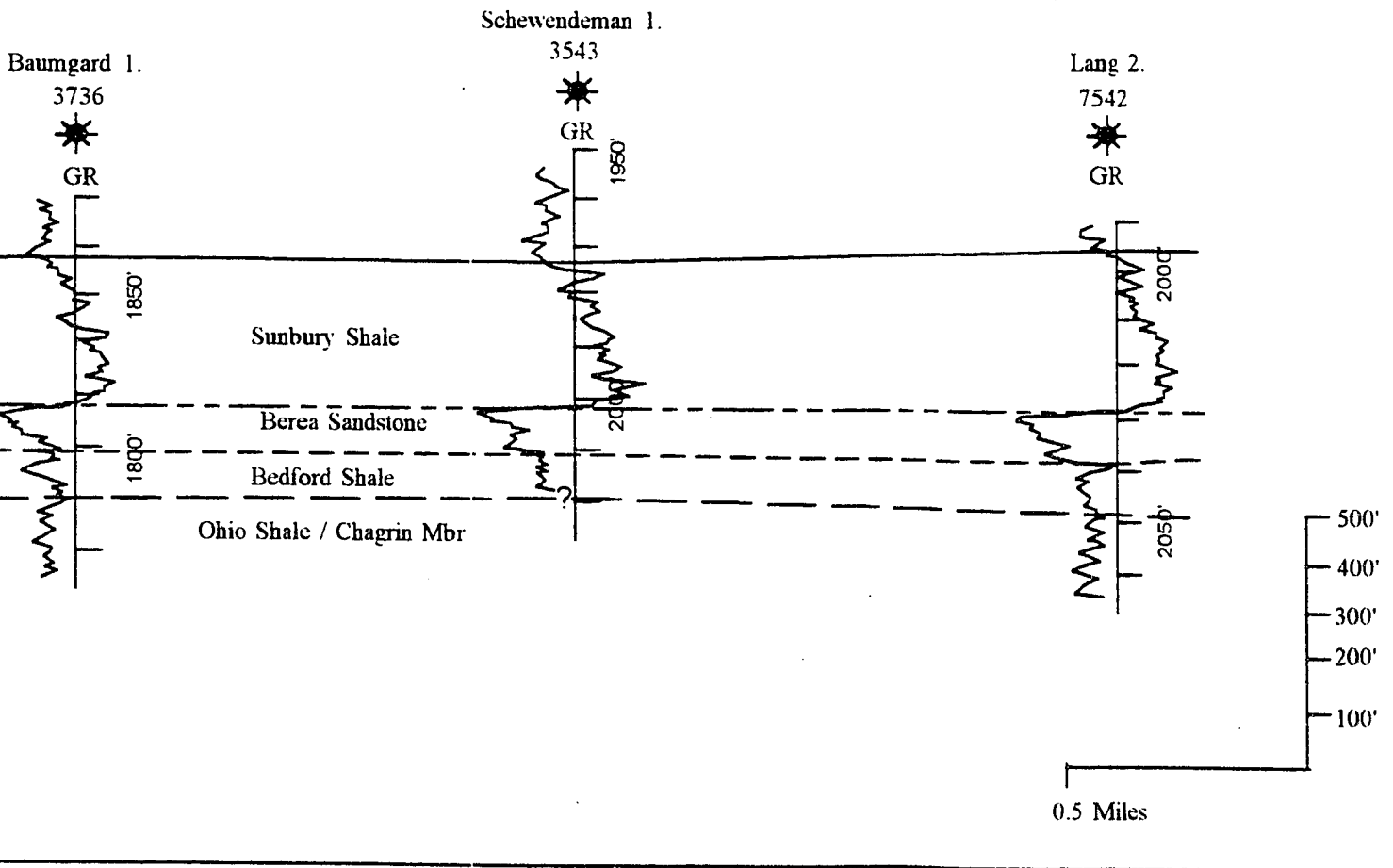
830



0.5 Mi

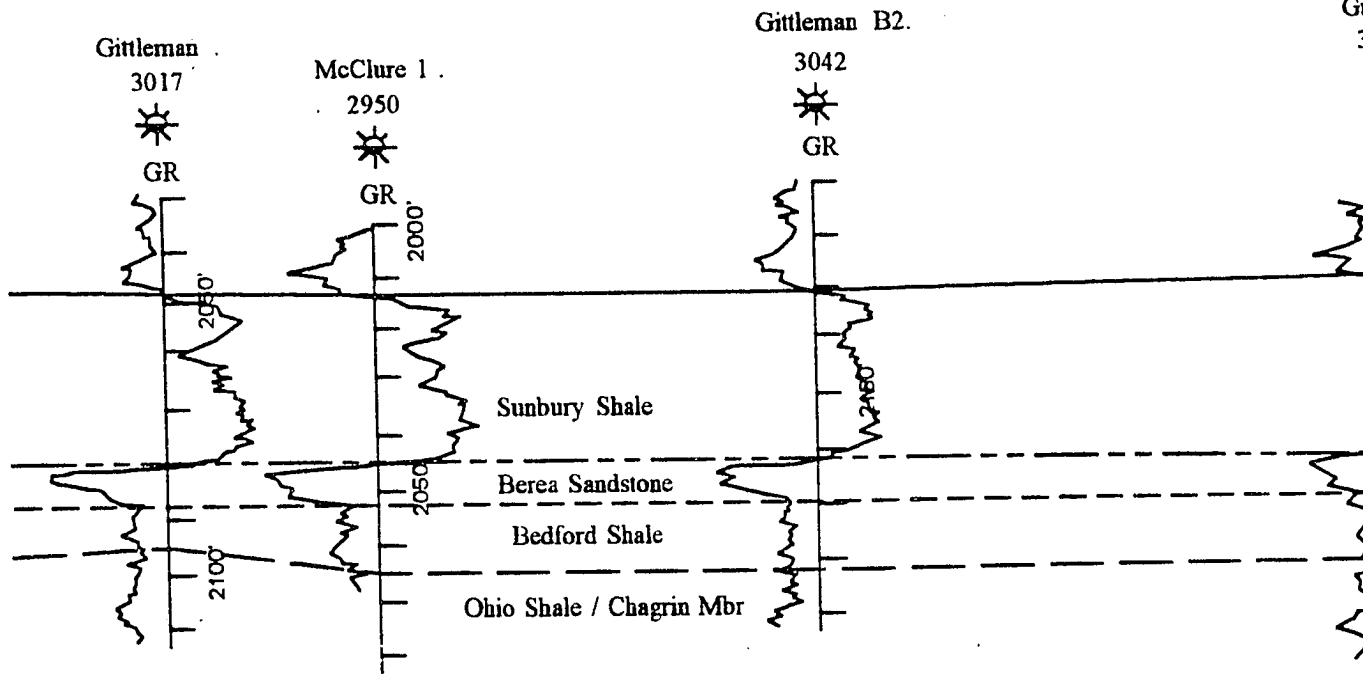
NORTHEAST

Fig. 1



SOUTHWEST

©



STRIKE LOG CROSS SECTION G - G'

stake 3.
559
GR

Hanna 5.
3633
GR

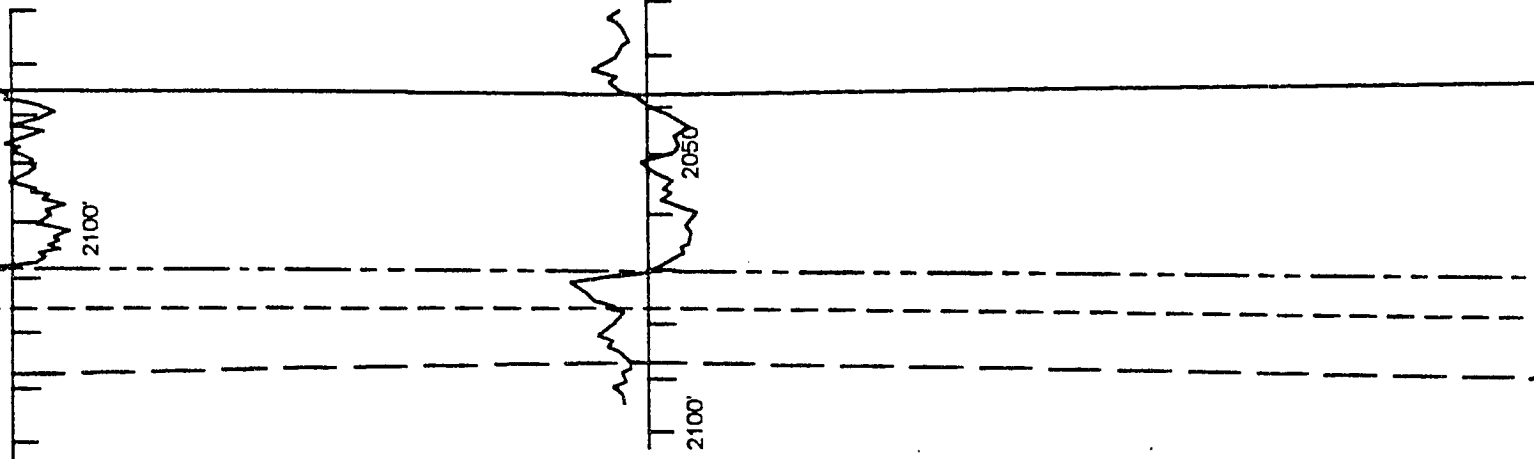


Figure 42.

Brown D2.
6126

GR



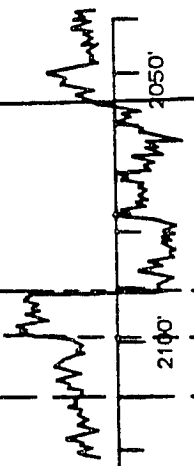
Hazel 1.
3444

GR



Fleming 1.
3778

GR



Sunbury Shale

Berea Sandstone

Bedford Shale

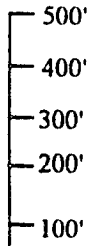
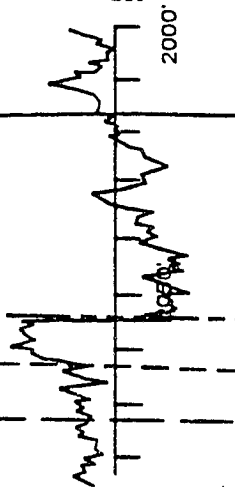
Ohio Shale / Chagrin Mbr

NORTHEAST
G'

Hazel 1.
3444
GR

Fleming 1.
3778
GR

Arnold 2.
4041
GR



0.5 Miles

CONCLUSIONS

The Berea Sandstone is an important source of gas and oil production in Washington County, southeastern Ohio. Evidence from subsurface mapping of the Berea Sandstone suggests the following:

1. The Berea Sandstone grades downward into the Bedford Shale. They are closely related and were treated as a facies sequence for purposes of this study. The Berea and Bedford facies sequence form a uniform cycle of deposition that can be interpreted on the gamma ray logs by the coarsening upwards grain size (decreasing radioactivity).
2. Correlation of log type gamma ray signatures and the Berea Isopach map suggests that the Berea Sandstone was deposited in a shallow marine environment in the early Mississippian time. The Berea Sandstone was deposited as a part of a complex deltaic system. Distributary mouth bars are identified from both the log types signatures and the isopach map. Although the presence, arrangement and the direction of the distributaries ensure a deltaic depositional environment, not enough evidence was present to conclusively determine the type of deltaic environment.
3. The Berea Sandstone and Bedford Shale represent a progradational regressive sequence in the form of a delta distributary system.
4. The Berea delta distributary configuration suggests a clastic source from the north east of the study area during early Mississippian time.

5. Production of hydrocarbons, as measure by initial production (IP), correlate mainly with log type signatures. Types II and III log signatures, the “inverted Christmas tree” log pattern seem to be the best for accumulating and producing hydrocarbons.
6. The structural map illustrated a slight relation with the initial production in the study area. It is suggested that the Berea sandstone has a minor structural component in the accumulation of oil and gas. Since the Berea Sandstone is lying between two shales that provide both source rocks and reservoir seals, it is also suggested that stratigraphic traps are the main mechanism for trapping the hydrocarbons.
7. The declination curves for a 10 year production period were considered to decline too slow for a normal reservoir. Therefore, it appears highly likely that the Berea Sandstone is being recharged through fractures in either the overlying Sunbury Shale and or the underlying Ohio Black shale.
8. The outcrops display a marine sandstone environment with sedimentary structures such as symmetrical ripples, planar and cross lamination, bioturbation and trace fossils, massive sandstone beds, and hummocky cross-stratification.

BIBLIOGRAPHY.

- Asquith, George, 1982: Basic Well Log Analysis for Geologist. The American Association of Petroleum Geologists. Tulsa, Oklahoma.
- Boggs, Sam Jr., 1987: Principles of Sedimentology and Stratigraphy. Macmillan Publishing Company, New York.
- Bush, Daniel A., 1974: Stratigraphic Traps in Sandstones - Exploration Techniques. The American Association of Petroleum Geologist. Tulsa Oklahoma. Memoir 21.
- Collins, Horace R., and Smith, Bradley E., 1977: Geology and Mineral Resources of Washington County, Ohio. Division of Geological Survey, Bulletin 66. Columbus.
- DeReamer, John, 1984. An environmental interpretation of the Berea Sandstone formation (lower Mississippian) in the south -central Ohio, northeastern Kentucky and adjacent West Virginia. Thesis (M.S.) University of Cincinnati.
- DeWitt, Wallace Jr., 1970: Age of the Bedford Shale, Berea Sandstone, and Sunbury Shale in the Appalachian and Michigan Basins, Pennsylvania, Ohio, and Michigan. Geological Survey Bulletin 1294 - G.
- Eames, Leonard E., 1974. Palynology of the Berea sandstone and the Cuyahoga group of northeastern Ohio. Thesis (Ph. D.) Michigan State University.
- Ettensohn, Frank R. and Barron, Lance S., 1981: Depositional Model for the Devonian - Mississippian Black Shale sequence of North America: A tectonic - Climatic Approach. Department of Geology, University of Kentucky. Lexington, Kentucky.
- Ettensohn, Frank R., 1992: Changing interpretations of Kentucky Geology - Layer Cake, Facies, Flexure, and Eustacy. Report No. 5. Division of Geological Survey. Columbus, Ohio.
- Galloway, William E., 1975: Process Framework for Describing the Morphologic and Stratigraphic Evolution of Deltaic Depositional Systems. Houston Geological Society.
- Hyde, Jesse E., 1953: Mississippian Formations of Central and Southern Ohio. Ohio Division of Geological Survey., Bulletin 51. Columbus, Ohio.

- Jackson, Dana S., 1985: The Petrology, Porosity, and Permeability of the Berea Sandstone (Mississippian) Perry Township, Ashland County, Ohio. Thesis (M.S). University of Cincinnati. Cincinnati, Ohio.
- Janssens, A., and DeWitt, Wallace Jr., 1976: Potential Natural Gas resources in the Devonian Shales in Ohio. Division of Geological Survey. Geological Note No.3. Columbus.
- Klein, G de V., 1985b: Sandstone depositional models for exploration for fossil fuels, third edition: Boston, IHRDC Press, 209 pp.
- Klein, G. de V., 1993: Sedimentary and Diagenetic Mineral deposits: A Basin Analysis Approach to exploration. Reviews in Economic Geology Vol. 5. Society of Economic Geologists.
- Larese, Richard E., 1974. Petrology and stratigraphy of the Berea sandstone in the Cabin Creek and Gay Fink trends, West Virginia. Thesis (Ph.D.) West Virginia University.
- Pepper, J., De Witt, W., and Demarest, D., 1954. Geology of the Bedford Shale and Berea Sandstone in the Appalachian Basin. Geological Survey Professional Paper 259. Washington.
- Pirson, Sylvain J., 1950: Elements of Oil Reservoir Engineering. McGraw-Hill Book Company, Inc. New York.
- Pirson, Sylvain J., 1983. Handbook of well log analysis; for oil and gas formation evaluation. Houston, Gulf Pub. Co.
- Pirson, Sylvain J.: Geologic Well Log Analysis. Gulf Publishing Company, Houston, Texas.
- Potter, Paul E., DeReamer, John H., Jackson, Dana S., and Maynard, J. Barry, 1983. Lithologic and environmental atlas of Berea sandstone (Mississippian) in the Appalachian Basin.
- Pryor, Wayne A., Maynard, Barry J., Potter, Paul E., Kepferle, Roy C., and Kiefer, John., 1981: Energy Resources of Devonian Mississippian Shales of Eastern Kentucky. Annual Field Conference of the Geological Society of Kentucky April 9-11. Kentucky Geological Survey.
- Roen, J., and Kepferle, R., 1993: Petroleum Geology of the Devonian and Mississippian Black Shale of Eastern North America. U.S. Geological Survey Bulletin 1909.

- Rotman, Edward M., 1978. The petrology of the Berea sandstone (early Mississippian) of south - central Ohio and a portion of northern Kentucky. Miami University.
- Russell, William L., 1960: Principles of Petroleum Geology. Mc Graw - Hill Book Company, Inc. New York Toronto London.
- Schlumberger., 1989: Log Interpretation Principles /Applications. Schumberger Educational Services.
- Tearpock, Daniel J., and Bischke, Richard E., 1991: Applied Subsurface Geological Mapping. Prentice Hall, Englewood Cliffs, New Jersey.
- VanBeuren, Victor., 1980. Stratigraphy of the Sunbury Shale (lower Mississippian) of the central Appalachian Basin. Thesis (M.S.) University of Cincinnati.
- Warrner, Charles J., 1978: Subsurface Stratigraphy of the Berea and Cussewago Sandstone in Eastern Ohio. Thesis (M.S.) Kentucky State University. Kentucky.

Appendix I. Cross Sections Data

Cross Section A - A'

Well Permit No.	Top Sunbury (feet)	Top Berea (feet)	Sunbury Thickness (feet)	Bottom Berea (feet)	Berea Thickness (feet)	Bottom Bedford (feet)	Bedford Thickness (feet)	Percentage of Sand %	Percentage of Shale %
7172	1813	1838	25	1842	4	1858	20	20.00	80.00
3816	1768	1787	19	1791	4	1808	21	19.05	80.95
5011	1856	1875	19	1880	5	1896	21	23.81	76.19
6118	1989	2011	22	2018	7	2033	22	31.82	68.18
3037	1856	1884	28	1890	6	1906	22	27.27	72.73
3016	1852	1884	32	1890	6	1904	20	30.00	70.00
2950	2015	2047	32	2055	8	2068	21	38.10	61.90
7536	1797	1827	30	1835	8	1848	21	38.10	61.90

Cross Section B - B'

Well Permit No.	Top Sunbury (feet)	Top Berea (feet)	Sunbury Thickness (feet)	Bottom Berea (feet)	Berea Thickness (feet)	Bottom Bedford (feet)	Bedford Thickness (feet)	Percentage of Sand %	Percentage of Shale %
7621	1840	1860	20	1863	3	1880	20	15.00	85.00
3659	1804	1824	20	1827	3	1841	17	17.65	82.35
3611	1793	1813	20	1817	4	1830	17	23.53	76.47
3942	1913	1932	19	1937	5	1950	18	27.78	72.22
3588	1899	1918	19	1924	6	1938	20	30.00	70.00
4268	1930	1952	22	1957	5	1972	20	25.00	75.00
7619	2086	2118	32	2124	6	2136	18	33.33	66.67
5262	1937	1970	33	1976	6	1990	20	30.00	70.00
3559	2075	2110	35	2117	7	2128	18	38.89	61.11

Cross Section C - C'

Well Permit No.	Top Sunbury (feet)	Top Berea (feet)	Sunbury Thickness (feet)	Bottom Berea (feet)	Berea Thickness (feet)	Bottom Bedford (feet)	Bedford Thickness (feet)	Percentage of Sand %	Percentage of Shale %
2574	1701	1720	19	1723	3	1739	19	15.79	84.21
3527	1841	1862	21	1866	4	1883	21	19.05	80.95
3750	1877	1899	22	1903	4	1919	20	20.00	80.00
3863	1845	1864	19	1869	5	1884	20	25.00	75.00
3531	1782	1810	28	1816	6	1828	18	33.33	66.67
3506	2036	2067	31	2074	7				
4407	1960	1992	32	1999	7	2013	21	33.33	66.67
2958	1950	1983	33	1989	6	2002	19	31.58	68.42
3633	2039	2074	35	2080	6	2092	18	33.33	66.67
4927	1828	1864	36	1872	8	1884	20	40.00	60.00
3847	1920	1952	32	1957	5	1974	22	22.73	77.27

Cross Section D - D'

Well Permit No.	Top Sunbury (feet)	Top Berea (feet)	Sunbury Thickness (feet)	Bottom Berea (feet)	Berea Thickness (feet)	Bottom Bedford (feet)	Bedford Thickness (feet)	Percentage of Sand %	Percentage of Shale %
7303	1770	1793	23	1797	4	1812	19	21.05	78.95
3584	1821	1842	21	1846	4	1860	18	22.22	77.78
3800	1750	1770	20	1775	5	1788	18	27.78	72.22
3707	1914	1938	24	1944	6		-1938	-0.31	100.31
3706	1815	1837	22	1842	5	1858	21	23.81	76.19
3472	1897	1921	24	1926	5	1940	19	26.32	73.68
4761	1992	2023	31	2031	8	2045	22	36.36	63.64
4306	2034	2067	33	2076	9	2088	21	42.86	57.14
6126	1999	2038	39	2044	6	2058	20	30.00	70.00
7594	1850	1883	33	1890	7	1902	19	36.84	63.16
7713	2070	2105	35	2110	5	2123	18	27.78	72.22

Cross Section E- E'

Well Permit No.	Top Sunbury (feet)	Top Berea (feet)	Sunbury Thickness (feet)	Bottom Berea (feet)	Berea Thickness (feet)	Bottom Bedford (feet)	Bedford Thickness (feet)	Percentage of Sand %	Percentage of Shale %
6974	1886	1904	18	1910	6	1923	19	31.58	68.42
4120	1831	1850	19	1854	4	1869	19	21.05	78.95
3816	1769	1787	18	1791	4	1809	22	18.18	81.82
3611	1793	1813	20	1817	4	1830	17	23.53	76.47
3796	1857	1876	19	1880	4	1897	21	19.05	80.95
3750	1879	1899	20	1903	4	1920	21	19.05	80.95
3800	1750	1770	20	1775	5	1788	18	27.78	72.22
3722	1895	1915	20	1922	7	1934	19	36.84	63.16

Cross Section F - F'

Well Permit No.	Top Sunbury (feet)	Top Berea (feet)	Sunbury Thickness (feet)	Bottom Berea (feet)	Berea Thickness (feet)	Bottom Bedford (feet)	Bedford Thickness (feet)	Percentage of Sand %	Percentage of Shale %
6118	1988	2012	24	2018	6	2034	22	27.27	72.73
3076	2010	2034	24	2041	7	2056	22	31.82	68.18
4268	1930	1952	22	1957	5	1972	20	25.00	75.00
7635	1890	1912	22	1916	4	1935	23	17.39	82.61
3531	1782	1810	28	1816	6	1828	18	33.33	66.67
3751	1946	1972	26	1978	6	1990	18	33.33	66.67
3734	1816	1844	28	1850	6	1863	19	31.58	68.42
3543	1977	2002	25	2012	10	2020	18	55.56	44.44
7542	1997	2031	34	2041	10	2051	20	50.00	50.00

Cross Section G - G'

Well Permit No.	Top Sunbury (feet)	Top Berea (feet)	Sunbury Thickness (feet)	Bottom Berea (feet)	Berea Thickness (feet)	Bottom Bedford (feet)	Bedford Thickness (feet)	Percentage of Sand %	Percentage of Shale %
3017	2050	2086	36	2092	6	2104	18	33.33	66.67
2950	2014	2048	34	2055	7	2067	19	36.84	63.16
3042	2082	2117	35	2124	7	2137	20	35.00	65.00
3559	2075	2110	35	2117	7	2128	18	38.89	61.11
3633	2039	2074	35	2080	6	2092	18	33.33	66.67
6126	1999	2038	39	2046	8	2058	20	40.00	60.00
3444	2056	2094	38	2101	7	2114	20	35.00	65.00
3778	2048	2087	39	2096	9	2107	20	45.00	55.00
4041	2020	2057	37	2065	8	2076	19	42.11	57.89

Appendix II. Sunbury Shale, Berea Sandstone and Bedford Shale Elevations

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea -Bedford Thickness (feet)
7172	1818	1838	20	1842	4	1858	20
7171	1812	1832	20	1836	4	1852	20
3816	1768	1787	19	1791	4	1808	21
3641	1764	1784	20	1788	4	1805	21
5011	1856	1875	19	1880	5	1896	21
4157	1840	1860	20	1864	4	1882	22
6118	1989	2011	22	2018	7	2033	22
6127	2014	2037	23	2044	7	2059	22
3037	1855	1884	29	1890	6	1906	22
3016	1852	1884	32	1890	6	1904	20
2950	2014	2047	33	2055	8	2068	21
7536	1797	1827	30	1835	8	1848	21
2574	1701	1720	19	1723	3	1739	19
3820	1732	1753	21	1756	3	1772	19
3527	1841	1862	21	1866	4	1883	21
3750	1877	1899	22	1903	4	1919	20
3606	1942	1963	21	1968	5	1983	20
3863	1845	1864	19	1869	5	1884	20
3489	1788	1812	24	1820	8	1830	18
3586	1887	1910	23	1917	7	1930	20
3531	1787	1810	23	1816	6	1828	18
3746	1994	2018	24	2025	7	2037	19
3506	2042	2067	25	2074	7		

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea -Bedford Thickness (feet)
4183	2007	2036	29	2043	7	2053	17
4407	1960	1992	32	1999	7	2013	21
2958	1950	1983	33	1989	6	2002	19
2880	2019	2054	35	2060	6	2072	18
2870	2027	2065	38	2072	7	2083	18
4927	1826	1864	38	1872	8	1884	20
5337	1886	1906		1914	8	1927	21
8037	1878	1918	40	1926	8	1940	22
8290	1850	1888	38	1894	6	1909	21
3847	1912	1952	40	1957	5	1974	22
5746							
7303	1770	1793	23	1797	4	1812	19
3667	1800	1824	24	1829	5	1844	20
3752	1866	1888	22	1892	4		
3584	1821	1842	21	1846	4	1860	18
3605	1758	1779	21	1784	5	1794	15
3530	1789	1813	24	1819	6	1832	19
3707	1914	1938	24	1944	6		
3706	1815	1837	22	1842	5	1858	21
3472	1897	1921	24	1926	5	1940	19
3428	1890	1916	26	1922	6	1936	20
3823	1831	1862	31	1867	5	1880	18
4761	1992	2023	31	2031	8	2045	22
4304	2018	2050	32	2059	9	2070	20
4305	2022	2055	33	2062	7	2076	21

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea - Bedford Thickness (feet)
4306	2034	2067	33	2076	9	2088	21
6126	1999	2038	39	2044	6	2058	20
7594	1844	1883	39	1890	7	1902	19
7713	2066	2105	39	2110	5	2123	18
7621	1840	1860	20	1863	3	1880	20
3659	1804	1824	20	1827	3	1841	17
3612	1874	1894	20	1897	3	1916	22
3640	1827	1846	19	1850	4	1866	20
3876	1864	1884	20	1888	4	1904	20
7137	1884	1904	20	1909	5	1922	18
3942	1913	1932	19	1937	5	1950	18
4336	1828	1848	20	1852	4	1866	18
3588	1899	1918	19	1924	6	1938	20
4268	1930	1952	22	1957	5	1972	20
7619	2086	2118	32	2124	6	2136	18
4736	2095	2126	31	2134	8	2145	19
5262	1937	1970	33	1976	6	1990	20
3559	2075	2110	35	2117	7	2128	18
3781	1812	1851	39	1857	6	1870	19
2763	1809	1849	40	1856	7	1870	21
6974	1886	1904	18	1910	6	1923	19
4120	1831	1850	19	1854	4	1869	19
3816	1768	1787	19	1791	4	1808	21
4006	1817	1837	20	1841	4	1857	20
3611	1793	1813	20	1817	4	1830	17

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea -Bedford Thickness (feet)
3796	1857	1876	19	1880	4	1896	20
3797	1812	1834	22	1838	4	1853	19
3750	1879	1899	20	1903	4	1920	21
3605	1758	1779	21	1784	5	1798	19
3800	1750	1770	20	1775	5	1788	18
3722	1895	1915	20	1922	7	1934	19
6118	1988	2012	24	2018	6	2034	22
3711	1918	1943	25	1949	6	1964	21
3076	2010	2034	24	2041	7	2056	22
7635	1890	1912	22	1916	4	1935	23
3531	1782	1810	28	1816	6	1828	18
3745	1945	1970	25	1976	6	1988	18
3751	1946	1972	26	1978	6	1990	18
3410	1905	1930	25	1937	7	1950	20
3534	1823	1848	25	1856	8	1867	19
3734	1816	1844	28	1850	6	1863	19
3543	1977	2002	25	2012	10	2020	18
7542	1997	2031	34	2041	10	2051	20
3017	2050	2086	36	2092	6	2104	18
2950	2014	2048	34	2055	7	2067	19
3042	2082	2117	35	2124	7	2137	20
7066	2008	2043	35	2055	12	2063	20
6216	2096	2131	35	2139	8	2152	21
3559	2075	2110	35	2117	7	2128	18
3633	2039	2074	35	2080	6	2092	18

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea -Bedford Thickness (feet)
6126	1999	2038	39	2046	8	2058	20
3444	2056	2094	38	2101	7	2114	20
3778	2048	2087	39	2096	9	2107	20
4041	2020	2057	37	2065	8	2076	19
7195	1686	1706	20	1711	5	1728	22
5748	1743	1763	20	1767	4	1782	19
7959	1767	1787	20	1790	3	1805	18
5493	1694	1715	21	1719	4	1736	21
4188	1741	1762	21	1768	6	1782	20
3776	1720	1742	22	1747	5	1764	22
5334	1800	1823	23	1828	5	1844	21
3935	1756	1777	21	1782	5	1798	21
3817	1795	1816	21	1819	3	1836	20
3722	1893	1915	22	1922	7	1934	19
3800	1849	1870	21	1875	5	1888	18
3571	1866	1887	21	1893	6	1907	20
4081	1911	1931	20	1936	5	1952	21
3620	1906	1929	23	1934	5	1949	20
3468	1889	1913	24	1918	5	1931	18
3507	1968	1990	22	1996	6	2012	22
3488	1809	1831	22	1837	6	1849	18
3466	1792	1816	24	1822	6	1836	20
3493	1912	1937	25	1943	6	1958	21
3656	1872	1891	19	1895	4	1912	21
3583	1901	1922	21	1926	4	1942	20

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea - Bedford Thickness (feet)
3726	1770	1790	20	1792	2	1808	18
3555	1752	1773	21	1776	3	1793	20
7958	1780	1801	21	1804	3	1821	20
6832	1787	1808	21	1812	4	1827	19
4522	1844	1863	19	1866	3	1882	19
3865	1934	1956	22	1960	4	1975	19
4153	1955	1975	20	1979	4	1997	22
4215	1916	1938	22	1941	3	1958	20
4175	1902	1923	21	1927	4	1942	19
3883	1909	1929	20	1934	5	1948	19
3712	1908	1930	22	1934	4	1950	20
3607	1900	1920	20	1924	4	1942	22
4042	1887	1908	21	1912	4	1927	19
3855	1980	2001	21	2006	5	2020	19
3497	1830	1851	21	1856	5	1870	19
3949	1918	1940	22	1946	6	1960	20
3703	1993	2015	22	2020	5	2033	18
3536	1841	1862	21	1868	6	1884	22
3492	1990	2012	22	2018	6	2032	20
3639	1978	2001	23	2007	6	2019	18
3526	1796	1819	23	1825	6	1840	21
4244	1935	1959	24	1965	6	1979	20
4262	1928	1952	24	1959	7	1973	21
4055	1833	1858	25	1864	6	1878	20
6385	1766	1786	20	1790	4	1805	19

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea -Bedford Thickness (feet)
6389	1781	1801	20	1805	4	1820	19
4521	1972	1994	22	1999	5	2013	19
5307	1818	1839	21	1845	6	1859	20
3880	1866	1886	20	1892	6	1906	20
4463	1876	1896	20	1900	4	1916	20
3782		1917		1923	6	1937	20
6636	1828	1848	20	1853	5	1868	20
4582	1842	1862	20	1866	4	1880	18
3657	2070	2098	28	2104	6	2120	22
6416	1955	1986	31	1992	6	2012	26
7453	1866	1886	20	1890	4	1904	18
3753	1891	1912	21	1916	4	1930	18
3642	1830	1849	19	1853	4	1868	19
3864	1814	1836	22	1840	4	1856	20
5319	1942	1970	28	1977	7	1989	19
3538	1996	2020	24	2026	6	2042	22
4099	1988	2011	23	2018	7	2030	19
3975	1821	1845	24	1852	7		
7315	1806	1830	24	1836	6	1852	22
3617	2000	2025	25	2032	7	2046	21
7519	1810	1832	22	1840	8	1851	19
6911	2001	2027	26	2036	9	2048	21
4640	1960	1986	26	1994	8	2008	22
3594	2032	2064	32	2070	6	2082	18
7443	1956	1988	32	1998	10	2009	21

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea -Bedford Thickness (feet)
7497	2019	2052	33	2062	10	2071	19
3851	2042	2076	34	2086	10	2098	22
4344	2037	2072	35	2082	10	2092	20
5267	2124	2160	36	2169	9	2182	22
6629	1900	1943	43	1950	7	1964	21
6487	1973	2004	31	2012	8	2026	22
3857	2020	2052	32	2062	10	2072	20
5568	1910	1941	31	1949	8	1961	20
5338	1830	1861	31	1868	7	1881	20
3208	2027	2061	34	2067	6	2082	21
5401		2070		2075	5	2089	19
6875	1908	1946	38	1954	8	1966	20
7712	2050	2088	38	2093	5	2107	19
7529	1984	2020	36	2024	4	2040	20
7305	2006	2045	39	2051	6	2064	19
7476	1998	2031	33	2036	5	2050	19
7245	2030	2065	35	2071	6	2084	19
7099	1966	2006	40	2012	6	2025	19
3663	1998	2030	32	2035	5	2048	18
7098	2024	2049	25	2054	5	2069	20
3474	1862	1896	34	1902	6	1916	20
3505	1930	1961	31	1968	7	1980	19
3694	1964	1996	32	2000	4	2018	22
3695	1986	2016	30	2022	6	2036	20
3662	2043	2074	31	2080	6		

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea - Bedford Thickness (feet)
3469	2014	2047	33	2055	8	2065	18
6057	1950	1984	34	1988	4	2003	19
7012	1950	1983	33	1988	5	2004	21
7508	2009	2041	32	2046	5	2060	19
7301	1992	2024	32	2030	6	2042	18
7503	2065	2097	32	2104	7	2118	21
3368	1972	2006	34	2015	9	2026	20
3992	2002	2036	34	2042	6	2056	20
6119	1912	1948	36	1954	6	1966	18
6932	1882	1922	40	1929	7	1943	21
6933	1912	1950	38	1958	8	1970	20
2902	2044	2078	34	2084	6	2100	22
6593	1950	1984	34	1990	6		
5259	1832	1863	31	1870	7	1882	19
5721	1828	1868	40	1876	8	1890	22
4561	1872	1912	40	1920	8	1932	20
4072	1885	1922	37	1930	8	1943	21
3152	1907	1934	27	1940	6	1954	20
4941	1914	1947	33	1950	3	1966	19
4560	1811	1842	31	1848	6	1863	21
4848	1979	2017	38	2022	5	2037	20
4062	1772	1807	35	1811	4	1826	19
4321	1821	1858	37	1863	5	1879	21
5084	1912	1946	34	1952	6	1965	19
3650	1998	2028	30	2034	6	2049	21

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea -Bedford Thickness (feet)
3649	2004	2031	27	2038	7	2050	19
3528	1977	2007	30	2013	6	2026	19
3647	1938	1968	30	1974	6	1989	21
3961	2010	2040	30	2048	8	2060	20
5148	1932	1962	30	1970	8	1982	20
3643	1952	1983	31	1989	6	2000	17
4386	2024	2054	30	2064	10	2075	21
6647	1936	1968	32	1974	6	1986	18
3524	1974	2005	31	2011	6	2024	19
4255	2078	2110	32	2114	4	2128	18
3664	2056	2088	32	2095	7	2110	22
5380	2097	2130	33	2139	9		
3601	1930	1965	35	1973	8	1984	19
4812	2034	2067	33	2075	8	2086	19
3580	2062	2096	34	2104	8	2116	20
3827	2022	2056	34	2064	8	2075	19
2934	1874	1915	41	1921	6	1934	19
3562	1873	1911	38	1918	7	1930	19
7309	1856	1889	33	1895	6	1909	20
7644	1947	1980	33	1986	6	2000	20
7887	1902	1935	33	1941	6	1954	19
7310	2022	2054	32	2060	6	2073	19
8291	1908	1946	38	1954	8	1966	20
7645	1962	2002	40	2008	6	2021	19
7646	1980	2017	37	2024	7	2037	20

Well Permit No.	Top Sunbury Sh. (feet)	Top Berea Ss. (feet)	Sunbury Sh. Thickness (feet)	Bottom Berea Ss. (feet)	Berea Ss. Thickness (feet)	Bottom Bedford Sh. (feet)	Berea - Bedford Thickness (feet)
7888	1924	1964	40	1971	7	1984	20
3547	1962	1987	25	1994	7		
3718	2016	2042	26	2049	7	2062	20
6618	2091	2123	32	2130	7	2142	19
8404		1974	1974	1981	7	1995	21
6927	1926	1957	31	1965	8	1976	19
7214	2056	2087	31	2094	7	2108	21
5899	1952	1984	32	1990	6		
7588	1967	1999	32	2007	8	2019	20
3003	2035	2069	34	2076	7	2089	20
7770	1890	1924	34	1932	8	1945	21
6764	2052	2086	34	2094	8	2106	20
6365	1879	1913	34	1921	8	1931	18
2958	1952	1984	32	1990	6	2006	22
3043	1979	2014	35	2022	8	2036	22
3013	2062	2097	35	2102	5	2117	20
7428	1786	1825	39	1831	6	1844	19

Well Permit No.	Percentage of Sand %	Percentage of Shale %
7172	20.00	80.00
7171	20.00	80.00
3816	19.05	80.95
3641	19.05	80.95
5011	23.81	76.19
4157	18.18	81.82
6118	31.82	68.18
6127	31.82	68.18
3037	27.27	72.73
3016	30.00	70.00
2950	38.10	61.90
7536	38.10	61.90
2574	15.79	84.21
3820	15.79	84.21
3527	19.05	80.95
3750	20.00	80.00
3606	25.00	75.00
3863	25.00	75.00
3489	44.44	55.56
3586	35.00	65.00
3531	33.33	66.67
3746	36.84	63.16
3506		

Well Permit No.	Percentage of Sand %	Percentage of Shale %
4183	41.18	58.82
4407	33.33	66.67
2958	31.58	68.42
2880	33.33	66.67
2870	38.89	61.11
4927	40.00	60.00
5337	38.10	61.90
8037	36.36	63.64
8290	28.57	71.43
3847	22.73	77.27
5746		
7303	21.05	78.95
3667	25.00	75.00
3752		
3584	22.22	77.78
3605	33.33	66.67
3530	31.58	68.42
3707		
3706	23.81	76.19
3472	26.32	73.68
3428	30.00	70.00
3823	27.78	72.22
4761	36.36	63.64
4304	45.00	55.00
4305	33.33	66.67

Well Permit No.	Percentage of Sand %	Percentage of Shale %
4306	42.86	57.14
6126	30.00	70.00
7594	36.84	63.16
7713	27.78	72.22
7621	15.00	85.00
3659	17.65	82.35
3612	13.64	86.36
3640	20.00	80.00
3876	20.00	80.00
7137	27.78	72.22
3942	27.78	72.22
4336	22.22	77.78
3588	30.00	70.00
4268	25.00	75.00
7619	33.33	66.67
4736	42.11	57.89
5262	30.00	70.00
3559	38.89	61.11
3781	31.58	68.42
2763	33.33	66.67
6974	31.58	68.42
4120	21.05	78.95
3816	19.05	80.95
4006	20.00	80.00
3611	23.53	76.47

Well Permit No.	Percentage of Sand %	Percentage of Shale %
3796	20.00	80.00
3797	21.05	78.95
3750	19.05	80.95
3605	26.32	73.68
3800	27.78	72.22
3722	36.84	63.16
6118	27.27	72.73
3711	28.57	71.43
3076	31.82	68.18
7635	17.39	82.61
3531	33.33	66.67
3745	33.33	66.67
3751	33.33	66.67
3410	35.00	65.00
3534	42.11	57.89
3734	31.58	68.42
3543	55.56	44.44
7542	50.00	50.00
3017	33.33	66.67
2950	36.84	63.16
3042	35.00	65.00
7066	60.00	40.00
6216	38.10	61.90
3559	38.89	61.11
3633	33.33	66.67

Well Permit No.	Percentage of Sand %	Percentage of Shale %
6126	40.00	60.00
3444	35.00	65.00
3778	45.00	55.00
4041	42.11	57.89
7195	22.73	77.27
5748	21.05	78.95
7959	16.67	83.33
5493	19.05	80.95
4188	30.00	70.00
3776	22.73	77.27
5334	23.81	76.19
3935	23.81	76.19
3817	15.00	85.00
3722	36.84	63.16
3800	27.78	72.22
3571	30.00	70.00
4081	23.81	76.19
3620	25.00	75.00
3468	27.78	72.22
3507	27.27	72.73
3488	33.33	66.67
3466	30.00	70.00
3493	28.57	71.43
3656	19.05	80.95
3583	20.00	80.00

Well Permit No.	Percentage of Sand %	Percentage of Shale %
3726	11.11	88.89
3555	15.00	85.00
7958	15.00	85.00
6832	21.05	78.95
4522	15.79	84.21
3865	21.05	78.95
4153	18.18	81.82
4215	15.00	85.00
4175	21.05	78.95
3883	26.32	73.68
3712	20.00	80.00
3607	18.18	81.82
4042	21.05	78.95
3855	26.32	73.68
3497	26.32	73.68
3949	30.00	70.00
3703	27.78	72.22
3536	27.27	72.73
3492	30.00	70.00
3639	33.33	66.67
3526	28.57	71.43
4244	30.00	70.00
4262	33.33	66.67
4055	30.00	70.00
6385	21.05	78.95

Well Permit No.	Percentage of Sand %	Percentage of Shale %
6389	21.05	78.95
4521	26.32	73.68
5307	30.00	70.00
3880	30.00	70.00
4463	20.00	80.00
3782	30.00	70.00
6636	25.00	75.00
4582	22.22	77.78
3657	27.27	72.73
6416	23.08	76.92
7453	22.22	77.78
3753	22.22	77.78
3642	21.05	78.95
3864	20.00	80.00
5319	36.84	63.16
3538	27.27	72.73
4099	36.84	63.16
3975		
7315	27.27	72.73
3617	33.33	66.67
7519	42.11	57.89
6911	42.86	57.14
4640	36.36	63.64
3594	33.33	66.67
7443	47.62	52.38

Well Permit No.	Percentage of Sand %	Percentage of Shale %
7497	52.63	47.37
3851	45.45	54.55
4344	50.00	50.00
5267	40.91	59.09
6629	33.33	66.67
6487	36.36	63.64
3857	50.00	50.00
5568	40.00	60.00
5338	35.00	65.00
3208	28.57	71.43
5401	26.32	73.68
6875	40.00	60.00
7712	26.32	73.68
7529	20.00	80.00
7305	31.58	68.42
7476	26.32	73.68
7245	31.58	68.42
7099	31.58	68.42
3663	27.78	72.22
7098	25.00	75.00
3474	30.00	70.00
3505	36.84	63.16
3694	18.18	81.82
3695	30.00	70.00
3662		

Well Permit No.	Percentage of Sand %	Percentage of Shale %
3469	44.44	55.56
6057	21.05	78.95
7012	23.81	76.19
7508	26.32	73.68
7301	33.33	66.67
7503	33.33	66.67
3368	45.00	55.00
3992	30.00	70.00
6119	33.33	66.67
6932	33.33	66.67
6933	40.00	60.00
2902	27.27	72.73
6593		
5259	36.84	63.16
5721	36.36	63.64
4561	40.00	60.00
4072	38.10	61.90
3152	30.00	70.00
4941	15.79	84.21
4560	28.57	71.43
4848	25.00	75.00
4062	21.05	78.95
4321	23.81	76.19
5084	31.58	68.42
3650	28.57	71.43

Well Permit No.	Percentage of Sand %	Percentage of Shale %
3649	36.84	63.16
3528	31.58	68.42
3647	28.57	71.43
3961	40.00	60.00
5148	40.00	60.00
3643	35.29	64.71
4386	47.62	52.38
6647	33.33	66.67
3524	31.58	68.42
4255	22.22	77.78
3664	31.82	68.18
5380		
3601	42.11	57.89
4812	42.11	57.89
3580	40.00	60.00
3827	42.11	57.89
2934	31.58	68.42
3562	36.84	63.16
7309	30.00	70.00
7644	30.00	70.00
7887	31.58	68.42
7310	31.58	68.42
8291	40.00	60.00
7645	31.58	68.42
7646	35.00	65.00

Well Permit No.	Percentage of Sand %	Percentage of Shale %
7888	35.00	65.00
3547		
3718	35.00	65.00
6618	36.84	63.16
8404	33.33	66.67
6927	42.11	57.89
7214	33.33	66.67
5899		
7588	40.00	60.00
3003	35.00	65.00
7770	38.10	61.90
6764	40.00	60.00
6365	44.44	55.56
2958	27.27	72.73
3043	36.36	63.64
3013	25.00	75.00
7428	31.58	68.42

Appendix III. Table 10. Initial Production Data.

Well Permit No.	Gas Production (MCF)	Oil Production (BO)	Productive Formation
7195	400		Be
5748			
7959		3	Be
5493	10	0.5	Be
4188	15		Be
3776	5	10	Be
5334	15		Be
3935			
3817	300	5	Be
3722			
3800			
3571	450	300	Be
4081	10	2	Go
3620	250	20	Be
3468	700	20	Be
3507	300	40	Be
3488	450	30	Be
3466	450	22	Be
3493		75	Be
3656	100	10	Be
3583	250	30	Be
3726	250	traces	Be
3555			
7958			
6832	189	5	Be
4522	15		Be
3865	100	10	Be
4153	10	5	Be
4215	50	5	Be
4175	50	5	Be
3883	50	5	Be
3712	50	10	Be
3607			
4042	50	10	Be

Well Permit No.	Gas Production (MCF)	Oil Production (BO)	Productive Formation
3855	40	10	Be
3497			
3949	30		Be
3703	60	15	Be
3536			
3492			
3639	100	20	Be
3526			
4244	50	10	Be
4262	50	10	Be
4055	100	5	Be
6385			
6389	90		Be
4521	10	1	Be
5307	10	8	Be
3880	100	10	Be
4463	20	8	Be
3782	475	2.5	Be
6636	3000		Be
4582	25	8	Be
3657	50	20	Be
6416	50		Oh Sh
7453	10		Be
3753	100	10	Be
3642	100	10	Be
3864	100	10	Be
5319	18	0.25	Be&Go
3538	750		Be
4099	100	5	Be
3975	750		Be
7315	100	5	Be
3617	1200		Be
7519	12	0.5	Be&Go
6911	60		Oh Sh
4640			
3594	50	10	Be
7443	70	15	Be

Well Permit No.	Gas Production (MCF)	Oil Production (BO)	Productive Formation
7497			Be
3851	750	8	Be
4344	70	3	Be
5267			Be&Go
6629	150	1	Be&Go
6487	10		Oh Sh
3857	10		Be
5568	80	0.5	Be&Go
5338	70	0.5	Be&Go
3208	19.6		Oh Sh
5401	10	1	Go
6875	30		Be
7712	25	1	Be
7529	30		Be&Go
7305	20	0.25	Be&Go
7476	20	0.5	Be
7245	20		Be&Go
7099	20		Be&Go
3663	25	8	Be
7098			
3474	400	20	Be
3505	30	15	Be
3694	50	18	Be
3695			
3662	40	10	Be
3469	30	1	Be
6057	20		Go
7012	10		Be
7508	30		Be
7301	30		Be
7503	20		Be
3368	42	1.5	Be
3992	806	15	Be
6119	30	3	Go
6932	8		Go
6933	6		Go
2902	980		Be

Well Permit No.	Gas Production (MCF)	Oil Production (BO)	Productive Formation
6593	100	15	Be
5259	10	traces	Be
5721	10	2	Go
4561	26		Go
4072	277		Be
3152	582		Be
4941	3		Go
4560	10	0.25	Be
4848	10	0.25	Be
4062	20		Be&Go
4321	10	1	Be
5084	10	0.5	Be
3650	50	15	Be
3649	50	15	Be
3528	25	10	Be
3647	50	10	Be
3961	700		Be
5148	350	15	Be
3643	50	10	Be
4386	100	2	Be
6647	30	2	Be
3524	40	15	Be
4255	250	4.5	Be
3664	100	10	Be
5380	30	8	Be
3601	75	10	Be
4812	10		Be
3580	75	10	Be
3827	200		Be
2934	250	50	Be
3562	475	8	Be
7309	393.6	5	Be
7644	15		Be
7887	10	1	Be
7310	120		Be
8291	2	traces	Be
7645	15		Be

Well Permit No.	Gas Production (MCF)	Oil Production (BO)	Productive Formation
7646	30	2	Be
7888	12	traces	Be
7172	15		Be
7171	10		Be
3816	100	10	Be
3641	50	12	Be
5011	12	3	Be
4157	680		Be
6118	10		Go
6127	50		Go
3037		10	Be
3016	60	40	Be
2950	240	20	Be
7536	50	3	Be
2574			
3820	100	traces	Be
3527	350	20	Be
3750			
3606	692	10	Be
3863			
3489	750	20	Be
3586	400	20	Be
3531	500	30	Be
3746			
3506		10	Be
4183			
4407	750		Be
2958	17		Be
2880	1000		Be
2870	1555	2	Be
4927	10	traces	Be
5337	15	0.25	Go
8037	5		Be&Go
8290	3	traces	Be
3847	10	traces	Be
5746	100		Be
7303	20	traces	Or

Well Permit No.	Gas Production (MCF)	Oil Production (BO)	Productive Formation
3667	579		Be
3752	125		Be
3584	250	10	Be
3605	40	8	Be
3530	350	40	Be
3707			
3706			
3472			
3428			
3823			
4761	150	5	Go
4304	600	20	Be
4305			
4306	30		Be
6126	50	10	Go
7594	120	2	Be
7713	30	2	Be&Go
7621	15		Be
3659	100	10	Be
3612	50	10	Be
3640			
3876	40	8	Be
7137	100	10	Be
3942			
4336			
3588			
4268			
7619	10		Be
4736	200	4	Be
5262	10	5	Be
3559			
3781	450	10	Be
2763	126		Be
6974	5		Be
4120			
3816	100	10	Be
4006	50	10	Be

Well Permit No.	Gas Production (MCF)	Oil Production (BO)	Productive Formation
3611	50	8	Be
3796			
3797			
3750			
3605			
3800	380	5	Be
3722	700	traces	Be
6118			
3711	8	0.5	Be
3076	2300	55	Be&Go
7635	30	traces	Be&Go
3531	500	30	Be
3745			
3751			
3410	25	30	Be
3534	300	15	Be
3736	300	15	Be
3543	450	20	Be
7542	20	1	Be
3017	60	30	Be
2950			
3042	10	8	Be
7066	20	4	Be
6216	100	10	Be
3559			
3633	500	5	Be
6126	380	8	Be
3444	230	20	Be
3778	500	30	Be
4041		4	Be