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Carbonate facies of the Kimmswick Limestone (Trenton/Galena) in southwestern Illinois : their relations as oil reservoirs and traps

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CARBONATE FACIES OF THE KIMMSWICK LIMESTONE (TRENTON/GALENA) IN SOUTHWESTERN ILLINOIS - Their Relations as Oil Reservoirs and Traps

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ABSTRACT

Four potentially productive oil horizons have been identified in the Kimmswick Limestone (Trenton/Galena), Ordovician of southwestern Illinois. Four non-porous caprock zones and four porous horizons were identified and informally named after corresponding members of the Dunleith Formation (Illinois State Geological Survey classification). The porous horizons generally consist of coarse-grained, fossiliferous limestone, which is overlain by finer grained, spar-cemented, impermeable limestone.

In order of production potential the horizons are the upper Moredock, lower Moredock, Beecher-St.James (lowermost stratigraphic unit), and New London (uppermost stratigraphic unit). Porosity in the upper Moredock horizon is relatively consistent throughout the study area, as determined by examination of 143 well log files (94 with E-logs) from nine oil fields and 98 thin sections. Vertical and lateral porosity variations in the lower horizons are complex. The New London horizon is truncated by the pre-Maquoketa unconformity in the western study area and is consistently permeable when present.

The New London horizon is about three feet thick and lower horizons are each about 20 feet thick. The upper Moredock is the most productive horizon throughout the area. Where the upper Moredock is non-productive the lower horizons are generally non-productive.

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A. GENERAL STATEMENT

After Kimmswick (Trenton/Galena) production from the Centralia and Salem oil fields (Figure 1) was established in the early 1940's, it became apparent that the productive zone was not limited to the top of the Kimmswick, as had been the rule in the Waterloo and Dupo fields which were developed in the early 1920's. Although many operators are interested in the potential stratigraphic level of oil in the Kimmswick, little research has been done on the subject.

Most of the Kimmswick oil fields in southwestern Illinois are relatively small; only the Dupo, St.Jacob, and Salem fields have cummulative production figures over one million barrels. An individual well may produce for over 20 years, but the production rates generally decline to 10-20 barrels/day within several years after completion (Schwalb, pers.comm.). Major oil companies have shown little interest in these relatively small producers and, understandably, have not published any significant studies in this area.

B. OBJECTIVES

The objectives of this investigation are: 1) to determine why more oil is produced from the top of the Kimmswick in the western fields, whereas the best

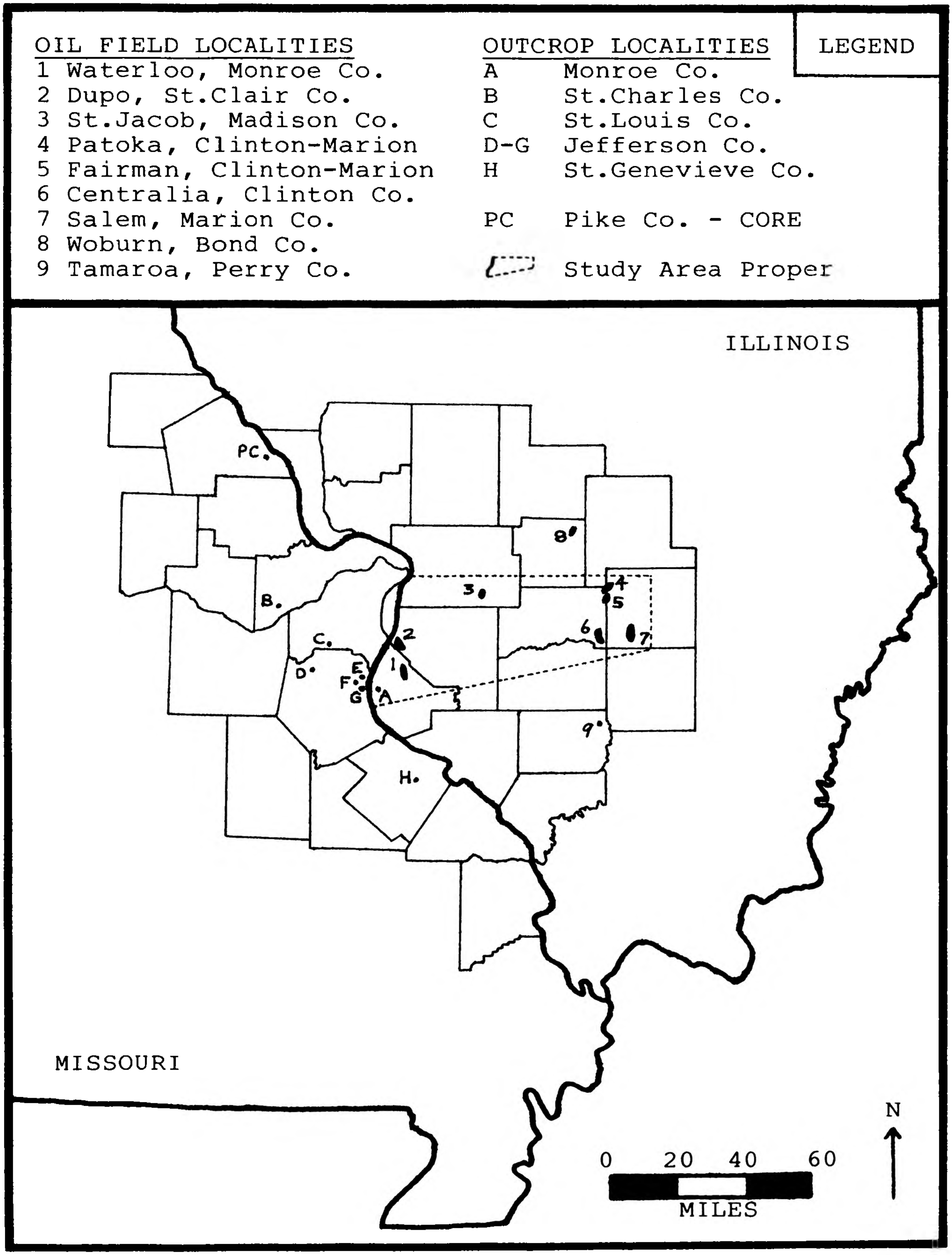


Figure 1.
Study area. (Scale: 1/3000000)

production is generally from lower zones in the eastern fields, and is produced from the base of the Kimmswick in the easternmost oil field; 2) to correlate porous horizons within the study area, and determine if such horizons are laterally persistent; 3) to determine why they produce oil in one field and not in another; and 4) to develop a facies model for deposition of the Kimmswick in the western Illinois Basin. Such a model would be helpful for predicting oil levels in undrilled areas.

C. ACKNOWLEDGMENTS

The subject of this study was selected for its significance to petroleum exploration and the fact that no recent work has been published on the area. The author is grateful to Dr. Alfred C. Spreng and Howard R. Schwalb for initially presenting this problem. Thanks are also due Dr. Spreng for his guidance in preparing this thesis and to Howard Schwalb for supplying well logs and his own knowledge of the subject. Appreciation is also extended to Dr. Robert C. Laudon and Dr. David J. Barr for their assistance as thesis commitee members.

Other thanks to Mike Roberson for thin section finishing and photography assistance at U.M.R., and to the staff of the Illinois State Geological Survey for research assistance. The author also acknowledges Ardel Rueff and the Missouri Divison of Geology and Land Survey for supplying a section of core from Pike County, Missouri.

Appreciation is extended the University of Missouri - Rolla for the faculty research grant awarded the author during the Summer of 1984, and for USDI support during the Autumn of 1984.

D. STUDY AREA

1. Geographical Location. The study area proper includes parts of the Illinois counties of Monroe, St.Clair, Madison, Clinton, and Marion. Relevant data available in this area is essentially limited to the Waterloo, Dupo, St.Jacob, Patoka, Fairman, Clinton, and Salem oil fields (Figure 1). Additional background research of the Kimmswick Limestone in Missouri and other Illinois counties was conducted for correlation of regional trends and development of depositional models.

2. Terminology. There are a number of terms that are used throughout this thesis which have a more specific meaning than is usually implied by the terms. The following will clarify potential misunderstandings:

When referring to the "study area," reference is to the area in Illinois delineated in Figure 1. Background research areas are referred to independently and specifically.

The study area is on the southwestern flank of the Illinois Sedimentary Basin. When referring to the "basin," unless otherwise noted, reference is to that part of the Illinois Basin in the study area.

Reference to the "western fields" indicates the Waterloo, Dupo, and St.Jacob oil fields. The "eastern fields" indicates the Patoka, Fairman, Clinton, and Salem oil fields.

The term "horizon" is used informally to describe permeable intervals as lithostratigraphic units. Horizons are identified and discussed whether or not they contain oil.

Unless otherwise noted, reference to production will always imply oil production, as very little gas is produced from the Kimmswick.

E. CLASSIFICATION OF STRATA

Classification of the oil horizons described in this study is based directly on the Illinois State Geological Survey (I.S.G.S.) classification of the Galena Group in Illinois (Templeton and Willman, 1963). The Galena is the uppermost group in the Champlainian Series (Middle Ordovician) in Illinois. The Galena Group shares common upper and lower limits with the Trentonian Stage (Figure 2).

Oil production from the collective horizons identified in this report has traditionally been referred to as "Trenton" production by the oil industry in Illinois. The Trentonian Stage and equivalent Galena Group is divided into the Decorah Subgroup (below) and the Kimmswick Subgroup (above). Since there is no recorded

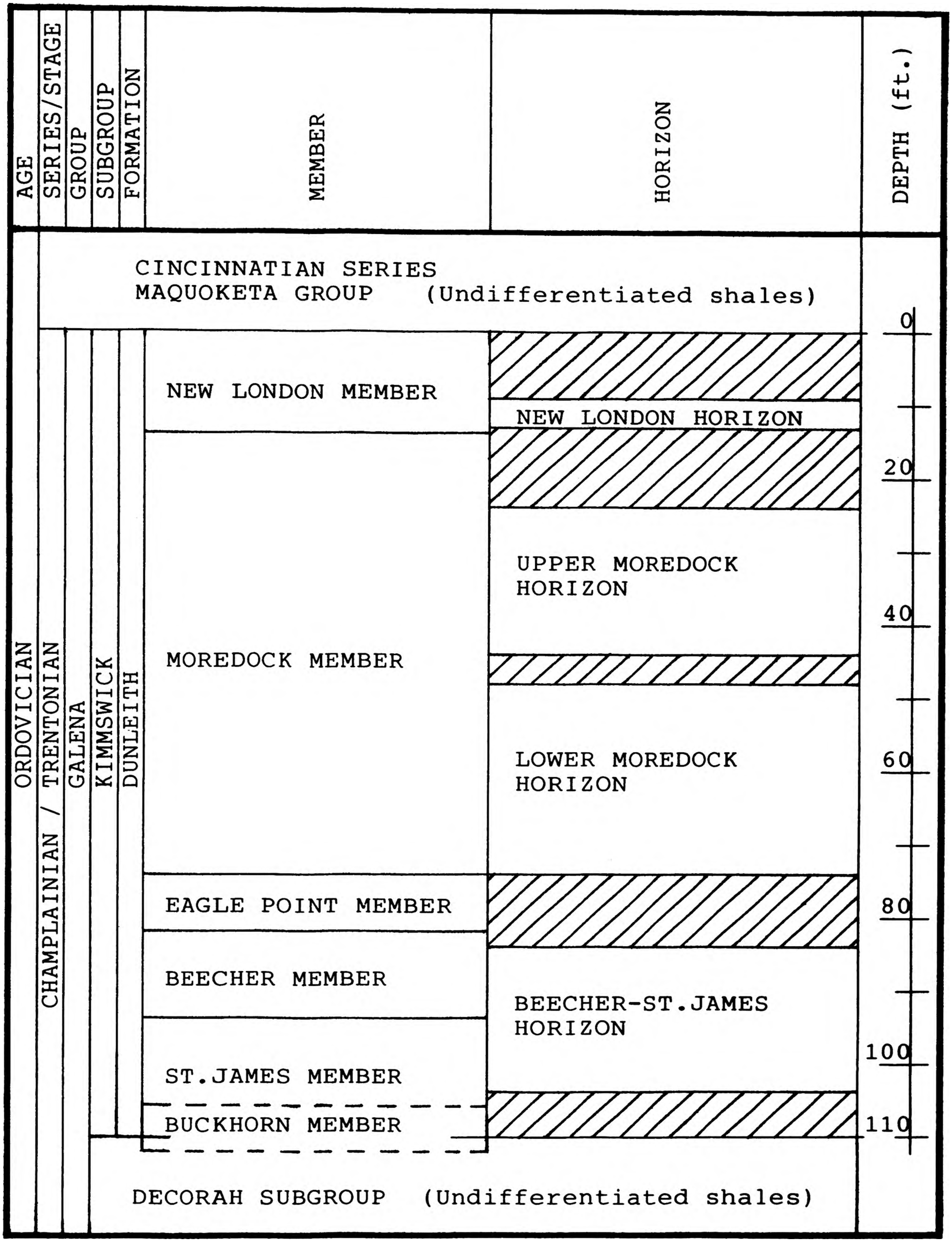
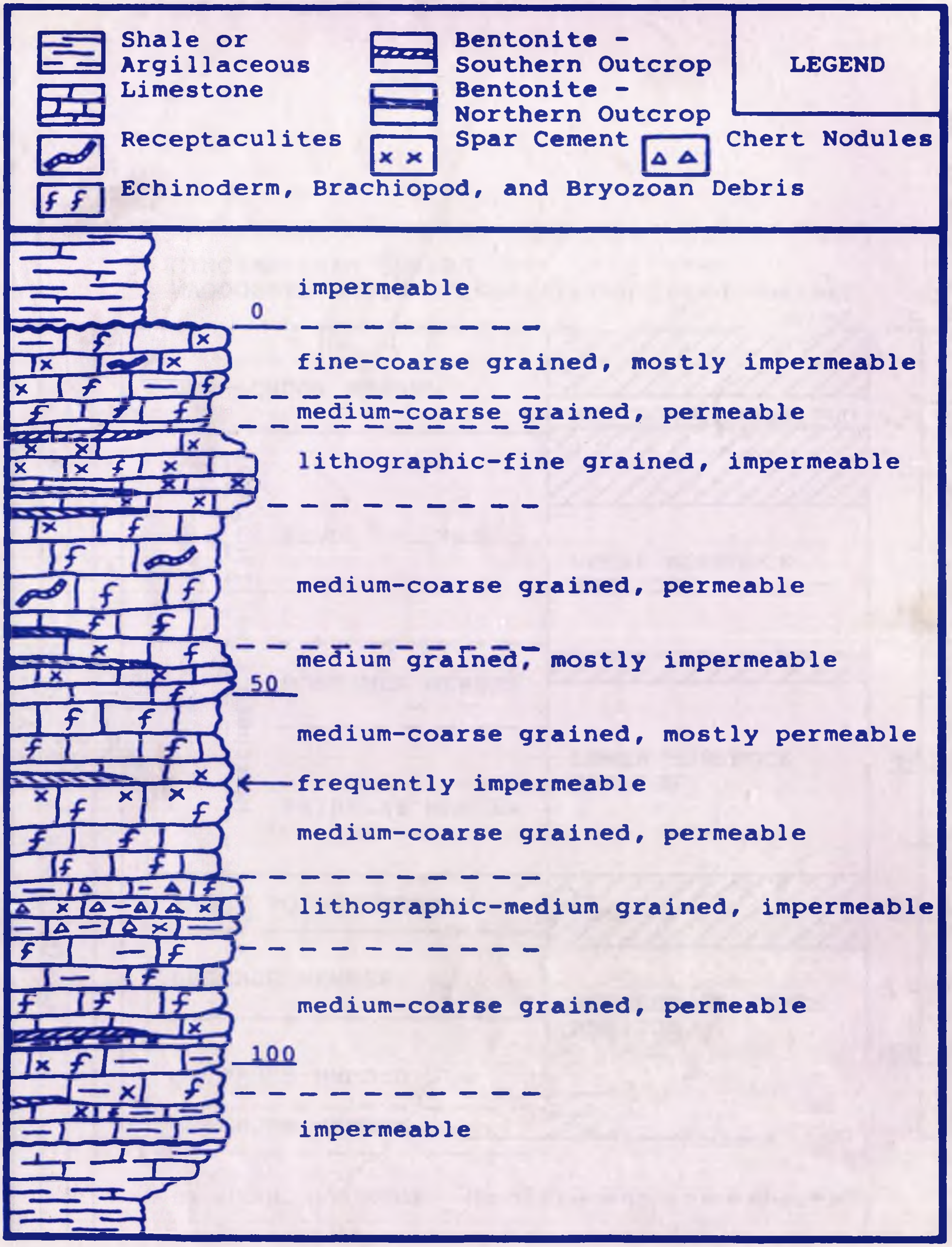


Figure 2. Classification of strata. (Average thicknesses depicted to scale: 1in.=20ft.)


LEGEND
Shale or Argillaceous Limestone
Receptaculites
Echinoderm, Brachiopod, and Bryozoan Debris
Bentonite - Southern Outcrop
Bentonite - Northern Outcrop
Spar Cement
Chert Nodules
impermeable
0
fine-coarse grained, mostly impermeable
medium-coarse grained, permeable
lithographic-fine grained, impermeable
medium-coarse grained, permeable
medium grained, mostly impermeable
50
medium-coarse grained, mostly permeable
frequently impermeable
medium-coarse grained, permeable
lithographic-medium grained, impermeable
medium-coarse grained, permeable
100
impermeable

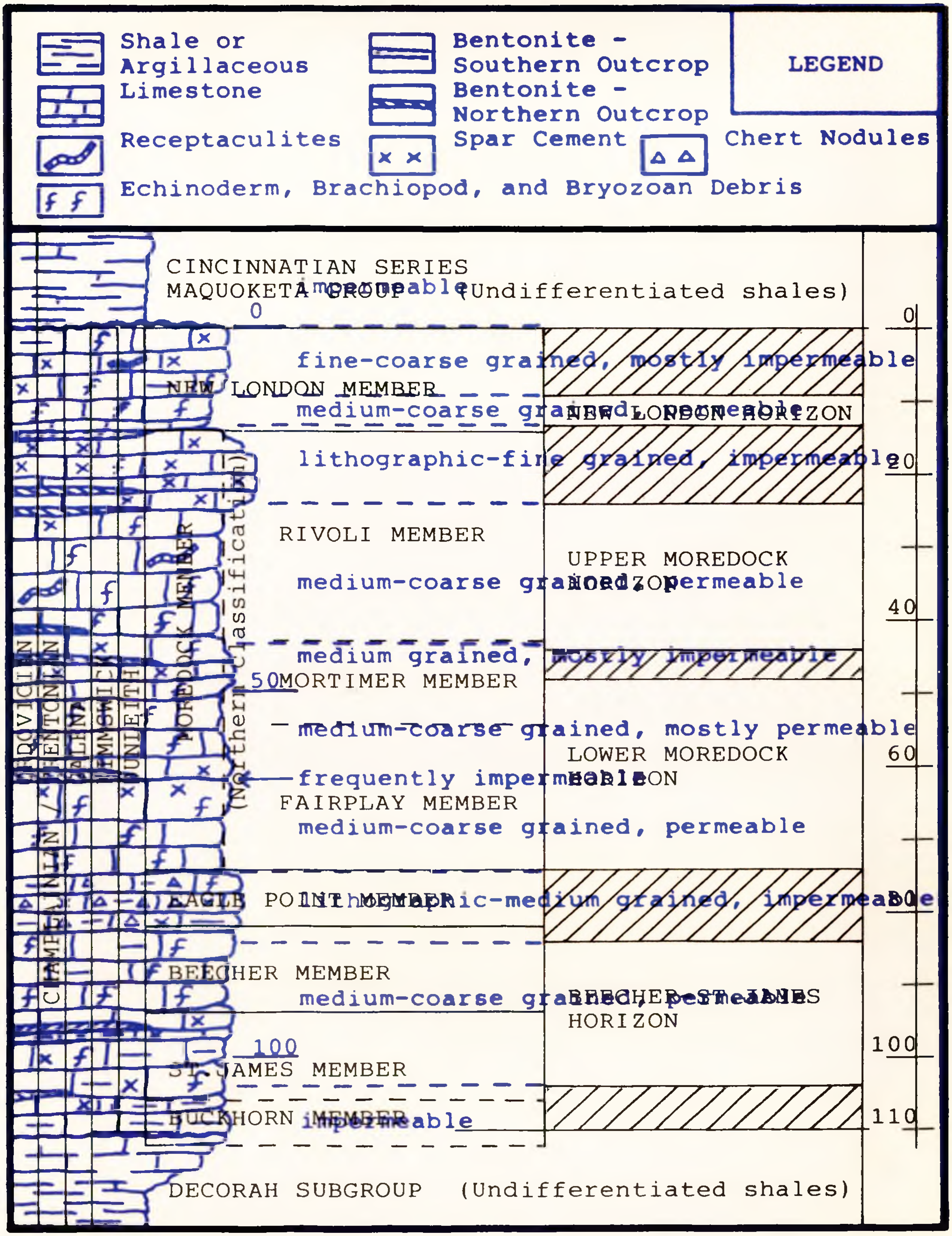
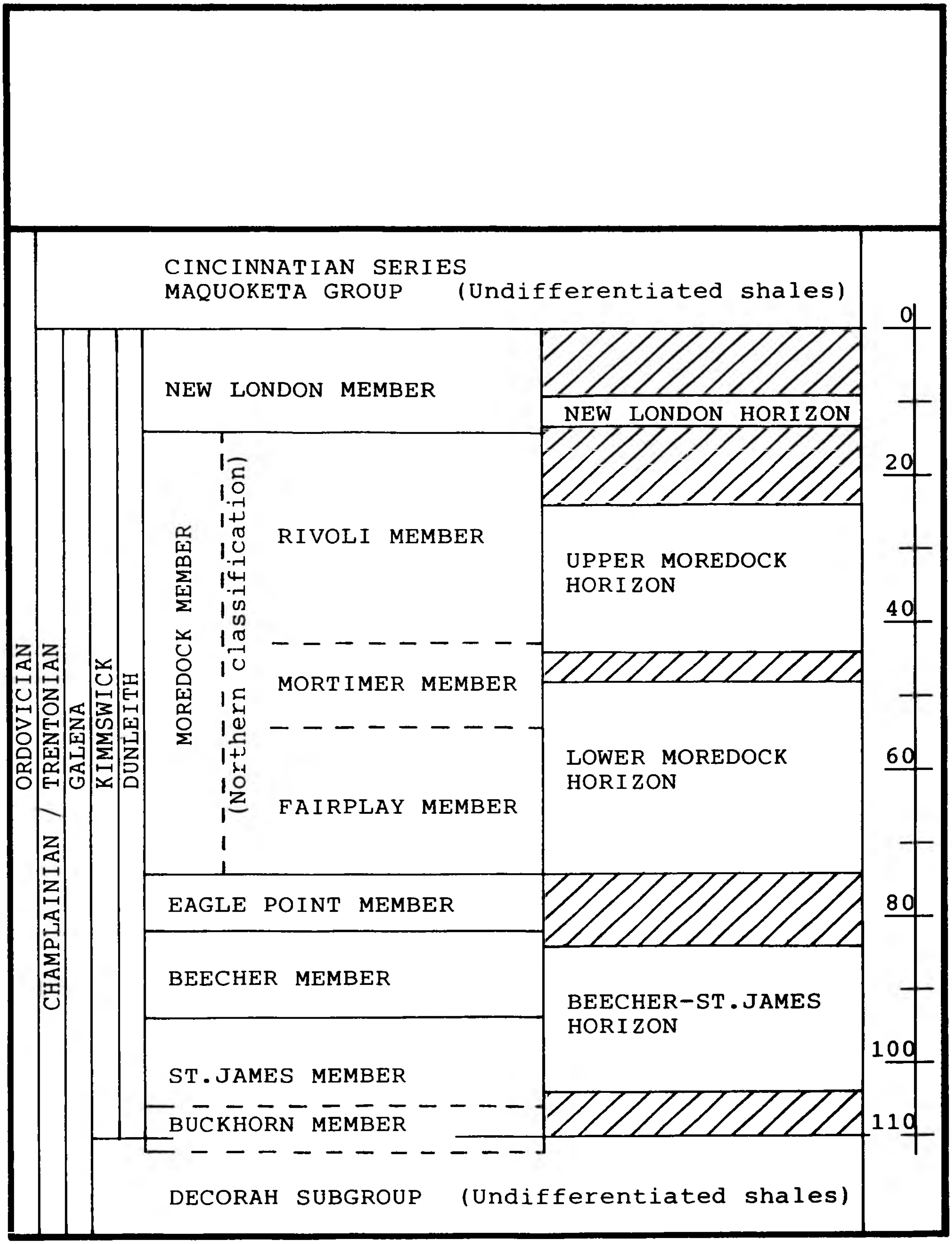


Figure 2a. Typical lithology of southwestern Illinois Kimmswick column, with northern bentonites. (1in.=20ft.)



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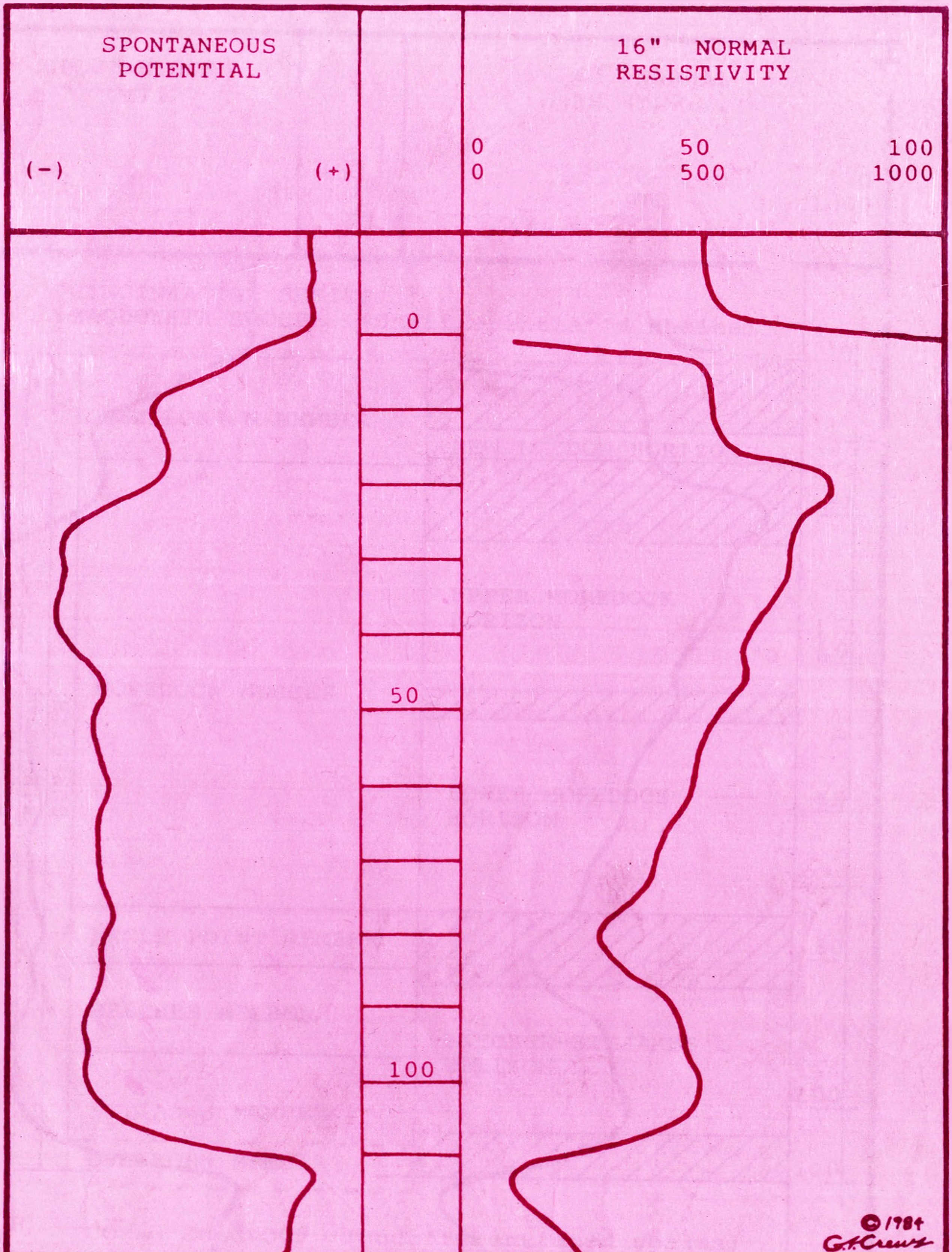

Figure 2b. Idealized model E-log, for southwestern Illinois Kimmswick column. (All horizons oil saturated.)

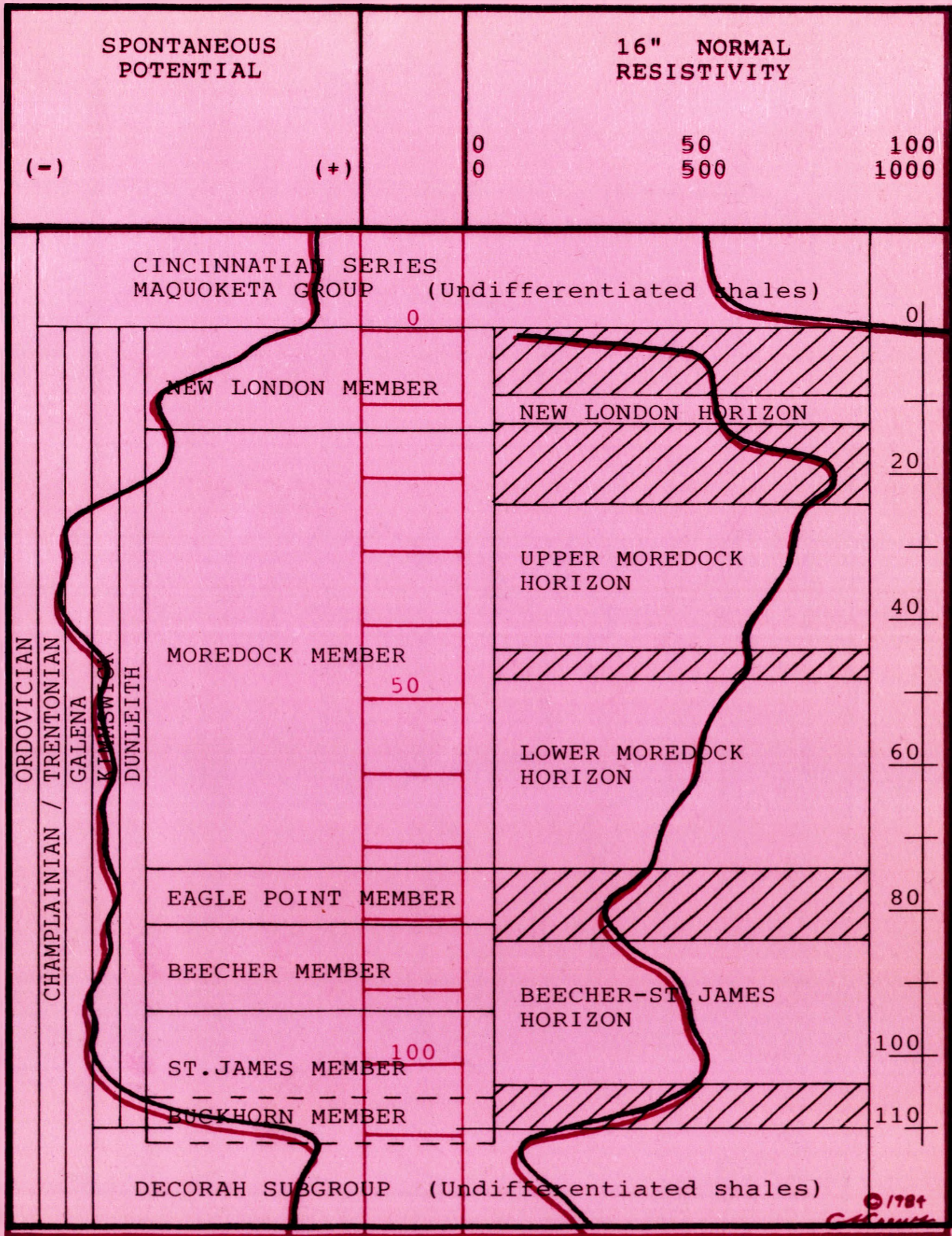

Figure 2b. Idealized model E-log, for southwestern Illinois Kimmswick column. (All horizons oil saturated.) [Transparency in Pocket]

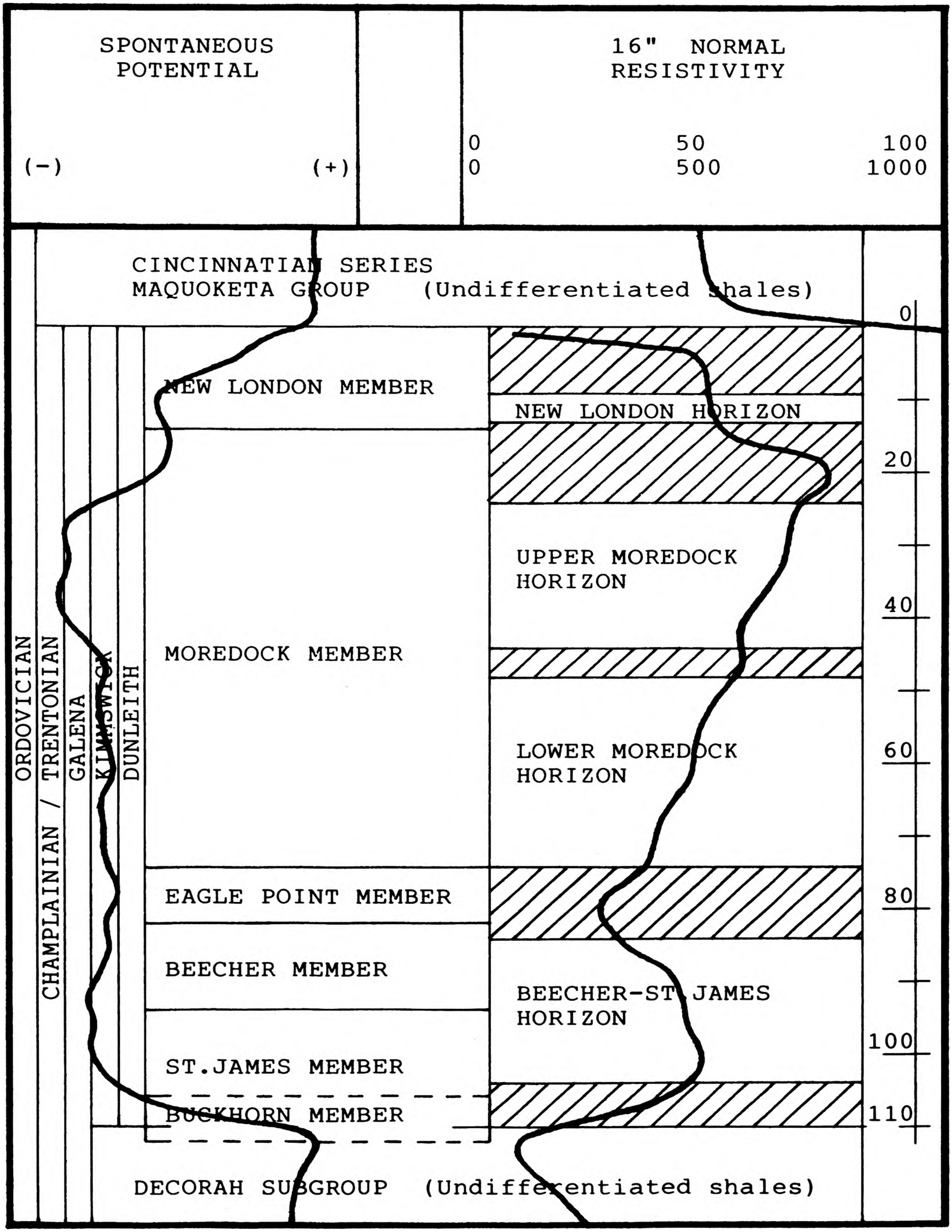

Figure 2b. Idealized model E-log, for southwestern Illinois Kimmswick column. (All horizons oil saturated.) [Transparency in Pocket]

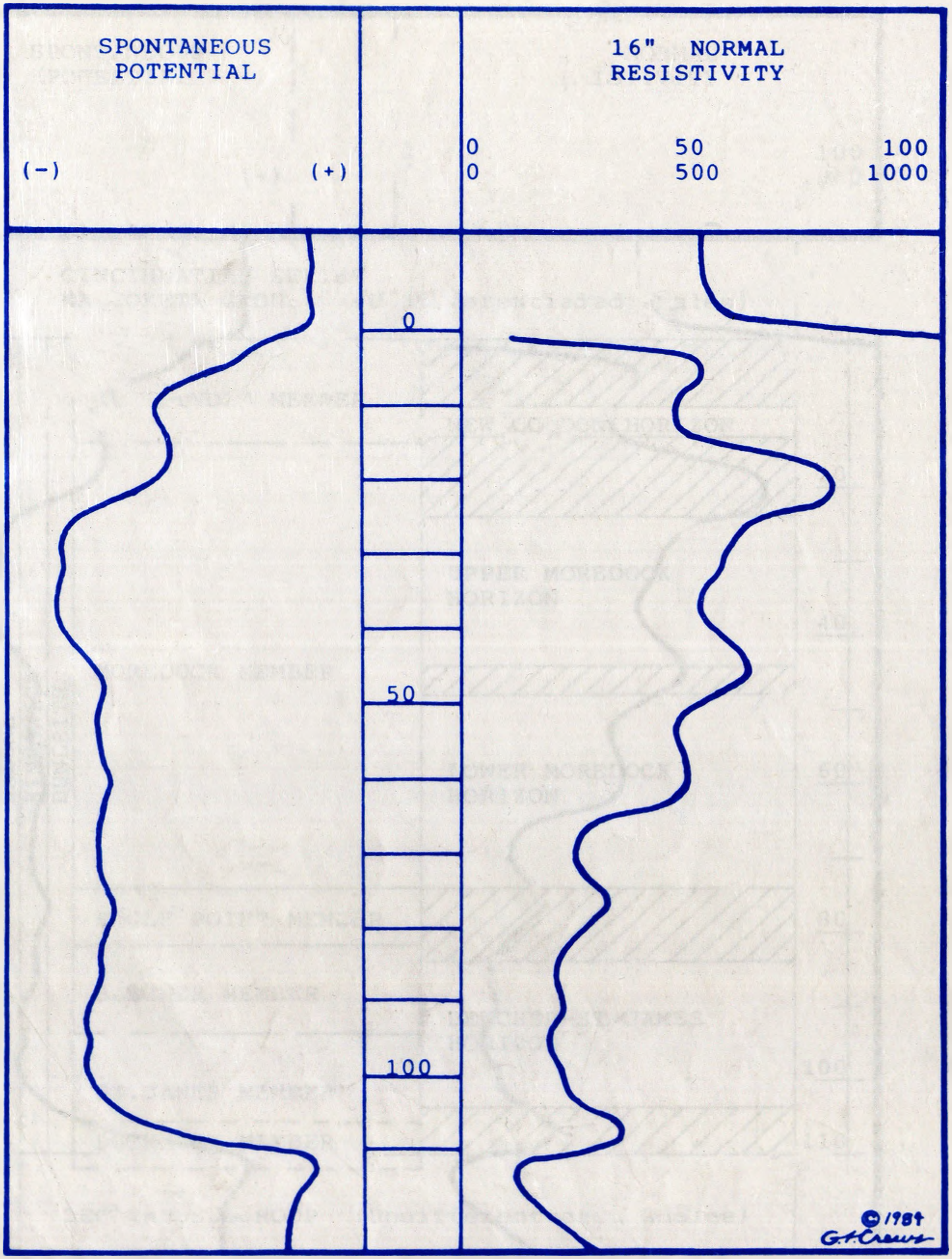

Figure 2c.
Idealized model E-log, for southwestern Illinois Kimmswick column. (All horizons dry.)

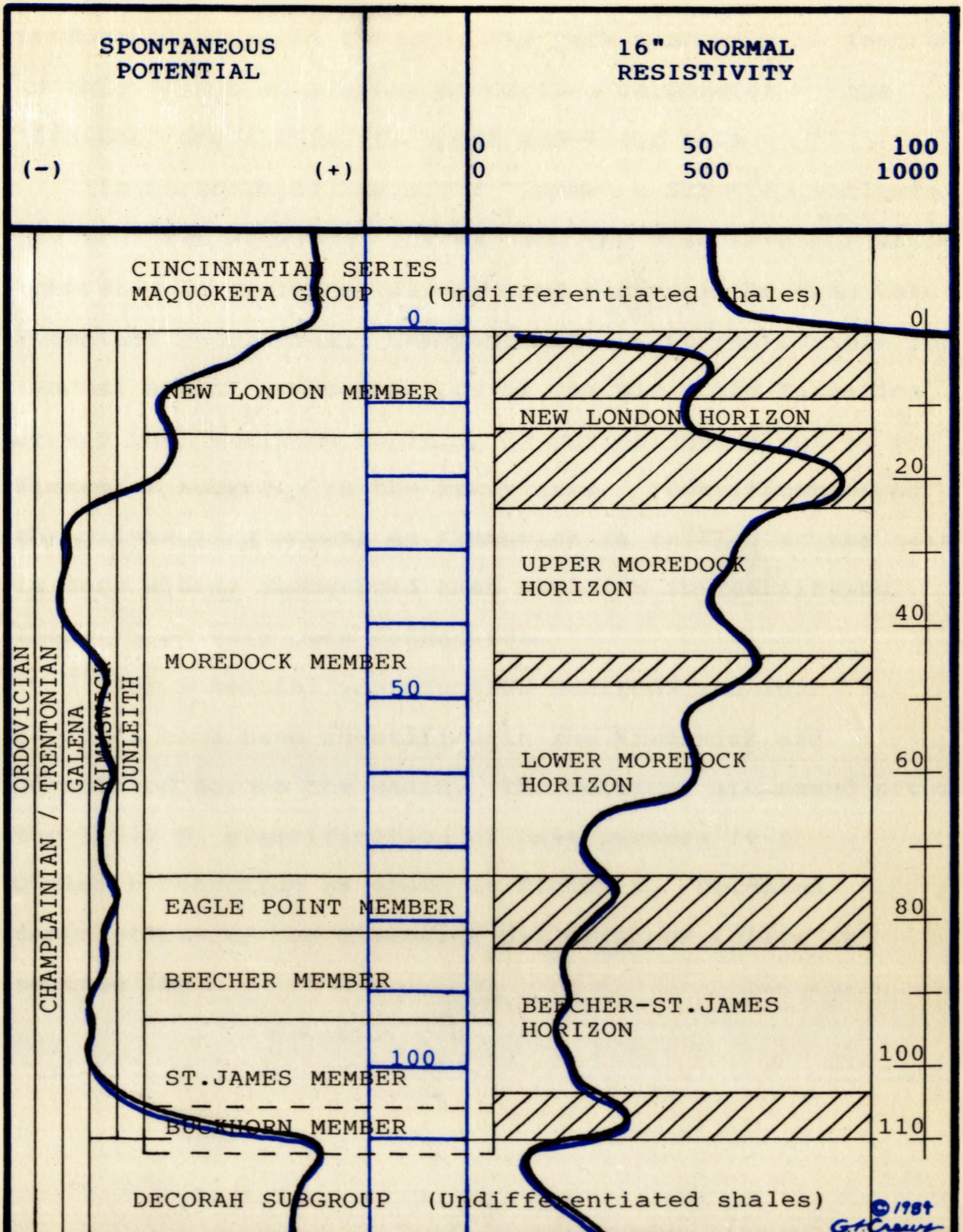

Figure 2c. Idealized model E-log, for southwestern Illinois Kimmswick column. (All horizons dry.)
(Transparency in Pocket)

Idealized model E-log, for southwestern
Illinois Kimmswick column. (All horizons dry.)

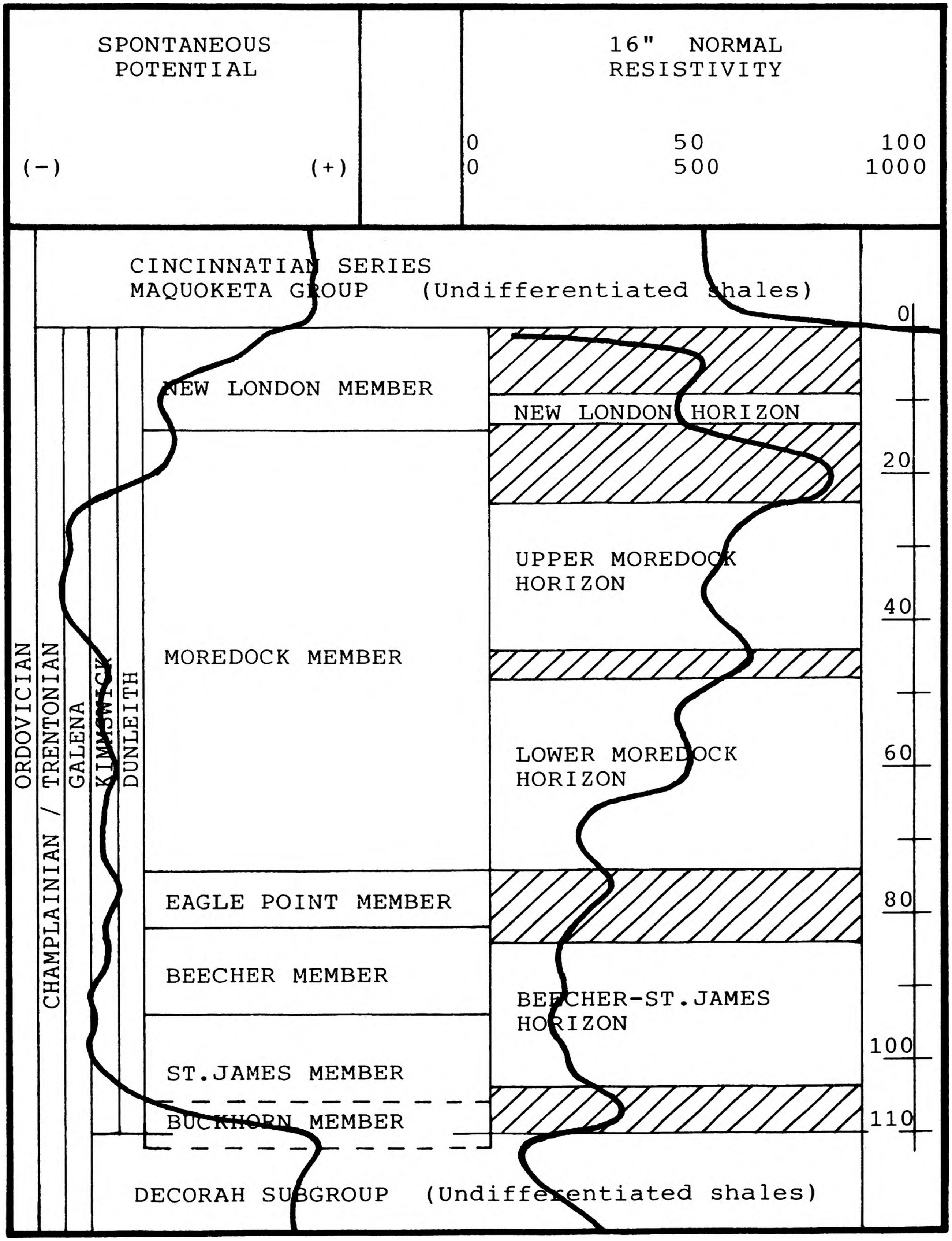

Figure 2c. Idealized model E-log, for southwestern Illinois Kimmswick column. (All horizons dry.) [Transparency in Pocket]

production from the Decorah, the term Kimmswick is favored in this report as all the productive carbonates of the "Trenton" are within its upper and lower bounds.

In northern Illinois the Kimmswick Subgroup includes the Dunleith Formation (below) and the Wise Lake Formation (above). In southern Illinois and Missouri the Wise Lake Formation is missing. The regional uplift responsible for removal and/or non-deposition of the Wise Lake Formation leaves the remaining Dunleith Formation equivalent to the Kimmswick Subgroup in the study area. Identification of the oil-bearing strata as Kimmswick is favored as the term is more widely recognized than Dunleith in identifying these relatively pure carbonates.

Four potentially productive horizons and four caprocks have been identified in the Kimmswick and correlated across the basin. The horizons are named after the I.S.G.S. classification of unit members in the Dunleith Formation as shown in Figure 2. Detailed descriptions of the Kimmswick oil horizons follow in section IV.

II. PREVIOUS WORK

A. KIMMSWICK OIL PRODUCTION

None of the literature published to date deals directly with the significance of the varying levels of oil production in the Kimmswick Limestone. A number of reports present evidence for the problem, but none acknowledges recognition or interest in its significance. Cohee (1941, Fig.2, p.3) presents the problem, without comment, in a sequence of stratigraphic sections which place the oil column near the top of the Kimmswick in the Waterloo field and at the bottom in the Salem field. Cohee and other authors have published reports that include numerous points of relevance or interest to this investigation, some of which are relayed in the following paragraphs.

A core study of four holes in the Dupo field was conducted by the I.S.G.S. to determine porosity and permeability through the producing zone. Cohee (1941, p.8) tabulates the values for 44 consecutive one foot intervals, in the Dyroff well No.27. Quoting Cohee's (1941, p.7) summary of the overall results:

> "The study of the cores showed the porosity to vary from 2.6 to 19.0 per cent with an average of 14 per cent; permeability ranged from 0 to 61 millidarcys with an average of 7.7 millidarcys; the average total fluid saturation of the pore space was 54.3 per cent. It is believed that where the "Trenton" is productive in Illinois the physical character of the producing zone is comparable to that in the Dupo pool."

The findings of this investigation agree with Cohee's statement, particularly in the upper Moredock horizon (which is the producing horizon represented by the Dyroff No.27 core). The table itself (Cohee, 1941, p.8) shows that porosity and permeability sometimes vary from maximum to minimum values in consecutive one foot intervals. Thin impermeable zones are common in core of oil horizons studied in this investigation also. They are interpreted as lenses in local facies variations; thinness and limited lateral extent prevent them from forming caprocks.

Bays (1945) and Misra (1964) contend that permeability in the Kimmswick is a result of solution that occurred during pre-Maquoketa erosion. They consider permeability to be unlikely in the northern dolomite facies of the Galena because pre-Maquoketa erosion was only significant in the southern facies.

Bristol and Buschbach (1973) present many pertinent facts and figures for Illinois oil fields producing from the Kimmswick. Of interest to this study is their report (on the Salem field) that the best oil saturation is in the top 50 feet of the Kimmswick, which contrasts with Cohee's (1941) report that places it at the base. This thesis identifies saturation in both, with the best porosity occurring near the base.

B. KIMMSWICK STRATIGRAPHY

I.S.G.S. Bulletin 89 (Templeton and Willman, 1963) does not include information about Kimmswick oil, but does provide concise lithologic descriptions of members in the Dunleith Formation, with notable coverage of facies variations throughout the greater Illinois Basin. This investigation follows Templeton and Willman's (1963) classification of the Galena Group, the Kimmswick Subgroup, and the Dunleith Formation. As defined by Templeton and Willman (1963, p.117), "the Dunleith has been divided into members consisting of a relatively pure unit at the base and a generally much thinner [relatively] argillaceous unit at the top." This cyclic (pure to argillaceous) characteristic and associated lithology variations (detailed in Templeton and Willman's (1963, p.114-25) section on the Dunleith Formation, which gives individual member descriptions) makes it possible to identify members on E-logs.

Misra (1964) classified the Kimmswick Limestone in Missouri, breaking it into the Upper, Middle, and Lower Members. Misra's (1964) dissertation is an asset to outcrop study, but his classification was not followed in this investigation because it has no relation to potential oil horizons and his classification is not followed by stratigraphers in the study area.

III. METHODS AND ANALYSES

A. DATA ACQUISITION

1. Well Logs. The major portion of identification and correlation of carbonate facies in the Kimmswick was substantiated by well log research. Log files at the Illinois State Geological Survey were examined for 143 wells in nine Illinois oil fields. Of these 143 files, 94 include electric logs, and 41 others contain data significant to this study. An additional six electric logs for wells in Pike County, Missouri, were examined for background research. Wells significant to this study are tabulated in Appendix A.

2. Drill Core. The availability of core samples for 15 wells, at the I.S.G.S., proved an invaluable aid in identifying the E-log responses to lithology variations in the Kimmswick. The best core samples filed at the I.S.G.S. core library consisted of a three inch interval for each one foot interval cored. The worst samples were small chips which were of minimal value for correlation. Of the 15 sets of core examined, 14 had at least a corresponding Spontaneous Potential / resistivity log on file. The remaining one had a Gamma Ray log and core description on file which was used to help identify the cored interval.

A quarter section from a two inch diameter core, drilled in Pike County, Missouri, was provided by the

Missouri Division of Geology and Land Survey. This core was a continuous 200 foot interval from the Maquoketa Group through the Decorah Subgroup. The nearest E-log available was from a hole 15 miles away.

Thin Sections. Using samples cut from core examined at the I.S.G.S. core library, 67 thin sections were prepared at U.M.R. The samples were selected to help identify marker beds, such as impermeable caprocks, and to determine the nature of the porosity in reservoir horizons. Other objectives were to identify fossils, argillaceous material and dolomitization. Thin sections are tabulated in Appendix C.

Confirmation of dolomite was accomplished by the use of Alizarin Red stain. The Alizarin Red test was reliable because dolomitization was only partial. In fact, most of the dolomite was in the form of euhedral rhombs along permeable fissures and was generally obvious without staining.

All limestone samples were vacuum impregnated with Epoxy cement before being glued to the slide. This insured that true porosity can be discriminated from areas that were damaged (extracted) by the surface grinder. Unfortunately, samples that were very oil-saturated did not adhere well to the Epoxy cement, so that in a few cases portions of the section were extracted from the slide. This left pinnacles of Epoxy where the pore spaces had been. The value of these thin sections was limited by the degree of damage.

3. <u>Field Research-Outcrops</u>. Kimmswick outcrops were examined at eight localities. Columbia Quarry, Monroe County, Illinois, is the only one in the study area proper. The other seven are Kimmswick sections in the Missouri counties of St.Charles, St.Louis, Jefferson, and St.Genevieve. Outcrop localities are tabulated in Appendix B and located on Figure 1.

The most valuable outcrops for regional correlation are those of active quarries because they provide the freshest exposures. Even in the shallowest Illinois oil fields the Kimmswick is relatively unaffected by surface weathering. Outcrop that has been directly exposed to the weather for a number of years develops a secondary porosity which obscures evidence of primary and/or previous secondary porosity. Every effort was made to find the freshest exposures at any given outcrop. Due to proximity to the surface, even fresh quarry faces show some effects of corrosion by surface waters.

<u>Thin Sections</u>. Outcrop samples were selected to prepare 33 thin sections. Samples were broken from limestone as far isolated from corroded surfaces as possible. This insured that outcrop thin sections were of comparable quality to core sample thin sections, particularly in low permeability zones. The outcrop thin sections were also Epoxy-impregnated before finishing. There were no adhesion problems, as all outcrop samples

were dry. Evidence of siderite was confirmed by staining with Alizarin Red in basic (30%NaOH) solution.

B. CORRELATION

In order to determine why oil is produced from various stratigraphic levels in the Kimmswick, porous and/or permeable horizons were correlated across the basin. Spar-cemented impermeable zones were also correlated. This section describes the factors that were instrumental to correlation.

1. Well Logs. Correlation across the basin was performed primarily by qualitative electric log analyses. The most frequently available E-logs were SP and Normal resistivity. The overall SP response through the Kimmswick Limestone is negative, and resistivity increases sharply relative to the Maquoketa shale above and the Decorah shale below (Figures 2b and 2c).

The SP response to dense, impermeable zones (caprock), is a positive shift, occasionally as far as the shale base line. Resistivity is higher through non-porous zones as a result of decreased grain size and/or increased sparry cement. The highest resistivity peak in the Kimmswick is usually the pure, lithographic limestone caprock over the upper Moredock horizon.

The SP curve shows little response to variations in argillaceous content because the Kimmswick is never very argillaceous; most positive trends can be attributed to decreases in porosity rather than increases in impurities. However, the increase of argillaceous content in the lower Kimmswick does result in lower resistivity values below the Moredock Member.

The upper Moredock horizon with oil saturation generally displays slightly lower resistivity than its pure limestone caprock. The Beecher-St.James horizon with oil saturation displays higher resistivity than its caprock in the Eagle Point Member. A dry Beecher Member displays lower resistivity than the caprock. The Eagle Point caprock is finer grained, less porous and more argillaceous than the Moredock Member above and the Beecher Member below.

Many of the wells drilled in the western fields were drilled by the Mississippi River Fuel Corporation for gas storage and many abandoned wells were converted to the same. Most of the Neutron-porosity logs on file were run for gas storage projects. Several productive wells in the Centralia field had porosity logs available. Use of Neutron logs for correlation in the Kimmswick is straightforward; absence of interbedded shales simplifies interpretation so that porosity can be read directly from the carbonate scale. Unfortunately, the number of Neutron logs available was insufficient to delineate regional porosity variations. Average porosity values are included in section IV.

Many of the files with E-logs available also include

Micro or Minilogs. Although relative porosities cannot be determined from these logs, permeable horizons are clearly delineated and permeability implies some porosity. Micrologs are most useful in determining horizon thicknesses. They can also be used to identify thin bentonites (or shales).

The lithologic strip logs are often a valuable aid in correlation. They frequently give depths of oil shows and/or productive zones. In the absence of E-logs, oil horizons are often correlatable from strip logs alone. Of additional value are core descriptions, particularly when samples are not available.

2. Drill Core. The greatest value derived from core research was in identifying the E-log responses to lithology variations, as described above. Additional value was derived in determining the nature of the porosity, the significance of dolomitization, and in identifying fossil content.

Thin Sections. The nature of the porosity in the oil horizons is generally consistent in the study area. With minor variations, all four horizons exhibit intergranular porosity which is best developed when fossil constituents are least abraded (Figures 3-6). The greatest volume of calcite in the Kimmswick is contributed by echinoderm plates and fragments. Hence, the larger the grain size, the larger the intervening pore spaces. However, an increase of fine-grained intergranular debris can lower

The abbreviations below are used to identify constituents of the carbonates in the following photomicrographs (Figures 3-21).

Br - brachiopod fragments

By - bryozoan fragments

D - dolomite

Ec - echinoderm fragments

S - siderite

Sp - sparry calcite

Ø - pore space

Note: Epoxy cement in pore space often contains air bubbles or pitted surfaces.

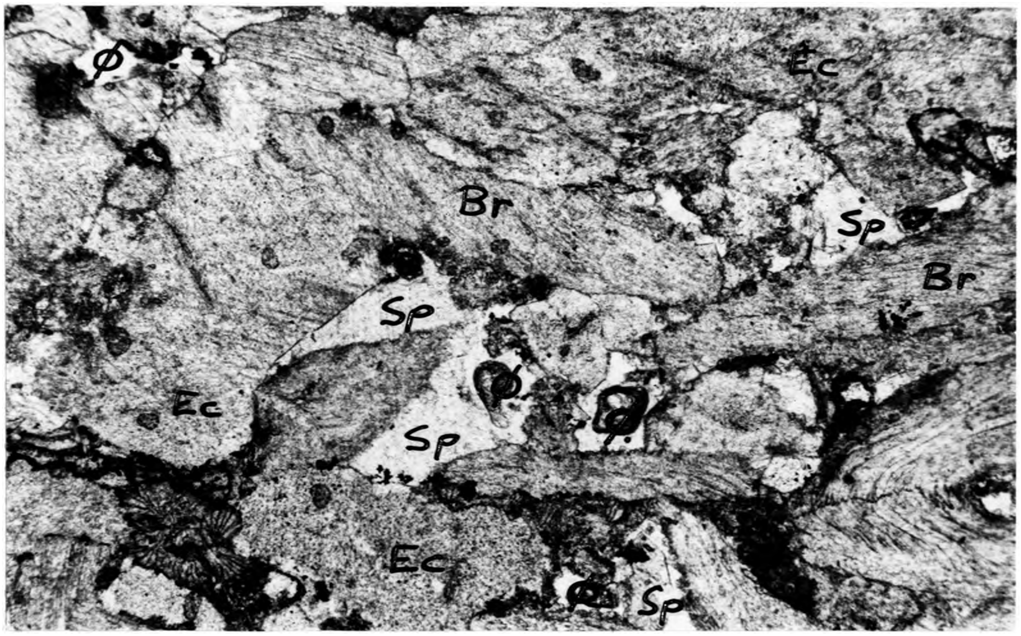

Figure 3.
Photomicrograph of New London Horizon, Salem field. Note abundance of echinoderm and brachiopod fragments, intergranular porosity, and argillaceous laminae (lower left). T.S.# CC-1. (X37)

Figure 4.
Photomicrograph of Upper Moredock Horizon, Centralia field. Note abundance of echinoderm fragments and intergranular porosity. T.S.# CP-7. (X37)

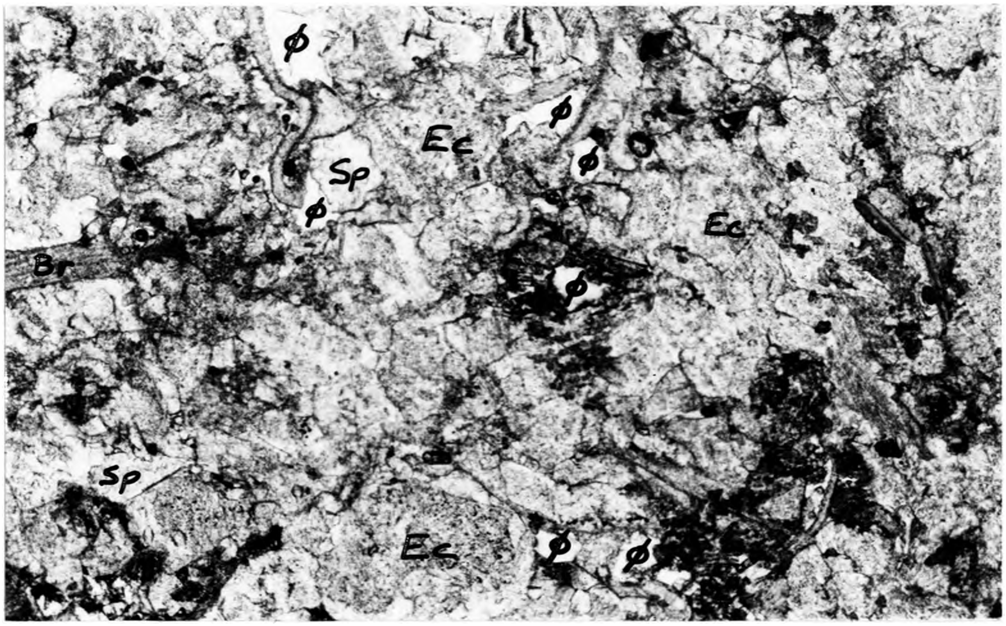

Figure 5.

Photomicrograph of Lower Moredock Horizon, Centralia field. Note abundance of echinoderm fragments, intergranular porosity, and oil in tight pore space. T.S.# CP-10. (X37)

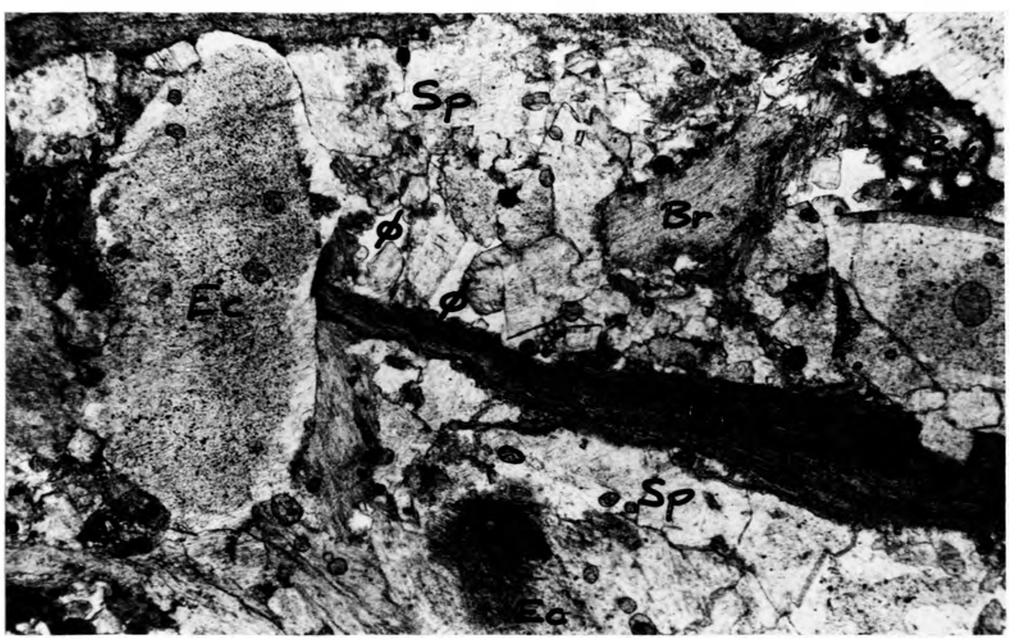

Figure 6.

Photomicrograph of Beecher-St.James Horizon, Centralia field. Note abundance of echinoderm and brachiopod fragments, intergranular porosity, and spar filling. T.S.# CB-17. (X37) the effective porosity. Note the abundance of fine-grained intergranular debris in the lower Moredock horizon (Figure 5) relative to the more porous upper Moredock horizon (Figure 4). Intergranular pore space is sometimes filled with sparry calcite, which potentially eliminates effective porosity and permeability. This is the nature of the lower Moredock caprock and the impermeable zone midway in the lower Moredock horizon (Figures 7 and 8). Sparry cement is also a factor in development of finer grained impermeable zones, but is generally indistinguishable from fine fossil debris. Spar filling primary fissures and cavities in the lithographic upper Moredock caprock, and in the Eagle Point caprock, indicate the presence of sparry cement (Figures 9 and 10).

"Vuggy porosity" is sometimes noted in I.S.G.S. core descriptions, but does not appear extensive enough to affect total pore volume significantly where observed in core samples. Vugs appear as secondary enhancement of intergranular porosity by solution, generally along permeable fissures as seen in Figure 11. Such solution has more effect on permeability than overall porosity. A balance of dissolution and reprecipitation is apparent along the borders of permeable fissures where intergranular pore space is less than in the surrounding rock. Permeable fissures are generally oriented horizontally and occur along minor fractures through zones of weakness (Figure 12) such as stylolites or paper-thin

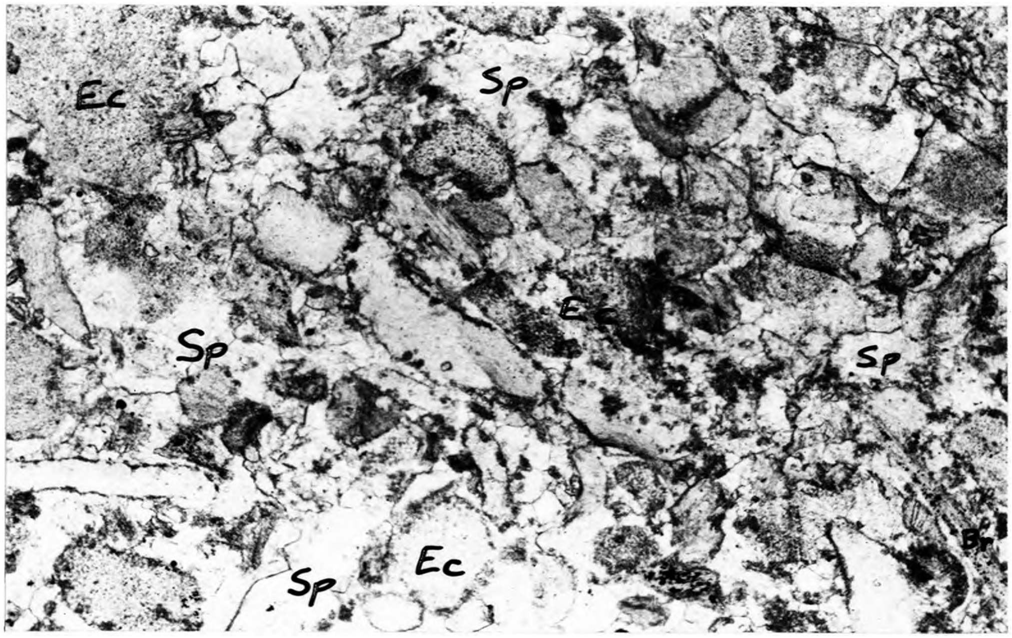

Figure 7.
Photomicrograph of Lower Moredock caprock, Centralia field. Note spar cementation and absence of porosity. T.S.# CP-14. (X37)

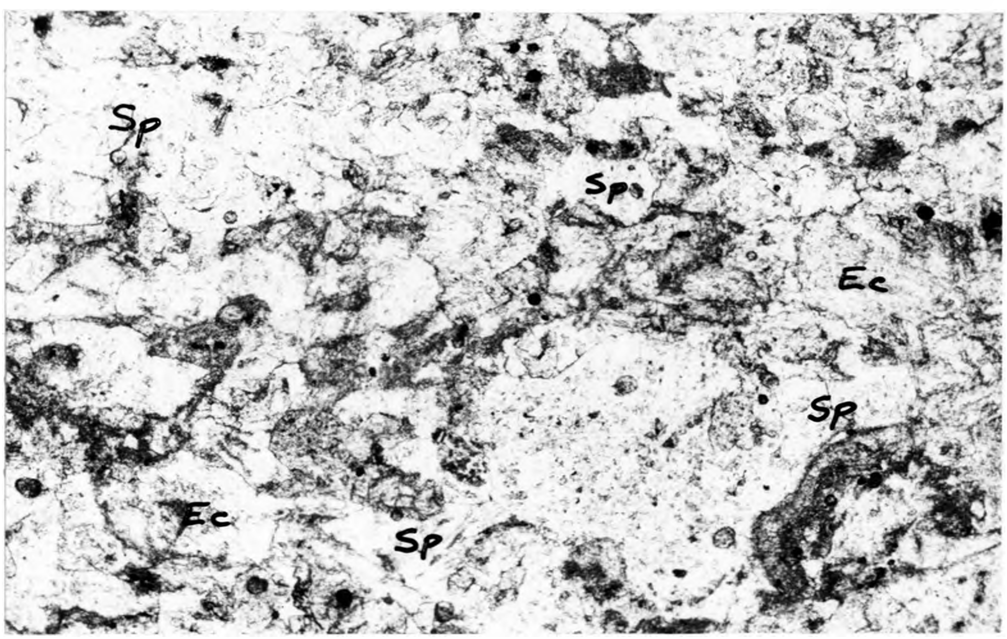

Figure 8.
Photomicrograph of Lower Moredock impermeable zone, Waterloo field. Note spar cementation and absence of porosity. T.S.# CK-21. (X37)

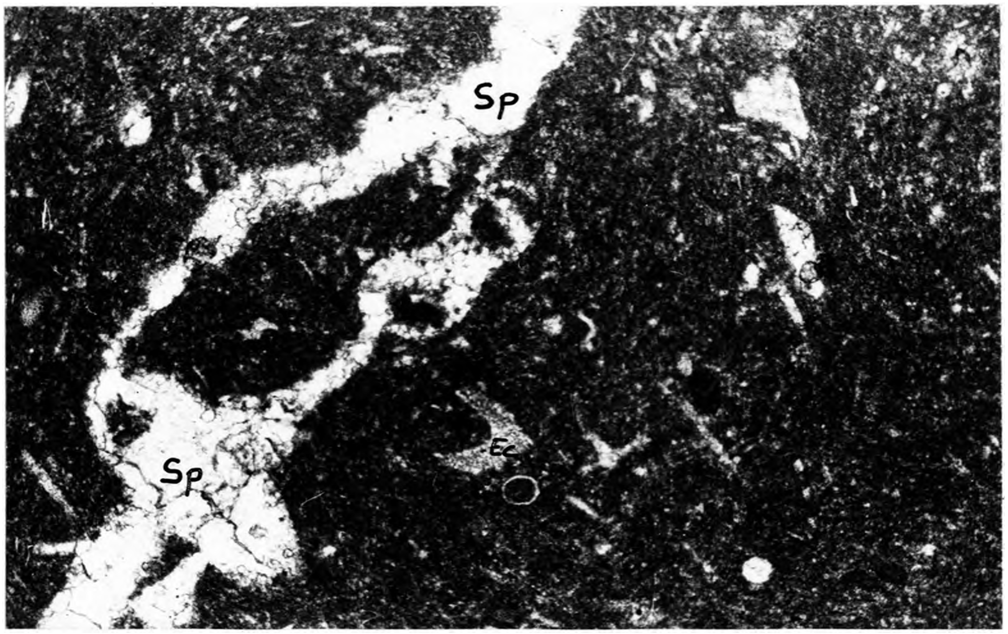

Figure 9. Photomicrograph of Upper Moredock caprock, Waterloo field. Note lithographic matrix and spar filling fissures and cavities. T.S.# CK-1. (X37)

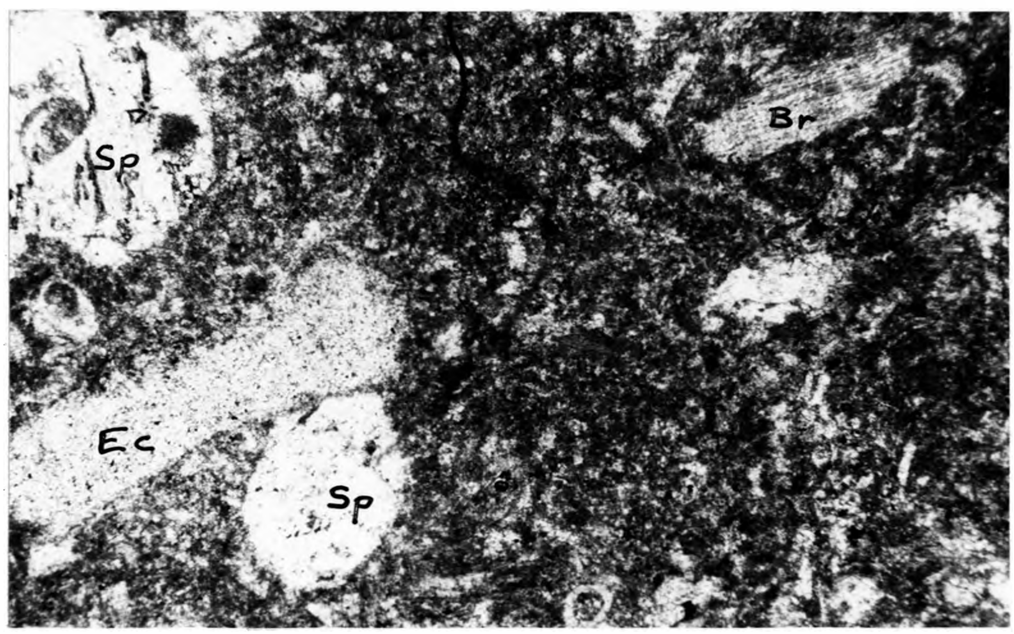

Figure 10. Photomicrograph of Eagle Point Caprock, Centralia field. Note lithographic matrix and spar filling cavities. T.S.# CP-16. (X37)

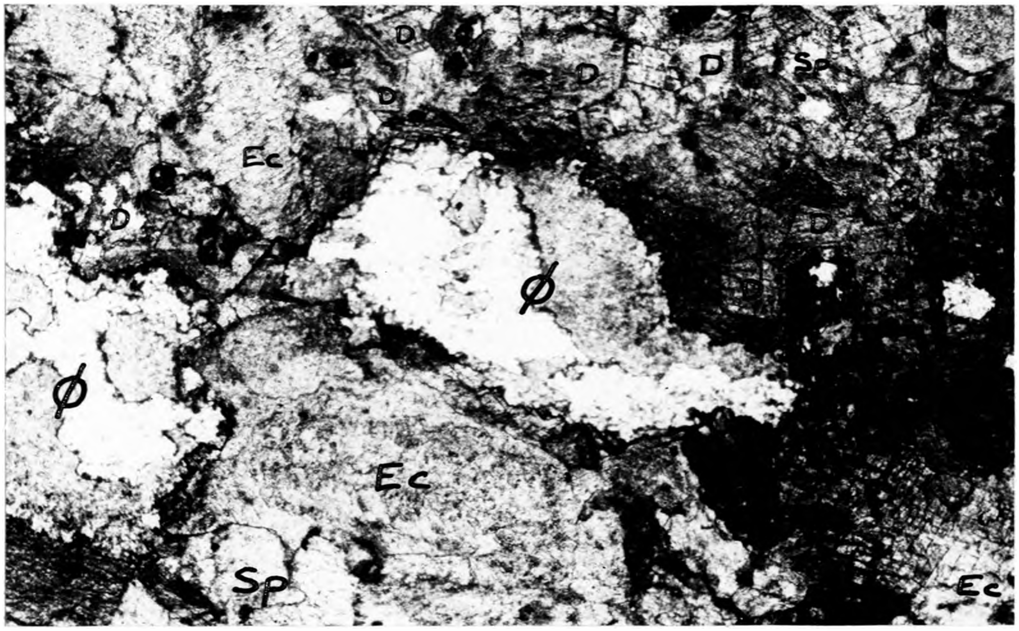

Figure 11.
Photomicrograph of Eagle Point Member, Waterloo field. Note solution vugs with associated secondary dolomite and oil in tight pore space. T.S.# CK-23. (X37)

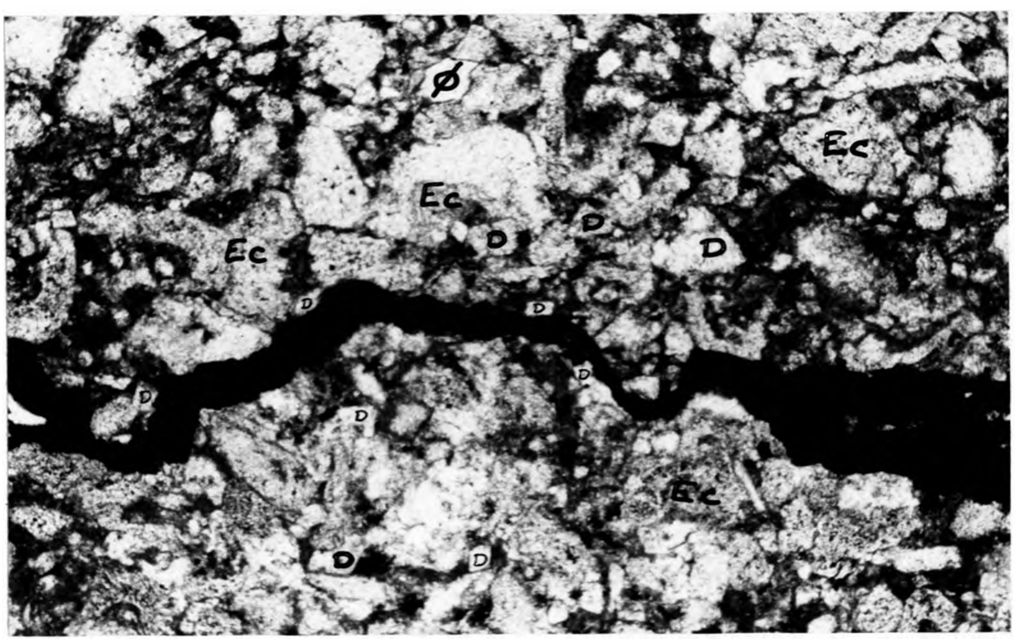

Figure 12.
Photomicrograph of Moredock Member, Waterloo field. Note secondary dolomite and dead oil in fissure. T.S.# CK-9. (X37)

clay 'drapes' (deposited on the irregular carbonate sea floor). In more porous zones such original fracture character is destroyed by extensive solution.

Dolomitization is most extensive in the Waterloo field, and even there, has no apparent effect on overall porosity. This is revealed in thin sections by the nature of its occurrence. Occurring almost exclusively as euhedral to subhedral dolomite rhombs along permeable fissures (Figure 12), dolomite is also found bordering solution vugs (Figure 11), and is absent in impermeable zones. Dolomitization occurs to some degree in all four horizons throughout the basin. However, dolomite rarely exceeds 10 percent of the rock constituents.

Fossils were not used for correlation due to the lack of significant marker species between members of the Kimmswick, and because the volume of available core is not enough to insure adequate sampling. Undifferentiated echinoderm fragments constitute over 50 percent of the reservoir rocks, based on thin section observations. Brachiopod shells are the second most abundant fossil constituents and develop primary porosity as seen in Figure 13. The third primary fossil constituents are bryozoans, which enhance effective porosity with increasing colony size. When oil is present, it occurs along zooecia of bryozoan colonies (Figure 14).

3. Field Research-Outcrops. A number of factors make correlation of potential oil horizons more difficult

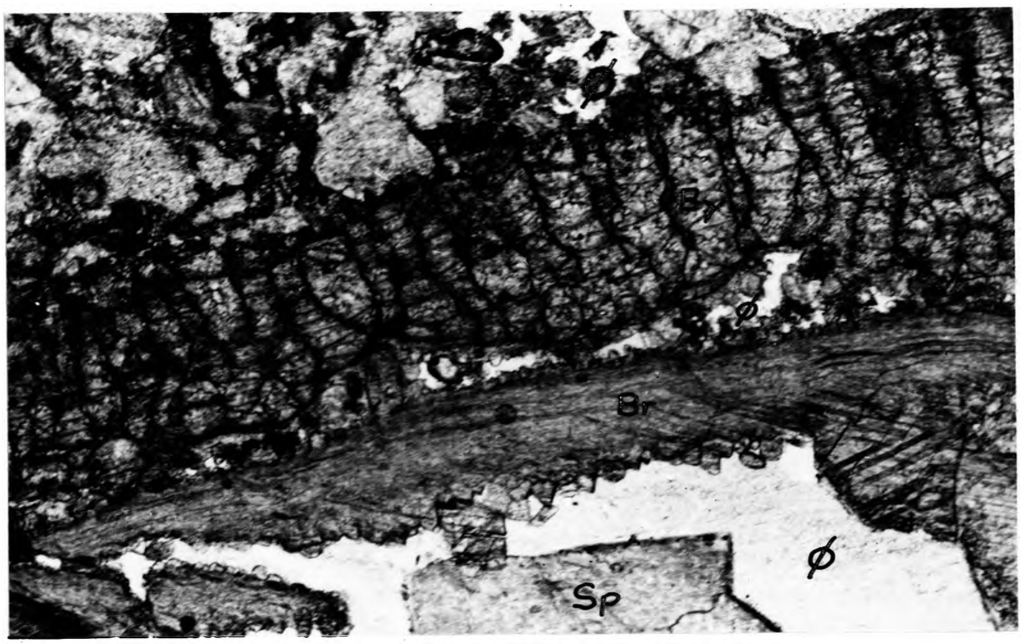

Figure 13.

Photomicrograph of Upper Moredock Horizon, Centralia field. Note bryozoan attached to brachiopod shell in growing position, with intergranular pore space beneath. T.S.# CB-13. (X37)

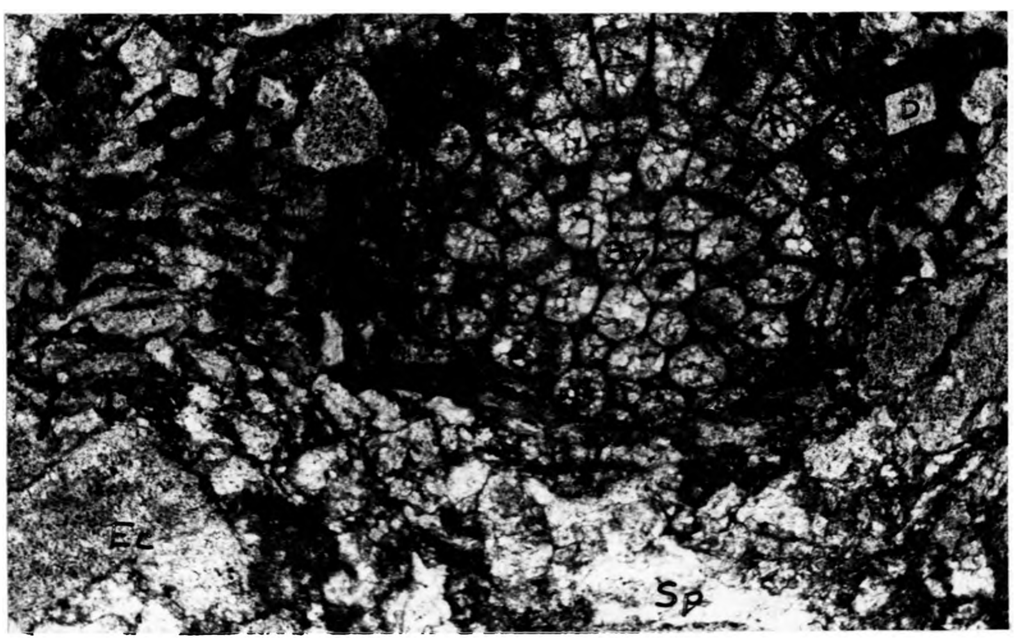

Figure 14.

Photomicrograph of Upper Moredock Horizon, Waterloo field. Note oil saturation in bryozoan. T.S.# CK-13. (X37) in outcrop than on well logs. Facies changes near the Kimmswick depositional shoreline of the Ozark Dome are more adverse than in the concurrent offshore Illinois Basin. Such variations break down cyclic lithology patterns, which is probably why Misra's (1964) Missouri Kimmswick classification differentiates members substantially by spar content, rather than by the lithologic factors described by Templeton and Willman (1963).

In outcrop, secondary porosity produced by surface waters tends to obscure intergranular porosity. Since the nature of the primary porosity and fossil fauna are fairly uniform in all four horizons, the extent of the impermeable caprocks essentially delineates the porous horizons. Impermeable zones can sometimes be identified by their resistance to weathering, although development of vuggy weathering in these zones can be misleading. In thin section a high spar content helps identify impermeable zones. Impermeable zones in the study area often correlate with chert zones in outcrop. A notable case is the Defiance Quarry, St.Charles County, Missouri, where the three major chert zones present all correlate with oil horizon caprocks. Chert is rarely noted on strip logs, and then only from the Eagle Point Member.

Vuggy porosity, of the nature and scale seen in Figure 15, develops along vertical fissures near the surface, is not present at depth, and often occurs in relatively low porosity rocks. The more easily corroded (pre-vug) material is generally dolomitized and/or includes limonite grains with associated siderite replacement. The limonite grains are distributed randomly in small clusters and therefore appear to be a primary inclusion (possibly oxidized pyrite), deposited sporadically in the agitated nearshore carbonates. Siderite replacement probably occurred during limonite leaching by subsurface fluids (See Figure 16, from the House Springs outcrop where the entire Kimmswick section is exposed, but is represented by only 17 feet of strata).

Figure 15.
Outcrop of New London Member, Barnhart Quarry, Missouri. Note the vuggy surface weathering. Locality E. (Rock pick for scale.)

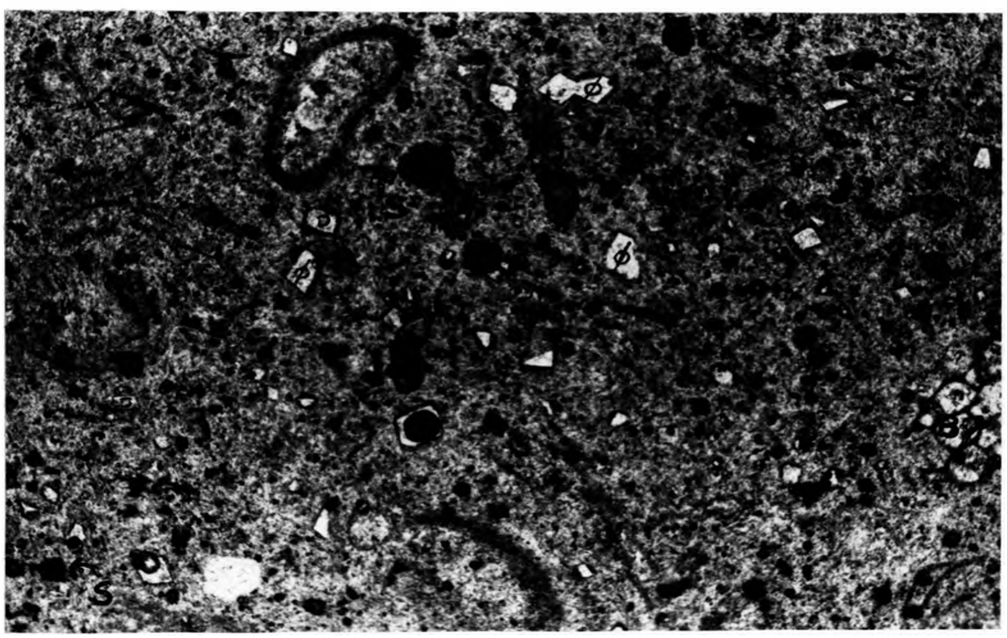

Figure 16.
Photomicrograph of dolomite and siderite alteration, House Springs outcrop, Missouri. Note: thin section stained with Alizarin Red in basic solution; siderite rhombs - black, eroded rhombs (pore space) - white, dolomite rhombs - intermediate. Some black irregular grains are limonite. T.S.# HS-1. (X37)

IV. THE KIMMSWICK OIL HORIZONS

A. NEW LONDON HORIZON

1. Lithology. The New London horizon is located near the base of the New London Member, in the Dunleith Formation (Figure 2). The New London horizon typically consists of calcirudite, interbedded with thin lenses of fine- to medium-grained calcarenitic limestone. The New London Member is mostly fine-grained calcarenite, interbedded with lenses of coarse-grained calcirudite. These calcirudite lenses are more porous and permeable than the finer grained calcarenites. It is the development of a continuous interval of porous calcirudite lenses that characterizes the New London horizon. Fossils are much the same as the lower Kimmswick horizons - mostly undifferentiated echinoderm, brachiopod, and bryozoan fragments. The New London Member, as well as the New London horizon, is slightly argillaceous compared with the Moredock Member below. Argillaceous material occurs as thin fissile laminae and as minute flecks throughout (Figure 3). Spar content is greater than in the Moredock horizons, up to 40 percent. The New London horizon is capped by the less permeable calcarenites of the New London Member and the Maquoketa shales above.

2. Occurrence and Thickness. The New London horizon occurs almost exclusively in the eastern fields, being truncated by the pre-Maquoketa unconformity in the western

fields (Figure 17). On the basis of total Kimmswick thickness at Dupo (about 100 feet, as opposed to about 95 and 90 feet at Waterloo and St.Jacob, respectively), oil reported at the top of the Kimmswick on strip logs for some Dupo wells is probably produced from the New London horizon. However, sufficient E-log data is not available to verify this. The top of the horizon is within two feet of the top of the Kimmswick in the Patoka and Fairman fields, and occurs within 10 feet of the top in the Centralia and Salem fields. The thickness is consistently about three feet, except in the Patoka field where an additional foot of permeable strata occurs below this three foot interval, separated from it by one foot of impermeable strata.

3. E-Log Characteristics. The SP curve is typically characterized by the first negative peak (beneath the Maquoketa shales) centered in the New London horizon (Figure 2b and 2c). The curve deflects positively in the upper Moredock caprock beneath. The peak response is generally 1/2 to 2/3 (negatively from the shale base line) that of the upper Moredock horizon; this is attributed to lower porosity and thinness of the horizon. The Short Normal curve exhibits lower resistivity in the New London than in the Moredock horizons - about the same as the Beecher-St.James horizon (both are slightly argillaceous). Resistivity of the horizon with oil saturation reads about equal to its finer grained caprock, and reads slightly

Figure 17. Generalized correlation section of Kimmswick oil horizons and impermeable zones in southwestern Illinois. Spar-cemented impermeable zones indicated by xxxxxxx. Vertical scale: 1in.=25ft. Zero base line at Kimmswick top. Horizontal distances not to scale. Oil field structures are not included due to extreme vertical exaggeration. See Figure 1 for oil field localities.

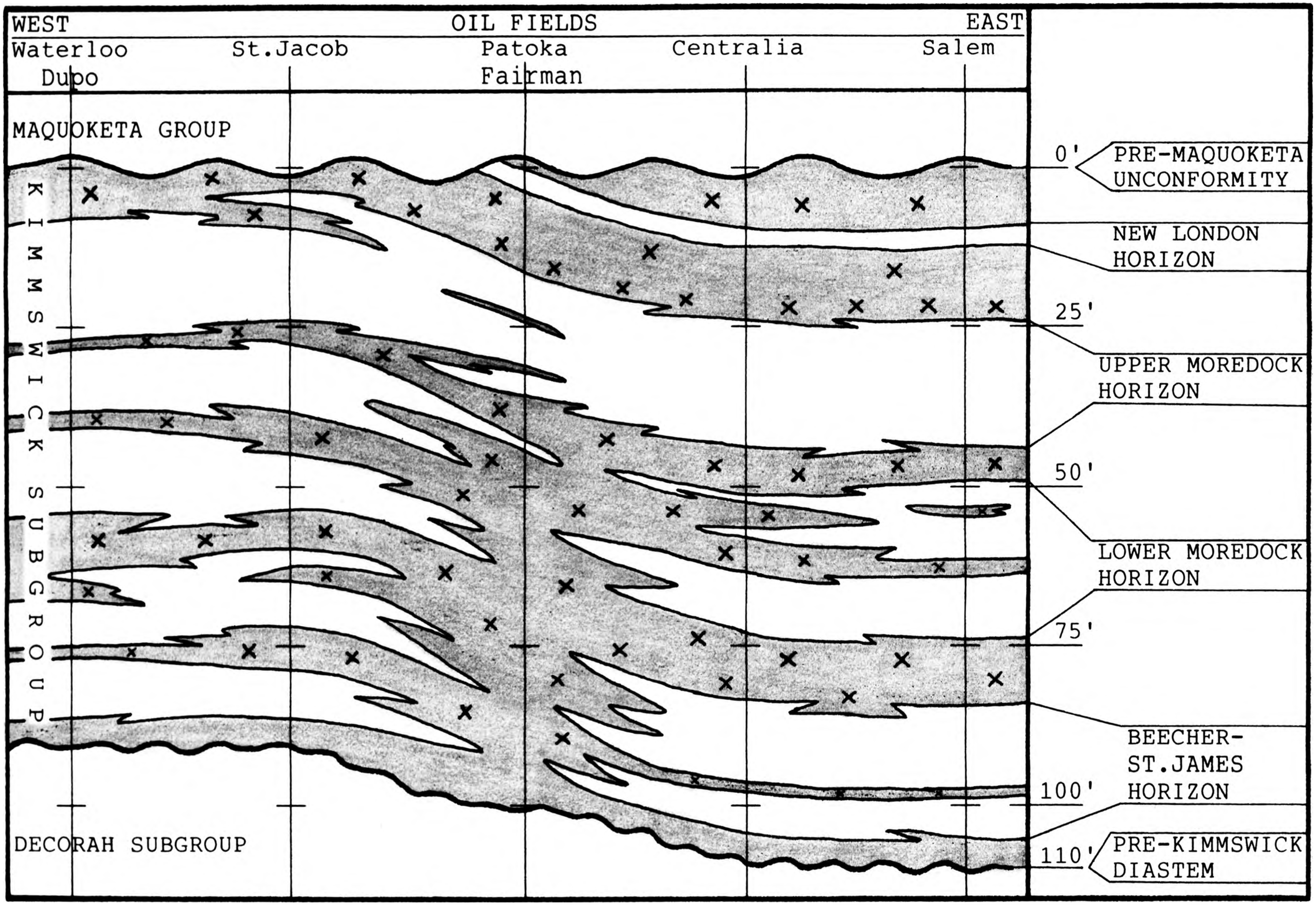
WEST
OIL FIELDS
EAST
Waterloo
Dupo
St.Jacob
Patoka
Fairman
Centralia
Salem
MAQUOKETA GROUP
KIMMSWICK SUBGROUP
DECORAH SUBGROUP
0'
25'
50'
75'
100'
110'
PRE-MAQUOKETA UNCONFORMITY
NEW LONDON HORIZON
UPPER MOREDOCK HORIZON
LOWER MOREDOCK HORIZON
BEECHER-ST.JAMES HORIZON
PRE-KIMMSWICK DIASTEM

Figure 17.

lower when the horizon is dry. The resistivity increases considerably in the pure caprock beneath. The Long Normal tool has too large a sphere of influence to identify the New London horizon. The Micrologs respond with a sharp delineation of the permeable interval (Figure 18).

4. Permeability and Production. Permeability is indicated by borehole mudcake build-up, as seen on the Micrologs. Porosity as indicated by SP and Neutron logs is generally about nine to 12%, comparable to the lower Moredock. The New London horizon should contribute production in productive wells, and does in the Patoka and Fairman fields. However, it rarely shows oil in the Centralia or Salem fields. At Centralia this may be partially attributed to the competency of the upper Moredock caprock. This generally lithographic caprock is a cemented calcarenite at Salem, which may allow more active oil migration into the New London horizon. Several wells record shows in the Maquoketa Group above, (one in the Centralia field). A core from one showed only traces of oil in the upper Moredock and New London horizons, with fair shows through a 20-foot interval of vuggy argillaceous limestone and shales at the base of the Maquoketa Group. This lends doubt as to the competence of the Maquoketa as the ultimate seal for the Kimmswick oil horizons.

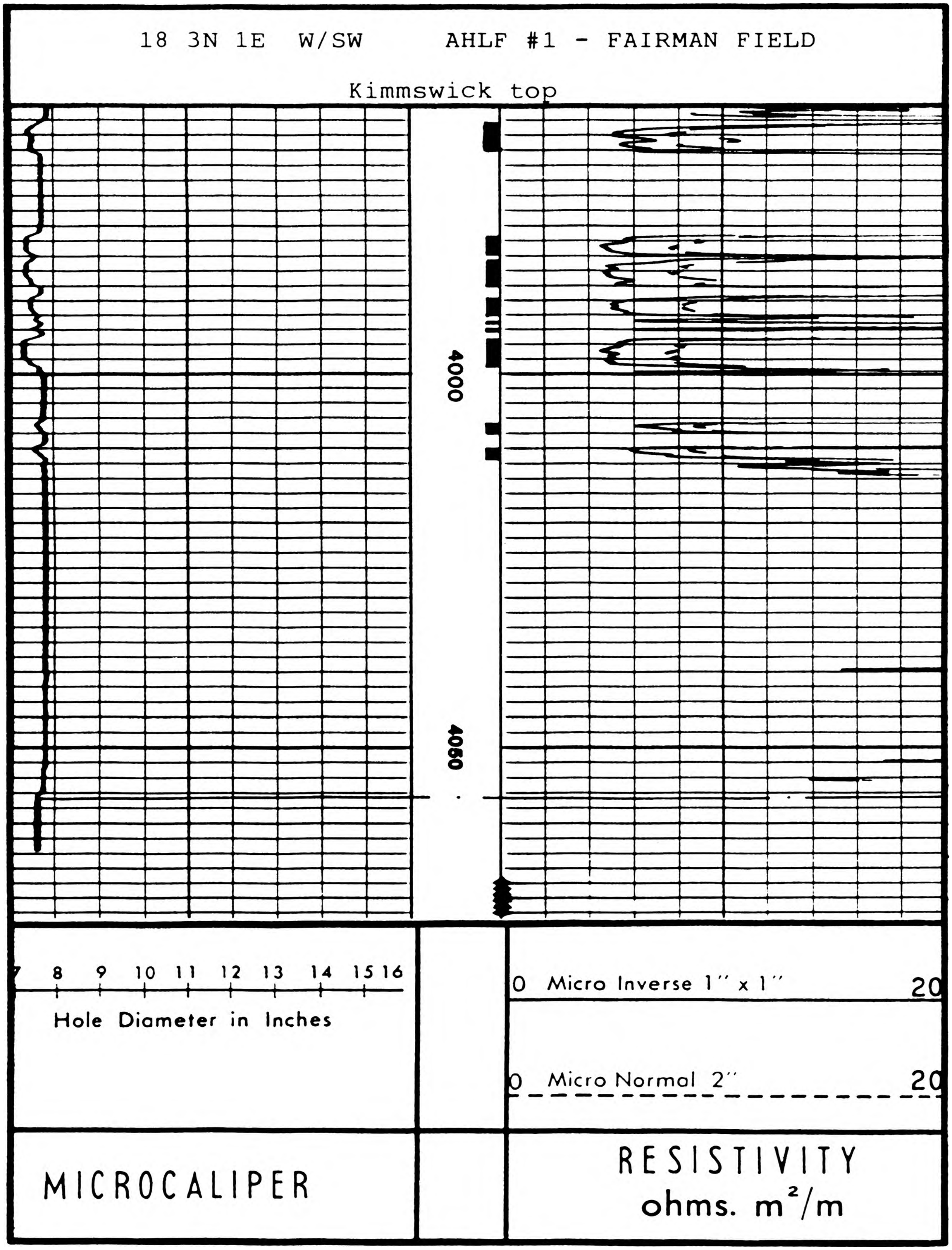

Figure 18. Example Microlog. (Note: New London Horizon; 3967-70', Upper Moredock Horizon; 3981-99'.)

B. UPPER MOREDOCK HORIZON

1. Lithology. The upper Moredock horizon is located in the upper half of the Moredock Member, in the Dunleith Formation (Figure 2). It typically consists of coarse-grained fossiliferous calcarenite to calcirudite with interbedded thin lenses of (often impermeable) fine-grained calcarenite. These lenses vary in frequency from rare occurrence in the western fields, to a frequency where they replace 1/3 of the permeable strata in the Patoka and Fairman fields (Figure 18). The upper Moredock is relatively rich in bryozoan fragments and *Receptaculites oweni* occurs most frequently in this horizon. It is notably pure and generally consists of less than 10 percent sparry calcite. In the St.Jacob field the top four feet of the upper Moredock horizon is segregated from the rest by about six to 12 feet of relatively impermeable calcarenite, cemented with over 40 percent spar (Figure 17). The upper Moredock caprock is the transition zone to the contact with the New London Member above. It is persistently a pure dense limestone of dominantly lithographic matrix and sparry cement (Figures 9 and 19). In the Salem field its density is lower due to a lack of lithographic matrix; in this facies, it is better described as a spar-cemented calcarenite (Figure 20).

2. Occurrence and Thickness. The upper Moredock horizon occurs throughout the basin. At Dupo and Waterloo

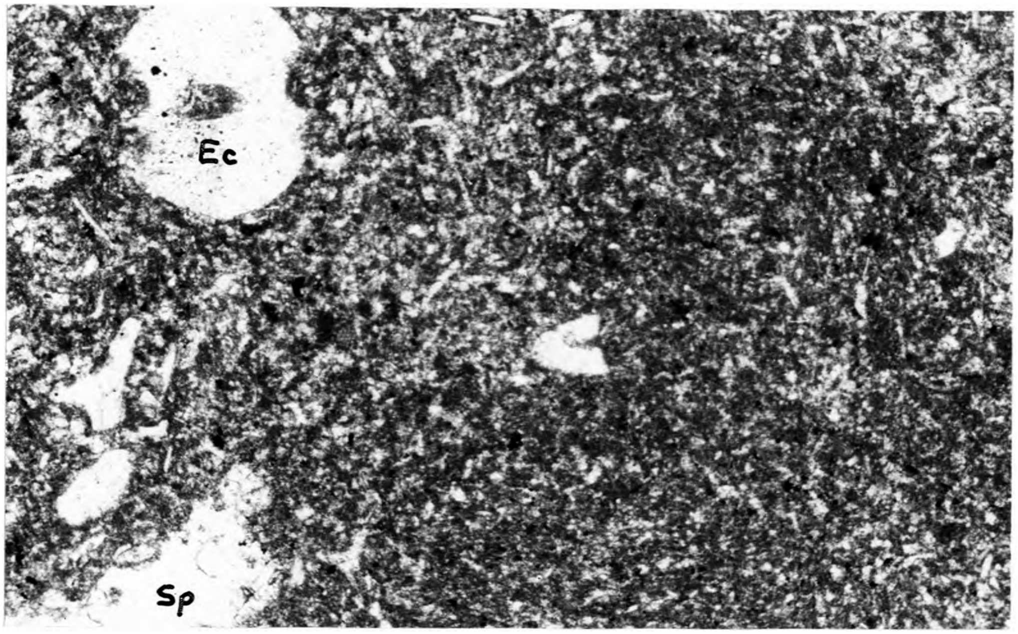

Figure 19.
Photomicrograph of Upper Moredock caprock, Centralia field. Note lithographic matrix and spar filling cavity. T.S.# CP-13. (X37)

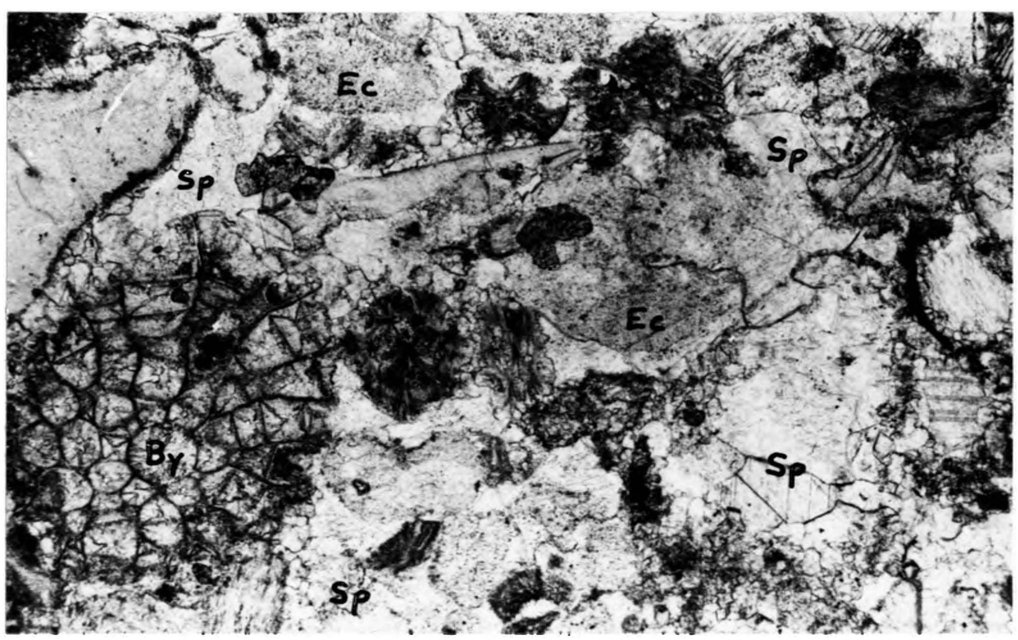

Figure 20.
Photomicrograph of Upper Moredock caprock, Salem field. Note spar cementation, lack of lithographic matrix, and absence of porosity. T.S.# CC-3. (X37)

its top is about 20 feet below the top of the Kimmswick and its thickness is about 20 feet. The lithographic upper Moredock caprock is within the top 10 feet, and the impermeable calcarenite (that divides this horizon in the St. Jacob field) is directly beneath the caprock, with no segregated permeable zone. In the St.Jacob field the segregated permeable zone is within two feet of the top of the Kimmswick; the major portion of the horizon is 10-15 feet from the top and is 15-20 feet thick. The upper Moredock horizon top is about 16 feet below the Kimmswick top and averages 18 feet thick in the Patoka and Fairman fields. It is 25-30 feet below the top and 15-20 feet thick in the Centralia and Salem fields.

3. E-Log Characteristics. The upper Moredock horizon generally exhibits the strongest negative SP peak of the Kimmswick limestone, and its caprock shows the most positive SP peak (Figures 2b and 2c). The Normal curves exhibit the highest resistivity in the upper Moredock caprock, except in its cemented calcarenite facies at Salem. Disregarding its caprock, the horizon with oil saturation displays the highest resistivity of the Kimmswick. When the upper Moredock horizon is dry the lower Moredock caprock and/or a lower horizon with oil saturation may display higher resistivity. The Micrologs clearly delineate the horizon and the frequency of interbedded impermeable lenses (Figure 18).

4. Permeability and Production. The upper Moredock is permeable throughout the basin. Porosity as indicated by Neutron logs is generally about 12-14%. Porosity as indicated by SP and Neutron logs is usually the greatest in the upper Moredock, and it is the most productive horizon in the basin. It contributes production in all productive wells except in a portion of the Salem field. Of 12 Salem wells that produced from the Beecher-St.James horizon, eight produced from the upper Moredock also. Of the remaining four wells, two had oil shows recorded in the New London horizon which again indicates oil migration through the upper Moredock caprock in the cemented calcarenite facies.

C. LOWER MOREDOCK HORIZON

1. Lithology. The Lower Moredock Horizon is located in the lower half of the Moredock Member, in the Dunleith Formation (Figure 2). It is mostly a coarse- to medium-grained fossiliferous calcarenite with some thin fine-grained zones. Fossil fauna is as in the upper Moredock, except for a lack of *Receptaculites oweni*. The purity and spar content is comparable also, except in its caprock and a two to 10 foot thick (often impermeable) zone midway through the horizon that are dense with sparry cement (Figures 7 and 8). The caprock is often vertically continuous with the middle lower Moredock impermeable zone in the eastern fields.

2. Occurrence and Thickness. In the western fields, total thickness is 25-30 feet with two to 10 feet of relatively impermeable strata about midway in the horizon. The caprock zone is correlatable, but too thin to seal the horizon in the western facies. In the Centralia and Salem fields, the bottom half of the horizon is about 10 feet thick and the top half is zero to 10 feet thick. The lower Moredock caprock is at least 10 feet thick in the eastern facies, and when vertically continuous with the middle impermeable zone it is about 25 feet thick. The lower Moredock horizon is impermeable in the Patoka and Fairman fields.

3. E-Log Characteristics. The SP response is usually slightly more positive than that of the upper Moredock horizon. Positive peaks (of varying intensity) occur at the lower Moredock caprock, the middle impermeable zone, and the Eagle Point Member below (Figures 2b and 2c). The Normal curves exhibit a resistivity peak through the caprock comparable to a reading in the upper Moredock horizon with oil saturation. The lower Moredock horizon itself displays lower resistivity than its impermeable caprock. In the western facies, the caprock zone often displays lower resistivity than the lower Moredock horizon with oil saturation. The middle lower Moredock impermeable zone displays a smaller peak than the caprock, about equal to (and therefore often concealed by) the horizon with oil saturation.

4. Permeability and Production. Permeability variations are discussed above. Porosity as indicated by SP and Neutron logs is generally about 10-12%, slightly lower than the upper Moredock horizon. The lower Moredock horizon contributes production in all but the Patoka and Fairman fields. Generally an oil column is present only in wells with an oil column in the upper Moredock also.

D. BEECHER-ST.JAMES HORIZON

1. Lithology. The Beecher-St.James horizon includes the Beecher and St.James Members, in the Dunleith Formation (Figure 2). It typically consists of medium- to coarse-grained fossiliferous calcarenite to calcirudite, with several feet of finer grained argillaceous limestone midway in the horizon which correlates with the top of the St.James Member (Figure 21). The fossil fauna is typical of the Kimmswick. This horizon contains more spar and is more argillaceous than the Moredock horizons; argillaceous material occurs as thin fissile laminae and as minute flecks throughout (Figure 22). The lower half is generally finer grained calcarenite than the top half, and often consists of up to 50 percent sparry calcite. The horizon is capped by fine-grained to lithographic limestones of the Eagle Point Member (Figure 10). Inconsistent permeable facies occur in the Eagle Point Member (particularly in the western fields); due to lack of persistence, they are included in the lower Moredock or

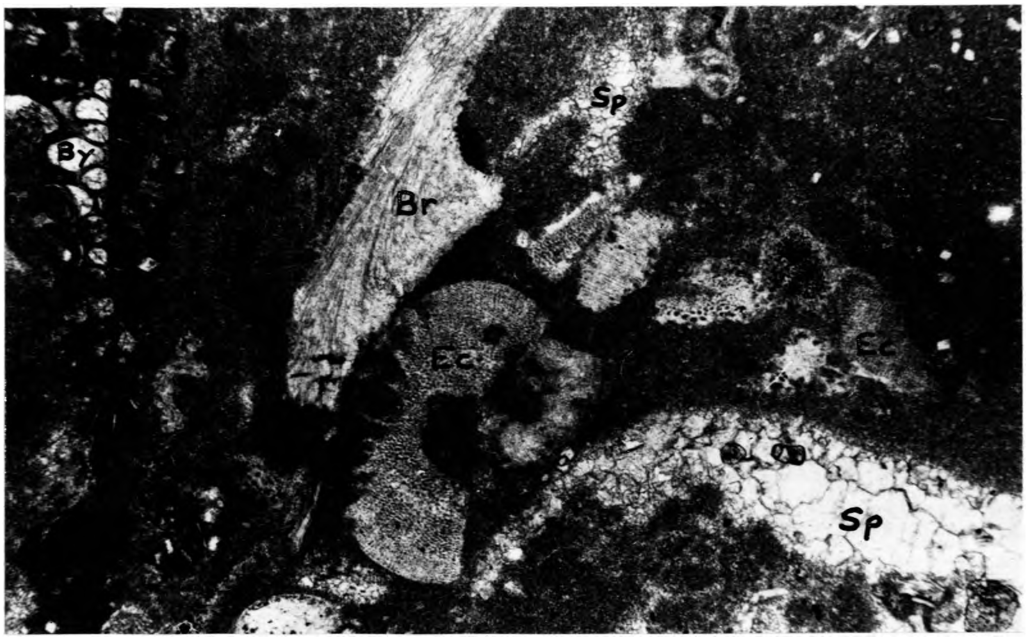

Figure 21.
Photomicrograph of top of St.James Member, Salem field. Note lithographic matrix and spar filling cavities. T.S.# CC-7. (X37)

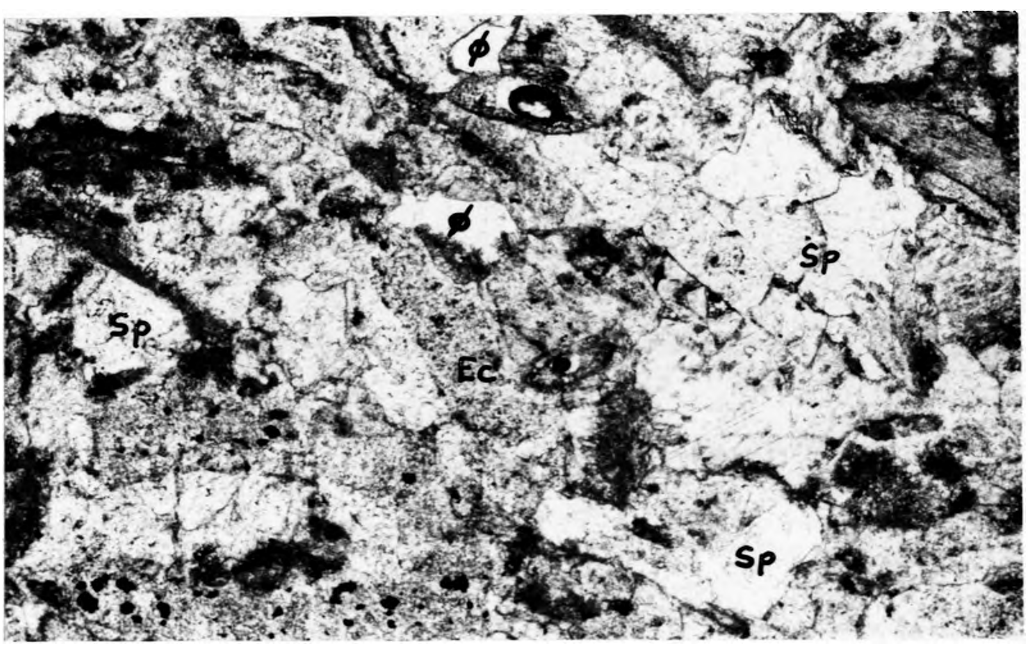

Figure 22.
Photomicrograph of Beecher-St.James Horizon, Waterloo field. Note argillaceous flecks (lower left), spar filling, and oil in tight pore space.
T.S.# CK-25. (X37)

the Beecher-St.James horizon, depending whether they occur above or below the Eagle Point caprock.

2. Occurrence and Thickness. The Beecher-St.James horizon is permeable in all but the Patoka and Fairman fields. It occurs at the base of the Kimmswick and is typically about 20 feet thick. A zero to eight foot thick impermeable zone occurs at the top of the St.James Member.

3. E-Log Characteristics. The Beecher-St.James SP response is slightly more negative than that of the lower Moredock horizon (Figures 2b and 2c), and occasionally more negative than that of the upper Moredock. A positive peak occurs through the Eagle Point caprock and a minor positive peak often characterizes the fine-grained zone (midway in the horizon). The Normal curves display generally lower resistivity through this horizon due to its slight argillaceous content. The Eagle Point caprock generally exhibits higher resistivity readings than a dry lower Moredock horizon. When the Beecher-St.James horizon is dry, the top half displays lower resistivity (with a minimum value through the argillaceous middle portion), and the lower half peaks at a value comparable to the caprock, (attributed to high spar content in the St. James Member). The Beecher-St.James horizon with oil saturation exhibits resistivity comparable to the lower Moredock horizon with oil saturation, and the Eagle Point Member is characterized by a minimum deflection between the two horizons.

4. Permeability and Production. Permeability is indicated by the Micrologs, and an impermeable zone breaks the horizon midway. Porosity as indicated by SP and Neutron logs is eight to 16%, comparable to the upper Moredock horizon but less consistent (lower in the western fields and often greater in the Centralia and Salem fields). The Beecher-St.James horizon is a significant producer in the Salem field only, although a few wells in the Centralia and Waterloo fields show oil in this horizon. An oil column is generally only present when the Moredock horizons include oil columns through their entire section. This indicates a poorly sealed caprock in most cases. However, several Salem wells produce from the Beecher-St.James where the upper Moredock horizon is dry, which indicates integrity of the Eagle Point caprock and/or the lower Moredock caprock in this facies.

V. KIMMSWICK FACIES MODELS

A. PRE-KIMMSWICK

The prevailing environment during the time of deposition of the Plattin (Blackriver/Platteville) and Decorah (Trenton/Galena) was that of a relatively deep water platform. The Plattin limestones are mostly fine-grained to lithographic, which indicates erosive transport from shallower water and/or deposition of primarily pelagic carbonates. The Plattin includes interbedded shales, derived from clastic influx associated with uplift and erosion of positive structural features surrounding the Illinois Basin. The deep water environment continued during Decorah deposition, and an increase of fine clastics resulted in a shaly facies in the study area. The Ozark Dome provided a Decorah shoreline and marks a zone of partial deposition of Decorah strata. A minor unconformity or depositional hiatus occurred just prior to Kimmswick time, which is marked by corrosion surfaces at the Decorah contact.

B. KIMMSWICK DEPOSITION

With transgression of the sea at the onset of Kimmswick deposition, a shallow water platform resulted in the western Illinois Basin. The Basin deepened in northern Illinois, where deposition was continuous from Decorah time. The Buckhorn Member (Figure 2) is somewhat transitional from the Decorah below, as indicated by its shaliness. Little or no Buckhorn strata are present in the study area. Their absence verifies the pre-Kimmswick hiatus in the southern facies.

The St.James Member is mostly medium-grained calcarenite, with argillaceous streaks and flecks distributed throughout. Lack of shaly beds indicates a relatively high energy environment in the study area. The close of St.James deposition is marked by an argillaceous zone, with a bentonite bed and chert nodules occasionally present on the flanks of the Ozark Dome. Bentonites indicate volcanic activity; the influx of volcanic ash temporarily choked the shallow water benthonic filter feeders, and dissolution of ash saturated the sea water with respect to silica. The resultant decay of organisms caused an increase of carbon dioxide and lowered the pH, which promoted superficial dissolution of the aerated carbonates and favored silica precipitation (chert nodules). As the slightly acidic carbonate-laden seawater circulated deeper through the relatively alkaline St.James sediments, precipitation of sparry calcite resulted. A short interval of prominently pelagic deposition followed, which is indicated by a thin zone of fine-grained limestone. In the study area, St.James porosity increases to the east, which is attributed to spar content diminishing with distance from the Kimmswick shoreline (the source of the relatively acidic carbonate-laden seawater). The basin deepened northeastward, which promoted pelagic deposition through mid-Moredock time in that corner of the study area.

The shallow water platform persisted during deposition of the Beecher Member. Volcanic quiescence is evident by the absence of bentonites and general decrease in argillaceous content. The Beecher lithology is relatively consistent across the basin and facies changes are only local variations.

The Eagle Point Member is mostly fine-grained calcarenite to lithographic limestone, which indicates prominently pelagic deposition in a relatively deep Kimmswick sea. The Eagle Point is slightly argillaceous as compared to adjacent members. In the western study area, the Eagle Point Member includes a shallower water facies of permeable calcarenite. The persistence of a chert facies, throughout the greater Illinois Basin, indicates uniform silica saturation of the Eagle Point seawater. Such widespread saturation is attributed to circulation of a perennial silica influx from submarine volcanism. Argillaceous material may have been derived from the same volcanic source.

A shallow water platform was the prevalent environment during Moredock deposition. Volcanic quiescence on the Ozark Dome is indicated by the purity of the entire Moredock Member. However, northern Illinois bentonites reported in the upper half of the Fairplay

Member and at the top of the Mortimer Member (Templeton and Willman, 1963, p.121-22), correlate with the sparry impermeable zone of the lower Moredock horizon and the lower Moredock caprock respectively (Figure 2a). Volcanism in the Appalachian mobile belt is the probable source of the northern bentonites (Willman and Kolata, 1978; Templeton and Willman, 1963). Westward circulation of volcanic ash along the northern Illinois Basin shoreline produced the same chemical influences discussed previously. Longshore currents continued southward, circulating the relatively acidic carbonate-laden seawater that then cemented the southern spar zones. The exceptionally thin, western facies of the lower Moredock caprock probably resulted from a slightly more acidic nearshore environment (favoring calcite dissolution and silica precipitation). This is supported by a correlated chert zone in Missouri outcrop. In the eastern study area, low porosity in the top half of the lower Moredock horizon probably resulted from deep circulation of carbonate-laden seawater, which precipitated spar amidst Moredock fossil debris.

Uplift of the impermeable northeastern facies occurred during Moredock time and a shallow water benthonic fauna dominated deposition of the upper Moredock. Deposition of calcarenite and calcirudite continued across the basin, with intermittent pelagic deposition (particularly in the northeastern facies). The sparry impermeable zone that splits the top of the upper Moredock horizon in the St.Jacob field correlates with a prominent bentonite reported near the top of the Rivoli Member (Figure 2a) in Iowa and Minnesota (Templeton and Willman, 1963, p.122). The same sparry zone has no permeable facies separating it from the lithographic upper Moredock caprock throughout the rest of the basin. General subsidence of the Illinois Basin and local uplift at Salem marked the close of Moredock time. The Salem area remained relatively shallow and the western seas deepened. The pure lithographic caprock was deposited from a primarily pelagic source and cemented by the same volcanic chemical influences previously discussed. The presence of volcanic ash is confirmed by a persistent bentonite that marks the top of the Moredock Member. Concurrently, the calcarenite caprock facies was cemented at Salem.

Uplift of the Ozark Dome in early New London time provided a shallow water platform for deposition of the New London horizon. Evidence for post-New London deposition in the study area was removed by pre-Maquoketa erosion.

C. POST-KIMMSWICK

1. Post-Depositional Changes. A maximum of 20 feet more Kimmswick strata was removed by pre-Maquoketa erosion in the western basin. Bays (1945) and Misra (1964)

contend that secondary permeability was developed by pre-Maquoketa erosion. This thesis does not dispute such reasoning, but neither does it support the theory. Permeability may have developed at any time prior to oil migration and not necessarily during pre-Maquoketa erosion. Significant secondary permeability in Kimmswick strata developed only in zones with primary porosity. Dewatering of the Kimmswick may have formed minor tension fractures (along zones of weakness), which were then modified by circulating acidic solutions (Figure 12). Fluid flow along permeable fissures improved inter-connection of pore space. Precipitation of minor amounts of sparry calcite and dolomite maintained overall porosity.

2. Structure. Late Mississippian deformation left the Kimmswick with its present structural character (Brownfield, 1954). Oil field structures are dominantly anticlinal domes on the gently dipping flanks of the Illinois Basin.

3. Oil Source and Migration. There are four possible sources for Kimmswick oil: 1) the Maquoketa Group above, 2) the Decorah Subgroup below, 3) strata older than Decorah, and 4) the Kimmswick itself. The Maquoketa Group is the most probable source, as advocated by Howard Schwalb (pers.comm.). He considers oil to have migrated laterally along permeable fissures, crossing into older strata as it moved updip from the deeper basin. Decorah

oil could have migrated directly into lower Kimmswick horizons. At the top of the Decorah Subgroup, the Guttenberg Formation is a confirmed source rock in northern Illinois, but is mostly absent in the south due to pre-Kimmswick erosion and/or non-deposition. The lower Decorah strata is not as likely as a source rock and would probably require oil percolation from an enormous area to saturate a single reservoir. Deeper sources are not as likely because, although deeper oil has been reported, such shows have yet to be substantiated. Least likely is the Kimmswick as its own source rock. The Kimmswick is so pure (in the study area) that the chance of sufficient kerogens having ever been present (to produce oil) is minimal. However, some oil may have migrated from a kerogen-rich Kimmswick facies.

VI. CONCLUSIONS

A. SUMMARY

Porous horizons and impermeable zones in the Kimmswick Limestone have been correlated between wells in the study area. Porous horizons are generally coarse-grained, fossiliferous limestone; impermeable zones are generally finer grained and spar-cemented. Impermeable zones were correlated with bentonites and chert zones in outcrops. Chemical influences associated with the influx of volcanic ash (bentonites) are considered to be responsible for precipitation of spar cement and chert nodules. Correlation was primarily delineated on E-logs. Analyses of thin sections, drill core, outcrops, strip logs, and core descriptions were all instrumental to diagnosis of the complex vertical and lateral variables that affect E-log responses.

The upper Moredock horizon is the most productive of the four potential oil horizons identified in this study; this holds true for each of the seven oil fields included in the study area. Porosity is greatest (12-14%) in this horizon and the most laterally consistent. Its caprock is the most competent of the Kimmswick caprocks. The upper Moredock oil column is encountered 25-30 feet below the top of the Kimmswick in the Centralia and Salem fields. The oil column is frequently five to 10 feet below the Kimmswick top in the western fields because pre-Maquoketa erosion has removed up to 20 feet more Kimmswick strata nearer to the Ozark Dome (Figure 17).

The lower Moredock horizon contributes production in wells favorably located on structural highs. Its oil contribution is limited by an impermeable zone midway in the horizon that is sometimes vertically continuous with the lower Moredock caprock. This can reduce the porous section to less than 10 feet. In the western fields the middle impermeable zone is thin and generally insignificant. The lower Moredock horizon is impermeable in the northeast corner of the study area.

A Beecher-St.James horizon with oil saturation contributes to production but generally only contains an oil column in wells with oil columns through the entire section of both Moredock horizons. Beecher-St.James porosity is comparable to the upper Moredock horizon, but is laterally inconsistent. The Eagle Point caprock provides a competent seal for the Beecher-St.James horizon in the Salem field, and some wells produce where the Moredock horizons are dry. At Salem, this horizon contains the oil column reported at the base of the Kimmswick by Cohee (1941) and Schwalb (pers.comm.). The Beecher-St.James horizon is impermeable in the northeast corner of the study area.

The New London horizon contributes production in the Patoka and Fairman fields, but is only three feet thick. It is generally truncated by pre-Maquoketa erosion in the western fields.

B. DRILLING RECOMMENDATIONS

1. Western Study Area. In the western half of the study area, if oil is not encountered in the upper Moredock horizon the possibility of an oil column in the lower horizons is slight. If the Moredock horizons do not include oil columns through their entire vertical section, an oil column in the Beecher-St.James horizon is unlikely because the Eagle Point caprock is generally not an adequate seal in the western facies.

2. Eastern Study Area. In the eastern half of the study area, generally the entire Kimmswick should be tested as there is the possibility of an oil column in the Beecher-St.James horizon even when the Moredock horizons are dry. An exception to this generalization is when the lower Kimmswick proves non-porous, such as in the Patoka and Fairman fields.

3. North of Study Area. In the Woburn field, northern Bond County, the lower Kimmswick horizons are permeable. Since the Patoka and Fairman fields (to the southeast) exhibit a deeper water (impermeable) facies for the lower Kimmswick, the Woburn area may have been a local high during deposition. If this was the case, there are likely to be other such porous facies farther north, which includes the possibility of stratigraphic traps.

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VITA

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APPENDIX A

TABULATION OF WELLS

LOCALITY 1
Waterloo Field - Monroe County, Illinois.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
35	1S	10W	SW/SE/SW	Friedrick #5	SP, Res.
2	2S	10W	NE/NW/SW	Acker #1	---
2	2S	10W	NW/SE/SW	Acker #2	---
2	2S	10W	W/SE/SW	Acker #3	---
2	2S	10W	SW/SW/NW	Gummersheimer #4	---
2	2S	10W	NE/SW/NW	Gummersheimer #5	---
2	2S	10W	NW/SE/NW	Gummersheimer #6	---
2	2S	10W	SW/NW/NW	Gummershmr. #A18	SP, Res., Micro.
2	2S	10W	SE/SE/SW	Gummershmr. #A21	SP, Res., GR, NN
2	2S	10W	NW/NE/NW	Kolmer #2	SP, Res., Micro.
2	2S	10W	SW/SE/NW	Kolmer #A3	SP, Res.
2	2S	10W	NW/NE/NW	Kolmer #A4	SP, Res., Micro. Core #2520
2	2S	10W	NW/NW/SE	Kolmer #A8	SP, Res.
2	2S	10W	NW/SW/SE	Mueller #A9	SP, Res., Micro.
11	2S	10W	SW/NE/NW	Acker #1	---
11	2S	10W	SW/NW/NE	Kolmer #A20	GR, NN
11	2S	10W	NE/NE/NW	Oehler #A10	SP, Res., Micro. Core #2577
11	2S	10W	SW/NW/SE	Schuler #2	---
14	2S	10W	SW/NE/NE	Rueck #1	---
24	2S	10W	SW/NW/NW	Hartman #2	---
24	2S	10W	NW/NE/NW	Hartman #3	---

24	2S	10W	NE/SE/NW	Kolmer #1	GR, NN
24	2S	10W	SW/SW/NW	Kolmer #3	---
24	2S	10W	NW/NW/SE	Paulter Add. #1	---

LOCALITY 2

Dupo Field - St.Clair County, Illinois.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
33	1N	10W	SW/NE/NE	Frye #11	---
33	1N	10W	NE/NE/NE	Klotz #1	---
33	1N	10W	SW/NE/NE	Nettle #1	SP, Res., GR, NN
34	1N	10W	NE/SE/SW	Eckert #2	---
34	1N	10W	NW/SW/NW	Frye #7	---
34	1N	10W	SW/NW/NW	Gaskill #2	---
34	1N	10W	SE/SE/NW	Gaskill #10	---

LOCALITY 3

St.Jacob Field - Madison County, Illinois.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
1	3N	6W	NE/SE/SE	Bellm #1	SP, Res., Micro., GR, NN, GG
1	3N	6W	SW/SE/SE	Kurz #1	SP, Res., Micro. Core #2683
1	3N	6W	SE/NE/SE	Leder #1	SP, Res., Micro., GR, NN, GG
4	3N	6W	NW/NW/SE	Cockrum Comm. #1	Micro.
12	3N	6W	SE/SW/NW	Leder #1	SP, Res. Core #2765
12	3N	6W	SW/SE/NW	Michael #1	SP, Res., Micro.
15	3N	6W	SW/SW/NW	Frey #1	SP, Res. Core #495
15	3N	6W	SW/NW/SW	Meyer #1	SP, Res.
15	3N	6W	NW/SW/SW	Meyer #2	---

15	3N	6W	SW/SE/SW	Orville #13	Res., GR, NN
16	3N	6W	NE/SW/SW	Aemisegger #11	Res., GR, NN
16	3N	6W	SW/NW/SE	Becker Comm. #1	SP, Res.
16	3N	6W	SW/SE/NE	Frey Comm. #1	SP, Res.
16	3N	6W	SW/SW/SE	Hart. Comm. #A1	SP, Res.
16	3N	6W	SW/SW/SE	Kelley #1	SP, Res., Micro. Core #4400
16	3N	6W	SW/SW/NE	Kirri Comm. #1	---
16	3N	6W	SW/NE/SE	Meyer #1	SP, Res. Core #338
16	3N	6W	SW/SE/SE	Meyer #2	SP, Res.
16	3N	6W	NE/NE/SE	Meyer #4	---
16	3N	6W	SE/NW/SE	Meyer #5	Micro., GR, NN
16	3N	6W	NE/SW/SW	Miller #1	---
16	3N	6W	SW/NE/SW	Rhein #1	SP, Res.
16	3N	6W	SW/SE/SW	Rhein #2	---
16	3N	6W	SE/NE/SW	Rhein #4A	Micro, GR, NN
16	3N	6W	SE/SE/NW	Wells #1	---
16	3N	6W	SW/SW/NE	Wilson #3	GR, NN
19	3N	6W	SW/SW/SE	Holtgrave #2	SP, Res.
21	3N	6W	NE/NW/NW	Becker #1	---
21	3N	6W	SW/NW/NE	Hartman #1	SP, Res. Core #515
21	3N	6W	NE/NW/NE	Hartman #2	---
21	3N	6W	SW/NE/NW	Noll #1	SP, Res.
21	3N	6W	NE/NE/NW	Noll #2	---
27	3N	6W	NE/SE/SW	Ellis #5	SP, Res., NN
27	3N	6W	SW/NW/SW	Ellis #6	SP, Res., NN

27	3N	6W	SW/NE/SW	Ellis #9	SP, Res., NN

LOCALITY 4
Patoka Field - Clinton and Marion Counties, Illinois.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
1	3N	1W	SE/NE/NE	Al Hopkins #1	SP, Res., Micro.
1	3N	1W	NE/NE/NE	Albert Unit #1	SP, Res., Micro.
1	3N	1W	NE/SE/NE	Williams #1	SP, Res.
5	3N	1E	SW/NE	Langenfeld #1T	SP, Res., Micro.
5	3N	1E	NE/SW	Nattier #5T	SP, Res.
6	3N	1E	NE/SE/NW	Brokelmeyer #1	SP, Res., Micro.
6	3N	1E	NW/NE/NW	Messamore #1	SP, Res., Micro.
6	3N	1E	NE/NW/NE	Oscar #7	SP, Res., Micro.

LOCALITY 5
Fairman Field - Clinton and Marion Counties, Illinois.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
13	3N	1W	SW/SW/NE	Adams Comm. #1	SP, Res.
13	3N	1W	NE/SW/SE	Ducomb #1A	SP, Res.
13	3N	1W	NW/SE/SE	Kreitler #1	SP, Res., Micro.
13	3N	1W	E/NE/SE	Kreitler #2	SP, Res.
33	3N	1W	NE/NE/SW	Wiedle #1	SP, Res., Micro.
34	3N	1W	NE/NE/SE	Moulton #1	SP, Res.
7	3N	1E	SW/SW/SE	Adams #C1	SP, Res.
7	3N	1E	SW/SE/SW	Adams Comm. #1	SP, Res., Micro.
7	3N	1E	NE/SE/SW	Adams Comm. #2	SP, Res., Micro.
8	3N	1E	NW/SW/NW	Deadmond #1T	---
18	3N	1E	NE/SW/NE	Ahlf #1A	SP, Res.
18	3N	1E	NE/NE/SW	Ahlf #3A	SP, Res., Micro. Core #5864

18	3N	1E	W/SW	Ahlf #1	SP, Res., Micro.
18	3N	1E	NE/NW/SE	Lutz Etux #1A	SP, Res.
18	3N	1E	S/NW/SE	Lutz Etux #2A	SP, Res.
18	3N	1E	N/NW/NE	Mason #1	SP, Res., Micro.
18	3N	1E	SE/NW/NE	Mason #2	SP, Res., Micro.
18	3N	1E	NE/NE/NW	Ververs #1	SP, Res., Micro.
18	3N	1E	E/SE/NW	Ververs #6C	SP, Res. Core #718

LOCALITY 6
Centralia Field - Clinton County, Illinois.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
1	1N	1W	SW/NW	Buehler #5	SP, Res. Core #2139
1	1N	1W	NW/NE/SW	Pitchford #5T	SP, Res., GR, NN Core #2281
2	1N	1W	NW/NW/SW	Buehler #6	SP, Res.
2	1N	1W	NW/SW/NE	Criley #2T	SP, Res.
2	1N	1W	NW/NE/NW	Criley #37T	SP, Res., GR, NN
2	1N	1W	NW/NE/NE	Criley #39T	SP, Res., GR, NN
2	1N	1W	SE/NW/NE	Criley #42T	SP, Res.
2	1N	1W	NW/NW/NW	Felton #A4	GR, NN
2	1N	1W	SE/NE/NE	Geary #5T	SP, Res.
2	1N	1W	NW/NW/SE	Hanseman #1	SP, Res.
2	1N	1W	NE/NW/NW	Hood #1T	SP, Res.
2	1N	1W	NW/SE/NW	Koch #1T	GR, NN
2	1N	1W	NE/NE/SE	Schmitz #2	SP, Res.
12	1N	1W	S/SW/NE	Allison #A4	---
12	1N	1W	S/NE/SE	Brown #1	SP, Res. Core #1192

12	1N	1W	N/NW/SW	Francois #3	SP, Res.
19	1N	1W	NW/NE/SW	Defend #1	SP, Res., Micro., GR, NN
30	1N	1W	NW/NW/NE	Wesselman #1	SP, Res., GR, Sonic
9	2N	1W	SE/SE/NE	Tate #1	SP, Res., Sonic

LOCALITY 7

Salem Field - Marion County, Illinois.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
5	1N	2E	SE/SW/NE	Centralia #74	GR, Sonic Core #4775
5	1N	2E	W/NW/SW	Richardson #10A	---
5	1N	2E	NE/NW/NW	Tate #21	SP, Res.
6	1N	2E	E/SE/NE	Canull #18	GR, NN
6	1N	2E	SE/NW/SE	Johnson #1	SP, Res., GR, NN, GG, Sonic
29	2N	2E	SE/SE/NW	Fossieck #14	---
29	2N	2E	NE/NE/SW	Fossieck #15	---
29	2N	2E	SE/SW/NW	Friedrich #16	---
29	2N	2E	SE/NW/SW	Friedrich #21A	---
29	2N	2E	NE/SW/NW	Friedrich #17	---
29	2N	2E	SW/SE/NE	Lee #12	---
29	2N	2E	SE/NE/NW	Young #19	---
29	2N	2E	SW/NE/NW	Young #22	---
29	2N	2E	NW/SE/NW	Young #42	---
32	2N	2E	SW/NW/NW	Wayman #28	---

LOCALITY 8

Woburn Field - Bond County, Illinois.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
28	7N	2W	NE/NE/SE	Folkers #1	SP, Res.
34	7N	2W	SW/SW/SW	Blankenship #1T	GR, NN
34	7N	2W	NW/SW/SW	Stoneburner #2	Micro., GR
30	7N	3W	SE/SW/NW	Sexton #1	SP, Res.

LOCALITY 9

Tamaroa Field - Perry County, Illinois.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
8	4S	1W	NE/SE/NW	Wisniewski #12X8	SP, Res., GR
23	4S	1W	NW/SW	Majewski #1	SP, Res. Core #4487
23	4S	1W	SW/NW	Majewski #2	SP, Res.
24	4S	1W	NW/SE/SW	Radake #1	GR, NN, GG

LOCALITY PC

Bowling Green - Pike County, Missouri.

SEC	TWP	RGE	LOCATION	WELL NUMBER	E-LOGS / CORE
4	51N	3W	NE/NW/NW	Wheatley #1	GR, GG
5	52N	3W	SE/SW/SW	Luebrecht #1	SP, Res.
9	52N	3W	SE/SE/SE	Orf #1	GR, NN
32	52N	3W	NW/NE/SW	McDonnald #1	GR, NN, GG
32	52N	3W	NW/NE/SW	McDonnald #2	SP, Res.
24	53N	1W	NW/NW/SE	CDH #84	--- Core 30-230
16	53N	3W	---	Beddies #1	GR, GG

APPENDIX B

TABULATION OF OUTCROPS

LOCALITY A

Columbia Quarry - Valmeyer, Monroe County, Illinois.

SEC	TWP	RGE	LOCATION	TOTAL KIMMSWICK EXPOSED
3	3S	11W	SW/NE/SW	74'

Base covered; 14' Beecher Member, 9' Eagle Point Member, 59' Moredock Member.

LOCALITY B

Defiance Quarry - Defiance, St.Charles County, Missouri.

SEC	TWP	RGE	LOCATION	TOTAL KIMMSWICK
14	45N	2E	SE/SW/NW	84'

10' St.James Member, 14' Beecher Member, 6' Eagle Point Member, 54' Moredock Member.

LOCALITY C

Bussen Antire Quarry - Eureka, St.Louis County, Missouri.

SEC	TWP	RGE	LOCATION	TOTAL KIMMSWICK
33	44N	4E	SW/SE	85'

16' St,James Member, 14' Beecher Member, 10' Eagle Point Member, 45' Moredock Member.

LOCALITY D

Hiway 30 roadcut - House Springs, Jefferson County, Missouri.

SEC	TWP	RGE	LOCATION	TOTAL KIMMSWICK
33	43N	4E	NW/SE/SE	17'

Entire Kimmswick section exposed; undifferentiated.

LOCALITY E

Barnhart Quarry - Sulphur Springs, Jefferson County, Mo.

SEC	TWP	RGE	LOCATION	TOTAL KIMMSWICK EXPOSED
32	42N	6E	SW/NE/NW	53'

43' Moredock Member, 10' New London Member.

LOCALITY F

I-55, Rt.M roadcut - Barnhart, Jefferson County, Missouri.

SEC	TWP	RGE	LOCATION	TOTAL KIMMSWICK
30	42N	6E	300' E of NEcor.	75'

14' St.James Member, 14' Beecher Member, 7' Eagle Point Member, 40' Moredock Member.

LOCALITY G

Abandoned quarry - Glen Park, Jefferson County, Missouri.

SEC	TWP	RGE	LOCATION	TOTAL KIMMSWICK EXPOSED
5	41N	6E	SE/NE/NW	65'

Quarry floor at top of Eagle Point Member; 58' Moredock Member, 7' New London Member.

LOCALITY H

Abandoned quarry - Beckett Hills, St.Genevieve County, Mo.

SEC	TWP	RGE	LOCATION	TOTAL KIMMSWICK EXPOSED
7	37N	9E	S/S	44'

4' St.James Member, 12' Beecher Member, 8' Eagle Point Member, 20' Moredock Member; top eroded.

APPENDIX C

TABULATION OF THIN SECTIONS

LOCALITY 1

2 T2S R10W Kolmer #A4 - Core #2520

T.S. #	DEPTH (from drill floor)	STRATA REPRESENTED
CK-1	425'	Upper Moredock caprock
CK-2	428'	"
CK-3 (2 slides)	431'	"
CK-4	433'	"
CK-5	434'	"
CK-6	435'	"
CK-7	436'	"
CK-8	437'	Moredock Member
CK-9	440'	"
CK-10	441 1/2'	"
CK-11	443 1/2'	"
CK-12	444 1/2'	Upper Moredock Horizon
CK-13	448 1/2'	"
CK-14	450 1/2'	"
CK-15	452 1/2'	"
CK-16	454 1/2'	"
CK-17	459'	"
CK-18	462'	Lower Moredock Horizon
CK-19	467'	"
CK-21	475'	Lower Moredock imperm. zone
CK-22	480'	Lower Moredock Horizon

CK-23	485'	Eagle Point Member
CK-24	489'	Eagle Point Caprock
CK-25	496'	Beecher-St.James Horizon
CK-26	500'	"
CK-27	504'	"
CK-28	509'	St.James Mbr. (imperm. top)

LOCALITY 3

15 T3N R6W Frey #1 - Core #495

T.S. #	DEPTH (from drill floor)	STRATA REPRESENTED
CF-1	2389'	Upper Moredock caprock

21 T3N R6W Hartman #1 - Core #515

T.S. #	DEPTH (from drill floor)	STRATA REPRESENTED
CJH-1	2372'	Upper Moredock caprock
CJH-2	2375'	"
CJH-3	2383'	Upper Moredock imperm. zone
CJH-4	2386'	"
CJH-5	2388'	"
CJH-7	2390'	Upper Moredock Horizon
CJH-8	2392'	"
CJH-9	2394'	"
CJH-10	2395'	"
CJH-11	2396'	"
CJH-12	2397'	"

LOCALITY 5

18 T3N R1E Ververs #6C - Core #718

T.S. #	DEPTH (from drill floor)	STRATA REPRESENTED
CV-1	3930'	Upper Moredock caprock
CV-2	3941'	"
CV-3	3956'	Upper Moredock Horizon

LOCALITY 6

1 T1N R1W Buehler #5 - Core #2139

T.S. #	DEPTH (from drill floor)	STRATA REPRESENTED
CB-13	3974'	Upper Moredock Horizon
CB-14	4009'	Lower Moredock Horizon
CB-15	4004'	"
CB-16	4007'	"
CB-17	4025'	Beecher-St.James Horizon
CB-18	4000'	Lower Moredock Horizon

1 T1N R1W Pitchford #5T - Core #2281

T.S. #	DEPTH (from drill floor)	STRATA REPRESENTED
CP-3	3957'	Upper Moredock caprock
CP-7	3978'	Upper Moredock Horizon
CP-9	3986'	Lower Moredock caprock
CP-10	4002'	Lower Moredock Horizon
CP-11	3951'	New London Horizon
CP-12	3954'	New London Member
CP-13	3965'	Upper Moredock caprock
CP-14	3991'	Lower Moredock caprock
CP-15	4004'	Lower Moredock imperm. zone

CP-16	4018'	Eagle Point Caprock
CP-17	4030'	Beecher-St.James Horizon

LOCALITY 7

5 T1N R2E Centralia #74 - Core #4775

T.S. #	DEPTH (from drill floor)	STRATA REPRESENTED
CC-1	4597'	New London Horizon
CC-2	4614'	Upper Moredock caprock
CC-3	4616'	"
CC-4	4618'	"
CC-5	4648'	Lower Moredock caprock
CC-6	4671'	Eagle Point Caprock
CC-7	4682'	St.James Mbr. (imperm. top)

LOCALITY A

3 T3S R11W Columbia Quarry - Outcrop

T.S. #	DEPTH (from Kimmsw. top)	STRATA REPRESENTED
V-1 (2 slides)	45'	Lower Moredock Horizon
V-4	13'	Upper Moredock Horizon
V-5	3'	"

LOCALITY B

14 T45N R2E Defiance Quarry - Outcrop

T.S. #	DEPTH (from Kimmsw. top)	STRATA REPRESENTED
D-1	28'	Lower Moredock caprock
D-2	42'	Lower Moredock Horizon
D-4	55'	Eagle Point Member
D-5	60'	"

D-6	66'	Beecher Member
D-7	76'	St.James Member
D-8	23'	Lower Moredock caprock
D-9	15'	Upper Moredock Horizon

LOCALITY D

33 T43N R4E Hiway 30 roadcut - Outcrop

T.S. #	DEPTH (from Kimmsw. top)	STRATA REPRESENTED
HS-1 (2 slides)	5'	undifferentiated

LOCALITY E

32 T42N R6E Barnhart Quarry - Outcrop

T.S. #	DEPTH (from Kimmsw. top)	STRATA REPRESENTED
W-1 (2 slides)	3'	New London Member

LOCALITY F

30 T42N R6E I-55, Rt.M roadcut - Outcrop

T.S. #	DEPTH (from Kimmsw. top)	STRATA REPRESENTED
BA-1	68'	St.James Member
BA-2	64'	"
BA-3	62'	"
BA-4	60'	Beecher Member
BA-5	59'	"
BA-6	30'	Lower Moredock Horizon
BA-7 (3 slides)	23'	"
BA-8	15'	"
BA-9	7'	Lower Moredock caprock

LOCALITY G

5 T41N R6E Glen Park quarry - Outcrop

T.S. #	DEPTH (from Kimmsw. top)	STRATA REPRESENTED
GP-1 (2 slides)	11'	Moredock Member
GP-2	40'	"

LOCALITY H

7 T37N R9E Beckett Hills quarry - Outcrop

T.S. #	DEPTH (from Kimmsw. top)	STRATA REPRESENTED
QB-1	32'	Beecher Member
QB-2 (2 slides)	9'	Lower Moredock Horizon