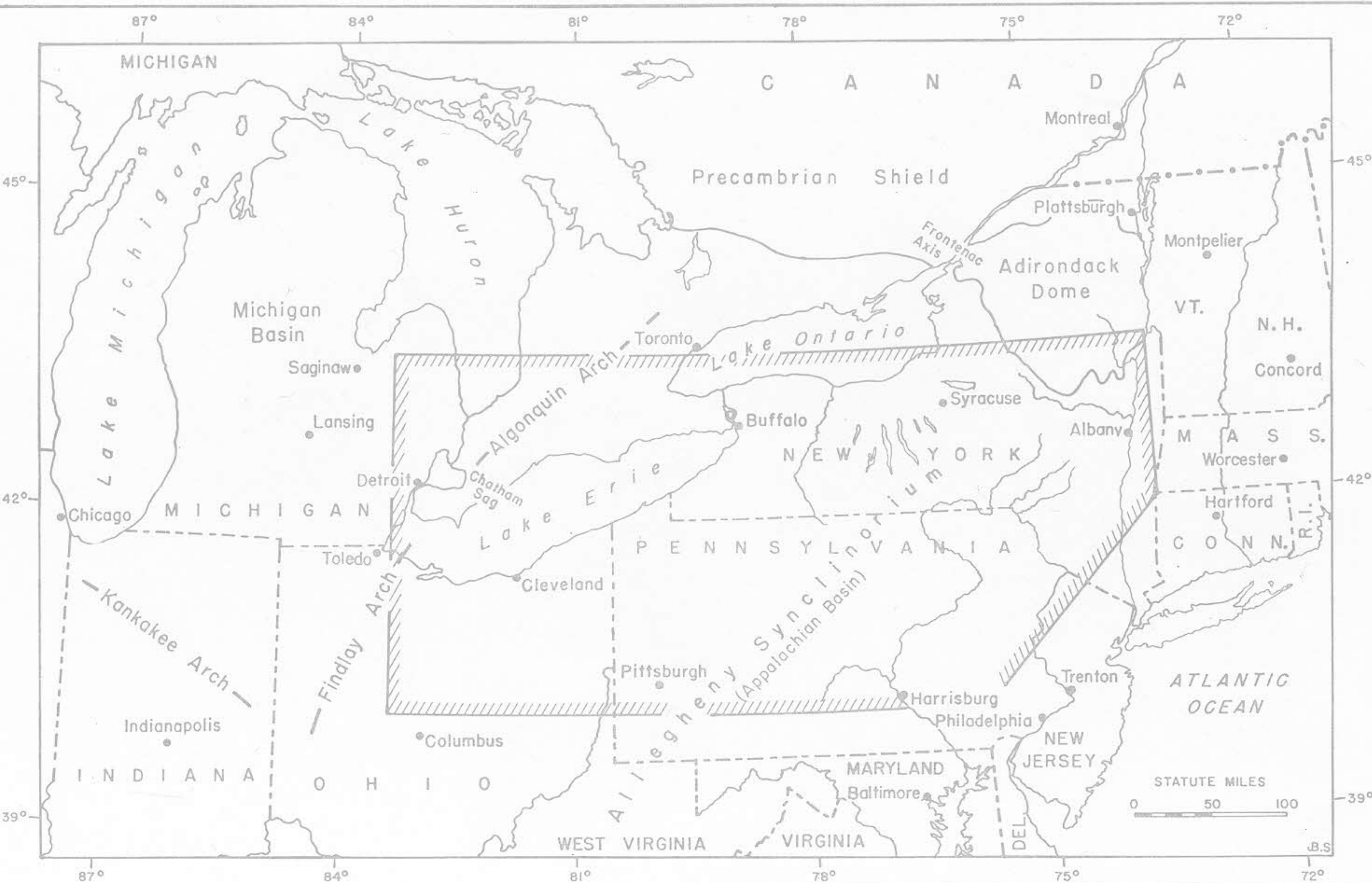
Stratigraphy of the Upper Silurian Salina Group New York, Pennsylvania, Ohio, Ontario

Lawrence V. Rickard, Senior Paleontologist

MAP AND CHART SERIES NUMBER 12

NEW YORK STATE MUSEUM AND SCIENCE SERVICE

The University of the State of New York, The State Education Department, Albany, 1969



MICHIGAN
CANADA
Montreal
Precambrian Shield
Plattsburgh
Montpelier
Frontenac Axis
Adirondack Dome
VT.
N.H.
Concord
Lake Michigan
Lake Huron
Michigan Basin
Toronto
Lake Ontario
Algonquin Arch
Saginaw
Lansing
Syracuse
Buffalo
Albany
MASS.
Worcester
Detroit
Chatham Sag
Lake Erie
NEW YORK
Hartford
Chicago
MICHIGAN
CONN.
R.I.
Toledo
Cleveland
PENNSYLVANIA
Kankakee Arch
Findlay Arch
Allegheny Synclinorium
(Appalachian Basin)
Pittsburgh
Trenton
ATLANTIC OCEAN
Harrisburg
Philadelphia
Indianapolis
Columbus
NEW JERSEY
INDIANA
OHIO
MARYLAND
Baltimore
STATUTE MILES
0 50 100
WEST VIRGINIA
VIRGINIA
DEL.
J.B.S.
87°
84°
81°
78°
75°
72°
45°
42°
39°

THE UNIVERSITY OF THE STATE OF NEW YORK

Regents of the University *(with years when terms expire)*

1969 Joseph W. McGovern, A.B., LL.B., L.H.D., LL.D.
Chancellor - - - - - - - - - - - - - - - - - New York

1970 Everett J. Penny, B.C.S., D.C.S., *Vice Chancellor* - - White Plains

1978 Alexander J. Allan, Jr., LL.D., Litt.D. - - - - - - Troy

1973 Charles W. Millard, Jr., A.B., LL.D., L.H.D. - - - Buffalo

1972 Carl H. Pforzheimer, Jr., A.B., M.B.A., D.C.S. - - Purchase

1975 Edward M. M. Warburg, B.S., L.H.D. - - - - - - - New York

1977 Joseph T. King, LL.B. - - - - - - - - - - - - - Queens

1974 Joseph C. Indelicato, M.D. - - - - - - - - - - Brooklyn

1976 Mrs. Helen B. Power, A.B., Litt.D., L.H.D. - - - - Rochester

1979 Francis W. McGinley, B.S., LL.B., LL.D. - - - - - Glens Falls

1981 George D. Weinstein, LL.B. - - - - - - - - - - Hempstead

1980 Max J. Rubin, LL.B., L.H.D. - - - - - - - - - - New York

1971 Kenneth B. Clark, A.B., M.S., Ph.D., Litt.D. - - - Hastings on Hudson

1982 Stephen K. Bailey, A.B., B.A., M.A., Ph.D., LL.D. - - Syracuse

President of the University and Commissioner of Education
James E. Allen, Jr.

Executive Deputy Commissioner of Education
Ewald B. Nyquist

Associate Commissioner for Cultural Education
Hugh M. Flick

Assistant Commissioner for State Museum and Science Service
John G. Broughton

State Paleontologist, State Museum Science Service
Donald W. Fisher

Contents

Illustrations

PAGE

Figures

Plates (in envelope)

Maps

Sections

Stratigraphy of the Upper Silurian Salina Group New York, Pennsylvania, Ohio, Ontario

Lawrence V. Rickard, Senior Paleontologist [1]

Abstract

A study and correlation of 435 sample and gamma-ray logs of the upper Silurian Salina Group and adjacent strata in New York, Pennsylvania, Ohio, and Ontario reveals the detailed stratigraphy of this evaporite sequence. Although the Michigan and Appalachian basins are distinct, nearly identical subdivisions of the Salina can be traced across the Findlay-Algonquin arches from one basin into the other. Consequently, the correlation of formations, named from exposures about the margin of the Appalachian basin and their relationship to the subsurface units established by Landes for the Michigan basin, can be determined.

The Vernon Shale of New York correlates with the Bloomsburg and Wills Creek Formations of Pennsylvania and divisions A, B, and C of the Michigan basin sequence. The recently redefined Syracuse Formation of New York corresponds to most of the Tonoloway of Pennsylvania and divisions D, E, and F1 thru F4 of Michigan. Divisions F5, F6, and G of Michigan correlate with the Camillus and Bertie Formations of New York, which are equivalent to the uppermost Tonoloway and much of the lower Keyser of Pennsylvania.

Salt beds occur in the Vernon (B) and Syracuse (D, E, F) Formations in New York, Pennsylvania, and Ohio. Those of Unit B appear to be continuous from the Michigan basin into the Appalachian basin. Gamma-ray logs suggest that thick halite beds formed very rapidly relative to the deposition of the intervening rock and anhydrite layers. Certain specific deflections on these logs can be traced from western Michigan to east-central New York, more than 600 miles (965 kilometers).

[1] Manuscript submitted for publication October 23, 1968.

Introduction

PURPOSE, METHOD, AND EXTENT OF STUDY

Interest in the subsurface Salina Group has grown in recent years, primarily due to its economic value as a source of oil, gas, salt, and gypsum. Prior to Landes' work (1945), detailed knowledge of the stratigraphy of the subsurface Salina Group was poor. Attempts to recognize and trace in the subsurface units originally defined in surface outcrops were not very successful. Landes' work on the Michigan basin provided a new stratigraphic standard whose units, only slightly modified, now have been recognized in, and traced across, Ontario and Ohio into New York and Pennsylvania. The exact relationship of these units to Upper Silurian formations defined many years earlier on the outcrop along the margin of the Appalachian basin now has been determined, with interesting results. It can be said that our knowledge of the Salina Group has made considerable progress over the past 20 years. It appears, furthermore, that much more has been learned from subsurface well data than from the relatively few, poor, and incomplete surface exposures of the Salina Group.

Figure 1 indicates the extent of the area covered by this report and the principal structural elements present. The Appalachian basin, as authors of papers on Silurian evaporites are wont to call it, is distinct from the Michigan basin but, at least during Late Silurian time, a connection between the two was effected through the Chatham sag. All Salina subdivisions can be traced across the Findlay-Algonquin arches from one basin into the other. Although

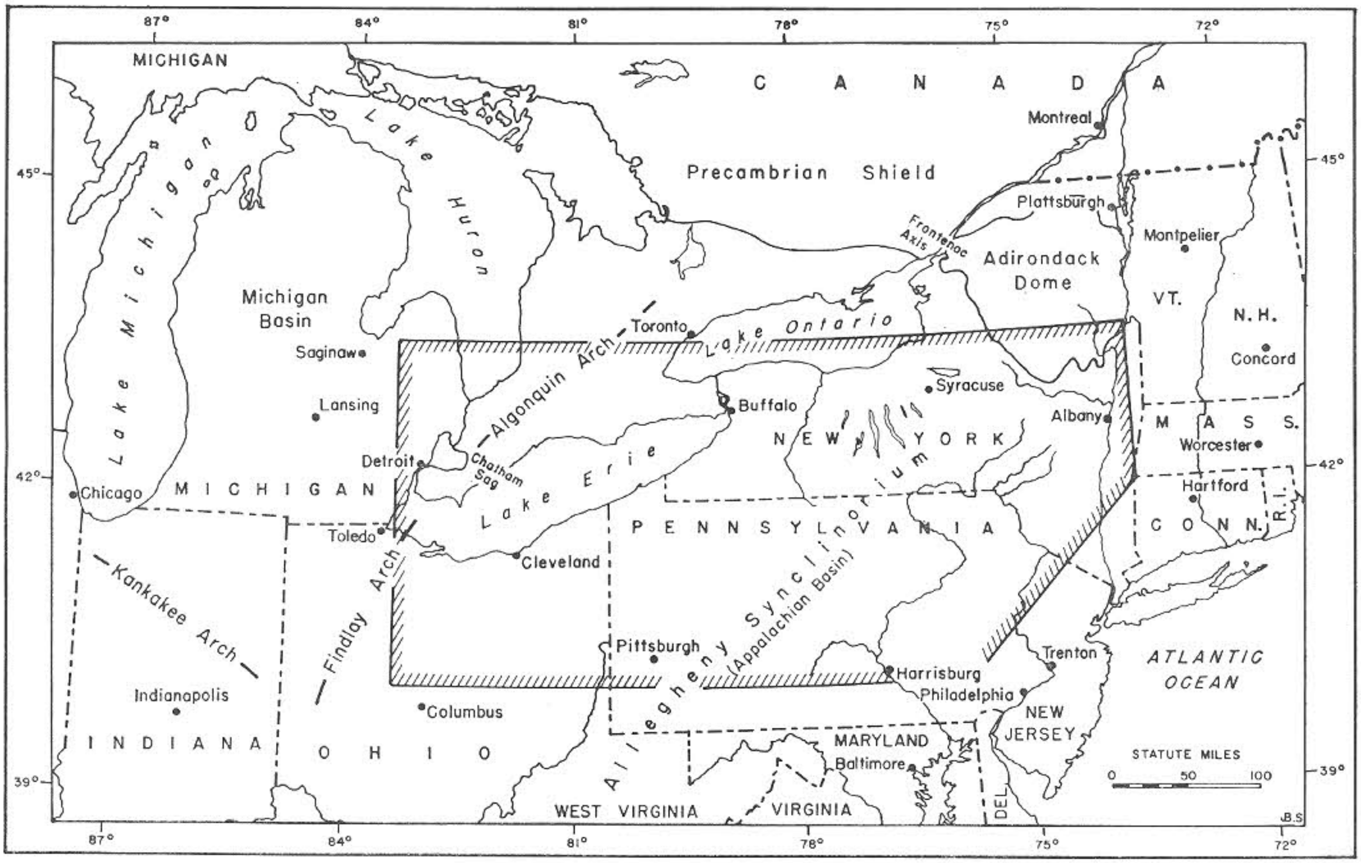


Figure 1. Tectonic framework of area studied.

the two basins are distinct, their late Silurian stratigraphy is very much alike. Nearly identical units are recognized in each utilizing essentially the same criteria.

This study has utilized data from sample logs, gamma-ray logs, or both for 159 wells in New York, 64 in Pennsylvania, 115 in Ohio, 92 in Ontario, and 5 in Michigan, a total of 435 control points. Not all wells, however, furnish data on all units so that the isopachous and structure contour maps presented herein do not have the full number of possible control points.

The Upper Silurian Salina Group is defined in New York State where it contains three formations—the Vernon, Syracuse, and Camillus—to which the writer adds a fourth by including the Bertie Formation at the top. All these units consist of lithologies common in the evaporite series, and are equivalent to strata included elsewhere in the Salina Group. They are underlain by dolomites referred to the Lockport and/or Albemarle Groups and overlain by the Cobleskill Limestone, Rondout Dolomite, and limestone of the Helderberg Group. The Salina Group and overlying Cobleskill and Rondout Formations define the Cayugan Series of late Silurian age. Separate disconformities in eastern New York beneath the Oriskany Sandstone and Onondaga Limestone merge in central and western New York into one that descends stratigraphically across successively lower formations. In western New York the Onondaga Limestone rests disconformably upon the Cobleskill (Akron) Dolomite or the Bertie Formation of the Salina Group.

By careful projection from known surface outcrops into nearby wells and matching of lithologic units in each, the subsurface equivalents of these outcropping formations and their lithologic and gamma-ray characteristics were determined. The principal well used for this purpose was the Doroshenko No. 1, Eaton Township, Madison County, bearing the designation NY 19 in this report. This well is located approximately 11 miles south of the excellent exposures of the Salina and Helderberg Groups in the northern portion of the Stockbridge Valley, studied and described by Fisher (1957), Leutze (1959), and Rickard (1962). Other wells provided additional correlations of surface and subsurface units about the northern end of Cayuga Lake (NY 27, 30, 42), in Herkimer (NY 10) and Otsego (NY 5) Counties, and in the Catskills (NY 1, 2). In western New York many wells have been drilled in the vicinity of the Retsof and Livonia (abandoned) mines of the International Salt Co. whose shafts were logged by Luther (1894). Correlation of these shafts with several nearby wells (NY 84, 94, 96, 97) was accomplished.

Once the subsurface representations of these outcropping formations were determined, it became possible to recognize and trace these formations throughout the subsurface of New York and northern Pennsylvania. Several were subdivided into two or three units of differing characteristics. Subsequently, all were traced westward across Ontario into Michigan where their relationship to the standard series of subsurface Salina units was established. The Michigan series utilized here is that currently employed by Garland Ells of the Michigan Geological Survey. Although the nomenclature is much the same, the units do not conform exactly to Landes' original definitions.

PREVIOUS WORK

Contributions to knowledge of the Salina Group, particularly its subsurface expression, have appeared more frequently since Landes' report of 1945. Only a few of these, however, of which the present report is one, have attempted a regional analysis and synthesis. The majority have been restricted in some fashion, usually geographically. In addition, significant differences in the definitions of units among these reports have inhibited comparisons. Publications since 1945 are mentioned below.

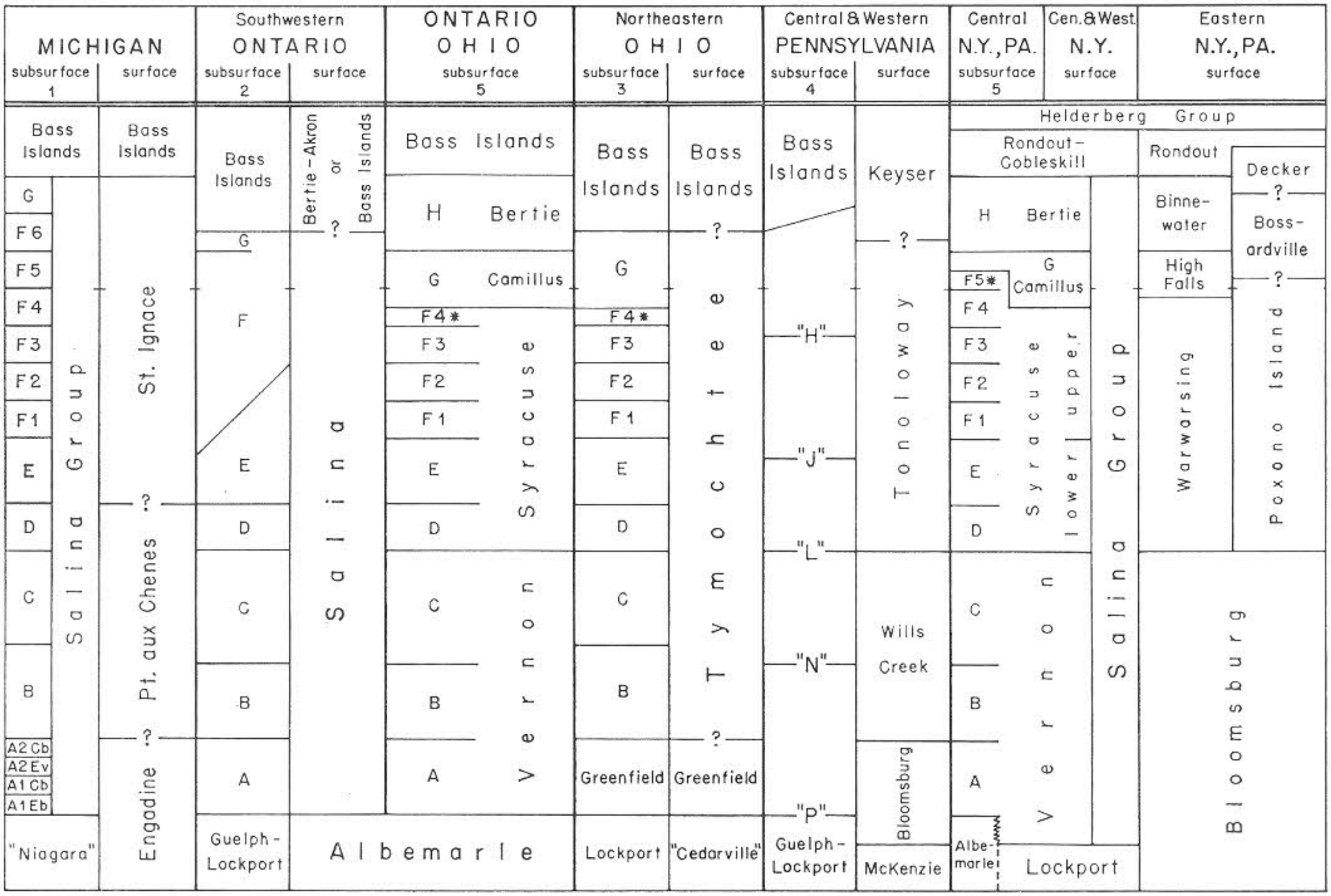
In New York, detailed study of surface exposures of the Salina Group by W. P. Leutze (1956, 1959), clarified several previously obscure relationships and established the Syracuse Formation as a valid stratigraphic unit. Other surface studies were conducted by D. W. Fisher and L. V. Rickard (1953) and Fisher (1957). Subsurface investigations were conducted by W. L. Kreidler (1957, 1963) who described the thickness, extent, and position of the salt-bearing portion of the Salina Group.

D. M. Hoskin's (1961) bulletin on the Bloomsburg Formation of Pennsylvania contributes new and useful information on that rock unit based on surface studies. Important reports on the subsurface Salina Group of Pennsylvania were published by C. R. Fettke (1955), A. S. Cate (1961, 1963, 1965), and W. B. Fergusson and B. A. Prather (1968).

An important contribution to knowledge of the Salina Group in Ohio was made by J. R. Ulteig in 1964. Papers by J. F. Pepper (1947), J. F. Hall (1963) and F. G. Stehli, J. N. Namy and M. D. Aten (1963) also deserve mention.

The discovery and production of oil from the lower portion of the Salina Group of Ontario has generated much interest in the group in that province. Following earlier reports by W. A. Roliff (1949) and C. S. Evans

Figure 2. Correlation of surface and subsurface units.



1. Courtesy G. D. Ells 2. After Sanford (1965) 3. After Ulteig (1964) 4. After Cate (1961, 1965) 5. This paper * Evaporite portion only

(1950) there appeared papers by W. J. Pearson (1963), D. F. Hewitt (1962), and an important summary of Salina salt beds by B. V. Sanford (1965).

Work on the Michigan Salina Group, following Landes (1945), has been conducted by G. D. Ells (1958, 1962, 1967) who has a detailed analysis of the group in progress.

The important regional analysis by H. L. Alling and L. I. Briggs (1961) served to integrate many of the earlier works. Their paper apparently inspired the more detailed state or provincial studies by Cate, Ulteig, Sanford, and Ells. The increasing number of good sample logs and gamma-ray logs permitted these authors to describe the stratigraphy of the subsurface Salina in their areas with greater accuracy and detail than Alling and Briggs. The present report unites data from all these efforts with new work on the New York and Pennsylvania subsurface into a second regional analysis.

ACKNOWLEDGMENTS

The writer is grateful to G. W. Rector of the Geological Sample Log Co., Pittsburgh, Pa., for permission to publish sample logs prepared by the company. Thanks are due to D. A. Sharp, Ontario Department of Energy and Resources Management, and to Garland Ells, Michigan Geological Survey, for gamma-ray logs and other data pertaining to the Upper Silurian of Ontario and Michigan.

This study was initiated late in 1965 and a preliminary report was published in the guidebook for the New York State Geological Association meeting at Buffalo in May 1966. It was continued, with interruptions, over a period of 2 years, culminating in this final report submitted for publication in October 1968. Abstracts and oral presentations were presented at the Northeastern Sectional meeting of the Geological Society of America in Albany, March 1969, and the third symposium on Salt in Cleveland, April 1969.

Stratigraphy of the Salina Group

The Salina Group of the Central Appalachian basin attains a maximum thickness of 2,500 feet (762 meters) in the subsurface of north-central Pennsylvania, as shown on the isopachous map of the group, plate 1. In Michigan the group exceeds 4,000 feet (1220 meters), the difference owing largely to thick beds of salt present in the Vernon Formation that are nearly lacking in the Appalachian basin. Along the outcrop in western and central New York, where the group and its four formations are defined, the thickness increases from 400 feet (122 meters) at Buffalo to a maximum of 1,000 feet (305 meters) at Syracuse. It then rapidly decreases eastwardly to less than 100 feet (30 meters) in Schoharie County. In southeastern New York, the group increases in thickness along the outcrop from Kingston to eastern Pennsylvania where it exceeds 2,000 feet (610 meters) principally because of the appearance of the thick Bloomsburg "delta" at its base. The isopach lines of plate 1 indicate that the rate of thickening increases significantly once the group exceeds 1,000 feet (305 meters). This marks the appearance of thick beds of salt in unit F, the major salt-bearing division of the Salina Group.

It is obvious from plate 1 that the principal axis of Salina deposition was that of the Appalachian basin extending northeastwardly across Pennsylvania parallel to, but some 20-40 miles west and north of, the outcrop belt along the Allegheny Front. Somewhat less apparent is a second axis, roughly perpendicular to the first, extending northwestwardly across northeastern Ohio through the Chatham sag into the Michigan basin. These axes indicate where subsidence and deposition were greatest during Salina time and where salt deposits attain their greatest thickness.

The present structural attitude of the Salina Group is suggested by the structure contour map, plate 2, drawn on the top of the Vernon Formation (or at the base of the overlying Syracuse Formation where the Vernon is absent in eastern New York). This map indicates that the Salina Group participates in the generally southeastward regional dip into the Allegheny synclinorium also shown by overlying and underlying rocks. The deepest part of the synclinorium would appear to be located in northeastern Pennsylvania beneath the Lackawanna syncline delineated at the surface by Devonian and Carboniferous rocks. Structure contours are not drawn across central Pennsylvania because of the lack of control points (very few wells have been drilled through the Salina in this area) and the presence of many folds and faults in this area (significantly affecting the value of a generalized contour map such as this). Presence of the Chatham sag is suggested by structure contours in southwestern Ontario.

VERNON FORMATION

J. M. Clarke suggested the name Vernon in 1903 for the red and green shale, gray shale, and thin dolomites of the Salina Group exposed in Vernon Township, Oneida County, New York. No specific exposure was cited as the type section. A reference section was subsequently established by Fisher (1957) along Downing Brook, an eastern tributary of Oneida Creek entering the creek 0.6 miles north of the southern boundary of Oneida County. Study of this section indicates that the type Vernon is a tripartite unit, having a central interval, 89 feet thick, composed predominantly of gray or green shales and dolomites but with a few red shales and green sandstones. A 2 foot bed near the top contains a small marine fauna of brachiopods, gastropods, pelecypods, cephalopods, ostracodes, fishes, and eurypterids. This central interval is underlain by 90 feet of red shale, base unexposed, and overlain by 94 feet of red and green shales, top unexposed. Estimates of the thicknesses of the unexposed intervals above (50 feet) and below (100 feet) the outcrop permit an approximation of 420 feet for the type Vernon.

This threefold division of the Vernon can be distinguished in nearby wells and traced throughout the subsurface in New York and Pennsylvania. Traced westward across Ontario it becomes evident that these divisions correspond closely to units A, B, and C of the Michigan basin Salina sequence. Important facies changes occur, of course, in all three divisions. The Vernon is red or red and green in eastern sections and wells but is entirely gray or green to the west. Shales are partially replaced by dolomites, anhydrites, and salt beds. Southeast of the type section, in Otsego and Delaware Counties, New York, the Vernon is one indivisible mass of red shales and sandstones, 0 to 500 thick. This undivided Vernon can be traced to the south where it becomes the very thick Bloomsburg of eastern Pennsylvania. The tripartite nature of the Vernon again becomes apparent as one moves westward into central Pennsylvania.

The discovery and study of the tripartite nature of the Vernon has thrown new light on the correlation of the Vernon of New York with the Bloomsburg of Pennsylvania. It has long been held that these two units were more or less equivalent. Now it is apparent that the type Bloomsburg of central Pennsylvania correlates with only the lower third of the type Vernon, not with all of it. It is the much thicker Bloomsburg of eastern Pennsylvania that corresponds to the complete Vernon of east-central New York where the entire formation consists of red shales and siltstones and its tripartite nature is not apparent.

Plate 3, an isopachous map of the entire Vernon, indicates that the formation attains maximum thickness in two areas; it exceeds 1500 feet along the outcrop in eastern Pennsylvania and is over 1000 feet thick beneath Tioga and Bradford Counties in north-central Pennsylvania. Consideration of plates 4, 5, and 6 indicates that the maximum in eastern Pennsylvania is a reflection of the largely non-marine Bloomsburg "delta" whereas that in north-central Pennsylvania is indicative of the initial development of the "Salina" basin wherein marine sedimentation predominated following early Vernon time. The latter area is apparent on the isopachous maps of younger Salina units.

During Vernon time, an area composed of portions of western Pennsylvania, eastern Ohio, and southern Ontario experienced much less subsidence and sedimentation than adjacent areas to the east or west. Less than 300 feet of strata are referred to the Vernon Formation in this region. Only part of this reduction in thickness can be ascribed to the lateral replacement of basal Vernon in the east by dolomites referred to the underlying Guelph in the west. The remainder apparently indicates the persistence of a relatively stable platform in this area.

Plate 3 discloses an area of relatively thicker Vernon in northern Ohio. Such a feature also was noted by Ulteig (1964, p. 20; figure 8). This suggests the development of a small depositional basin located in Lake Erie, south of Kent County, Ontario, and extending south into Lorain and Medina Counties, Ohio.

UNIT A

The lower Vernon of central New York and north-central Pennsylvania appears to be a direct continuation of the Bloomsburg "delta." It consists of red shales and siltstones that grade westwardly into mixed red and green shales which, in turn, are replaced farther west by interbedded gray or green shales and dolomites. A similiar westward replacement of the red Bloomsburg by the red, green, and gray Wills Creek in south-central Pennsylvania has been known for some time (Swartz and Swartz, 1931, p. 659-660). Traced westward across New York and Ontario by means of gamma-ray logs it becomes apparent that this portion of the Vernon correlates with Unit A of the Michigan sequence (plate 11). No extensive development of salt deposits, such as those so prominent in Unit A in Michigan, appears in the Appalachian basin. Indeed, the depositional history of the latter basin during this time is entirely different, perhaps more analagous to the partially red Point aux Chenes of northern Michigan.

A broad, relatively stable platform centered along the Ohio-Pennsylvania State line (plate 4), on which less than 100 feet of sediments were deposited, clearly separated the Appalachian basin into two distinct parts during early Vernon time. The larger, located in central Pennsylvania and New York, received an influx of terrigenous sediments from the southeast. The smaller, in northern Ohio, was filled with a thinner sequence of carbonates and shales similar to those deposited on the intervening platform.

In the Appalachian basin, the lower Vernon, Unit A, attains its maximum thickness in eastern Pennsylvania within the undifferentiated Bloomsburg. About 500 feet are present in the Good well (PA 5, Luzerne County), the easternmost well wherein a possible separation can be made. The shape of the isopachs shown on plate 4 suggests that Unit A equivalents may attain 600 to 700 feet along the outcrop in Schuylkill, Carbon, and Monroe Counties.

The lower contact of Unit A, with the underlying dolomites of the Lockport-Albemarle Groups, is usually evident in gamma-ray logs by a relatively sharp drop in radioactivity levels. This is apparently due to a marked reduction in clay content across this boundary. In sample logs the disappearance of anhydrite, a reduction in number or a complete loss of shale beds, and the appearance of more crystalline dolomites indicates the lower contact.

Lateral replacement of some 60-70 feet of Guelph dolomite by Vernon gray or green shales with interbedded dolomite is apparent from gamma-ray and sample logs. This change occurs across a line extending from Lockport, New York, southward to and beyond Bradford, Pennsylvania. Evidence for this interpretation is (1) the appearance of shaly beds in the upper Guelph, indicated by higher radioactivity levels in the gamma-ray patterns, as in wells ONT 4 and ONT 1 (plate 11), or PA 23 (plate 12), and (2) the presence of dolomite beds in the lower half of Unit A slightly farther east, as in wells NY 118 and NY 96 (plate 11), or PA 16 (plate 12). Complementary changes in the thicknesses of Unit A and the underlying Guelph also occur. This facies relationship thus suggests that the basal Vernon of central New York and part of the Bloomsburg of central Pennsylvania are contemporaneous with late "Niagaran" rocks in Ohio, Ontario, and Michigan (figure 2).

In the Michigan basin Unit A has been subdivided into two divisions, A1, and A2, each of which consists of a lower evaporite (salt or anhydrite) and an upper carbonate. This four-fold subdivision of Unit A is restricted to the Michigan basin although A1 can be separated from A2 across much of the Ontario peninsula (plate 11, wells MICH 3 to ONT 4). A similar separation of A1 and A2 may be possible in Ohio but no such subdivision has been made in the remainder of the Appalachian basin and it is doubtful if it ever will be accomplished. The influx of terrigenous sediments of the Bloomsburg "delta" prevented the basin-wide deposition of precipitated dolomites and evaporites. Consequently, it was not possible to develop a characteristic gamma-ray pattern traceable over wide areas without significant modification, such as those obtained for higher Salina subdivisions.

UNIT B

The middle Vernon, at its type section in east-central New York, is composed of gray or green shales, a few dolomites and siltstones, and is somewhat less than 100 feet thick. Southeastwardly, these green shales rapidly grade into the undivided red shales of the Vernon. To the southwest, gray or green shales and siltstones remain dominant lithologies but to the west dolomites replace shales, and anhydrite appears. West of Seneca Lake, six, sometimes seven, salt beds occur in the middle Vernon attaining a maximum aggregate thickness of about 75 feet in the Genesee River Valley. No salts are known in the northwestern parts of Erie and Chautauqua Counties, New York, nor in the eastern portion of the Ontario peninsula. Here the middle Vernon consists of dolomites and shales with anhydrite. Traced into Michigan, it is seen that this portion of the Vernon corresponds to Unit B of the Michigan sequence.

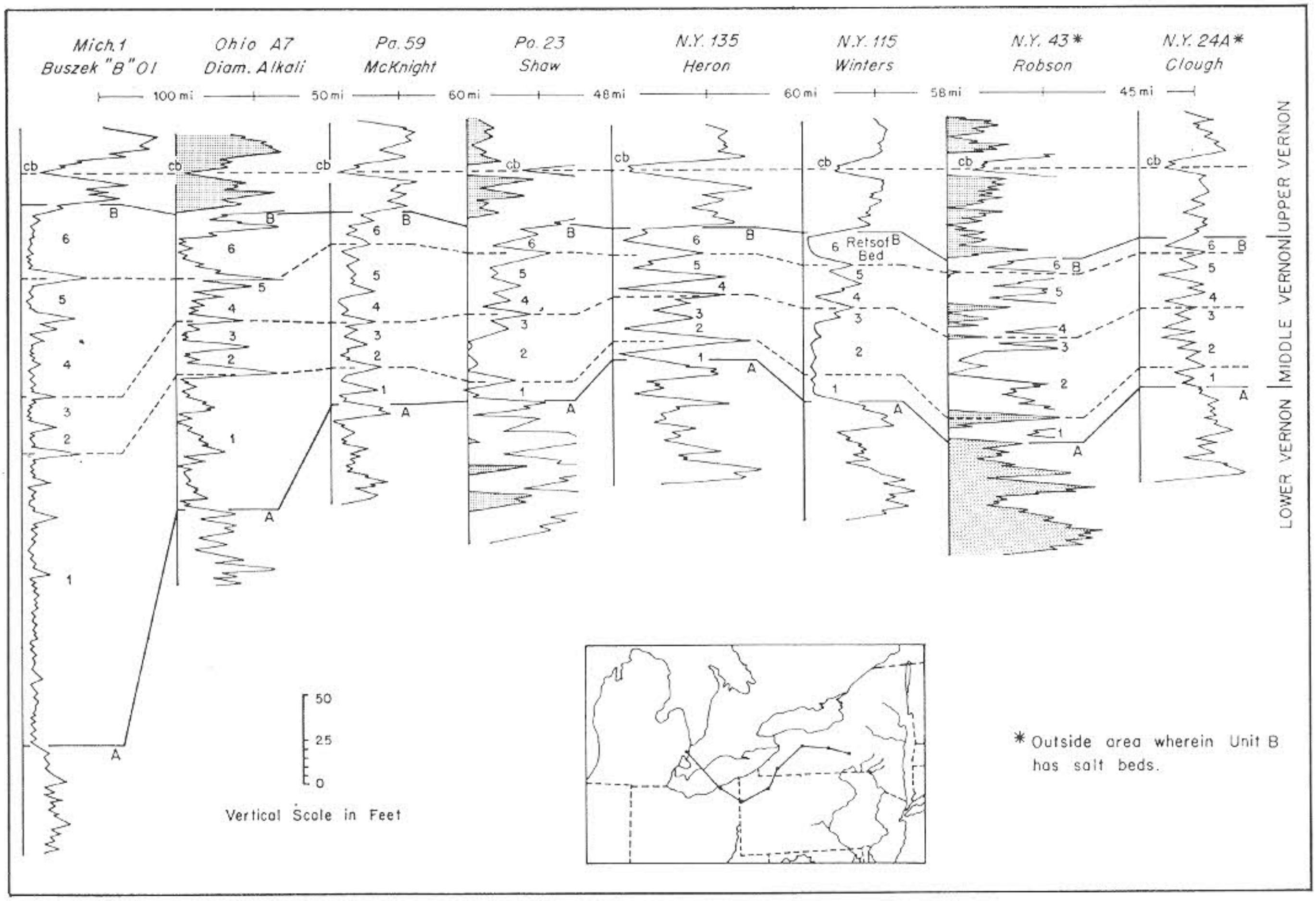
Plate 5 is an isopachous and lithofacies map of Unit B indicating that the unit probably exceeds 300 feet in central Pennsylvania. It is apparent that Unit B does not reflect construction of the Bloomsburg "delta" in the east to the same degree as the earlier Unit A. This may imply that delta construction was completed by this time or that it was proceeding at a much reduced rate. One possible indication of the Bloomsburg delta seems to be the presence of significant intervals of siltstone and sandstone in Unit B in a few wells in north-central Pennsylvania. In any event, the isopachous and lithofacies map of Unit B is somewhat more typical of Salina units in the Appalachian basin and contrasts strongly with that of the preceding Unit A.

The stable platform centered along the Ohio-Pennsylvania State line during early Vernon time experienced some modification during deposition of Unit B. Its axis appears to have shifted eastwardly to a new position extending southward across Chautauqua County, New York, to Warren and Forest Counties, Pennsylvania. Separation of the Appalachian basin into two parts, as in early Vernon time, remained but it is obvious that the distinction was much less complete. The Ohio portion was centered in Lake County.

The salts of Unit B found in the Genesee River Valley occur in the northeastern end of an elongate area extending southwestward across Allegany and Cattaraugus Counties, New York, into northwestern Pennsylvania. As shown on plate 5, this area then turns westward into northeastern Ohio. It appears to continue northwestward across Lake Erie, through the Chatham sag and into the Michigan basin. Throughout all this area, Unit B contains up to eight beds of salt that can be identified and traced by gamma-ray logs (figure 3;[1] plates 11-14). They produce a unique and characteristic gamma-ray pattern for the unit. The highest of these salt beds, usually 15 to 20 feet thick, is mined at Retsof, New York (NY 98, Livingston County), by the International Salt Co. For that reason it is convenient to refer to this layer as the Retsof bed. It is thought probable that the Retsof bed is also the source of the salt obtained by the Morton Salt Co. through a brining process at Silver Springs, New York (NY 123, 124, Wyoming County). The Retsof bed appears to be the thickest and the purest salt throughout this area. In wells drilled outside this area, such as NY 43 and NY 24A on figure 3, the position of the Retsof bed and other salt beds of Unit B can be determined by

[1] In figure 3, where the amplitude of a gamma-ray pattern is large, the higher peaks are cut off on the right and reproduced on the left along the base line. The area beneath such peaks has been stippled to indicate this transfer.

Figure 3. Correlation of salt beds, Unit B.

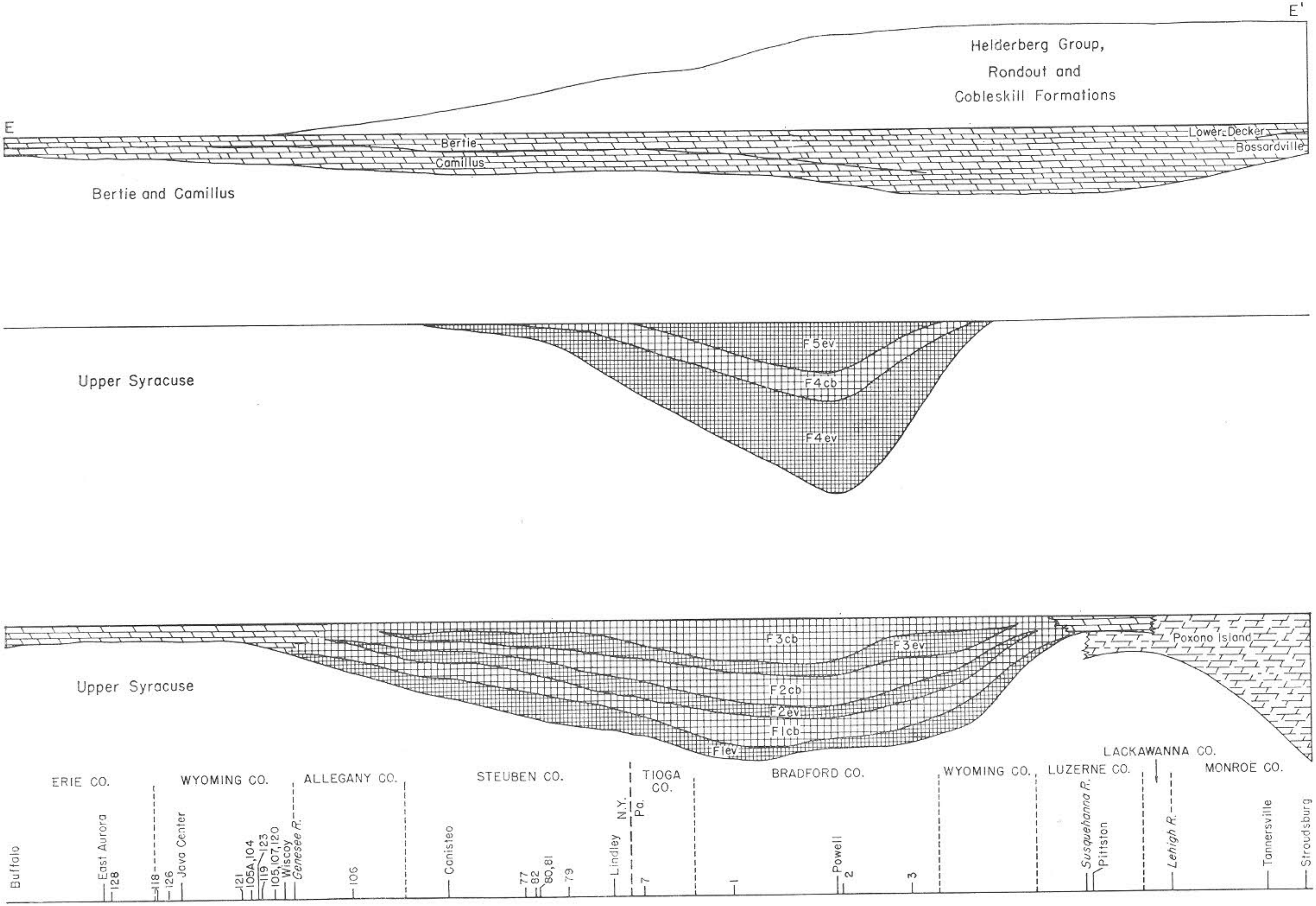


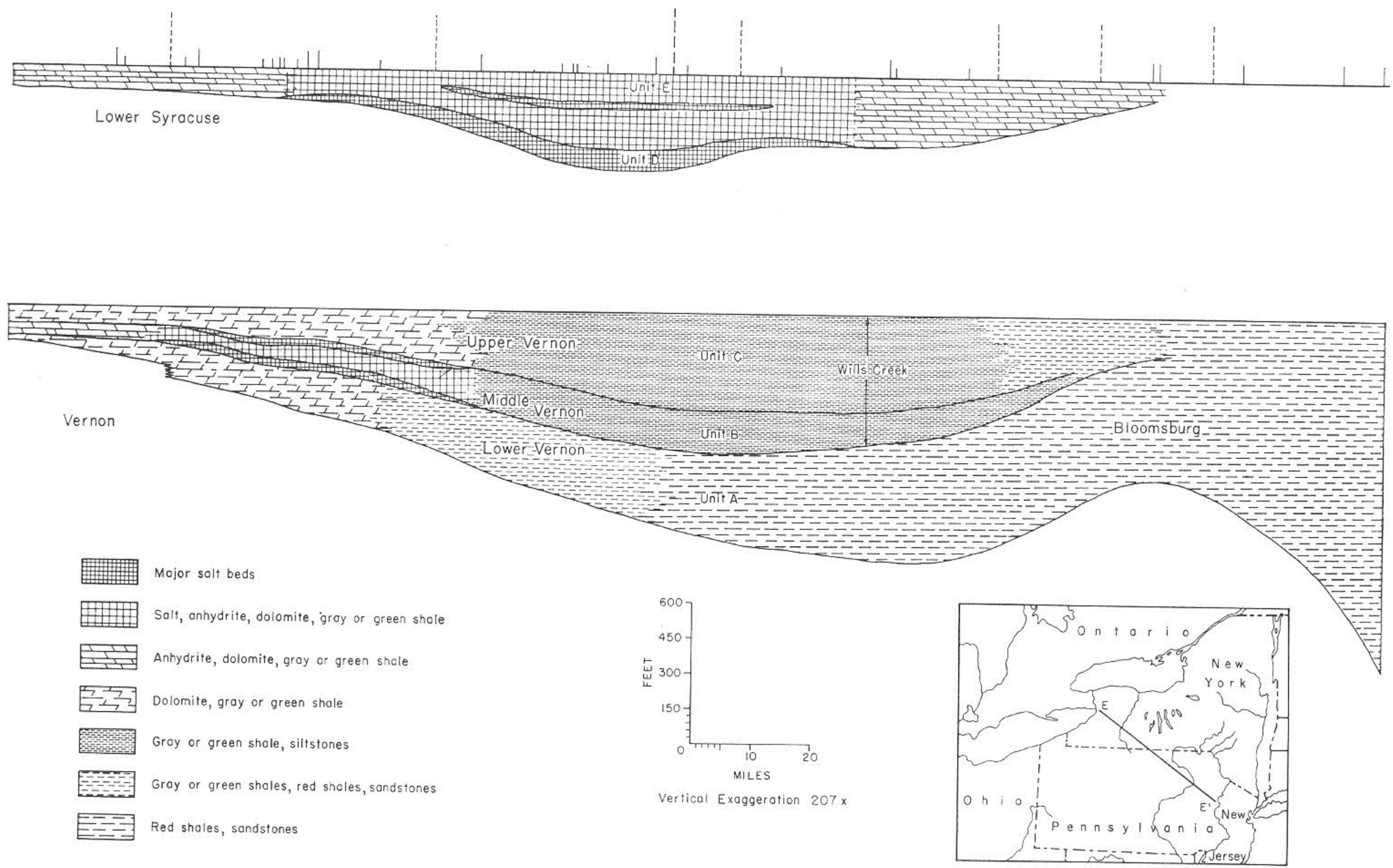
sharp drops in radioactivity levels in gamma-ray logs. Such drops probably record the presence of thin anhydrite beds at equivalent horizons.

The lower contact of Unit B is drawn at the base of the lowest salt bed or its equivalent position in those areas where salt is absent. This position is easily recognized in gamma-ray logs but often cannot be detected in sample logs from extreme western New York and Ontario where similar lithologies exist in both Units A and B. East of the salt-bearing area, the dolomites, anhydrites, and gray-green shales of Unit B contrast strongly with the red shales of the underlying Unit A.

Disagreement over the placement of the top of Unit B has become apparent during this study (figure 2). In Ohio, Ulteig (1964), following the Michigan definition, placed the contact at the top of a thin evaporite bed marked "cb" in figure 3 and on plate 12. Cate (1961, 1965), while not utilizing Landes' nomenclature, recognized and traced via gamma-ray logs in Pennsylvania, an important horizon he called "N." Horizon "N" subsequently has proven to be that generally utilized in Ontario as the top of Unit B. It was chosen by the present writer as the best position for this contact in New York principally because the lithology of the interval between the top of the Retsof salt bed (=horizon "N" of Cate) and horizon "cb" was the same as the overlying Unit C. Ulteig also recognized this similarity (1964, p. 25). No salt beds are known at horizon "cb" anywhere in the Appalachian basin. It was concluded that the shales immediately beneath horizon "cb" were better classified as a part of the overlying Unit C. Consequently, the top of Unit B in the Appalachian basin is placed at the top of the Retsof salt bed or its equivalent position outside the salt-bearing area. This position is easily determined in gamma-ray logs and is often apparent in sample logs by the change from the shales of Unit C to the interbedded dolomites, shales, and anhydrites of Unit B. In the Michigan basin the top of Unit B is drawn slightly higher, at the prominent drop in radioactivity shown in gamma-ray logs that is identified here as horizon "cb."

Figure 4. Cross section, Buffalo (E) to Stroudsburg (E′).





Exact location of this section is shown on Plate I

UNIT C

The red and green shales of the upper Vernon at its type section become gray or green shales with interbedded siltstones to the southwest and grade into the undifferentiated red shales of the Vernon to the southeast. West of Seneca Lake, gray or green shales predominate, dolomite beds also occur and in northwestern Pennsylvania anhydrite appears. Traced across Ontario into Michigan it is seen that this portion of the type Vernon corresponds to Unit C of the Michigan sequence.

The shales of Unit C constitute a remarkably persistent subdivision characterized by relatively high radioactivity levels throughout all of the Appalachian basin. Evaporites are not common in this unit and no extensive salt beds are known to occur. The maximum thickness of Unit C in the Appalachian basin is attained, as shown on plate 6, beneath Tioga County in north-central Pennsylvania. Here the unit exceeds 400 feet in thickness and in a considerable portion of the interval, siltstones and sandstones have replaced the typical shales. The presence of these coarser sediments probably constitutes evidence for continued construction of the Bloomsburg delta to the southeast.

The stable platform of western Pennsylvania and eastern Ohio, so obvious during deposition of Unit A, and somewhat less evident during the formation of Unit B, was eliminated during or just prior to the time of Unit C. Plate 6 does not indicate any separation of the Appalachian basin into two parts as was shown on plates 4 and 5.

One of the most remarkable stratigraphic horizons in the writer's experience is that persistent drop in radioactivity found in the lower portion of Unit C in gamma-ray logs of wells all over the Appalachian basin. This horizon, designated earlier as horizon "cb," also occurs throughout the Michigan basin (Ells, 1967, figure 5) where it is utilized as the top of Unit B. It does not seem to have the same origin everywhere. In Michigan and Ohio it apparently is caused by a thin evaporite bed. Sample logs from New York and Pennsylvania often record a dolomite bed in this position within the shales of Unit C. Horizon "cb," whatever its nature, rivals the widespread Tioga bentonite of Middle Devonian age as a stratigraphic marker of considerable extent and utility.

SYRACUSE FORMATION

The name Syracuse was proposed by J. M. Clarke (1903) for the salt beds of the Salina Group. No type section was designated, for indeed, the salt beds do not crop out at the surface. W. P. Leutze (1959) conducted a thorough investigation of nearly all Salina outcrops across central New York. He clearly differentiated the outcropping dolomites, gypsum and clay layers that are associated with salt beds in the subsurface, which he redefined as the Syracuse Formation, from the overlying green shales of the Camillus Formation. Leutze did not select any specific exposure as a reference section for the redefined Syracuse but pointed out the excellent outcrop in the railroad cut at Manlius Center as "the single most nearly complete section . . . in the type area" (1959, p. 47). Leutze subdivided the outcropping Syracuse Formation into five members which he traced across central New York but it has not been possible to identify these in the subsurface. Subdivisions of the Syracuse Formation recognized and utilized herein are derived from Landes' work on the Michigan Salina sequence.

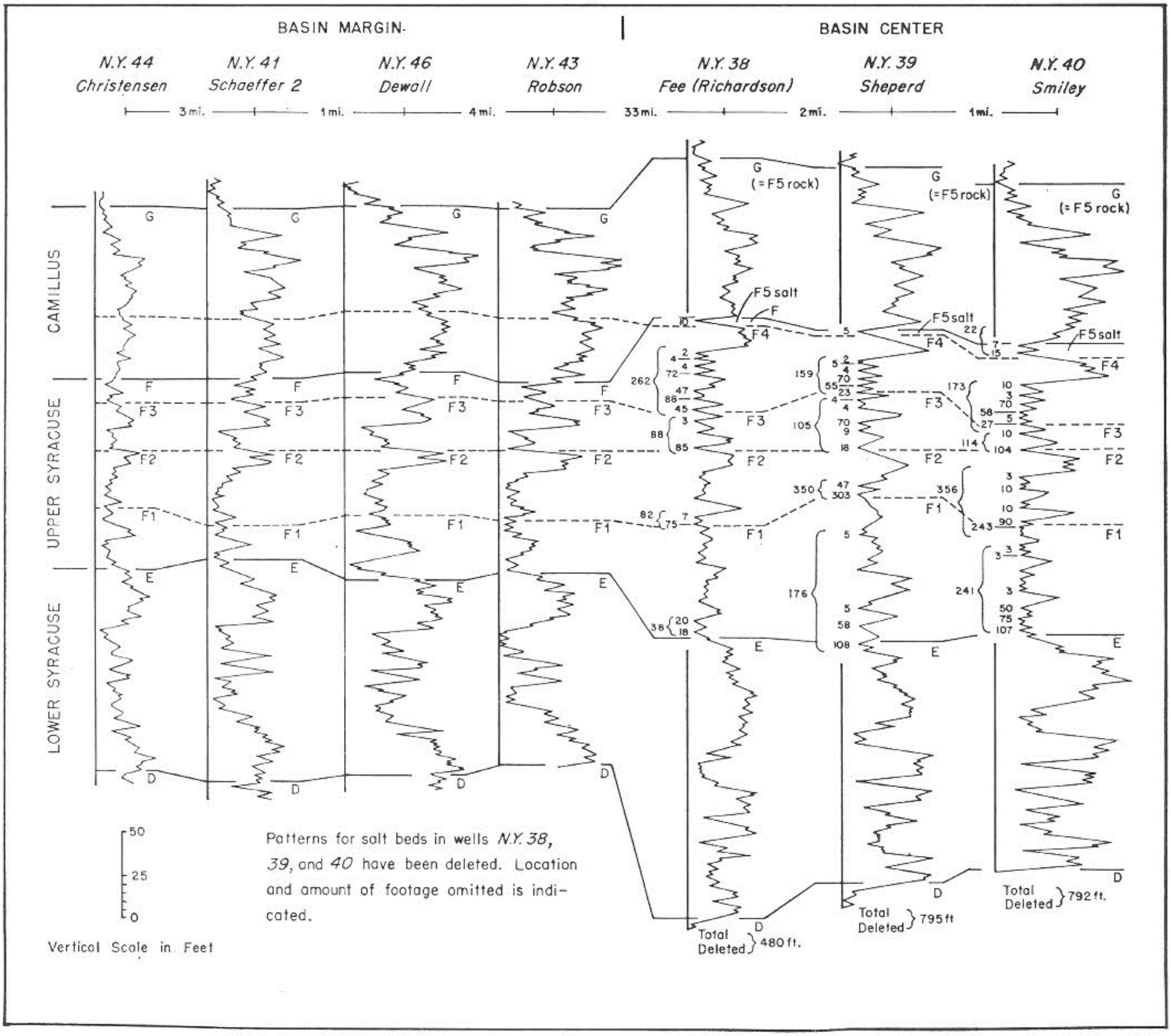
Projection of the Syracuse Formation from selected outcrops cited by Leutze into nearby wells has served to identify a sequence of dolomites, shales and evaporite beds as the subsurface expression of the formation. Several subsurface members have been recognized and traced westward across New York and Ontario into the Michigan basin (plate 11) where it has been determined that these correspond to the Michigan units D, E, and F (in part).

UNITS D AND E

In the subsurface, the basal portion of the Syracuse Formation is a relatively thin unit consisting of dolomite, clay, or evaporite beds. Salt occurs in two, sometimes three beds throughout a large area in the central and western parts of New York and Pennsylvania, extending into northeastern Ohio (plate 7). This portion of the Syracuse Formation corresponds to Unit D of the Michigan sequence. Its thickness varies from 10 to 175 feet.

Overlying Unit D is a thicker interval of interbedded shales, dolomites, and evaporites characterized by a unique pattern in gamma-ray logs. One or two beds of salt are frequently present near the center of this interval in south-central New York, central, and western Pennsylvania. Traced westward into Michigan it is seen that this interval represents Unit E of Landes' Salina sequence. It varies from 50 to 200 feet thick, exceeding 500 feet in southern Potter County, Pennsylvania. The gamma-ray pattern of Unit E is different from that of other predominately shaly subdivisions of the Salina, such as Units A, C, or G, and can be recognized by its unique series of high and low radioactivity readings (figure 5; plates 11-14). This pattern also can be recognized on logs from central Michigan (Ells, 1967, figure 5).

Figure 5. Correlation of Units E, F, and G—margin to center of basin.



These two subdivisions of the Syracuse Formation constitute the lower portion of the formation and are combined on plate 7. Except where it contains significant beds of salt, Unit D seldom exceeds 40 feet in thickness. Consequently, the isopach lines of plate 7 reflect principally changes in the thickness of the overlying Unit E. These units usually can be distinguished in gamma-ray logs but often cannot be separated in sample logs, particularly in areas where Unit D lacks evaporite beds.

Plate 7 indicates that Units D and E attain a maximum thickness of about 700 feet in north-central Pennsylvania. Approximately three-fourths of this is Unit E in which a salt bed, up to 70 feet thick but usually considerably less, frequently is encountered. The total salts of Unit D exceed 80 feet in Schuyler and Steuben Counties, New York, and Tioga and Potter Counties, Pennsylvania. The D salts are more persistent and more extensive than the E salt and appear, judging from gamma-ray logs, to be purer.

At present, there is no commercial use in New York or Pennsylvania of either D or E salts. The Livonia, New York, mine (NY 83, Livingston County) whose shaft was logged by Luther in 1894, utilized the salts of Unit D until the mine was abandoned.

UNIT F

The upper portion of the Syracuse Formation consists predominately of dolomites and evaporites. Shales are not a common rock type, except along the margins of the basin. The upper Syracuse can be recognized not only by its characteristic pattern shown on gamma-ray logs (figure 5; plates 11-14) but also by its lithologic contrast with the shales above and below. It corresponds to the major portion of Unit F of the Michigan basin, specifically units F1 thru F4.

Plate 8 indicates that Unit F exceeds 1000 feet in thickness beneath Chemung and Tioga Counties, New York, and Bradford County, Pennsylvania. Owing to the introduction of many thick salt beds, the closely spaced isopachs shown in central New York indicate a sudden increase in the rate of thickening towards the basin center. The distribution of isopachs on plate 8 can be interpreted to suggest the presence of a second center within the Appalachian basin in southwestern Pennsylvania. Drilling information available to the writer is insufficient to demonstrate this.

In the center of the Appalachian basin the upper contact of the Syracuse Formation is drawn at the top of the highest salt bed. About the margins of the basin, and in intermediate areas where less than four or no salt beds are present, the upper contact is placed at the top of the interval composed predominately of dolomites. This does not result in placement of the upper contact everywhere at precisely the same horizon. While it is possible to propose and utilize a definition of the upper contact based on gamma-ray logs that would be very precise and applicable everywhere, such a definition could not be utilized in sample logs. Hence, the compromise suggested above which has been followed here.

Six major salt beds, separated by intervals of dolomite and/or shale have been identified in Unit F in Michigan (Landes, 1945; G. D. Ells, 1962, 1967). Each combination of a salt and overlying dolomite has been established as a subunit and assigned a number, such as F1, F2, etc., in ascending order. Owing to the unique character of the gamma-ray log patterns of the dolomite-shale intervals, it is possible to recognize the same subdivisions of Unit F in the Appalachian basin. Compare, for example, the gamma-ray logs of Michigan well MICH 3 (plate 11,) with New York well NY 40 (plate 13), or with the Ohio well OHIO B8 and Pennsylvania well PA 59 (plate 12). Consequently, it is now known that only four of the Michigan F subunits are normally present in the Appalachian basin. Near the center of this basin, however, in wells NY 40, 52, and PA 1, 3, the salts of subunit F5 are present. No evidence of F6 salts has been discovered although gypsum and anhydrite are common at the equivalent horizon.

Careful study of gamma-ray logs has revealed the somewhat complex relationship between Units F and G in the Appalachian basin. Figure 5 indicates that the rocks at the top of subunit F4 in the center of the basin are included in the lower portion of Unit G about the basin margin, in areas where Unit F lacks salt beds. Detailed comparison of gamma-ray logs from New York and Michigan indicates that the major portion of Unit G in the Appalachian basin corresponds to the rock interval at the top of subunit F5 in the Michigan basin. Further comparison indicates that Unit H of the Appalachian basin correlates with Units F6 and G of the Michigan basin. These relationships are shown at the left end of section A - A', plate 11. Early in his studies the writer chose to follow rather closely Ulteig's Ohio application of Landes' terminology throughout the Appalachian basin. Subsequent correspondence with G. D. Ells and a study of Michigan gamma-ray logs furnished by Ells has revealed the true relationships. Consequently, the Appalachian units F, G, and H are not identical to the Michigan units bearing the same letter designations, as shown in figure 2.

In the Appalachian basin the salts of Unit F are utilized for commercial purposes in New York and Ohio. In New York State salt is produced from brine wells in or near Watkins Glen, at the southern end of Seneca Lake, by International Salt Co. and Watkins Salt Co., Inc. Brine wells have been operated near Tully by the Solvay Process Division, Allied Chemical Corp., for many years. The salt of subunit F1 is mined at Myers by the Cayuga Rock Salt Co., Inc., and formerly was extracted through brine wells at Ludlowville, by International Salt Co.

Ohio salt production occurs in Lake, Summit, Cuyahoga, and Wayne Counties by Morton Salt Co., Diamond Alkali Co., Pittsburgh Plate Glass Co., Diamond Crystal Salt Co., and International Salt Co. Mines are located at Fairport, Lake County, and at Cleveland, Cuyahoga County. Information available to this writer suggests that most, if not all, Ohio production utilizes salts of the Syracuse Formation (Units D or F) rather than that of the Vernon (Unit B).

Gypsum is produced in Erie, Genesee, and Monroe Counties, New York, by National Gypsum Co., Bestwall Gypsum Division of Georgia-Pacific Corp., United States Gypsum, and the Ruberoid Co. The gypsum beds utilized by these companies are calculated to lie 150 to 225 feet below the base of the Onondaga (projected to the mine shaft location) which indicates that they occur within the Syracuse Formation, probably in Unit F.

CAMILLUS FORMATION, UNIT G

J. M. Clarke (1903) proposed the name Camillus for the shales, gypsum, and platten dolomites exposed in the vicinity of Camillus in Onondaga County, central New York. Although many of the exposures about Camillus have subsequently proven to be outcrops of the Syracuse Formation, Leutze (1959, pp. 45-47, 76) believed it best to retain the name for the predominately green shale interval overlying the Syracuse. This application of the name Camillus is followed here.

In the subsurface the Camillus consists of green shales, anhydrites, and occasional dolomites, varying from 50 to 175 feet thick. In sample logs it usually is separable from the underlying Syracuse and overlying Bertie, being a shale in contrast to the dolomites of these adjacent units. More precise identification of its limits can be made from gamma-ray logs where its relatively higher radioactivity levels contrast with the lower readings of the Syracuse and Bertie. Gamma-ray logs also indicate that the Camillus corresponds to subunits F4-F5 of the Michigan sequence.

The Camillus does not show much variation in its lithology throughout the Appalachian basin (plate 9). Gray or green shales, usually with dolomites and anhydrites, persist nearly everywhere. In the northeastern portion of the basin, in Madison, Otsego, and Delaware Counties, New York, red and green shales have been discovered in surface exposures of the Camillus (Leutze, 1959, p. 86) and are common in well samples. The High Falls Shale of the Rosendale Quadrangle, Ulster County, is a reappearance of this red and green facies of the Camillus. In northeastern Pennsylvania, well samples indicate the presence of siltstones and sandstones in the subsurface Camillus.

West of the Genesee River, a transitional interval of unusually dolomitic shales immediately beneath the Bertie Formation was identified by Chadwick (1917) as the O-atka Shale. Leutze (1959, p. 83) and the writer have included these beds in the Camillus Formation. They are indicative of the larger amount of dolomite generally found throughout the Camillus in western New York and Ontario.

Owing to the fact that neither the Camillus nor the Bertie are very thick or experience much lateral variation in lithology, they are treated together on plate 9. This plate indicates that the combined Camillus-Bertie attains a maximum thickness of 300 feet in northeastern Pennsylvania. As was also true of the Syracuse Formation, some evidence exists for the interpretation of a second center in the Appalachian basin in southwestern Pennsylvania and eastern Ohio. Extension of the isopachs in plate 9 into central Pennsylvania is not possible because of the difficulty of separating the Camillus-Bertie from the Syracuse. The Syracuse-Bertie interval constitutes the Tonoloway Formation and most of the lower Keyser of Pennsylvania, Maryland, and West Virginia. The Tonoloway remains undifferentiated into members although the formation exceeds 1000 feet in many localities. Gamma-ray logs may provide the only possible means of recognizing Units D, E, and F (Syracuse), G (Camillus), and H (Bertie) in this area.

BERTIE FORMATION, UNIT H

Overlying the Camillus is a 50 foot sequence of dolomites and shales, the Bertie Formation of Chapman (1864, p. 190), long noted for its abundance of fossil eurypterids. The type section is located near Bertie, Ontario, 6 miles west of Buffalo. In western New York this formation consists of three members—the Falkirk dolomite, Scajaquada shale or shaly dolomite, and Williamsville dolomite (all Chadwick, 1917, 1918) in ascending order. The Bertie of central New York also contains three members—The Fiddlers Green dolomite (Hopkins, 1914), Forge Hollow shale, and Oxbow dolomite (both Rickard, 1962), in ascending order. Despite the efforts of several stratigraphers and paleontologists, it has not yet been satisfactorily demonstrated that these two sequences are the same. Recent highly detailed field work still in progress by S. J. Ciurca, however, may eventually accomplish this. In any event, the exact subdivision and nomenclature of the outcropping Bertie does not affect study of its subsurface features and distribution. Indeed, a similar subdivision of the subsurface Bertie does not appear to be possible.

The subsurface Bertie Formation appears to be a 50 to 100 foot thick sequence of dolomites, usually with anhydrite, that does not exhibit much geographic variation. A large area of the Bertie in western New York (plate 9), however, lacks shales and anhydrite. Because of this, it has sometimes been omitted from the Salina Group and confused with the overlying Cobleskill (Akron).

The Bertie usually exhibits relatively low radioactivity readings on gamma-ray logs. But such logs characteristically show two significant deflections; (1) a small interval of high level readings at the top of the formation, and (2) a single high peak ("hp" on plates 11-14) near the center or in the lower portion of the formation. Both are persistent deflections of value for regional correlation. Both have been observed on gamma-ray logs of wells distributed across Michigan (Ells, 1967, figure 5), Ontario, and western and central New York (plates 11-14). Wells in northeastern Ohio and northern Pennsylvania frequently show these deflections. The first corresponds to Unit G of the Michigan basin Salina sequence, the remainder of the Bertie correlating with subunit F6. The first also serves to identify the top of the Salina Group, and the base of the overlying Cobleskill (Akron) Formation in New York or an equivalent stratigraphic position in Pennsylvania, Ohio, Ontario, and Michigan. These deflections constitute two more examples of the remarkable lateral persistence of many features shown on gamma-ray logs of the Salina Group.

Post-Salina Stratigraphy

Included in this report is an isopach map (plate 10) of the combined Cobleskill, Rondout, and Helderberg carbonates of New York and equivalent strata elsewhere. In the central Pennsylvania outcrop belts this includes the *Gypidula prognostica* peak zone near the top of the lower Keyser and all overlying strata up to the base of the Oriskany Sandstone or its correlatives. The recent work of J. D. Harper and J. W. Head, III, at Brown University has supported the earlier suggestion of F. M. Swartz (1929, p. 38) and the writer (Rickard, 1962, p. 110) that this fossil zone correlates with the *G. circularis* zone of the Decker Ferry Formation in New Jersey and the Wilbur and Cobleskill limestones of eastern and central New York. It is further supported by the facies change from the dolomites and anhydrites of the Bertie into the limestones of the lower Keyser. This is shown in the Carver, Blemle, and Bennett wells at the southern end of section C-C', plate 13.

The identification in gamma-ray logs of an horizon in the basal portion of the Bass Islands of Ohio and Ontario that is equivalent to the base of the Cobleskill Limestone of New York has permitted the extension of the isopachs into these western areas.

Plate 10 illustrates several features of the highest Silurian and lower Devonian. The two depositional centers shown in northeastern and southwestern Pennsylvania appear to be inherited from the Salina Group. A shallow area or shoal seems to have developed in west-central Pennsylvania and persisted throughout much of the lower Devonian. The highest Silurian and lower Devonian are missing in eastern Pennsylvania (Dauphin, Lebanon, and Schuylkill Counties) owing to nondeposition or later erosion, most probably the former. In western New York a second, broader area lacks latest Silurian and early Devonian strata.

Deposition of Salina Evaporites

New York State ranks fourth in production and third in value among salt-producing states. Approximately 4.3 trillion tons of salt underlie 10,000 square miles of central and western New York. Eighty percent of this salt is in Unit F, 14 percent in Unit D, and 6 percent in Unit B. The following paragraphs are devoted to a few remarks concerning the origin of this salt; a comprehensive discussion is not undertaken.

ESSENTIAL CONDITIONS

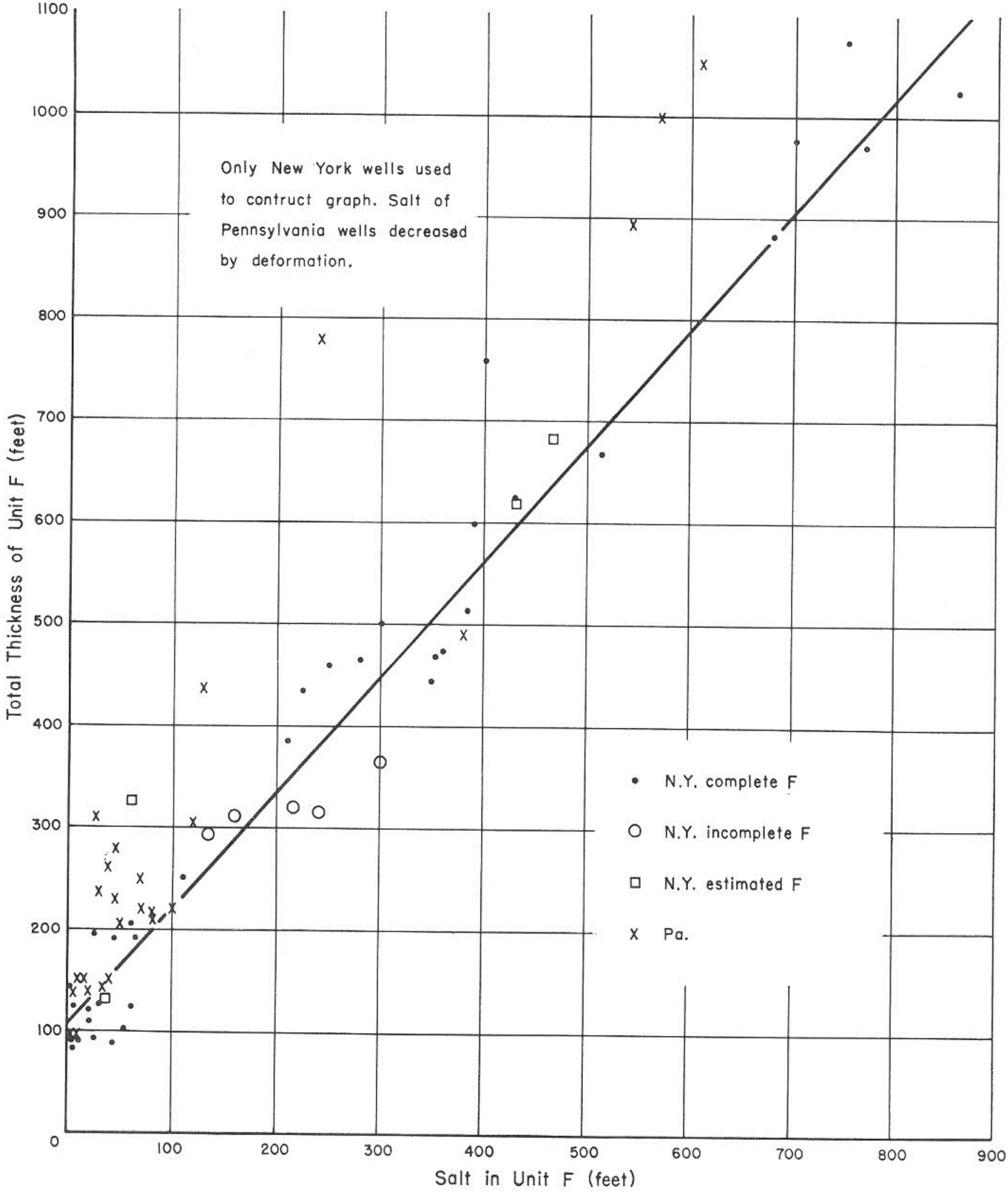
Schmalz (1966) has written a concise but informative paper on the environments of marine evaporite deposition. Borchert and Muir (1964) have produced a more detailed discussion of evaporite deposits utilizing the German Zechstein Series of Permian age as an example. Dellwig (1955) has contributed a paper on the origin of the Salina salt of Michigan. From these reports one can learn much of what is now known or inferred on the subject.

Three conditions generally are held essential for marine deposition of the evaporites gypsum, halite, and potash: (1) an arid, but not necessarily hot climate is required to maintain an adequate rate of evaporation; (2) a depression or basin in which the concentrated brine and precipitates may be collected, whose connection with the open sea or ocean is more or less restricted by reefs, a bar, or sill, a long fetch of very shallow water, or a series of smaller, shallower "forebasins"; and, of course, (3) an abundant supply of sea water containing the dissolved minerals. Subsidence of the basin floor is necessary for the accumulation of thick evaporite deposits but is not considered a basic requirement for their formation.

Following the suggestion of Richter-Bernberg, both Schmalz (1966) and Borchert and Muir (1964) point out that where thick evaporite sequences occur, the major portion of basin subsidence evidently took place prior to the deposition of salt. The latter process is a much more rapid event than the former. Halite may accumulate at rates up to 140 mm/yr. For the Zechstein, rates of 20 to 80 mm/yr have been suggested. In contrast, a rate of subsidence in excess of 1 mm/yr is considered unlikely except in tectonically very active areas. Values of 0.3 and 0.03 mm/yr have been calculated for the Gulf Coast and Appalachian geosynclines. We may conclude that, although the overall average rate of sedimentation may be less than or only slightly greater than the rate of subsidence, the initial depth of the basin must be of the same order as the thickness of salt which accumulates within it. The alternatives, increasing the subsidence rate or decreasing the sedimentation rate imply implausably violent tectonism or preservation of the essential but delicately balanced climatic, structural, and chemical conditions for hundreds of thousands, indeed, millions of years.

Two observations made by the writer lend support to the conclusion given above. First, if the patterns for the salt beds of Unit F, for example, are deleted from the gamma-ray log of a well in the center of the basin where many thick salt beds exist, the remaining pattern is very similar to that of a well at the margin of the basin where salt was not deposited. This is shown in figure 5. The total thickness of rock strata in Unit F in both types of wells is nearly the same despite the presence of hundreds of feet of salt in the deep basin well. Indeed, in the deep basin well it is only 23 percent larger. It is suggested, therefore, that the deposition of a salt bed, often scores of feet thick, is an extremely rapid event relative to the deposition of the intervening anhydrite and rock layers. If this were not so, one could reasonably expect that some sort of deposition would have occurred in the marginal areas during the supposedly long period of salt precipitation in the center of the basin and that consequently one could not match gamma-ray logs in the fashion shown in figure 5. A similar observation and conclusion was made by Evans (1950, p. 58) who noted that "locally in any area, say of 20 square miles, the total thickness of Salina, less the thickness of salt, will give a fairly uniform thickness of limestones and dolomites. In other words, when salt was being deposited little or no other sediments were being deposited."

Figure 6. Relationship of salt thickness to total thickness of Unit F.



Second, a plot of the total aggregate thickness of salt in Unit F against the thickness of the unit for salt-bearing wells of Unit F in New York and Pennsylvania is shown in figure 6. This graph indicates that the increase in thickness in Unit F is almost wholly owing to the addition of salt. Only 15 feet of rock and/or anhydrite is added for every 100 feet of salt. Once again, the data suggest significantly different rates of deposition for salt and the intervening anhydrite-rock strata. Several Pennsylvania wells fall well beyond the line drawn in figure 6. It is believed that modification of the original thickness of salt may have occurred in these wells owing to their location in areas of moderately folded and faulted strata.

If, then, the accumulation of thick deposits of salt requires the prior establishment of a basin whose depth is of the same order of magnitude, one might suggest that at least before, and alternating with, deposition of the salt beds, the sedimentation rates for associated rock strata were significantly less than the subsidence rate. Otherwise, deepening of the basin would not occur and space for thick salt deposits could not develop. An alternative is to infer long periods of subsidence without deposition of any type. This would permit the formation of widespread disconformities in the sequence. No evidence of such disconformities has been observed in this study.

SALINA DEPOSITIONAL MODEL

The writer has attempted to gain some understanding of the quantitative aspects of Salina evaporite deposition through the use of a hypothetical model. Seven wells were selected for analysis: three in the center of the Appalachian basin (PA 3 Blemle, NY 52 Kesselring, NY 37 Grund), three near its margin (NY 96 McDonald, NY 135 Heron, NY 3 Hirsch), and one in the center of the Michigan basin (State-Foster, see Ells, 1967, p. 11). Analysis of five of these are given in Appendix C.

Initially each lithology was assigned a specific depositional rate. Where several lithologies were interbedded an average rate was applied. Calculation of the number of years represented by each Salina unit followed. An examination of these initial calculations showed an expected variation in the length of time determined for each unit. Inasmuch as each division is a time-rock unit whose boundaries approximate time planes, further examination suggested an appropriate length of time for each unit (see Appendix C). The depositional rates for each unit in each well were then adjusted to produce this time interval or the nearest approach to it without, of course, resorting to adoption of improbable rates. This adjustment resulted in the adoption of more rapid depositional rates for a well near the center of the basin (Blemle, average 0.5 mm/yr) than one in a marginal area (McDonald, average 0.2 mm/yr). It also suggested the incompleteness of the depositional record in the marginal well (time intervals unrecorded, indicated in parenthesis in Appendix C).

An average subsidence rate was determined and, if reasonable, applied throughout the column at each well. In several wells, a more rapid initial rate for Unit A was assumed for the thick, presumably more rapidly deposited, red shale section. In general, however, these rates also reflected the position of the well, lower subsidence rates occurring in marginal wells (average of 0.2 vs 0.5 mm/yr). Calculation of the rate of change and amount of change in water depth followed. A final assumption of an initial water depth at the site of each well was then made, this assumption in part, dictated by the net loss in depth and by the obvious requirement that deposition at no time could proceed above sea level (because all the sediments apparently were marine). Calculation of the depth of water at the end of the deposition of each unit completed the model.

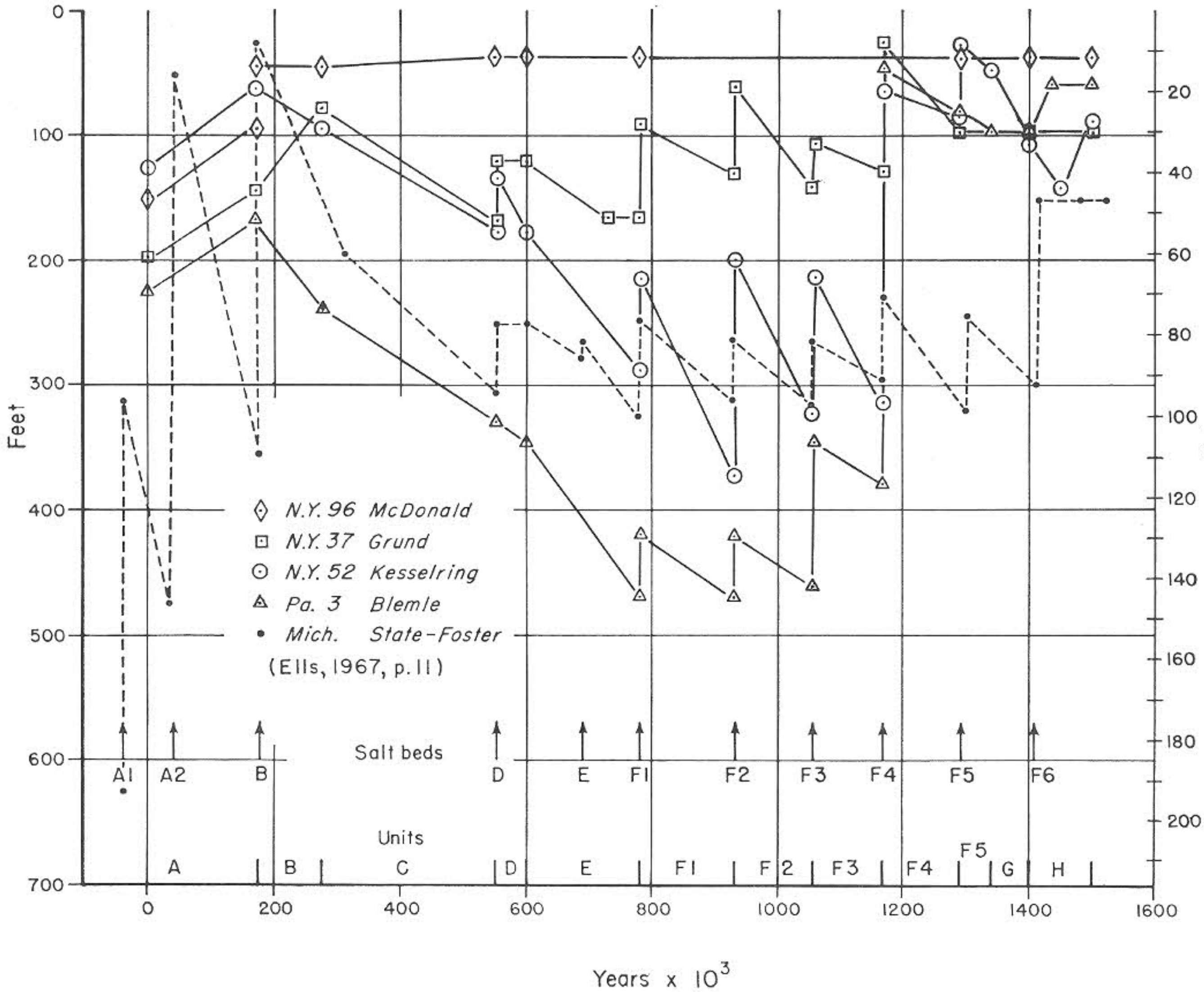
The major assumptions made in the construction of this depositional model involve the rates of deposition and subsidence and the initial water depth. Other data are established by simple calculations. Depositional rates generally assumed in the model are given below. Lower rates occur more frequently in Unit F than in older or younger units.

anhydrite, dolomite, gray or green shale, singly or in combination	0.2 to 0.4 mm/yr (minimum 0.1, max. 0.8)
red and green shale	0.3 or 0.4
red shale	0.6 or 1.0

In accordance with the theory established earlier, that halite is deposited much more rapidly than the adjacent rocks, a depositional rate of 20 mm/yr was assumed for salt. This is relatively conservative, compared with rates cited for halite derived by solar evaporation in modern salt pans. Yet it is 100 times the rate frequently assumed for shale and/or dolomite in the depositional model. It yields a calculated evaporation rate of 128 cm/yr (50 in/yr), a rate that also is quite conservative, perhaps more characteristic of temperate than tropic climates.

Subsidence rates assumed in the model range from 0.2 to 1.0 mm/yr but average 0.2 or 0.3 mm/yr for marginal wells and 0.3 to 0.5 mm/yr for wells near the center of the basin. The highest subsidence rates are assumed for Unit A in the Pennsylvania Blemle well (0.9 mm/yr) and Units A and B in the Michigan State-Foster well (1.0 and

Figure 7. Water depths suggested by Salina depositional model.



0.6 mm/yr), both wells located near their respective basin centers.

The model suggests that deposition of the entire Salina Group took about 1.5 m.y. An estimate of 5 m.y. has been made from a recent Silurian correlation chart and available radiometric dates. Depositional rates assumed in the model and thought to be reasonable, would have to be reduced to less than ⅓ their present values to account for such a long period. Alternatively, one might infer long periods of little or no subsidence or deposition and no significant subaerial or subaqueous erosion of earlier sediments.

The water depths calculated for the end of each Salina unit in each well are shown in figure 7. This graph emphasizes several assumptions made in the development of the model and suggests certain other points. It emphasizes the rapidity of salt deposition and consequent rapid basin filling by the nearly vertical segments of each plot. But it also suggests that the deposition of thick beds of salt can be inhibited if the basin is too shallow. Note that the F4 salts essentially filled the Appalachian basin. There are wells in which F3 salts perform the same function. Apparently D, E, or F salts failed to develop at the site of the McDonald well because this area remained shallow after filling by B salts. In contrast, the Michigan basin was not filled by F4 salts, leaving space for the additional F5 and F6 beds. Although the model is highly speculative and involves a certain amount of "circular reasoning," it is in keeping with the theory that the deposition of thick evaporite beds requires the prior establishment of a "deep" basin.

The water depths of the depositional model suggest very low slopes for the sea floor. Calculated paleoslopes for the Appalachian basin at the end of Unit E, the apparent time of maximum depths, are 1.8 ft/mi. McDonald to Grund, 3.5 McDonald to Blemle, and 5.0 Grund to Blemle.

It is of interest to note that an excellent correlation of the Michigan well with those from the Appalachian basin can be obtained if one assumes an earlier date for the beginning of Salina deposition in Michigan, as shown in figure 7.

Friedman (1965) and Neeve and Emery (1967) have postulated a decomposition of gypsum through the activities of sulphate-reducing bacteria operating in the deeper, anaerobic waters (over 130 feet) of the Dead Sea. In the shallower, aerated, marginal waters the gypsum precipitate is preserved. This decomposition results in the formation of calcium carbonate and hydrogen sulfide. The former may be deposited as calcite and some of the latter becomes available to reduce iron oxides to black iron monosulphides, eventually converted to pyrite. Most of the hydrogen sulphide, however, is thought to diffuse upward where, in the oxygenated surface waters, it is converted to sulphate. This process was proposed to explain the comparative deficiency of gypsum in the bottom sediments of the Dead Sea, in spite of its nearly continuous precipitation from the surface. Consequently, Friedman (personal communication) has suggested that significant quantities of gypsum (and halite?) cannot accumulate at depths much in excess of 100 feet. The writer's depositional model suggests that *most* of the Salina evaporites were deposited in waters 100 to 400 feet and possibly as much as 600 feet deep.

But were the physical, chemical, and biological features of the ancient Salina Sea similar to those of the modern Dead Sea? The Late Silurian Sea appears to have been a broad epicontinental sea whose access to the open ocean was somewhat restricted. In area it exceeded 100,000 square miles. In contrast, the Dead Sea, 360 square miles, is located in a narrow, deep graben. Deoxygenation of the deeper waters of the Dead Sea is not an unexpected development in view of its size and shape. The abundance (up to 2 percent) of organic material in Dead Sea bottom sediments probably contributes to this. Similar deoxygenation of the bottom sediments of the Salina Sea cannot be assumed. Indeed, its size, shape, and the very low organic content of its sediments suggest otherwise. Dellwig (1955, pp. 107-108) noted that "iron associated with the halite layers is in the form of hematite, indicating that oxidizing conditions were normal for the basin." Furthermore, the sediments of the Salina Sea do not appear to have experienced the blackening caused by the gypsum decomposition process nor is there any evidence of native sulfur. Pyrite occurs but is not especially abundant. But, of course, what changes may have been incurred during diagenesis are uncertain. The available evidence does not suggest that the Dead Sea and the Salina Sea are analagous situations.

Kuhn (1955) and Holser (1966) have suggested initial brine depths utilizing the bromide content of basal halites for the Strassfurt and other evaporite deposits. Kuhn (ibid, pp. 659-662) calculated a wide range of 2 to 130 m. (7 to 425 ft.). Holser (ibid, p. 254) proposed the concept of "fictive brine depth," defined as "the depth the brine would have had in the beginning if the basin were cylindrical." He listed (ibid, p. 272) fictive depths ranging from 20 to 250 m. (66 to 820 ft.) and gave a value of 50 m. (164 ft.) for the A1 salt in central Michigan. He noted, however, that the calculated fictive depths were less than the thickness of the overlying salt formation so that subsidence of the basin or a previously formed basin was required.

ADDITIONAL FEATURES

A major feature of the Salina Group noted during this study is that Salina rock and evaporite units have characteristic, often unique, gamma-ray log patterns that can be recognized over broad areas, hundreds of miles across. Certain specific deflections of widespread occurrence have been pointed out as important horizon markers. The stratigraphy and inferred geologic histories of the two basins, Michigan and Appalachian, are, consequently, very similar. Three conclusions seem warranted by these observations. (1) Salina units are essentially time-rock divisions for if they varied in age, it is unlikely that their characteristic or unique patterns would be maintained. (2) Both the Michigan and Appalachian basins lay in the same climatic zone with few or no important differences between them; and (3) this climate must have been the most important factor controlling the kind of sedimentation that took place. Events, such as the initiation and cessation of halite deposition, or the formation of such thin beds as horizon "cb," seem to have occurred simultaneously in both basins. No factor other than climate seems able to account for the widespread occurrence and uniformity of depositional sequences during Salina time.

Briggs (1958), and Alling and Briggs (1961), among others, have indicated the importance of reefs constructed during the earlier Lockport-Guelph ("Niagaran") time. These reefs, surrounding the Michigan basin, may have exhibited as much as 400 feet of relief. Briggs and Pollack (1967) have obtained a fairly realistic computer simulation of Salina salt deposition by assuming 80 percent radial influx through the reefs around the entire margin of the Michigan basin, 20 percent via two presumed major open inlets. It seems evident that "Niagaran" reefs were the principal restrictive structural element of the Michigan basin at least during early Salina time (Unit A). But the reefs were overwhelmed and buried beneath younger Salina units, several of which contain significant volumes of salt.

No salts are known in Unit A in the Appalachian basin although those of Units B, D, E, and F are represented. The absence of Unit A salts could be explained by a lack of sufficient depth to the Appalachian basin during this time, the absence of restrictive structural elements preventing development of concentrated brines, or the influence of the Bloomsburg delta in the east.

Except for those along its common border with the Michigan basin, no reefs are known around the margins of the Appalachian basin. Much of the eastern border of this basin was a land mass whose erosion supplied the sediments of the Bloomsburg delta. This land may have persisted throughout all of Salina time effectively separating the Salina Sea from the Atlantic Ocean. But no evidence of similar land masses to the north or south is known. Consequently, the nature of the restrictive structural elements for both the Michigan and Appalachian basins after the deposition of Unit A is uncertain.

Conclusions

The utility and value of this study for commercial purposes, especially the salt industry, seems obvious. The data assembled and interpreted herein permit the delineation of areas underlain by salt beds and a prediction of the number and aggregate thickness of these beds. Depths to the salt beds can be determined, thereby facilitating estimates of the costs of exploration, development, and production.

Among the more interesting and important correlations determined by this study and indicated in figures 2 and 4 are the following.

(1) The upper 60 to 70 feet of the Guelph dolomite of Ontario grades laterally into basal Vernon in New York across a line extending south from Lockport, New York, to Bradford, Pennsylvania, (plates 4, 11, 12).

(2) The type Vernon of New York is a tripartite unit as disclosed by the measured section of Fisher (1957) and several nearby well logs. The lower division, red shale, retains the characteristic red color of the Vernon westward to Seneca Lake. Mixed red and green beds extend to the Genesee Valley. The middle Vernon division is gray or green in color, largely shales, dolomites, and a few siltstones, and can be traced westward to the Genesee Valley, where it contains the salt mined at Retsof, and beyond. The upper Vernon division rapidly loses its red color westward from the type section although red layers are encountered near the top of this unit as far west as the Genesee Valley (plates 4, 5, 6, 11, 12).

(3) These three divisions—the lower, middle, and upper Vernon—correlate with Units A, B, and C of the Michigan sequence (plate 11). The lower division is the type Bloomsburg of central Pennsylvania and the middle and upper divisions correspond to the Wills Creek Formation of central Pennsylvania (plate 13). Southeastward from the type section the entire Vernon becomes one indivisible mass of red shales and siltstones. This undivided Vernon of eastern New York correlates with the thick Bloomsburg of eastern Pennsylvania (plate 3).

(4) The gray and green shales, dolomites, and clay beds (leached salt beds) overlying the type Vernon, and identified by Leutze (1959) as the Syracuse Formation, form the principal salt-bearing unit of the New York-Pennsylvania subsurface and correlate with Units D, E, and F (F1 thru F4 only) of the Michigan sequence (plates 7, 8, 11). The gray-green shales of the Camillus constitute much less of the Salina Group than formerly believed. The Camillus and the overlying Bertie correlate with Unit F (F5 and F6 only) and Unit G of the Michigan sequence (plate 9, 11). The combined Syracuse and Camillus of New York correlate with the Tonoloway Formation of central Pennsylvania (plate 13).

(5) The base of the Bass Islands of Michigan correlates with the base of the Cobleskill of New York and the *Gypidula prognostica* peak zone of the Keyser of Pennsylvania (plate 10, 11, 13). Upper Bass Islands may be as young as parts of the Helderberg of New York and consequently would be early Devonian in age.

(6) In New York and northern Pennsylvania salt beds occur in the middle Vernon (Unit B), and in the Syracuse (Units D, E, and F). The salts of Unit B appear to be continuous from the Michigan basin through the Chatham sag into the Appalachian basin (plate 5). Indeed, it appears to be possible to trace six specific salt beds of Unit B over 300 miles from central Michigan to central New York via northeastern Ohio and northwestern Pennsylvania (figure 3). Generally only four of the six principal beds of salt found in Unit F in Michigan occur in the New York-Pennsylvania area. Although not continuous between the two basins, they are distinguished in both by intervals of rock whose gamma-ray patterns are surprisingly similar (plate 11).

(7) If the patterns for the salt beds of Unit F, for example, are deleted from a gamma-ray log of a well in the center of the basin where many thick salt beds exist, the remaining pattern is very similar to that of a well at the margin of the basin where the salt was not deposited (figure 5). The total thickness of rock strata in Unit F in both wells is often nearly the same despite the presence of hundreds of feet of salt in the deep basin well. This suggests that the deposition of salt beds, sometimes scores of feet thick, is an extremely rapid event relative to the deposition of the intervening rock layers.

(8) The writer has been impressed by the general similarity of gamma-ray logs of the Salina Group from wells throughout the Appalachian and Michigan basins. Wells hundreds of miles apart maintain the unique patterns shown by many Salina units. Certain specific deflections on these logs, such as horizons "hp" and "cb" (figure 3; plates 11-14), can be traced from western Michigan (Ells, 1967, figure 5) to east-central New York, over 600 miles. These features bespeak the uniformity of climate and widespread occurrence of specific events during Salina time.

Bibliography

Alling, H. L. & Briggs, L. I., 1961, Stratigraphy of Upper Silurian Cayugan evaporites: Am. Assoc. Petroleum Geologists Bull., 45:515-547

Borchert, H. & Muir, R. O., 1964, Salt Deposits: London, Van Nostrand Co., Ltd., 338 pp.

Briggs, L. I., 1958, Evaporite Facies: Jour. Sed. Petrology, 28:46-56

——— **& Pollack, H. N.,** 1967, Digital model of evaporite sedimentation: Science, 155:453-456

Cate, A. S., Stratigraphic Studies of the Silurian rocks of Pennsylvania, part 1: Pa. Topog. and Geol. Survey Spec. Bull. 10

———, 1963, Stratigraphy of Cayugan Series in northwestern Pennsylvania, *in* Symposium on Salt: Northern Ohio Geol. Soc., pp. 19-26

———, 1965, Stratigraphic Studies of the Silurian rocks of Pennsylvania, part 2: Pa. Topog. and Geol. Survey Spec. Bull. 11

Chadwick, G. H., 1917, Cayugan waterlimes of western New York (abstract): Geol. Soc. America Bull., 28: 173-174

———, 1918, *in* Clarke, J. M., Fourteenth report of the director of the State Museum and Science Department: N. Y. State Mus. Bull. 207-208

Chapman, E. J., 1864, A popular and practical exposition of the minerals and geology of Canada: Toronto, 236 pp.

Clarke, J. M., 1903, Classification of New York series of geologic formations: N. Y. S. Museum Handb. 19, 28 pp.

Dellwig, L. F., 1955, Origin of the Salina salt of Michigan: Jour. Sed. Petrology, 25:83-110

Ells, G. D., 1958, Notes on the Devonian-Silurian in the subsurface of southwest Michigan: Mich. Geol. Survey Prog. Rept. 18, 55 pp.

———, 1962, Silurian rocks in the subsurface of southern Michigan, *in* Silurian rocks of the southern Lake Michigan area: Mich. Basin Geol. Soc., 96 pp.

———, 1967, Michigan's Silurian oil and gas pools: Mich. Geol. Survey Rept. Inv. 2, 49 pp.

Evans, C. S., 1950, Underground hunting in the Silurian of southwestern Ontario: Geol. Assoc. Canada Proc., 3:55-85

Fergusson, W. B. & Prather, B. A., 1968, Stratigraphy of the Salina Group in Pennsylvania: Pa. Topog. and Geol. Survey Mineral Resources Rept. M58

Fettke, C. R., 1955, Preliminary report occurrence of rock salt in Pennsylvania: Pa. Topog. and Geol. Survey Prog. Rept. 145

Fisher, D. W., 1957, Lithology, paleoecology and paleontology of the Vernon Shale (Late Silurian) in the type area: N. Y. State Mus. and Sci. Service Bull. 364, 31 pp.

——— **& Rickard, L. V.,** 1953, Age of the Brayman Shale: N. Y. State Mus. and Sci. Service Circ. 36, 11 pp.

Friedman, G. M., 1965, On the origin of aragonite in the Dead Sea: Israel Jour. of Earth-Sciences, 14: 79-85

Hall, J. F., 1963, Distribution of salt in Ohio, *in* Symposium on Salt: Northern Ohio Geol. Soc., pp. 27-30

Hewitt, D. F., 1962, Salt in Ontario: Ontario Dept. of Mines, Indus. Mineral Rept. 6, 38 pp.

Holser, W. T., 1966, Bromide geochemistry of salt rocks, *in* Second Symposium on Salt: Northern Ohio Geol. Soc., pp. 248-275

Hopkins, T. C., 1914, The geology of the Syracuse quadrangle: N. Y. State Mus. Bull. 171, 80 pp.

Hoskins, D. M., 1961, Stratigraphy and paleontology of the Bloomsburg formation: Pa. Topog. and Geol. Survey Bull. G36, 125 pp.

Kriedler, W. L., 1957, Occurrence of Silurian salt in New York State: N. Y. State Mus. and Sci. Service Bull. 361, 56 pp.

———, 1963, Silurian salt of New York State, *in* Symposium on Salt: Northern Ohio Geol. Soc., pp. 10-18

Kuhn, R., 1955, Tiefenberechnung des Zechsteinmeers nach dem Bromgehalt der Salze: Deutsche. geol. Gessel. Zeitschr., 105:646-663

Landes, K. K., 1945, The Salina and Bass Island rocks in the Michigan basin: U. S. Geol. Survey Oil and Gas Inv. (Prelim.) Map 40

Leutze, W. P., 1956, Faunal stratigraphy of Syracuse formation, Onondaga and Madison counties, New York: Am. Assoc. Petroleum Geologists Bull., 40: 1693-1698

———, 1959, Stratigraphy and paleontology of the Salina group in central New York: Ohio State University, unpub. Ph.D. thesis, 463 pp.

Luther, D. D., 1894, Report on the geology of the Livonia salt shaft: N. Y. State Mus. Ann. Rept. 47: 219-312

Neeve, D. & Emery, K. O., 1967, The Dead Sea, depositional processes and environments of evaporites: Israel Geol. Survey Bull. 41, 147 pp.

Pearson, W. J., 1963, Salt deposits of Canada, *in* Symposium on Salt: Northern Ohio Geol. Soc., pp. 197-239

Pepper, J. F., 1947, Areal extent and thickness of the salt deposits of Ohio: Ohio Jour. Sci., pp. 47:225 239

Rickard, L. V., 1962, Late Cayugan (Upper Silurian) and Helderbergian (Lower Devonian) stratigraphy in New York: N. Y. State Mus. and Sci. Service Bull. 386, 157 pp.

Roliff, W. A., 1949, Salina-Guelph fields of southwestern Ontario: Am. Assoc. Petroleum Geologists Bull., 33:153-188

Sanford, B. V., 1965, Salina salt beds southwestern Ontario: Geol. Survey Canada Paper 65-9, 7 pp.

Schmalz, R. F., 1966, Environments of marine evaporite deposition: Mineral Industries, 35:1-7

Stehli, F. G., Namy, J. N. & Aten, M. D., 1963, Evaporite facies in northeastern Ohio, *in* Symposium on Salt: Northern Ohio Geol. Soc., pp. 31-46

Swartz, C. K., & Swartz, F. M., 1931, Early Silurian formations of southeastern Pennsylvania: Geol. Soc. America Bull., 42:621-661

Swartz, F. M., 1929, The Helderberg group of parts of West Virginia and Virginia: U. S. Geol. Survey Prof. Paper 158-C: 27-75

Ulteig, J. R., 1964, Upper Niagaran and Cayugan stratigraphy: Ohio Geol. Survey Rept. Inv. 51, 48 pp.

Appendix A

IDENTIFICATION OF CONTROL WELLS

New York State

Well	*County*	*Township*	*Operator*	*Lease*	*NYSGS File*
1	Greene	Windham	United Prod.	Gans	3904
2	Ulster	Shandaken	Dome O. & G.	Herdmann	3199
3	Delaware	Franklin	United Prod.	K. Hirsch	4073
4	"	Franklin	Warner et al	M. Hazlet	879
4 A	"	Franklin	Gulf Oil Corp.	Leslie	4455
4 B	"	Sidney	Gulf Oil Corp.	Finch	4364
4 C	"	Hamden	Gulf Oil Corp.	Campbell	4214
4 D	"	Roxbury	Gulf Oil Corp.	Lanzilotta	4379
5	Otsego	Worcester	N.Y.S. Nat. Gas	Lum	4055
6	"	Maryland	N.Y.S. Nat. Gas	Russ	4429
7	"	Maryland	N.Y.S. Nat. Gas	E. Baum	4245
8	"	Maryland	N.Y.S. Nat. Gas	Burkard	4547
9	"	Pittsfield	Prensett et al	W. Elliot	4050
10	Herkimer	Warren	Benedum et al	J. Skramko	3993
11	Oneida	Sangerfield	N.Y.S. Nat. Gas	Keith	3928
12	"	Sangerfield	N.Y.S. Nat. Gas	Northrup	3955
13	Madison	Brookfield	N.Y.S. Nat. Gas	Miller-Letts	1173
14	"	Brookfield	N.Y.S. Nat. Gas	J. Danisevich	4032
15	"	Brookfield	N.Y.S. Nat. Gas	Head	3981
16	"	Madison	N.Y.S. Nat. Gas	Keith	3963
17	"	Brookfield	Con. Gas Supply	Helmes	4556
18	"	Madison	N.Y.S. Nat. Gas	Albee	4510
19	"	Eaton	N.Y.S. Nat. Gas	Doroshenko	4085
20	"	Lebanon	N.Y.S. Nat. Gas	Branagan	3970
21	Madison	Lebanon	N.Y.S. Nat. Gas	Parteko	4002
22	"	Eaton	N.Y.S. Nat. Gas	Bikowski	4185
23	Chenango	Columbus	Bradley Prod.	Lobdell	1160
24	Cortland	Harford	Fralich et al	Overbaugh	2308
24 A	"	Freetown	Gulf Oil Corp.	Clough	4714
24 B	Broome	Triangle	Felix & Scisson	Richards	5087
25	Onondaga	Tully	Solvey	well M 21	(none)
26	"	Marcellus	Reliance Oil	Frost	4902
27	Cayuga	Sennett	Frankfurt Oil	Johnson	4365
28	"	Aurelius	Midwest Oil	Ford	4038
29	"	Aurelius	Midwest Oil	Case	4562
30	"	Springport	United Prod.	Shoemaker	4068
31	"	Springport	Essex Explor.	Modern Tissue	4651
32	"	Springport	Ashland Oil & Ref.	Downing	4580

Well	*County*	*Township*	*Operator*	*Lease*	*NYSGS File*
33	Cayuga	Ledyard	Reserve Oil	Mahaney	478
34	Tompkins	Lansing	Int. Salt Co.	well #20	3938
35	”	Lansing	Cayuga Rock Salt	mine shaft and core	(none)
36	”	Lansing	Reserve Oil	Farkas	481
37	”	Enfield	N.Y.S. Nat. Gas	Grund	4130
38	”	Newfield	N.Y.S. Nat. Gas	Fee (Richardson)	4467
39	”	Danby	N.Y.S. Nat. Gas	Sheperd	3973
40	”	Danby	N.Y.S. Nat. Gas	Smiley	4007
41	Seneca	Fayette	United Prod.	Schaffer #2	4203
42	”	Fayette	Benedum	Stein	4082
43	”	Fayette	N.Y.S. Nat. Gas	Robson	4244
44	”	Fayette	N.Y.S. Nat. Gas	Christensen	4600
45	”	Fayette	N.Y.S. Nat. Gas	Garrett	4215
46	”	Fayette	United Prod. Co.	Dewall	4064
47	”	Waterloo	Roberts & Murphy	Unger	4408
48	Schuyler	Reading	Int. Salt Co.	well #29	3940
49	”	Dix	Texas Eastern	Watkins Terminal	4400
50	”	Dix	New Penn. Dev.	Federal Land Bank	519
51	”	Tyrone	Belmont Quad. Drlg.	Best #2	561
52	Chemung	Van Etten	N.Y.S. Nat. Gas	Kesselring	443
52 A	Ontario	Phelps	Burns et al	Mowers	632
53	”	Seneca	Williams et al	Fordon	4160
54	”	Canandaigua	Reed	Brown	891
55	”	Farmington	Duchscherer	Crowley #3	4916
56	”	Farmington	Duchscherer	Potter	4870
57	”	Farmington	Duchscherer	Wyman #3	4915
58	”	E. Bloomfield	Allegany Prod.	Birx	4057
59	”	W. Bloomfield	Eason Oil	Gonsenhauser	4450
60	”	E. Bloomfield	Eason Oil	Neenan	4402
61	”	E. Bloomfield	Allegany Prod.	Murphy	4159
62	”	E. Bloomfield	Joyce Pipeline	Metsinger	4084
63	”	Canandaigua	Strudwick et al	Pierce	4947
63 A	”	Canandaigua	United Prod.	Outhouse	3999
64	”	Canandaigua	Eason Oil	Purdy	4395
65	”	Canandaigua	Eason Oil	Outhouse	4409
66	”	Farmington	Strudwick	Bowermann	4871
67	”	Bristol	Franchot	Gladding	4035
68	”	Richmond	Franchot	Cruger	3945
69	”	Richmond	Franchot	Clement	3997
70	”	Richmond	Franchot	Allen	4005
71	”	Richmond	Franchot	Treble	3971
72	”	Bristol	Franchot	Kage	3991
73	”	Bristol	Franchot	Mills	4027
74	”	W. Bloomfield	Eason Oil	Huff	4394
75	”	S. Bristol	Drury	Hale	3866
76	Yates	Benton	C. G. S. Mgmt.	Borglum	4796
77	Steuben	Bath	Anchor Petrol.	Blair	2679
78	”	Urbana	General Foods	Champlin	329
79	”	Erwin	Cabot	Collins	109
80	”	Woodhull	N. Penn. Gas et al	Harrington	216

Well	*County*	*Township*	*Operator*	*Lease*	*NYSGS File*
81	Steuben	Woodhull	N.Y.S. Nat. Gas	Hargrave	3894
82	”	Woodhull	N.Y.S. Nat. Gas	Olin	3924
83	Livingston	Livonia	Int. Salt Co.	Livonia mine shaft	3277
84	”	Livonia	United Prod.	Nivers	4053
85	”	Lima	Eason Oil	York	4458
86	”	Avon	Eason Oil	Mulligan	4451
87	”	Avon	Kissinger et al	Marshall	4056
88	”	Conesus	Livingston Oil	Hunt	3305
89	”	Conesus	Livingston Oil	Martuccio	3942
90	”	Sparta	Blair & Weaver	Kennedy	4630
91	”	Avon	N.Y.S. Nat. Gas	Wadsworth Est.	4149
92	”	Geneseo	N.Y.S. Nat. Gas	Wadsworth #2	4213
93	”	Geneseo	N.Y.S. Nat. Gas	Austin	4188
94	”	Caledonia	N.Y.S. Nat. Gas	Johnson	4567
95	”	York	N.Y.S. Nat. Gas	Walton	4218
96	”	York	N.Y.S. Nat. Gas	McDonald	4069
97	”	York	N.Y.S. Nat. Gas	McClurg	4552
98	Livingston	York	Int. Salt Co.	Fuller mine shaft	(none)
99	”	York	Ventura Oil	Hunn	4531
100	”	York	N.Y.S. Nat. Gas	Smith	4151
101	”	Leicester	N.Y.S. Nat. Gas	Yunkers	4089
102	”	Leicester	Partee	Brophel Est.	4234
103	”	Leicester	Partee	Christiano	4217
104	Allegany	Wellsville	Ravening et al	King	1159
105	”	Hume	N.Y.S. Nat. Gas	Wolfer	4248
105 A	”	Centerville	Butera Oil	McElroy	2967
106	”	Angelica	Heiser et al	Herdmann	3264
107	”	Hume	Parsons Bros.	Cook #2	3956
108	”	Wirt	Belmont Quad et al	Chadwick	246
109	Genesee	Byron	Blair-Weaver	Tyler	4593
110	”	Pavilion	Weaver	Carmichael	4110
111	”	Darien	Edzold	Edzold	652
112	Wyoming	Covington	Partee	Bell	4343
113	”	Covington	Ventura Oil	De Lavergne	4532
114	”	Perry	N.Y.S. Nat. Gas	Cornwell	4008
115	”	Perry	Ventura Oil	Winters	4468
116	”	Middlebury	Trans. Amer. Petr.	Cox	4464
117	”	Middlebury	Trans. Amer. Petr.	Page	4536
118	”	Bennington	Great Lakes Expl.	Schuelte	4432
119	”	Gainesville	N.Y.S. Nat. Gas	Veith	4092
120	”	Genesee Falls	Farmers Oil	Lockwood	3865
121	”	Gainesville	Great Lakes Expl.	Johns	4385
122	”	Gainesville	Flint Oil & Gas	Cummings	940
123	”	Castile	Morton Salt	Fee 14	3880
124	”	Gainesville	Morton Salt	Fee 17	4162
125	”	Middlebury	Trans. Amer. Corp.	Warren	4447
126	”	Sheldon	T & S Gas Wells	Tozier #2	4342
127	Erie	Evans	Iroquois Gas	well 807	4101
128	”	Aurora	Garoc Dairy	Fee #3	3902
129	”	Concord	Iroquois Gas	well 796	3269

Well	*County*	*Township*	*Operator*	*Lease*	*NYSGS File*
130	Erie	North Collins	Iroquois Gas	well 2355	4665
131	Cattaraugus	Conewango	Dusenberry et al	See	2673
132	”	S. Valley	Devonian G. & O.	Seneca Nations #3	4088
133	”	Red House	Brunt et al	Sharp	1806
134	”	Randolph	Arkansas Fuel	Hotchkiss #2	3267
135	”	New Albion	Humble Oil	Heron	4153
136	”	Ischua	Sunburst O. & G.	Pettingill	3920
137	Chautauqua	Gerry	Penn. Gas	Barmore	2964
138	”	Poland	Hart et al	Marsh	2955
139	”	Cherry Crk.	Humble Oil	Shadle	4154
140	”	Sheridan	Republic LH & P	Aldrich	1194
141	”	Ellery	Pennzoil	Harrington	4437
142	”	Ellery	Minard Run Oil	Gage	4561
143	”	Gerry	Neeley	Homes	1857
144	”	Harmony	Univ. Delta	Morse #3	3249
145	”	Busti	Pettigrew et al	Donelson	51
146	”	Westfield	Lapage Corp.	Kiester	2672
147	”	Chautauqua	R. K. Petroleum	Tucker	4190
148	”	Mina	Penn. Gas	Heckers	3887
149	”	Mina	Apache & Texaco	Carnahan	4152
150	”	Mina	Texaco	Warnshuis	4204

Pennsylvania

Well	*County*	*Township*	*Operator*	*Lease*	*Quadrangle*
1	Bradford	Ridgebury	Parsons Bros.	Carver	Sayre A
2	"	Wysox	Felix & Scisson	Strickland	Towanda
3	"	Wilmot	Pure Oil	Blemle	Monroeton I
4	Sullivan	Davidson	California Co.	Bennett	Eagles Mere F
5	Luzerne	Dorrance	United Prod.	Good	Wilkes-Barre G
6	Northumberland	Point	Matthews et al	Hilbish	Sunbury F
7	Tioga	Lawrence	Lycoming Nat. Gas	Shoemaker	Tioga
8	Snyder	Adams	Middlecrk Valley	Albert	Mifflinburg
9	Juniata	Tuscarora	Waggner	Rambler	E. Waterford C
10	Blair	Allegheny	Hollidaysburg	Rankey	Hollidaysburg B
11	Bedford	Napier	Appalachian B.A.	Miller	Bedford
12	Fayette	S. Union	PNG (Snee et al)	Heyn	Uniontown E
13	Potter	Keating	Potter Dev.	Crawford Est.	Emporium D
14	"	Hebron	Potter Dev.	Matteson	Coudersport
14 A	"	Stewardson	Consol. Gas Supply	Pa. Dept. of Forests & Waters (N-972)	Renova West C
15	McKean	Liberty	Potter Dev.	Zerbe	Smethport
16	"	Liberty	Allegheny Gas	Nunn #2	Smethport E
17	"	Lafayette	S. Penn. Oil	Wilson #18	Bradford G
18	"	Lafayette	Thornton	Warrent 3410	Kinzua I
19	Elk	Highland	United Nat. Gas	Warrent 3788	Kane
20	"	Highland	Penn. Gas	Warrent 3653	Halton B
21	Jefferson	Eldred	Deemer	Verstine & Kline #8	Marienville I
22	Clarion	Clarion	Fairman et al	May	Clarion B
23	Warren	Limestone	Biery & Johnson	Shaw	Tidioute E
24	"	Limestone	Biery & Johnson	Kapp	Tidioute B
25	"	Southwest	Northern Ordnance	Reeves	Titusville C
26	"	Brokenstraw	Penn. Gas	Keester	Youngsville F
27	"	Pittsfield	Potter Dev.	Spetz	Youngsville
28	"	Sugar Grove	Pettigrew et al	Anderson	Youngsville C
29	"	Eldred	Mideast Oil	Smith	Corry I
30	Erie	Venango	Texaco	Hoag	Northeast I
31	"	offshore	N.Y.S. Nat. Gas	Block #2, Well #1	
32	"	Wayne	Plymouth Oil	Sill	Corry A
33	"	Washington	Allegheny Ind.	Ethridge	Cambridge Spr. F
34	"	Washington	Redfern & Hurd.	Vanco	Cambridge Spr. D
35	"	offshore	N.Y.S. Nat. Gas	Block #1, Well #1	Fairview G
36	"	Springfield	New Penn. Dev.	Miles #3	Fairview
37	"	Summit	Stephens et al	Goodwill-Curly	Erie
38	"	Springfield	Ohio Oil	Childs	Girard
39	"	Conneaut	McConnell	Borst	Girard D
40	"	Springfield	Ohio Oil	Blickensderfer #22	Girard
41	"	Conneaut	Britton et al	Roberts	Girard D
42	"	Elk Creek	Penn. Gas	Miller	Girard F
43	Crawford	Rome	Albaugh	Halfast	Corry G
44	"	Bloomfield	Garrett	Morton	Union City E
45	"	Rockdale	Garrett	Marzka	Union City G
46	"	Rockdale	Potter Dev.	Chapin	Union City G

Well	*County*	*Township*	*Operator*	*Lease*	*Quadrangle*
47	Crawford	Cambridge	Atlas Expl.	Hindle	Cambridge Spr. H.
48	"	Cussewago	Atlas & Sun Oil	Revak	Cambridge Spr. G
49	"	Spring	Penn. Gas	Conn. Valley Farms	Girard E
50	"	Beaver	Penn. Gas	Sergeant	Girard D
51	"	Beaver	Felmont	Foro	Girard G
52	"	Spring	Hall et al	Lehman	Girard H
53	"	Spring	Imperial Oil	Shadeland	Girard H
54	"	Conneaut	McClusky	Carter	Andover C
55	"	Summerhill	Benedum et al	Kardosh	Linesville C
56	"	E. Fallowfield	Sylvania	Calvin	Linesville I
57	Mercer	Lake	Mercer O & G	Miller	Stoneboro E
58	"	W. Salem	Hickman & Hart	Smith	Shenango D
59	"	Pymatuning	Melben Oil	McKnight	Shenango G
60	"	Hickory	Sharon Steel	Cromarti	Youngstown C
61	Butler	Parker	Walker et al	Walker et al	Foxburg G
62	"	Mercer	Mfger'Light & Heat	Hochenberry	Mercer F
63	Beaver	S. Beaver	Duff & Galey	Teunis Heirs	New Castle G

Ohio

Well	County	Township	Operator	Lease	State Permit
A 1	Wyandot	Crawford	Ohio Oil	Heck	72
A 2	Seneca	Clinton	Sun	UAM	20
A 3	Sandusky	Townsend	E. Ohio Gas	Hoff	77
A 4	Erie	Huron	Nickel Plate	NYCRR	5
A 5	Lorain	Henrietta	E. Ohio Gas	Born	794
A 6	Cuyahoga	Cleveland	Sohio	Sohio	----
A 7	Lake	Painesville	Diamond Alkali	Diamond Alkali	204
B 1	Morrow	Cardington	Cassidy	Barton	23
B 2	Richland	Washington	Gant	Channell	223
B 3	Ashland	Lake	Stewart	Mosher	1762
B 4	Wayne	Plain	Kubot	Sanger	1169
B 5	Wayne	Green	Wehmeyer	Hohenshil	979
B 6	Summit	Franklin	E. Ohio Gas	Kiminecz	311
B 7	Portage	Brimfield	E. Ohio Gas	Heichel	40
B 8	Portage	Ravenna	Hinton	Hinmann	56
B 9	Portage	Freedom	N. Nat. Gas	Wilson	85
B 10	Trumbull	Mesopotamia	N. Nat. Gas	Wengerd	16
B 11	Ashtabula	Rome	Wehmeyer	Kellogg	86
B 12	Ashtabula	Monroe	McConnell	Brydle	73
C 1	Licking	Hartford	Patten	Martin	1803
C 2	Knox	Jackson	Alkere & Floto	Earlywine	1265
C 3	Coshocton	Bedford	Natol	Gilmore	1203
C 4	Coshocton	Keene	Roberson et al	Geib	880
C 5	Tuscarawas	Sugar Creek	Nat. Assoc. Pet.	Borntrager	794
C 6	Tuscarawas	Sandy	Status Dev.	Sattler	676
C 7	Stark	Paris	Nat. Gas W. V.	Czekomski	963
C 8	Mahoning	Smith	Atlas	Miller	121
C 9	Trumbull	Hartford	Dinger	Blaney	12
D 2	Wyandot	Antrim	Ohio Oil	Chatlain	----
D 3	Marion	Claridon	White	Baker	3
D 5	Delaware	Porter	Monk	Thurston	2
E 1	Ottawa	Catawba	Hilliard	Wiechel	20
E 4	Medina	Westfield	King	Hawley	72
E 6	Wayne	East Union	Heyser	Yoder	833
E 7	Wayne	Salt Creek	Ohio Fuel Gas	Petersheim	1229
F 2	Portage	Aurora	McIntyre	Tacl	51
F 4	Portage	Atwater	Atlas	Franks	77
G 3	Trumbull	Gustavus	N. Nat. Gas	Runkle	15
1	Morrow	Troy	Pan. Am.	Windbigler	47
2	Ashland	Ruggles	Dalton Hanna	Eshtruth	1784
3	Knox	Pike	Ringler	Drushawl	1418
4	Knox	Harrison	Mammoth	White	1251
5	Knox	Howard	Alkire & Floto	Welker	1265
6	Knox	Union	Collins	Simmons	1039
7	Knox	Jackson	Blood	Miller	800

Well	*County*	*Township*	*Operator*	*Lease*	*State Permit*
8	Medina	Hinckley	Wiser	Divoky	1256
9	Medina	Medina	Ohio Fuel Gas	Deiss	1296
10	Medina	Sharon	Natol	Shanafelt	1014
11	Wayne	Canaan	King	Smith	1098
12	Wayne	Canaan	Wehmeyer	Fetzer	966
13	Wayne	Milton	Parker Chapman	Rufever	1133
14	Wayne	Milton	Storey	McConnell	945
15	Wayne	Chippewa	East Ohio Gas	Steiner	822
16	Wayne	Canaan	Slagter	Armstrong	460
17	Wayne	Baughman	East Ohio Gas	Brillhar	925
18	Wayne	Chippewa	East Ohio Gas	Magyar	498
19	Wayne	Plain	Acitelli Hackel	Guenther	834
20	”	Wayne	Vanson	Borman	894
21	”	Baughman	East Ohio Gas	Shisler	900
22	”	Baughman	Ohio Fuel Gas	Eberly	1188
23	”	Wooster	Phillips	Stockdale	790
24	”	Clinton	Arrowhead	Johnson	987
25	”	Franklin	Natol	Grosjean	1148
26	”	Franklin	Vanson	Lloyd	795
27	Holmes	Prairie	Fields	McCurdy	1055
28	”	Killbuck	Natol	Zangg	1143
29	”	Hardy	Parker Chapman	Reining	1094
30	”	Berlin	Arrowhead	Hockstetler	1115
31	”	Killbuck	Hinton	Snow	932
32	”	Killbuck	Nepple	Snow	1064
33	”	Mechanic	Davis	Weltbrecht	995
34	Coshocton	Tiverton	Bears	Day	1379
35	”	Monroe	Natol	Hawkins	1439
36	”	Newcastle	Rixieben	Conservancy	1002
37	”	Perry	Bears	Rine	102
38	”	Jackson	Arrowhead	Foster	1269
39	Summit	Northampton	East Ohio Gas	Wheatley	17
40	”	Tallmadge	Brannon	Streitenberger	377
41	”	Coventry	Diamond Crystal	Diamond Crystal	366
42	”	Green	East Ohio Gas	Costello	D 10
43	”	Green	East Ohio Gas	Groves	348
44	Stark	Lake	Atlas	Bledsoe	1038
45	”	Lake	East Ohio Gas	Coblenta	1002
46	”	Marlboro	Natol	Hall	967
47	”	Lawrence	East Ohio Gas	Rohr 3	D 7
48	”	Lawrence	East Ohio Gas	Tippel	1020
49	”	Jackson	East Ohio Gas	Hixon	D 3
50	”	Lawrence	East Ohio Gas	Neisel	1056
51	”	Perry	East Ohio Gas	Dielhenn	1021
52	”	Canton	Ashland	Ashland	----
53	”	Bethlehem	Nat. Gas W. V.	Stansberger	949
54	Tuscarawas	Lawrence	Status Devel.	Wassem	671
55	Portage	Mantua	N. Nat. Gas	Frost	73
56	”	Shalersville	N. Nat. Gas	Goodell	70

Well	*County*	*Township*	*Operator*	*Lease*	*State Permit*
57	Portage	Freedom	N. Nat. Gas	Moore	68
58	"	Windham	N. Nat. Gas	Showalter	76
59	"	Rootstown	Fields	Arnette	55
60	"	Edinburg	East Ohio Gas	McConnell	86
61	"	Rootstown	East Ohio Gas	Smith	71
62	"	Suffield	Atlas	Schweikert	63
63	Carroll	Brown	Humble	Davies	212
64	Ashtabula	Kingsville	Atlas	County	27
65	"	Conneaut	East Ohio Gas	Collet	148
66	"	Monroe	Britton	Frigi	90
67	"	Austinberg	N. Nat. Gas	Judson	91
68	"	Morgan	Mousee et al	Jamison	88
69	"	Lenox	N. Nat. Gas	Harmon	96
70	"	Richmond	N. Nat. Gas	Romanowski	98
71	"	Dorset	Benedum	Power	113
72	"	Hartsgrove	Mousee et al	Roach	82
73	"	Hartsgrove	N. Nat. Gas	Musial	99
74	Ashtabula	Orwell	N. Nat. Gas	Haznos	131
75	"	Windsor	N. Nat. Gas	Clark	103
76	Trumbull	Bloomsfield	N. Nat. Gas	Frandrich	13
77	Columbiana	Hanover	Atlas	Batzli	539

Ontario

Well	County	Township	Lot	Concession	Operator	Permit
1	Welland	offshore	Bertie		Consumers Gas	2034
2	”	offshore	Humberstone		Consumers Gas	2035
3	”	Humberstone			Sherkston well	M224 p131
4	Haldimand	offshore	Sherbrooke		Long Point G & O	----
5	”	Moulton	14	II LE	Dickout Bros.	1428
6	”	offshore	Dunn		Long Point Gas	1078,2151
7	”	Dunn	1	I NDR	Haldimand Gas	1417
8	”	N. Cayuga	37	II STR	Haldimand Gas	1424
9	”	Rainham	11	IV	Bachelor farm	M224 p121
10	”	offshore	Walpole		Mitchell + Mitchell	1425
11	”	Walpole	1	III	Jarvis Hereford	1396
12	Brant	Brantford	4	III EMPR	Herkules Oil	1911
13	”	Burford	15	II	Imperial Oil	1910
14	”	Burford	18	II	Canadian Kewanee	1916
15	Norfolk	offshore	Woodhouse		Long Point G & O	----
16	”	offshore	Woodhouse		Consol. W. Petrol.	2018
17	”	offshore	Walsingham		Northcal Oil	----
18	”	offshore	Charlotteville		Mitchell + Mitchell	1448
19	”	S. Walsingham	13	I	Bolivar Gas	1930
20	”	Charlotteville	10	III	New Metalore	2014
21	”	Charlotteville	17	III	Roberts	1939
22	”	Charlotteville	14	V	New Metalore	1903
23	”	Charlotteville	10	VII	Stafford + Perdue	1917
24	”	Windham	9	VIII	Norfolk Gas	2040
25	Oxford	Dereham	24	VI	Imperial Oil	1938
26	”	Dereham	3	III	Canadian Essex	1908
27	”	Blenheim	23	I	Imperial Oil	1923
28	”	Blandford	4	III	Canadian Kewanee	1926
29	Elgin	Malahide	24	VIII	Seemack Oil	1935
30	”	Yarmouth	14	V	Baslen Petrol.	1932
31	”	Southwold	31	STREB	Home Oil	1787
32	”	Dunwich	16	XII	Halpin	M237 p 87
33	”	Dunwich	22	II	Imperial Oil	2002
34	”	Aldborough	15	I	Imperial Oil	1786
35	Middlesex	N. Dorchester	14	IV STR	Imperial Oil	1913
36	”	Westminster	50	TRNBW	Bluewater Oil	1922
37	”	Metcalfe	1	VIII	Pennzoil	1989
38	”	Mosa	13	II	Anchor Petrol.	1594
39	”	West Williams	20	X	Corden	1993
40	”	McGillivray	3	XXVI	Imperial Oil	1964
41	”	Ekfrid	10	V S	Birchwood Petrol.	1591
42	Lambton	Bosanquet	18	IV	Home Oil	1890
43	”	Warwick	10	V NER	Rowe et al	1996
44	”	Brooke	19	XIV	Earl-Tostik	1599
45	”	Brooke	10	XII	Canadian Delhi	1597
46	”	Brooke	5	XII	Canadian Delhi	1995
47	”	Brooke	1	XIV	Roth & Roth	2031

Well	*County*	*Township*	*Lot*	*Concession*	*Operator*	*Permit*
48	Lambton	Plympton	27	V	B P Expl.	1955
49	”	Enniskillen	20	VIII	Corden	1976
50	”	Enniskillen	22	XI	Corden	1960
51	”	Euphemia	25	V	Union Gas	M237 p 83
52	”	Enniskillen	18	II	Oil Springs	M240 p 60
53	”	Dawn	23	III	Union Gas	1965
54	”	Dawn	22	II	Union Gas	1963
55	”	Dawn	23	I	Pennzoil	1593
56	”	Sombra	29	X	Anchor Petrol.	1962
57	”	Sombra	30	XIV	Bron	1977
58	”	Sombra	25	XIII	Bron	2005
59	”	Enniskillen	4	X	Elgin Petrol.	2024
60	”	Enniskillen	10	XIV	Imperial Oil	1994
61	”	Moore	1	XII	Graham	1595
62	”	Sarnia	4	I	Imperial Oil	1981
63	”	Sarnia	11	V I.R.	Imperial Oil	1889
64	”	Plympton	2	II	Imperial Oil	1971
65	”	Moore	20	X	Imperial Oil	1899
66	”	Moore	20	IX	Tecumseh Gas	1898
67	”	Moore	18	VII	Imperial Oil	1839
68	”	Moore	18	V	Imperial Oil	1836
69	”	Moore	28	IV	B P Expl.	1973
70	”	Moore	28	II	Argor Expl.	1992
71	”	Moore	4	VI	Pere Marquette	1978
72	”	Enniskillen	2	IV	Union Gas	1584
73	”	Sombra	13	XIV	Imperial Oil	1982
74	”	Sombra	15	XI	Pennzoil	1954
75	”	Sombra	11	IX	Imperial Oil	1583
76	”	Sombra	8	VI	Imperial Oil	1598
77	”	Sombra	3	VI	Imperial Oil	1957
78	Kent	Howard	8	II	Zenmac Metal	1784
79	”	Raleigh	7	IV	Mills	1780
80	”	Chatham	6	II Gore	Home Oil	1827
81	”	Chatham	5	XIII	Union Gas	M240 p 75
82	”	Chatham	6	I	Rowe	M240 p 13
83	”	Tilbury E	15	V	Union Gas	M240 p 82
84	”	Oxford	54	TRN	Union Gas	M237 p 91
85	”	Romney	194	TRN	Erie Petrol.	M240 p 15
86	”	Camden Gore	10	IX	Union Gas	M240 p 77
87	Essex	Colchester S	50	Front	Putnam + Trenton	1783
88	”	Pelee Island	57	----	Stover	1789
89	”	Malden	36	IV	Volcanic O & G	M240 p 98
90	”	Colchester S	83	I	Volcanic O & G	M240 p 97
91	”	Grosfield S	3	V	Glenwood Nat. Gas	M240 p 92
92	”	Tilbury W	5	X	Rosslyn	M240 p 12

Michigan

Well	*County*	*Location*	*Operator*	*Lease*
1	St. Clair	S12, T4N, R15E	Panhandle Eastern	Buszek "B" 01
2	"	S27, T4N, R15E	Panhandle Eastern	Lyszczyk 04
3	"	S18, T7N, R16E	Panhandle Eastern	Collins 1-18
4	Oakland	Avon Twp.	S. & P. Investment	Pettibone et al
5	Sanilac	Argyle Twp.	Simpson	Hemlinger

Appendix B

SUBSURFACE DATA FROM CONTROL WELLS

KEY:

Log—G = gamma ray
S = lithic sample

NR = not reached
Blank = not identified
abs = absent

NS = no sample
NL = not logged

New York State

			Bertie	*Camillus*		*Syracuse*			*Vernon*		
Well	*Log*	*Elevation*	*H*	*G*	*F*	*E*	*D*	*C*	*B*	*A*	*Base*
1	GS	1928	4370	abs	abs	abs	abs	abs	abs	abs	4415
2	GS	1270	5980		6043	6092	6125	6135	abs	abs	6150
3	GS	1990	4486	4556	4682	4734	4816	4840			5190
4	GS	1457	4195	4275	4380	4428	4520	4557?	NR		
4A	GS	1485	3845	3915	4040	4095	4175	4200			4510
4B	G	1657	4600	4685	4870	4950	5030	5055			5530
4C	GS	1775	5855	5925	6065	6135	6215	6245			6650
4D	G	1834	5055	5095	5135	5190	5260	5280			5430
5	GS	1979	2175		2250	2307	2360	abs	abs	abs	2375
6	G	1851	2740	2770	2875	2925	3000	3015			3135
7	GS	1610	2610	2675	2750	2787	2857	2880			3015
8	G	1262	2630	2680	2760	2830	2883	2900			2930
9	GS	1530	2460	2525	2665	2740	2825	2850			3175
10	GS	1515	310		380	435	523	abs	abs	abs	545
11	GS	1319	825	900	1045	1120	1195	1220	1305	1380	1600
12	G	1429	715	800	925	1005	1080	1100	1180	1255	1475
13	GS	1255	770	840	980	1060	1140	1155	1260	1315	1517
14	GS	1506	1410	1483	1625	1703	1775	1803	1895	1980	2195
15	G	1273	815	890	1030	1105	1185	1200	1270	1355	1575
16	G	1485	1055	1130	1272	1350	1430	1442	1545	1620	1850
17	G	1605	1060	1130	1265	1345	1420	1430	1510	1568	1768
18	G	1526	1237	1310	1447	1533	1600	1630	1750	1830	2063
19	GS	1565	1240	1315	1465	1548	1635	1670	1850	1953	2212
20	GS	1544	1570	1660	1800	1890	1995	2035	2200	2305	2560
21	G	1694	1645	1730	1880	1955	2055	2095	2270	2375	2630
22	G	1494	1305	1385	1530	1610	1695	1730	1900	1995	2240
23	GS	1373	1815	1880	2040	2115	2195	2220	2340	2395	2607
24	S	1177	2800	2935	3055	NR					
24A	G	1569	3033	3125	3300	3685	3795	3805	4015	4097	4430
24B	G	1000	3540	3640	3825	4260	4357	4400	4625	4700	5086
25	G		918	1002	1124	NR?					
26	GS	1070	810	910	1005	1210	1336	1362	1542	1637	1905
27	S	750	210	300	398	498		680	878	1013	1236
28	GS	505			70	190	312	330	550	652	915
27	G	517		30	115	245	360	370	590	695	950
30	G	669	230	315	405	525	650	660	883	985	1255
31	GS	460			115	235	355	375	600	705	985

Well	Log	Elevation	Bertie H	Camillus G	F	Syracuse E	D	C	Vernon B	A	Base
32	G	524			140	270	395	410	630	735	1010
33	S	824	1233	1330?	1425?	1750	1893	1925		2247	2545
34	GS	590	1464	1558	1674	2141	2267	NR			
35	S	410	1200?		1403?	2084	2209	2290	NR		
36	S	850			2212?	2582	2707	2760	2945	3074	3408
37	GS	1454	2840	2935	3035	3515	3650	3750	3973	4100	4430
38	GS	1051	2625	2725	2820	3470	3633	3725	3978	4060	4425
39	GS	1295	2710	2810	2905	3883	4025	4115	4373	4490	4825
40	GS	1328	2690	2785	2880	3945	4083	4175	4435	4525	4895
41	GS	542	190	260	360	467	598	608	835	937	1195
42	GS	469	115	180	274	386	512	526	745	850	1110
43	G	660	472	555	655	770	880	890	1108	1210	1465
44	G	500	210	270	370	480	600	612	833	940	1190
45	G	536	280	360	440	560	740	755	925	1020	1270
46	G	552	230	305	405	525	640	660	880	982	1240
47	S	502						405	575	710	968
48	GS	605	1750	1844	1938	2411	2563	NR			
49	S	447			1797?	2417	2572	2708	NR		
50	S	1206	2330	2423	2515	3542	3714	3872	4150	4290	4650
51	S	1248	1988	2075	2156	2600	2740	2844	3170	3270	3580
52	GS	1077	3420	3600	3690	4580	4745	4820	5145	5280	5655
52A	S	469				250	365	418	632	735	962
53	GS	770	598	656	736	848	942	956	1178	1286	1558
54	S	633	160	230	300					770	953
55	G	581			54	162	260	274	464	550	723
56	G	583		47	124	225	332	345	530	612	786
57	G	576			16	138	254	267	438	514	687
58	GS	996	690	770	848	938	1052	1066	1244	1376	1562
59	S	914	625	709	772	875		1005	1175	1315	1513
60	S	878	460	540	615	690		808	955	1137	1320
61	S	1158	855?	945	1018	1093	1185	1200	1320	1496	1682
62	S	871	570?	655?	747	845		975	1090	1167	1380
63	G	1050	860	948	1026	1126	1242	1254	1488	1574	1784
63A	G	1170							1808	1925	2106
64	S	725	233	304	393	500		633	750	880	1070
65	S	785	480	572	650	747	825	851	972	1117	1330?
66	G	556				34	140	150	324	400	566
67	GS	1477	1500	1594	1670	1780	1906	1948	2100	2230	2442
68	S	1162					1590	1670		2008	2200
69	G	793	800	890	970	1060	1203	1243	1440	1587	1780
70	G	1100	1102	1192	1270	1358	1500	1540	1752	1874	2060
71	G	936	1006	1102	1180	1275	1425	1475	1665	1785	1975
72	G	1330	1400	1495	1570	1660	1830	1873	2035	2165	2365
73	G	1529	1556	1652	1730	1854	1956	2004	2196	2328	2538
74	S	940	492	560	650	743		895	1038	1140	1340
75	S	1735	2100	2170	2245	2435	2535			3052	3254
76	G	961	1206	1270	1358	1484	1592	1688	1928	2020	2286
77	S	1073	2800	2894	2976	NR					
78	S	847		2170	2280	2740	2900	3000	3310	3450	3752

			Bertie	Camillus		Syracuse			Vernon		
Well	*Log*	*Elevation*	*H*	*G*	*F*	*E*	*D*	*C*	*B*	*A*	*Base*
79	S	1718	4070	4144	4225	4825	5070	5174	5420	5580	5875
80	S	546	4190	4260	4326	5085	5340	5500	5805	6000	6235
81	GS	1718	4165	4260	4345	4985	5270	5400	6015	6200	6488
82	GS	1645	4277	4360	4447	4970	5340	5423	5920	6105	6390
83	S	1082	1024	1085	1183	1260	1369	NR			
84	GS	1370	1482	1560	1634	1724	1832	1880	fault	2252	2438
85	S	753				505?		630	750	860	1025
86	S	685	180	243	308	405	509	533	662	738	905
87	S	909	580	619	702	820	910	943	1055	1228	1405
88	GS	1610	1920	2006	2082	2176	2312	2366	2558	2690	2884
89	GS	1630	2005	2095	2165	2255	2430	2480	2675	2820	3010
90	GS	599	1112	1182	1267	1404	1534	1584	1746	1870	2058
91	G	563	150	210	295	380	480	490	630	740	908
92	G	562	385	450	520	595	705	715	860	990	1165
93	G	1146	1210	1290	1365	1440	1560	1610	1780	1920	2090
94	GS	785	265	320	390	470	560	570	685	775	945
95	G	893	525	590	655	735	830	840	955	1065	1225
96	GS	881	570	630	695	780	870	880	995	1110	1275
97	S	986	838	905	960	1057		1154	1287	1418	1548
98	S	737	594	666	720	806		920	1056	NR	
99	G	1106	948	1008	1078	1158	1252	1264	1388	1484	1648
100	G	957	850	920	985	1065	1165	1170	1300	1418	1585
101	G	951	885	945	1015	1085	1190	1200	1330	1445	1610
102	S	1055							1628	1757	1926
103	S	579	628	693	790	900		975	1100	1244	1420
104	S	1479	4046	4100	4195	4445	4580	4633	4920	NR	
105	GS	1560	2637	2695	2760	2877	2995	3015	3180	3283	3450
105A	S	1967	3015	3055	3135	3230	3315	3330	3448	3620	3776
106	S	1952	3900	3970?		4250	4380	4437	4563	4717	4930
107	GS	1672	2825	2895	2960	3060	3165	3205	3375	3490	3660
108	S	1860	4455	4510	4620	4812	NR				
109	G	703								175	295
110	S	445	394	442							1038
111	S	860	257	300	375	415	455	502	600	650	773
112	S	1155	1093	1145	1200	1290?		1375	1516	1615	1785
113	G	1197	1093	1150	1218	1298	1390	1400	1518	1624	1786
114	S	1081	1037	1098	1169	1255		1332	1478	1586	1750
115	GS	1223	1160	1224	1294	1374	1468	1478	1595	1694	1858
116	G	1163	900	960	1030	1110	1200	1210	1320	1430	1585
117	G	1501	1260	1320	1385	1465	1560	1570	1675	1780	1935
118	S	1442	1230	1275	1345	1405		1507	1605	1656	1774
119	GS	1560	2150	2205	2276	2370	2466	2478	2614	2740	2910
120	S	1592	2307	2375?	2438		2635	2660	2778	2948	3117
121	S	1768	2184	2235	2295	2410	2500	2520	2646	2745	2910
122	S	1400	1685	1725	1800		1990	2000	2130	2220	2380
123	G	1329	1783	1835	1900	1990	2095	2110	2235	2355	NR
124	S	1481	1866	1910	1980		2167	2198	2300	NR	
125	G	1556	1400	1450	1515	1595	1690	1700	1805	1910	2065
126	S	1280			1440	1505					1920

Well	Log	Elevation	Bertie	Camillus		Syracuse			Vernon		
			H	G	F	E	D	C	B	A	Base
127	S	600	630	670	720	790	855	865	915	977	1078
128	S	875	858	919	965	1050	1113	1154	1213	1270	1343
129	S	1560	1974	2020	2070	2140	2215	2230			2466
130	G	1266	1628	1660	1708	1778	1862	1870	NR		
131	S	1787	3156	3205				3495	3605	3675	3821
132	S	1300	3408	3465	3565	3680	3775	3800	3935	4027	4207
133	S	1439							3922	3995	4165
134	S	1760	3534	3588				3873	3973	4070	4210
135	GS	1824	3140	3192	3254	3338	3439	3448	3546	3620	3760
136	S	1746	3609					4020?			4475?
137	S	1775	3010	3040	3110	3225	3310	3325	3409	3485	3569
138	S	1359	3110	3160	3237	3353		3473			3790
139	GS	1606	2535	2600	2662	2746	2840	2850	2936	2996	3124
140	S	765	1225	1270	1340	1390		1465	1530	1598	1693
141	GS	1760	3000	3058	3120	3210	3308	3318	3422	3495	3582
142	GS	1524	2670	2730	2780	2860	2943	2953	3015	3055	3105
143	S	1340	2620	2660	2715	2852		2940			3229
144	S	1579	3148	3185	3253	3385					3885?
145	S	1521	3323	3369	3440	3565	3640	3675		3910?	4032?
146	S	675	1350?	1410?	1485	1585		1665			1822
147	G	1410	2330	2384	2438	2509	2590	2600	2656	2700	2748
148	S	1572	2845	2889	2955	3045		3125			3299
149	GS	1485	2615	2672	2724	2806	2882	2892	2950	2995	3048
150	G	1484	2677	2730	2786	2858	2940	2950	3006	3048	3102

Pennsylvania

Well	Log	Elevation	H	G	F	E	D	C	B	A	Base
					Tonoloway			*Wills Creek*		*Bloomsburg*	
1	S	1350	4778	4900	4991	6045		6314	6750	6885	NR
2	G	705	6170	6340	6420	NR					
3	GS	1561	8605	8805	8910	10200	10385	10450	10815	10920	11475
4	GS	1478	9100	9300	9420	9510	9695	9740	10060	10190	10650
5	S	1070	5967?	6115				6333		6650	7140
6	S	704	3438					4727	5020	5398	NR
7	S	1474	4261	4341	4424	5320	5527	5658	fault,	section repeated	
						6166	6447	6508	6880	7034	NR
8	S	652	2143					3358	3665	4064	4668
9	S	650	3468					NR			
10	S	1065	2405?	(fault contact)				3100		3518	3606
11	S	1670	330					1300		1682	1730
12	S	2316	7425					9618			10065
13	S	1933	5134	5200	5340	6120	6565	6670	6945	7188	7505
14	S	2180	5250	5312	5442	NR					
14A	GS	1850	6650	6750	6836	7840	8410	8515	8750	8957	9208
15	S	1751	4783	4832		NR					
16	S	1488	4565	4630	4750	4965	5177	5285	5605	5820	5980
17	S	1550	4830	4910	4995	5180	5340	5420	5515	5605	5668
18	S	2040	5086	5175	5250	5470	5615	5655	5730	5790	5959
19	S	1836	5420	5480	5572	5801	5994	6100	6370	6530	6696
20	S	1572	5720	5800	5870	6080	6315	6460	6660	6740	6810
21	S	1496	6280	6360?	6445	6755	6995	7050	NR		
22	GS	1451	6000	6100	6180	6500	6715	6740	6900	6985	7070
23	GS	1708	4630	4705	4765	4910	5075	5110	5240	5330	5410
24	S	1583	4443	4520	4595	4732	4882	4982	5082	5150	5246
25	S	1649	4255	4340	4410	4515		4700	4795	4860	4940
26	S	1262	3630?	3700	3780	3880	3977	4035	4210	4240	4315
27	S	1849	3918	3963	4040?	4150	4277	4320	4470	4515	4586
28	S	1360	3215	3285	3347	3475	3550	3605		3765	3820
29	S	1745	4040	4110	4160	4310	4445	4490	4582	4645	4740
30	S	1558	2925	2991	3055	3160		3250	3327	3400	3470
31	S	604	1315	1382	1445	1520		1600	1653	1700	1773
32	G	1440	3170	3230	3290	3386	3486	3516	3604	3678	3740
33	S	1413	2965	3030	3103	3200	3300	3355	3445	3530	3610
34	S	1473	2935	3010	3090	3190	3295	3325	3400	3495	3568
35	S	602	1615	1688	1755			1945	1988	2062	2155
36	S	593	1635	1704				1946	2002		2154
37	G	1240	2435	2500	2560	2635	2720?	2740	2800	2880	2930
38	S	638	1740	1803				2046	2105	2224	2292
39	S	965	2370	2427	2490	2573		2650	2710	2810	2890
40	S	642	1720?			1920		2030	2103	2216	2286
41	S		2170	2230?	2290	2375		2452	2517	2600	2700
42	S	878	2413	2520				2820	2865	2965	3060
43	S	1744	4085	4150	4210?	4350	4445	3405	4612	4675	4745
44	GS	1640	3480	3550	3610	3710	3800	3850	3940	4030	4100

					Tonoloway			Wills Creek		Bloomsburg	
Well	*Log*	*Elevation*	*H*	*G*	*F*	*E*	*D*	*C*	*B*	*A*	*Base*
45	S	1443				3475	3560	3615	3705	3795	3880
46	S	1220	3050	3100	3170	3295	3400	3445	3555	3645	3725
47	S	1303	3033	3100	3190	3295	3390	3450	3560	3635	3712
48	S	1243	2751	2815	2885	3005	3090	3125	3215	3315	3405
49	S	983	2416	2485	2550			2780?	2852	2920	3010
50	S		2375	2435	2508			2680	2740	2842	2955
51	S	1148	2536	2621	2680	2830	2942	2995	3055	3160	3249
52	S		2476	2560	2620	2765	2850	2920	2980	3077	3185
53	G	929	2400	2468	2530	2625	2722	2755	2832	2954	3012
54	S	1120	2665?	2735	2795	2945	3035	3120	3150	3280	3390
55	GS	1337	3033	3105	3173	3305	3410	3455	3540	3675	3730
56	S	1342	3447	3547	3615	3820	3935	3978	4055	4170	4276
57	S	1287	4110	4195	4250	4470	4620	4652	4750	4860	4968
58	S	1275	3478	3595	3645	3895	4005	4040	4173	4280	4330
59	GS	950	3390	3490	3535	3760	3925	3948	4045	4153	4220
60	S	905	3580	3677	3763	4025	4160	4217	4325		4480
61	S	1120	5700	5780	5860?	6140	6365	6420	6555	6630	6684
62	S	1306	4985	5097	5185?	5422	5610	5650	5787	5875	5935
63	S	983	4930	5030	5113	5550		5785	5885	5965	6015

Ohio

			Put-in-Bay			Tymochtee			Greenfield	
Well	*Elevation*	*H*	*G*	*F*	*E*	*D*	*C*	*B*	*A*	*Base*
A1	860	abs	abs	abs	abs	abs	abs	abs	abs	surface
A2		abs	abs	abs	abs	abs	abs	abs	abs	surface
A3	641	abs	abs	15	85		155	240	323	514
A4			530	565	640	735	745		920	1110
A5	848	1050	1130	1178	1258	1345	1355	1430	1520	1693
A6		1620	1700	1762	1977	2086	2125		NR	
A7	701	1810	1880	1943	2124	2220	2262	2335	2500	2561
B1	1007	abs	abs	488	545		636	695	718	905
B2		abs	1765	1810	1905		2007	2080	2155	2284
B3	1190	2130	2255	2295	2390		2474	2555	2640	2773
B4	1072	2230	2340	2380	2484	2590	2608	2680	2764	2893
B5		2370	2455	2495	2620	2760	2787	2880	2957	3094
B6		2665	2785	2835	3004	3152	3190	3275	3366	3477
B7	960	2800	2915	2961	3255	3463	3441	3530	3618	3687
B8		2890	2990	3039	3332	3469	3506	3585	3680	3743
B9		2965	3075	3121	3406	3542	3566	3650	3766	3830
B10	1032	2600	2695	2740	2957	3075	3115	3195	3320	3383
B11	868	2240	2325	2372	2553	2661	2703	2785	2932	3000
B12	853	2150	2210	2264	2337	2426	2436	2525	2644	2708
C1	1185	abs	abs	1246	1353		1432	1500	1518	1760
C2		abs	2055	2102	2210		2294	2370	2390	2490
C3	1096	2500	2575	2620	2735		2834	2900	2923	3002
C4	807	2760	2850	2898	3024		3130	3205	3226	3308
C5	1031	3150	3270	3315	3483		3660	3715	3745	3807
C6		3490	3655	3703	3910	4102	4117	4195	4283	4341
C7		3775	3920	3976	4240	4405	4435	4540	4622	4692
C8	1067	3385	3515	3566	3880	4055	4098	4205	4288	4350
C9	1204	3500	3610	3668	3917	4071	4110	4220	4315	4426
D2	910	abs	abs	135	210		275	360	380	435
D3	990	abs	abs		322		375		472	658
D5	1180	abs	abs	970	1104		1197	1255	1275	1527
E1				128	200		265		425	500
E4		2005	2090	2132	2255	2377	2402	2485	2567	2736
E6	1184	2665?	2780	2830	2950	3096	3110	3193	3283	3382
E7	1150	2700?	2815	2861	2966	3085	3095	3155	3227	3289
F2			2740	2780	3090	3200	3241		3421	3500
F4	1133	3325	3455	3504	3796	3965	4000	4100	4197	4265
G3	1141		3065	3111	3306	3416	3467	3560	3662	3746
1	1398			1190	1234		1316		1446	1479
2				1634	1712		1796		1960	2074
3				1864	1959		2051		2137	2190
4				1880	1985		2077		2171	2288
5				1886	1992		2083		2175	2276
6				2075	2181		2274		2372	2458
7				2075	2187		2277		2370	2421
8	1250			2480	2695	2813	2848		3050	3233
9	1105			2335	2515	2632	2665		2867	3044

Well	Elevation	H	Put-in-Bay G	F	E	Tymochtee D	C	B	Greenfield A	Base
10				2640	2824	2975	3007		3187	3358?
11				2108	2223	2344	2383		2570	2703?
12				2337	2449	2585	2616		2790	2942
13	980			2270	2404	2530	2560		2734	2898
14	960			2397	2542	2686	2720		2900	3059
15	950			2553	2721	2850	2890		3069	3213
16				2407	2500	2626	2655		2828	2990
17				2765	2929	3062	3092		3290	3424
18	1060			2825	3006	2155	3185		3360	3467
19	1087			2236	2325	2426	2450		2610	2784
20	1168			2456	2558	2695	2712		2870	3021
21	1072			2820	2981	3127	3155		3330	3465?
22	1030			2843	3037	3187	3210		3384	3510
23	903			2358	2460		2575		2760	2904
24	969			2302	2401		2484		2650	2718
25				2453	2554		2652		2832	2898?
26	1012			2548	2648		2733		2888	2933
27	1065			2488	2584		2647		2803	2847
28	1100			2397	2502		2569		2715	2758
29				2776	2881		2952		3116	3170
30	1181			3018	3129		3246		3400	3458
31				2376	2482		2570		2690	2742
32				2330	2445		2531		2665	2752
33	1173			2865	2980		3066		3217	3268
34				2310	2420		2506		2590	2700
35				2623	2735		2815		2895	2997
36				2063	2175		2262		2360	2462
37	1122			2364	2475		2566		2668	2796
38	856			2630	2753		2839		2969	3040
39				2357	2602	2744	2763		2943	3018
40	1140			2934	3200	3362	3404		3584	3655
41	992			2735	2937	3097	3132			
42	1019			2915	3141	3235	3270		3450	3507
43				3155	3370	3495	3523		3671	3725
44	1201			3345	3600	3650	3777		3943	4000
45				3310	3556	3736	3760		3933	3991
46	1115			3380	3648	3798	3847		4023	4085
47				3029	3238	3382	3400		3573	3630
48	960			2845	3031	3174	3194		3364	3451
49				3165	3417	3572	3598		3752	3798
50	1074			3085	3303	3440	3457		3604	3647
51	1007			3154	3366	3541	3563		3716	3764
52	1069			3409	3626	TD				
53				3246	3438	3595	3620		3799	3862
54				3583	3785		3965		4146	4167
55	1202			2853	3112	3220	3260		3418	3471
56	1135			3014	3290	3436	3460		3670	3742
57	1198			3151	3458	3598	3629		3826	3896
58	1100			3141	3416	3549	3587		3784	3844

			Put-in-Bay			Tymochtee		Greenfield		
Well	*Elevation*	*H*	*G*	*F*	*E*	*D*	*C*	*B*	*A*	*Base*
59	1087			3108	3400	3560	3598		3790	3856
60				3216	3498	3647	3686		3885	3956
61	1180			3297	3562	3709	3746		3931	3994
62	1167			3189	3441	3590	3612		3769	3823
63	1257			4305	4573	4780	4803		4988	5032
64				2102	2180		2278		2465	2540
65	836			2215	2292	2380	2391		2573	2637
66	895			2299	2378		2472		2659	2722
67	852			2214	2350	2450	2493		2710	2778
68	880			2244	2402	2500	2543		2774	2841
69	1018			2422	2578	2685	2725		2960	3027
70	1067			2683	2816	2923	2968		3195	3255
71	1088			2724	2887	2992	3030		3263	3326
72	1078			2545	2732	2848	2882		3101	3170
73	976			2477	2668	2780	2820		3053	3110
74	862			2498	2682	2794	2834		3051	3118
75	1064			2715	2915	3029	3075		3288	3354
76	904			2794	3015	3135	3166		3370	3430
77	1221			4417	4718	4922	4948		5155	5212

Ontario

Well	Log	Elevation	H	G	F	Salina Formation E	D	C	B	A	Base
1	G	570	185	237	292	345	425	432	490	545	570
2		570	222	270							580
3	S	600?	30	65	120			265	320		485
4	G	572	95	162	227	277	360	370	415	458	510
5		581						262		365	412
6		572	85	126		252		325			460
7		603		70		145		230?		290	368
8		664	21	80		180		270		380?	395
9	S	650	105	161	217	273		322	399	427	462
10		570		249				455		526	577
11				240		375		430		490	555
12	G	752				88	160	165	208	245	310
13		881						190		285	341
14		906						218		335	398
15	G	572	219	272	332	390	472	477	517	557	618
16		570	270	320		450		550		620	688
17	S	593	975	1050	1123	1200		1255	1317		1410
18		570		620		689		810		883	950
19		631	627	709		810		898		989	1046
20		749	538	616		711		815		895	949
21		730	505	585		660		767		849	911
22		691	425	508		600		700		778	836
23		754	448	558		651		753		820	886
24		782	205	221						488	540
25	G	900	540	595	665	722	803	805	851	885	970
26	G	948	373	420	490	550	628	635	674	707	778
27		943		136		238		356		420	482
28	G	988		180	237	275	365	372	410	445	500
29		755						794		895	967
30	G	789	810	858	927	981	1063	1073	1115	1155	1250
31		718		786		910		1000		1090	1203
32	S	632	830	874	952	1011		1083	1155	1246	1336
33		716		894		1004		1108		1194	1346
34	G	693	1005	1072	1132	1204	1283	1293	1357	1400	1585
35		929		708		816		924		1000	1105
36	G	790	735	808	873	933	1015	1020	1065	1110	1215
37		730		990		1100		1205	1380	1472	1686
38		700				1028		1145	1220	1372	1600
39		787		1090			1470	1480	1515	1710	2025
40		621		905		1070	1152	1193	1279	1518	1895
41		650		870		966		1060		1148	1296
42		686		1123		1340	1425	1464	1550	1811	2176
43		738		1208		1440	1525	1550	1647	1928	
44		789		1132		1220	1326	1350	1450	1696	2010
45		702		1126		1234		1362	1474	1730	2036
46	G	692	1098	1173	1240	1310	1388	1430	1505	1755	2055
47		691		1155		1324	1405	1445	1510	1770	

								Salina Formation			
Well	*Log*	*Elevation*	*H*	*G*	*F*	*E*	*D*	*C*	*B*	*A*	*Base*
48	G	740	1203	1260	1330	1505	1597	1645	1725	1988	2365
49		678		1210		1400	1520	1550	1600	1890	2243
50		674		1166		1403	1460	1515	1582	1833	2187
51	S	657	850	920	970	1120		1210	1300	1455	1760
52	S	650		1005	1045	1150	1210	1225	1300	1590	1950
53		633		1252		1368		1510	1593	1609	1904
54		627		1216		1295		1421	1520	1625	1933
55		626		1158		1265		1385	1464	1634	1931
56	G	623	1093	1155	1220	1295	1377	1390	1445	1630	1952
57		625		1140		1262		1386	1464	1688	2044
58		620		1150		1278		1375	1470	1722	2083
59		656		1148		1445	1525	1570	1663	1916	2292
60		673		1180		1482	1555	1594	1687	1960	2330
61		655		1174		1475	1574	1610	1715	1985	2378
62		647		1182		1552	1625	1660	1760	2043	2454
63	G	603	1375	1445	1500	1875	1965	2000	2085	2395	2810
64	G	655	1178	1240	1295	1558	1645	1680	1763	1965	2105
65		644		1320		1660	1730	1760	1830	2045	2180
66		649		1348		1593	1665	1695	1761	1970	2142
67		638		1264		1476	1574	1600	1696	1858	1985
68		631		1249		1472	1530	1565?	1695	1908	2244
69		630		1511		1820	1911	1948?	2114	2202	2520
70		598		1425		1560		1690	1760	2065	2405
71	G	633	1155	1210	1285	1350	1428	1457	1538	1748	1856
72		640		1205		1315		1436	1510	1756	2108
73	G	614	1215	1280	1355	1427	1510	1517	1590	1835	2180
74		610		1179		1288		1402	1490	1734	2083
75		600		1268		1373		1490		1612	1680
76		589		1140		1250		1370	1450	1664	
77		588		1390		1494		1625?		1723	2042
78		617		1230		1335?		1460		1566	1728
79		578		948		1065		1184	1280	1452	1604
80	G	583	1250	1308	1380	1454	1536	1544	1631	1716	1940
81	S	583		1325	1420			1550	1665	1715	1895
82	S	598		1000	1070			1215	1270	1485	1650
83	S	581		933	1005			1166	1256		1460
84	S	660	1160	1224	1320			1440	1525	1536	1637
85	S	631		905	990			1125	1205		1360
86	S	615		1152	1224			1374	1422		1713
87		637		445		550?		701		794	936
88		583		418		514?		653		755	890
89	S	580		499	587			746	818		1016
90	S			333	430			577?	719		851
91	S	635		645	750			880	965		1110
92	S	610		660	760			900	982	1100	1140

Michigan

Well	*Log*	*Elevation*	Salina Group *H*	*G*	*F*	*E*	*D*	*C*	*B*	*A*	*Base*
1	G	634	1552	1615	1700	1825	1920	1958	2045	2342	2740
2	G	635	1510	1570	1645	1760	1855	1890	1965	2270	2630
3	G	697	1960	2060	2130	2570	2660	2695	2790	3125	3655
4	G	*	108	175	253	620	735	768	945	1180	1620
5	G	*	90	270	340	840	945	1000	1115	1425	2300

* Arbitrary depths, taken from unmarked log in Ulteig, 1964.

Appendix C

SALINA DEPOSITIONAL MODEL

After initial calculations to yield some approximation of the length of Salina Time and its various subdivisions, the following values were selected as appropriate intervals.

N. Y. Unit	*Mich. Unit*	*Length*
H	F6 & G	100,000 yrs.
G } F5 }	F5	110,000
F4	F4	125,000
F3	F3	110,000
F2	F2	125,000
F1	F1	150,000
E	E	180,000
D	D	50,000
C	C*	275,000
B	B*	100,000
A	A	175,000
	Total	1,500,000

* Michigan definition differs from New York.

In the following tables the abbreviations given below are used.

dol	dolomite	sdy	sandy	an	anhydrite
sh	shale	dep	deposition	sub	subsidence

N.Y. 52 Kesselring
N.Y.S. Nat. Gas
Van Etten Twp.
Chemung Co.

Unit	*Lithology*	*Thickness*		*Deposition Rate*	*Time*	*Water Depth*			
						Rate Change	*Amount Change*		*Depth*
		feet	*m*	*mm/year*	*years*	*mm/yr.*	*m*	*feet*	*feet*
H	dol, an	130	40	0.8	50,000	—0.3	—15	—49	92
	sh, dol, an	50	15	0.3	51,000	+0.2	+10	+33	141
G	sh, dol, an	90	27	0.3	91,000	+0.2	+18	+60	108
F5	sh, dol	5	1.5	0.1	15,000	+0.4	+ 6	+20	48
	salt	60	18	20	900	—19.5	—18	—58	28
F4	sh, dol	50	15	0.1	15,000	+0.4	+ 6	+20	86
	salt	255	78	20	3,900	—19.5	—76	—249	66
					(106,000)				
F3	sh, dol	25	8	0.1	76,000	+0.4	+30	+100	315
	salt	110	34	20	1,700	—19.5	—33	—107	215
					(32,000)				
F2	sh, dol, an	30	9	0.1	91,000	+0.4	+37	+120	322
	salt	175	53	20.	2,700	—19.5	—52	—171	202
F1	sh, dol	105	32	0.2	160,000	+0.3	+48	+158	373
	salt	75	23	20	1,100	—19.5	—22	—73	215
E	sh, dol	165	50	0.3	168,000	+0.2	+34	+110	288
					(20,000)				
D	dol	30	9	0.2	46,000	+0.3	+14	+45	178
	salt	45	14	20	700	—19.5	—13	—44	133
C	sh, an	325	99	0.4	248,000	+0.1	+25	+81	177
					(27,000)				
B	sh, dol, an	135	41	0.4	103,000	+0.1	+10	+34	96
A	red sh	375	114	0.6	191,000	—0.1	—19	—63	62
	Rock	1515	461		1,300,000	Sub. rate			assume 125 at start
	Salt	720	220		(+216,000)	681,000/1,300,000 = 0.5	gain 781 loss 814 net loss 33		
	Total	2235	681	Av. dep. rate excl. salt 0.3	1,516,000				

N.Y. 96 McDonald
N.Y.S. Nat. Gas
York Twp.
Livingston Co.

Unit	*Lithology*	*Thickness*		*Deposition Rate*	*Time*	*Water Depth*			
						Rate Change	*Amount Change*		*Depth*
		feet	*m*	*mm/year*	*years*	*mm/yr.*	*m*	*feet*	*feet*
H	dol	60	18	0.2	91,000	0			38
G	sh, dol	65	20	0.2	99,000	0			45
F	dol, an	85	26	0.2	130,000	0			38
					(380,000)				
E	sh, dol, an	90	27	0.2	137,000	0			38
					(43,000)				
D	sh, dol	10	3	0.2	15,000	0			38
					(35,000)				
C	red & green sh	20	6	0.3	20,000	—0.1	—2	—7	38
	sh, dol	95	29	0.2	145,000	0			45
					(110,000)				
B	sh, dol	65	20	0.2	99,000	0			38
	salt	50	15	20	760	—19.8	—15	—50	45
A	sh, dol	165	50	0.3	168,000	—0.1	—17	—55	95
	Rock	655	199		905,000	Sub. rate		gain 0	assume
	Salt	50	15		(+568,000)	$\frac{214{,}000}{905{,}000}=0.2$		loss 112	150 at
				Av. dep.				net	start
	Total	705	214	rate excl.	1,473,000			loss 112	
				salt 0.2					

N.Y. 37 Grund
N.Y.S. Nat. Gas
Enfield Twp.
Tompkins Co.

Unit	*Lithology*	*Thickness*		*Deposition Rate*	*Time*	*Water Depth*			
						Rate Change	*Amount Change*		*Depth*
		feet	*m*	*mm/year*	*years*	*mm/yr.*	*m*	*feet*	*feet*
H	dol, an	95	29	0.3	97,000	0	0	0	97
G	dol, an	100	30	0.3	102,000	0	0	0	97
F4	dol, an	35	11	0.1	107,000	+.2	+21	+70	97
	salt	105	32	20.	1,600	—19.7	—32	—103	27
F3	dol, an	45	14	0.2	69,000	+.1	+ 7	+23	130
	salt	35	11	20	500 (41,000)	—19.7	—11	—34	107
F2	dol, an	40	12	0.1	122,000	+.2	+24	+80	141
	salt	70	21	20	1,000	—19.7	—21	—69	61
F1	dol, an	75	23	0.2	114,000	+.1	+11	+38	130
	salt	75	23	20	1,000 (35,000)	—19.7	—23	—74	92
E	sh, an	50	15	0.3	51,000	0	0	0	166
	dol, an	85	30	0.2	130,000	+.1	+13	+43	166
D	sh, dol, an	50	15	0.3	51,000	0	0	0	123
	salt	50	15	20	800	—19.7	—15	—49	123
C	sh	185	56	0.2	282,000	+.1	+28	+93	172
B	sh, dol	165	50	0.5	101,000	—.2	—20	—66	79
A	red sh	330	101	0.6	168,000	—.1*	—17	—55	145
	Rock	1255	386		1,400,000		gain 347		assume
	Salt	335	102		(+76,000)		loss 450		200 at
						Sub. rate	net		start
	Total	1590	488	Av. dep.	1,476,000	488,000=0.3	loss 103		
				rate excl.		1,400,000			
				salt 0.3					
						*Unit A 0.5			

PA 3 Blemle
Pure Oil
Wilmot Twp.
Bradford Co.

Unit	*Lithology*	*Thickness*		*Deposition Rate*	*Time*	*Water Depth*			
						Rate Change	*Amount Change*		*Depth*
		feet	*m*	*mm/year*	*years*	*mm/yr.*	*m*	*feet*	*feet*
H	dol	100	30	0.5	61,000	0	0	0	60
	dol, an	100	30	0.8	38,000	—0.3	—11	—38	60
G	sh, dol	105	32	0.5	64,000	0	0	0	98
F5	sh, dol	65	20	0.4	50,000	+0.1	+ 5	+16	98
	salt	5	1.5	20.	80	—19.5	— 1.6	— 5	82
F4	sh, dol	160	49	0.4	122,000	+0.1	+12	+40	87
	salt	340	104	20	5,200	—19.5	—101	—332	47
F3	sh, dol	140	43	0.4	107,000	+0.1	+11	+35	359
	salt	120	37	20	1,800	—19.5	—37	—117	344
F2	sh, dol	160	49	0.4	122,000	+0.1	+12	+40	461
	salt	50	15	20	800	—19.5	—15	—49	421
F1	sh, dol	200	61	0.4	152,000	+0.1	+15	+50	470
	salt	50	15	20	800	—19.5	—15	—49	420
E	sh, dol	185	56	0.3	188,000	+0.2	+38	+123	469
D	sh, dol	65	20	0.4	50,000	+0.1	+ 5	+16	346
C	sdy sh	365	111	0.4	278,000	+0.1	+28	+91	330
B	sdy sh, dol	105	32	0.3	107,000	+0.2	+21	+70	239
A	red sh	555	169	1	169,000	—0.1*	—17	—56	169
	Rock	2305	702			Sub. rate	gain 481		assume
	Salt	565	173			875,000=0.5 / 1,500,000	loss 646		225 at
	Total	2870	875	Av. dep. rate excl. salt 0.5	1,500,000	*Unit A 0.9	net loss 165		start

MICH State-Foster
Brazos Oil & Gas
Foster Twp.
Ogemaw Co.

Unit	*Lithology*	*Thickness*		*Deposition Rate*	*Time*	*Water Depth* *Rate Change*	*Water Depth* *Amount Change*		*Water Depth* *Depth*
		feet	*m*	*mm/year*	*years*	*mm/yr.*	*m*	*feet*	*feet*
G	sh	70	21	0.4	53,000	0	0	0	152
F6	sh, dol	80	24	0.4	61,000	0	0	0	152
	salt	150	46	20.	2,300	—19.6	—45	—147	152
F5	sh, dol	105	32	0.3	107,000	+.1	+16	+53	299
	salt	75	23	20	1,100	—19.6	—22	—74	246
F4	sh, dol	90	27	0.2	137,000	+.2	+27	+90	320
	salt	65	20	20	1,000	—19.6	—19	—64	230
F3	sh, dol	30	9	0.2	46,000	+.2	+ 9	+30	294
	salt	55	17	20	800	—19.6	—16	—54	264
					(63,000)				
F2	sh, dol	55	17	0.2	84,000	+.2	+17	+55	318
	salt	50	15	20	800	—19.6	—15	—49	263
					(40,000)				
F1	sh, dol	65	20	0.2	99,000	+.2	+20	+65	312
	salt	80	24	20	1,200	—19.6	—24	—78	247
					(50,000)				
E	sh, dol	60	18	0.2	91,000	+.2	+18	+60	325
	salt	13	4	20	200	—19.6	— 4	—13	265
	sh, dol	82	25	0.3	83,000	+.1	+ 8	+27	278
D	salt	55	17	20	800	—19.6	—16	—54	251
					(50,000)				
C	sh	110	34	0.2	168,000	+.2	+34	+110	305
B	sh, dol	85	26	0.2	130,000	+0.4	+52	+170	195
	salt	340	102	20	5,100	—19.4	—101	—330	25
					(72,000)				
A2	dol	130	40	0.3	132,000	+.7	+92	+303	355
A2	salt	445	136	20	7,000	—19	—128	—423	52
A1	dol	70	21	0.3	71,000	+.7	+50	+163	475
A1	salt	330	101	20	5,000	—19	—96	—313	312
	Rock	1032	314		1,287,300	Sub. rates			assume 625 at start
	Salt	1658	505		(275,000)	C-G $\frac{393,000}{939,000}$ = 0.4 used 0.4			
	Total	2690	819	Av. dep. rate excl. salt 0.3	1,562,300	B $\frac{128,000}{135,100}$ = 0.9 used 0.6			
						A $\frac{298,000}{215,000}$ = 1.3 used 1.0			


PLATE 1
Isopachous Map
of
Salina Group
with
Location of Cross Sections
Outcrop of Salina Group
Isopach line - Interval variable, usually 100 or 500 feet
SCALE IN MILES
10 0 10 20
Lake Huron
Lake Ontario
Lake Erie
Canada
United States
Quebec
New York
Michigan
Ohio
Plate 11
A
A'
B
B'
Plate 12
Plate 13
C
C'
Plate 14
D
D'
Figure 4
E
E'
CLEVELAND


PLATE 2
Structure Contours
on top of
Vernon Formation
Outcrop of Salina Group
Contour Interval – 500 feet
Datum – Mean sea level
SCALE IN MILES
10 0 10 20
Lake Huron
Lake Ontario
Lake Erie
Michigan Basin
Chatham Sag
Algonquin Arch
Findlay Arch
Canada
United States
New York
Pennsylvania
Quebec
New York
New Jersey
Vt.
Mass.
Conn.
Lackawanna Syncline
Allegheny Synclinorium
("Appalachian Basin")
Western limit of strong folding in Oriskany sandstone
BUFFALO
ROCHESTER
SYRACUSE
ALBANY
KINGSTON
LOCKPORT
BRADFORD
CLEVELAND
PITTSBURG
HARRISBURG
DETROIT


PLATE 3
Isopachous Map
of
Vernon Formation
Units A, B, and C
Outcrop of Salina Group
Isopach line - Interval variable, usually 100 feet
SCALE IN MILES
10 0 10 20
Type section of Vernon
Type section of Bloomsburg
Type section of Wills Creek Fm. at Gumberland, Md.
Lake Huron
Lake Ontario
Lake Erie
Quebec
New York
Pennsylvania
New Jersey
Canada
United States
Michigan
Ohio
Vt
Mass
Conn
CLEVELAND
ROCHESTER


PLATE 4
Isopachous and Lithofacies Map
of
Lower Vernon, Unit A
Salt, anhydrite, dolomite, gray or green shale
0 to 50 feet
50 to 100 feet
over 100 feet
Aggregate salt*
Anhydrite, dolomite, gray or green shale
Dolomite, gray or green shale
Gray or green shale, red shale
Red shale
Outcrop of Salina Group
Isopach line – Interval variable, usually 100 feet
* Ontario – after Sanford, 1965
SCALE IN MILES
10 0 10 20
Lake Huron
Lake Ontario
Lake Erie
Canada
United States
Quebec
New York
Pennsylvania
Michigan
Ohio
Type section of Vernon
Across this area 60 to 70 feet of upper Guelph to west becomes lower Vernon to east
Vernon and Tully identified
CLEVELAND
PITTSBURG
BUFFALO
ROCHESTER
SYRACUSE
HARRISBURG
DETROIT
BRADFORD
LOCKPORT
KINGSTON
ALBANY

PLATE 5
Isopachous and Lithofacies Map
of
Middle Vernon, Unit B
Salt, anhydrite, dolomite, gray or green shale
0 to 50 feet
50 to 100 feet
over 100 feet
Aggregate salt*
Anhydrite, dolomite, gray or green shale
Dolomite, gray or green shale
Gray or green shale, siltstone
Red shale
Outcrop of Salina Group
Isopach line – Interval variable, usually 50 feet
Structure contour – Top of Unit B, datum mean sea level
* Ontario – after Sanford, 1965 Ohio – after Ulteig, 1964
SCALE IN MILES
10 0 10 20
Type section of Vernon
Quebec
New York
Lake Huron
Lake Ontario
Lake Erie
Canada
United States
Michigan
Ohio
Pennsylvania
New Jersey
Vt.
Mass.
Conn.
Vernon Undifferentiated


PLATE 6
Isopachous and Lithofacies Map
of
Upper Vernon, Unit C
Anhydrite, dolomite, gray or green shale
Dolomite, gray or green shale
Gray or green shale, siltstone
Gray or green shale, red shale
Red shale
Outcrop of Salina Group
Isopach line – interval variable, usually 50 or 100 feet
SCALE IN MILES
10 0 10 20
Type section of Vernon
Lake Huron
Lake Ontario
Lake Erie
Canada
United States
New York
Pennsylvania
Quebec
New York
Vernon nondifferentiated
Michigan
Ohio
Vt.
Mass.
Conn.
New Jersey


PLATE 7
Isopachous and Lithofacies Map
of
Lower Syracuse, Units D and E
Salt, anhydrite, dolomite, gray or green shale
0 to 40 feet
40 to 80 feet
over 80 feet
Aggregate salt in D*
Anhydrite, dolomite, gray or green shale
Dolomite, gray or green shale
Outcrop of Salina Group
Isopach line – Interval variable, usually 100 feet
Structure contour – Top of Unit D, datum mean sea level
* Ontario – after Sanford, 1965 Ohio – after Ulteig, 1964
SCALE IN MILES
10 0 10 20
Reference section Syracuse Formation
Type section of Tonoloway Formation on Tonoloway Ridge, Md.
Lake Huron
Lake Ontario
Lake Erie
Canada
United States
New York
Pennsylvania
Ohio
Michigan
New Jersey
Quebec
Vt.
Mass.
Conn.
margin of e salt
margin of salt


PLATE 8
Isopachous and Lithofacies Map
of
Upper Syracuse, Unit F
Salt, anhydrite, dolomite, gray or green shale
0 to 250 feet
250 to 500 feet
over 500 feet
Aggregate salt *
Anhydrite, dolomite, gray or green shale
Dolomite, gray or green shale
Outcrop of Salina Group
Isopach line - interval variable, usually 100 feet
Structure contour - Top of Unit F, datum mean sea level
* Ontario - after Sanford, 1965 Ohio - after Ulteig, 1964
SCALE IN MILES
Reference section
Syracuse Formation
Type section of
Tonoloway Formation
on Tonoloway Ridge Md.
Lake Huron
Lake Ontario
Lake Erie
Canada
United States


PLATE 9
Isopachous and Lithofacies Map
of
Camillus and Bertie Formations, Units G and H
Both formations consist of shales, dolomites and anhydrites-
shales predominate in the Camillus, dolomite in the Bertie-
except as noted below
Red shales present in Camillus
No shales or anhydrite in Bertie
Outcrop of Salina Group
Isopach line - Interval variable, usually 25 feet
SCALE IN MILES
10 0 10 20
Lake Huron
Lake Ontario
Lake Erie
Canada
United States
Quebec
New York
Pennsylvania
Ohio
Michigan
New Jersey
Type section
Bertie Formation
Camillus
Type section
High Falls Fm.
DETROIT
CLEVELAND
BUFFALO
ROCHESTER
SYRACUSE
PITTSBURG
ALBANY
Mass
Conn
Vt


PLATE 10
Isopachous Map
of
Cobleskill and Rondout Formations
and the
Helderberg Group
Outcrop of Salina Group
Isopach line - Interval variable, usually 100 feet
SCALE IN MILES
10 0 10 20
Lake Huron
Lake Ontario
Lake Erie
Canada
United States
Quebec
New York
Pennsylvania
Michigan
Ohio
New Jersey
absent
CLEVELAND
PITTSBURG
BUFFALO
DETROIT
ROCHESTER
LOCKPORT
BRADFORD
0
100
200
250
300
400
500

Plate II

Section A - A'

Eastern Michigan to Eastern New York

Parallel to Outcrop

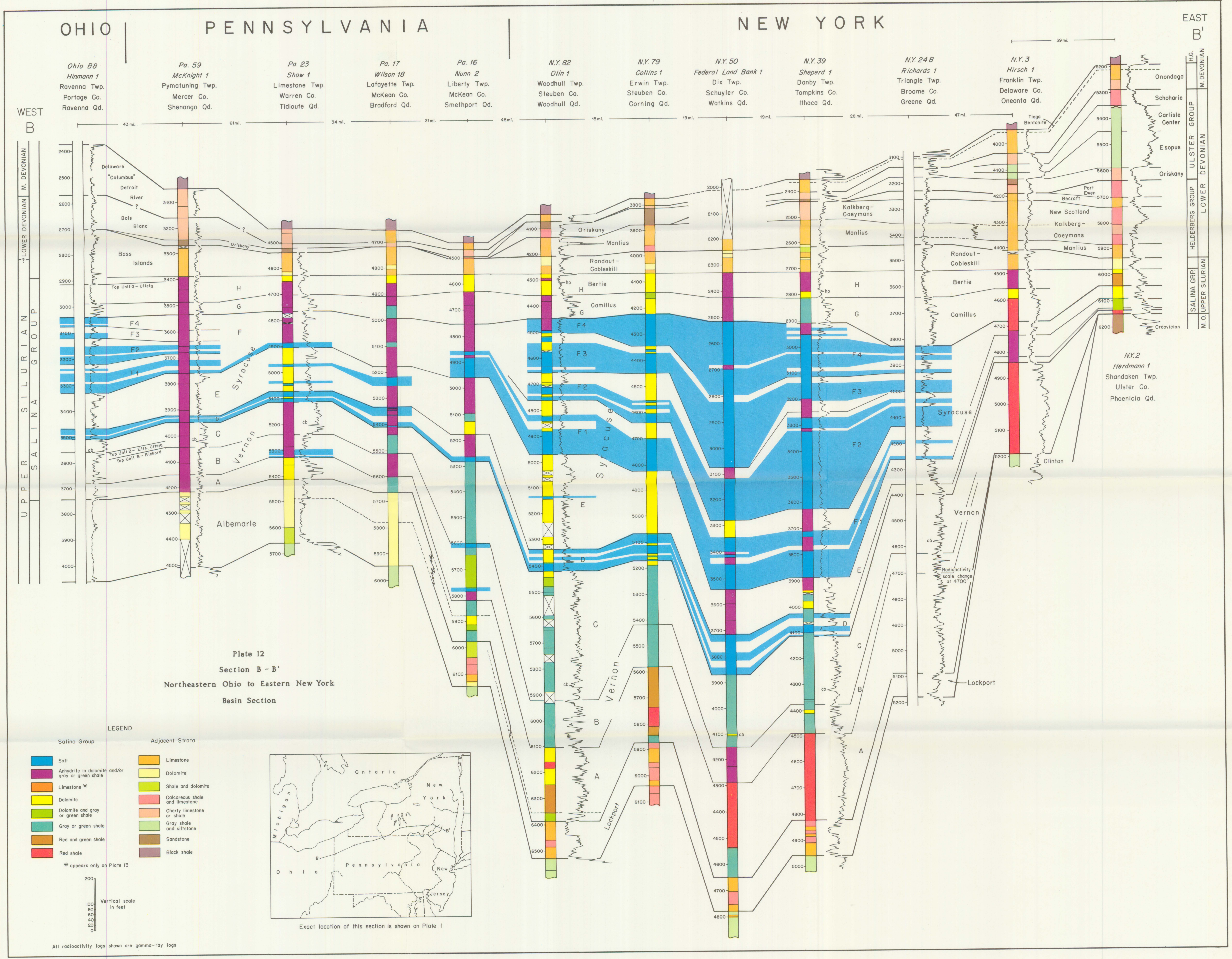


Plate 12

Section B - B'

Northeastern Ohio to Eastern New York

Basin Section

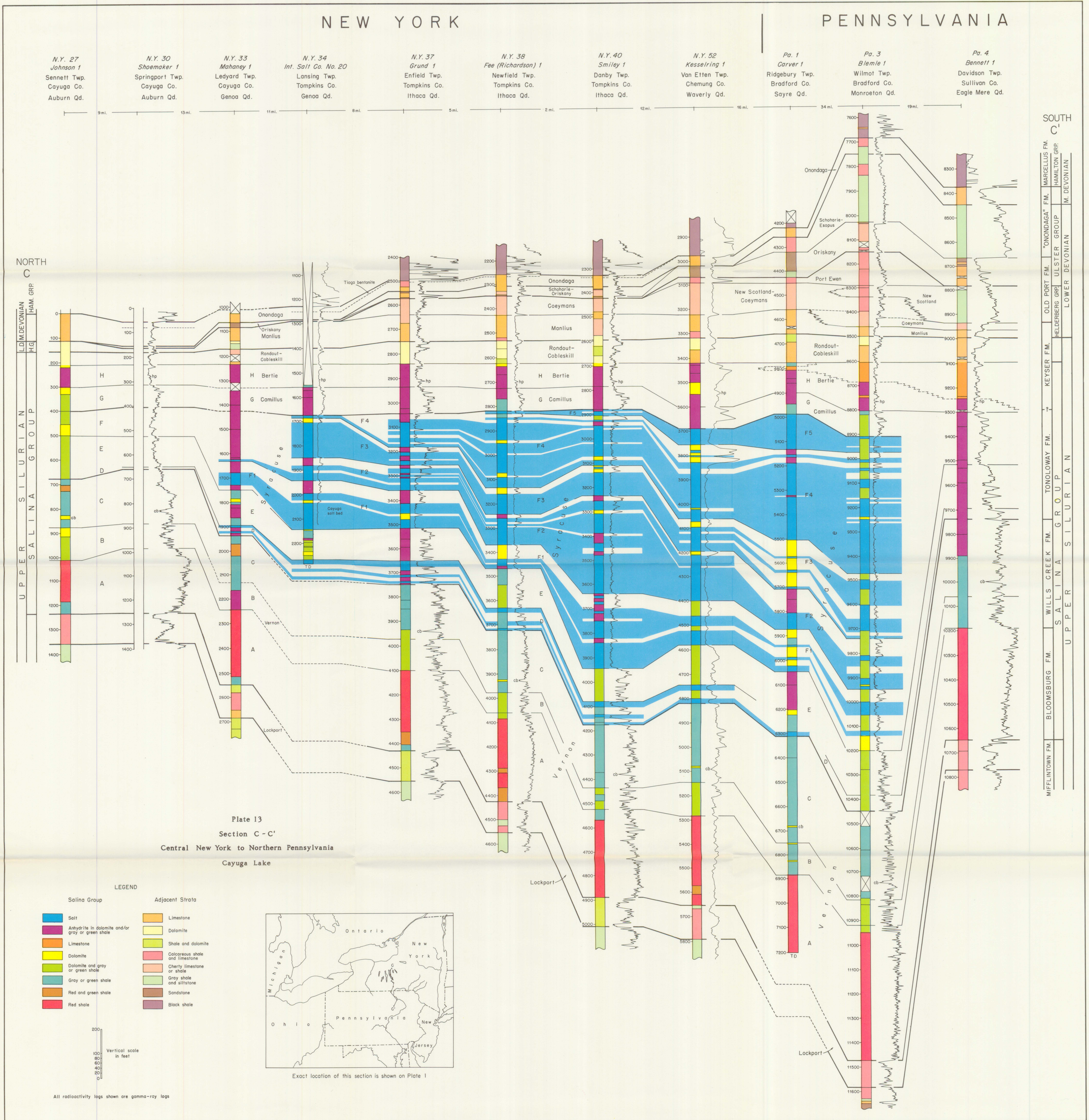


Plate 13

Section C - C'

Central New York to Northern Pennsylvania

Cayuga Lake

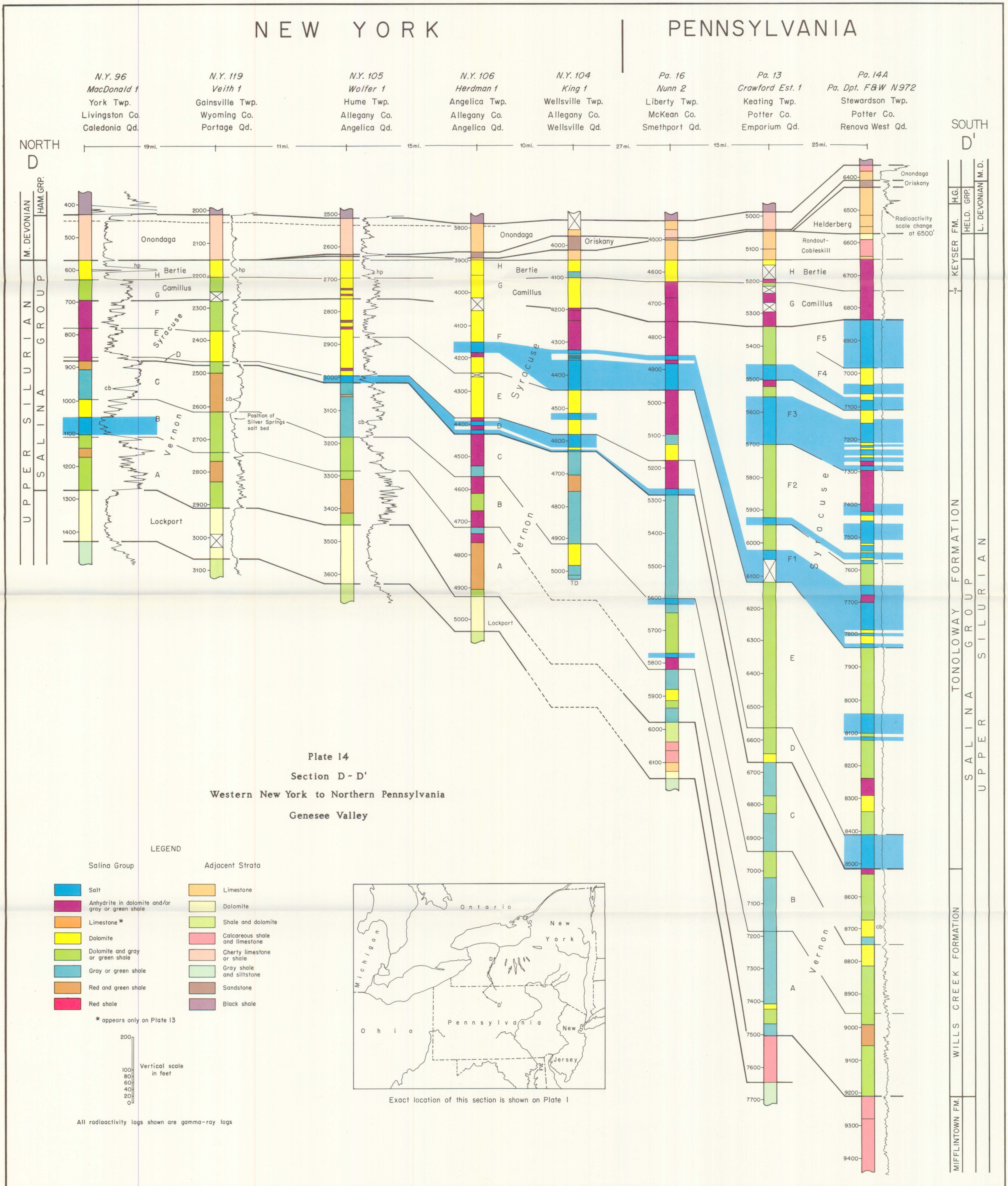


Plate 14

Section D - D'

Western New York to Northern Pennsylvania

Genesee Valley