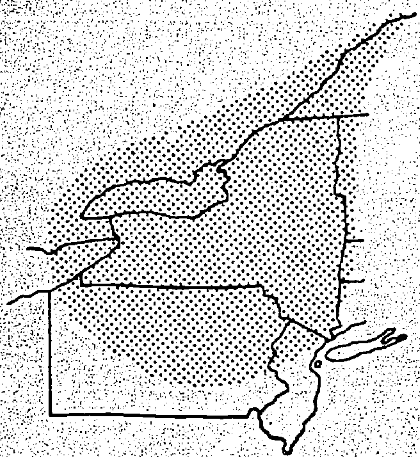
DOCUMENT RESUME

ED 093 640 SE 017 316

AUTHOR	Rickard, Lawrence V.
TITLE	Stratigraphy and Structure of the Subsurface Cambrian and Ordovician Carbonates of New York.
INSTITUTION	New York State Education Dept., Albany.
PUB DATE	73
NOTE	30p.
EDRS PRICE	MF-$0.75 HC-$1.85 PLUS POSTAGE
DESCRIPTORS	Bibliographies; Earth Science; *Geology; Instruction; *Instructional Materials; *Maps; *Paleontology; Science Education
IDENTIFIERS	New York State Museum and Science Service

ABSTRACT

This publication presents a description of 137 wells in New York State and adjacent parts of Pennsylvania. Correlations with surface exposures are established. Maps and cross sections display the thickness, structure, and stratigraphic relationships of the carbonates described. A paleogeologic map of New York State at the end of the Early Ordovician is presented. Two distinct series of rocks which comprise the Cambrian and Ordovician carbonates of New York are described and studied in detail. The monograph includes an extensive bibliography, several schematic figures and diagrams, and two appendices which give data relevant to the identification of control wells and subsurface data from control wells. (Author/EB)



Stratigraphy and Structure of the Subsurface Cambrian and Ordovician Carbonates of New York

LAWRENCE V. RICKARD

NEW YORK STATE MUSEUM AND SCIENCE SERVICE
MAP AND CHART SERIES NUMBER 18

The University of the State of New York / The State Education Department / Albany, 1973

Stratigraphy and Structure of the Subsurface Cambrian and Ordovician Carbonates of New York[1]

by Lawrence V. Rickard[2]

ABSTRACT

Subsurface carbonates of Cambrian and Ordovician age in New York State, and adjacent parts of Pennsylvania, Ontario, and Quebec, are present in 137 wells described herein. Correlations with surface exposures are established. Maps and cross sections display the thickness, structure, and stratigraphic relationships of these carbonates. A paleogeologic map of New York State at the end of the Early Ordovician is presented.

The Cambrian and Ordovician carbonates of New York comprise two distinctly different series of rocks. The older series consists of quartzose sandstones, quartzose dolostones, dolostones, and limestones deposited on an Early Paleozoic carbonate shelf. This series thickens seawardly and is composed of the Cambrian Potsdam, Galway (Theresa) and Little Falls Formations, and several formations of the Early Ordovician Beekmantown Group. A major regional unconformity separates this series from the overlying one. The younger series consists of dolostones and limestones deposited in a miogeosyncline during Medial Ordovician time. It is composed of the Black River and Trenton Groups whose maximum thickness is near the axis of the *miogeosyncline*.

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[1] Submitted for publication February 16, 1973.

[2] Senior scientist (paleontology), New York State Museum and Science Service.

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INTRODUCTION

The Cambrian and Lower Ordovician carbonates of New York form a southerly and easterly thickening wedge of rock 4,000 to 5,000 feet thick in southeastern New York and southwestern Vermont. This wedge was formed in Early Paleozoic time on a carbonate shelf or miogeocline that gave way seawardly to a carbonate-slide-breccia and lutite facies and a turbidite facies along the former continental slope and rise (figure 1A). Rocks of the latter areas now overlie those of the shelf in eastern New York, emplaced there by the gravity slides and thrusts of the Taconic allochthone.

The Early Paleozoic carbonate shelf extended along the margin of the North American continent from Newfoundland to Alabama. It was covered by the marine waters of an early or proto-Atlantic Ocean formed by rifting and separation of the North American and African continents during the late Proterozoic. At the time this carbonate wedge was forming, Africa and North America were separated by several hundred miles, perhaps several thousand. The separation was sufficient to prevent the acquisition of terrigenous sediments, derived from erosion of the African landmass, along the American coast. Only a few such sediments, chiefly quartz, were available from the North American continent; thus the continental shelf was dominated by carbonate deposition.

This Early Paleozoic sea slowly spread westwardly upon the North American continent; consequently older rocks are restricted to the more seaward (distal) portion of the miogeocline as shown on plate 1. The basal quartz sandstone is known by various names—Hardyston, Poughquag, Cheshire, Potsdam—depending upon age and locality. These are all time-transgressive units that merge into a single basal sandstone present nearly everywhere at the bottom of the carbonate sequence. Nearshore basal sandstones of the proximal portion of the miogeocline are equivalent in age to offshore carbonates of the distal portion.

The rocks of the carbonate shelf consist of basal quartz sandstones, a few with conglomerates, overlain by quartzose dolostones and purer dolostones, all of shallow water origin (figure 2). Calcitic dolostones and dolomitic limestones occur in Early Ordovician units near the top of the sequence. The great thicknesses of relatively uniform lithologies and subtle lateral changes from one rock type to another have made this sequence very difficult to subdivide and correlate. Stratigraphic units and correlations have been proposed based upon the presence or absence of sandstone, chert, oolite, shale, and limestone and fossil content. Fossils are not abundant in these rocks; trilobites and gastropods are the principal groups utilized for correlation.

One of the more perplexing aspects of this sequence is the origin of its sediments. Most of these rocks have been interpreted as peritidal or even supratidal dolostones. Yet they comprise intervals hundreds of feet thick extending for hundreds of miles. Precisely how such thick and widespread units of supposedly very shallow water sediments are formed has not been satisfactorily explained.

Following deposition of the Lower Ordovician carbonates, most of the continental shelf was uplifted and exposed to subaerial erosion. Block faulting occurred in eastern New York, perhaps accompanied by some minor folding. Much more severe deformation and uplift of the sediments of the continental slope and rise took place at this time, producing an island arc or elongate landmass ("Appalachia") along the American coast (figure 1B). It is thought that this deformation resulted from the establishment of a subduction zone beneath an oceanic trench along the coast, consumption of the proto-Atlantic oceanic plate in this trench, and the approach of the African continent as the ocean began to close. Whatever their origin, these movements reversed the direction of major terrigenous sediment supply from west to east. The former continental rise became the source of the thick sequences of flysch (Normanskill, and later, Martinsburg) deposited upon the former slope and carbonate shelf in a Middle Ordovician miogeosyncline.

In marked contrast to the earlier carbonates, those of the overlying Middle Ordovician Black River and Trenton Groups exhibit a significantly different distribution pattern, owing to their origin in an entirely different tectonic setting. These carbonates, 1,200 feet thick in west central New York, formed in shallow epicontinental seas occupying a miogeosyncline along the eastern margin of the North American craton (figure 1C). These seas lacked wide and deep connections with the proto-Atlantic Ocean, and, at least in New York, spread both westward over the craton and eastward over the former continental shelf. As the miogeosyncline deepened in the east, carbonate deposition was restricted to the western craton and the former shelf became the site of a miogeosyncline into which a huge volume of terrigenous sediments was poured—the Canajoharie-Utica-Schenectady of New York, the Martinsburg of the central Appalachians (figure 1D). These clastics were eroded and carried westward from an island arc or a landmass composed of the earlier slope and rise sediments.

The Middle Ordovician carbonates of the miogeosyncline consist of various peritidal dolostones and limestones in

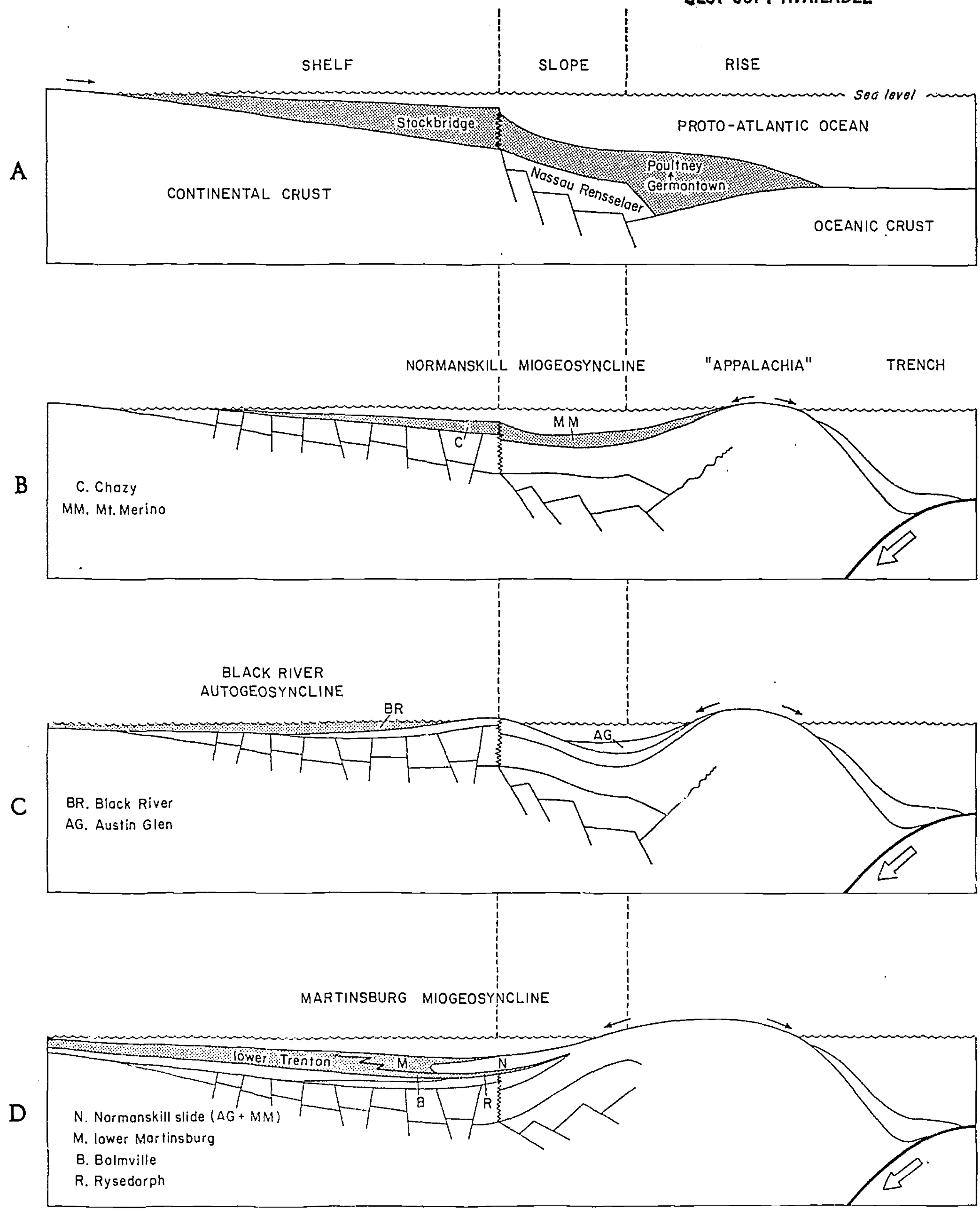

Figure 1. North American continental margin during the Early Paleozoic.

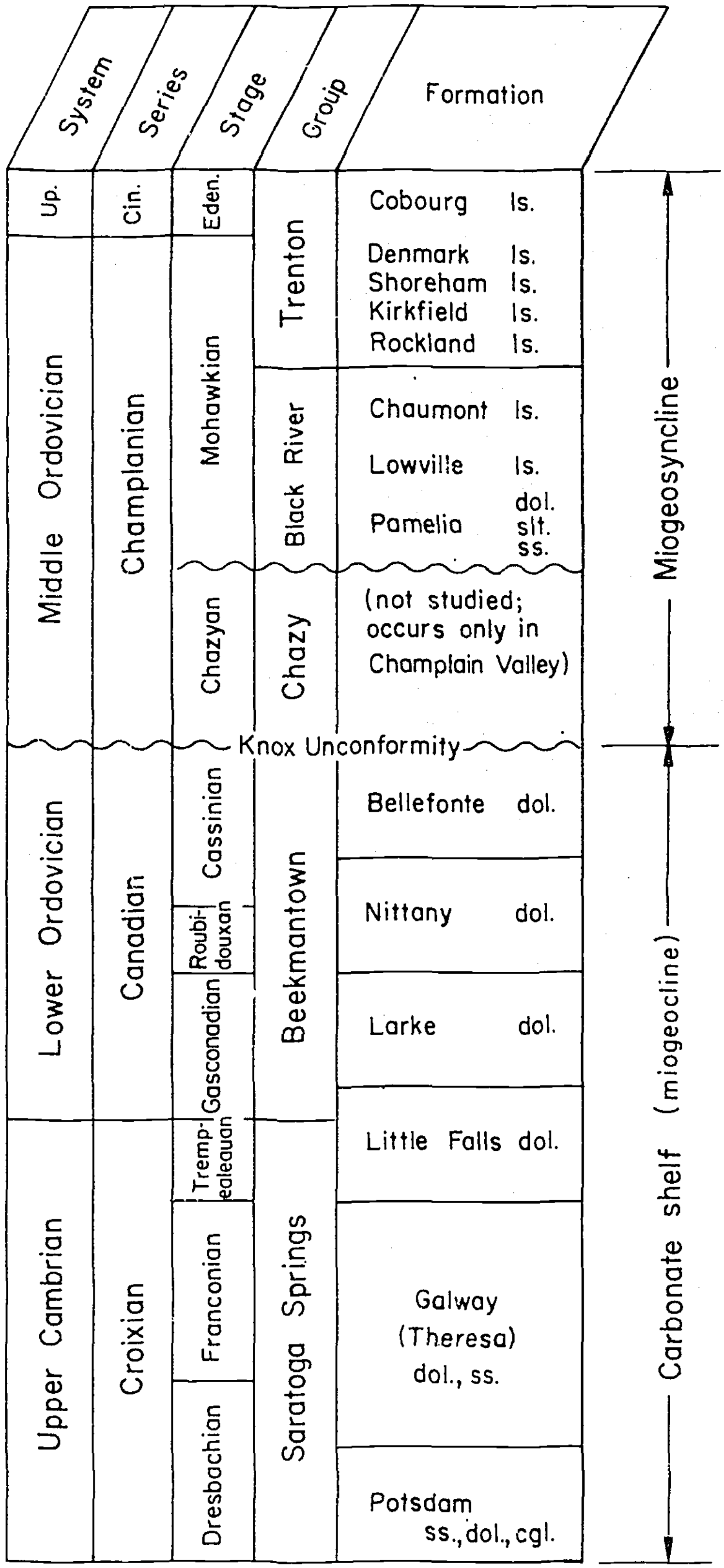

Figure 2. Generalized geologic column for New York subsurface.

the Black River Group overlain by the subtidal limestones of the Trenton Group. The former are fine-grained and poorly fossiliferous; the latter usually are coarser and contain abundant benthonic faunas. Bentonite beds occur in both groups.

PREVIOUS STUDIES

There is a large amount of geologic literature on the Cambrian and Ordovician carbonate rocks of New York State and adjacent areas describing the appearance, distribution, composition, fossil content, and correlation of these rocks along their outcrop belts. Only a very few papers deal with their subsurface features and distribution. Many of the former are included in the bibliography; those in the latter category also are listed below.

New York	Flagler, 1966; Kreidler, 1969
Ohio	Calvert, 1963a, 1963b, 1964
Ontario	Sanford and Quillian, 1959; Sanford, 1961; Beards, 1967
Pennsylvania	Wagner, 1966

In New York State the initial research on these carbonates in the subsurface was largely based upon sample studies; i.e., lithology, as was done by Flagler in 1966. He and other oil and gas geologists attempted subdivision and correlation of these rocks based on lithologic characteristics alone, and made significant progress. However, this practice sometimes has resulted in misidentification of units because of a repetition of the same lithology in different parts of the stratigraphic column and subtle changes in the lithology of a given unit from place to place. Elsewhere, hundreds of feet of uniform lithology could not be subdivided and correlated. The key to accurate and detailed stratigraphic studies of these rocks in the subsurface lies in the use of gamma-ray logs, supplemented by the lithologic data. Early in this study it appeared that various subsurface rock units had distinct and unique gamma-ray patterns, permitting their recognition even where lithologic changes have occurred. It remained to determine the relationship of these subsurface divisions to the well-known formations of the outcrop belts and to establish the correct nomenclature for use in the subsurface.

While it is not nearly so obvious in the Cambrian and Lower Ordovician carbonates as it is in those of the Middle Ordovician, all these rocks produce gamma-ray logs whose patterns can be traced for scores of miles without significant change. For example, a typical gamma-ray pattern of the Black River Group exhibits six major radio-activity peaks (see plates 10-15) that can be identified throughout New York and into Ontario, Ohio, and Pennsylvania. These peaks seem to be associated with shale or siltstone beds in some wells, but in others bentonites are reported. The shape of the log between some of these peaks is also a characteristic feature, such as the curves between peaks 2, 3, and 4 of the Black River logs. A satisfactory explanation for the origin and persistence of these features in the gamma-ray logs of these carbonates has not been achieved. If these features record the occurrence of specific, traceable beds, as they appear to do in the Black River and Trenton, it would seem that changes in the sediments being deposited in these seas were uniform and widespread. Consequently, it does not seem unreasonable to suggest that these peaks may be indicators of time lines or planes. If so, the Black River peritidal carbonates are not time-transgressive to any great degree, as some have claimed, nor is any significant part of this group contemporaneous with a portion of the overlying subtidal Trenton Group. Indeed, this presently is the preferred interpretation. Otherwise one must explain how these persistent patterns can be repeated many times by rocks of completely different ages, that is, how the exact sequence of various lithologies deposited at a given place and time can be precisely duplicated at other times and places hundreds of miles away in order to produce a gamma-ray log of exactly the same appearance. It seems unlikely that the sequence of rocks and the gamma-ray pattern produced by it could remain unchanged over such long periods of time and such great distances.

ACKNOWLEDGMENT

The writer is grateful to G. W. Rector of the Geological Sample Log Co., Pittsburgh, Pa., for permission to publish modified sample logs prepared by the company.

The Isopach Maps

Isopach maps, and sometimes structure contour maps, frequently are misleading or misinterpreted by readers because of uncertainties in exactly what stratigraphic units have been included in each map. To avoid this difficulty two charts, plates 1 and 2, included in this report, show exactly how the recognized stratigraphic units of each outcrop area and the subsurface have been correlated and the precise content of each isopach map.

Plate 3 contains an isopach map of the combined Dresbachian and Franconian Stages of the Late Cambrian. This includes principally the Potsdam and Galway (Theresa) Formations of New York and their age equivalents elsewhere, as shown on plate 1. These units form the major portion of the carbonate miogeocline. Beyond the line indicating the northern margin of Lower and Middle Cambrian rocks, they form the basal portion of this carbonate wedge, lying unconformably upon the Precambrian basement. Thicknesses range from zero to 2,000 feet. Isopachs have been restored across the Adirondack massif to the extent that the present distribution of these rocks suggests. At least half and quite possibly all of the Adirondack area was once covered by these carbonates. North of the edge of the overlying Trempealeauan strata, these carbonates have been eroded and are overlain unconformably by rocks of the Black River Group. Elsewhere Potsdam and Galway strata are overlain conformably by rocks of Trempealeauan age.

The name Theresa commonly has been used by oil and gas geologists for the greater portion of the rocks of plate 3. However, the type Theresa occurs north of Watertown and is not continuous with the so-called "Theresa" of the subsurface. The type Theresa is Ordovician in age whereas the subsurface "Theresa" is Cambrian. Consequently the name Galway (Clarke, 1910, pp. 11-12; Fisher and Hanson, 1951, p. 802) is preferred.

The Potsdam and Galway Formations are considered together as one unit because there is no stratigraphic horizon along which they may be consistently separated, either lithologically or in the gamma-ray logs. Potsdam sandstones are gradually replaced upwards by quartzose dolostones and dolostones of the Galway; the position of the contact varies considerably from well to well, and in some wells the Potsdam is missing altogether.

The Potsdam-Galway interval has been subdivided into eight units, but these are all present only along the southern margin of the State. The lower units pinch out by overlap to the northwest along the basal unconformity; upper units were eroded from the top of the sequence at the end of the Early Ordovician. Study of the lithologies of these units shows that sandstones in the lower part of the Galway in the south probably are fingers of the Potsdam in the north, as shown in figure 3.

Rocks principally of Trempealeauan age, the youngest stage of the Late Cambrian, are shown in plate 4. This is the Little Falls Formation of New York and its equivalents (see plate 1). The upper limit of the Trempealeauan Stage is the Cambrian-Ordovician boundary, as commonly defined in North America. However, this boundary, defined by fossils, is not a lithologically recognizable horizon in the subsurface and frequently cannot be determined precisely on the outcrop. It occurs near the top of the Little Falls and its equivalents. For practical purposes, then, some strata of earliest Ordovician age are included in plate 4 although most of the interval mapped is believed to be of Late Cambrian age.

The Little Falls Formation of plates 1 and 4 is essentially that of the oil and gas geologists. It differs from the Little Falls of the type locality in the Mohawk Valley where this formation has included all dolostones between the Precambrian and the Tribes Hill. Yet the lower portion of this type Little Falls unquestionably is equivalent to the Galway and to rocks mapped as "Theresa" between the Mohawk Valley and the Adirondack Precambrian. As used in this report, the name Little Falls is restricted to the upper portion of the type. The Little Falls and its equivalents consist principally of dolostones and attain a maximum thickness of 300 feet in southeastern New York. They are overlain by rocks of the Beekmantown Group except along the northern and western margins. Here carbonates of the Black River Group rest unconformably upon eroded Little Falls or its equivalents. Isopachs have been restored across the Adirondack Precambrian as suggested by their present distribution in adjacent areas. It is thought that probably all of the Adirondack area was once covered by the Little Falls dolostones.

A large portion of the Early Paleozoic shelf rocks con-

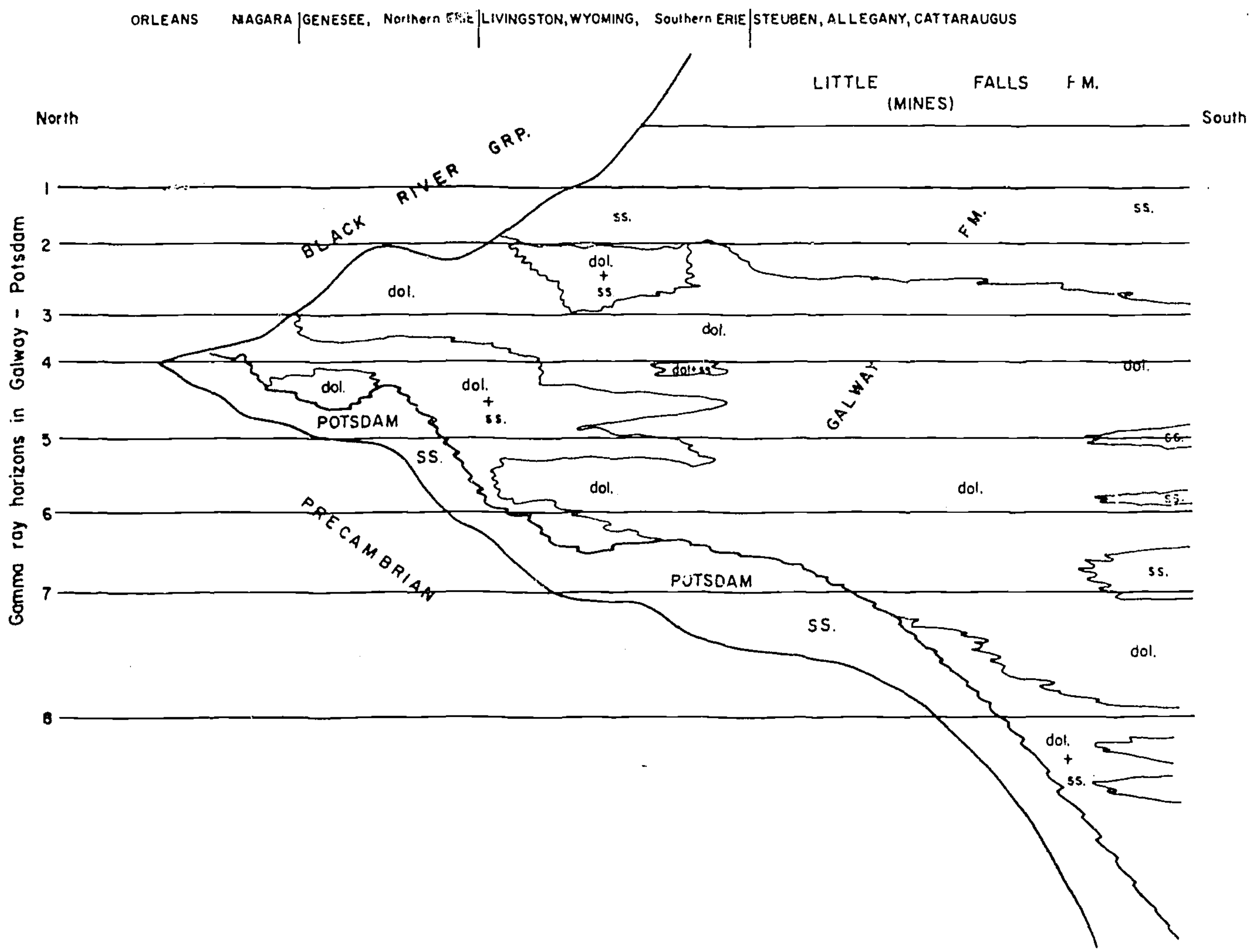

Figure 3. Diagram of lithofacies relationships, Potsdam and Galway Formations, western New York.

sists of carbonates assigned to the Beekmantown Group, as shown on the isopach map, plate 5. These carbonates are referred to the Early Ordovician Gasconadian, Roubidouxan, and Cassinian Stages. They exceed 1,000 feet in thickness in Sullivan County, in southeastern New York, and in the Champlain Valley of northeastern New York and Vermont. Beekmantown strata consist of quartzose dolostones, dolostones, and dolomitic limestones assigned to the Tribes Hill-Chuctanunda or Larke, Nittany, and Bellefonte Formations and their equivalents (see plate 1). There is inconclusive evidence that they may lie unconformably upon the Little Falls and its equivalents in some areas of the State, both outcrop and subsurface. In other areas, the presence of an unconformity at the base of the Beekmantown is fairly certain. The upper surface of the Beekmantown dolostones everywhere is eroded. They are overlain unconformably by either Black River or Trenton Group carbonates.

Several important unconformities occur within the Beekmantown Group and assist in its subdivision. These occur beneath the Cutting, Fort Ann, and Fort Cassin Formations and, in some places, beneath their equivalents elsewhere (see plate 1). Karst topography along these unconformities has been noted in several outcrop areas. Apparently an appreciable amount of Early Ordovician time is unrepresented in New York at the unconformity between the Fort Ann and Fort Cassin Formations.

An attempt has been made to subdivide the subsurface Beekmantown Group into units corresponding to those in the outcrop areas. This was made largely through the use of gamma-ray logs, supplemented by lithologic data. It proved to be quite a difficult task and the results are not entirely satisfactory. However, the attempt does give the reader some feeling for the relationships that exist within the Beekmantown Group and with overlying rocks. Lines indicating the approximate northern and western limits of these Beekmantown subdivisions in the subsurface are drawn on plate 5. As with previous units, the present distribution of isopachs suggests that the Adirondack massif was at least partially covered with Beekmantown strata. Restored isopachs across the Precambrian area portray this suggestion.

Plate 6 is an isopach map of the entire Cambrian and Lower Ordovician carbonate sequence. It displays the seawardly thickening wedge of quartz sandstones, quartzose dolostones, dolostones, and limestones as it is now preserved, and indicates the inferred extent across the Adirondack massif. This map is a summation of plates 3, 4, and 5 and the stratigraphic interval is the Sauk Sequence of Sloss, Krumbein, and Dapples (1949). The unconformity at the top of this sequence is the widespread and well-known Knox unconformity familiar to many oil and gas geologists. Among other purposes, this isopach map is quite useful for predicting the thickness to the Precambrian basement for any well that has penetrated the Knox unconformity.

Plates 3, 4, 5, and 6 seem to show evidence of at least two depocenters that may have existed along the Early Paleozoic shelf. These occur in the Champlain-St. Lawrence Valleys and in eastern Pennsylvania, New Jersey, and southeastern New York. They may be similar to depocenters described for the present Atlantic continental shelf.

As described in the introduction to this report, the diastrophic movements that occurred at the end of the Early Ordovician produced an entirely new tectonic setting for sedimentation in the Medial Ordovician. This new setting is reflected in the significantly different distribution of isopachs shown by the Black River Group in plate 7. The outline of the newly established miogeosyncline is suggested by these isopachs; its axis extended from central Pennsylvania northward across central New York and down the St. Lawrence River Valley. Black River carbonates thin and disappear into unconformities both above and below the group to the east and west of this axis. There is no evidence of gradation into terrigenous rocks in either direction. The easternmost occurrence of Black River carbonates appears to be that at Pleasant Valley in Dutchess County described by Knopf (1927, p. 439). Here the Balmville (basal Trenton) limestone is underlain by 65 feet of gray argillaceous limestone that in turn overlies 15 feet of dove limestone (Lowville) containing *Tetradium cellulosum* and other fossils.

The Black River and Trenton carbonates of the outcrop and subsurface have been correlated as shown in plate 2 from which the exact content of the isopach maps, plates 7 and 8, may be ascertained. The lower Black River Group consists principally of dolostones, but red and green shales, siltstones, and arkosic sandstones often occur near the base of the group. (In earlier reports these basal sandstones, shales, and interbedded dolostones, frequently and erroneously have been referred to the Chazy Group and/or to "Glenwood.") Limestones are interbedded with dolostones near the center of the group and dominate the upper portion where dolostones are rare or absent. Paleoecological analyses have been undertaken by Textoris (1968) and Walker (in press). The Black River carbonates rest unconformably upon Precambrian basement in the north and west, then unconformably upon progressively younger Cambrian and Lower Ordovician carbonates to the south and east.

Maximum thickness of Black River carbonates occurs in central Pennsylvania where gamma-ray logs demonstrate that all of the Loysburg Formation is part of the Black River Group and is not Chazyan (see plate 13). The present distribution of Black River isopachs strongly suggests that these carbonates once covered most, if not all, of the Adirondack massif and the Frontenac axis. This suggestion is illustrated by the restored isopachs drawn across these areas. Areas within which an unconformity separates the Black River and overlying Trenton carbonates have been ruled diagonally. Generally, upper Black River horizons are missing in these areas (see plates 10-15).

The Trenton Group carbonates, shown on plate 8, exhibit a distribution similar to those of the earlier Black River; maximum thickness occurs in northcentral New York along the same miogeosynclinal axis. The reader must bear in mind, however, that only carbonate rocks are included in this isopach map. Shales and sandstones (Canajoharie, Utica, Schenectady) of equivalent age but much greater thickness, occurring in eastern New York and sometimes referred to the Trenton Group (Kay, 1937), are not included, as shown on plate 2. The eastward thinning of the Trenton carbonates, therefore, is principally the result of an important facies change in this direction. The lack of rapid thinning northward suggests that Trenton carbonates may have extended for a considerable distance over the Canadian Shield. To the southwest, however, a sudden decrease in thickness in northwestern Pennsylvania forecasts the thin Trenton limestone present in Ohio. Trenton carbonates also probably extended across the Adirondack massif, as suggested by the restored isopachs in that area. The upper contact of the Trenton is an unconformity in the central and western parts of New York (see plates 2, 10-15) but is gradational in eastern New York.

The Paleogeologic Map

The data available in plates 1, 3, 4, and 5 permit the compilation of a paleogeologic map of New York at the end of the Early Ordovician. This map, plate 9, shows the surface distribution at that time of the bedrock formations that comprise the ancient carbonate shelf. It can be used to determine which rock unit probably will be encountered beneath the Knox unconformity and the proper nomenclature to be applied.

This map suggests that an initial mild doming of the Adirondack massif may have occurred at the end of the Early Ordovician. If the Cambrian and Lower Ordovician carbonates once covered all of the Adirondack and Lake Ontario areas, a not unreasonable assumption, they were nearly removed from these areas at this time. The overlying Black River group was deposited directly upon the Precambrian in the areas now beneath Lake Ontario and in Oswego, Lewis, and northern Oneida Counties, and for an unknown distance farther east into the Adirondack massif. This doming must have been mild for it seems that both the Black River and Trenton carbonates later covered the Adirondack area.

Plate 9 also indicates the exact location of five cross sections of the Cambrian and Ordovician carbonates. Section 1 passes around the southern margin of the Adirondack massif and is based almost entirely upon measured outcrops. It serves to establish many of the stratigraphic changes known to occur between the west and east sides of the Adirondacks. It indicates the changes that can be expected to occur in section 2, a parallel section utilizing principally subsurface data. However, these two sections really supplement each other, for while many more features of the rocks can be seen and studied on the outcrop than in well samples, the complete penetration of each rock formation in wells affords data not available from the incomplete surface outcrops.

Sections 1 thru 4 are roughly parallel and lie at various angles to the strike of the Early Paleozoic carbonate shelf. Generally, they display the stratigraphic changes that occur across the shelf. Sections 1 thru 3 lie more or less perpendicular to the axis of the Medial Ordovician miogeosyncline whereas section 4 is roughly parallel to that axis. Section 5 lies parallel to the carbonate shelf and at an acute angle to the axis of the miogeosyncline.

The Cross Sections

Five cross sections that display important stratigraphic and chronologic relationships among the Cambrian-Ordovician carbonate rocks are presented in plates 10 thru 15. These sections portray gamma-ray logs typical of these rocks in various parts of the State, give a generalization of the lithologies involved, and indicate the presence of several important unconformities. All sections have one major feature in common—the Lower-Middle Ordovician boundary; i.e., the Knox unconformity, is used as a datum. This separates the rocks of the carbonate shelf from those of the miogeosyncline. The one exception to these statements is the Chazy Group that appears only in section 1. It is placed below the datum although it is the oldest portion of the Middle Ordovician miogeosynclinal sequence.

The wells used in these cross sections were selected for their relatively complete penetration of the Cambrian-Ordovician carbonate sequence, the greater amount of lithological and electrical data available for them, and their spacing along the proposed section lines. The reader may question certain correlations made via the gamma-ray logs, but bear in mind that gamma-ray logs for all wells were studied, not just those utilized in these sections. Consequently, correlations in these cross sections are supported, in many cases, by the use of data from intermediate wells not included in the section.

A major facies change from Trenton limestones into black shales of equivalent age is shown in the correlation chart, plate 2, and in sections 1, 2, and 3. Section 1, based principally on measured fossiliferous outcrops, indicates that much of the central and higher portions of the Trenton Group grade eastwardly into the Canajoharie and Utica Shales. Each of these shales is subdivided into two biostratigraphic zones defined by graptolites. Similar facies changes shown in sections 2 and 3, based on subsurface data, are suggested by the lithologies involved and their stratigraphic positions. The presence of the graptolite zones in these sections is inferred from the outcrop because no biostratigraphic data is available from these wells.

Sections 1, 2, and 3 indicate that the Trenton limestone of eastern New York is a thin and shaly representative of the basal portion of the much thicker Trenton of central and western New York. In eastern New York and western New England the early Trenton is known as the Jacksonburg or Balmville Limestone. It also includes the Rysedorph Conglomerate, the Whipple Limestone member of the Wallomsac Shale, and carbonate beds often found at the base of the Ira and Hortonville shales. The Isle LaMotte, Larrabee, Orwell, and Amsterdam limestones of the Champlain and upper Hudson Valleys are correlated with the early Trenton. Sections 1, 2, and 3 also portray the eastward thinning and eventual pinchout of the underlying Black River Group which lacks any indication of a facies change from carbonates to terrigenous rocks. Unconformities occur both above and below the Black River beds. Loss of stratigraphic units along these unconformities occurs in several ways. Some of the basal portion of the Trenton Group appears to be missing in the Hirchy and Keith wells (section 2) and in the Richards well (section 3). The upper portion of the Black River Group is absent in the Consumers Gas well (section 2) and in the Glanford, Hooker, and Klotzbach wells (section 3). Lower Black River units are absent in the Consumers Gas and House wells (section 2) and the Glanford well (section 3). Both upper and lower Black River are missing along the pinchout of the group in eastcentral New York (sections 2 and 3).

Sections 2 and 3 show subdivisions of both the Trenton and Black River Groups that can be recognized in the subsurface via the patterns of the gamma-ray logs. These subdivisions do not correspond to the formally named members distinguished on the outcrop (section 1). Members of the Trenton Group defined in the outcrops are not easily distinguished there (Johnsen, 1971, p. 18) and are virtually impossible to recognize with confidence in the subsurface. The Trenton interval of low radioactivity between horizons M and N can be traced throughout New York and into adjacent regions. This interval appears to be younger than the Shoreham Limestone, probably equivalent to some portion of the Denmark. The abrupt decrease in radioactivity at horizon J is widespread and characteristic of the higher Trenton. Additional relationships between lettered or numbered points in the gamma-ray logs and members defined on the outcrop are suggested in plate 2.

Each of the sections 1, 2, and 3 is continued eastward into an important outcrop in eastern New York or western Vermont. This is particularly important for the rocks of the carbonate shelf. Section 1 includes the classic sequence at East Shoreham, Vermont, described by Brainerd and Seely (1890). The type area of the Stockbridge Group in western Massachusetts is placed at the end of section 2 (Zen and Hartshorn, 1966). The important exposures of the Wappinger Group, the equivalent of the Kittatiny Formation of New Jersey, in the Goshen quadrangle (Offield, 1967) are included in section 3. These and other measured outcrops along the New York-New England border permit estimates of the thickness and distribution of autochthonous Cambrian and Ordovician carbonates beneath the Taconic allochthone. This information and the meager data on depth to basement beneath the allochthone (Griscom and Bromery, 1968) permit crude estimates of the thickness of the allochthone in a few localities.

These sections illustrate the appearance of successively younger divisions of the Cambrian and Lower Ordovician across the carbonate shelf in a seaward direction. Sections 2 and 3 show that older subdivisions of the Potsdam-Galway appear at the base of the sequence in the same direction. In addition to the major unconformity with the Precambrian basement at the base of the sections, three younger breaks occur in the Beekmantown Group. Fossil occurrences given in section 1 permit an estimate of the position of the Cambrian-Ordovician boundary. The increase in thickness at the east ends of sections 2 and 3 suggests that rocks of Medial Cambrian age may be present there near the base of each section.

Owing to the great thickness of shelf rocks at the southern end of section 4, it was necessary to draft this section in two parts, plates 13 and 14. However, these are drawn at the same scale and can be fitted together along the datum plane at the Knox unconformity, should the reader desire. The section is carried south into the important outcrops near Bellefonte, Pennsylvania, described by Kay (1944), Thompson (1967), Rones (1969), Spelman (1966) and Lees (1967).

Section 4, Part I, is nearly parallel to the axis of the Middle Ordovician miogeosyncline and illustrates a southward thickening of the Trenton and Black River Groups into central Pennsylvania. Continuity of subdivisions based upon the patterns of the gamma-ray logs is especially well illustrated. The upper boundary of the Trenton Group with the overlying Utica Shale is unconformable; higher divisions of the Trenton are missing in the Olin well and in Pennsylvania. The Black River-Trenton also is unconformable in the northern portion of the section as shown by the absence of higher units of the Black River Group.

Rocks of the carbonate shelf thicken very rapidly southward across the shelf along section 4, part II. Progressively older units appear above the basal unconformity and younger units beneath the Knox unconformity at the top. Subdivision of the Potsdam-Galway via gamma-ray patterns is illustrated. Rocks of Early and Medial Cambrian age (Rome and Pleasant Hill Formations) are present in the Pa. Tract 129 well in Potter County, Pa. Interpreted relations with the Olin well, Steuben County, N.Y., suggest that this well may have penetrated a basal sandstone of Medial Cambrian age. The appearance of the Warrior Formation between the Galway and Potsdam (Gatesburg and Pleasant Hill) in both wells should be noted. Also significant is the presence of a thick sandstone at the top of the Galway in the McClurg, Kennedy, and Olin wells. This sandstone occurs throughout much of southwestern New York (see figure 3). The high radioactivity peak characteristic of the base of the Little Falls contrasts strongly with the low and flat pattern shown by the Galway sandstone beneath.

Section 5 shows many of the same features described for the preceding sections—subdivisions based on gamma-ray log patterns; various unconformities causing loss of beds from the Trenton and/or Black River Groups; sandstone at the top of the Galway (Gatesburg); maximum thickness of the Middle Ordovician carbonates in central New York; thickening of carbonate shelf rocks southwestwardly away from the Adirondacks. Section 5 includes a correlation into the type area of the Trenton and Black River Groups, specifically the outcrop at Lowville, N.Y. The greatly reduced representation of the Trenton in the Kardosh well to the southwest should be noted.

Although there is general agreement between Calvert, Wagner, and myself on the recognition and correlation of the major units (groups), certain points of disagreement should be mentioned and discussed. Contrary to Calvert (1963b, plate 1), I do not believe there are any rocks of Chazy age or group in the Kardosh well, section 5. The beds so called by Calvert lithically are identical to the basal portion of the Black River Group as seen in many wells in New York and Ontario. Their gamma-ray log pattern is identical to that of the basal Black River and bears no resemblance to that of the Chazy. The writer agrees with Calvert that the base of the Trenton is about 6,343 feet in the Kardosh well. Wagner (1966, plates 6, 7), however, includes much of the upper Black River in his Trenton, placing the base of the Trenton near 6,450 feet.

Wagner (op. cit.) frequently correlates the high radioactivity peak at the base of the Black River with the upper Bellefonte. This seems to be erroneous because of the great difference in the ages of these units. The presence of this peak everywhere, regardless of what the underlying unit may be, clearly indicates that these beds belong with the Black River and not to the Early Ordovician or Cambrian. It would appear that Wagner has misplaced the Knox unconformity in the Kardosh well, the Olin well and several others.

Regarding the pre-Knox unconformity units of the Kardosh well, I see no justification for the recognition of anything other than Late Cambrian rocks—the Potsdam (Mt. Simon), Galway (Gatesburg), and Little Falls (Mines). The correlation into the Kardosh well via section 5 is quite firm. I doubt Calvert's correlation of the shaly beds at 7,400 feet with the Conasauga Shale and his correlation of the beds below with the Rome and Shady dolostones. Wagner (1966, plates 2, 3) refers to the beds at 7,400 feet as the lower sandy member of the Gatesburg. I agree that it is Gatesburg but I do not agree with him that this is the base of that formation nor that the beds below should be referred to the Warrior. We do agree, however, on the presence of the Mines dolostone around 6,900 although the contacts are drawn differently.

I believe that Wagner (1966, plates 1, 2) made a major *miscorrelation* into the *Olin well. His lower sandy member* of the Gatesburg between 11,770 and 12,050 feet really is his upper sandy, the sandstone at the top of the Galway or Gatesburg. The lower portion of his Little Falls is correctly identified, but the New York wells clearly show that this Little Falls passes above his upper sandy, not into it. Wagner's lower sandy member really occurs around 12,300 in the Olin well at the same gamma-ray peak as in the Kardosh well. In the Olin well the upper portion of Wagner's Little Falls is correlated by me with the Tribes Hill (Larke).

Figure 4 is a simple diagram illustrating the distribution of some lithologic features of the Cambrian and Lower Ordovician carbonates. It indicates that quartzose sandstones and oolites are rare in the Ordovician, very common in the Cambrian. Chert occurs commonly in the Ordovician but is abundant only in the higher portion of the Cambrian. Limestone, while always rare, has not been noted below the base of the Little Falls.

The Structure Contour Maps

Although the lack of control wells in several areas results in a more generalized map than one might anticipate for these rocks, the structure contour maps do indicate several features of interest and suggest the presence of others. Plates 16 and 17 display structure contours on the top of the Trenton and the top of the Cambrian-Lower Ordovician (Knox unconformity) where the maximum amount of data for these relatively deep rocks are available. Plate 18 displays a similar map for the Precambrian basement.

The primary feature shown on these maps is a regional southward dip varying from a minimum of 70 feet per mile in western New York to nearly 400 feet per mile in parts of eastern New York. There is little doubt of the existence of the Clarendon-Linden fault in Orleans, Genesee, and Wyoming Counties. The presence of a graben *in* southern Herkimer County also seems certain. The remaining faults shown in the subsurface are not firmly established and may be only a small percentage of the actual number present. It is my opinion that these carbonates may have experienced block faulting, similar to that known in the Mohawk Valley, throughout the eastern half of the State. Present control data is not sufficiently dense to delineate such faulting. That shown for the subsurface in Otsego, Schoharie, Montgomery, Schenectady, and Saratoga Counties is largely a continuation southward of the known structures of the Mohawk Valley. Previously unsuspected faulting is suggested by offset elevations in Ontario and Cayuga Counties.

The structure contours on the Precambrian basement, plate 18, are thought to be somewhat better estimates than those made on previous maps. These contours were drafted using not only all wells that penetrated the Precambrian, but also an addition of the isopachs of the Sauk Sequence, plate 6, to the structure contours of the Knox unconformity, plate 17, thereby making use of the greater control available at the higher horizon.

Several important structures are shown in plates 17 and 18—the Neelytown anticline and Marlboro syncline in southeastern New York. The delineation of these structures is primarily the result of recent mapping in this area and a better understanding of the age and structural position of the Normanskill Formation. Four cross sections, figure 5, illustrate these structures and their relationships to other geologic features of southeastern New York.

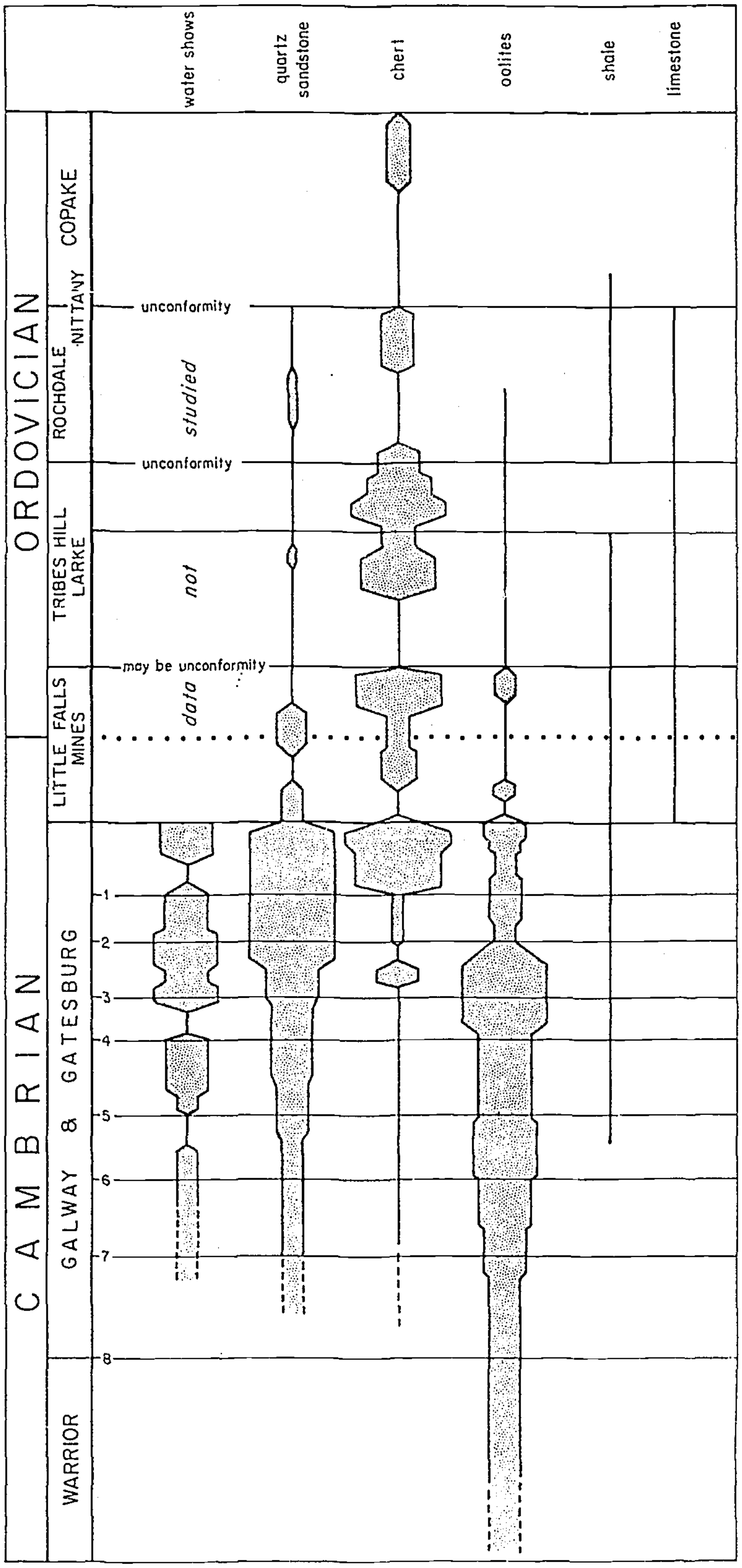

Figure 4. Distribution of some lithologic features.

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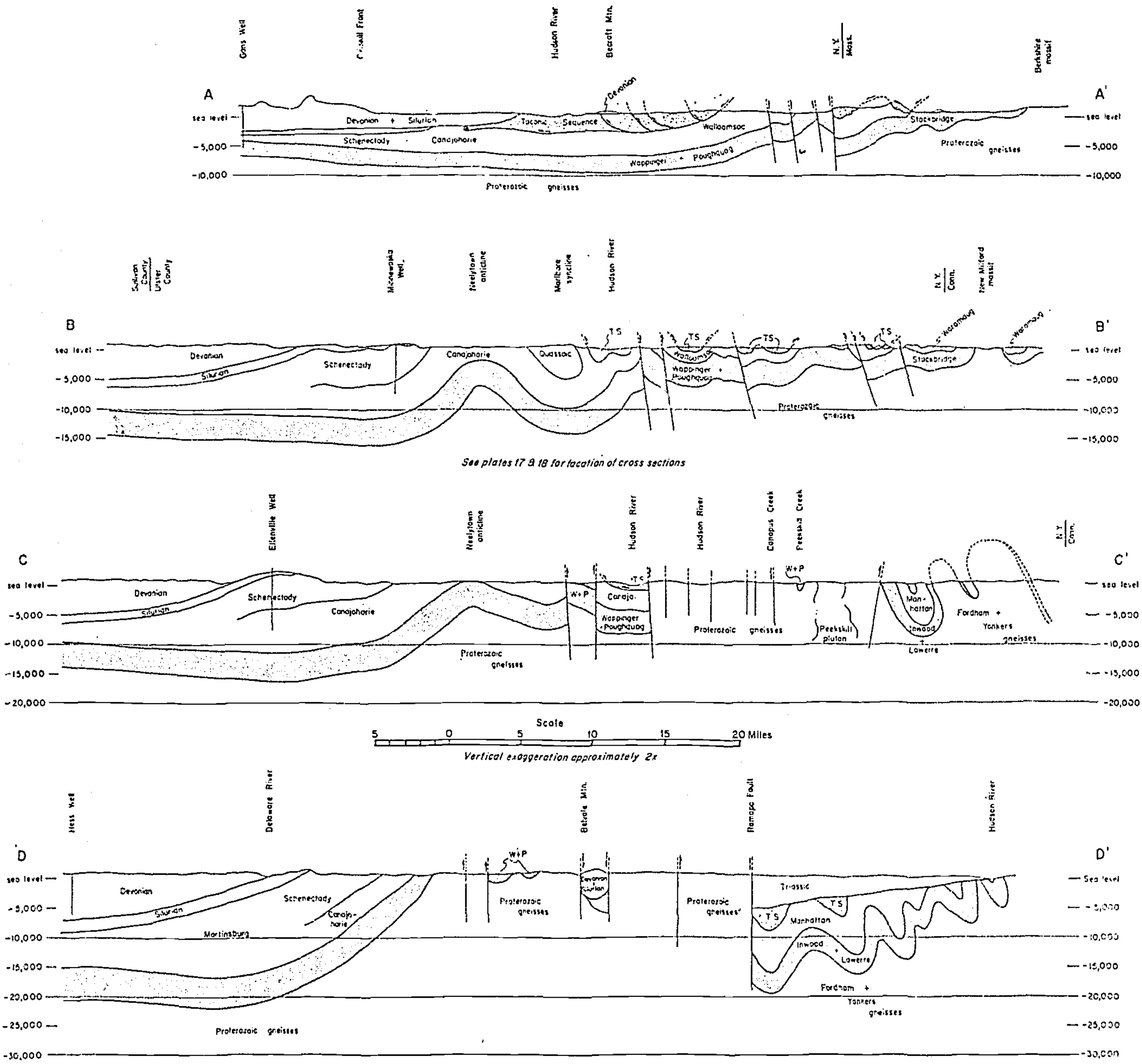

Figure 5. Structural cross sections, southeastern New York.

The St. Lawrence Cross Section

Plate 19 presents a cross section extending from the Hirchy well, Prince Edward County, Ontario, northeastward down the St. Lawrence River Valley to Quebec City, Quebec. Despite two long steps of approximately 100 miles each between Kingston, Ottawa, and Montreal, correlations along this cross section are reasonably clear and firm. It is apparent that the Simcoe Group of southwestern Ontario is equivalent to the Ottawa Limestone of eastern Ontario and the combined Black River and Trenton at Montreal, southern Quebec. The Ottawa sequence does not differ greatly from those at Kingston or in the Hirchy well. But at Montreal most of the Black River is missing and the group pinches out half way to Quebec City. Both upper and lower contacts of the Black River Group are unconformable. At Montreal the upper portion of the Trenton (Tetreauville) contains much shale and, traced to the northeast, this portion loses all limestone and becomes the lower portion of the Utica Shale. The Tetreauville rests unconformably upon the middle and lower Trenton, portions of which are missing in some wells in Yamaska and Nicolet Counties, Quebec. Basal Trenton limestone beds also pinch out to the northeast. At Montreal the Trenton rests unconformably upon the Black River Group. To the northeast it may overlie the Chazy Group but certainly overlies the Potsdam and eventually the Precambrian at Quebec City.

Major unconformities occur both above and below the Chazy Group, but which of these might be identified as the widespread "Knox unconformity" is in doubt, probably the latter. In any event, the Chazy disappears both to the southwest and northeast along this section. It overlies dolostones of the Beekmantown Group in all wells investigated in this study but conceivably could rest upon the Potsdam south of Quebec City. The Beekmantown and Potsdam exhibit a lateral facies relationship; at both ends of this cross section the Potsdam probably is latest Cambrian in age.

Economic Aspects

Owing to their greater depths, the subsurface Cambrian and Ordovician carbonates remain relatively unknown and untested for commercial oil and gas deposits. Throughout much of the southern half of New York State there are no wells penetrating these rocks—the average is about one or two wells per county. Probably several hundred more wells must be drilled before the area will be adequately known and its economic potential assessed. At present there is no oil production from these rocks but gas has been obtained from nearly all known formations or groups. Activity by major petroleum companies has increased in recent years, stimulated mainly by the increased consumption and higher price of gas in the northeastern United States.

The most obvious intervals for exploration include (1) the post-unconformity shales, siltstones, and sandstones of the basal portion of the Black River Group, (2) the pre-unconformity sandstone at the top of the Galway-Gatesburg, reported to be very poorly cemented in some wells, and (3) the basal sandstones; i.e., the Potsdam. Other possibilities include (4) various sandstones of lesser thickness and extent in the Little Falls and Galway, and (5) fracture zones in these carbonates developed in the vicinity of faults. Original porosity and permeability in these carbonates does not seem to have been high but they have been improved where dolomitization or fracturing have occurred.

The number of structures, potential traps for oil or gas, known to occur in the subsurface Cambrian-Ordovician carbonates, is few. Consideration of the geologic history of these rocks suggests that there are many undetected faults, perhaps also folds or domes. Delineation of such structures is dependent upon a knowledge of the stratigraphy of these carbonates. This report, it is hoped, will provide many of the essential stratigraphic details.

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Appendix A

Identification of Control Wells

New York State

Well	County	Township	Operator	Lease	NYSGS File
1	Orange	Wawayanda	Crom Wells Inc.	Fee (High Barney)	1001
2	Greene	Windham	United Prod.	Gans	3904
3	Albany	Guilderland	——	Altamont	1071
4	Warren	Queensbury	Imperial Paper	Imperial Paper	2636
5	Delaware	Hamden	Gulf Oil Corp.	Campbell	4214
6	Delaware	Roxbury	Gulf Oil Corp.	Lanzilotta	4379
7	Delaware	Sidney	Gulf Oil Corp.	Finch	4364
8	Delaware	Franklin	Gulf Oil Corp.	Leslie	4455
9	Otsego	Maryland	N.Y.S. Nat. Gas	Burkard	4547
10	Otsego	Worcester	N.Y.S. Nat. Gas	Lum	4055
11	Herkimer	Warren	Benedum et al.	Skranko	3993
12	Herkimer	Stark	Devonian Gas	Puskeranko	4034
13	Broome	Triangle	Felix & Scisson	Richards	5087
14	Chenango	Columbus	Bradley Prod.	Lobdell	1160
15	Madison	Lebanon	N.Y.S. Nat. Gas	Branagan	3970
16	Madison	Brookfield	N.Y.S. Nat. Gas	Danisevich	4032
17	Madison	Brookfield	N.Y.S. Nat. Gas	Letts-Miller	1173
18	Oneida	Sangerfield	N.Y.S. Nat. Gas	Keith	3928
19	Oneida	Verona	Cady	Ainsworth	698
20	Lewis	Highmarket	Humble Oil	Gould	4150
21	Lewis	Martinsburg	Tug Hill Nat. Gas	Finn	828
22	Cortland	Freetown	Gulf Oil Corp.	Clough	4714
23	Oswego	Hastings	Humble Oil	E. House	4208
24	Oswego	Palermo	Humble Oil	Heaphy	4209
25	Oswego	Oswego	Duchscherer	E. S. Hall	5012
26	Oswego	Scriba	Tower et al.	Beckwith	1008
27	Oswego	Richland	Scully et al.	Nicholson	4520
28	Oswego	Williams	Humble Oil	Kellogg	4357
29	Oswego	Sandy Creek	Reserve Gas	Fee	4201
30	Jefferson	Brownville	Dexter Village	Dexter Water	2289
31	Chemung	Van Etten	N.Y.S. Nat. Gas	Kesselring	443
32	Tompkins	Danby	N.Y.S. Nat. Gas	Sheperd	3973
33	Tompkins	Newfield	N.Y.S. Nat. Gas	Fee (Richardson)	4467
34	Tompkins	Enfield	N.Y.S. Nat. Gas	Grund	4130
35	Cayuga	Ledyard	Reserve Oil	Mahaney	478
36	Cayuga	Aurelius	Midwest Oil	Alnutt	4715
37	Cayuga	Brutus	Duchscherer	Parker	4999
38	Cayuga	Cato	Duchscherer	Ripley	5000
39	Cayuga	Cato	Mustang	House	5467
40	Cayuga	Conquest	Midas Gas Co.	Slayton	1003

Well	County	Township	Operator	Lease	NYSGS File
41	Cayuga	Cato	Duchscherer	O'Neill	5011
42	Cayuga	Victory	Duchscherer	L. W. Smith	5031
43	Cayuga	Ira	Humble Oil	Wasielewski	4624
44	Seneca	Fayette	United Prod.	Schaffer #2	4203
45	Seneca	Junius	Duchscherer	G. N. Reed	5095
46	Steuben	Woodhull	N.Y.S. Nat. Gas	Olin	3924
47	Ontario	Gorham	Hoover	Frankish	6395
48	Ontario	Farmington	Hammerstone	Wyman	4760
49	Ontario	Farmington	Strudwick et al.	Bowermann	4871
50	Wayne	Galen	Union Oil Calif.	Martin	6719
51	Wayne	Galen	Duchscherer	Kaiser	5032
52	Wayne	Butler	Duchscherer	O. & T. Reed	5041
53	Wayne	Lyons	Duchscherer	Olson	5114
54	Wayne	Arcadia	Duchscherer	Hammond	5116
55	Wayne	Macedon	Hammerstone	F. Smith	4754
56	Allegany	Hume	Parsons Bros.	Cook #2	3956
57	Allegany	Hume	N.Y.S. Nat. Gas	Wolfer	4248
58	Livingston	Sparta	Blair & Weaver	Kennedy	4630
59	Livingston	York	N.Y.S. Nat. Gas	McClurg	4552
60	Livingston	York	N.Y.S. Nat. Gas	McDonald	4069
61	Livingston	Caledonia	N.Y.S. Nat. Gas	Johnson	4567
62	Monroe	Sweden	Hammerstone	Yantz	4724
63	Monroe	Hamlin	Weaver Expl.	Hazen	4502
64	Wyoming	Arcade	K. R. Wilson	Arcade	615
65	Wyoming	Gainesville	N.Y.S. Nat. Gas	Veith	4092
66	Wyoming	Orangeville	N.Y.S. Nat. Gas	Werner	(none)
67	Wyoming	Warsaw	Flanigan Bros.	Fisher	6073
68	Wyoming	Middlebury	Trans. Amer. Petr.	Strathearn	4133
69	Wyoming	Middlebury	Trans. Amer. Petr.	Warren	4447
70	Wyoming	Middlebury	Trans. Amer. Petr.	Wellman	4436
71	Wyoming	Middlebury	Trans. Amer. Petr.	Page	4536
72	Wyoming	Middlebury	Trans. Amer. Petr.	Cox	4464
73	Genesee	Byron	Blair & Weaver	Tyler	4593
74	Genesee	Byron	Ashland	Naylor	4806
75	Genesee	Alabama	Duchscherer	Klotzbach	5117
76	Genesee	Alabama	Duchscherer	Brundage	5115
77	Orleans	Barre	Hammerstone	Daum	4730
78	Orleans	Barre	Humble Oil	Kelley	4611
79	Orleans	Shelby	Duchscherer	Domoy	5096
80	Orleans	Shelby	Hammerstone	D. R. Cook	4722
81	Orleans	Ridgeway	Duchscherer	Thaxter	5008
82	Orleans	Kendall	Duchscherer	Stevens	5086
83	Orleans	Kendall	Duchscherer	Herman	4994
84	Orleans	Kendall	Duchscherer	Nowak	5069
85	Orleans	Gaines	Duchscherer	Malone	4912
86	Orleans	Carlton	Duchscherer	Helfer	5007
87	Orleans	Carlton	Weaver Expl.	Brakenbury	4476

Well	County	Township	Operator	Lease	NYSGS File
88	Orleans	Gaines	Duchscherer	Woolston	5091
89	Orleans	Yates	Duchscherer	Morrison	4764
90	Orleans	Carlton	Duchscherer	Green	4873
91	Orleans	Yates	Weaver Expl.	Foss	4489
92	Orleans	Yates	Duchscherer	Searles	4752
93	Orleans	Yates	Duchscherer	Weil	4753
94	Cattaraugus	Perrysburg	Iroquois Gas	Ellis	3868
95	Chautauqua	Harmony	Univ. Delta	Morse #1	3200
96	Chautauqua	Ellery	Pennzoil	Harrington	4437
97	Chautauqua	Ellery	Minard Run Oil	Gage	4561
98	Chautauqua	Cherry Creek	Humble Oil	Shadle	4154
99	Chautauqua	Sheridan	Appal. Basin Oil	Sommers-Tuttle	4460
100	Erie	Sardinia	Iroquois Gas	La Scala	4440
101	Erie	Hamburg	Bethlehem Steel	68-D2	6668
102	Erie	Tonawanda	——	Weinheimer #2	3917
103	Niagara	Royalton	FMC Corp.	68-D1	6667
104	Niagara	Niagara Falls	Hooker Chemical	68-D3	6669
105	Niagara	Somerset	Hammerstone	Wolfe	4719

Pennsylvania

Well	County	Township	Operator	Lease
1	Potter	Stewardson	Consolidated N-972	Pa. Tr. 129
2	Warren	Limestone	Biery & Johnson	Shaw
3	Crawford	Summerhill	Benedum	Kardosh
4	Crawford	Bloomfield	Garrett	Morton
5	Crawford	Rockdale	Garrett	Marzka
6	Erie	Washington	Allegheny Inc.	Ethridge
7	Erie	Conneaut	McConnell	Borst
8	Erie	offshore	N.Y.S. Nat. Gas	Block 2, No. 1
9	Erie	offshore	N.Y.S. Nat. Gas	Block 1, No. 1

Ontario

Well	County	Township	Operator	Lease
1	Prince Edward	Marysburgh S	Putman et al.	Hirchy
2	Prince Edward	Athol	Consumers Gas	Consumers #11945
3	Prince Edward	Ameliasburgh	Consumers Gas	Consumers #11943
4	Durham	Hope	Gallagher	Beebe
5	Peel	Chinguacousy	M & M Oil	Lyons
6	Wellington	Puslinch	Birchfield	Telfer
7	Lincoln	Grantham	——	Grantham No. 3-3
8	Welland	Crowland	Crowland Gas	Pearson #2
9	Haldimand	Sherbrooke	——	ERCO #2
10	Wentworth	Glanford	——	Glanford No. 9-3
11	Brant	Brantford	Herkules et al.	Brantford 4-3
12	Norfolk	Windham	Vanderburg #6	Barnard #2
13	Russell	Russell	Consumers Gas	Consumers #16308

Quebec

Well	County	Parish	Operator	Lease
1	Vercheres	Vercheres	Imperial Oil	Imp-Low 1 Vercheres
2	L'Assumption	L'Assumption	L'Assumption O & G	Louvicourt-Metal 8
3	Berthier	——	Bald Mtn. Oil	Berthierville 1
4	Yamaska	——	Laduboro Oil	LaBaie 5
5	Nicolet	——	Imperial Oil	Imp-Low 2
6	Champlain	St. François	Bald Mtn. Oil	Batiscan 2
7	Lotbiniere	St. Louis	Imperial Oil	Imp-Low 4 Lotbiniere

Appendix B

Subsurface Data From Control Wells

Keys:
- G = gamma ray log
- S = lithic sample log
- Data expressed in feet
- F = fault in or near Trenton
- NR = not reached
- ABS = absent
- NI = not identified
- KB = Kelly bushing
- DF = derrick floor
- GL = ground level

New York State

Well	Log	Elevation	Trenton	Black River	Beekman-town	Little Falls	Galway	Potsdam	Pre-Cambrian	Total Depth
1	G S	600 est.	F	ABS	4900	5530	5800	NR		6470
2	G S	1928 GL	6029	ABS	6055	6400	6610	NR		7185
3	S	510	2965	ABS?	3012					3012
4	S	265 GL			19	330	555	880	NR	1012
5	G S	1785 KB	8237	8290	8300	9180	9445	10850	10965	
6	G S	1830 GL	ABS	ABS	6770	7265	7505	8790	8920	
7	G S	1668	7340	7450	7463	NR				7962
8	G S	1486 GL	6125	6175	6197	6755	7022	7823	7878	
9	G S	1252 GL	4340	4355	4385	4690	4965	NR		5126
10	G S	1979 GL	4264	4280	4305	4645	4925	5295	5362	
11	G S	1515 GL	F	3067	3105	3258	3555	NR		3581
12	G S	1590 GL	1750	2115	2130	2260	2555	NR		2716
13	G S	996 GL	7668	7907	8167	8815	9090	NR		9640
14	G S	1373 DF	4280	4500	4555	4710	5000	5476	5548	
15	G S	1549 DF	4492	4695	4847	4900	5210	5631	5661	
16	G S	1506 GL	3915	4128	4200	4273	4555	NR		4889
17	G S	1255 DF	3080	3423	ABS	3535	3755	4155	4162	
18	G S	1319 GL	3190	3545	ABS	3635	3887	4297	4316	
19	S	430 GL	1507	1976	ABS	ABS	2154	2372	2405	
20	G S	1788 DF	1054	1560	ABS	ABS	ABS	ABS	1766	
21	S	1752 GL	716	1262	ABS	ABS	ABS	ABS	1473	
22	G S	1569 GL	6920	7157	7420	7765	8040	NR		8272
23	G S	504 DF	1482	2006	ABS	ABS	ABS	ABS	2196	
24	G S	465 DF	1614	2237	ABS	ABS	ABS	ABS	2560	
25	G S	318 DF	1431	2106	ABS	ABS	ABS	2461	2505	
26	S	385 GL	1316	1976	ABS	ABS	ABS	2297	2317	
27	G	307 DF	632	1247	ABS	ABS	ABS	ABS	1517	
28	G S	745 DF	841	1425	ABS	ABS	ABS	ABS	1660	
29	S	421 DF	458	1050	ABS	ABS	ABS	ABS	1324	
30	S	340 GL		14	ABS	ABS	ABS	ABS	260	
31	G S	1081 DF	8899	9342	9810	10567	10915	NR		11145
32	G S	1295 DF	7767	8223	8617	9095	9388	10250	10278	
33	G S	1051 DF	7346	7820	8270	8720	9004	NR		9390
34	G S	1454 GL	7300	7750	8175	8495	8785	NR		8903

Well	Log	Elevation	Trenton	Black River	Beekman-town	Little Falls	Galway	Potsdam	Pre-Cambrian	Total Depth
35	S	824 GL	5055	5635	ABS	6045	NR			6156
36	G	515 DF	3252	4023	ABS	4444	4502	NR		4853
37	G S	589 DF	3110	3790	ABS	4168	4192	NR		4260
38	G S	435 DF	2555	3246	ABS	ABS	3626	NR		3756
39	S	452 GL	2621	3290	NR					3372
40	S	476 GL	2492	3220	ABS	ABS	3590	3760	3865	
41	G	404 KB	2328	3012	ABS	ABS	3376	NI	3570	
42	G S	441	2254	2927	ABS	ABS	ABS	3300	NR	3402
43	G S	447 GL	1922	2592	ABS	ABS	ABS	2948	3026	
44	G S	542 DF	3553	4368	ABS	4820	4883	5340	5409	
45	G	401 GL	2857	3620	ABS	ABS	3979	NR		4152
46	G S	1645 DF	9675	10315	10870	11405	11751	13065	NR	13500
47	G S	1080 GL	4283	5040	ABS	ABS	5515	5960	NR	6000
48	G S	597 GL	2955	3687	ABS	ABS	4110	NR		4305
49	G S	556 GL	2813	3503	ABS	ABS	3915	ABS	4210	
50	S	392 GL	2775	3525	ABS	ABS	3825	3962	NR	4050
51	G S	483 DF	2745	3495	ABS	ABS	3905	NR		3918
52	G S	433 DF	2348	3068	ABS	ABS	3435	3660	NR	3681
53	G S	487 GL	2485	3205	ABS	ABS	ABS	3615	3705	
54	G S	587 GL	2433	3163	ABS	ABS	3565	3662	NR	3750
55	G S	497	2500	3187	ABS	ABS	3585	NR		3641
56	G S	1672 DF	6110	6650	ABS	7103	7220	NR		7337
57	G S	1572 GL	5895	6450	ABS	6900	7015	NR		7560
58	G S	584 GL	4483	5083	ABS	5528	5623	6295	NR	6385
59	G S	986 DF	3856	4478	ABS	ABS	4880	5460	5560	
60	G S	881 GL	3573	4206	ABS	ABS	4600	NR		5090
61	G	795 DF	3200	3856	ABS	ABS	4243	4677	4740	
62	G S	644 GL	2105	2797	ABS	ABS	3137	NR		3274
63	G S	309 GL	1152	1873	ABS	ABS	ABS	2163	2178	
64	S	1483 DF	5340	5900	ABS	6195	6325	6968	NR	7144
65	G S	1573 KB	5310	5850	ABS	6260	6345	7020	NR	7182
66	S	1609 DF	4700	5263	ABS	ABS	5568	NR		5722
67	G S	1504 DF	4540	5110	ABS	ABS	5525	NR		5718
68	G	1524 DF	4258	4862	ABS	ABS	5251	NR		5500
69	G	1559 DF	4355	4960	ABS	ABS	5362	NR		5650
70	G	1605 GL	4330	4928	ABS	ABS	5315	NR		5597
71	G	1508 KB	4200	4800	ABS	ABS	5197	5705	5790	
72	G	1166 DF	3864	4457	ABS	ABS	4850	5295	5375	
73	G S	712 DF	2460	3137	ABS	ABS	3520	3763	3813	
74	S	666 GL	2143	2788	ABS	ABS	3157	3357	NR	3410
75	G	862 GL	2713	3282	ABS	ABS	3553	3787	3857	
76	G	733 DF	2460	3047	ABS	ABS	3320	3517	NR	3600
77	G S	681 GL	2163	2782	ABS	ABS	3055	NR		3172
78	G S	658 DF	2007	2615	ABS	ABS	2880	2967	3020	
79	G S	630 GL	2122	2712	ABS	ABS	2965	3015	3105	

Well	Log	Elevation	Trenton	Black River	Beekman-town	Little Falls	Galway	Potsdam	Pre-Cambrian	Total Depth
80	G S	612 GL	2013	2610	ABS	ABS	2847	2875	2980	
81	G	501 GL	1746	2352	ABS	ABS	2604	NI		2664
82	G	375 GL	1470	2115	ABS	ABS	ABS	2380	2440	
83	G S	316 GL	1261	1895	ABS	ABS	ABS	2148	2197	
84	G S	354 GL	1382	2013	ABS	ABS	ABS	2263	2308	
85	G S	434 GL	1562	2186	ABS	ABS	ABS	2435	2518	
86	G S	297 GL	1216	1842	ABS	ABS	ABS	ABS	2085	
87	G S	359 GL	1331	1953	ABS	ABS	ABS	ABS	2193	
88	G S	364 GL	1398	2010	ABS	ABS	ABS	2252	2340	
89	G S	335 DF	1310	1920	ABS	ABS	ABS	2160	2185	
90	G S	277 GL	1135	1760	ABS	ABS	ABS	ABS	1985	
91	G S	315 GL	1232	1830	ABS	ABS	ABS	ABS	2045	
92	G S	350 GL	1383	1960	ABS	ABS	ABS	2177	2208	
93	G S	319 GL	1198	1783	ABS	ABS	ABS	ABS	1995	
94	G S	1328 GL	4850	5362	ABS	ABS	5621	6280	6460	
95	G S	1572 DF	6155	6625	ABS	6945	7045	NR		7100
96	G S	1760 GL	5968	6463	ABS	6758	6850	7600	NR	7692
97	G S	1524 GL	5460	5950	ABS	6222	6274	NR		6292
98	G S	1617 DF	5430	5935	ABS	6192	6250	NR		6281
99	G S	614 DF	3665	4170	ABS	ABS	4410	NR		4460
100	G S	1410 GL	5004	5583	ABS	ABS	5850	NR		5913
101	G S	583 GL	2994	3590	ABS	ABS	3794	4131	4251	
102	G S	583 DF	2418	2935	ABS	ABS	3165	NR		3168
103	G	549 DF	1845	2425	ABS	ABS	2660	NI	2765	
104	G S	579 DF	2107	2625	ABS	ABS	2835	2935	3026	
105	G S	329 GL	1250	1815	ABS	ABS	ABS	ABS	1994	

Pennsylvania

Well	Log	Elevation	Trenton	Black River	Beekman-town	Little Falls	Galway	Potsdam	Pre-Cambrian	Total Depth
1	G S	1867 DF	13430	14105	14714	15975	16285	NI		
2	G S	1708 DF	8300	8530	8985	9050	9385	NR		9410
3	G S	1337 DF	6215	6343	ABS	6840	6950	7820	7913	
4	S	1640 GL	6600	NI	ABS	7325	7420	NR		7450
5	S	1443 KB	6330	6700	ABS	7058	7163	NR		7200
6	S	1413 DF	5870	6320	ABS	6630	6675	NR		6840
7	S	965 DF	5220	5520	ABS	ABS	5888	NR		5935
8	G S	604 DF	3970	4430	ABS	ABS	4705	NR		4741
9	S	602 DF	4290	4700	ABS	ABS	5055	NR		5098

Ontario

Well	Log	Elevation	Trenton	Black River	Beekman-town	Little Falls	Galway	Potsdam	Pre-Cambrian	Total Depth
1	G S	254	0	500	ABS	ABS	ABS	ABS	875	
2	G	324 KB	0	542	ABS	ABS	ABS	ABS	899	
3	G	346 KB	0	385	ABS	ABS	ABS	ABS	605	
4	G S	472	<200	633	ABS	ABS	ABS	ABS	800	
5	G S	822	1070	1655	ABS	ABS	ABS	ABS	1725	
6	G S	1033	1650	2240	ABS	ABS	ABS	ABS	2320	
7	G S	307	1465	1960	ABS	ABS	ABS	2150	2215	
8	G S	617	2345	NI	ABS	ABS	ABS	3050	3215	
9	G S	589	2520	3040	ABS	ABS	ABS	3225	3555	
10	G S	714	1855	2365	ABS	ABS	ABS	ABS	2540	
11	G S	754	2150	2665	ABS	ABS	ABS	2860	2895	
12	G S	718	2510	3015	ABS	ABS	ABS	3220	3380	
13	G	239	655	1150*	1685			2020	2605	

* Chazy 1470

Quebec

Well	Log	Elevation	Trenton	Black River	Chazy	Beekman-town	Potsdam	Pre-Cambrian	Total Depth
1	G	62 DF	1600	2345	2470	2875			3065
2	G	57 DF	735	1455	1550	1900	2555	NR	2614
3	G	——	1420	2180	2278	NR			2532
4	G	——	2625	3060	3140	3405	3808	4400	
5	G	——	2645	3170	3245	3605	3910	NR	4110
6	G	——	2105	ABS	ABS	2740	2820	3270	
7	G	213 DF	1138	ABS	ABS	ABS	1755	1820	