# Potential Plays in Eastern New York; A New Evaluation to Identify Exploration Fairways

or

Frontier Basin Geologic Investigation For Hydrocarbons:
Emphasis on Capital-Saratoga Region of Eastern New York

Prepared and Presented to the Independent Oil & Gas Association of New York (IOGANY)

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by

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## Executive Summary

Although the western regions of New York State has established commercial production of hydrocarbons, the eastern half has not. On the other hand, there is evidence to prove that some home owners and small businesses in eastern New York have been enterprising enough to use natural gas, from wells originally drilled for water, as a source of fuel for periods in excess of twenty years; some of those wells continue to produce this very day. The geologic community has known for a nearly a century that the geologic history in eastern New York includes the deposition of source rocks and sediments equivalent in age to the commercially producing units of the west, but also recognize that the east has factors that some researchers view as highly negative with respect to the thermal and trapping history of hydrocarbons. Not withstanding these negative aspects, this present study, funded mainly by NYSERDA, has uncovered reasons why hope is still alive for exploration drilling that may lead to discovery of commercial reserves of natural gas in eastern New York. Relatively few deep tests have been drilled in the region, leaving vast volumes of geologic section ripe for exploration.

The findings of this study were presented and discussed in a preliminary format to attendees of the Independent Oil & Gas Association of New York (IOGANY) on July 9 and 10, 1997 meeting at Clymer, New York. The main targets are in the lower Upper Ordovician sandstone and siltstone units, with secondary targets in Pre-Cambrian granite wash, and in the Cambrian (Potsdam). Silurian and Devonian formations are also prospective, but receive only cursory treatment in this report.

Based upon the numerous gas shows and our exploration concepts, it is our professional opinion that probable, possible, and speculative reserve potentials (per field) range from a low, one-well field of 310 mmcfg, to a high of 31 Bcfg for a 50-100 well field, and speculative potential in granite wash and other units is 150 Bcfg.

Although in some respects the term "proven" could be used to describe the gas used by homeowners, we will not use the term because of the lack of the standard and customary flow tests and reservoir delineations that are expected to accompany and quantify the determination and pronouncement of such accumulations. We therefore consider reserve potential for prospects at these homeowner wells as "probable". The term "possible" as defined by the Potential Gas Committee, is the most appropriate qualitative term for the majority of the reserve potential; the geographic area of our study is an extension of a producing basin, and the prospective formations are equivalent to the producing trends in the western areas of the basin. For some of the prospective section, we believe the potential is speculative; 1) for those areas east of the Adirondack arch that are nearing the metamorphosed terrain of the Taconics, and 2) for the fractured Precambrian and granite wash prospects, for which we are not aware of a western basin equivalent.

The exploration concepts described in this report are not complicated; the decades old ideas are simply adapted to this eastern New York fairway. The potential reservoirs include structural traps (fault traps mainly), stratigraphic (pinch outs and unconformity) traps, combination structural/stratigraphic traps, and late-stage migration fractured shale reservoirs (See Appendix B figures). The evidence to date suggests that the sandstone/siltstone reservoirs will be relatively thin (less than fifty feet thick in the main) but potentially areally extensive. Reservoir pressures and per well recovery, on average, are likely to be somewhat lower than in western areas of the state, but the depth to many of these marginal "homeowner" reservoirs, and to the potential larger reservoirs, is

so shallow (100 to 500 feet below grade), that development costs could be low enough to justify such an effort. There are deeper targets in portions of the main focus area to about 5000 feet below the surface.

The screening mechanisms of this study, that included some field reconnaissance, winnowed the number of counties of interest from an initial thirteen, down to five. This is not to say that the unselected eight counties do not have potential. The evidence and information stream that came to light during the study process channeled the effort to five counties: Albany, Montgomery, Saratoga, Schenectady and Schoharie. Existing gas pipelines and end users provide the key transportation elements and markets for the areas' potential reserves. The prudent selection and combinations of current, available and relatively low-cost technology can be applied to further define the prospects. That future effort, which includes standard reflection seismology, is likely to provide subsurface geologic details that provide an impetus to investment in the next stage of drilling exploration of the area.

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## Introduction

### Purpose of the Study

The New York State Energy Research and Development Authority (NYSERDA) contracted with Wilbur Smith Associates (WSA) and WSA's sub-contractor team of geological specialists from SUNY College at Oneonta, to perform a study of the eastern New York geologic frontier. The objective was to collect, review and assess data to ascertain whether there is potential for commercial hydrocarbons in the region. If warranted by the review and analysis effort, as achievable under the project Scope and Budget constraints, the study report would include descriptions and/or maps to portray exploration prospects. Subsidiary to the effort was a compilation of data and a bibliography deemed useful to future investigative efforts. The gas industry active in western New York is the perceived major audience for this study.

### Research Staff

WSA's Senior Earth Scientist, John C. Kucewicz, Jr. is a geologist with a background in oil and gas exploration and development. He is credited with a number of discoveries of commercial hydrocarbons in the United States Gulf of Mexico (onshore and offshore), and was designated as the project manager for the effort. James Walrath, P.E. provided engineering input and business perspective on an as needed basis. James Ebert, Ph.D., Peter Muller Ph.D., and James Albanese, Ph.D. are faculty at the State University College at Oneonta, with teaching and research responsibilities in the Department of Earth Sciences. Their major roles for the SUNY team centered on their individual and collective experience in the areas of structural geology, stratigraphy, paleontology, remote sensing, geologic computing, INTERNET connectivity, plus the ready access to a large library at the college.

## Methods of Investigation

### Project Organization

The project approach and delegation of the Scope of Work tasks was determined in an initial meeting of the primary research team members. The SUNY(Oneonta) team geologists were charged with the largest share of library search for available documents, reports and studies. The report and database included the procurement of materials from the New York State Geological Survey (NYSGS), notably for obtaining and reviewing electronic data (via diskette) from the NYSGS, that might prove useful to this study. Their designated tasks included: identification of known or suspected, potentially trapping, structural and stratigraphic anomalies; procurement/review of any other useful information uncovered in the course of their search; and ground truthing.

John Kucewicz of WSA was designated as the researcher of New York State Department of Environmental Conservation (NYSDEC) records, other NYSGS records (i.e., those not reviewed by the SUNY geologists), Potential Gas Committee Reports, coordinator of the press releases, collection of local anecdotes, meetings facilitator, prospect generator, and the project manager for the team.

Literature and Data Sources

Useful items were retrieved or inspected from such sources as: Potential Gas Committee (Colorado School of Mines) Biennial Reports and other publications, United States Geological Survey Bibliographies, New York State Geological Survey, American Association of Petroleum Geologists, New York State Energy Research and Development Authority, various professional journals, geophysical data companies, remote sensing and processing companies, responses to a Press Release, and personal interviews with landowners and geologists who were found to have an interest in the region. These sources are referenced in the sections below, and in the Bibliography of this report.

This report does not attempt to reinvent or reorganize data tables or maps already available in the public domain, but it does present drillable prospect concepts that we believe are both geologically sound and economically justifiable. Several figures presented in the Appendix are items that we have reproduced /copied (with permission), in whole or in part, from previous publications; customary credit is given to the author/publisher as is standard practice in scientific endeavors of this type. In some instances we have added symbols to the original figures by using text blocks, arrows, photo scale modifications or other annotations. Apart from the aforementioned additions we have not otherwise modified the original rendering of previous maps, charts etc.

Discussion

The geologic record of New York State has been studied in a systematic manner for more than one hundred years. There is a substantial knowledge base and understanding of the history and general architecture of the surficial units, sedimentary rocks and the underlying and exposed Proterozoic crystalline basement. Geologic knowledge of the subsurface, particularly in western New York has been enhanced as a result of the establishment of commercial gas and oil production in the early to mid 1800's, and the subsequent decades of drilling, geophysics, geochemical studies, and data analysis. Production comes mainly from reservoirs ranging in age from Cambrian to Devonian.

To date, hydrocarbon production in significant volumes has an eastern limit near a line extending from about Binghamton to Utica (The Ordovician age Trenton unit and the Silurian age Herkimer and Oneida Units produce in Madison and Oneida Counties). The Stagecoach gas field in Tioga county is one of the more recent notable discoveries located near the eastern limits of commercial production in New York. Hence the initial limits of this present study extended eastward from known production limits (roughly the Unadilla River) to the Hudson river, and a northern boundary at the southern limits of outcropping of the Adirondack crystalline Proterozoic rocks (Herkimer, Fulton, and Saratoga County) to the New Jersey and Pennsylvania borders in the south. The Hudson River was a convenient eastern limit of the study area, albeit proximal to the metamorphosed terrain

(Chloritization zone on east side of River) of the Ordovician Taconian Orogeny (Jenden, Drazan, Kaplan, 1993, and others).

## Data Review

With respect to eastern New York, several articles dating back between 40 and 100 years ago reported on wells drilled for specifically for hydrocarbons. The articles contain information that allows for the generation of new exploration ideas that are presented in this current study.

The largest number of deep wells in the area are located in Delaware County where, not surprisingly, there is also a sizable amount of available brokered seismic data (for trade or purchase). Our study team has not had the opportunity to see any of the reflection seismic lines that have been shot in the region, and as far as we could determine there are no reconnaissance lines in the area for which we have a greater interest. Our search efforts did not locate any exploration company mapping that may exist for the area.

## Field Work

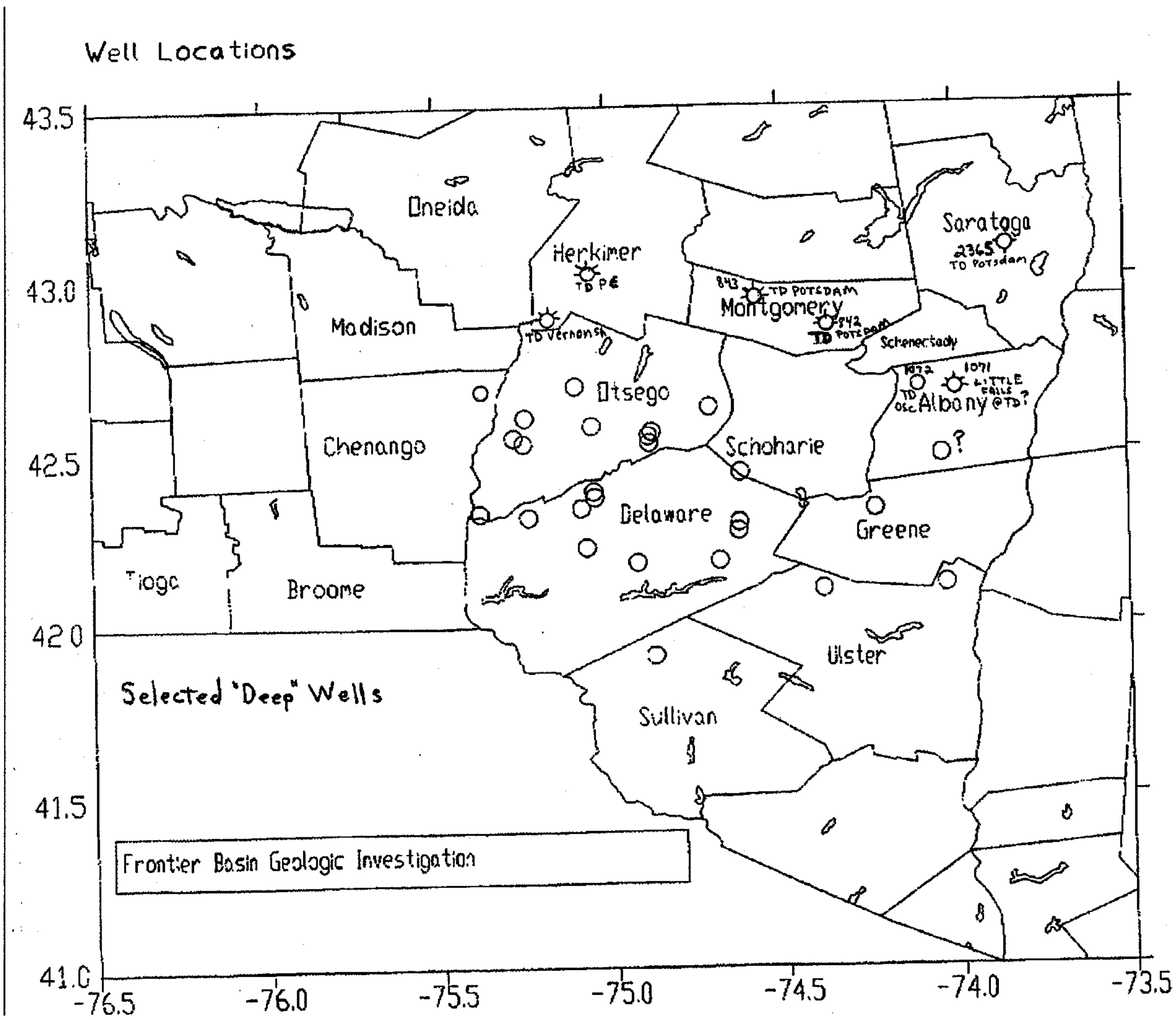
Published results of structural mapping efforts based on field investigations of outcrops and data on the base of the Middle Devonian Tully formation (Stevenson, 1948 and 1949) reported the observation and discernment of low relief folds (Delaware and Otsego Counties) in areas where the sedimentary rocks were thought to be monoclinal, gently dipping units.

Our team had some initial interest in these mapped folds because post 1940's water wells and some deep wildcats encountered gas shows proximal to the reported folds. The study team conducted field checks to locate and confirm these reported structures, but has found no evidence at the surface to support their existence in the areas described in the old reports. Our opinion is that the previous researcher may have made mistakes in discerning elevations and location of outcrops studied, or that correlation of the contact units was not accurate across the thousands of feet on the ground. It is also possible that undetected faulting, possibly a trapping mechanism, is at work here.

## Existing Wells, Drill Samples and Logs

Bulletins Number 373 and 418A of the New York State Museum and Science Service, of The State Education Department have reported the locations and results of selected deep wells and gas production in southeast New York up to 1972. One or more of drillers logs, sample logs and in some cases downhole wireline logs are available for these wells, and for newer wells at the offices of the DEC and NYSGS. Selected cuttings and cores are also available for inspection via the NYSGS, however due to time and budget constraints our team did not examine them.

We have reviewed these data as relates to "picks" for the various formation tops, gas show data, and well completion reports; no doubt with some similar perspectives as those of previous researchers.



Well Locations
43.5
43.0
42.5
42.0
41.5
41.0
-76.5
-76.0
-75.5
-75.0
-74.5
-74.0
-73.5
Oneida
Herkimer
TD PE
TD Vernon Sh
Madison
843
TD POTSDAM
Montgomery
842
TD POTSDAM
Saratoga
2365
TD Potsdam
Schenectady
1072
TD OSC
1071
LITTLE FALLS
Albany @TD?
Otsego
Chenango
Schoharie
Delaware
Greene
Tioga
Broome
Ulster
Sullivan
Selected "Deep" Wells
Frontier Basin Geologic Investigation

It is not surprising that the encountered reservoir thicknesses, flow tests and show data were in the main not of the type that would inspire too many explorationists of that time. None the less we are not dissuaded. There is a significant volume of untested and under evaluated section.

Prospective Section

L.V. Rickard (1973) authored work that includes a plate with structure contours on top of the Precambrian crystalline basement. He used more than 40 deep wells for control, 14 of which are located in the initial 13 County area of this study. His map showed that basement might be as deep as 22,000 feet below sea level in the southern part of Sullivan County, based on very little control in that area. The most recent New York State Geological Highway Map (1990) --See Figures 1 & 2 in Appendix A -- indicates a depth of between 4000 and 4500 meters (13,000 to 14,750 feet) below sea level to the Proterozoic, we presume, based on more well data than the Rickard map. In any event, there is a great thickness of prospective section in eastern New York.

Screening Mechanisms

As more data were gathered, our focus area shifted away from many of the places where the deep tests were drilled. The "new" data came from information in the "gassy water wells" files of the DEC and responses to a Press Release that was given to all the major Newspapers in the study area. The Press Release, as approved by NYSERDA, gave a little background about this study, and was entitled "Search for Local Legends: Do You Have a Gaseous Experience to Share?" one local newspaper reporter did investigatory work and wrote a follow up article in conjunction with the press release.

In total, the responses to the Press articles numbered about a dozen. Most of the responses were from homeowners that encountered flammable volumes of natural gas in the bedrock while drilling for water wells; in a few cases the gas production has persisted for up to 20 years, water free. The homeowners were called and interviewed as part of this study process. From the information gathered at the interviews we conclude that the largest number of gas shows are from wells with their total depths in upper and middle Ordovician units, in particular the Schenectady Formation (sandstones, siltstones and shales). Those water wells tend to be shallow tests of the subsurface, from about 100 to 500 feet deep. See Appendix A, Figures 3, 4 and 5 for geological maps and well/show locations.

Perhaps by default, our study became narrowed to the areas where we received Press Release responses that were near to the areas of historic gassy water well phone logs contained in the DEC files. The geographic distribution we observed in the responses may in fact only be a function of newspaper coverage and associated response. None the less the "trend" was geologically consistent, with only a few outliers in Otsego County and Greene County. Appendix A includes Figure 5 that is a copy of a portion of the Geologic Map of New York (by permission of the NYSGS), that we have annotated with "X" symbols that indicate the locations of the respondent homeowner gas shows.

As relates to the greatest geographic concentration of these homeowner "shows", one particularly notable gas well in the area of present day Altamont, New York produced/tested gas for a period of at least several months in the late 1880's, apparently from a thin sandstone at an elevation 13 feet above sea level within the Ordovician Schenectady formation. Charles A. Ashburner, M.S. C.E., reported on the well in the 1888 edition of Petroleum and Natural Gas of New York State. This 1888 report is available for viewing through the New York State Geological Survey.

The Altamont well (sometimes referred to as the Knowersville or Devenpeck well) did not reach the Proterozoic crystalline basement rocks (Appendix A, Figure 7). Its Total Depth (TD) was initially reported to be in the Middle Ordovician Trenton Group, but later interpretations suggest it is Cambrian in age, in particular, the Little Falls Formation of the Beekmantown group.

Within a short period of time after the completion of the Altamont well, an offset well (Finch #1) was drilled 4.5 miles to the west with no success. The Finch well is reported to have TD'd in the Schenectady Formation and was thought to have tested the equivalent interval as the age of the gas sand of the Altamont Well. In the ninety years that have transpired since the offset well was drilled, there has not been any "deep" commercial drilling specifically for hydrocarbons in that locale. However, many recently drilled water wells for rural homes in the area are approaching the depth and elevation of the original gas show, and are reported to have significant and often persistent gas volume in their water. The inherent danger from one of these gassy wells was dramatically illustrated when a home exploded in the area several years ago, reported in the press, due to ignition of natural gas that had accumulated within the residence.

With respect to deep wells, we visually inspected some of the available downhole wireline logs toward the end of the data collection process. Some of the copies on public file were marked with penciled correlation notes; some notes offering differing opinions as to the formations encountered. These correlation differences are not trivial because the estimated thickness of prospective section is dramatically different dependent on the correlation.

It was our opinion that reduced log cross sections from wells distant to our focus area were not needed for the purposes of illustrating the prospect concept that has arisen in this study. Figure 6 in Appendix A is a simplified structure map of the play concept for the Ordovician sandstone and silstone reservoir potential. The Figure 7 cross section was produced in a previous NYSERDA sponsored project; we have added annotations on this later figure to illustrate the hydrocarbon migration concept.

**Reduction and Analysis**

Reserve Potential

Each of the articles and materials obtained or consulted were reviewed for key elements related to hydrocarbon exploration: source and reservoir rock, trapping conditions, hydrocarbon generation windows, migration timing and preservation of the foregoing conditions. Appendix B contains figures from a NYSGS publication that illustrate the geologic history of the State through the Ordovician of about 440 my bp. Numerous previously published geological maps, block diagrams and cross sections of the study area indicate that hydrocarbons were and are present in eastern New York. Thermal history, trap persistance and commerciality of the accumulations are the key elements in question. It should be noted that we have taken a decidedly optimistic approach to the reserve potential in this area. We estimate probable reserves of 310 mmcfg, possible reserves of 31 Bcfg, and speculative reserves of 150 Bcfg for each of four prospective fields.

Economic Viability

Let us for a moment assume that in an exploration effort of the prospective Ordovician section that the very first well is a "success". Herein we can use a simplified approach to derive a "feel" for the economic threshold by estimating exploration and production costs for a theoretical shallow discovery well:

Let us assume that a well can be drilled and completed for $40,000,
That we spend another $40,000 in seismic and downhole wireline, coring and lab costs,
We incur initial lease costs of $2,000 per year for the prospect area, and
Pay $18,000 annually in salary, wages and operating costs related to the exploration effort, for a total of $154,000.

Without accounting for the time value of money, $154,000 at $2.50/mcfg would require 40,000 mcfg gross recoverable gas for payout of the investment. If we are to estimate that the time value of $100,000 is worth 20% annual rate of return over a four-year period it is valued at about $207,360 which translates to 82,944 mcfg gross recoverable gas @ $2.50/ mcfg (constant price), that is, average annual production of 20,736 mcfg for four years.

On a daily basis the above gas volume equates to less than 57 mcfg/day, plus 1/8 minimum royalty payments or 64mcfg/day needed ($160.00/ day gross revenue) for a one well field.

If successful offset wells are drilled, and the incremental costs per well are $40,000 each and the economics of the project become considerably better. Two wells at 128mcfg/day combined production equates to $320.00 day, $116,800/year, $467,200 in four years. A similar $140,000 investment at 20% for four years equals $290,304. Therefore payout on our theoretical two-well field occurs sometime in the second year of production. Significant returns above 20% accrue to the four year life of the well.

Conclusion

The question arises as to what is a reasonable expectation and risk assessment of the potential in this area. The answer is partly indicated in the flow test of a water well in Schenectady County (Figure 8 of Appendix A) completed by backyard technology and used by a homeowner: it was gauged at 110 cubic feet/minute (158 mcf/d) by the DEC in 1965. That gauged well continued to produce for nearly 30 years for the homeowners' domestic needs, although the volume of production is unknown. If we estimate that the well produced at the homeowners' constricted rate of 10% the original gauged volume (includes losses to the atmosphere) we are left with the recoverable volume of no less than 155 mmcfg. We believe that this well, properly completed, could have produced more than this volume in a considerably shorter period of time.

In terms of well-field potential it is important to once again note that the responses to our Press Release indicate that homeowners encounter natural gas in water wells in the offset area as a nearly a routine occurrence. We conclude that the potential gas reserves in this area merit further exploration effort.

**Acknowledgments**

WSA thanks IOGA NY for the opportunity to address the membership and guests on July 9, 1997, particularly Bonnie Kirisits. NYSERDA's John Martin was tremendously helpful with ideas for networking. Members of the written Press are to be thanked for carrying Press Releases, in particular The Schenectady Gazette's Meredith Kruse. The work could not have progressed without the Team Members from SUNY Oneonta, James Ebert, James Albanese and Peter Muller. Invaluable sources of information were provided through the New York State Geological Survey (Rich Nyahay, Donna Jurnov and others), the NYS DEC's, Don Drazen and Christine Reed were very gracious and responsive to our inquiries. I can not fail to mention the input we received from hosts of others: commercial and private sectors, and in particular the homeowners who took time to write and speak with me about their gaseous encounters of the subsurface kind. Gerald Freidman and several colleagues from the Hudson Mohawk Professional Geological Association provided encouraging support and occasional information that added to the value of the project.

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Gordon P. Eaton, Director

# Appendix A

Figure 1

# TECTONIC MAP OF NEW YORK AND SURROUNDING AREAS

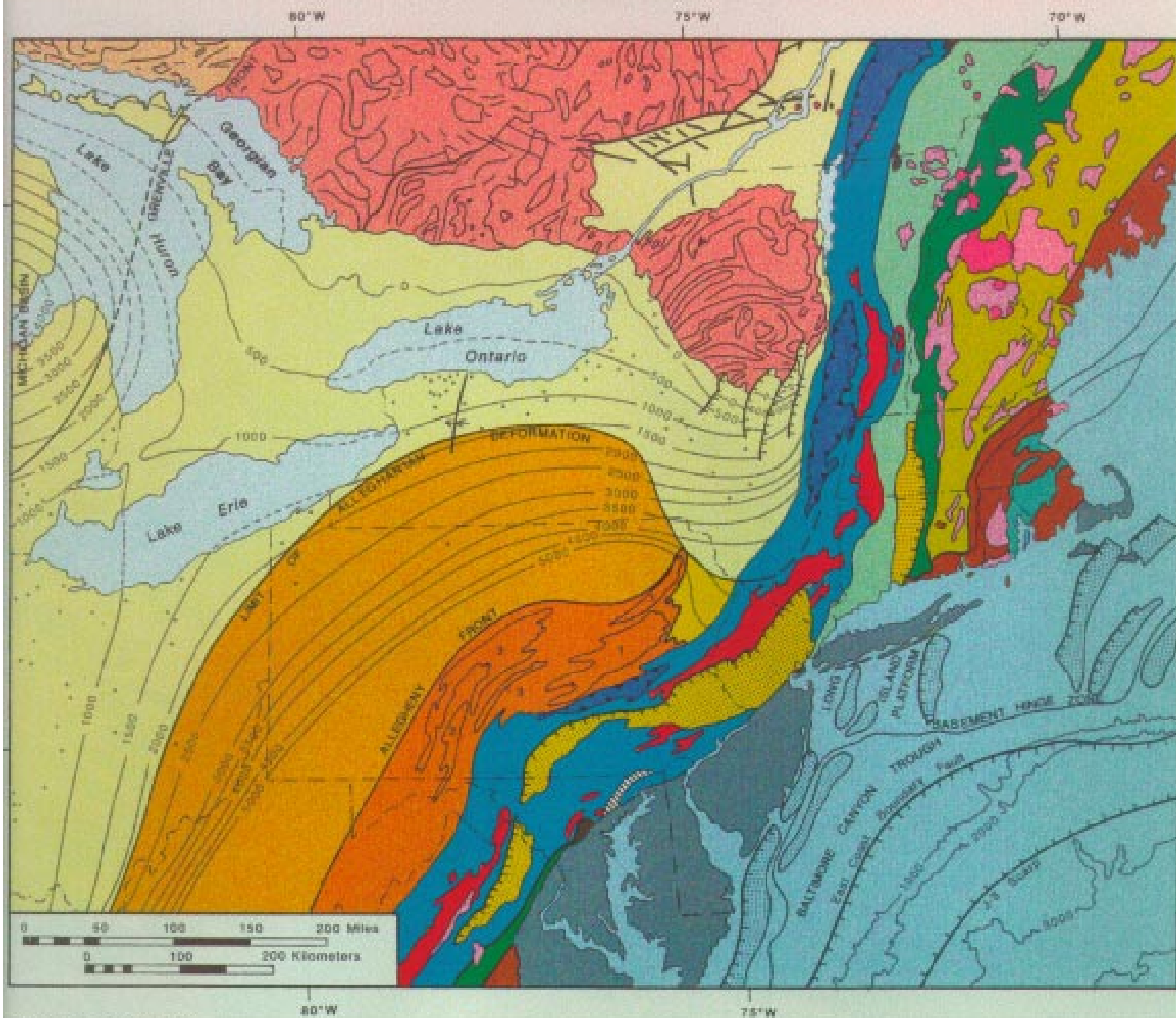


Figure 2

# TECTONIC MAP EXPLANATION

## Symbols

High-angle normal fault, hachures on downthrown side.

Low-angle thrust fault, barbs on overthrust block.

Boundary along which a terrane was welded to North America.

Clarendon-Linden monocline; draped over buried normal fault. Displacement is down to the west.

–500– On land, depth to basement in meters below sea level (not shown below 5000 m due to complexity of basement contours); offshore; depth of water in meters. Circle shows location of drill hole to basement.

## UNDEFORMED ROCKS

**Listed in General Order from Oldest to Youngest**

Sedimentary rocks of the North American platform. Late Proterozoic to Paleozoic in age. Deposited in shallow seas on the stable North American craton. Tectonically passive.

Rift basins of Late Triassic to Early Jurassic age, onshore and offshore, filled with non-marine sedimentary rocks as well as basaltic lava flows and their diabase feeders. Offshore basins are buried beneath younger marine sediments. Records a period of crustal stretching and rupture during opening of the Atlantic Ocean.

Mesozoic plutons, mainly granitic, of Jurassic and Cretaceous age. Includes the White Mountains in New Hampshire and the Monteregian Hills in southern Quebec. Plutons were intruded late in the crustal stretching related to opening of the Atlantic Ocean.

Marine and continental sediments of the Atlantic Coastal Plain, Cretaceous to Recent in age. Deposited near sea level as part of a passive continental margin on the east coast of North America.

Offshore, submarine sediments and sedimentary rocks deposited since the North Atlantic Ocean began to open about 200 million years ago in the Jurassic Period. Passive continental margin.

## DEFORMED ROCKS

**Listed in Order of Deformation or Addition to North America**

Archean volcanic and granitic rocks of the Superior Province, metamorphosed at low grade about 2.7 billion years ago. Lines show the trends of rock bodies.

Middle Proterozoic basement of the North American craton, last deformed and metamorphosed to high grade during the Grenville orogeny about 1 billion years ago. Exposed in the Grenville Province of the Canadian Shield and the Adirondack Mountains, elsewhere buried beneath sedimentary rocks of the platform.

Middle Proterozoic basement deformed at high metamorphic grade during the Grenville orogeny, and again, at medium grade, during the Taconian orogeny. Some areas also deformed during the Acadian and Alleghanian orogenies.

Marine sedimentary rocks of an ancient continental shelf and slope, but also includes rift volcanic and rift sediments. Late Proterozoic to Ordovician in age. Primarily deformed during the Taconian orogeny, with some areas deformed by the Acadian orogeny in New England, and the Alleghanian orogeny in the Mid-Atlantic Region. Low to high metamorphic grade. Toothed areas are remnants of Taconian thrust sheets that were transported westward onto the platform.

**Frontier Basin Geologic Investigation**

SOURCE: New York State Geological Highway Map 1990



WSA

Figure 3

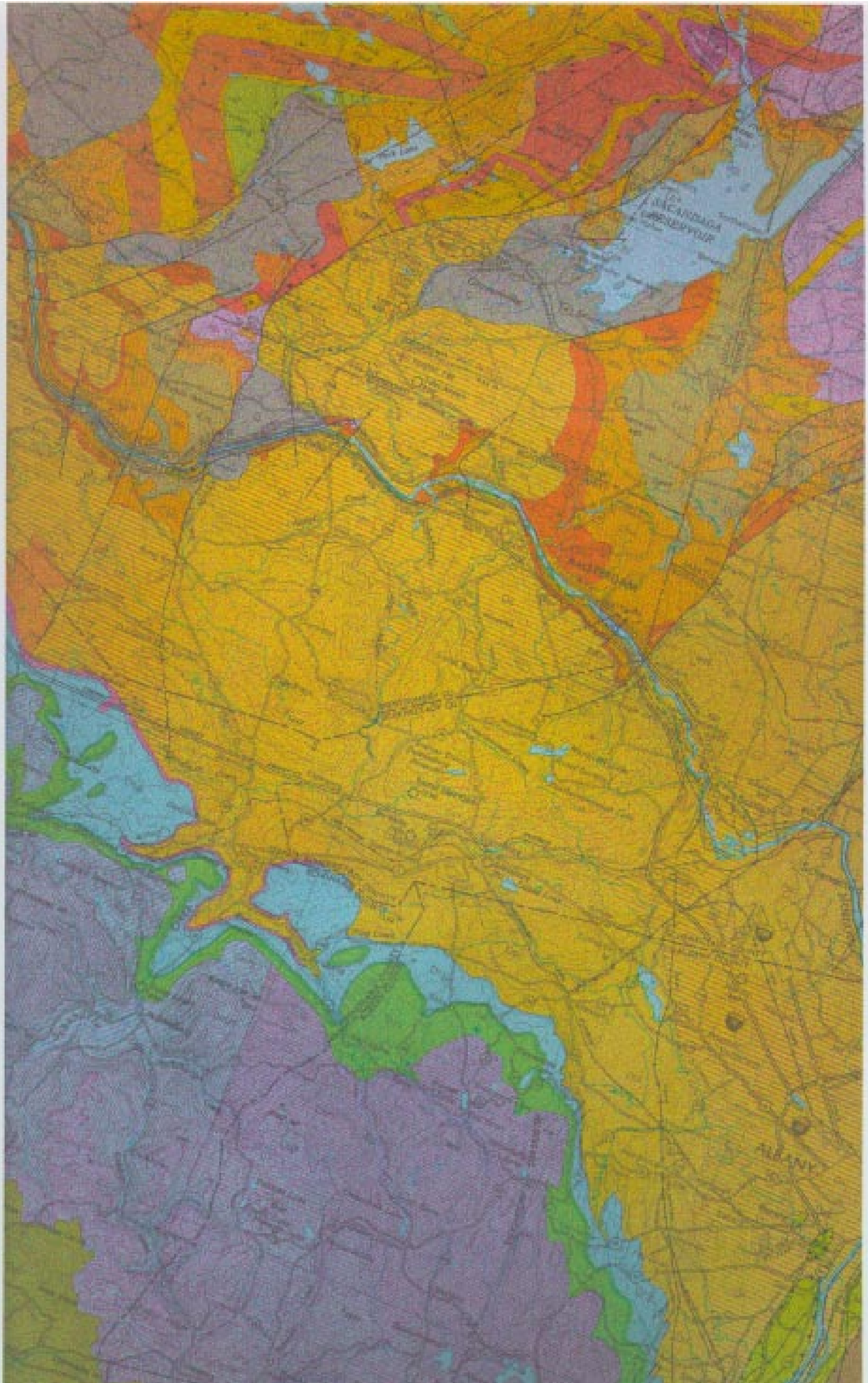
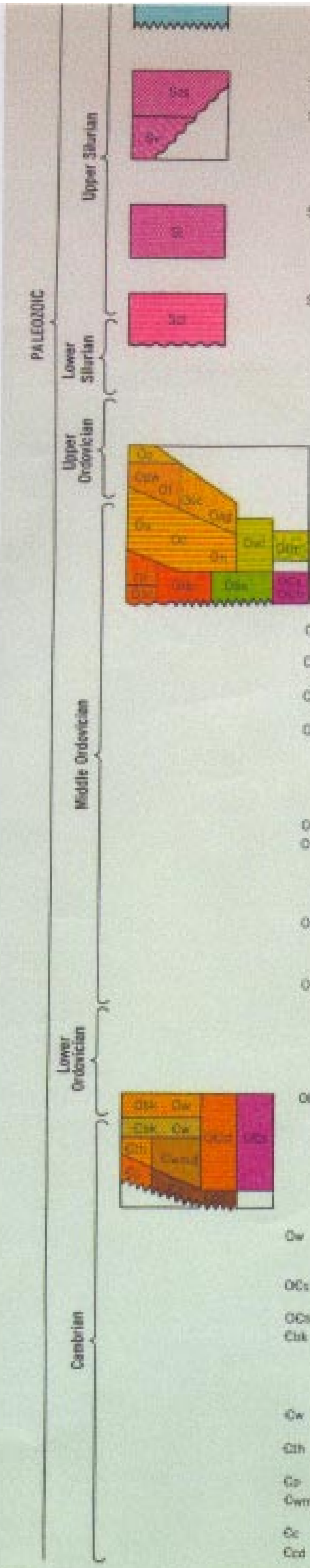

ALBANY

Figure 4




COBLESKILL LIMESTONE AND SALINA GROUP
0-700 ft. (0-210 m.)

Scs Cobleskill Limestone; Bertie, Camillus, and Syracuse Formations—shale, dolostone; Brayman Shale.

Sv Vernon Shale.

LOCKPORT GROUP
0-75 ft. (0-23 m.)

Sl Ilion Shale.

CLINTON GROUP
0-350 ft. (0-110 m.)

Scl Herkimer Sandstone including Joslin Hill and Jordanville Members; Kirkland Hematite; Willowvale Shale; Westmoreland Hematite; Sauquoit Formation—sandstone, shale; Otsquago Sandstone; Oneida Conglomerate.

LORRAINE, TRENTON, AND BLACK RIVER GROUPS
up to 4,500 ft. (1400 m.)

Oo Oswego Sandstone.

Opw Pulaski and Whetstone Gulf Formations—shale, siltstone.

Of Frankfort Formation—shale, siltstone.

Osc Schenectady Formation—graywacke, sandstone, siltstone, shale.

Oag Austin Glen Formation—graywacke, shale.

Ou Utica Shale.

Oc Canajoharie Shale.

On Normanskill Shale—minor mudstone, sandstone.

Owl Walloomsac Formation—slate, phyllite, schist, metagraywacke.

Ot Trenton Group. Denley, Sugar River, Kings Falls, and Rockland Limestones.

Obr Black River Group: Chaumont Limestone—chert; Lowville Limestone; Pamelia Dolostone.

Otbr Mohawk Valley: Trenton and Black River Groups—Dolgeville, Denley, Sugar River, Kings Falls, Glens Falls, Rockland, Amsterdam, and Lowville Limestones.
Washington County: Glens Falls and Orwell Limestones.

Obe Balmville Limestone. Vermont: Whipple Limestone.

Otm Taconic Mélange—chaotic mixture of Early Cambrian thru Middle Ordovician pebble to block-size angular to rounded clasts in a pelitic matrix of Middle Ordovician (Barneveld) age. Rims and floors earlier submarine gravity slides of Taconian Orogeny.

OCs Cambrian thru Middle Ordovician (Barneveld) carbonate rocks occurring as slivers caught along thrusts of later allochthones, or carbonate blocks in Taconic Mélange.

OCh Horses along normal faults.

BEEKMANTOWN AND STOCKBRIDGE GROUPS, POTSDAM SANDSTONE, AND VERMONT VALLEY SEQUENCE
up to 3,500 ft. (1100 m.)

Obk Beekmantown Group.
Mohawk Valley: Chuctanunda Creek Dolostone; Tribes Hill Formation—limestone, dolostone; Gailor Dolostone.
Washington County: Providence Island Dolostone; Fort Cassin Formation—limestone, dolostone; Fort Ann Formation—limestone, dolostone; Cutting Formation—dolostone, local chert, limestone at top, siltstone at base.

Ow Columbia County: Copake Formation—limestone, dolostone; Rochdale Limestone; Halcyon Lake Formation—chert, calc-dolostone.

OCst Stockbridge Formation—calcitic and dolomitic marble.

OCs slivers, as OCs above.

Cbk Beekmantown Group.
Mohawk Valley: Little Falls Dolostone—chert; Hoyt Formation—limestone, dolostone, oolite.
Washington County: Whitehall Formation—dolostone, limestone; Ticonderoga Dolostone—chert.

Cw Columbia County: Briarcliff Dolostone; Pine Plains Formation—dolostone, oolite, shale.

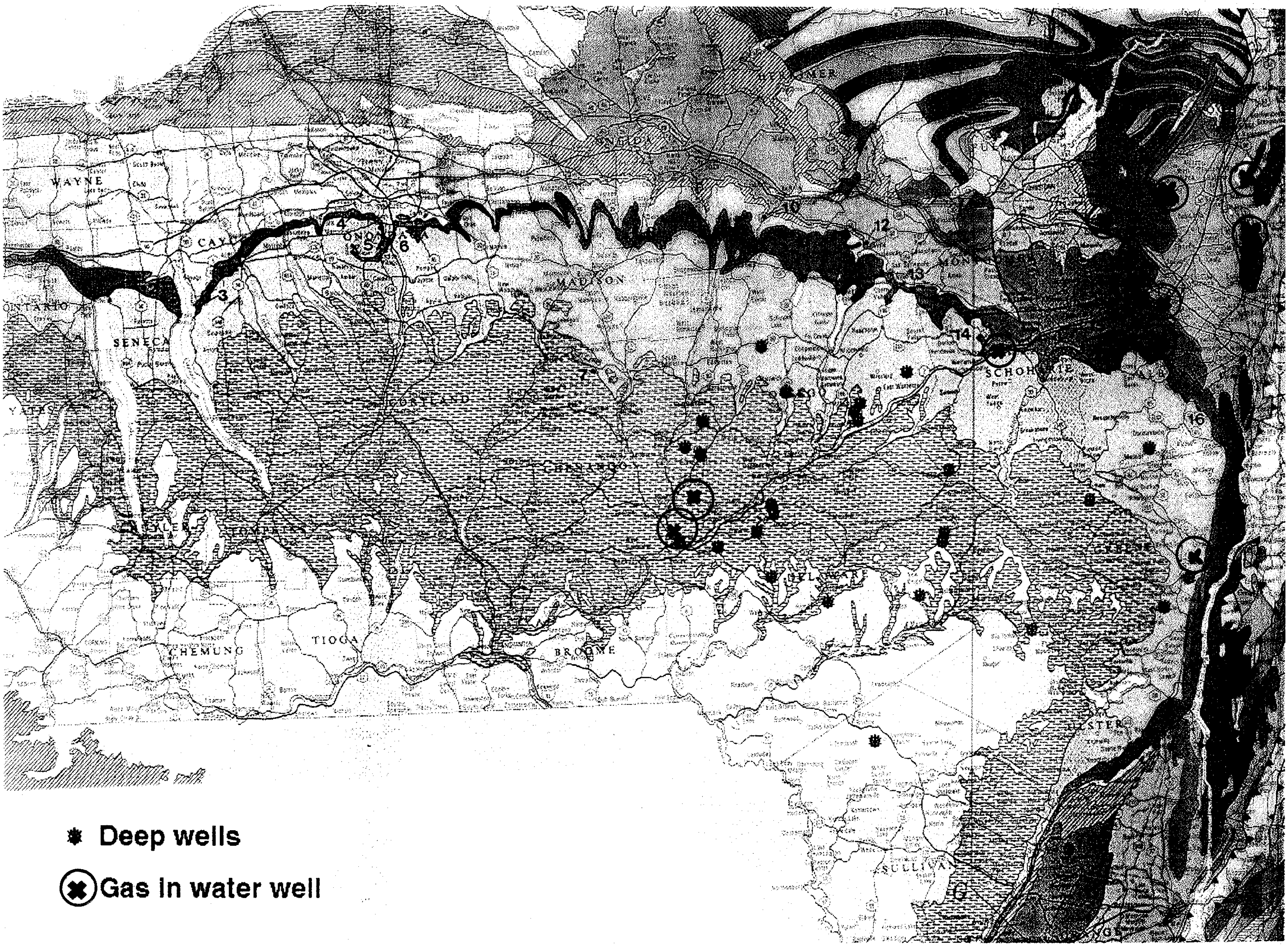
Cth Theresa (Galway) Formation—dolostone, sandstone, shale.

Cp Potsdam Sandstone.

Cwmd Vermont: Winooski Dolostone, Monkton Quartzite, and Dunham (Rutland) Dolostone.

Cc Cheshire Quartzite.

Ccd Cheshire Quartzite and Dalton Formation.

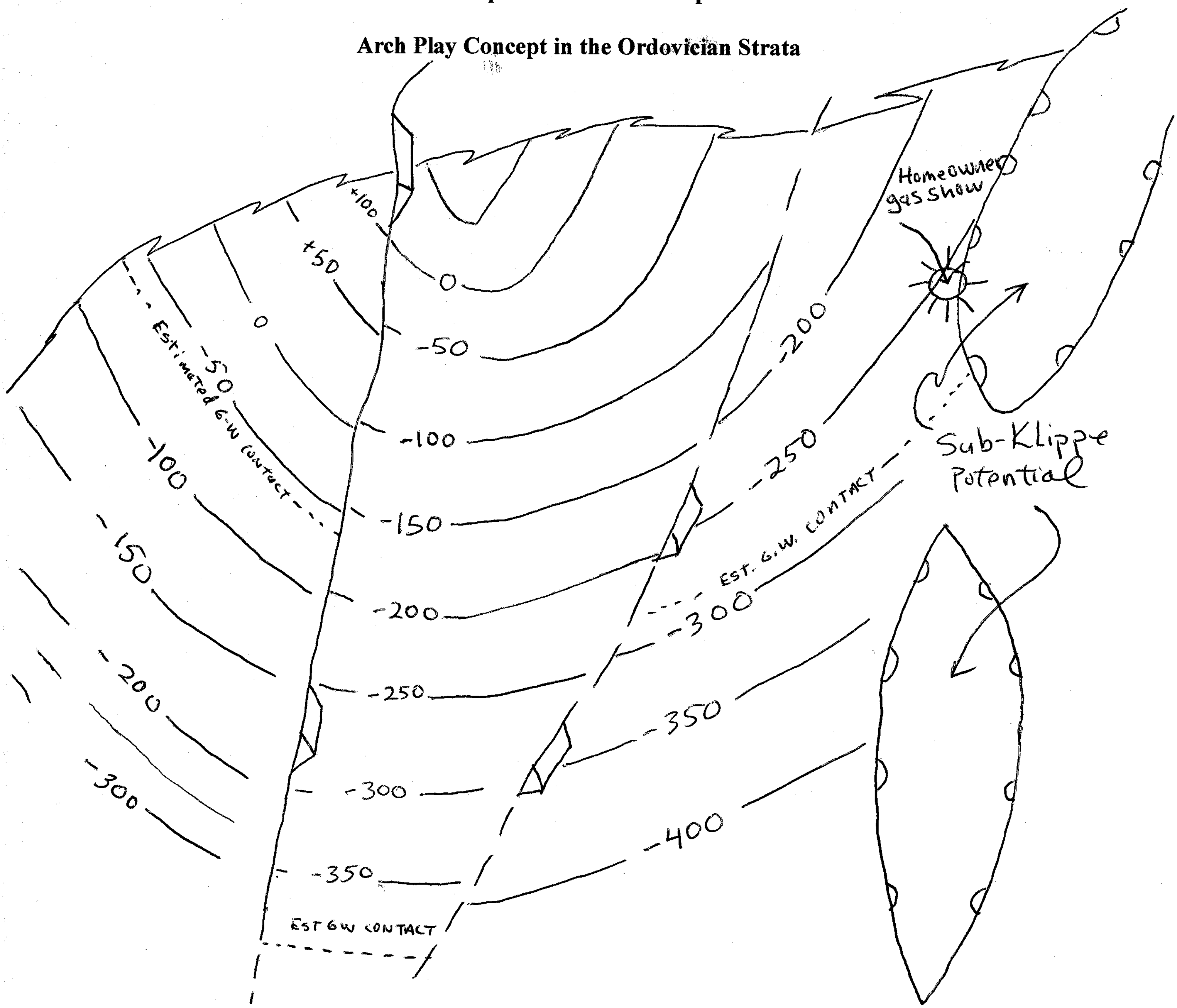



* Deep wells

(✖) Gas in water well

**Simplified Structure Map**

**Arch Play Concept in the Ordovician Strata**




**Scale: Approximately 1:250,000**
**Elevations (meters) are relative, not actual.**

**Figure 6**

Figure 7

## Structure Cross Section From Saratoga Springs To Altamont, New York

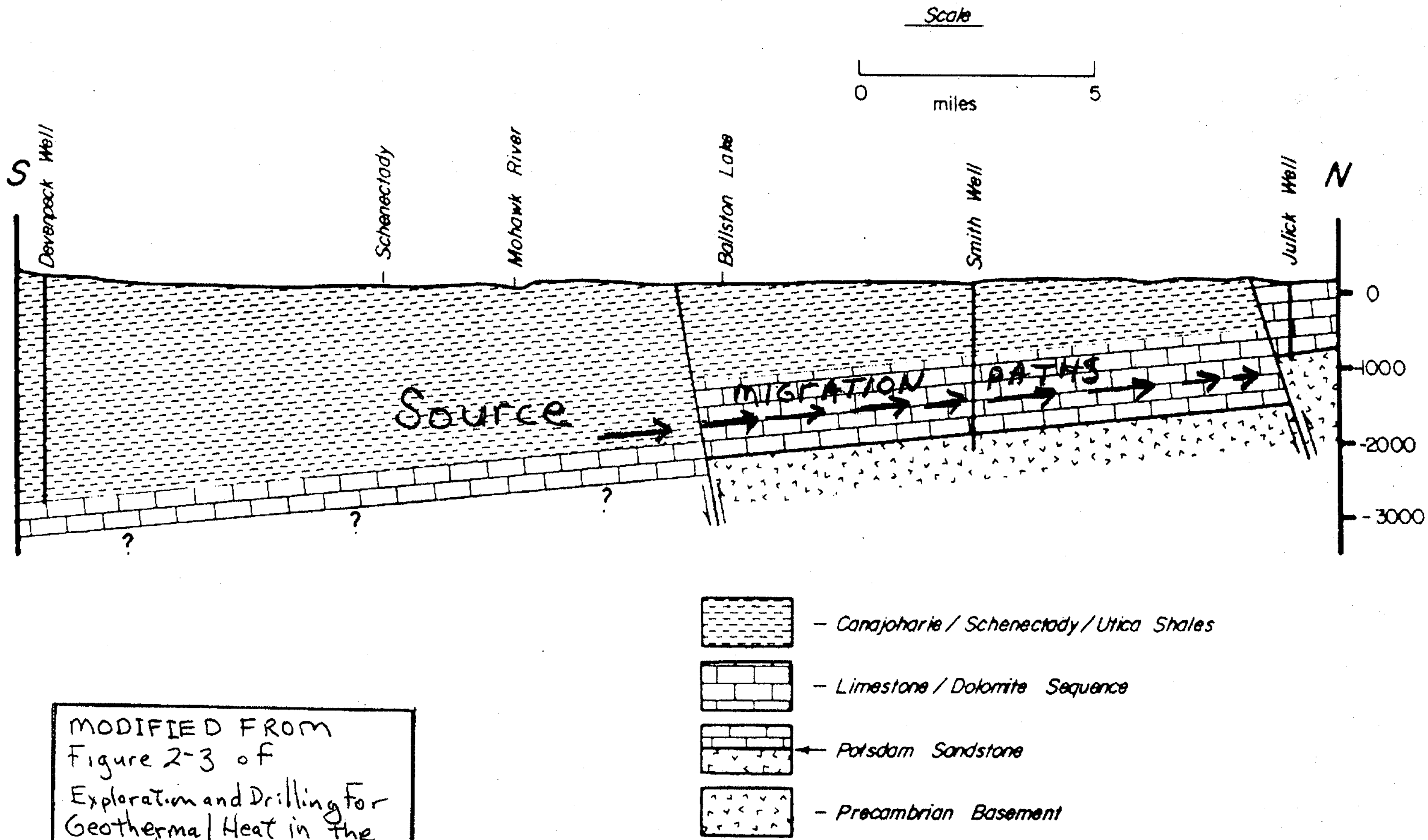



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Figure 2-3 of
Exploration and Drilling for
Geothermal Heat in the
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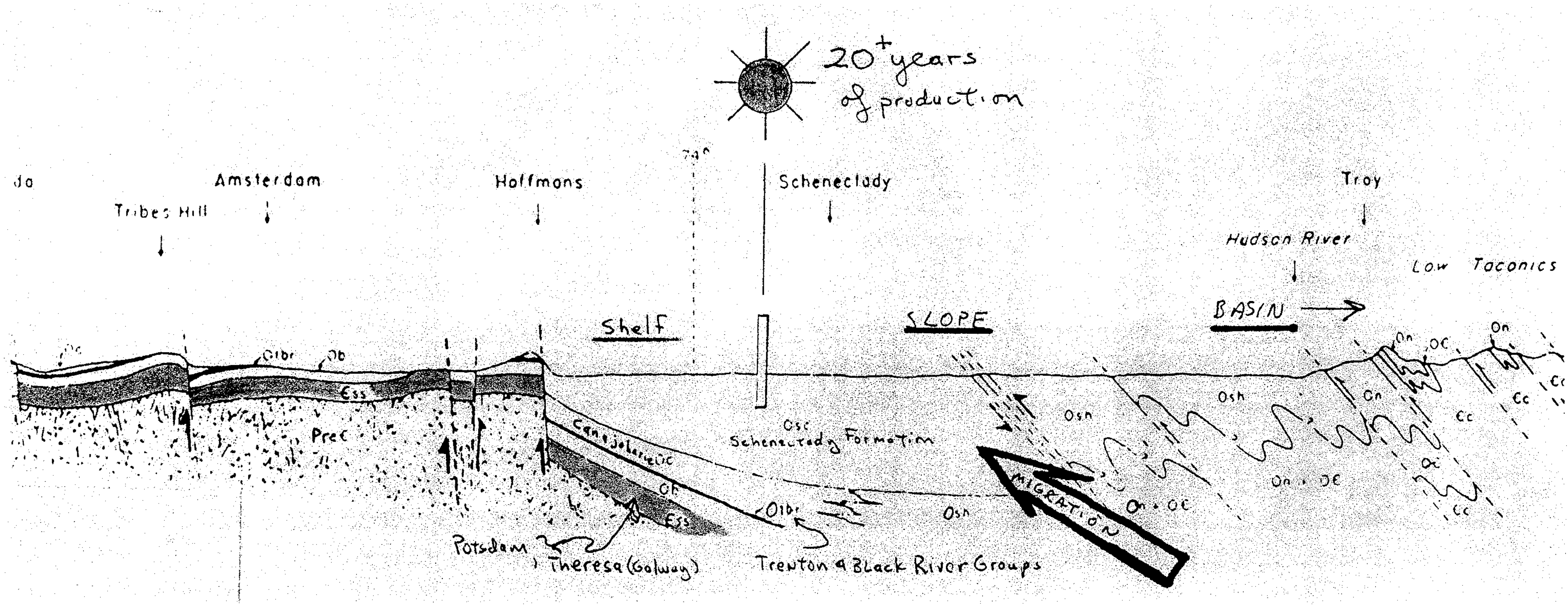
Figure 7

Figure 8

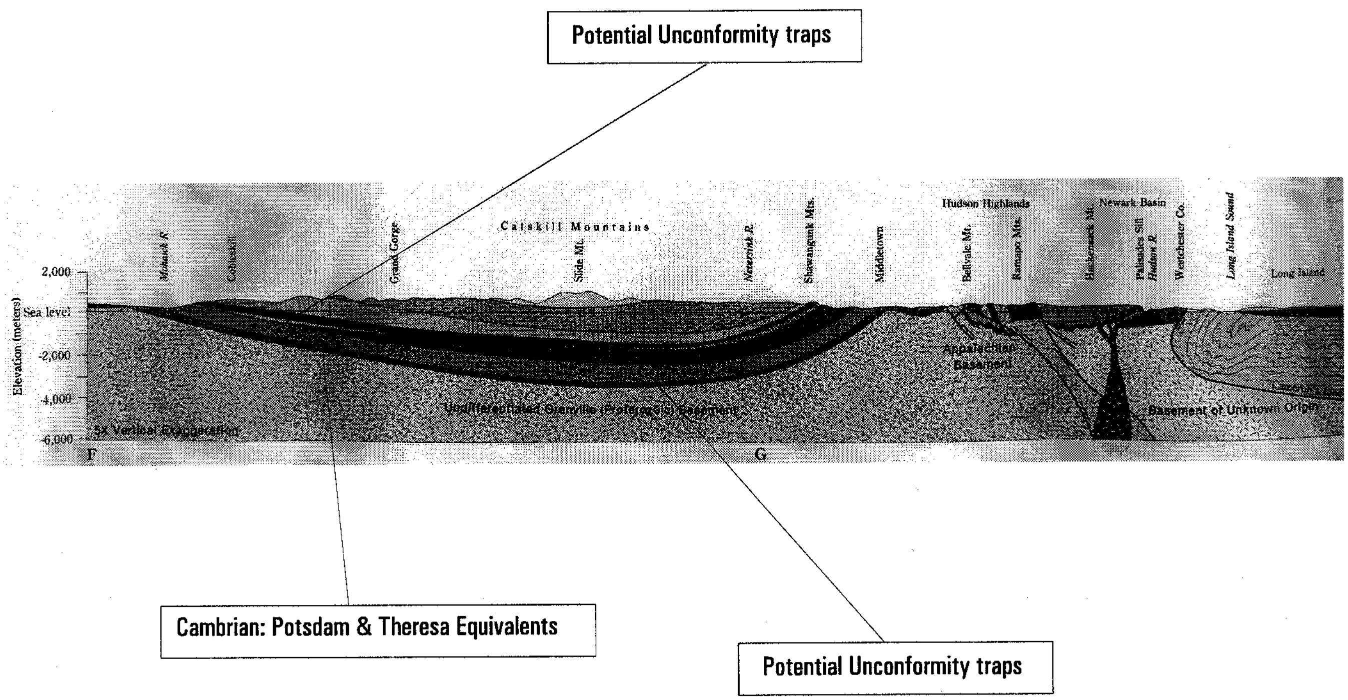


20+ years of production
Amsterdam
Tribes Hill
Hoffmons
Schenectady
Troy
Hudson River
Low Taconics
Shelf
SLOPE
BASIN
Olbr
Ob
Ess
Prec
Canajoharie OC
Osc
Schenectady Formation
Osh
On
Cc
On + OC
MIGRATION
Potsdam
Theresa (Galway)
Trenton & Black River Groups

# Appendix B

Figure I

# Focus of Study: Structural (fault) & Stratigraphic Traps




| Frontier Basin Geologic Investigation |
|---|
| SOURCE: New York State Geological Highway Map 1990 |
| Duplicated with the permission of N.Y.S.G.S./ State Museum, Albany, NY |
| Text Block illustrations added by WSA |

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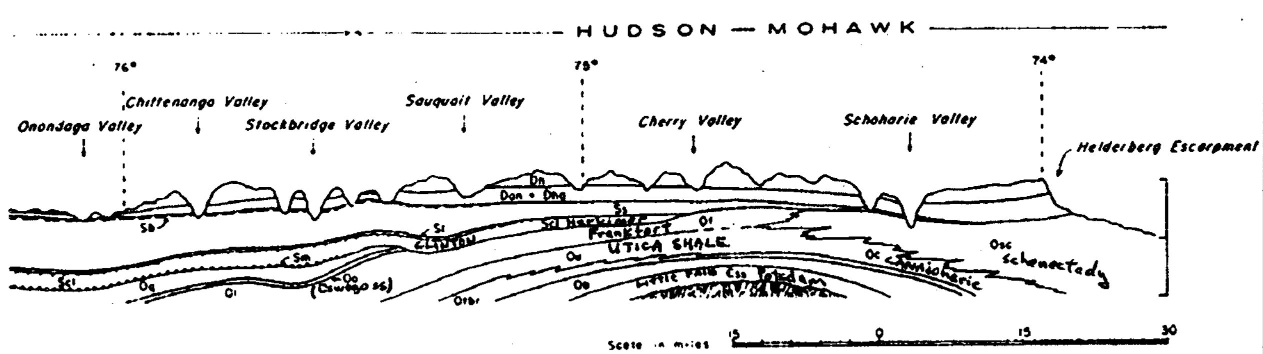
Figure II

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SOURCE: Hudson-Mohawk Sheet, Preliminary Brittle Structures Map of New York, 1977

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Text Block Illustrations added by WSA

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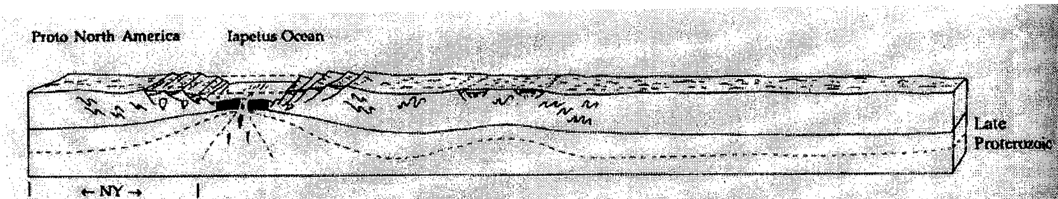
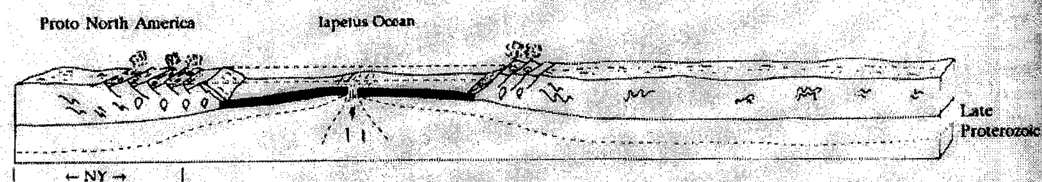
Figure III



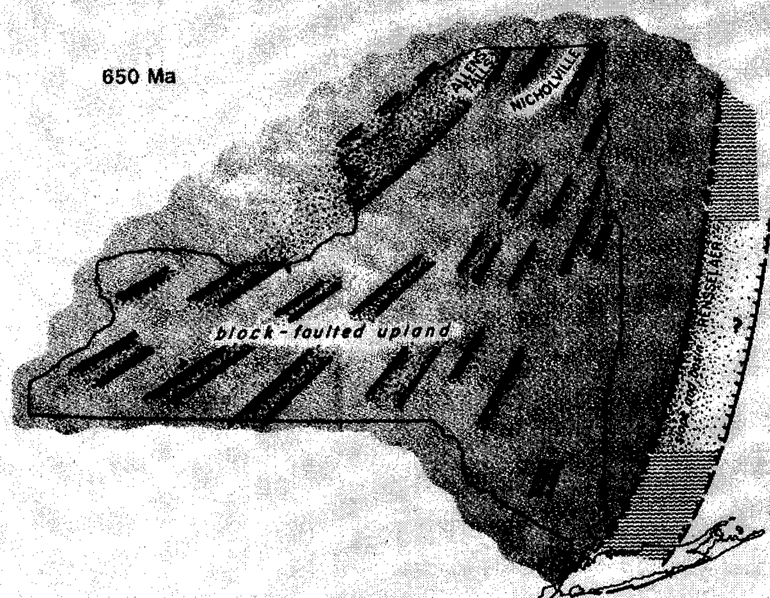

**Rifting and Initial Opening of Iapetus Ocean**

**Figure 7.3.** Rifting of the Grenville supercontinent. (A) A stretching event thins and splits the Grenville crust. Rift basins develop in the stretched crust. A main rift widens and floods with sea water to form the Iapetus Ocean. Some rift basins remain above sea level; some near the edges of the main rift become submerged. Debris eroded from the rift margins is deposited in the basins. (Compare with Figure 3.1 to recognize continental and oceanic crust and the boundaries of the crust, lithosphere, and asthenosphere.)



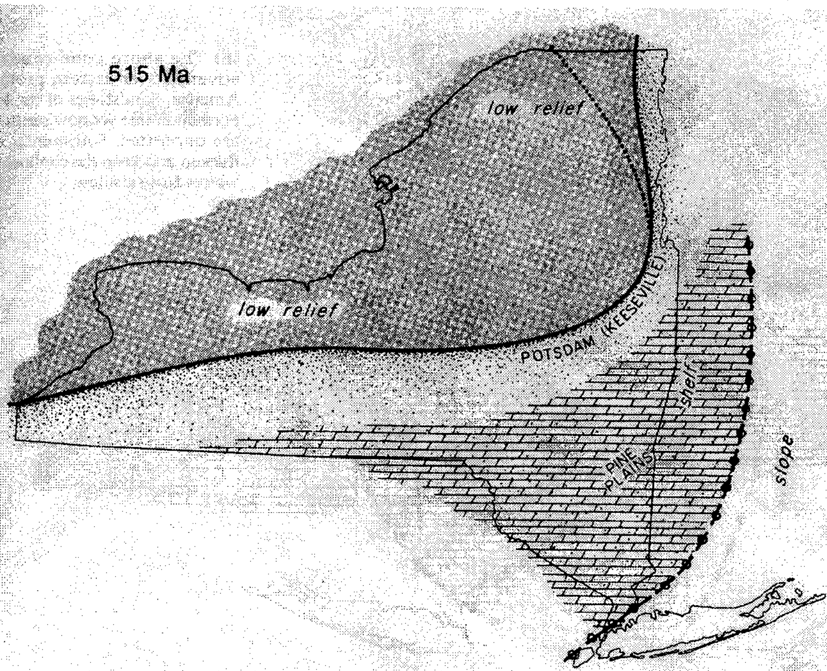

**Continued Rifting and Opening of Iapetus Ocean**

(B) Rifting continues and the Iapetus Ocean widens. Volcanic activity occurs in the rift basins, and deposition continues in the basins.

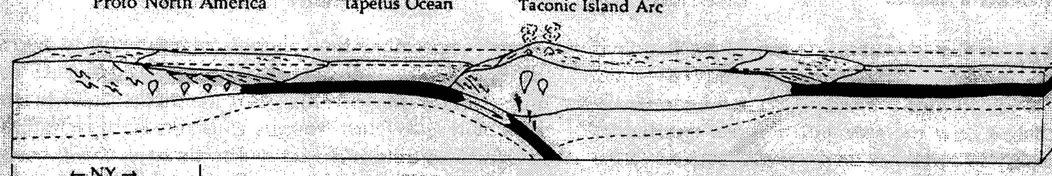



(C) Probable appearance of the region in the late Proterozoic. Rift valleys are filled with sediment and the western edge of the main rift is buried by offshore sediment.

Figure IV




(C) The shore zone advances farther onto proto-North America. A layer of sand is left in its wake. The sand deposit is progressively covered by carbonate sediment offshore.



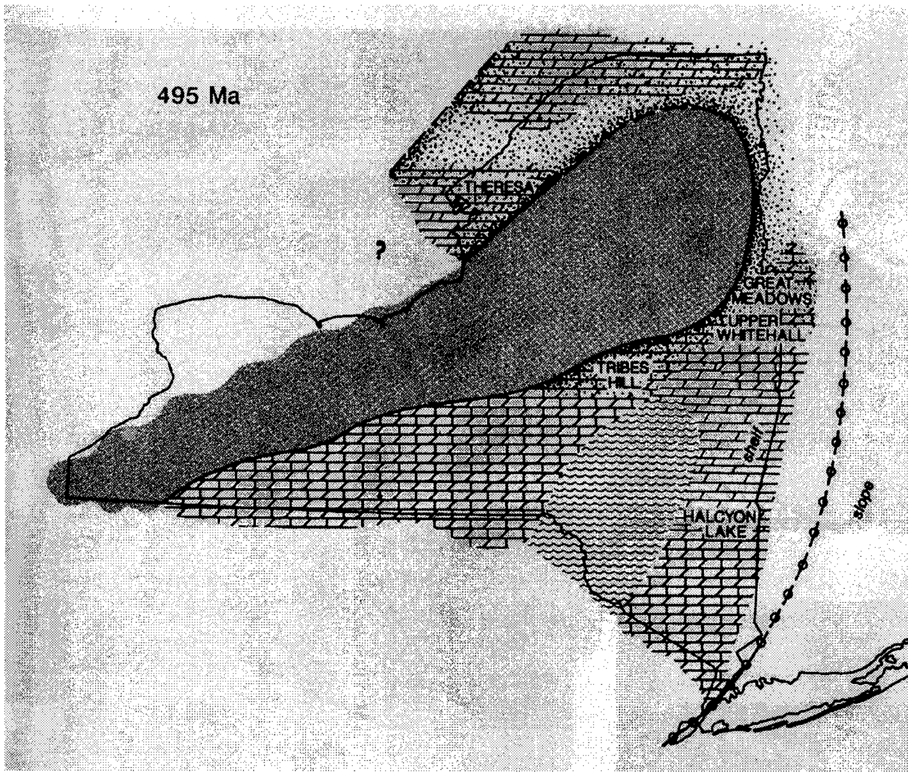

Continued Subduction

(D) The western part of the Iapetus Ocean narrows as the island arc approaches proto-North America. Sediments cover the widening continental shelf and extend to the ocean floor as continental slope and rise deposits.



SOURCE: Educational Leaflet No. 28
Geology of New York

Figure V




(G) Sea level drops, and eastern proto-North America begins to emerge from the sea.



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Figure VI

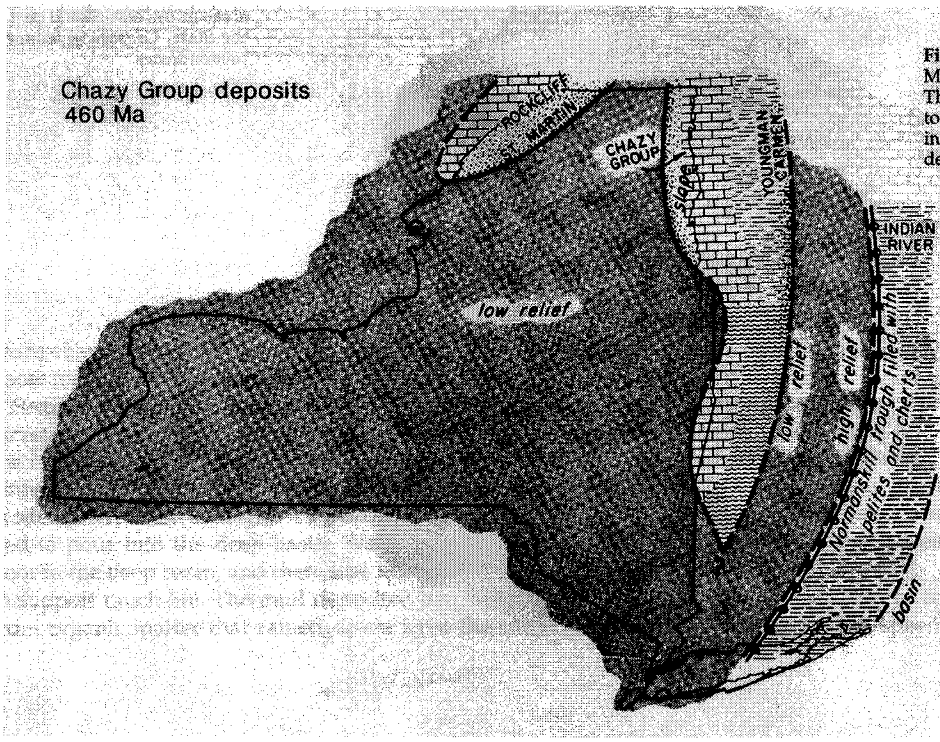
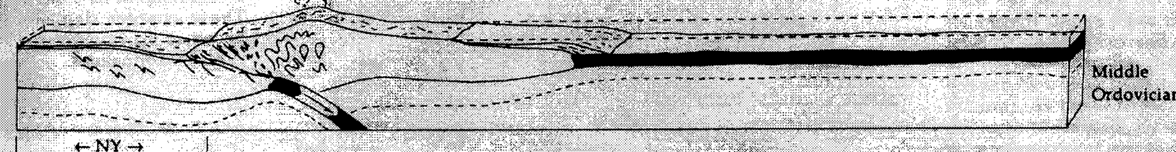


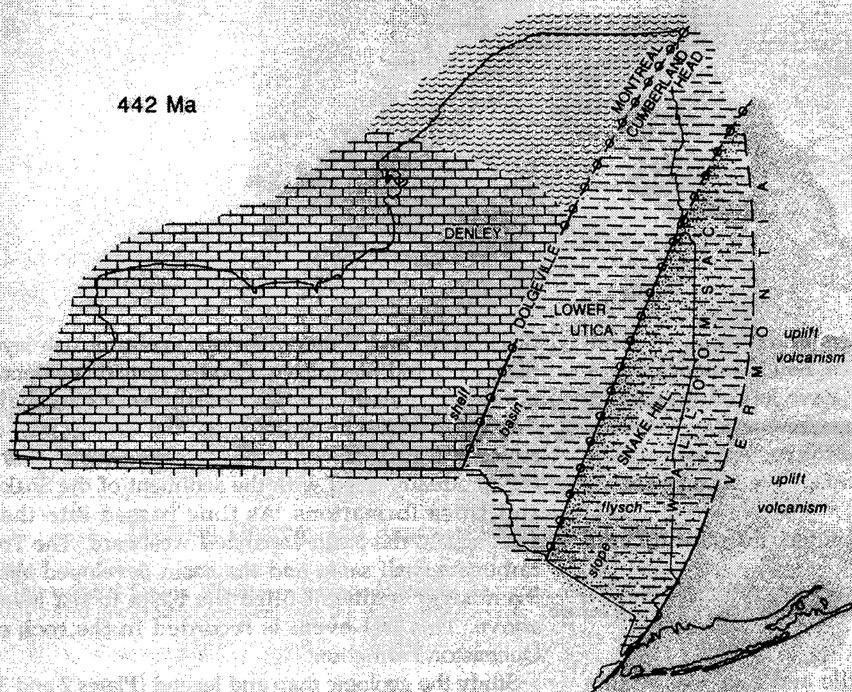

**Figure 7.9.** Geography during Middle Ordovician time. (A) The edge of the continent begins to be submerged again by a rise in sea level. The Chazy Group is deposited in eastern areas.

Figure VII




## Taconian Orogeny - Collision of Island Arc and Proto North America

(D) The collision between the volcanic island arc and the continent is well under way. Sedimentary rocks originally deposited far to the east are thrust into eastern New York. The eastern part of what was earlier a carbonate shelf is now depressed to form a basin. The ancestral Taconic Mountains develop.




(E) Mud eroded from the ancestral Taconic Mountains pours into the basin. Today, this mud is the Snake Hill Formation and Utica Shale. Farther west, deposition of limestone continues. This sediment will eventually become the upper part of the Trenton Group.

**Frontier Basin Geologic Investigation**

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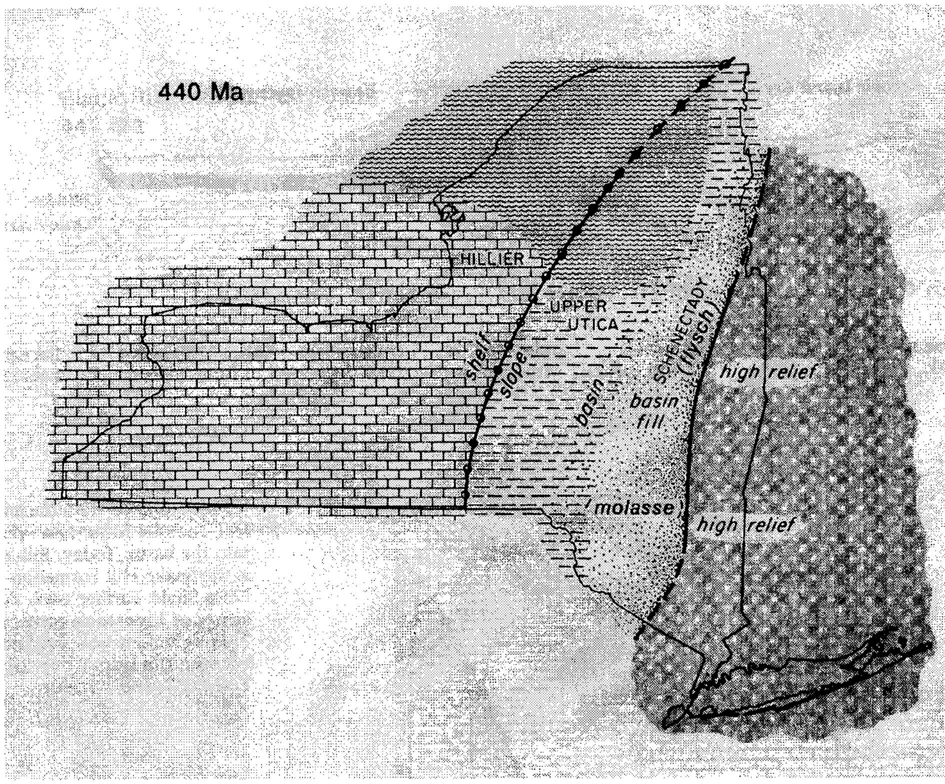
Figure VIII




(F) The filling of the basin continues, and coarser material accumulates in its eastern part. These coarser deposits are known as the Quassaic and Schenectady Formations.

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