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Errata sheet for Proceedings of The Rochester Academy of Science, Inc., Vol. 15 (2)

p. 81 - bottom line

"Cohocton River" should read "Canisteo River"

PREFACE

by
Elizabeth Y. Pixley, Chairman
Publications Committee
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The Rochester Academy of Science was organized in 1881. It has had a long history of publication of scientific papers, especially those which relate to the Genesee region. In 1981, the Academy celebrated its centennial with a day of special programs, including a geology colloquium on current findings in the Genesee region and a review of Herman Fairchild's contributions to our knowledge of regional geology. This issue of the Proceedings contains the text and illustrations of papers given at that colloquium in April 1981.

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FAIRCHILD'S NEW YORK: THE CONTRIBUTIONS OF HERMAN LEROY FAIRCHILD

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INTRODUCTION

Herman Leroy Fairchild (Figure 1) was born on April 24, 1850, in Montrose, Pennsylvania. Thirty-eight years later he became Professor of Geology and Natural History at the University of Rochester. He used this position as a base for carrying out a broad range of geologic studies and other activities during a long and productive career. At first, he taught botany, zoology, physiology, and physical geography; later he added paleontology, mineralogy, and meteorology. He was a founding member in 1888 of the Geological Society of America, an early president (1889-1901) of the Rochester Academy of Science, and the person responsible for establishing the publication of the Proceedings of the Rochester Academy of Science. He was an extremely active geologist and scholar, and a conspicuously active spokesman on natural resource conservation and use in the Rochester area.

Before coming to Rochester, his publications were entirely biological in content. After coming to Rochester in 1888, he turned to geology and especially to Pleistocene geology, the field in which he had his greatest influence. He devoted much of his energy to creating a panoramic and vivid history of the advance and retreat of the latest Pleistocene ice sheet and of its effect on the lakes and streams that appeared and disappeared along its edge.

Fairchild's work and the Rochester Academy of Science began at about the same time, and he published extensively in its Proceedings. The occasion of the Academy's Centennial is an excellent opportunity to remind the scientific community about the New York of Fairchild's lifetime and of what it meant to him. This paper presents samples of Fairchild's own descriptions of New York and of photographs taken by him almost 100 years ago. It includes his explanation of the attractions of the climate of Rochester, New York, and his expressions of affection for the landscape of upstate New York.

It contains a sample of his ideas about the development of this unique landscape during the Pleistocene when it was buried under ice and water, and a few of his thoughts on preservation of the landscape he had described with such affection.

Most of the words are his. The intent is to present some of his ideas on Pleistocene geology, many of which have served as stimuli for modern studies such as those represented in this symposium by Muller and Young.

THE ROCHESTER CLIMATE

Professor Fairchild expressed particular fondness for the Rochester climate and even the weather as demonstrated by the following remarks, published in the Proceedings of the Rochester Academy of Science (Fairchild, 1906, p. 306-307, 315-316).

> There are two elements wherein Rochester appears at a disadvantage. One is the cloudiness, the other the large number of rainy days. Granting it true that we have frequent rains and a high percentage of cloudiness, what can be said in reply to the Rochester grumbler? Just this; that upon the whole the cloudiness which we have is a distinct advantage. Astronomy is not an important industry here. The advantages are much greater than the disadvantages. The latter are chiefly a matter of imagination or sentiment; the former are real. The clouds interfere but little with most occupations, and not as much with the real comfort of people as they think. Continuous clear skies in summer are not desirable. Clouds not only temper the heat but add a beauty and variety to nature which nothing else can supply . . . the somber skies of the colder months may be an aesthetical or sentimental disadvantage, but they are practically beneficial in conserving heat and preventing low temperatures, specially at night . . . In winter, the canopy of clouds protects us from cold as effectually as the blankets on our beds, and is worth to Rochester thousands of dollars in the saving of coal and clothing . . .

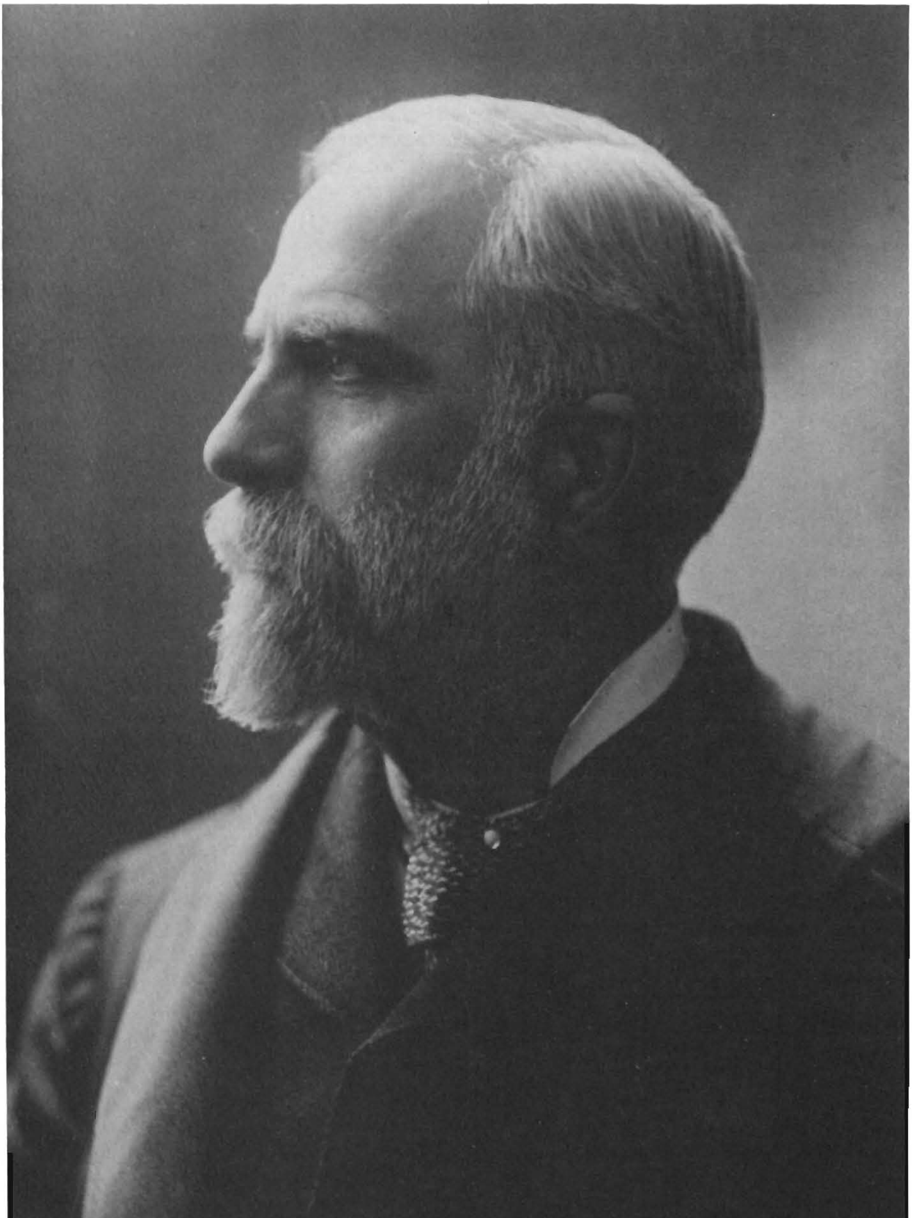

FIGURE 1: Herman Leroy Fairchild

> The climate of Rochester has unquestionable superiority in the moderate temperature, the normal and well distributed precipitation, and the absence of severe winds . . .
>
> The last two weather observers stationed in Rochester . . . agree that Rochester's climate is ideal for the latitude, and remarkably good; that taking all elements into consideration it is the finest inland climate in America . . .
>
> If Rochester has so choice a climate why do so many people speak ill of it? One does not often hear a Californian say ungenerous things of his climate, which, if the truth be told, has some undesirable features. One answer might be that the Californian is whistling to keep up his courage, and that the Rochester climate is good enough to endure abuse. Another answer is that Rochester may have a beautiful climate but that its weather is sometimes pretty bad. Still another reply is that the somber winter skies make people depressed, and that it has become the habit to grumble at the weather. There is a psychological problem involved here.

It is evident from these remarks that Fairchild had adapted well to the move to upstate New York and would be happy to work there on a Pleistocene history of the region.

PLEISTOCENE EVOLUTION OF WESTERN NEW YORK

The Kame Moraine at Rochester, New York

Some of Fairchild's earliest work on glaciation in western New York was concerned with the form and content of masses of sediment deposited under or adjacent to the ice sheets. He began by studying the range of hills known as the Pinnacle Hills, which lie at the southern boundary of the City of Rochester, rising above the flat plain on which the major part of the city was built (Figure 2). The University of Rochester was at that time located a short distance north of this range; during Fairchild's lifetime, it was moved to a location directly at the western end of the range.

Because these hills were close at hand, he was able, as he said, to make preliminary studies that were ". . . the results of but a few weeks study of the subjects in the hours free from college duties (Fairchild archives)." He made the following observation:

> . . . (Because of) their conspicuous position, unusual topography, and complex structure, these hills have not escaped the notice of glacial geologists, but until 1882, no one ventured any detailed description or any explanation of their origin (1895, p. 40). At the Ottawa meeting of the Geological Society of America in December of that year, Mr. Warren Upham read a paper describing these and other deposits of the region under the title 'Eskers near Rochester, N.Y.', subsequently published in the Proceedings (Upham, 1893). In that paper Mr. Upham describes the hills with considerable detail and concludes that they were deposited in the ice-walled channel of a stream of water, 'open to the sky.'
>
> Since that time, the writer (HLF) has been able to make a long and close study of these particular hills and has been forced to a conclusion radically different from that of his friend, Mr. Upham. The opinions as to their origin, which the writer (HLF) holds with full confidence is that the hills are a kame series forming part of a frontal moraine (1895, p. 40).

The difference was an important one. In presenting his view, Fairchild was stating that he had located a marker (frontal moraine) indicating the exact position of the southern edge of the ice sheet during a period of retreat marked by minor readvance. The observations on which Fairchild based his conclusion are presented below. They included observations on the external form of the deposits and on the material of which the deposits were made.

He understood that he had an advantage over his friend as expressed in these remarks: "Mr. Upham's brief examination of the hills was made under the disadvantages that the forests were in full leaf and the gravel pits in active working. Only when the thick timber and undergrowth which covers the roughest portions are bare of foliage does some of the most significant topography appear to good advantage (1895, p. 40)."

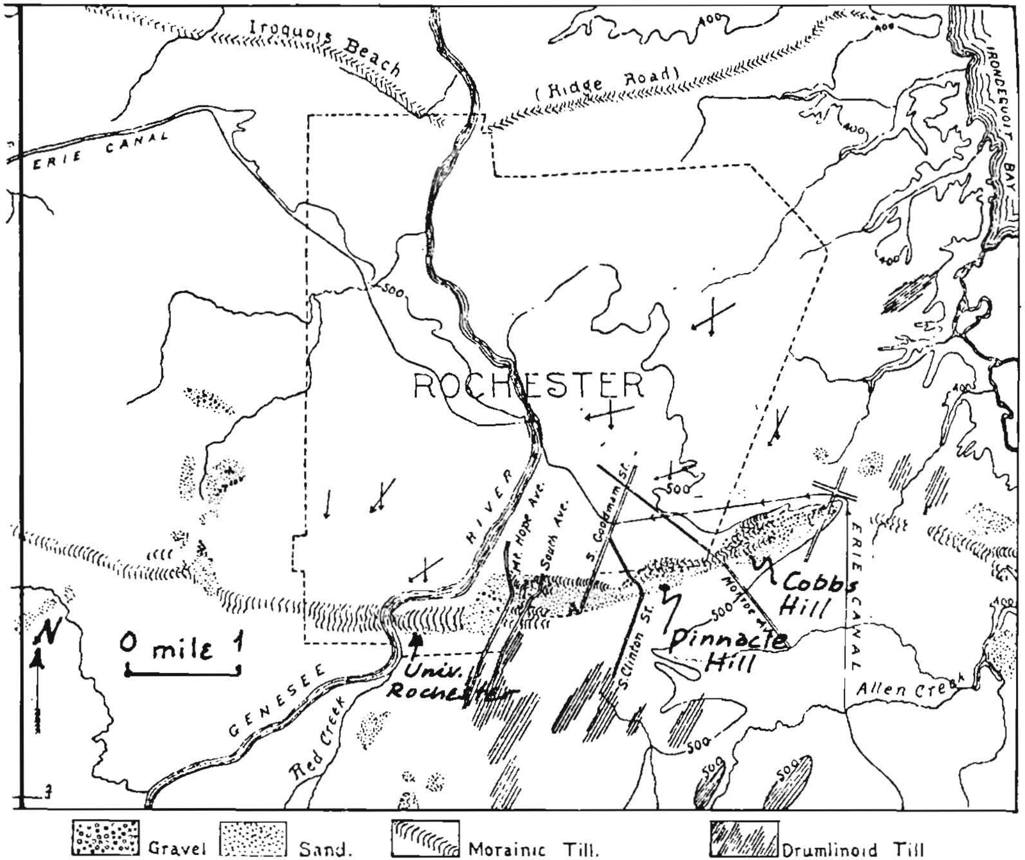

FIGURE 2: Fairchild's map of the Pinnacle Hills showing locations of significant features

This advantage may be understood from a study of his photographs (Figures 3 and 4), which show that the surface morphology was clearly displayed, unobscured by vegetation, and at the outset, unscarred by excavation. Today, much of that glacial topography has been modified by excavation and obscured by the growth of forest cover. Fairchild's description of salient features follows (Fairchild, 1895, p. 42-44):

> The eastern portion of the range consists of a series of overlapping ridges or elongated mounds having their longer diameters parallel in general with the trend of the range (Figure 3). . .
>
> The crest line is very irregular, nowhere level for any distance, varying 100 to 180 feet in height between the groups of hills. The northern slopes of the range are irregular, with spurs and hillocks and deep ravines and, over the eastern half of the range, are usually steep as the material will rest, 25 to 30 degrees. The southern slopes are smoother and more uniform, commonly with gentle inclination to the southern plain into which they blend (Figure 3). . .
>
> A striking feature which has not been sufficiently noted is the frequent occurrence of 'kettle holes' and basins. A better example of mound and basin topography might not be desired . . .

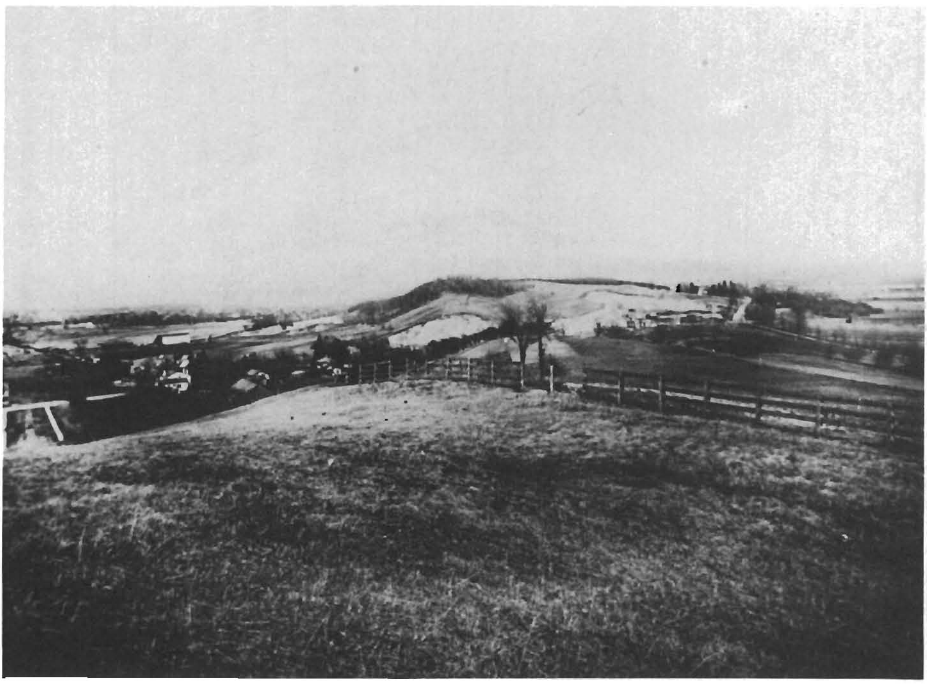

FIGURE 3: Pinnacle kame-moraine—Cobbs Hill as seen from Pinnacle Hill-1895. Note the gentle slope to the south and the steep slope on the ice-contact (north) side.

> The materials composing these hills are so various and with such irregular arrangement that a brief description is difficult. The greater mass of material is sand and gravel, of all sizes up to large cobbles and of every admixture. The large pit in the heart of the north ridge near Brighton is mainly sand and silt. The dip of the beds here is generally southward. A minor portion is true till, which forms a thick sheet over Cobb's Hill and probably the very summit of the Pinnacle. The great pit on the south side of the Pinnacle, reaching almost to the core of the hill and exposing a full 100 feet of vertical section is very nearly all gravel (Figure 4).

FIGURE 4: Internal structure of Pinnacle kame-moraine showing till overlying sand—Cobbs Hill 1914. The water-laid stratified sand makes up the bulk of the Pinnacle Hill; the non-stratified till capping the hills was deposited from ice during a re-advance.

> The structure of the hills would seem to be explained by supposing them to have been built up from several centers of accumulation by shifting torrential streams pouring over a changing ice front. At the time of formation of the Rochester moraine, the Ontario glacier had probably become quite stagnant, and ablation of the surface had doubtless exposed the lower portion of the ice which was heavily charged with material from the Ontario excavation. The hills are regarded as a frontal moraine. The hills were accumulated in the waters of Lake Warren, which laved the front of the glacier.

The present-day reader can follow in Fairchild's footsteps in the field, and by so doing obtain an excellent introduction to the nature of an ice-marginal moraine. The least-modified terrain lies within Highland Park, Highland Park Cemetery, and in what is now called Warren Grove at the east end of Cobbs Hill Park. Much of the rest of the moraine has been modified by the excavations depicted in Fairchild's excellent photographs. These photographs, included here and in Fairchild's publications, illustrate the nature of the material contained within ice-marginal moraines. They also show clearly the kind of evidence used by the glacial geologist to document a readvance of the ice. This evidence consists of the unsorted till deposited directly from moving ice, which is quite different from the water-laid stratified sands on which it was deposited.

Kames and Eskers - Mendon Ponds

Fairchild then turned his attention to the

> . . . remarkable group of gravel hills in the Town of Mendon, 10 miles south of Rochester which he found . . . deserving of special description, because they have no superior in their display of the peculiar characters of morainal deposits (Figure 5).
>
> In the varied and beautiful topography of western New York, there is nothing more unusual and attractive than the Mendon kames . . . The area is not appreciated because the features are not really seen from the highways. Few people today (1926) see anything that is invisible from their automobile. But a little climb up almost any of the roadside knolls will give a view of the hills and hollows with surprising form and relief (Figure 6).

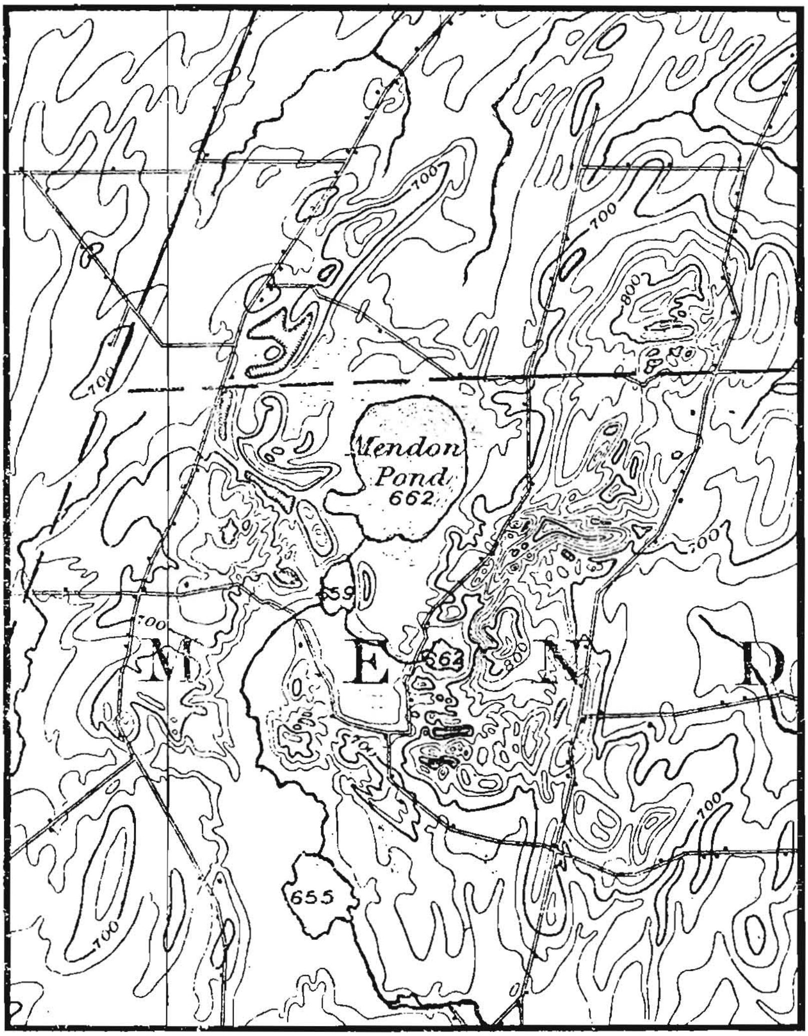

FIGURE 5: Map of Mendon Ponds

FIGURE 6: Mendon Kames from east of Douglas Road

> Through the midst of the eastern high track there winds an esker ridge. This is not very conspicuous, but from some points of view the knolls blend so as to form a very evident eskerine (Fairchild, 1896, p.148).
>
> The topography of the hills is of pronounced knob and basin type and strikingly in contrast with the neighboring drumlins. They are conical, mammillary, billowy, enclosing numerous basins and deep kettles. One mile south of the kame area (on the western side) occurs a singular group of knolls that must be regarded as an esker (also) (Fairchild, 1896, p. 148). (See Figure 7 of this paper.)

> The precise manner of formation of the kame hills is the most obtrusive question . . . There can be no doubt that the greater part of the material of all the groups has been derived from the Ontario excavation and rock degradation upon the north and has been carried southward up hill. It has been lifted hundreds of feet by either ice or water, or both combined . . . The theory advanced by Professor Shaler several years ago seems the most acceptable. In some manner the lifting of the gravel and sands may have been done by forceful upward currents of water at the ice front, impelled by the hydraulic pressure of water in the lofty ice sheet to the northward. The kame deposits under discussion were doubtless formed in the waters of Lake Warren, along a belt where the deep static waters opposed the detritus-burdened glacial torrents (1896, p. 157).

Fairchild correctly understood that the actual materials of which the Mendon hills were made had been plucked by the moving ice from the bedrock in the vicinity of present-day Lake Ontario. He was less clear about the manner in which this material had been transported from its source to its final resting place and even less clear about the setting in which it was deposited. It is now believed that the material was plucked from bedrock sources, incorporated in the basal part of the moving ice, and transported southwards in the ice. As the ice stagnated along its southern edge, channels and tunnels were formed in the ice, and these became, at least briefly, the channels or conduits for streams. Sand and gravel released from the melting ice were moved along these streams and deposited by them. The end results were the two prominent eskers displayed in Mendon Ponds Park to the present day.

Although he described the conical hills (kames) at Mendon as the products of deposition in the waters of Lake Warren, many of them were more likely deposited in contact with irregular large masses of stagnant melting ice. These deposits filled in holes and crevasses in and between ice blocks. The melting of the remaining ice left kettle holes such as the Devil's Bathtub and the broad lake area in the central part of Mendon Ponds Park.

Glacial Lakes and Rivers

Perhaps the major contribution of Fairchild was his effort to determine the location, water-level elevation, and time of formation of the many different lakes which formed between the ice-sheet margin and barriers beyond that margin. We have already seen, for example, that he viewed the Pinnacle Hills as deposits formed between the edge of the ice sheet and the waters of Lake Warren to the south. Where there were lakes, there were also rivers, and he made a major effort to determine the location and age of now-abandoned stream channels.

The elements of Fairchild's interpretation and of the approach that he followed may be understood by examining a sample of one of his drainage maps (Figure 7) and reading his words:

> The glacier acting as barrier to northward drainage is the fundamental fact to be apprehended . . . The ice sheet was a melting dam during both its retreat, and waters were flowing copiously from it, not into it. Valleys or land depressions sloping toward the ice front were by the ice barrier made into lake basins (1909, p. 7). The earliest outlets for the ice-dammed waters were at the heads of the greater valleys . . . A later escape of the waters was by flow past the ice margin across the ridges between lakes . . . (These) rivers of glacial water had no less power of carving channels and building deltas than other streams and these effects of the ancient rivers are still conspicuous evidence of their existence (1909, p. 7).

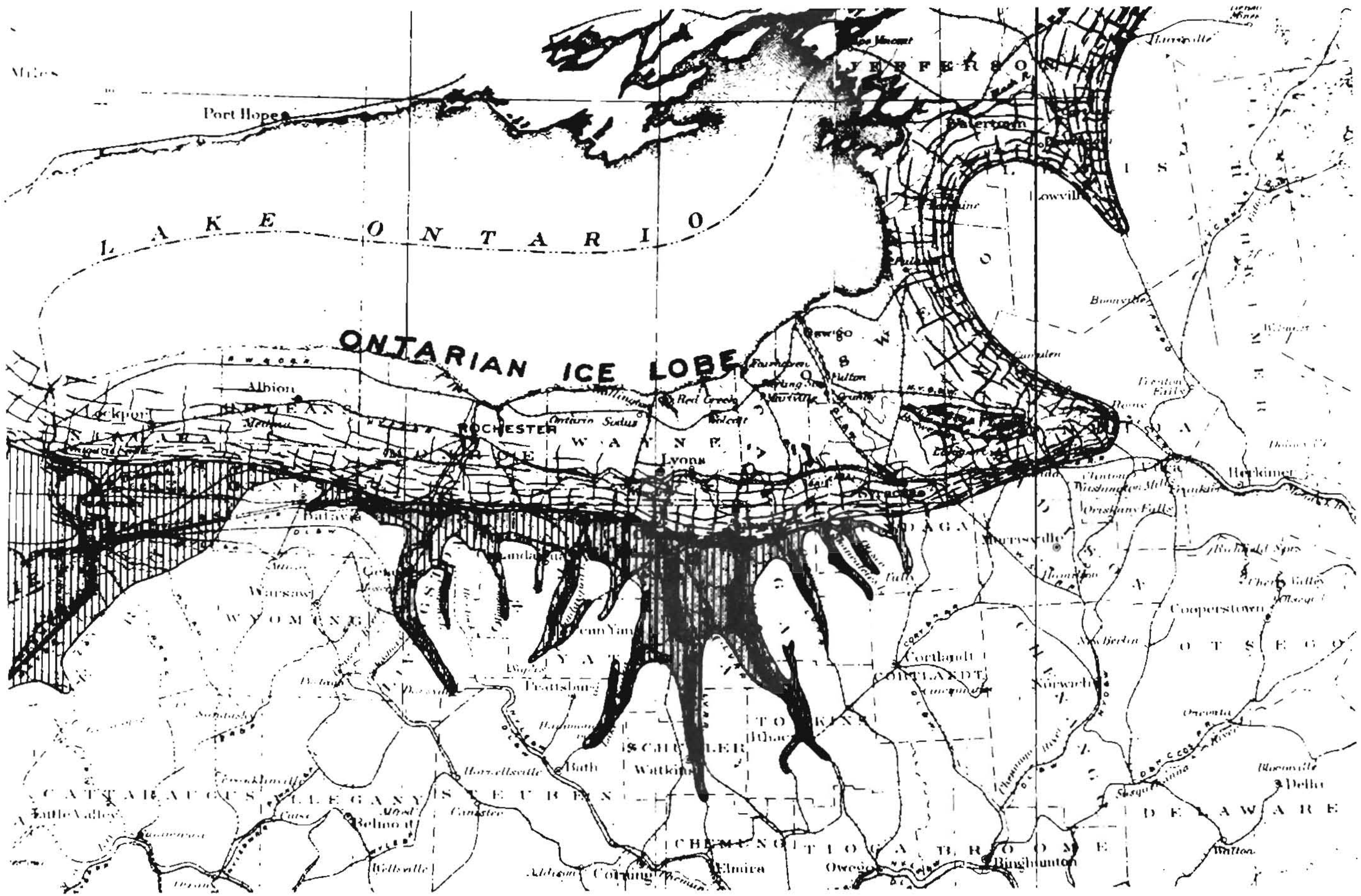

FIGURE 7: Map of Lake Warren

Each ice marginal lake had a shoreline; if this shoreline persisted long enough, it could leave its mark on the landscape — a mark that might still be recognizable even after the lake had vanished. Similarly, a stream channel will remain even after the stream has vanished, so the drainage into and out of glacial lakes could be traced by mapping these abandoned channels. Many of these streams also were capable of building deltas at the point at which each stream entered standing water. These deltas also remain after the water of both lake and stream has vanished. Therefore, Fairchild had only to locate these shorelines, channels, and deltas to determine the position of these now vanished lakes and rivers. He explained his motivation in the following words:

> The records of these extinct waters are the very latest phenomena connected with the ice invasion, and are the connecting link between the glacial condition and the present . . . The matter is of lively interest to perhaps only a few persons, but the details are necessary to the more general study of the Pleistocene. No economic or practical result from the knowledge is foreseen, but as pure science the study of these waterless lakes, waveless shores, and streamless channels has a fascination and romance. Its immediate results are of some value in helping to determine the conformation of the glacier front during its recession, and the deformation of the land surface since the shoreline features were produced (1899, p. 29-30).

When Fairchild began these studies of now-vanished lakes and rivers, he was able to build on the work of some illustrious predecessors. G. K. Gilbert, who had attended the University of Rochester, had already established the existence of certain very large lakes and channels and had suggested to Fairchild that he carry out detailed investigations. Fairchild then set out to make *complete* maps of the lakes and channels in New York State. In doing this, he found that ". . . the glacial lake history in central New York is somewhat more complicated than has been supposed and the drainage phenomena are involved in the problems (Fairchild, 1909, p. 5)."

A sample of this work is provided by his work on the glacial lakes, which we call Lake Warren and Lake Iroquois, and on the drainage associated with these lakes.

> Lake Warren (Figure 7) is a name given by geologists to an extensive body of water held at a high level in a portion of the Laurentian Basin by a barrier of glacial ice which blocked the low eastern outlets. The Laurentide continental glacier, which at its maximum covered all the upper Mississippi Valley and the basin of the Great Lakes, had at this time receded so as to leave at least the southernmost part of the Laurentian Basin exposed. The ice still lay over Canada and northeastern New York, and the water in the uncovered parts of the basin being unable to escape by the Saint Lawrence or Mohawk Valleys, these being still closed by the ice sheet, was compelled to find an outlet to the sea by the Mississippi.

The lake that discharged west to the Mississippi River was called Lake Warren. Since the existence of a Lake Warren had already been postulated, Fairchild began his work on glacial lakes by looking for local evidence of Lake Warren's effects. He describes these beginnings as follows:

> The first search for Warren beaches in the Genesee district was made in the spring of 1896 and with immediate success. The first discovery was of the bars and spits (Figure 8) near East Avon (Figure 9), which were traced eastward to Lima. Later the beach was found at Morganville, east of Batavia, and traced both eastward and westward (1899, p. 269-270).

He also found many wave-cut notches in drumlins, the elongate inverted spoon-shaped hills for which the region is deservedly famous. Each drumlin was originally a smooth, streamline-shaped hill. Fairchild reasoned that the rise of lake waters around these drumlins must have isolated them as islands. Wave action at the shore of these islands could be expected to erode the shore line, thus creating a break in the smooth, steamline-shaped hill. Fairchild reasoned that the rise of lake waters around these drumlins must have isolated them as islands. Wave action at the shore of these islands could be expected to erode the shore line, thus creating a break in the smooth profile. After the lake waters drained away, this break or notch would remain as evidence of the existence of that lake. Fairchild found many such notches; one cut in the north end of a drumlin in the Town of Rush is shown in Figure 9. Here, and at all other locations, he determined the elevations himself by spirit leveling. From these clues, one can see what he meant by the study of waterless lakes and waveless shores. There is no Lake Warren now; the land is high and dry. Yet, the shore of Lake Warren still stands, now at an elevation of about 880 feet above sea level.

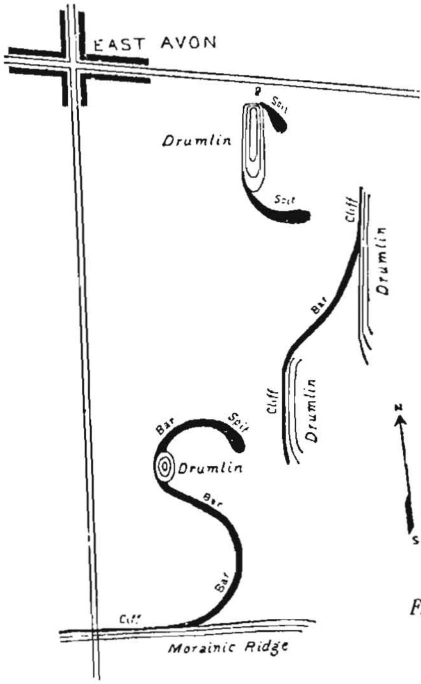

FIGURE 8: Map of East Avon showing drumlins

FIGURE 9: Rush Drumlins showing wave-cut notch on north end (1898)

Fairchild then explained how the retreat of the ice front could in time provide the lake waters with a different, lower outlet, which would cause a drop in lake level, a new shoreline, and a torrent of water released through the new outlet. Here is his description of the end of Lake Warren:

> For a long period, perhaps several thousand years (Lake Warren) . . . waters had been tributary to the Mississippi, but for some centuries they had been creeping eastward along the ice front as if in patient search for a new escape that was sure to come. The life of Lake Warren was determined by the opening of a new and lower outlet, eastward, past the ice front to the Mohawk-Hudson . . . (where) . . . the great Warren waters found lower escape to the sea and excavated in their flow toward the Mohawk a series of remarkable channels, piling the debris in great deltas in the more quiet waters of the intersected valleys (1899, p. 250, 259).

Fairchild found fine examples in the Syracuse region of these channels cut by the waters escaping from Lake Warren. A map of some of these channels (Figure 10) shows the great ancient waterway with its several branches and very extensive deltas. Fairchild described some of the features shown on the map as follows:

> As a whole the channels and its deltas are the most imposing among the features in New York State . . . The delta is of magnificent size and form even in its present fragmentary state (1909, p. 28).
>
> The western one of the two (Marcellus) canyons is called in lack of some geographic name, after the local appellation the "Gulf" . . . The bare limestone at the intake covers many acres (as) shown in plate 18 (Figure 11), a characteristic view of a water-swept limestone surface.
>
> It is apparent that the great channel was not cut by merely local waters, for the features require the work of an enormous volume of water (1909, p. 26). The lowest of the group of (Jamesville) channels is one of the most convincing illustrations of the work of ice-dammed water, and in its form, preservation of features, and accessibility to observation is the handsomest glacial lake outlet channel in the state. The western end of the channel (Plate 19, Figure 12) is 3 miles southeast of Syracuse. The channel is 2½ miles long, 800-1000 feet wide at the bottom, and 125-150 feet deep (1909, p. 33).

Flow of the waters from Lake Warren through these channels and the retreat of the ice led to a lowering of the water level, allowing Niagara Falls and Lake Erie to come into existence. At this time, the lower (600 ft) channels at Syracuse were recut and later the channel leading east from Fairport, near Rochester (Fairchild, 1909, p. 58).

> The last long-permanent water level in the Ontario Basin was that maintained by Lake Iroquois (Figure 13). Its level was determined by the pass at Rome leading to Mohawk Valley. Shoreline features of Iroquois have an altitude of 430-440 feet, but are about 460 feet near Rome (Fairchild, 1909, p. 59).

Fairchild summed up his studies of glacial lakes with these remarks:

> It is probable that future and more detailed studies will discover new elements in the glacial history and find the series of events more complicated. It is therefore possible that some of the theory may be wrong. However, there is no doubt of the existence of the several planes of glacial waters as discriminated . . . (by him), nor of the production of the channels by the ice-border rivers. These facts of observation will stand even if the interpretation may change (1909, p. 59).

FAIRCHILD'S VIEW ON PRESERVATION

As a geologist working across New York State over a period of many decades, Fairchild had an unusual opportunity to view the way in which the American people were making use of their natural resources. He also had ample opportunity to view and record changes made in the New York State landscape between 1880 and 1930. This led him, on several occasions, to become involved in discussions about the use and conservation of natural resources in both New York State and the entire United States. He assembled a fine collection of photographs of the Pinnacle Range, which showed:

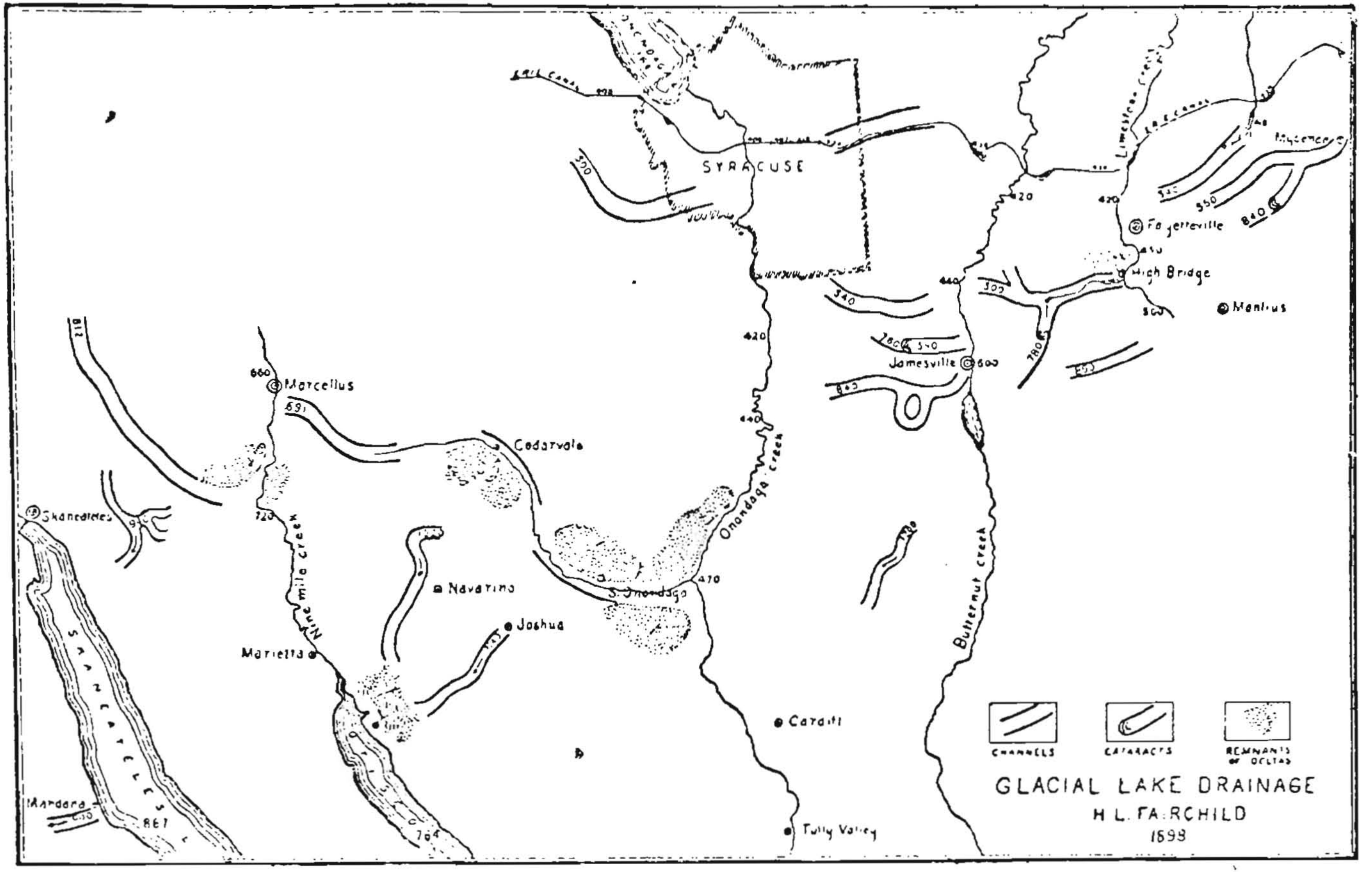

FIGURE 10: Map of the Syracuse channels

FIGURE 11: Intake of the Gulf Channel showing bare limestone surface

FIGURE 12: Abandoned Lake Warren discharge channels

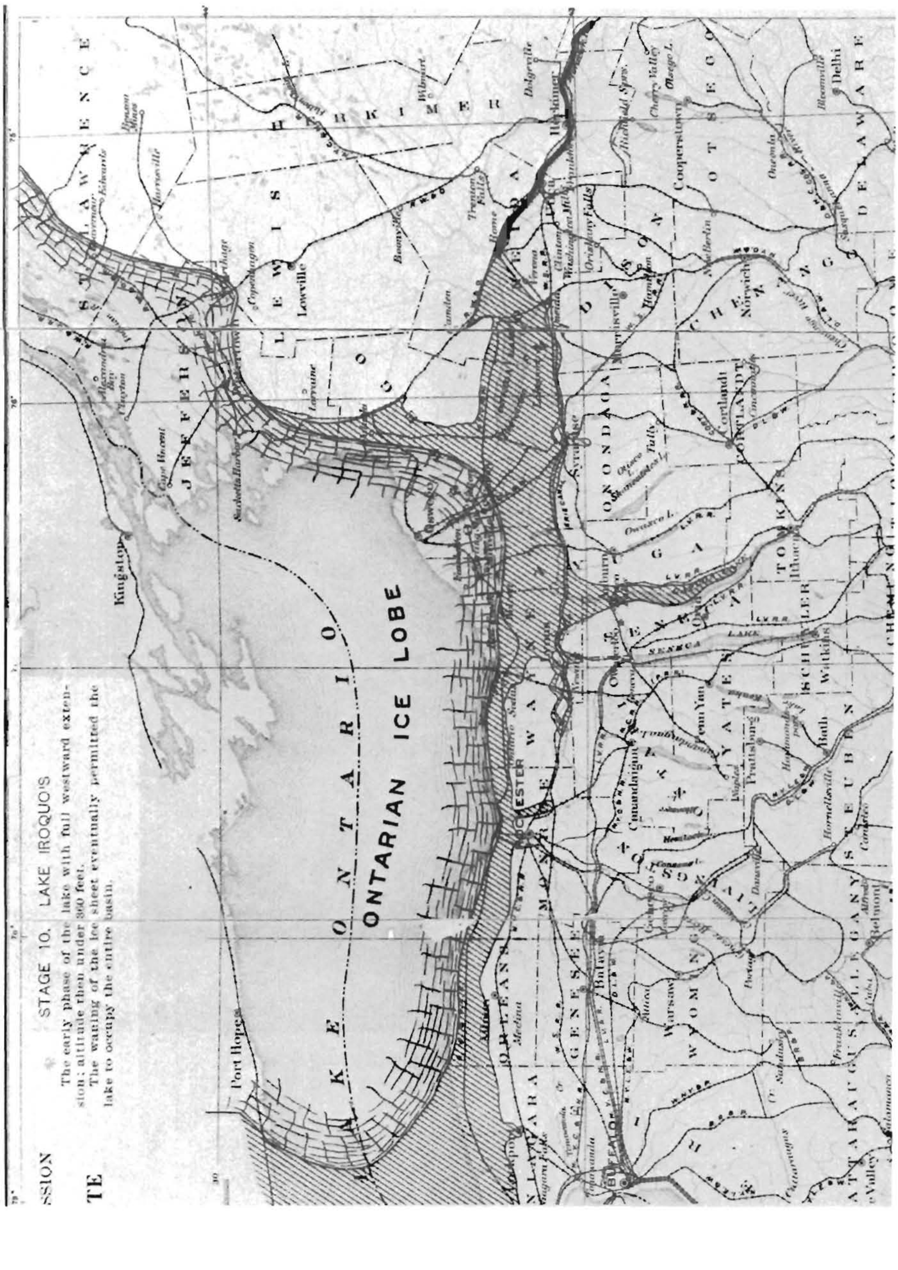

FIGURE 13: Map of Lake Iroquois

FIGURE 14: Excavation of the Pinnacle Hills

> . . . some of the despoilment of this splendid scenic feature (the Pinnacle Range), which came about when it was discovered early in the growth of Rochester that much of the Pinnacle Range was sand and gravel . . . useful for building material. The eastern ridge at Brighton was largely cut away, and (was) filled and graded . . . The same sad story is true of the very interesting stretch between the Pinnacle and South Goodman Street (Figure 14). Fortunately, some portions of the Pinnacle Range have been reserved from private exploitation. Mount Hope Cemetery, Highland Park, Cobbs Hill and the Dingle, east of the Cobb's Hill Reservoir, are the preserved areas (1929, pp. 68-69).

A battle to preserve the Pinnacle itself, a battle in which he was very much involved, was lost. After losing this battle, he turned his camera towards the Mendon Ponds area. He explained why in the following words (Fairchild, 1926, p. 195):

> The pictorial record is made in anticipation of the possible defacement by the growth of population and the march of improvement(!). The destruction of some of the most beautiful portions of the Pinnacle Range is a warning of the danger to other features of our finest scenery. The whole area should be preserved as either a State or County Park.

Fairchild also recommended, on the basis of his studies of the buried valley of the pre-glacial Genesee, that it be investigated as a water resource. In 1930, he wrote that . . .

> It would appear worthwhile for the city engineers to probe to the bottom of the drift in the middle of the valley, and to measure the flow and pressure (of the water . . . The artesian supply could never be a major service for the great city (of Rochester) like that from Honeoye Valley or from Lake Ontario. But it might be a useful supplementary supply (1930, p. 243).

This proposal became more controversial than he perhaps expected, as can be seen from headlines in the Rochester *Democrat and Chronicle* and the *Times Union* for 1935. Fairchild's involvement in this question was based on studies he had made of the buried valley. Yet, the headlines and the stories that accompanied them demonstrate that scientists then as now who participate in public discussion of the use of natural resources may find themselves involved in unpleasant controversy.

One of Fairchild's honors, growing out of his long interest in the resources of New York State, was to be named to President Theodore Roosevelt's Conservation Congress in 1910. As a result of his participation, he wrote the following words, published in 1911.

> The American people are the most extravagant and wasteful that ever inhabited the earth. This statement is absolutely true. In a single century, with the aid of science and invention we have so drawn on the natural resources of a great continent as to justify alarm for the future. The public-be-damned way of treating the products of nature is unscientific, unaltruistic, and undemocratic (1911, p. 539-540).

These were strong words. Happily, Fairchild's wish that Mendon Ponds be preserved was fulfilled, and the area continues to provide a superior display of ice-contact glacial features. The same is true for the parts of the Pinnacle Range which he had characterized as preserving their original features.

Fairchild's work and his photographs continue to provide a context in which modern work takes place. That work has added many chapters to a story that is longer and more complex than he could realize, but the development of this story continues to owe as much to him as to any other single person.

ACKNOWLEDGEMENTS

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GLACIAL GEOLOGY IN WEST-CENTRAL NEW YORK: PROGRESS SINCE THE PIONEERING INVESTIGATIONS OF H. L. FAIRCHILD

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ABSTRACT

Although based primarily on landscape interpretation and therefore focussed on the latest glacial episode, Fairchild's concepts of New York glacial geology still serve, more than 50 years later, to stimulate current studies.

Isolated, fortuitously preserved drift exposures, such as those at Fernbank, Otto, and Gowanda, fragmentally document prior glacial history unknown to Fairchild.

Relationships among glacial moraines and shorelines of proglacial lakes, increasingly substantiated by stratigraphic information, record a complex history of Wisconsinan glacial fluctuations. The restudy of meltwater channels, described earlier by Fairchild, provides new insight about the catastrophic events which they record.

INTRODUCTION

During an immensely productive lifetime of some 60 years, Fairchild published approximately 265 articles, of which one half deal with aspects of physiography, glacial geology, and Pleistocene history of New York (Anon. 1932; Chadwick, 1945). Indeed, Fairchild's facile interpretations of New York glacial landscapes continue, more than half a century later, to be the foundation for current investigations.

Fairchild began his investigations in the days of the horse and trolley. When he concluded his work, geophysical surveys and geochemical analyses were yet to be applied to Pleistocene problems. The chronologic framework of the Ice Ages which we know today from the record in continuous seafloor sedimentation, was then only suggested in fragmentary records left by continental glaciers. Lacking an adequate basis for assessing the duration of the Pleistocene, Fairchild was handicapped in interpreting its record.

Codification of multiple bases for stratigraphic classification was yet to be developed. In any case, Fairchild relied heavily on morphostratigraphy, since only rarely did he have the data for rock stratigraphic correlation. Concepts of weathering profiles were newly developing, and techniques of absolute dating were yet to be conceived.

Fairchild interpreted the glacial record primarily on the basis of topographic relationships among glacial and proglacial features. In so doing, he recognized glacial recession as oscillatory and developed evidence of a late glacial renewal that had restored westward drainage from the Great Lakes to the Mississippi River. While acknowledging multiple glaciation, he recognized that the latest glacial episode was all dominant in the geologic record he studied. Without the benefit of remote sensing, air photographs, or even adequate topographic maps, he drew astute conclusions as to the meaning of landscape features of New York State.

PLEISTOCENE EROSION

So completely has the record of previous glaciation been obliterated in New York that for Fairchild, as for many other investigators, the Pleistocene virtually begins and ends with the recessional phase of the Wisconsinan Stage. Fairchild could conveniently refer to the onset and end of glaciation as a single discrete event, unaware of the duration and complexity of the Pleistocene Epoch.

Most of what one can learn of pre-Wisconsinan history in New York must be interpreted from evidence that is missing — removed by Pleistocene erosion. Accordant summits in unglaciated northwestern Pennsylvania and western New York are conceived as vestiges of a preglacial erosion surface (Cole, 1938; 1941). Extrapolation of this hypothetical erosion surface northward into the glaciated area affords a crude basis for estimating total reduction of uplands by glacial erosion (Muller, 1963a). Within 50 miles north of the glacial limit, one quickly loses confidence that existing summits bear a determinable relationship to the preglacial surface.

Glacial scour was more effective in widening, deepening, and smoothing valleys than in reducing adjacent uplands. This resulted from the greater thickness, velocity, and duration of iceflow over valley floors. Although tending to underestimate the effectiveness of glacial erosion, Fairchild recognized bedrock floors lower than sea level as evidence of glacial deepening of Finger Lake troughs.

Northward from the glacial limit, present trough patterns bear a diminishing relationship to preglacial drainage. Clearly, the anastamotic pattern of trough valleys is not characteristic of stream erosion (Clayton, 1965). Rather, it represents the product of multiple episodes of drainage derangement (Coates, 1966) and of glacial erosion laterally across saddles between major troughs. Subglacial iceflow was channeled by, and significantly transformed, the underlying topography.

With respect to the preglacial drainage pattern in west-central New York, less is known for fact today than was assumed in Fairchild's time. Ancestral Ontarian and Erian Rivers persist in hypothesis, but we know better today how conjectural are their hypothesized courses. Glaciation has obliterated the evidence. Although northward drainage of the Ancestral Allegheny River is well established (Carll, 1883), its precise course across the Erie lake plain north of Gowanda remains elusive (Ellis, 1980).

Instances of stream diversion are numerous, but present knowledge of the complexity of the Pleistocene Epoch prevents the easy assumption that all diversions resulted from the same glaciation. In Fairchild's accounts of such drainage modification, one must be prepared to substitute "interglacial" for "preglacial," keeping alert to the simplistic view of the Pleistocene which prevailed at that time.

PRE-WISCONSINAN DEPOSITS

The terrestrial sedimentary record of Pleistocene glaciation is rather like the record at day's end on a chalkboard in a classroom used in turn by a number of different classes. Each lecturer erases most of the record of what went on before, then makes his own chalkmarks on the board. When the day is over, only the record of the final part of the last class remains intact. Here and there, however, vestiges of previous lecture notes can be perceived around the edges of erasures, or blurred where erasure was incomplete.

Because each glaciation destroys the evidence of previous, less extensive glacial episodes, only fortuitous location either beyond all subsequent glacier limits, or in protected situations, permits preservation of deposits of pre- or Early Wisconsinan age. A dozen localities across New York State are now recognized as preserving stratigraphic documentation of glaciations prior to the Late Wisconsinan.

Bordering the Salamanca Re-entrant in southwestern New York are deeply weathered terrace remnants (Figure 1) which have been variously considered as Wisconsinan or pre-Wisconsinan (MacClintock and Apfel, 1944). Beyond them, across the Allegheny River are isolated patches of drift and cols, vestiges of a probably pre-Wisconsinan ice border (Bryant, 1955). All are deeply inset in the valley carved 600 feet deep across the Kinzua Col following glacial reversal of the Ancestral Allegheny River (Muller, 1963b). The time of this initial diversion cannot be firmly established, but it probably began with the earliest approach of the ice sheet to the Salamanca Re-entrant and preceded Illinoian glaciation.

More specific evidence of the Sangamon Interglacial which preceded the Wisconsinan Glacial Stage has been documented by Bloom and McAndrews (1972) at Fernbank on the west shore of Cayuga Lake. Invertebrate tests first reported by Maury (1908) and pollen spectra studied by McAndrews point to environments comparable with those of the Don Beds of Toronto during the Sangamon Interglacial. The location of these sediments on the trough slope indicates that Cayuga Trough had already achieved essentially its present form as a product of long glacial erosion before deposition of the Fernbank beds.

The upper part of the Fernbank section records an abrupt change to boreal conditions following an interval of unknown duration. Like two other intrastadial sites in the Cayuga Trough, the age of the upper Fernbank beds has not been established as being within the range of C-14 dating.

A finite date of 63,900 ± 1700 years B.P. (GrN-3213) has been obtained for highly compacted peat beneath two till sheets exposed in a streambank on the western edge of the Cattaraugus County community of Otto (Muller, 1964). The organic remains record a boreal forest assemblage indicative of intrastadial conditions between substadial episodes of the Wisconsinan. Detailed supporting stratigraphic evidence of the Otto Intrastadial site is developing at the Gowanda Hospital Site (Calkin et al., in press).

AGE OF THE WISCONSINAN TERMINAL MORAINE

Contrasts in depth of leaching, drift constitution and topographic modification led MacClintock and

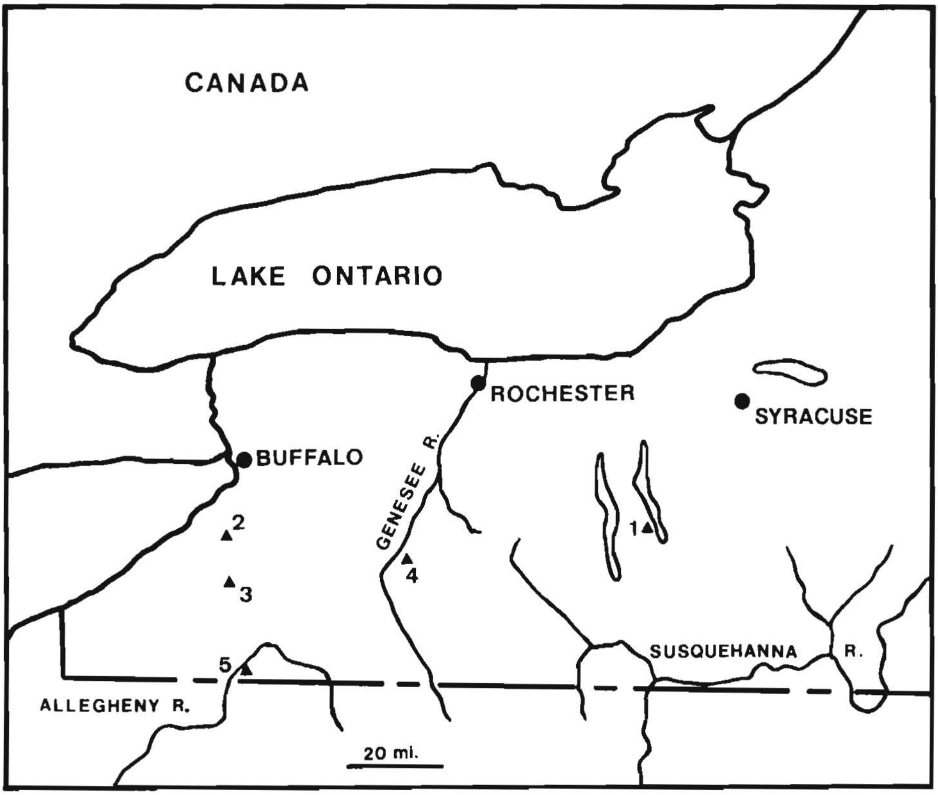

FIGURE 1: Western New York, showing location of sites, mentioned. 1. Fernbank; 2. Gowanda Hospital (Clear Creek); 3. Otto; 4. Rush Creek; 5. Salamanca Reentrant and terrace remnants.

Apfel (1944) to distinguish the Wisconsinan terminal moraine northwest of the Salamanca Re-entrant as being younger than marginal deposits northeast of the Re-entrant. The latter they named the Olean Moraine and Olean Drift. The age distinction thus inferred has recently been questioned by Crowl and Sevon (1980) on the basis of westward tracing of the terminal moraine from eastern Pennsylvania where it is considered to be Woodfordian.

Data are not yet adequate to resolve this difference. On the one hand, morphologic and stratigraphic evidence cited by MacClintock and Apfel is now either inconclusive or inaccessible. On the other hand, radiocarbon data invoked by Crowl and Sevon postdate recession by an indeterminate amount. The age first proposed for the terminal moraine by Crowl and Sevon (1980) in accord with a 12,760 ± 135 year B.P. (SI-1341) age for wood ostensibly collected from outwash at Brodheadsville, is in direct conflict with well-established regional relationships. An earlier Woodfordian age for the terminal moraine merits consideration, although pre-Woodfordian Wisconsinan glaciation is also well documented in northwestern Pennsylvania (White et al., 1959).

KENT STADIAL

Alone among major New York rivers, the Genesee River rises near the Wisconsinan terminal moraine and drains northward. Thus proglacial meltwaters were imponded within the Genesee Basin whenever a glacial barrier existed in central New York. The general validity of Fairchild's chronology of Genesee Valley lake succession has been supported by recent investigations.

The youngest radiocarbon date on organic material contained within or beneath till in west-central New York affords a minimum date for the onset of Late Wisconsinan Kent Glaciation. A small wood fragment imbedded in unweathered till near stream level in Rush Valley, east of Fillmore, yielded an age of 25,450 (+ 6657/ – 3600) years B.P. (QC-238). It is thus evident that the upper Genesee Basin was unglaciated during an interstadial correlative with the Plum Point Interstadial of western Ontario, but was early overridden during the Kent Glaciation.

Glacial advance to the Kent Moraine imponded glacial Lake Wellsville with its outlet west across the Stone Dam Col via Honeoye Creek along the State Line into the Allegheny drainage basin. This meltwater spillway occupies a valley so deep and narrow that it must have experienced more than one episode of glacial derangement.

Recession from the Kent Moraine exposed a lower westward outlet with present threshold elevation of 1495 feet. This permitted drainage southwest past Cuba via Oil Creek to the Allegheny. The lake level controlled by this outlet, Fairchild named Lake Belfast-Fillmore (Fairchild, 1928). In places laminated lake sediments of Belfast-Fillmore are exposed between till sheets.

In the high bluff 0.5 miles north of Caneadea, however, varved sediments comprise a 30-foot thick unit at blufftop. In connection with ongoing paleomagnetic studies, William Brennan (S.U.C. at Geneseo, pers. commun., 1981) has recently obtained a radiocarbon date of 16,380 (+ 660/ – 710) years B.P. (DIC 1884) for organic carbon within clay at the base of this unit. This date is in good accord with the age of 15,300 ± 190 years B.P. reported by Clarence Gehris (S.U.C. at Brockport) for the base of a shallow bog west of South Dansville (Muller, 1976).

VALLEY HEADS GLACIATION

The Valley Heads Moraine System is the most massive and conspicuous glacial feature in the plateau, forming the watershed between northward drainage to the St. Lawrence and southward drainage to the Susquehanna and Allegheny Rivers. Its prominence is partly a function of position on the drainage divide, but it also reflects deposition at the margins of nearly co-extensive minor glacier oscillations.

In westernmost New York and southwest into Pennsylvania and Ohio, the equivalent Lake Escarpment Moraines diverge as a series of arcuate ridges, curving concentrically toward the axis of the Erie Basin. These moraines of the Lake Escarpment System mark marginal deposition by a fluctuating ice border which terminated in Glacial Lake Maumee, an ancestral lake in the Erie Basin with an outlet southwest via the Wabash to the Ohio River.

Retreat from the Valley Heads Moraine in the Genesee Valley yielded access for meltwater escape southeast to the Cohocton River and thence to the Susquehanna. Simultaneously, morainal Portageville

Lake, the much reduced remnant in the basin of Lake Belfast-Fillmore, drained north across the Valley Heads Moraine in the broad bedrock sag at Portageville. Minor recession of the Port Huron ice lobe lowered Lake Maumee after deposition of the innermost of the Lake Escarpment Moraines (the Girard Moraine of Leverett (1902)).

PORT HURON STADIAL

Minor readvance of the ice margin in eastern Michigan raised the level of imponded waters in the Erie Basin to the Whittlesey level, controlled by drainage across "The Thumb" of Michigan to the Grand River. This readvance reached its maximum at the Port Huron Moraine of Michigan. Long-distance correlation of New York moraines with the Port Huron maximum is based upon their relationship to the Lake Whittlesey strand. Whereas Fullerton (1980) considers the Girard and Gowanda Moraines to be of Port Huron age, Muller (1977) and Calkin and McAndrews (1980) relate the Hamburg and Marilla Moraines to the Port Huron Stadial.

By 12,730 ± 220 years B.P. (I-3665), waning of the ice margin in eastern Michigan lowered impondment in the Erie Basin to the Warren level. This lake stage, which began in New York before glacial retreat from the Marilla Moraine, ended before retreat from the Alden Moraine. During this interval, imponded waters in the Genesee Valley drained west as the Pearl Creek Channel south of Pavilion was uncovered, initiating Lake Hall as an early contemporary of Lake Warren.

Lowering of the threshold of the Grand River outlet west across Michigan was followed by opening of drainage eastward across New York by the Mohawk Valley to the Hudson River.

MELTWATER CHANNELS

Among the most striking landscape features along the north margin of the Allegheny Plateau are the cross valleys carved by eastward escape of imponded meltwaters. Impondment in most troughs north of the Valley Heads Moraine was initiated as Fairchild's "primitive lakes" with outflow south across the moraine barrier. As the retreating ice margin uncovered progressively lower outlets, some of the lakes coalesced, and others drained laterally into major troughs. The largest of these coalescent lakes was Lake Newberry, which included the basins of Seneca and Cayuga Lakes.

Two northward salients of the Onondaga Limestone outcrop belt served as critical thresholds, preventing eastward outflow of the proglacially imponded lakes. For waters dammed in the Finger Lakes and Genesee Basins, the salient northwest of Syracuse was critical. For waters imponded in the Erie Basin, the salient north of Batavia exerted control.

Uncovering of the Onondaga scarp northwest of Syracuse permitted drainage of Lake Newberry, initiating the Syracuse Channels eastward toward the Mohawk. By the time the waning ice border permitted escape of Lake Warren waters into the Genesee Valley, the level of impondment in the Genesee area was already rapidly lowering through the Rush-Victor Channels.

BATAVIA GLACIATION

Cross-cutting relationships of the Batavia Moraine, transecting earlier moraines, and the similar relationship of its eastward correlative, the Waterloo-Auburn Moraine, suggest readvance, perhaps a surging readvance on a broad front. Proglacial meltwaters were again imponded with progressively rising levels until renewal of westward drainage at a lowered level of Lake Warren. This strandline truncates the Buffalo and Niagara Falls Moraines (Muller, 1975).

During subsequent recession, the threshold north of Batavia appears to have cleared before the threshold northwest of Syracuse. This permitted the waters of Lake Warren to enter the Genesee Valley before eastward outflow resumed.

Insights gained from studies of geomorphic, sedimentologic and hydrologic relationships involved in cutting of the channeled scablands of the Columbia Plateau (Bretz, 1969; Baker, 1973) have been applied in a number of recent studies of the cross channels. Catastrophic outflow involved in the release of imponded waters was an impressive geologic agent, as attested by the canyons, plunge pools, hanging deltas, and anastamotic pattern of floodways.

Following retreat from the Onondaga Limestone belt, the ice sheet in western New York built the Barre Moraines, largely composed of stratified drift deposited in imponded waters on the lake plain west of Rochester. Minor readvance is suggested by the Albion-Pinnacle Hills Moraine. East of Rochester, the several levels of overflow into the Fairport Channels, and the plexus of channels that spread east past Macedon, Palmyra, and Lyons, all suggest a catastrophic discharge marking the demise of Lake Scottsville as impondment in the Genesee Valley dropped to the level of Lake Dawson.

Youngest of the moraines in west-central New York is the Carlton Moraine, which has been correlated eastward with the Oswego Moraine. ''Fishtailing'' of drumlins in the Williamson Quadrangle northeast of Rochester suggests minor readvance to this position, presumably briefly restoring Lake Dawson.

Recession from the Carlton Moraine permitted westward spread of Lake Iroquois waters. Isostatic rebounding of the Rome outlet caused transgression of the lake along its southern and western margins. This partly accounts for prominence of the Iroquois strand along present Ridge Road west of Rochester. Similarly prominent development along the west flank of the Tug Hill may be attributed to the plentiful sand supply exposed to the full fetch of dominating west winds.

CONCLUSION

If this brief account of the current status of glacial geology in west-central New York bears the unmistakable imprint of Fairchild's genius, it should come as no surprise. Rather, one can reasonably inquire why no greater progress has been achieved since Fairchild's time. With the initiation of geologic surveys in New York State now nearly 150 years ago, it is surprising that the surficial geology of the state is still incompletely mapped. Recent commitment by the New York State Geological Survey to direct all available resources to the completion of a five-sheet Quaternary map of the state affords a basis for hope that within the next few years this condition will change.

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THE GEOLOGIC EVOLUTION OF THE GENESEE VALLY REGION AND EARLY LAKE ONTARIO: A REVIEW OF RECENT PROGRESS.

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ABSTRACT

When the last glacial ice sheet retreated from the northern Adirondacks and the St. Lawrence valley became the major glacial meltwater outlet for the Ontario basin, a series of low-level lakes were created as the isostatically depressed crust slowly rose concurrently with the glacially lowered sea level. The progressive southwestward tilting of the Ontario basin produced emergent shoreline features at the east end of the lake as the west end became submerged. The Irondequoit Bay bar sediments near Rochester contain a unique record of these events that can be compared with lake level indicators already tentatively correlated from the Thousand Island region across the Lake to Hamilton, Ontario. The shorelines at Rochester were at least 140 to 200 feet below the present level of Lake Ontario. As the lake basin was gradually tilted to the southwest, Irondequoit Bay was flooded, submerging the ancestral Genesee River valley located beneath it. Most of the southwest shore of the lake continues to be submerged at a rate of about 1 foot each century.

Recent engineering borings for deep sewer tunnel construction near Rochester have defined several zones of faulting and open folding that are not parallel to the prominent Appalachian structures to the south. Care must be taken to distinguish these deep-seated structures from surficial ice-thrust deformation, which also appears to be a common regional phenomenon.

The northwest trending folds and fault zones may correlate with some of the glacially scoured gaps in the Niagara Escarpment, and may be reflecting the influence of deeper seated, Grenville age basement structures exposed further north in Ontario.

Our ability to understand and interpret many of these regional events and features owes much to the basic observations and writings of the early scientists such as H. L. Fairchild.

INTRODUCTION

The region around Rochester, N.Y., contains a variety of interesting landforms and sedimentary deposits created or modified by the processes of continental glaciation. The most recent ice advance (the Wisconsin Stage) began about 75,000 years ago, and the ice finally retreated from the Rochester area about 13,000 years ago. Events during the glacial recession were dominated by the formation of a series of proglacial lakes that paralleled the ice margin. The relict shorelines of these glacial lakes and the buried valley beneath Irondequoit Bay (presumed to represent an ancestral Genesee River course) are two of the many glacial features studied by H. L. Fairchild that are most familiar to area naturalists, amateur geologists, and the public. Because of their influence on the geography of the Rochester area and its surroundings, the geologic explanations of these features have intrigued many individuals outside the academic community of Quaternary and Pleistocene geologists.

Fairchild and the other geologists who first described the extent and nature of these glacial features in detail provided modern geologists with the broad framework of the important geologic events that characterized the late glacial history of central and western New York. These early geologists also have preserved in their writings an important photographic and descriptive record of many glacial features that have since been paved over or destroyed by urban expansion and excavation.

Prior to the 1950's, geologists did not have the advantage of the extensive radiocarbon chronology that has since helped to resolve some of the controversial interpretations of events in the late glacial history of the northern United States. In addition to an improved chronology, the radiocarbon ages have permitted some of the basic data, such as post-glacial uplift rates, to be used in the development of more quantitative models of the earth's geophysical properties, such as the elastic properties of the lithosphere and the viscosity of the upper mantle. Thus, as in many basic geologic investigations, information obtained in the course of numerous local studies ultimately contributes to the solutions of more fundamental or theoretical geologic problems.

Fairchild's studies of the sequence of proglacial lakes that formed as the last ice sheet retreated from central New York state provide the basic chronologic framework for ongoing studies of many directly or indirectly related phenomena. The changes in proglacial lake levels, especially those following Lake Iroquois, place significant constraints on the behavior of the retreating ice sheets, the chronology of deglaciation in the St. Lawrence Valley, and the worldwide rise of sea level during deglaciation.

The thickness and nature of the glacial deposits in the ancestral Genesee River valley beneath Irondequoit Bay contain important clues to the final sequence of glacial events, shedding light on the limits of earlier fluvial erosion, changes in local base levels (Lake Ontario), and the competency or magnitude of subglacial erosion and deposition processes. In addition, the barrier bar at the mouth of the bay has preserved a unique sequence of postglacial lacustrine and shoreline deposits that can be used to verify speculative correlations of early Lake Ontario low water stages, which have only been studied in detail at the eastern end of the lake.

The ice erosion that reshaped the eroded bedrock surface in the vicinity of Rochester is inferred to have produced shallow deformational structures in the bedrock, termed "ice-thrust features." Although deformation produced by this mechanism may have been correctly interpreted in some surficial exposures or shallow excavations, there are also significant, unmapped, high-angle faults and compressional folds that extend to greater depths and probably reflect regional tectonic stresses produced during the Appalachian orogeny.

The primary purpose of this paper is to review recent discoveries that can be used to update and refine Fairchild's work on the youngest series of proglacial lake levels and on ice erosion processes. A secondary purpose is to describe the existence of significant structural deformation in the bedrock that has not been well documented in the past and that might be confused with features formed by shallow ice-thrust deformation.

POST IROQUOIS LOW-LEVEL LAKE STAGES

Lake Iroquois is the name given to the highest, major late Wisconsin stage of the proglacial lakes in the Ontario basin before ice recession opened the much lower outlet through the St. Lawrence valley region (Figure 1). The outlet for Lake Iroquois was through the Mohawk valley, and the shoreline at Rochester is marked by the prominent ridge followed by Ridge Road, approximately 190 feet above Lake Ontario (Figure 2).

Fairchild (1906) and others (Coleman, 1922) described the existence of a postglacial low water lake stage(s) that was created when the ice first withdrew from Covey Hill on the north side of the Adirondacks and allowed the glacial meltwaters to exit via the St. Lawrence valley. Such low water stages were made possible due to the combined effects of a lowered glacial sea level and isostatic depression of the land surface from the weight of the ice sheet. Postglacial rebound of the land surface began as the ice sheet was retreating. Most of the isostatic compensation (postglacial rebound) was completed soon after the ice retreated, but postglacial differential tilting continues even to the present at a reduced rate of about 1 foot every hundred years across the Ontario basin. The uplift has been greatest in the vicinity of Hudson Bay.

When the new outlet opened near Covey Hill (about halfway between the St. Lawrence River and Lake Champlain on the U.S.-Canadian border), the ice-dammed Lake Iroquois phase ended. The meltwater flowed northeastward through the St. Lawrence Valley, which was then depressed 360 to 460 feet lower than its present elevation. When the ice retreated, the maximum rate of postglacial rebound of the land along the St. Lawrence lowland was greatest in the vicinity of Montreal and decreased southwestward toward Lake Ontario. Sea level rose slowly in concert with the wasting ice sheets. The resulting balance between the isostatic rebound, the recession of the ice, and the rise of sea level created an arm of the ocean, the Champlain Sea, which penetrated at least as far up the St. Lawrence as Brockville, Ontario, before the steady uplift blocked a further marine invasion (Figure 1). Fairchild had envisioned a more westerly extension of the Champlain Sea into the Lake Ontario basin, which he called the Gilbert Gulf. However, the current evidence, recently reviewed by Terasmae (1980), indicates that the Champlain Sea invasion stopped about 40 miles short of the eastern end of Lake Ontario. The more rapidly rising land to the northeast had the effect of tilting the Lake Ontario basin to the southwest, toward Buffalo, about a hinge line trending N 75° W. This regional tilting gradually forced the Champlain Sea to retreat eastward as the level of Lake Ontario at Rochester rose toward its present level. The low water lake stage that connected with the advancing Champlain Sea was called the Admiralty Lake (Coleman, 1922), and it could only have existed during the short interval when sea level was still low and only a limited amount of isostatic rebound had occurred.

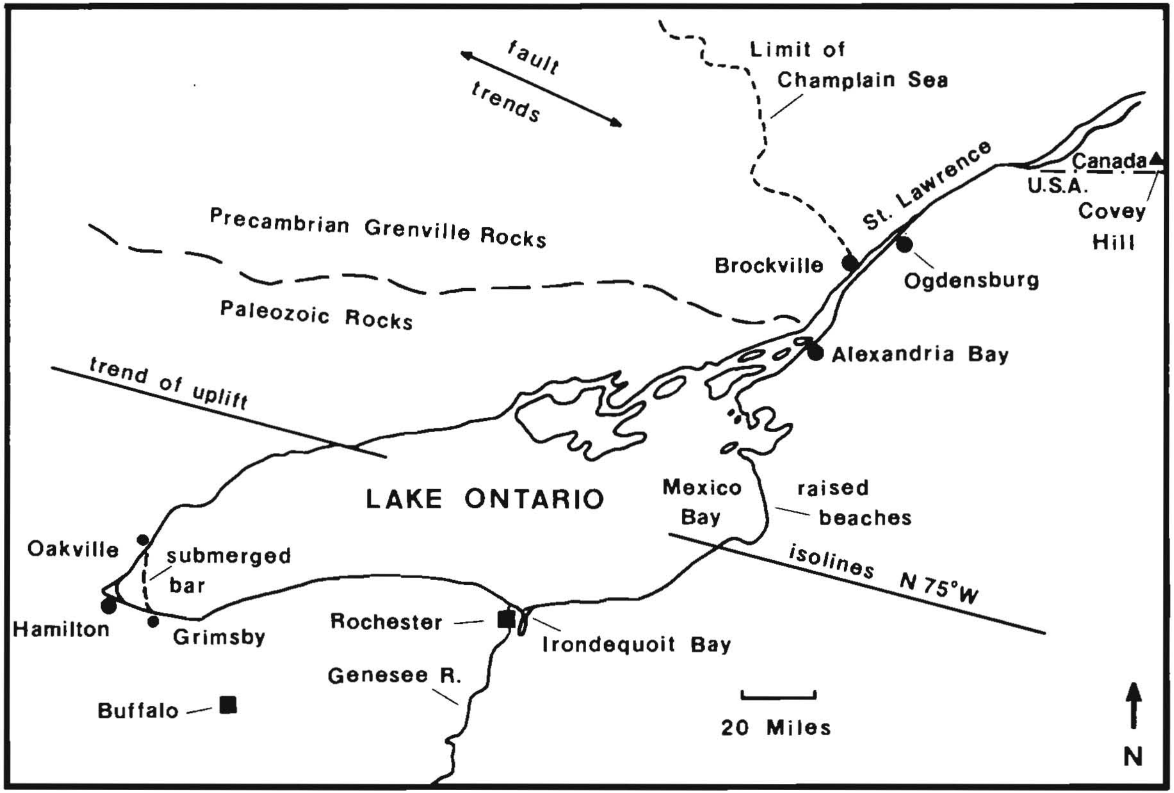

FIGURE 1: Important geologic features and locations in the Lake Ontario-St. Lawrence valley region. Trend of uplift isolines approximate.

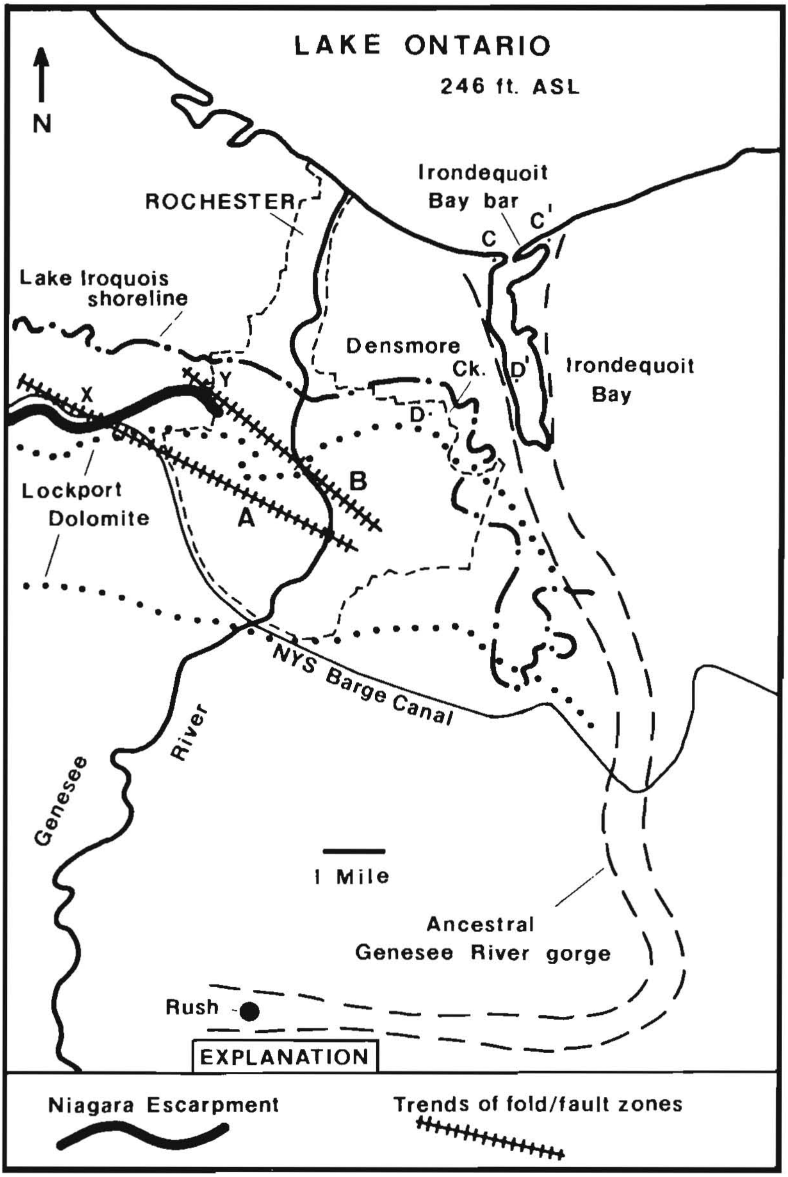

FIGURE 2: Geologic features in the Rochester-Irondequoit Bay region. Letters X and Y locate places where deformational structures (folds, faults) appear to intersect the Niagara Escarpment and account for increased differential ice erosion. C-C' and D-D' locate composite profile of ancestral Genesee River valley on Figure 6. Lake Iroquois shoreline. (Chadwick, 1917).

The southwestward tilting of the Ontario lake basin gradually created a series of emergent shorelines around the eastern end of the lake while those same shorelines were being submerged near Rochester and further west. Sutton et al. (1972) described the evidence for the different shoreline stages following Lake Iroquois and documented the amount of tilting across the lake basin. They speculated on an important relationship between the Lake Iroquois shoreline and the Sandy Creek shoreline about 325 feet below it. These two parallel shorelines (330 to 320 feet apart) formed during a time when rapid differential uplift was occurring from northeast to southwest across the Lake (Figure 3). They inferred that the distance between these two prominent shorelines represented the rapid fall of the lake level following the draining of Lake Iroquois, when the St. Lawrence valley first became the meltwater outlet. However, they were hesitant to specifically correlate the low Sandy Creek Stage with Coleman's Admiralty Lake. In addition, their correlations were based on the elevations of water level planes (beaches) projected northward into the Alexandria Bay area (Thousand Islands) and correlated with some deeply buried organic horizons (Figure 3) near Hamilton, Ontario, at the opposite (west) end of the lake (Karrow et al., 1961). At that time a tentative date of 11,000 to 12,000 years was assigned to the buried deposits (Karrow et al., 1961, Sutton et al., 1972). Thus the correlations and the ages of the shoreline features were speculative. However, the individual shoreline stages are well developed above the modern lake at its eastern end. Since those correlations were made in 1972, the approximate date for the draining of Lake Iroquois has been suggested as closer to 12,000 ± years B.P., (Terasmae, 1980), and deep borings in the vicinity of Irondequoit Bay have provided significant new data (Young, 1980) with which to test the ideas of Sutton et al. (1972).

The evidence from deep borings occurs within the ice-scoured, sediment-filled valley of the ancestral Genesee River at the mouth of Irondequoit Bay (Figure 4). Several test wells drilled for the Village of Webster during water-supply investigations have defined the bedrock profile of the ice-scoured trough and have penetrated old beach and lacustrine deposits at depths of approximately 40 feet, 140 feet, and 200 feet below the present lake level (246 feet). If the most persistent beach deposit (140 feet below lake level) is plotted on a diagram similar to that constructed by Sutton et al (1972), it falls precisely on the line connecting their Sandy Creek Stage with the buried peat deposit near Hamilton (Figure 3). In addition, the younger (less tilted) Dune Stage shoreline, which documents the effect of differential isostatic rebound between the Lake Iroquois phase and 4,800 ± years B.P., appears to be represented by sand and peat deposits at a mean depth of 40 to 60 feet below lake level.

The fit of the points of these two shorelines curves was determined by measuring all distances perpendicular to the inferred tilt axis, which trends N 75° W. The excellent fit of all the points on both the Sandy Creek and Dune shoreline curves gives added confidence to the correlations suggested by Sutton et al. (1972).

In the Irondequoit Bay cores there are other sand lenses 40 to 60 feet below what is inferred to be the Sandy Creek Stage. These lower sands are below silts and clays that are similar to the lacustrine sediments in the higher sections of the cores. When compared with the raised beaches described at the east end of the lake (Sutton et al., 1972), these sands are the same distance below the Sandy Creek shoreline as are the Skinner Creek shoreline features. If the lowermost sands at Irondequoit Bay are projected westward, parallel to the Sandy Creek and Iroquois shorelines, they intersect a submerged bar (Figure 1), described by Lewis and Sly (1971), which runs under the lake between Grimsby and Oakville (about 10 miles east of Hamilton).

Sutton et al. (1972) suggested that the Skinner Creek shoreline represented a *drop* in lake level from the Sandy Creek shoreline and thus considered it a younger feature. The evidence at Irondequoit Bay implies that the Skinner Creek stage formed first and that it correlates with the Oakville-Grimsby bar, which Lewis and Sly (1971) equated with the Admiralty Lake phase. The Irondequoit Bay bar represents a continuous sequence of increasingly younger deposits from the lowest lacustrine sediments upward. Unlike the raised terraces at the east end of the lake, the sediments in the barrier bar cannot become *younger* with decreasing elevation (increasing depth in the cores) (Figure 5).

The uniform parallelism of the three shorelines, Iroquois, Sandy Creek, and Skinner Creek, as projected through the Irondequoit Bay section to the west end of the lake, suggests that the Skinner Creek Stage is the oldest and lowest shoreline. All three stages cannot be significantly different in age if they are essentially parallel to each other. A calculation of the differential tilt rate across the Lake Ontario basin immediately following the draining of Lake Iroquois indicates a ***minimum*** differential tilting of the basin of 6 to 7 feet per 100 years at that time. Therefore, any shorelines in the range of 11,000 to 12,000 years old would have measurably different slopes if they differed in age by 200 years or more.

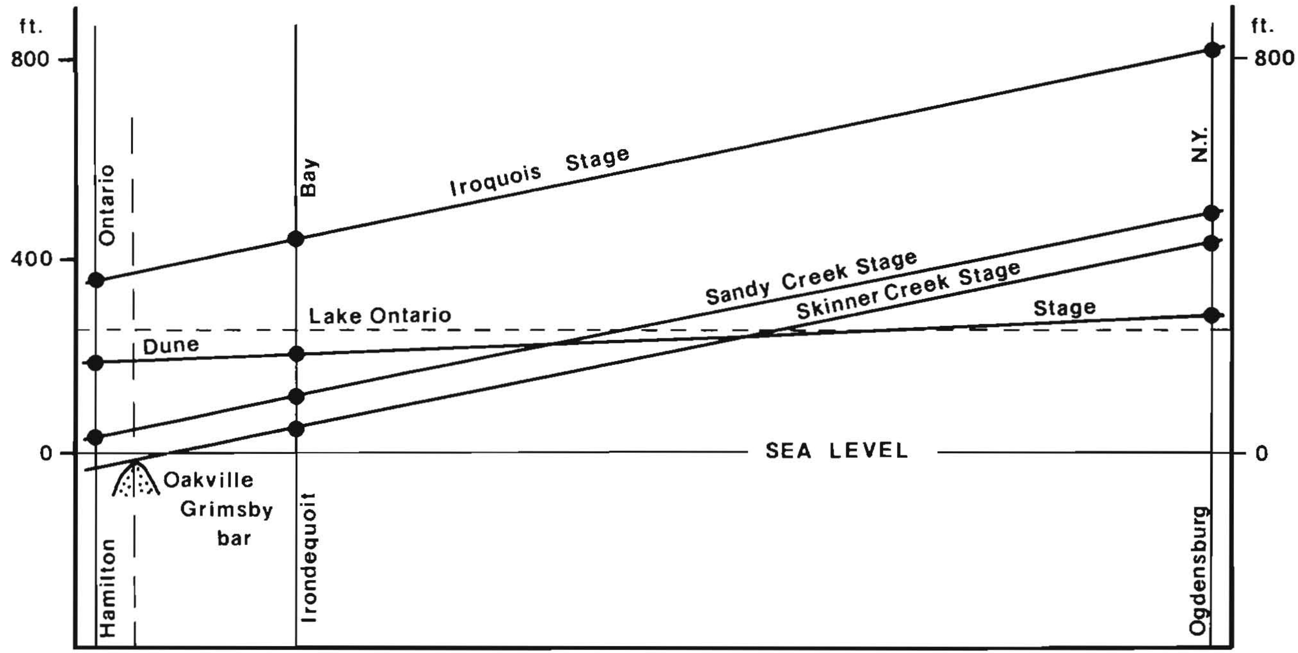

FIGURE 3: Elevation relations of shoreline stages from the St. Lawrence valley to the west end of Lake Ontario. See stages defined by Sutton et al. (1970) for comparison. Locations on Figure 1.

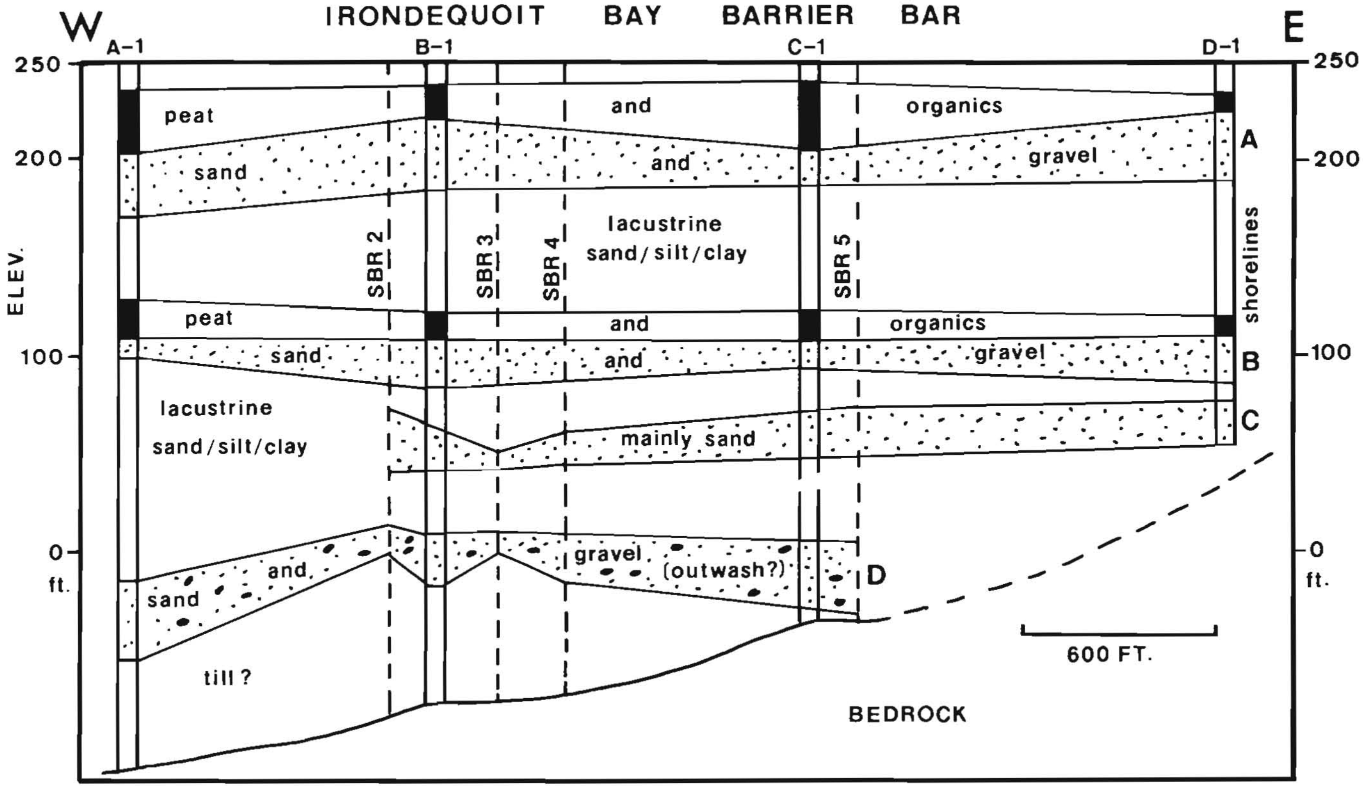

FIGURE 4: Subsurface cross section (generalized) interpreted from 8 borings through Irondequoit Bay bar. Dashed lines are approximate locations of preliminary borings (Village of Webster, 1975). Compare with Figure 5.

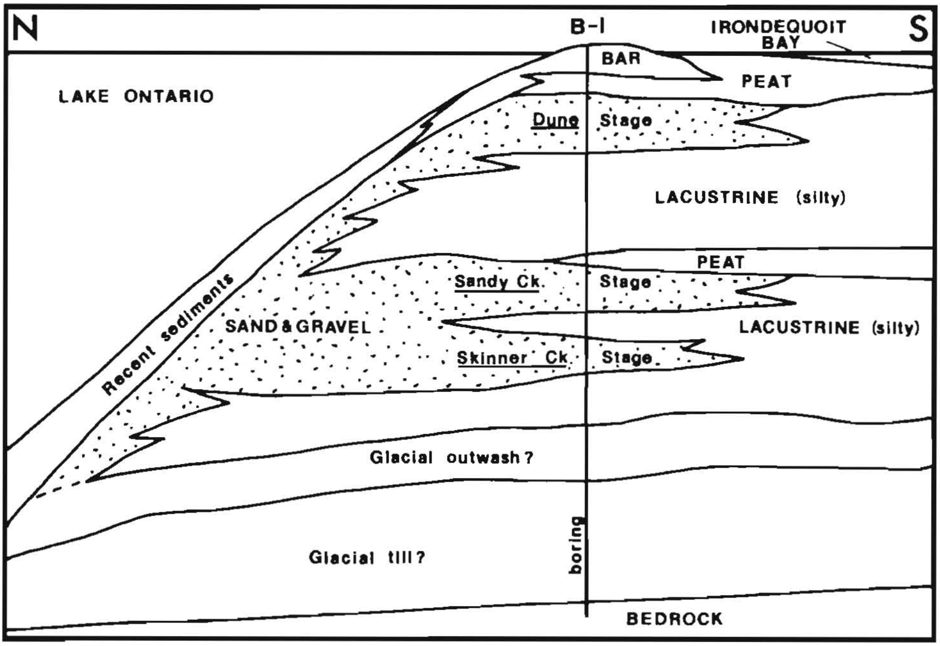

FIGURE 5: Diagrammatic north-south section through Irondequoit Bay bar to illustrate hypothetical facies relations created by rising lake stages as barrier bar grew by longshore transport. Development and stabilization of bar created lagoonal environments in bay, accounting for organic horizons. Vertical scale similar to Figure 4; horizonal scale diagrammatic only.

The correlations depicted on Figure 3 provide strong evidence of the probable sequence of low water (post Iroquois) lake levels in the Ontario basin immediately following the ice withdrawal from the St. Lawrence valley.

The elevation relationships form east to west across the lake explain why the Champlain Sea probably did not invade the Ontario basin. Restoration of the total maximum tilting from Hamilton to the vicinity of Ogdensburg would put the Skinner Creek stage near presentday sea level. The line of zero postglacial uplift lies very close to the Hamilton area and implies that the west end of the lake has undergone little absolute uplift. Thus, in order for the sea to invade Lake Ontario, postglacial sea level recovery would have to have occurred almost immediately after the ice retreated from the St. Lawrence Valley and before significant isostatic rebound of the land had begun. However, the recovery of sea level to its present position could not have occurred while the shrinking ice sheet still extended as far south as the St. Lawrence. Several studies have shown that sea level was more than 100 feet below its present position about 12,000 years ago and that a return to near its present position could not have occurred until about 6,000 years ago (Moran and Bryson, 1969).

CHARACTER AND ORIGIN OF THE ANCESTRAL GENESEE RIVER GORGE

The drill hole data along the Irondequoit Bay bar can be combined with the deep borings completed for the Cross-Irondequoit and the Culver-Goodman sewer interceptor tunnels to provide a composite profile of the bedrock surfaces beneath Seneca Lake (the most deeply eroded Finger Lake basin) and the Letchworth Park gorge (the largest postglacial gorge along the Genesee River). These true scale profiles demonstrate that, although such features are impressive when viewed at ground level, they do not represent extreme departures from the general surface formed and modified by differential ice erosion of the region. The Letchworth gorge profile is included to indicate what portion of the other glaciated valleys could be attributed to fluvial erosion prior to any glacial enlargement.

The bedrock trough beneath Irondequoit Bay has obviously been considerably enlarged by the processes of glacial scouring, which deepened and widened an older valley that had formed during either

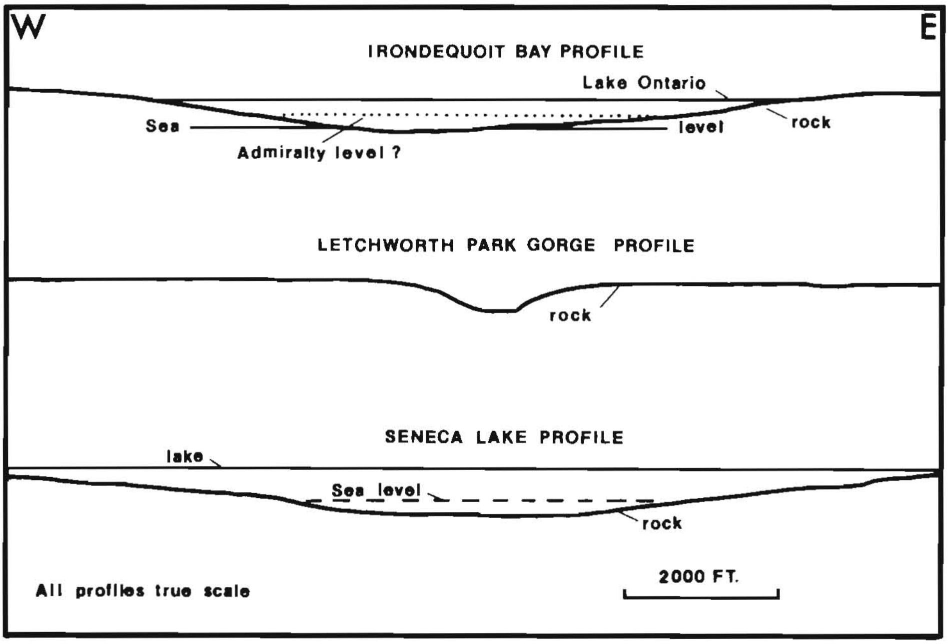

FIGURE 6: True scale bedrock profiles of 2 glaciated valleys compared with the postglacial Letchworth gorge to emphasize the effects of glacial scouring. Irondequoit Bay profile on Figure 2. Data for Seneca Lake from von Engeln (1961).

preglacial or interglacial time. Neither the apparent low level of the Admiralty Lake nor the low stand of sea level at about the time that Lake Iroquois probably drained out through the St. Lawrence was low enough to permit fluvial erosion to operate at the lowest level of the rock profile beneath the center of the bay. Furthermore, it is likely that any extended interglacial erosion of an ancestral Genesee River channel would have to be accomplished while a moderately deep lake occupied the Ontario basin. Any periods of low sea levels and low lake stages following other glacial recessions would have been equally brief. The redevelopment of any ancestral Genesee River between glaciations would require that erosion of the older glacial drift be accomplished before any preexisting bedrock gorge could be fluvially deepened. Borings on the western edge of Irondequoit Bay used to construct the profile of Figure 6 indicate a minimum of 132 feet of glacial till above bedrock near the axis of the glaciated valley. Seventy feet of fine sands and silts overlie the till. A newly reestablished river would also have to simultaneously transport its normal sediment load out into the Lake Ontario basin while any postulated downcutting was occurring.

All of the aforementioned conditions and limitations make it extremely unlikely that the bedrock profile beneath Irondequoit Bay was formed mainly by fluvial erosion during times of low lake levels. It is more likely that a volume of rock similar to that represented by the Letchworth Gorge section was initially removed by a river that developed prior to or between glacial epochs. This valley, of unknown size, was then glacially scoured by one or more ice advances to create the modern profile preserved in the bedrock surface beneath the glacial drift. It is likely that glacial scouring of the rock only occurred when the ice sheets were thickest, and that basal till deposition then took place during ice thinning and recession (Sugden, 1977).

BEDROCK DEFORMATION: SHALLOW ICE-THRUST FEATURES OR DEEP-SEATED TECTONIC STRUCTURES

It is well known that advancing glacial ice can produce shallow, thrust-like dislocations or superficial folds in relatively incompetent bedrock, especially where ice sheets encounter escarpments such as the one along the southern shore of Lake Ontario (Flint, 1971). James Hall (1843) reported features that probably were formed by this mechanism along the south shore of Lake Erie. Shallow ice-thrust structures exposed in excavations have been reported in the Rochester area, but few have been documented or described in the literature. One such instance may have occurred during excavation for the Resources Recovery facility on Emerson Street (informal communication and photographs, H and A of New York, Inc.).

Recently, a well-exposed, shallow ice-thrust feature was described in Rochester along Densmore Creek (Andrews, 1980). Coincidentally, borings for the Culver-Goodman sewer interceptor tunnel encountered a deeper, more vertical fault in bedrock almost directly below the ice-thrust feature. Because few other faults had been reported in the Rochester area, the two structures were initially presumed to be related in some way. However, examination of the deeper fault during construction of the Culver-Goodman sewer interceptor tunnel demonstrated that the deeper structure is a small reverse fault with a more northwesterly strike. The bedrock offset in the tunnel is at a depth of over 100 feet below the top of rock, whereas the shallow glacial thrust surface is at a depth of only 10 to 15 feet throughout most of its exposed length. The discovery of other high angle faults and small folds extending to depths in excess of 140 feet during continuing sewer interceptor design studies has demonstrated that tectonic structures, unrelated to ice deformation, are probably common in the region (Figure 2). Fairchild photographed the surface exposure of one such fault zone in the Barge Canal (Fairchild, 1928), and other zones of structural deformation have been located (Figure 7). Some of the faults are visible in the Genesee River gorge (H and A of N.Y., 1981). It appears likely that the faults are commonly associated with open folds of low amplitude, such as the feature shown in Figure 7, located along the Barge Canal.

The faults in the bedrock along these structures are not apparent as offsets at the top of rock. Thus they predate the glacial erosion. No evidence of offset in any glacial deposits has yet been detected.

The structures are most likely related to the stresses accompanying the Appalachian Orogeny in late Paleozoic time. However, the trends of the structures in the Rochester area are approximately northwest, whereas the known Appalachian structures immediately to the south have ENE trends (Engelder and Geiser, 1980). It is possible that the structural trends in the Rochester area reflect the influence of older Grenville Province (Precambrian) basement structures exposed farther north in Ontario (Figure 1). It is not uncommon for younger faulting to involve reactivation of older basement structures, which represent natural zones of weakness in the underlying rocks (Young, 1979, 1982).

INFLUENCE OF STRUCTURAL FEATURES ON SURFACE TOPOGRAPHY AND ICE EROSION

The two best documented zones of folding and faulting shown on Figure 2 can be projected northwestward to the Lockport (Niagara) Escarpment, which parallels Ridgeway Avenue north of the N.Y. State Barge Canal and the abandoned segment of the old Erie Canal. The projected intersections of these two structural zones with the prominent Niagara Escarpment are marked by conspicuous gaps. The easternmost curve in the scarp parallels the west edge of Driving Park Avenue (Figure 2). Two and one half miles further west along the scarp another conspicuous gap occurs between Elmgrove and Long Pond Roads (Figure 2). Both of these irregularities in the scarp are in line with the projected trends of the structures shown on Figure 2.

It is inferred that where the escarpment was intersected by the zones of folded or faulted rocks, subaerial and glacial erosion and chemical weathering have been locally enhanced. Glacial scouring of the fracture zones and more deeply weathered rock probably account for these two relatively localized gaps or irregularities now expressed in the surface topography.

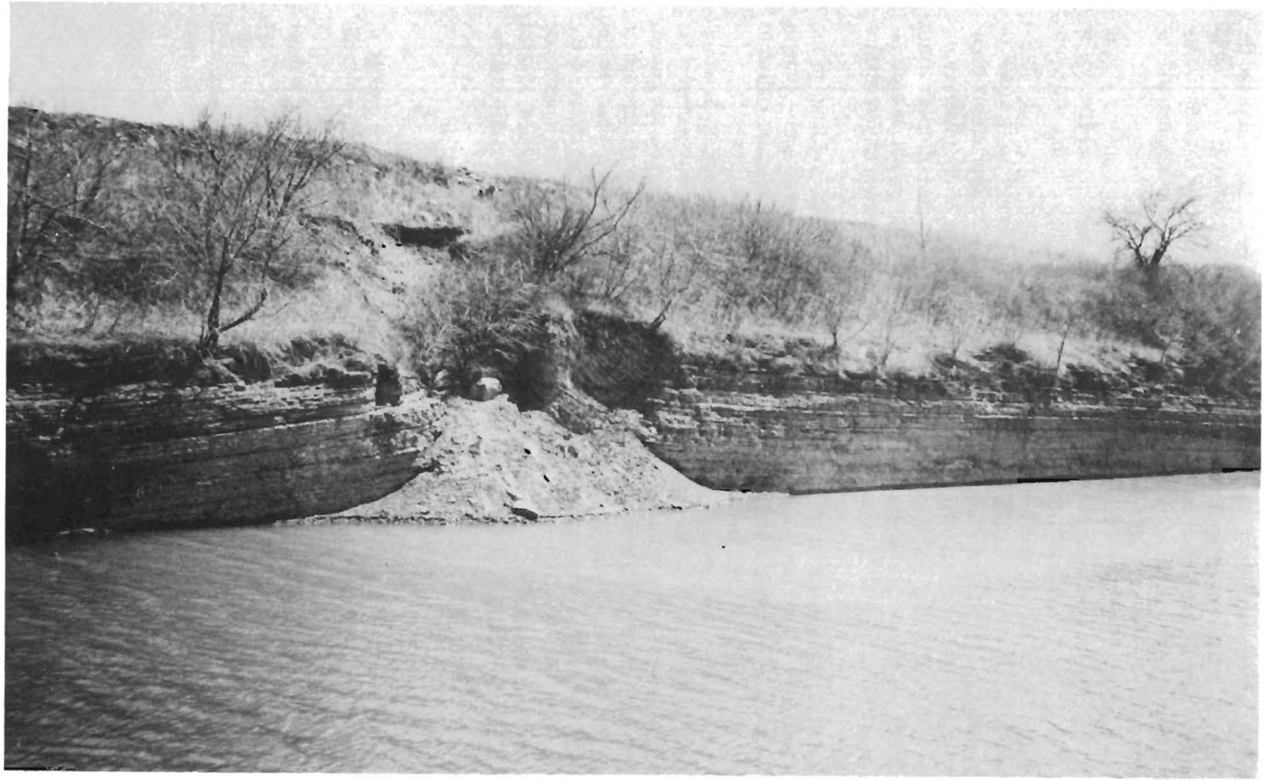

FIGURE 7: Central portion of broad fold-fault structure visible in N.Y. State Barge Canal (structure zone A, Figure 2). View to southeast. Zone A and B are inferred to consist of numerous subparallel offsets or flexures with a maximum measured displacement of 18 feet on one fault penetrated by a boring (H & A of New York, 1981).

SUMMARY AND CONCLUSIONS

To fully appreciate the present physiography and surficial geology of the Rochester region, it is necessary to understand both the direct and indirect influences that have combined to produce the modern landscape. Irondequoit Bay has been flooded by the regional postglacial isostatic tilting and the accompanying rise in the level of Lake Ontario, which amounts to approximately 200 feet at Rochester in the last 12,000 years. More precise radiocarbon dating of the shorelines buried in the Irondequoit Bay bar could help resolve the uncertainty concerning the timing of the draining of Lake Iroquois and the precise interval during which the low lake stages occupied the Ontario basin.

These events, in turn, place limits on the amount of fluvial erosion that could have been realistically involved in the creation of the present depth and shape of the ancestral Genesee River valley beneath Irondequoit Bay. It can be concluded that the present depth and shape of this valley are predominantly due to glacial scouring of a much smaller fluvial valley.

In an area where glacial drift covers much of the bedrock, some care must be exercised to discriminate between glacially induced, shallow, ice-thrust deformation and older structures of deep-seated, tectonic origin. In addition, the older, preglacial structures may have significantly influenced the differential ice erosion of the underlying bedrock. In such regions, where mapping of bedrock structure is difficult and incomplete, it may be possible to use topographic variations in prominent bedrock-controlled landforms as a clue to the location of major zones of structural deformation (differential ice erosion of fault zones).

A better understanding of the origin of the northwest-trending bedrock folds and faults in the Rochester area might improve our knowledge of the regional tectonics of the St. Lawrence — Ontario Basin region. Clearly, the structural trends are very different from those in the Appalachian Plateau to the south and nearly at right angles to the Clarendon-Linden fault zone to the west.

Progress in our understanding of the geology of an area with as little apparent complexity as central New York can still benefit greatly from the integration of knowledge obtained by many geologists far beyond the confines of the Genesee Valley. Although geologists have tended to become more specialized, it is still important to attempt an integrated analysis of data which, upon first examination, may appear to be unrelated. Fairchild and many of his contemporaries exemplified this kind of approach to the understanding of earth history. It is also important for us to remind ourselves that many of the relationships we uncover in our sometimes limited field research are made possible by the fundamental observations of the early geologists like H.L. Fairchild, who studied large areas without benefit of aerial photography, detailed topographic maps, extensive subsurface boring logs, comfortable transportation, or modern laboratory equipment.

ACKNOWLEDGEMENTS

I am grateful to H & A of New York for providing their reports on the subsurface geology of Rochester compiled during the Pure Waters Combined Sewer Overflow Abatement Program, in which the author participated. The excellent information in these reports, little of which was used in this paper, should be of great value in many future geologic studies. Thanks are also due to the Village of Webster and Mr. William Shearer for providing copies of the report on the Irondequoit Bay sand bar by Hydrology Consultants Limited. The wealth of subsurface engineering data that now exists on the Rochester-Irondequoit Bay area could form the basis for a number of detailed reports on the stratigraphy and structural geology, which will be better understood after completion of the deep sewer tunnel construction projects currently in the design stage.

Dr. Robert G. Sutton (University of Rochester) and Dr. Peter G. Sly (Canada Centre Inland Waters) reviewed the final draft of the manuscript.

ADDENDUM

Dr. Peter G. Sly has generously provided the author with an unpublished manuscript relating to his long-term studies of late glacial and postglacial lake levels in the Ontario basin, as well as a lengthy discussion of the possible significance of the Irondequoit Bay bar deposits (personal communications, 1982). Dr. Sly has significant unpublished data from cores, echosounder profiles, and bathymetry bearing on the early history of Lake Ontario. He has suggested that the history of post-Lake Iroquois lake level changes is more complex than has been commonly supposed or discussed in the most readily available literature.

There are two main difficulties involved in lake level correlations where the shoreline features are not continuous. The first involves a slow migration of the center of maximum uplift, thereby producing water planes that differ by more than a simple angular separation about a common axis. This could produce an apparent alignment of discrete points that do not, in fact, lie on the same shoreline. Three-dimensional constructions of several shorelines of different ages are necessary to resolve this problem.

A second complication results from the possibility that two distinct post-Iroquois low lake stages were produced by glacial events in the St. Lawrence lowlands. Data bearing on this problem are being studied by Sly and his co-workers. Until some of the preceding complications are resolved by this interesting work, it should be kept in mind that the shorelines shown on Figures 3, 4, and 5 might represent only the most recent postglacial rise in lake level. Because only limited radiocarbon chronology is available on the ages of the Irondequoit Bay section and other undated post-Iroquois lake stages, it may be premature to assume that the simple correlations on these diagrams can be accurately equated with the Admiralty and/or younger levels of early Lake Ontario.

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SILURIAN AND DEVONIAN HISTORY OF THE GENESEE VALLEY: A SYNOPSIS

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INTRODUCTION

> *"The territory about the city of Rochester is unsurpassed in variety and excellence of its geologic structure and in its physiographic and scenic features . . . its display of Silurian and Devonian strata is classic in American geology and for the glacialist and physiographer this region is a paradise."*
>
> Herman L. Fairchild (unpublished manuscript; date unknown)

Although Fairchild may have been somewhat overzealous in extolling the geologic virtues of the Rochester area, especially with regard to its geologic structure, he was quite accurate concerning the bedrock and glacial aspects. His work on the Pleistocene geology of New York has set a standard of excellence surpassed by few.

This paper describes the stratigraphic sequence exposed in the Genesee Valley region, and the general paleoenvironmental setting of each major unit. The pertinent literature for each of the major rock units is summarized, but these citations are incomplete. Many of the references are distilled from Rickard's (1975) excellent compilation. A brief comparison between "Fairchild's geology" and that of the present day concludes this paper.

The rock formations exposed in the Genesee Valley were deposited during the Late Ordovician, Silurian, and Devonian Periods, with Mississippian and Pennsylvanian strata capping the hills near the southern border of the state. The geologic time scale is shown on Table 1. The strata dip to the south at approximately ½ degree, exposing an orderly stratigraphic sequence from older in the north to younger in the south (Figure 1). Rocks of Late Ordovician and Silurian age are exposed in the Rochester Gorge and south to Avon, whereas the Middle Devonian is exposed from there to the village of Leicester, and the Late Devonian southward through Letchworth State Park to the state line.

UPPER ORDOVICIAN AND SILURIAN SYSTEMS

The sequence of formations in the gorge at Rochester begins with the red shaley Queenston Formation (Upper Ordovician) overlain by the red and green mottled Grimsby Sandstone (Lower Silurian). These red beds are best seen below the Driving Park Bridge and comprise nearly all of the Lower Falls. Only the upper 45 feet of the 1,000 foot thick Queenston are exposed (Figure 2).

At the time the Queenston and Grimsby Formations were deposited, newly formed mountains existed in eastern New York and western New England. This mountain building episode, known as the Taconic Orogeny, probably resulted from compressive forces generated by the near collision of an island arc complex with eastern North America. The Taconic Mountains of New York, the Green Mountains of Vermont, and the Berkshires of Massachussets were created by this event. Streams flowing westward off the "Taconic Landmass" or "Vermontia" deposited a large deltaic complex that eventually covered New York west of "Vermontia."

The Grimsby Sandstone represents the coastal edge of this great delta. Its medium to thick beds of red sandstone, crossbedding, scour and fill structures, mudcracks, shale pebble conglomerates, ripple marks, and numerous worm burrows of ***Arthrophycus*** and ***Daedalus***, are testimonials to the Grimsby being deposited near or just above sea level (Fisher 1966, Martini 1971).

The Grimsby Sandstone is the largest natural gas producer in the subsurface of New York; and its massive beds of sandstone make the formation ideal for building stone. The original Erie Canal Aqueduct over the Genesee River, completed in 1823 (the site located just north of the Enlarged Erie Canal Aqueduct or Broad Street Bridge), was constructed of Grimsby Sandstone. The old curbstone in many parts of the city is made of Grimsby, as is the old stone warehouse (Gilberts Canal Warehouse 1821-1822) on the corner of Mt. Hope and South Avenues, the oldest complete structure still standing in Rochester.

The Clinton Group, overlying the Grimsby, is a mosaic of shallow marine and lagoonal environments. Complexities in the Clinton Group, such as west to east facies changes, numerous

GEOLOGIC TIME SCALE

			TIME BEFORE PRESENT (MILLIONS OF YEARS)	
ERA	PERIOD	EPOCH	BEGINNING	DURATION
CENOZOIC	Quarternary	Holocene (recent)	0.01	
		Pleistocene	3±	2.99
	Tertiary	Pliocene	5	2±
		Miocene	25	20
		Oligocene	34	9
		Eocene	49	15
		Paleocene	64	15
MESOZOIC	Cretaceous		130	66
	Jurassic		180	50
	Triassic		220	40
PALEOZOIC	Permian		270	50
	Pennsylvanian		325	55
	Mississippian		355	30
	Devonian		410	55
	Silurian		430	20
	Ordovician		500	70
	Cambrian		600	100
PRECAMBRIAN				
FORMATION OF THE EARTH			4,600	

NOTE: Table derived from various geologic sources.

TABLE 1: Geologic time scale.

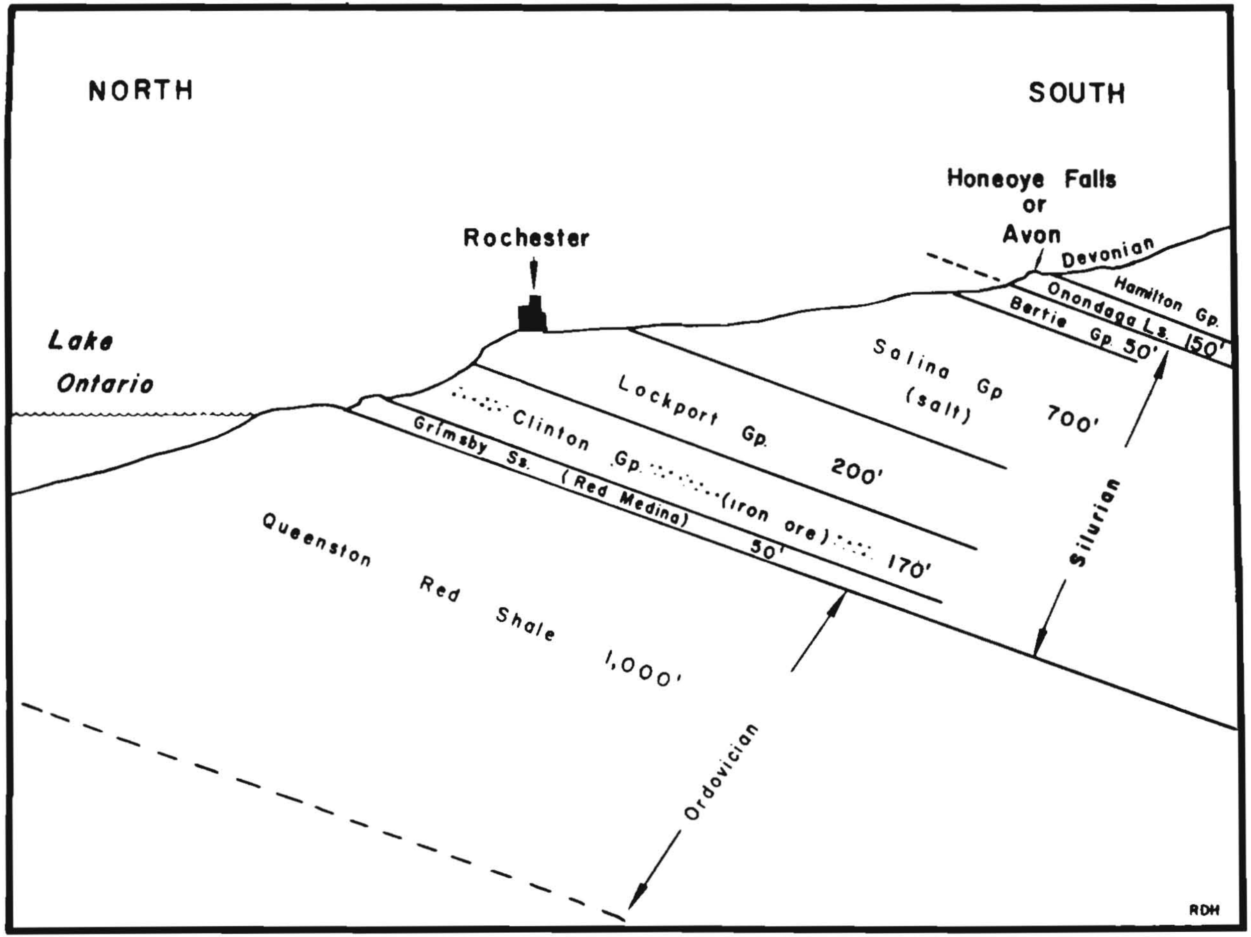

FIGURE 1: Generalized cross section of northern Genesee Valley - dip greatly exaggerated.

Stratigraphic Section - Genesee Valley - Monroe Co.

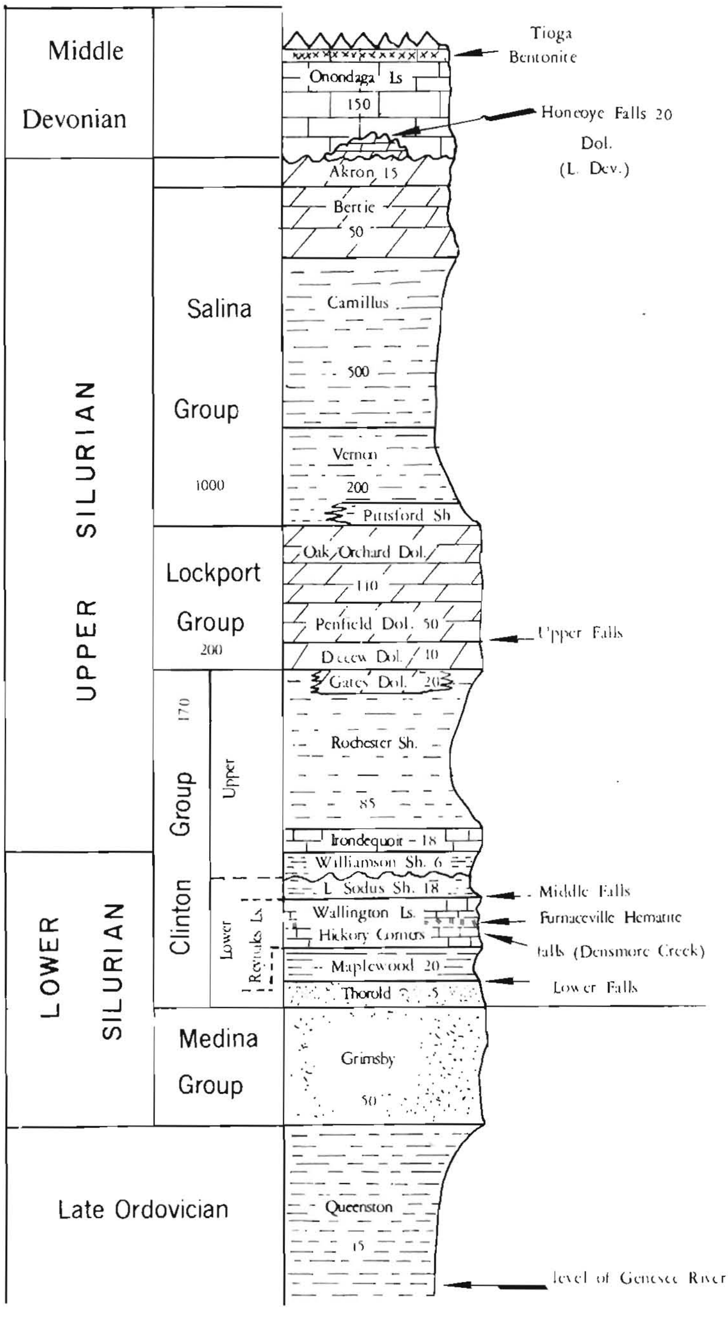

FIGURE 2

disconformities, and a general lack of good exposures have rendered the details of the stratigraphy, biostratigraphy, and paleoecology difficult to resolve. The work of Brett (this volume), Gillett (1947), Kilgour (1963), Muskatt (1972), Zenger (1966, 1971), Ziegler (1971), Rexroad and Rickard (1965), Rexroad and Nicoll (1971), and Gartland (1973), have aided greatly in unravelling this complex unit.

In the Genesee Gorge at Rochester, as shown in Figure 2, Kodak Sandstone (lowermost Clinton) caps the Lower Falls, whereas the Reynales Limestone forms the Middle Falls. The Middle Clinton is totally absent at Rochester, since the Upper Clinton Williamson Shale rests directly on the Lower Clinton Sodus Shale.

The Kodak Sandstone through Reynales Limestone interval represents a transgressive sequence over the Grimsby deltaic deposits. The Kodak Sandstone is a bioturbated, shallow, subtidal, high energy, sand bar containing few fossils. Above it the green, unfossiliferous Maplewood Shale probably represents a lagoonal deposit, and the moderately diverse Reynales Limestone represents a shoal to deeper, subtidal, shallow, marine environment. The Reynales is cherty and rich in brachiopods and corals. The brachiopod *Pentamerus* is highly distinctive, especially in the upper third of the unit where it commonly forms biostromes.

Except for the Williamson Shale, which is probably indicative of a high stress environment (poorly oxygenated, possibly lagoonal), the Upper Clinton at Rochester in general represents subtidal, low to moderate energy, offshore, normal marine conditions. The upper part of the Irondequoit Limestone is more fossiliferous, containing crinoid stems, bryozoans, brachiopods, and rugose corals. Small bioherms or reefs, several feet across and a few feet high, characterize the uppermost Irondequoit Limestone and arch the overlying beds upward at the base of the Rochester Shale.

The Rochester Shale is by far the most fossiliferous unit in the Clinton Group. It contains a high diversity of brachiopods, bryozoans, cephalopods, corals, trilobites and echinoderms, deposited in a normal marine environment from a shoreline to the north (Brett, this volume).

The Lockport Group forms the Upper Falls at Rochester and is exposed along the expressways in and near the city. Zenger (1962, 1965, 1966) published detailed studies of the stratigraphy and paleontology of the Lockport Group. Crowley (1973) has worked extensively on the reefs in the lower Lockport of western New York, Crowley et al. (1978) studied on the subsurface Lockport in western New York, and Domagala (1982) studied the Lockport in Central New York.

The Lockport Group at Rochester appears to have been deposited as a barrier island complex (Penfield Formation) and a shallow subtidal marine and lagoonal or tidal flat complex (Oak Orchard Formation). The importance of the Lockport Group to the development of Rochester cannot be overstated. The main Upper Falls at Rochester over the DeCew Formation and a smaller 14-foot cascade (Penfield Formation), once present just north of the Broad Street Bridge, attracted a small enclave of early settlers to harness the water power for milling. Later the settlement exploded into phenomenal growth, when in 1823, the original Erie Canal provided an easy and inexpensive route for the products of these mills to tidewater. As a result, Rochester soon became known as the Flour City.

Approximately 700 feet of weak, unfossiliferous shales belonging to the Salina group overlie the Lockport Group. The Salina is poorly exposed between the southern part of Rochester and the Honeoye Falls-Avon area. A stratigraphic and paleontologic study of the Salina Group was accomplished by Leutze (1959). Rickard (1969) discussed the surface and subsurface stratigraphy, and Treesh (1973) completed a paleoecological analysis.

The basal unit of the Salina Group is the Pittsford Shale. It was first discovered when the Old Erie Canal prism was being enlarged to a width of 90 feet and a depth of 9 feet in 1897-1898 behind what is now the Spring House and Pittsford Plaza. The Pittsford Shale yielded an excellent assemblage of eurypterids that was later described by Sarle (1903).

The Salina Group is most noted for its salt production in the subsurface at Retsof and for its gypsum deposits found in the upper portion, especially near Oakfield-Alabama and Scottsville. This group represents a peritidal and often restricted, hypersaline, depositional setting.

Fifty feet of waterlimes, dolostones, and shaley dolostones exposed near Honeoye Falls, Avon, Leroy, and Batavia comprise the eurypterid-bearing strata of the Bertie Group. Rickard (1969, 1975) places the Bertie as a formation at the top of the Salina Group. Additional research by Ciurca (1973, 1978, 1982) and Hamell (1981) reveals the Bertie to be a cyclic complex of supratidal, lagoonal, and semi-open marine environments deposited during transgressive and regressive phases off a shoreline to the north. The eurypterids, for which the Bertie is most famous, do not occur uniformly throughout but are most abundant in those units representing the lagoonal setting. Fine laminae, mudcracks, rip-up and collapse breccias, and evaporite deposits characterize the Bertie Group.

The Bertie Group is better exposed than the Salina Group, since it is commonly found in the face of waterfalls capped by the overlying resistant Onondaga Limestone of Middle Devonian Age.

The Akron Dolostone (Cobleskill Formation) completes the Silurian section in western New York and is a relatively thin unit carrying a low diversity fauna of corals.

DEVONIAN SYSTEM

The Devonian System in the Genesee region begins with carbonates (Honeoye Falls Dolostone, Onondaga Limestone) overlain by a generally upward coarsening clastic sequence (Hamilton through Canadaway Groups), culminating in coarse red beds of the Conneaut and Conewango Groups at the top of the section (Figures 3-5). The Devonian System, after Onondaga deposition, represents a westward prograding deltaic complex, the Catskill Delta. It was deposited as a consequence of the Acadian Orogeny that affected New England, eastern New York, and the northern portion of the Appalachian chain.

The Devonian section begins with the geographically isolated Honeoye Falls Dolostone (Ciurca, 1973), exposed below the Onondaga Limestone along Honeoye Creek. The Honeoye Falls strata were called Bertie by Fairchild (1928) and other authors. However, the Honeoye Falls Dolostone overlies the Akron which is exposed downstream. The Honeoye Falls Dolostone represents an erosional outlier of the Lower Devonian Chrysler Dolostone (Helderberg Group) exposed to the east. The presence of the eurypterid *Erieopterus microphthalmus,* known only from Lower Devonian rocks in Central and Eastern New York, indicates an early Devonian age for the Honeoye Falls Dolostone. It appears to be an intertidal deposit due to its sparse fauna, fine-grained lithology, even-bedded laminations, mudcracks, and rip-up breccias.

The younger, Lower Devonian rocks of the Helderberg and Tristates Group, well exposed in central and eastern New York, have been removed by erosion. Consequently the Middle Devonian Onondaga Limestone rests directly on the Honeoye Falls Dolostone.

Excellent papers on the paleontology and stratigraphy of the Onondaga Limestone and its coral reefs are those of Oliver (1954, 1956a, 1956b, 1960, 1963, 1966). The Onondaga is distinctive for its chert and carries an abundant and diverse fauna of corals, brachiopods, bryozoans, gastropods, bivalves, trilobites, and crinoids. Well-developed bioherms are locally conspicuous in the lowermost member, the Edgecliff. The Onondaga Limestone was deposited in warm, clear, shallow, normal marine waters that stretched across the entire state. As such, it represents the first return of normal marine conditions to western New York since Rochester Shale time.

The Hamilton Group begins with the first influx of clastics, which brought Onondaga carbonate deposition to an end, first in eastern New York and later in western New York. It was the precursor of a clastic wedge (Catskill Delta) that ultimately prograded westward during the Acadian Orogeny to the east and southeast. This orogenic episode was apparently caused by the collision of Europe with Greenland and North America. The Paleozoic Atlantic (Iapetus), which had begun to close during the Taconic Orogeny, was now completely closed, at least in the Northern Appalachians.

The Catskill Delta is a wedge of sedimentary rock that thickens and coarsens eastward. The clastic wedge is pierced at several horizons by relatively thin, but geographically widespread, lithologically distinct units that do not undergo facies changes as rapidly as the rocks above and below. These key beds or time planes subdivide the clastic wedge into a number of major time-stratigraphic units (Figure 6, Table 2).

In the Middle Devonian Hamilton Group three carbonate key beds (Stafford-Mottville, Centerfield, Tichenor-Portland Point) serve to subdivide the unit into four formations: the Marcellus, Skaneateles, Ludlowville, and Moscow in ascending order. In the Upper Devonian, black shale tongues (Geneseo, Middlesex, Rhinestreet, and Dunkirk) are used to subdivide the wedge into the Genesee, Sonyea, West Falls, and Canadaway to Conewango Groups (Figure 6, Table 2). Above the Dunkirk Black Shale (base of the Canadaway Group) stratigraphic relationships remain unclear, since there are no black shales higher in the section. Further research and field work are needed to clarify the stratigraphy in this part of the section.

The Hamilton Group is the most fossiliferous unit in the state and in conjunction with its structural simplicity lends itself to detailed faunal, stratigraphic, and paleoecological analysis. Cooper's (1930, 1933) classic papers on the Hamilton Group are the definitive works and mark a point of departure for all

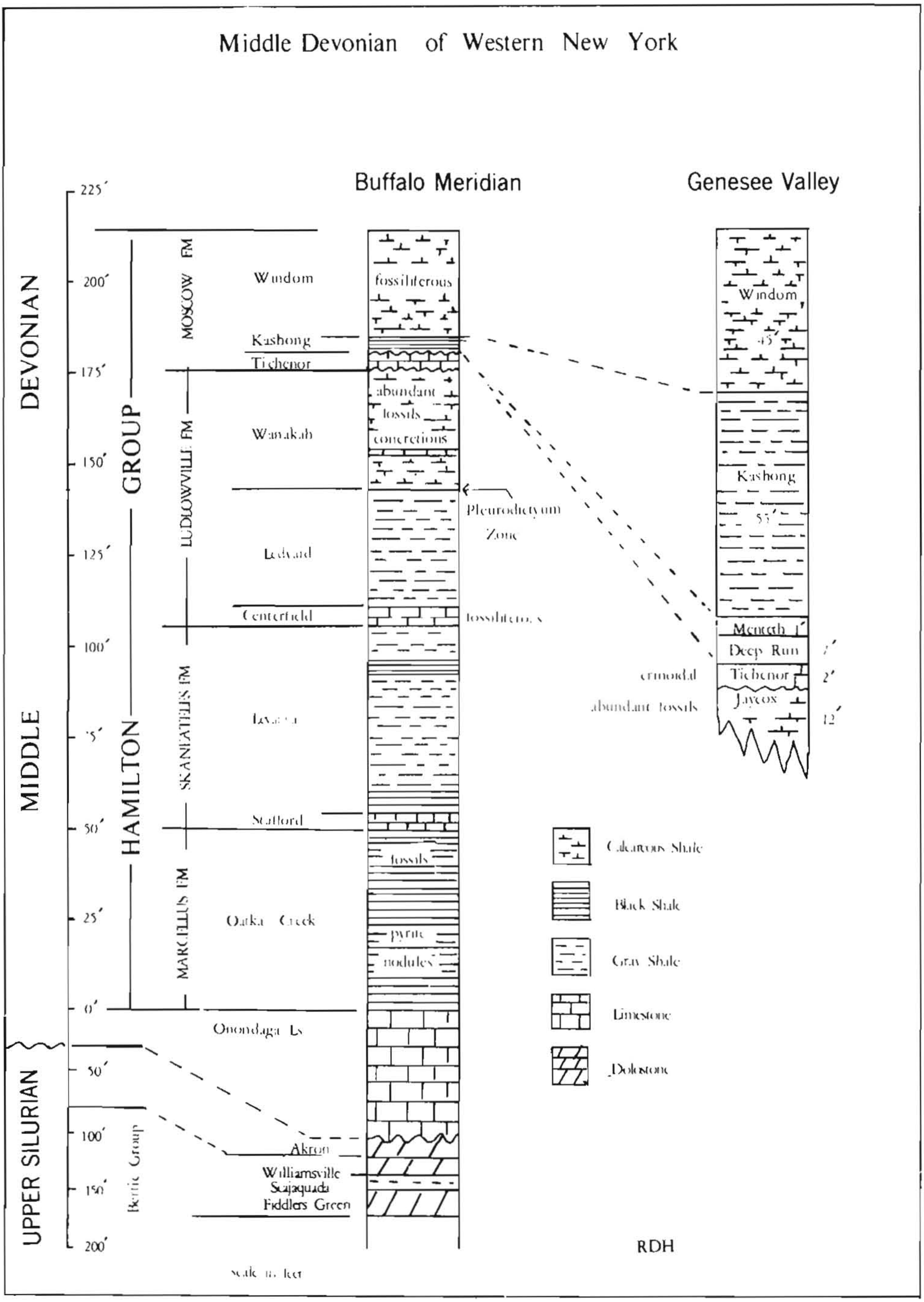

FIGURE 3: (Modified after Buehler, 1966, Figure 1, p. 45).

Generalized Stratigraphic Column for the Upper Devonian of SW N.Y.S.

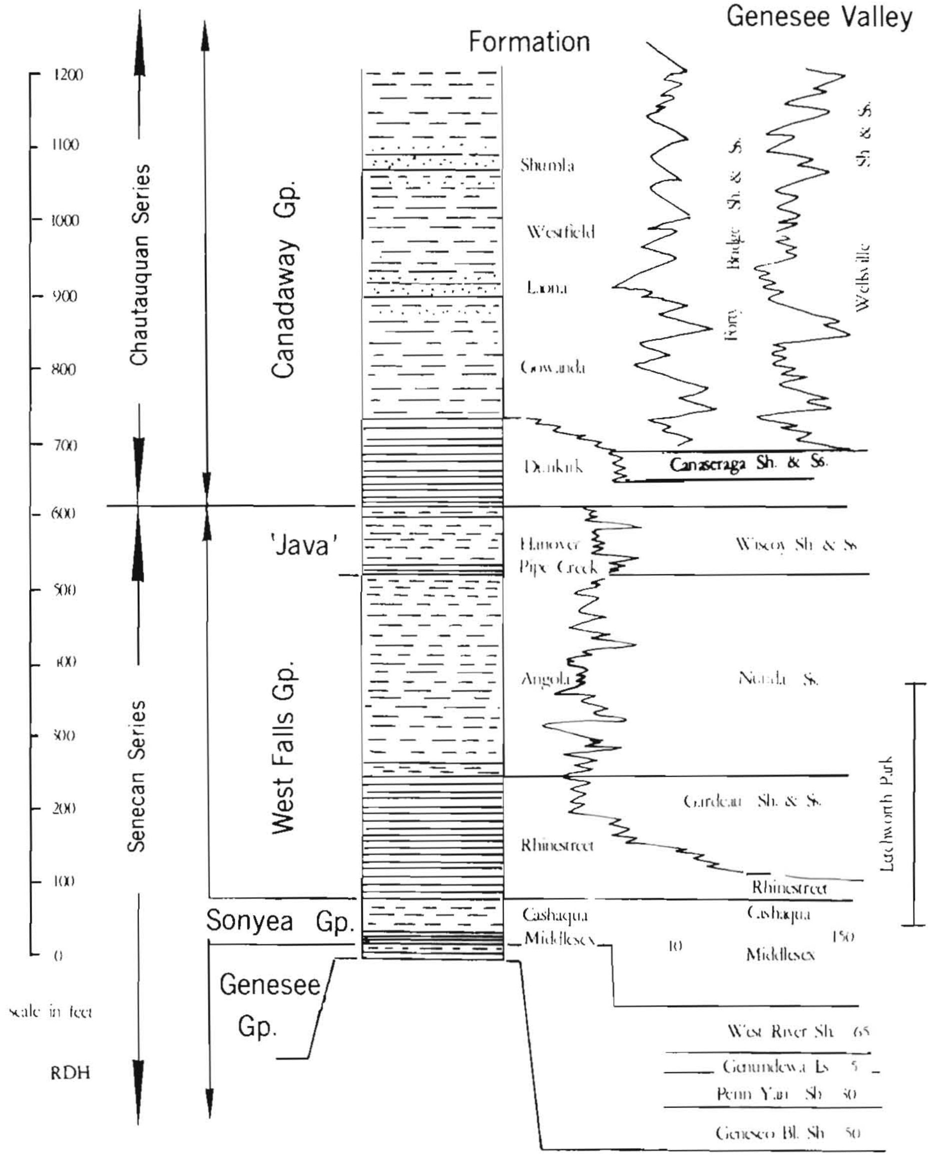

FIGURE 4: (Modified after Tesmer, 1966, Figure 1).

UPPER DEVONIAN

Stratigraphic Section

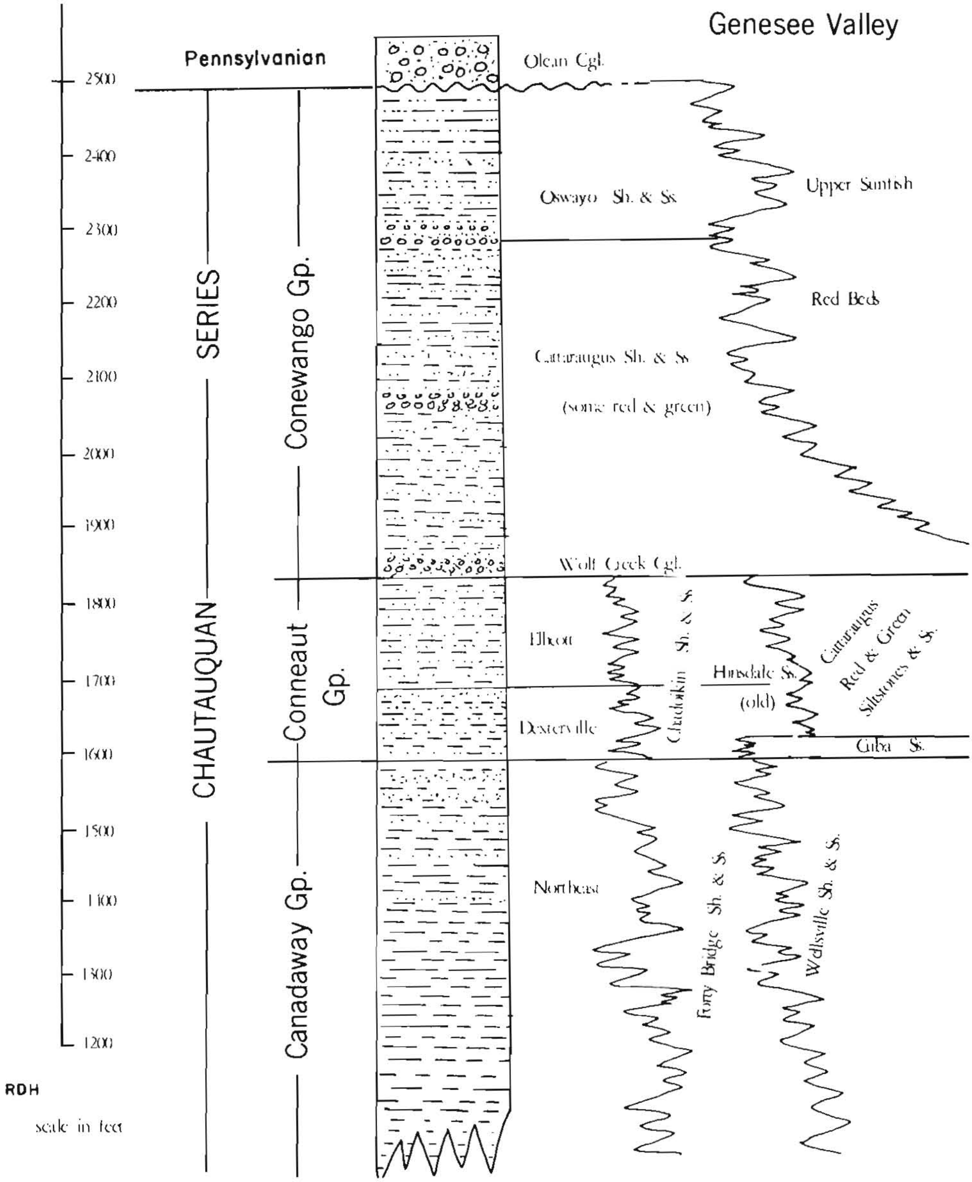

FIGURE 5: (Modified after Tesmer, 1966, Figure 1).

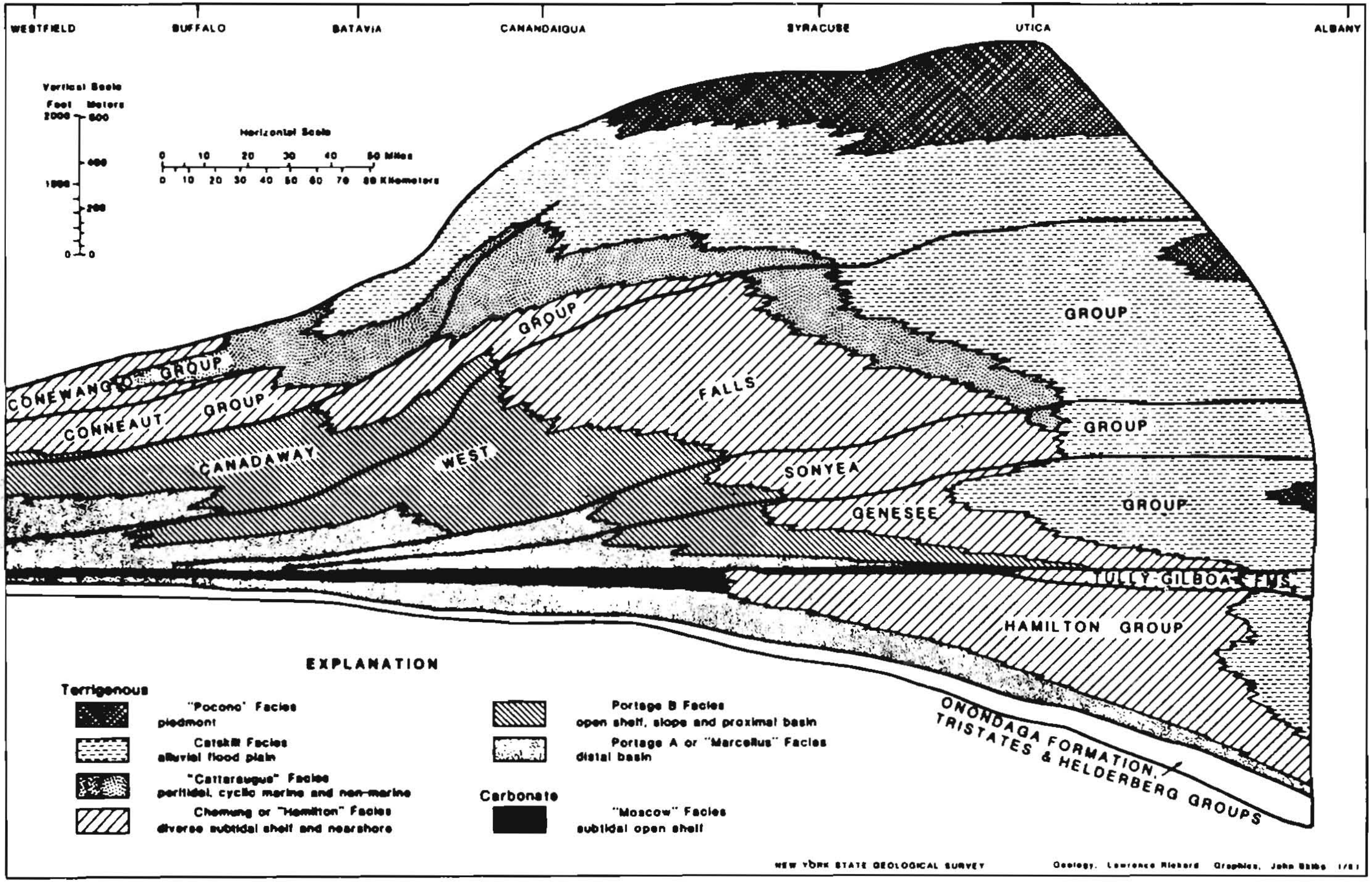

FIGURE 6: Catskill deltaic complex showing major stratigraphic units and paleoenvironments (from Rickard, 1981, p. 20).

research. Numerous Hamilton paleoenvironmental studies have been completed by Fernow (1961), Grasso (1970, 1978, 1981, 1983), Grasso and Wolf (1977), Brett (1974), Baird and Brett (1981), Brett and Baird (1982), and many others too numerous to mention. House (1965, 1966, 1978, 1981) has worked extensively on the ammonoid zonation in the Hamilton, whereas Klapper (1971, 1981), Klapper et al. (1971), Klapper and Ziegler (1967), and Ziegler (1971) have worked out the conodont succession.

In the Genesee Valley, the Hamilton Group is composed of two primary facies. The lower encompasses the Marcellus and Skaneateles Formations (excluding the Stafford Member), whereas the Ledyard Member of the Ludlowville Formation is a fissile black and dark gray shale facies with a few argillaceous limestones and limey lenses. It represents an anaerobic distal basin and carries a low-diversity, primarily pelagic and epipelagic fauna. The remainder of the Genesee Valley Hamilton Group is a subtidal, offshore, distal platform (outer stable shelf) environment of gray calcareous mudstones with numerous, thin argillaceous limestone layers, and limey bands. It is characterized by a high diversity benthonic fauna.

The major stratigraphic problems of the basal part of the New York Upper Devonian (Genesee, Sonyea, West Falls Groups) were not resolved until the 1930's, with the classic works of Chadwick (1933, 1935a, 1935b, 1935c).

The stratigraphy and paleontology of the Genesee Group have been interpreted by Grossman (1944), Sutton (1963), deWitt and Colton (1959), Sutton et al. (1962), Kirchgasser (1973), and Thayer (1974). Information regarding the geology of the Sonyea Group can be obtained from Sutton et al. (1970), Bowen et al. (1974), Colton and deWitt (1958), Sutton (1960), and Kirchgasser (1975). Papers on the West Falls Group have been published by Pepper and deWitt (1950), deWitt (1960), Pepper et al. (1956), deWitt and Colton (1959), Sutton et al. (1962), Woodrow and Nugent (1963), and Woodrow (1968).

Perhaps the most difficult and least understood portion of the Upper Devonian lies above the West Falls Group. The studies of Woodruff (1942), Pepper and deWitt (1951), Tesmer (1955, 1963, 1966, 1967, 1974, 1975), and Kirchgasser (1974) have been instrumental in unravelling the stratigraphy and paleontology of the Canadaway, Conneaut, and Conewango Groups.

Correlating the Upper Devonian is accomplished primarily by ammonoid and conodont zonation. Pertinent conodont papers are those of Huddle (1969, 1974), Oliver et al. (1967), Klapper et al. (1971), and Kirchgasser (1973, 1975). Ammonoid distribution is described by House (1962, 1965, 1966, 1967), Kirchgasser (1973, 1974, 1975), and Kirchgasser and House (1981).

The Upper Devonian sequence records a major westward progradation of the Catskill Delta. This is displayed along the Genesee Valley meridian by the upward coarsening of strata and by the replacement of a largely pelagic fauna in the basal Upper Devonian by a more diverse benthonic assemblage in the upper part. Consequently, in the Genesee Valley the Genesee and Sonyea Groups represent deposits in a distal, relatively deep, anaerobic or dysaerobic basin westward of the main delta platform located in central New York. These units are fissile, black shales yielding a pelagic fauna with a few thin-shelled bivalves and brachiopods. At this time the near shore and subaerial portion of the delta, represented by red beds, was located in the Catskill region.

The overlying West Falls Group was deposited on the prodelta slope and proximal basin. Lithologically it consists of black and dark-to-medium gray shales with mudstones, siltstones, and some fine sandstones. Turbidites are common with flute casts on the undersides of crossbedded siltstones. The low diversity fauna is a mixture of benthonic and pelagic types.

The Canadaway Group in the Genesee Region records a further shallowing of the paleoenvironment. It was deposited primarily on the submarine delta platform and consists of gray shales, mudstones, siltstones, and fine-to-medium sandstones. Coquinites, crossbedding, and ripple marks are common. The shelly fauna is of moderate-to-high diversity with brachiopods and bivalves being the most conspicuous elements. Upper Devonian glass sponges have been found at some horizons within this environmental setting.

The Conneaut and Conewango Groups were deposited on the inner (near shore) delta platform and subaerial (continental) portions of the delta. The rocks are mainly coarse grained gray and green siltstones, sandstones and shales and/or red and green sandstones, siltstones and shales. Scour and fill structures, trough crossbedding, and desiccation cracks are present. Plants are found along with tracks, trails, and burrows. Brachiopods, bivalves and crinoid stems are less common, and fish scales have also been reported from some beds. The lithologies and structures, combined with a very low diversity fauna, suggest that these rocks were deposited in a high energy, high stress environment.

SUB-SYSTEM	SERIES	STAGE	GROUP	PRINCIPAL MARINE FORMATIONS AND MEMBERS	EUROPE
UPPER DEVONIAN	CHAUTAUQUAN	BRADFORD	Conewango	Riceville, Oswayo; Venango, Cattaraugus	FAMENNIAN
		CASSADAGA	Conneaut	Ellicott, Dexterville, Chadakoin	
			Canadaway	Northeast, Westfield, Gowanda, Forty Bridge, Wellsville; Dunkirk	
	SENECAN	COHOCTON	West Falls	Hanover, Pipe Creek, Java, Wiscoy; Angola, Rhinestreet, Nunda	FRASNIAN
		FINGER LAKES	Sonyea	Cashaqua, Middlesex, Rock Stream, Johns Creek, Glen Aubrey, Triangle	
			Genesee	West River, Penn Yan, Geneseo, Genundewa, Lodi, Ithaca, Sherburne, Cincinnatus, Otselic, Unadilla	
MIDDLE DEVONIAN	ERIAN	TAGHANIC		Leicester, Tully, Gilboa, Leicester	GIVETIAN
		TIOUGHNIOGA	Hamilton	Moscow, Menteth, Tichenor, Portland Point	
				Ludlowville, Centerfield; Panther Mountain	
		CAZENOVIA		Skaneateles, Stafford	
				Marcellus, Cherry Valley	
		SOUTHWOOD		Seneca, Tioga Bentonite	EIFELIAN
				Moorehouse, Nedrow, Edgecliff, Onondaga	
LOWER DEVONIAN	ULSTERIAN	SAWKILL	Tristates	Bois Blanc; Schoharie, Carlisle Center, Esopus	? EMSIAN
		DEERPARK		Oriskany, Glenerie; Port Jervis	? SIEGENIAN
		HELDERBERGIAN	Helderberg	Port Ewen, Alsen, Becraft, New Scotland, Kalkberg, Coeymans, Manlius	GEDINNIAN
				Rondout (part)	

NEW YORK STATE GEOLOGICAL SURVEY — Geology Lawrence Rickard, Graphics John Skiba

TABLE 2: Current classification of the New York Devonian (from Rickard, 1981, p. 9).

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS

At the close of the Devonian Period, western New York was largely a piedmont or an alluvial flood plain. Some marine sediments known as the Knapp Formation were deposited in southwestern New York during the Mississippian Period. It is bounded above and below by disconformities and is therefore not present everywhere above latest Devonian strata.

The Pennsylvanian Olean Conglomerate is more widespread geographically and caps the tops of hills near the New York-Pennsylvania border. The Olean is a massive conglomerate containing spherical quartz pebbles, crossbedding, and almost no fossils. Those which have been reported may represent older reworked forms. Meckel (1967) suggests a sediment source to the north or northeast and characterizes the Olean as an alluvial deposit.

SUMMARY AND CONCLUSIONS

The sedimentary sequence in the Genesee Valley was determined in large measure by tectonic events that took place in eastern New York and New England. These events came about in response to a closing or contracting Paleozoic Atlantic (Iapetus) with the initial stages of closing resulting in compressive forces in eastern North America. The North American and Euro-African Plates moved closer together causing the Taconic Orogeny (Middle Ordovician-Early Silurian). The clastic wedge that was constructed westward across the state included the Queenston and Grimsby Formations.

The Early Silurian (Lower Clinton Group) through Middle Devonian (Onondaga Limestone) was characterized by a stable period of little or no tectonic activity. Through much of this time a shoreline lying somewhere to the north of Rochester may have had greater influence on sedimentation in the Genesee Region than the easterly shoreline. During Hamilton and Late Devonian time, the collision of the North American and Euro-African Plates closed Iapetus, producing the Acadian Orogeny and its classic wedge, the Catskill Delta.

Since Fairchild's time much has been added to the geologic knowledge of the Genesee Valley. One of the major advances, since the mid-1960's, has been the wide acceptance of plate tectonics. This technology has led to a better understanding and interpretation of the orogenic episodes, paleoclimates, paleogeography, and paleoecology.

Through the use of conodonts, ammonoids, and to some extent graptolites and brachiopods, correlation of the New York Silurian and Devonian with the type sections of Europe has now been firmly established. In addition, correlation of the various formations and groups within the state has been refined and advanced by many workers through careful tracing of key beds, detailed measurements of many closely spaced sections, and careful plotting and tracing of faunal elements. Many revisions in the nomenclature and subdivision of the New York Silurian and Devonian have resulted since Fairchild's time (Figures 7, 8).

Since the early 1930's the Devonian strata above the Onondaga Limestone have been recognized as a deltaic complex. This has greatly altered the stratigraphic relationships and interpretations used by Fairchild throughout much of his career. The redbed sequence of the Catskill region is now known to have marine equivalents in western New York, and each of the facies, from onshore to offshore, shifts westward with time (Figure 6). These facies overlie one another along any single meridian, and any one facies is diachronous, older in the east and younger in the west.

Greater focus has recently been placed on the paleoenvironmental setting of the various rock units. These endeavours have escalated greatly since the 1950's, resulting in new paleoecological interpretations of many formations. A more northerly shore line, once considered unimportant, greatly influenced sedimentation, especially in western New York. This is certainly true for the Silurian section above the Grimsby and may have continued into Hamilton time as well. Many units in the Clinton Group and nearly all the Lockport Group, once thought to be open marine, are now believed to be lagoonal and peritidal in origin.

However, notwithstanding all the data and subsequent knowledge gathered over the years, much has yet to be resolved. Positions of some of the major biostratigraphic boundaries, especially as they relate to the European standards, are still being debated. Boundary disputes in the European sections further complicate the picture. The base of the Upper Devonian, for example, may not be at the top of the Hamilton Group but within the overlying Genesee Group.

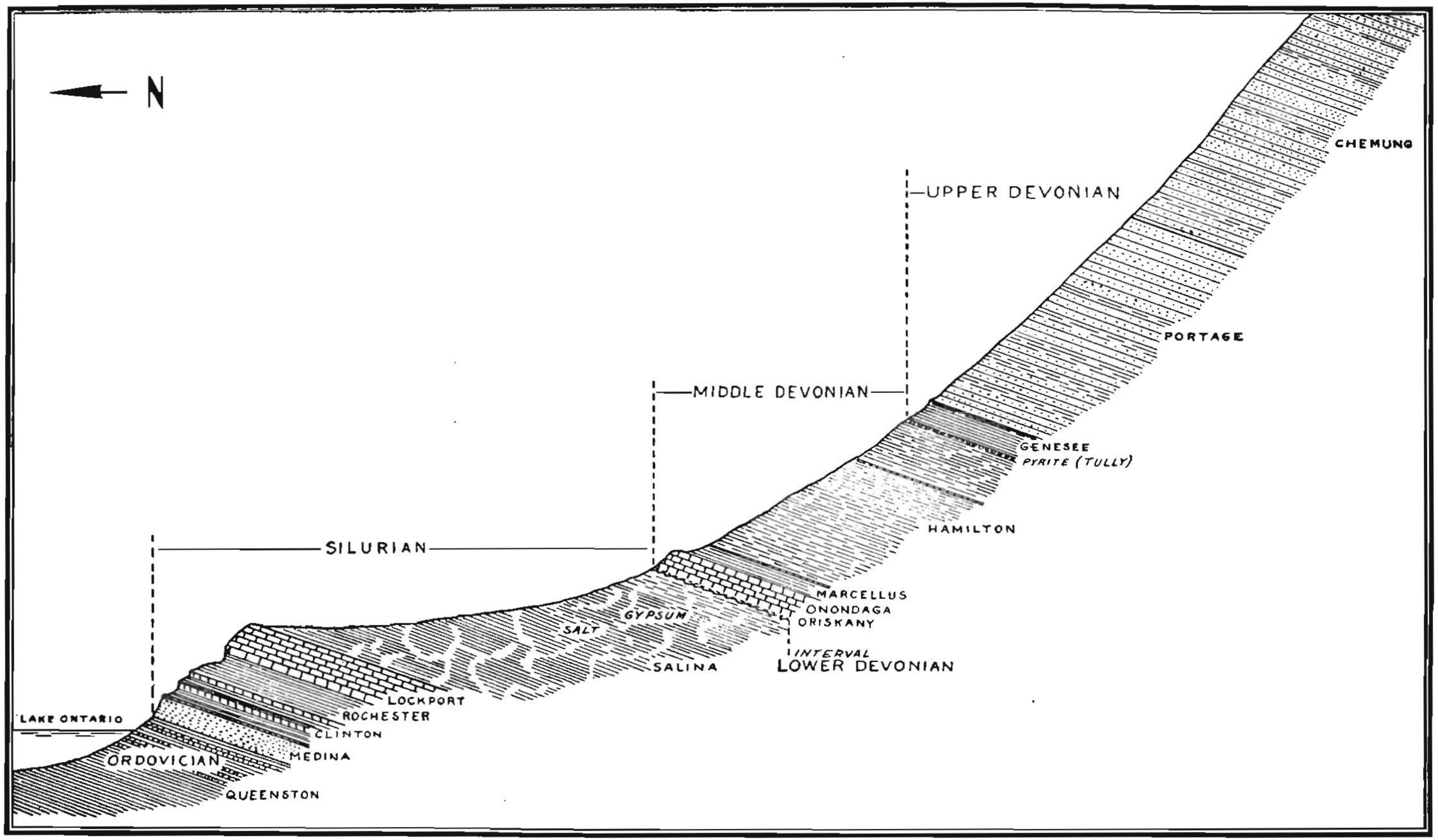

FIGURE 7: Genesee Valley rock strata vertical north and south section; looking eastward (from Fairchild, 1928, Figure 25, p. 29).

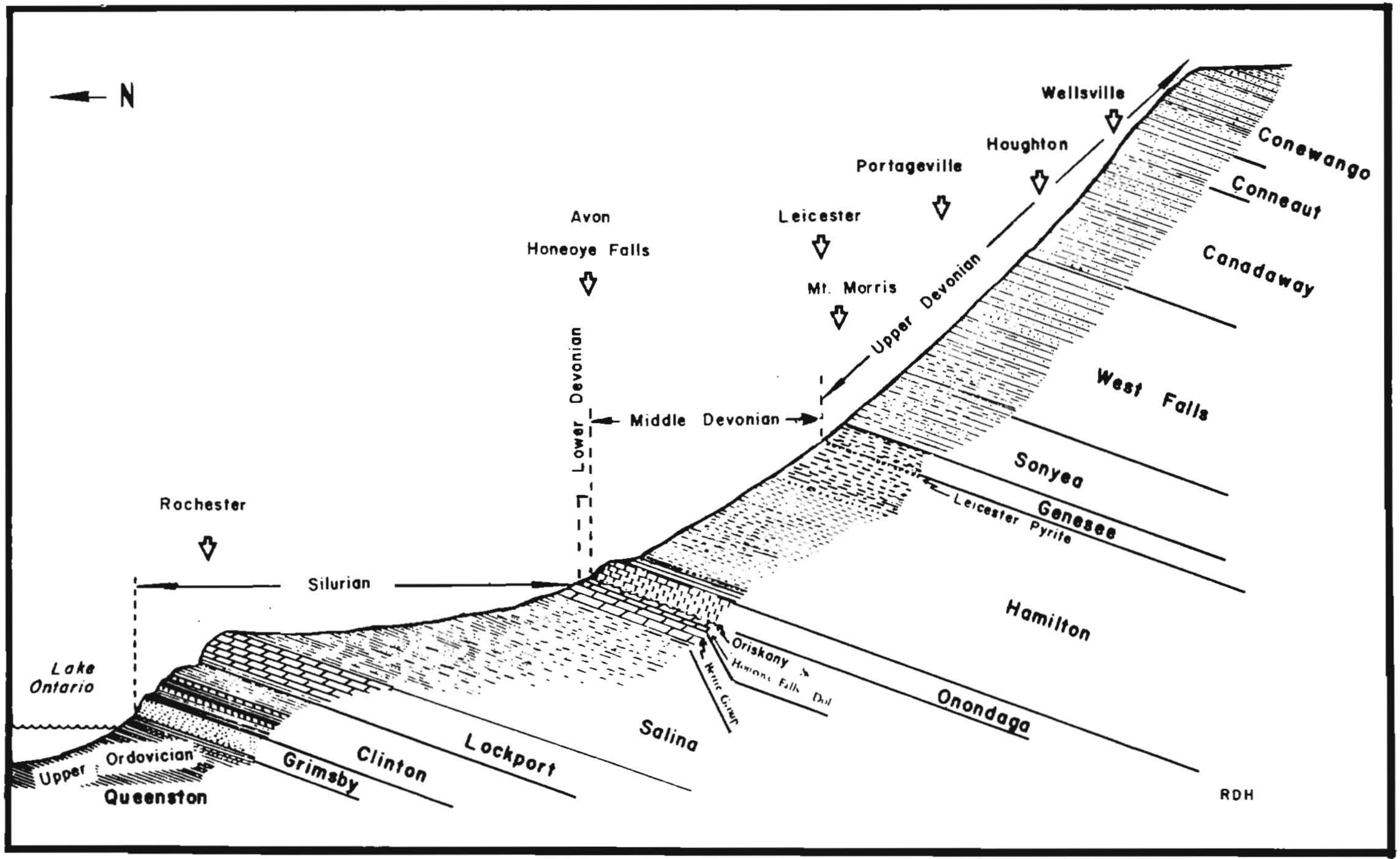

FIGURE 8: Present interpretation of the Genesee Valley stratigraphic sequence. Compare with Figure 7.

Much paleoecologic work has yet to be accomplished using fossil communities, their structure, evolution, and geographic extent, as exemplified by the work of McGhee and Sutton (1981). Furthermore, the stratigraphic relationships of the Upper Devonian, above the West Falls Group, have not been refined to the point of general agreement.

The geologic history of New York State in general and western New York in particular has advanced greatly since Fairchild's day, but there is still much to learn. To paraphrase Albert Einstein . . . "as a circle of illumination grows larger, so does the circumference of darkness that surrounds it."

ACKNOWLEDGEMENTS

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STRATIGRAPHY AND FACIES RELATIONSHIPS OF THE SILURIAN ROCHESTER SHALE (WENLOCKIAN; CLINTON GROUP) IN NEW YORK STATE AND ONTARIO

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ABSTRACT

The medial Silurian (Wenlockian) Rochester Shale occupies an important position in the history of stratigraphy, as the first formally designated rock unit in North America; nevertheless, this formation has received little recent study. Detailed studies permit an updated analysis and interpretation of stratigraphy and facies relations of the Rochester Shale in western New York and Ontario. Several mappable subdivisions are recognized in the Rochester shale, including four new members proposed here. West of Brockport, New York, the Rochester shale exhibits a division into two subequal units. A lower Lewiston Member is typified by bryozoan-brachiopod-rich mudstones and thin limestones at the base and top (units A, B, D, E) separated by an interval of sparsely fossiliferous shales and calcisiltites (unit C). The upper Rochester shale consists of unfossiliferous shales and argillaceous dolostones (Stoney Creek Member) west of Grimsby, Ontario, and calcareous shales and calcisiltites (Burleigh Hill Member) to the east. In Monroe County, New York, the Rochester shale is more homogeneous and has not been subdivided except for the uppermost gradational dolomitic shales, previously named Gates Member. Further east, in Wayne County, the Rochester Shale exhibits a tripartite subdivision with lower and upper shale members separated by a middle unit of micritic limestones, termed the Glenmark Member.

Subdivisions of the Rochester Shale are traceable for distances of over 150 km (95 mi.) in outcrops along the east-west trending Niagara Escarpment in western New York and Ontario. This contrasts strongly with abrupt north-south facies changes observed in the relatively short (5-13 km) Niagara Gorge and Fonthill sections. This observation strongly suggests that the present main outcrop belt in western New York and Ontario coincides approximately with elongate (east-west) facies belts of the Silurian epeiric sea.

INTRODUCTION

The Rochester Shale (medial Silurian, Wenlockian) was named by James Hall (1839, p. 290) for exposures on the Genesee River gorge in Rochester, N.Y.; it thereby became the first formally designated stratigraphic unit in North America. Although Hall (1843) later substituted the Niagara Shale for this rock. Clarke and Schuchert (1899) revived the name Rochester Shale, and subsequent authors have accepted this term. Contributions to the stratigraphy and paleontology of the Rochester Shale were made by numerous later authors (Hall, 1852; Ringueberg, 1886, 1888; Grabau, 1901; Sarle, 1901; Bassler, 1906; Kindle and Taylor, 1914; Schuchert, 1914; Chadwick, 1918; Caley, 1940; Gillette, 1940, 1947; Bolton, 1957; Berry and Boucot, 1970). These sources should be consulted for measured sections and complete faunal lists.

The Rochester Shale belongs to a sequence of four genetically related formations in the upper Clinton and lower Lockport Groups; in ascending order, these are the Irondequoit Limestone, Rochester Shale, DeCew Dolostone, and Gasport Limestone. General stratigraphic relationships among these units have been established and are summarized by Rickard (1975). Comprehensive stratigraphic studies of the Clinton and Lockport Groups were made by Gillette (1947) and Zenger (1965).

The Rochester Shale is a prominent stratigraphic unit, well exposed in numerous road cuts and creeks in the Silurian outcrop belt in New York and Ontario, where it frequently crops out in waterfalls below the capping Lockport Dolostones. It has long been noted as a classic source of Silurian fossils; over 200 species of invertebrate fossils have been reported from the Rochester Shale, including more than 80 taxa of bryozoans. The Rochester has also yielded some of the best preserved fossils in the North American Silurian section, including complete trilobites, crinoids, cystoids, and stelleroids.

Yet, despite its historical, stratigraphic, and paleontologic significance, the Rochester Formation has received very little recent study. Preliminary studies of the Rochester Shale depositional environments and paleoecology were made by Thusu (1972) and Narbonne (1977). However, these papers are restricted in geographic scope, and their conclusions necessarily generalized and tentative.

In particular no comprehensive stratigraphic or facies study of the Rochester Formation has previously been undertaken. Hence, the major objective of the present study is to provide a detailed and updated interpretation of the stratigraphy and facies relations of this rock unit.

Over 50 exposures of the Rochester Shale were studied along the Silurian outcrop belt between Hamilton, Ontario, and Walcott, New York, a distance of about 265 km (165 miles) (Figure 1). Each major section was measured and described in detail, and the occurrence of sedimentary structures, body fossils, and trace fossils was systematically recorded. These studies permit subdivision of the Rochester Formation into several mappable units, including four new members proposed herein.

Detailed mapping of these units also reveals a previously unrecorded paradox of the Rocnester Shale stratigraphy: thin units within the formation can be traced for considerable distances along the main east-west trending outcrop belt, with little or no facies change. However, in rare north-south oriented sections (e.g., Niagara Gorge) facies changes are rapid and substantial. Field and subsurface data both strongly suggest that the modern outcrop belt in western New York closely parallels facies belts within the Silurian epeiric seas. This single factor is of crucial importance to the development of a depositional model for the Rochester Shale. Indeed, it also may be a key to the understanding of many similar rock units in New York which exhibit apparent "layer cake" stratigraphy.

STRATIGRAPHY OF THE ROCHESTER SHALE

Background: In New York State and Ontario the Rochester Shale consists of medium to dark gray, calcareous mudstones and thin limestones (Gillette, 1947; Bolton, 1957; Thusu, 1972). This formation ranges in thickness from 0.6 m (2 ft) at Clappisons Corners, Ontario, in the west, to over 37 m (122 ft) in Wayne County, New York. Eastward, the Rochester Shale thins slightly before grading into the Herkimer Sandstone in Oneida County, New York (Gillette, 1940; 1947). Throughout much of its extent, the Rochester Shale is conformably underlain by crinoidal Irondequoit Limestone (Clinton Group) and overlain gradationally by dolostones (Gasport, DeCew, or Sconondoa formations) of the Lockport Group (Zenger, 1965; Rickard, 1975).

Previous workers have tended to regard the entire Rochester Shale as a rather uniform stratigraphic unit, essentially lacking mappable subdivisions (Thusu, 1972). However, local subdivision of units has been attempted by others. Ringueberg (1888) recognized three subequal units of the Rochester Shale at Lockport, New York: a lower third of fossiliferous shale, a middle third including interbedded fossiliferous limestones and shales, and an upper third comprising sparsely fossiliferous calcareous to dolomitic shales gradational into the overlying Lockport Group. At Niagara Gorge, Grabau (1901) differentiated the Rochester Shale into the lower fossiliferous shales overlying the Irondequoit Limestone, and included at their top four feet of interbedded bryozoan-rich thin limestone and shale which he termed the "bryozoa beds." The upper shales are calcareous or dolomitic and less fossiliferous. In fact, the Niagara Gorge and Lockport sections are very similar, and it is clear that Ringueberg's lower and middle thirds together correspond with Grabau's lower shales, the middle third representing Grabau's "bryozoa beds."

This twofold subdivision of the Rochester Shale can be recognized from Hamilton, Ontario, in the west through Brockport, New York, in the east (Figure 2). A lower unit of fossiliferous shale and thin, bryozoan-rich limestones, herein termed the Lewiston Member, is present at all exposures in this portion of the outcrop belt. The upper portion of the Rochester Shale is consistently distinct from the Lewiston Member but exhibits sufficient lateral variation that two facies are recognized within it . An argillaceous dolostone-dolomitic shale facies, the Stoney Creek Member, occupies this interval west of Grimsby, Ontario; east of Grimsby the Stoney Creek grades into sparsely fossiliferous, calcareous to dolomitic shale, termed the Burleigh Hill Member herein.

East of Brockport, in Monroe County, N.Y., the entire Rochester Shale becomes more homogeneous, and separate upper and lower members are no longer recognizable at the type section. Only the uppermost transitional strata have been recognized as a separate lithologic entity (Chadwick, 1918). Still farther east, in Wayne County, the Rochester Shale exhibits a tripartite subdivision, with lower and upper shale members (unnamed) separated by a middle interval of ledge-forming micritic limestones termed the Glenmark Member. Detailed descriptions of the Rochester subdivisions follow.

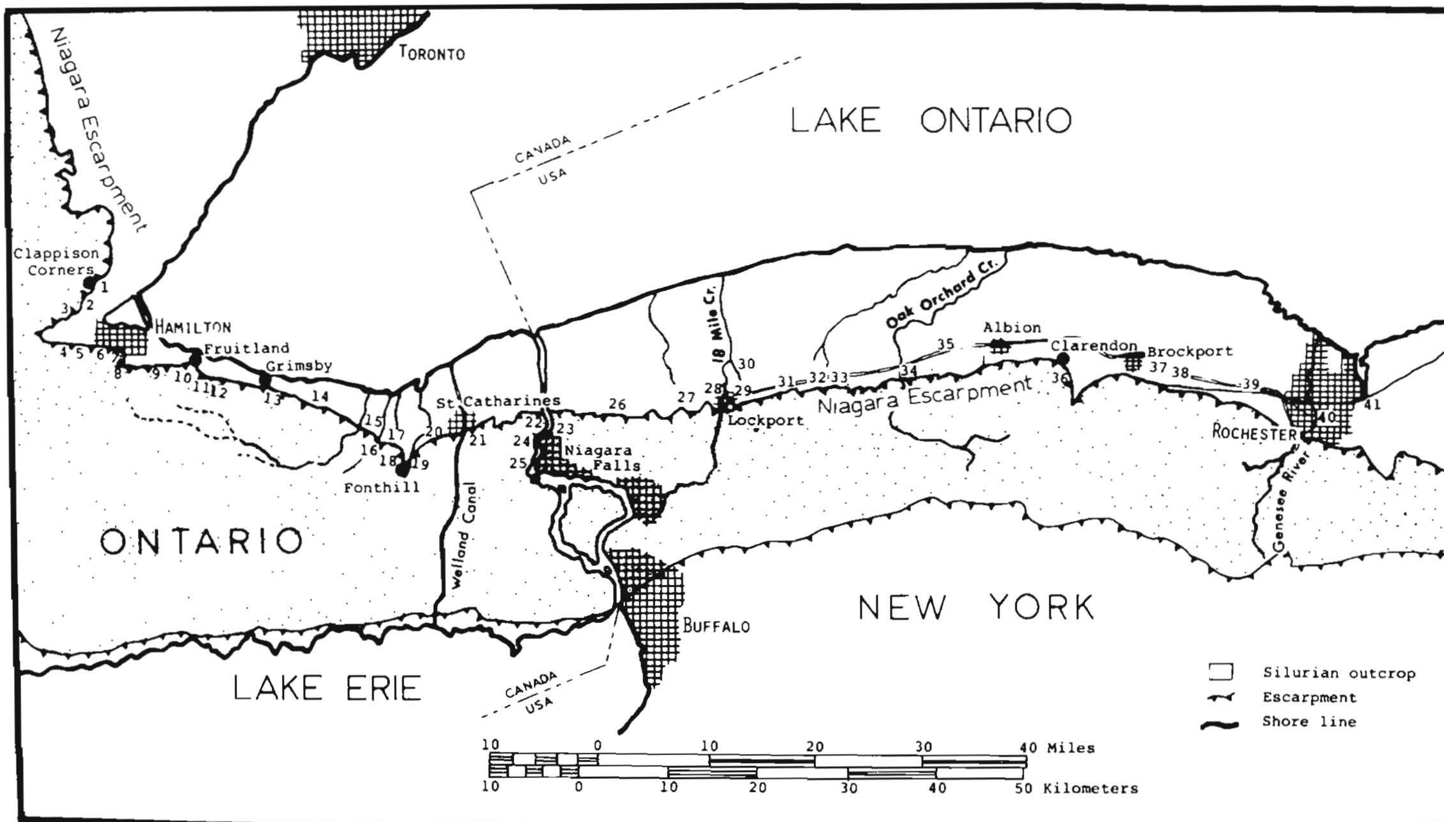

FIGURE 1: Location map for outcrops of Rochester Shale in western New York and Ontario. Numbers refer to localities described in Appendix A.

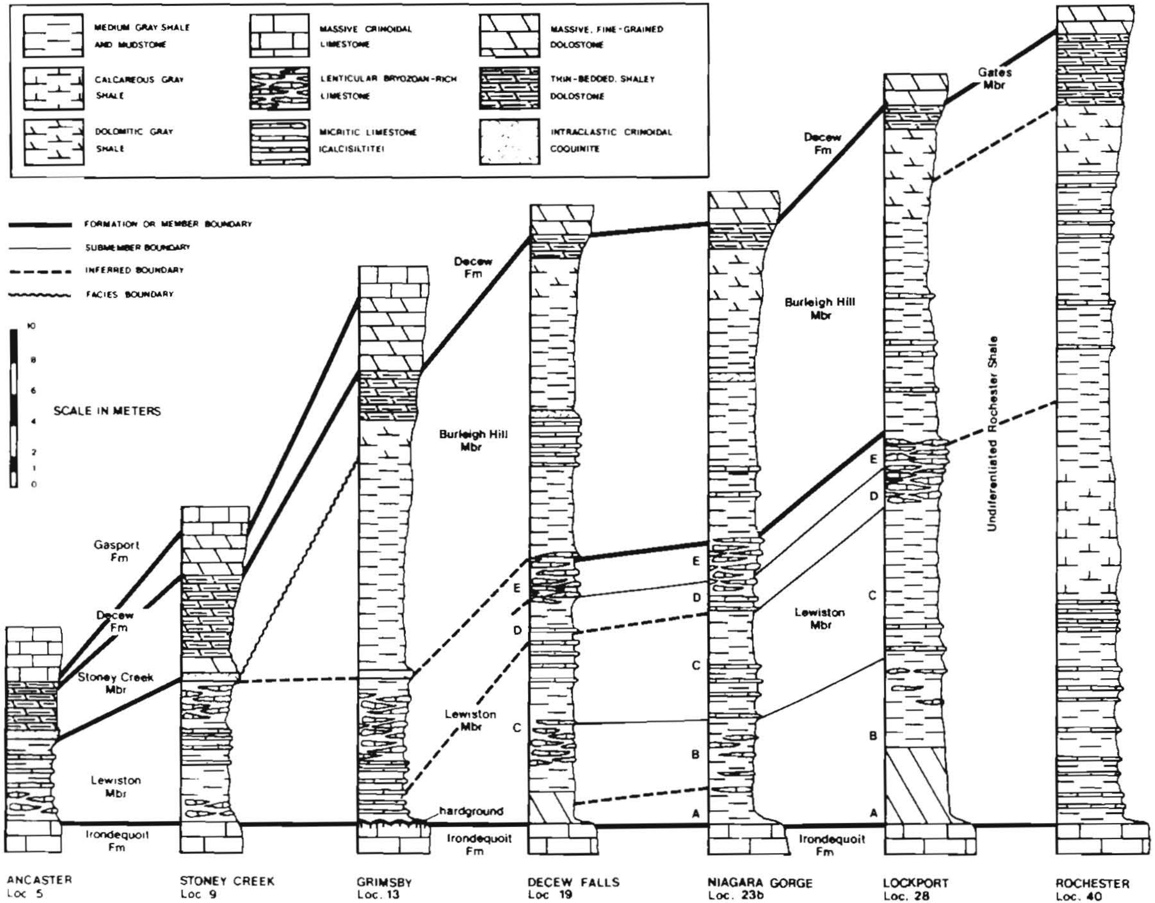

FIGURE 2: Stratigraphic sections of Rochester Shale for seven localities in Ontario and western New York. Locations of numbered sections are shown in Figure 1. See Appendix A for descriptions of localities.

Lewiston Member

Type locality: Cliff exposures in the east wall of Niagara Gorge, 1 km south of the Lewiston-Queenston bridge and 0.6 km (0.4 mi) north of the Robert Moses power plant, 2.3 km south of Lewiston, Niagara County, New York; (Lewiston 7.5′ Quadrangle) (Figs. 2, 3).
Thickness: At the type locality, the Lewiston Member is 8.6 m (28.6 ft) thick and it varies from 2.6 m (8.5 ft) at Ancaster, Ontario, to about 12.2 m (40 ft) near Brockport, New York.
Extent and Lithology: The name Lewiston Member is proposed herein to designate the shales and fossiliferous limestones of the lower unit of the Rochester Shale from Hamilton, Ontario, to Brockport, New York. This unit corresponds to Grabau's (1901) lower shales and to Ringueberg's (1888) lower and middle third subdivisons. The Lewiston Member consists of medium gray, brownish weathering, sparsely to highly fossiliferous, shaley mudstone with thin interbedded lenses of biomicrite and burrowed micrites (calcisiltites). The Lewiston Member can be further subdivided into several units (submembers) as follows:

A. A basal transition zone usually about a meter in thickness, consisting of brachiopod-crinoid-rich, argillaceous, silty biomicrite or biosparite lenses in shale. This unit can be discerned in outcrops from Middleport, New York, westward to St. Catharines, Ontario; farther west, it is generally absent, probably due to nondeposition (Figure 4A).

B. A one to three meter interval of fossiliferous, brownish-gray, slighly calcareous mudstone with abundant bryozoan clusters and bryozoan biomicrites (Figure 5A). Again this unit thins westward.

C. A middle unit, variable in thickness, consisting of sparsely fossiliferous shale and interbedded, dark gray, burrowed, cross-laminated calcisiltites (pelmicrites) (Figure 5 B).

D. An upper interval, up to two meters thick, of fossiliferous mudstone and interbedded bryozoan-rich limestones, closely resembling submember B, and gradational into the overlying bryozoa beds of unit E. This interval is apparently absent south of Whirlpool Park in Niagara Gorge.

E. A zone, typically about 1.5 m or less in thickness, of bryozoan-rich biomicrites with minor interbedded shale and rare biosparite (Figure 5C). The uppermost limestone band of this interval, which is frequently the thickest (up to 30 cm), invariably exhibits a sharp contact with barren laminated shales of the overlying upper member. Locally, this unit is glauconitic or chamositic and contains shale-pebble intraclasts. Unit E thus forms a readily recognizable upper boundary of the Lewiston Member; it corresponds to the "bryozoa beds" of Grabau (1901). The bryozoa beds thin rapidly southward along Niagara Gorge, and near Niagara Falls they are represented only by a 5-10 cm thick bed of bryozoan and

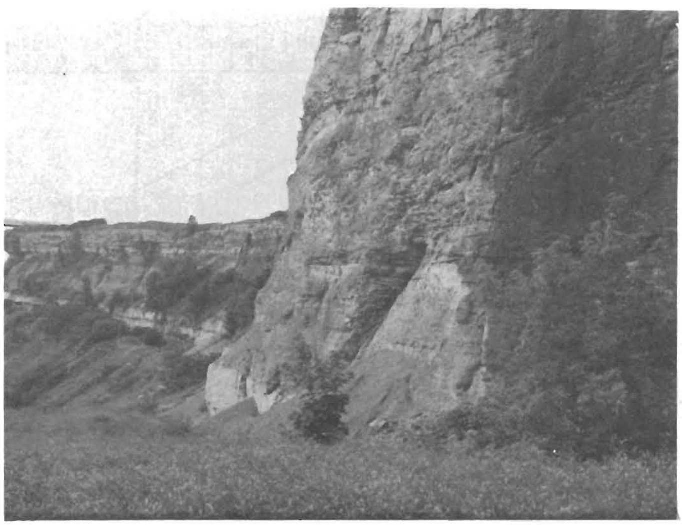

FIGURE 3: Outcrop of Irondequoit Limestone (lowest ledge), Rochester Shale and Lockport Group (overhanging ledge); cliffs along east side of Niagara Gorge, south of Lewiston, New York (Loc. 23B); type section of the Lewiston Member. Arrows indicate upper and lower contacts of Lewiston Member.

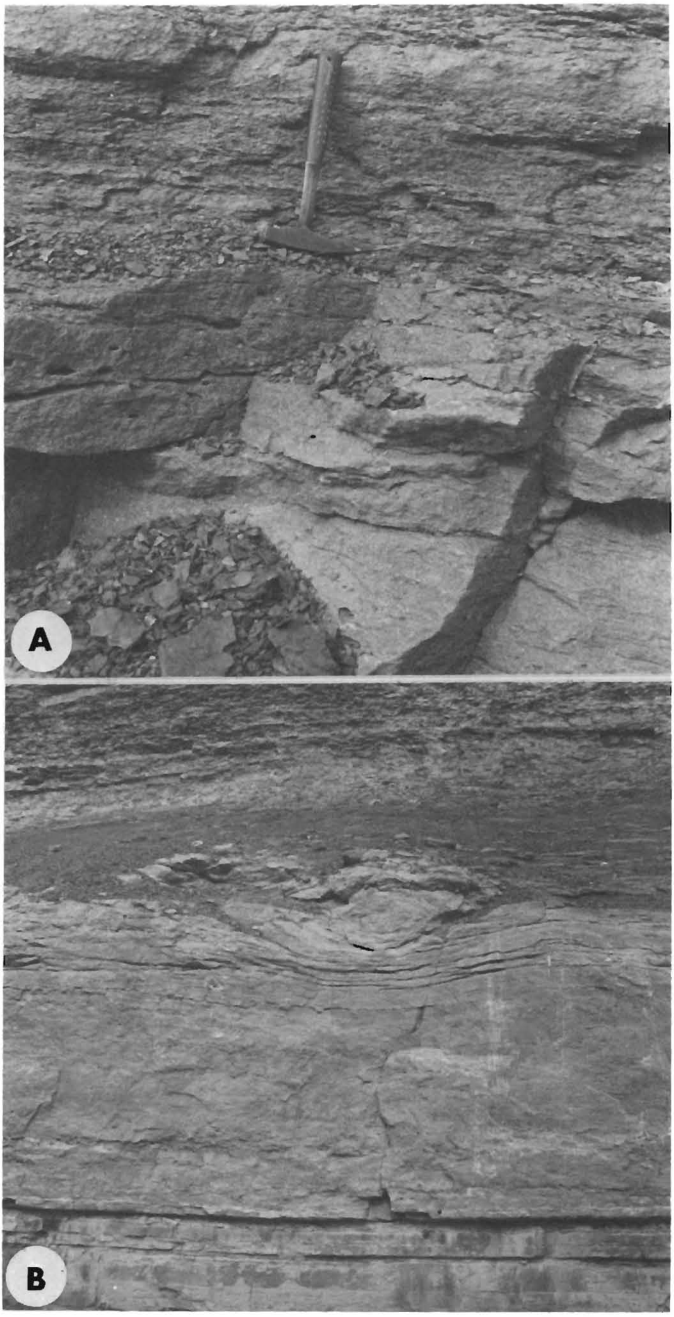

FIGURE 4: Lower contact of Lewiston Member. A) gradational contact between upper Irondequoit Limestone and shell-rich basal unit (submember A) of Rochester Shale; hammer marks position of lowest mudstone. B) bryozoan-bioherm at Irondequoit/Rochester contact; bioherm, described by Sarle (1901, p. 243) is 10 m across. Full thickness of Irondequoit Limestone - including upper and lower (Rockway) members-is exposed. Both photos Niagara Gorge south of Lewiston, New York (Loc. 23B).

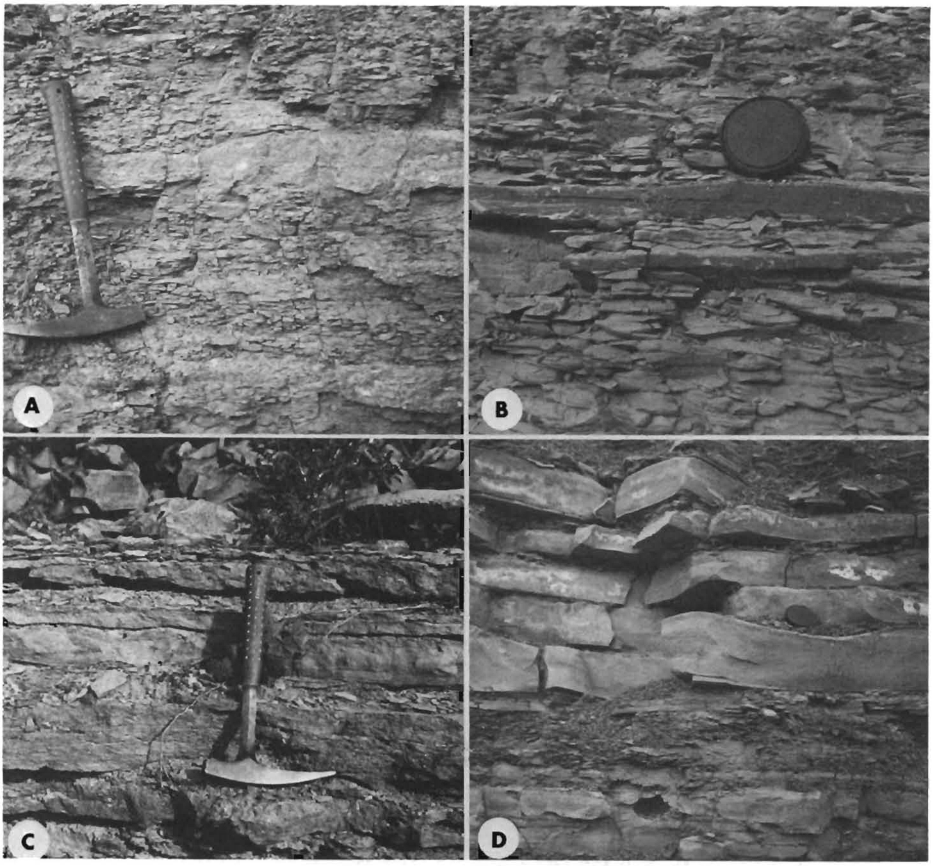

FIGURE 5: Lithologic features of the Lewiston Member. A) portion of submember B; note bryozoan-rich mudstone (below hammer) and lens of calcarenite (biomicrite); (Loc. 23B). B) submember C, showing bands of laminated, burrowed calcisiltite, (Loc. 23B). C) unit E of interbedded calcarenite (at head and top of hammer), calcisiltite, and thin shale, marking the top of the Lewiston Member (Loc. 19A). D) closely-spaced calcisiltite bands at top of Lewiston Member; the lateral equivalent of submember E, at the south end of Niagara Gorge. Note rippling of limestone below lens cap (Loc. 25B).

crinoid biosparite. The remainder of the interval is replaced southward by relatively thick units of dolomitic calcisiltite (Figure 5D), these finally merging into a single bed of argillaceous dolostone south of the former Schoellkopf hydroelectric plant site in Niagara Falls.

Contacts: In the Niagara Region, west as far as the St. Catharines area, the contact between the Irondequoit and the Rochester Formations is gradational through nearly a meter of calcareous shale and argillaceous limestone, containing a brachiopod-dominated fauna which is also intermediate between that of the upper Irondequoit and Lewiston Members (submember A) (Figure 4A). Small bryozoan mounds or bioherms, which occur in the upper Irondequoit Limestone throughout much of western New York, occasionally protrude upward for over a meter into the overlying shale (Figure 4B). Interfingering of these biohermal micrites with typical Rochester Shale proves that the two lithologies were formed contemporaneously (Sarle, 1901). Such bioherms have been recognized only as far west as Queenston, Ontario (Loc. 22), on the west side of Niagara Gorge. Except for one small example these are entirely restricted to the basal meter of the Rochester Shale and are thus closely associated with the Rochester/Irondequoit transition (submember A).

West of St. Catharines, along the main escarpment, the transitional interval (submember A) is absent and the contact between the Rochester and Irondequoit Formations is sharp. At Fifteen Mile Creek in Rockway, Ontario (Loc. 17), about 3 m of fossiliferous shale containing numerous bryozoan beds (submember B) overlie this contact. This fossiliferous unit thins rapidly towards the west; at Sixteen Mile Creek only 0.5 m of bryozoan-rich submember B overlies the Irondequoit. Most of the fossils of this interval are poorly preserved, suggesting reworking and condensation of this section. Although there are no exposures of the basal Rochester Shale for several km west of Sixteen Mile Creek (Loc. 16), this trend appears to continue westward, toward Grimsby, where both A and B submembers are apparently missing and a thin section of barren shale (submember C?) lies directly upon a discontinuity surface (hardground) on the top of the Irondequoit Limestone.

Contact relationships between the Irondequoit and Rochester Formations are somewhat obscure due to dolomitization of both formations in the area immediately west of Grimsby, Ontario. The contact appears to remain sharp, but no evidence of a hardground on the upper surface of the Irondequoit Limestone was observed at most outcrops. Shale immediately overlying the Irondequoit contains a few lenticular bryozoan biomicrites, which may be equivalent to the upper fossiliferous units (D and E submembers) of New York.

As noted above, the upper contact of the Lewiston Member with the overlying upper Rochester unit (Burleigh Hill or Stoney Creek Member) is sharp, although not undulatory, at most outcrops from Hamilton, Ontario, to Brockport, New York (Figure 9A).

Fossils: Most of the diverse Rochester Shale fauna of western New York and Ontario reported in the literature is derived from the Lewiston Member. Lists of fossils have been compiled by Grabau (1901) and Gillette (1947). This unit, except for submember B, is characterized by an abundance of bryozoans, which typically occur in thin, lenticular clusters embedded in mudstones (especially in unit B, D and E). Over 80 species of bryozoans were identified from the lower Rochester Shale by Bassler (1906). Associated with the bryozoan patches are abundant brachiopods, especially *Atrypa, Whitfieldella, Striispirifer, Dicoelosia,* and pelmatozoans, of which *Stephanocrinus* and *Caryocrinites* are the most abundant and widespread. Unit C contains a sparser, low-diversity fossil assemblage dominated by the brachiopods *Striispirifer, Parmorthis, Leptaena,* and *Strophonella,* as well as trilobites such as *Dalmanites, Trimerus,* and *Arctinurus.* This fauna also characterizes the less fossiliferous undifferentiated Rochester Shale east of Brockport, New York, and parts of the Burleigh Hill Member.

The transition zone between the lower fossiliferous unit (B) and unit C contains some of the best preserved fossils in the entire Rochester Shale, including the well-known *Homocrinus* bed crinoid assemblage (Ringueberg, 1888; Springer, 1920; Brett, 1978). Calcisiltites of the Lewiston Member contain abundant ichnofossils including large vertical tunnels, *Chondrites, Planolites,* and *Teichichnus.*

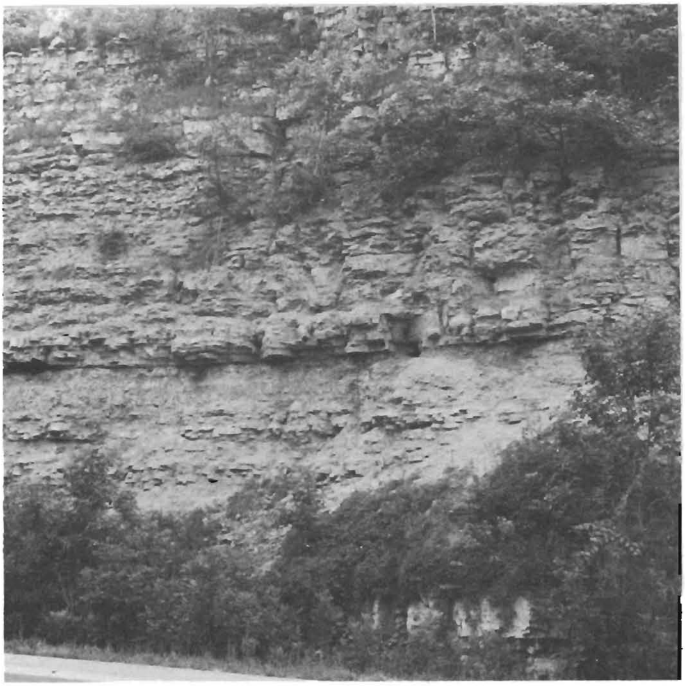

FIGURE 6: Outcrop of Rochester Shale at Highway 20 roadcut, Stoney Creek Ontario (Loc. 9). Irondequoit Limestone appears as the lowest unit (lower right); note sharp contact between softer Lewiston and more calcareous Stoney Creek members of the Rochester Shale (arrow). DeCew and Gasport Formations form top of exposure.

Stoney Creek Member

Type Locality: Road cuts along both sides of Highway 20 in the Niagara Escarpment 1 km south of Stoney Creek, Ontario (Loc. 9; Figure 6).

Thickness: At Stoney Creek roadcut this unit attains a thickness of 2.8 m (9 ft); it thickens eastward to 4.7 m at Fruitland, Ontario (Loc. 12) as it grades into the Burleigh Hill and thins westward to 2.6 m (8.5 ft.) near Ancaster, Ontario (Loc. 5, Figure 6).

Extent and Lithology: The Stoney Creek Member consists of unfossiliferous, dark-gray, bioturbated, argillaceous dolostones typically in bands about 10 cm thick, interbedded with thinner (2-5 cm), dark bluish gray dolomitic shales. The alternation of these lithologies gives the unit a strongly banded appearance in most weathered outcrops, with alternating layers of buff and bluish-gray colored rock.

Contacts: The Stoney Creek Member is bounded at the base by a thin layer of crinoidal biosparite usually containing dolomitic shale intraclasts (Figure 7). Around Hamilton and Stoney Creek, Ontario, this thin crinoidal bed has been hydrothermally altered and contains abundant sulfides such as pyrite and galena. Consequently, it there exhibits rusty weathering and is an obvious marker bed. At Stoney Creek, Ontario, this unit grades upward into a laminated, coarse, burrowed, dolomitic calcisiltite band about 30 cm thick that strongly resembles the DeCew Dolostone.

The upper contact of the Stoney Creek with the overlying DeCew Dolostone is gradational but typically rather distinct due to weathering. DeCew stands out as a slightly more massive band with distinct wavy lamination and discrete small burrows. West of Hamilton, the Gasport dolomitic limestone rests with sharp contact on the Stoney Creek Member, the DeCew Dolostone being absent.

Fossils: Body fossils are generally lacking in the Stoney Creek Member, and none was found at most outcrops, except in the basal crinoidal limestone where pelmatozoan debris and bryozoan and brachiopod fragments are abundant. However, at Route 403 road cut (Loc. 5) in Hamilton, Ontario, a single layer near the top of the Stoney Creek Member contains abundant fenestrate and ramose

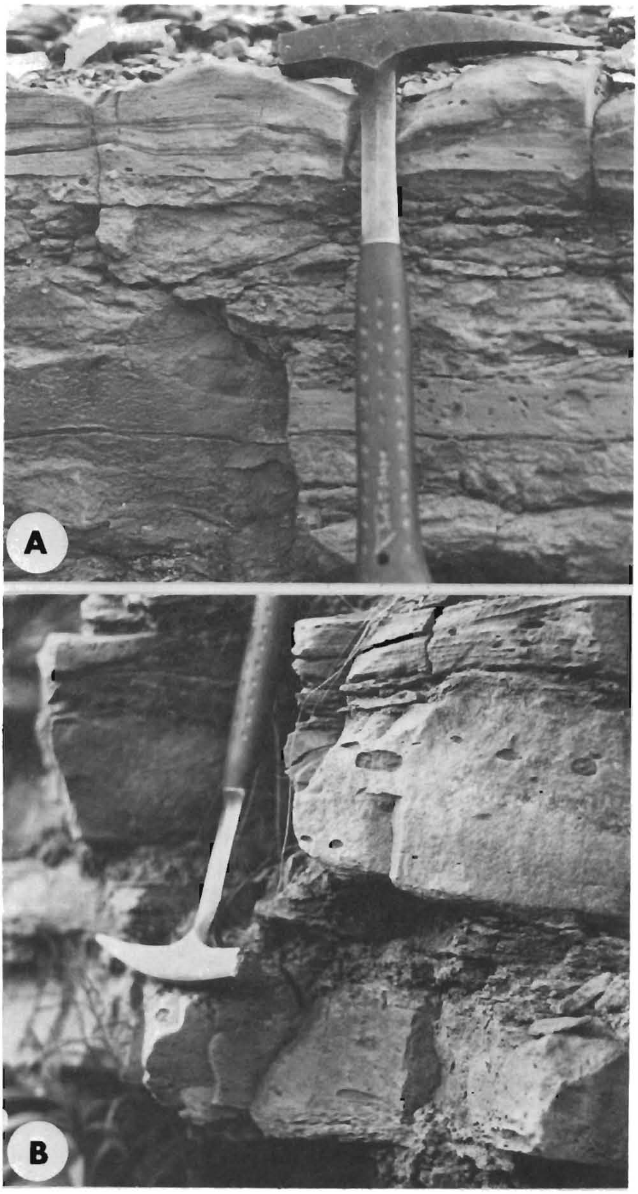

FIGURE 7: A) Rippled, laminated and burrowed calcisiltite in Stoney Creek Member, (Loc. 5) B) shale clasts in basal calcarenite of Stoney Creek Member, (Loc. 9).

FIGURE 8: Outcrop of upper Rochester Shale along Burleigh Hill Drive, Thorold, Ontario (Loc. 20), exposes a complete section of Burleigh Hill Member (type section); lower contact is in ditch in lower left of view; arrow marks Burleigh Hill/DeCew Dolostone contact.

bryozoans and brachiopods. Burrow mottling is prevalent throughout the Stoney Creek Member, although discrete burrows are generally not recognizable. In the basal DeCew-like band, however, distinct cylindrical burrow tubes *(Chondrites)* are abundant.

Burleigh Hill Member

Type Locality: A road cut on both sides of Burleigh Hill Drive in Thorold, Ontario (Loc. 20A), exposes this unit in its entirety (Figure 8).
Thickness: The Burleigh Hill Member is 11.2 m (34 ft) thick at Thorold, Ontario; this unit thins westward to 4.3 m (14 ft) at Grimsby, Ontario (Loc. 13), where it grades laterally into the Stoney Creek Member.

The upper Rochester thins southward in Niagara Gorge from 9.1 m (30 ft) to 4.9 m (16 ft) apparently due to erosional truncation at the top.
Extent and Lithology: The Burleigh Hill Member comprises the upper calcareous portion of the Rochester Shale from the top of the bryozoa beds (unit E) of the Lewiston Member to the DeCew Dolostone. This unit consists of sparsely fossiliferous medium-to-dark gray, whitish weathering, platy and typically well-laminated shale, with thin micritic limestone (calcisiltite) interbeds. Shale is increasingly calcareous to dolomitic upward and grades into argillaceous limestone and dolostone near the top (typically 40-60 percent carbonate). The lowest portion of this member usually comprises 1-2 m of nearly barren shale with few interbeds. Higher portions are typified by alternating thin (2-5 cm) bands of burrowed, laminated calcisiltites closely similar to those of unit C in the Lewiston Member (Figure 9). Dolomitic calcisiltite bands become increasingly numerous and thick in the upper 2 to 3 m of the Burleigh Hill, ultimately merging into argillaceous dolostone which is transitional into the overlying DeCew Formation (analogous to Gates Member) (Figure 9B). Burleigh Hill Member contains no bryozoan clusters and very few fossiliferous limestones. Rare stringers and lenses of crinoid columnals occur sporadically in the upper few meters of the member, and at the type section a thick band of crinoidal biosparite with shale rip-up clasts occurs 10.6 m above the base of the member (Figure 10B). Around St. Catharines, Ontario, a shell bed containing abundant *Dalejina* and *Coolinia* brachiopods occurs 5.8 m above the base of the Burleigh Hill. Otherwise the unit is largely barren of body fossils.
Contacts: The basal contact of the Burleigh Hill Member is sharp at all localities where observed; laminated barren shales abruptly overlie the highest bryozoan-rich limestone of unit E of the Lewiston Member (Figure 9A). In contrast, the upper contact is completely gradational with the overlying DeCew Dolostone, at nearly all localities, through a transition zone (Gates Member) up to 3 m thick (Figure 9B).

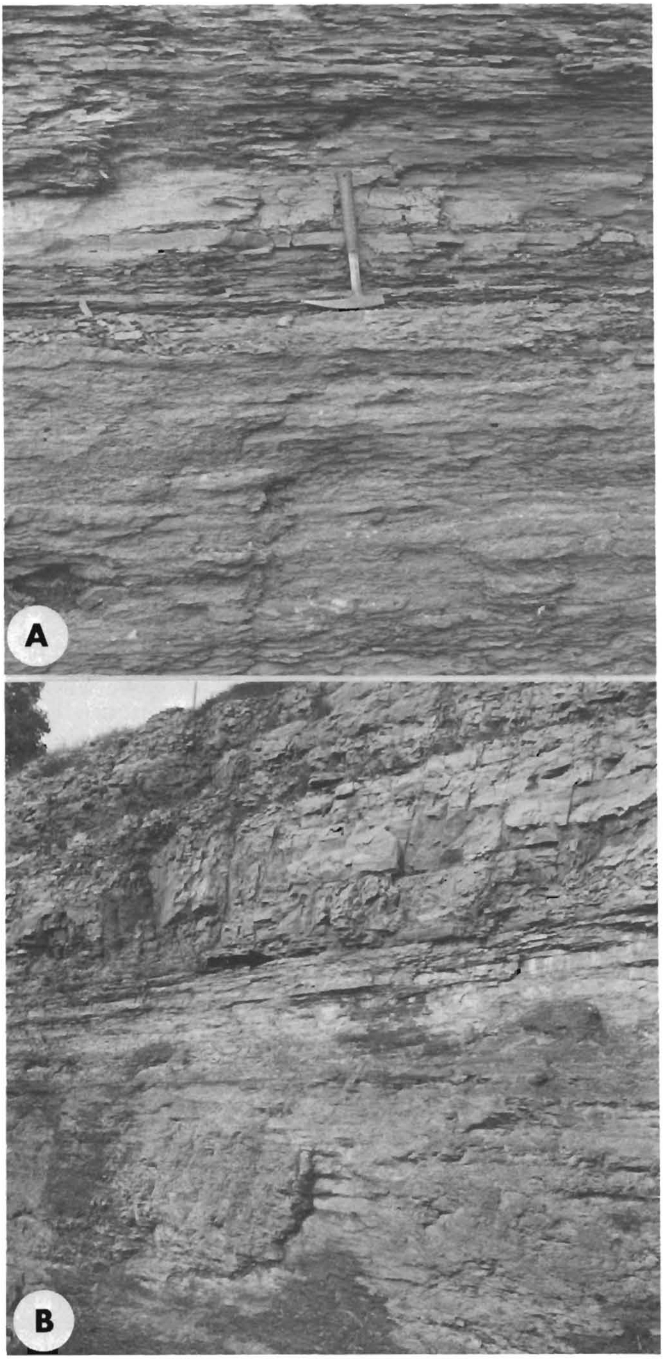

FIGURE 9: A) Abrupt contact between Lewiston and Burleigh Hill members (at hammer); note abrupt change in weathering character from rubbly, fossiliferous limestone of Lewiston - E submember to fissile, friable shale of lower Burleigh Hill (Loc. 23B). B) Upper gradational contact of Burleigh Hill with DeCew Dolostone (approximate position of contact marked by arrow), (Loc. 23B).

However, in the south end of Niagara Gorge, no transitional zone is present, and the lowest band of enterolithic DeCew Dolostone (about 1 m thick) rests on the upper Rochester Shale with sharp undulatory contact. A 1.1 m thick shaley dolostone interval splits the DeCew into two portions. The lower unit shows a sharp contact with the Burleigh Hill, whereas the upper portion of the DeCew also exhibits the same kind of sharp erosional base with its middle shaley division. The apparent interbedding of DeCew and upper Rochester (Burleigh Hill) lithologies here suggests an interfingering of coarse carbonate silt and fine sand with terrigenous muds.

Fossils: A faunal, as well as a lithologic separation, between the lower and upper portions of the Rochester Shale, has been recognized by several previous authors (Ringueberg, 1888; Grabau, 1901, Bassler, 1906; Narbonne, 1977). But the abruptness of this distinction has not been adequately emphasized. In contrast to the fossiliferous Lewiston Member, the shale overlying the bryozoa beds in western New York is nearly barren. Bryozoan clusters terminate abruptly at the top of the Lewiston Member and, with rare exceptions, bryozoans do not recur at all in the Rochester Shale above this boundary. Disappearance of these fossils is paralleled by the complete absence of many associated species including various brachiopods, e.g., many spiriferids, atrypids, *Dicoelosia, Whitfieldella,* and nearly all pelmatozoans. The Burleigh Hill Member contains a sparse low-diversity assemblage resembling that of submember C in the Lewiston Member; characteristic forms include brachiopods such as *Parmorthis, Strophonella,* and *Leptaena* and the trilobites *Dalmanites* and *Trimerus.* Rare lenses of well-preserved crinoids, mainly *Dendrocrinus* and *Dimerocrinites,* have been discovered near the top of the Burleigh Hill Member around St. Catharines. Trace fossils are abundant in the thin calcisiltites of the Burleigh Hill Member, and include oblique to vertical shafts up to a centimeter in diameter and branching feeding burrows *(Chondrites).*

Undifferentiated Rochester Shale of the Type Section

Near the type section in the Genesee River Gorge the distinction between upper and lower portions of the Rochester Shale becomes less obvious than farther west. Bryozoan clusters are rare, and the distinction between lower or Lewiston and upper or Burleigh Hill members can no longer be maintained. Except for the basal 1.5 to 1.8 m (5-6 ft) the entire formation is only moderately to sparsely fossiliferous, medium-gray shale with abundant thin-to-medium beds (5-15 cm) of burrowed, laminated calcisiltites. These units, which typically show cross-lamination and abundant sole marks, are most numerous and thickest near the center of the formation, where they form a band of interbedded limestone and shale beds approximately 8 m in thickness (Figure 10). In Genesee Gorge this unit often forms a salient ledge in the cliffs due to the slightly greater weathering resistance of the limestone interbeds. The upper and lower boundaries of this interval are ill-defined, and it appears to grade into synjacent shales which have more widely spaced calcisiltites; for this reason, the middle interval is not distinguished as a separate member. However, it very likely represents the stratigraphic equivalent of the Glenmark Member (see below) of Wayne County, and it may correlate approximately with the "bryozoa beds" of the Lewiston Member further westward. The upper portion of the Rochester Formation in Genesee Gorge contains an interval, approximately 9 m thick, which is predominantly sparsely fossiliferous shale, and this in turn grades upward into calcareous shales and dolostones of the Gates Member.

Contacts: The lower contact of the Rochester Shale at Genesee Gorge appears to be sharp, above the highest bed of micritic limestone of the Irondequoit Formation. This unit is overlain by about 0.5 m of greenish-gray, nearly barren, burrowed shale. The upper part of the undifferentiated Rochester Shale is completely gradational into the overlying Gates Member.

Fossils: Above the basal half-meter of the Rochester Shale occur approximately 1-2 m of fairly fossiliferous, greenish to brownish-gray shale, which contains a distinctive fauna unlike that of the Lewiston Member farther west. This assemblage is dominated by brachiopods, particularly *Plectodonta* and *Whitfieldella.* Bryozoans are not nearly as common here as farther west but are represented by lamellate fistuliporoid and ceramoporoid colonies with rare fenestrate and ramose bryozoans. Echinoderms are represented by *Stephanocrinus gemmiformis* and *Eucalyptocrinites caelatus. S. angulatus* and *Caryocrinites,* which typify the Lewiston Member, are very rare here. Trilobites and the large orthoconic nautiloid *Dawsonoceras* are also locally abundant. Higher portions of the Rochester Shale at Rochester Gorge contain a rather homogeneous fauna similar to that of unit C in the Lewiston Member or that of the Burleigh Hill Member of the west. It is composed of *Striispirifer, Leptaena, Parmorthis, Coolinia,* the rugose coral *Enterolasma,* trilobites *Dalmanites* and *Trimerus,* and the nautiloid *Dawsonoceras.* Again, the calcisiltites contain a rich ichnofauna.

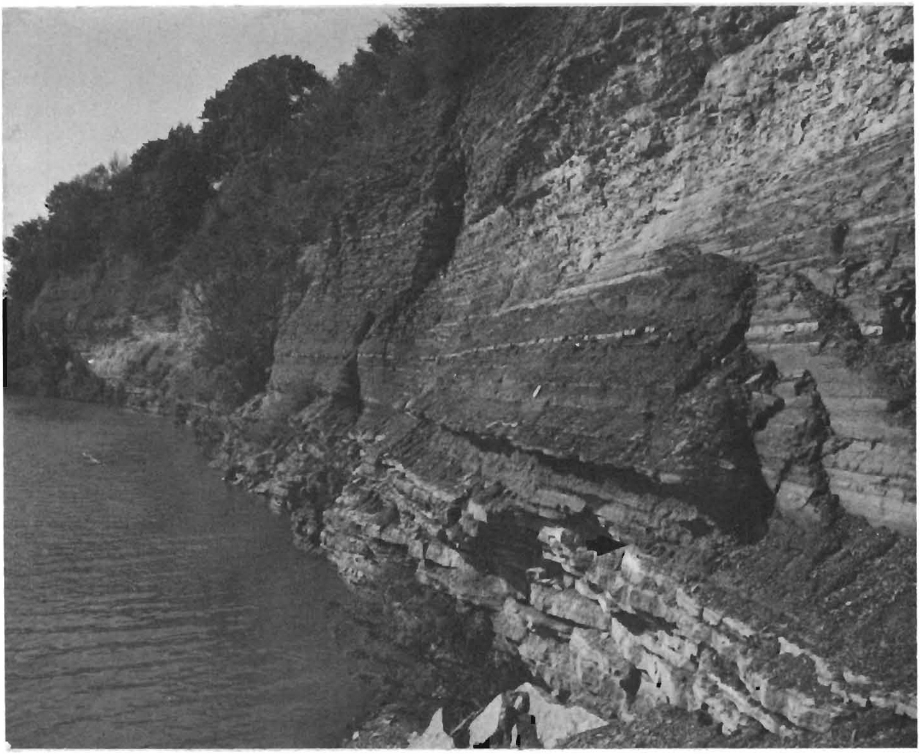

FIGURE 10: Irondequoit Limestone/Rochester Shale (formational contact marked by arrow) exposure in Genesee River Gorge, Rochester, New York (Loc. 40). Note abundant calcisiltite bands.

Gates Member

Type Locality: Chadwick (1918) applied the name Gates to the upper transitional portion of the Rochester Shale along the Erie Barge Canal near Lyell Avenue (Route 31), New York, in the town of Gates, Monroe County, New York (Rochester East 7.5′ Quadrangle).
Thickness: The Gates Member consists of the uppermost 3-4 m (9-12 ft) of Rochester Shale.
Extent and Lithology: The Gates Member comprises transitional strata between the typical Rochester Shale and DeCew Dolostone in Monroe County and is medium- to thick-bedded, buff-weathering, laminated argillaceous dolostone. The Gates typically exhibits irregular cross-lamination, planar lamination and numerous small burrows. The lower portion exhibits buff and gray banding in weathered outcrops, and so resembles the Stoney Creek Member.

The Gates Member is essentially continuous with, and laterally gradational into, the upper portion of the Burleigh Hill Member.
Contacts: The lower contact of the Gates Member is completely gradational with the underlying upper part with the undifferentiated Rochester Shale. Chadwick (1918) observed an undulatory sharp upper contact between the Gates and the overlying DeCew Dolostone, and he postulated a major diastem (Gillette, 1947).
Fossils: The Gates Member characteristically exhibits small-diameter *Chondrites* burrows, but it is otherwise sparsely fossiliferous to completely barren.

Glenmark Member

Type Locality: Glenmark Falls on Sodus Creek near Sodus, Wayne County, New York (Sodus Bay 7.5′ Quadrangle).
Thickness: The Glenmark Member comprises about 9 m (30 ft) of section in the outcrops of Wayne County. In the subsurface of Cayuga County this unit thins to approximately 4.5 m (15 ft).
Extent and Lithology: The Glenmark Member is a distinctive, ledge-forming calcareous unit within the middle part of the Rochester Formation of Wayne and Cayuga Counties. It consists of dark bluish-gray, argillaceous limestone (micrite) with thin shaley partings. Farther eastward, a medial limestone unit partly correlative with the Glenmark Member can also be recognized in drill cores and cuttings from Cayuga County (Gillette, 1947). In a drill core from Lakeport, New York, argillaceous limestones are predominant in an interval about 20-24 m (65-80 ft) above the base of the Rochester Shale. The base of this interval contains coarsely crystalline limestone (biosparite) with hematitic stringers. This band of lean iron ore was also observed at approximately the same position west as far as North Victory, New York (Gillette, 1947) It appears to mark the base of the Glenmark Member.
Contacts: In outcrops in Wayne County, the lower contact of the Glenmark Member is gradational upward from the calcareous lower part of the Rochester Shale; however, its upper contact with the upper Rochester Shale is abrupt and sharp.
Fossils: The unit is nearly barren of fossils except near the base, where it contains a sparse fauna of brachiopods and trilobites.

FACIES VARIATION OF THE ROCHESTER SHALE

The subdivisions of the Rochester Shale are remarkably consistent along a sizeable portion of the outcrop belt between Hamilton, Ontario, and Brockport, New York, a distance of approximately 144 km (90 mi). The major changes in this section involve a gradual westward thinning from 21 to 4 m (69-13 ft) and a change of the upper unit from Burleigh Hill to Stoney Creek facies. All of the subunits of the Lewiston Member (A-E) can be recognized from St. Catharines, Ontario, to Brockport, New York, although the lower units (A-C) are absent west of St. Catharines, probably due to nondeposition. East of Brockport, outcrops are scattered, but the Rochester Shale apparently changes rather rapidly southeastward to the undifferentiated formation exposed in the Genesee Gorge. Eastward into Wayne County, the Rochester Shale thickens but appears similar to the strata in Monroe County, except that the Glenmark Member becomes a distinctive ledge-forming unit. Near Lakeport, New York, the Rochester Shale is distinctly sandy in its basal portion as it grades into the Herkimer Sandstone, but details of this transition are obscured due to poor outcrops.

In contrast to the rather gradual changes of facies observed in the Rochester formation along the east-to-west-trending outcrop belt, north-south variations in facies appear to be both rapid and substantial. Detailed stratigraphic studies of the Rochester Shale in the Niagara Gorge provide new insights into the stratigraphy and depositional environments of this unit (Figure 11). The nearly continuous outcrops along the 11-kilometer gorge section reveal striking north-south variation in the lithology of the Rochester Shale. The percentage of limestone interbeds in the Lewiston Member decreases toward the south, and much of the lower Rochester consists of barren silty shale with calcisiltites. At the base of Niagara Falls itself, the Rochester Shale closely resembles the undifferentiated units seen at the type section in the upper falls of the Genesee Gorge, but it does not at all resemble that of the Niagara Escarpment, a short distance to the north. The bryozoa beds interval thins from a 1.5 m (4-5 ft) band to a single 10 cm (4 inch) band near Niagara Falls, and the top of the unit (marking the Lewiston/Burleigh Hill contact) rises from 9 m (27 ft) to 14 m (44 ft) above the Irondequoit Limestone.

The entire Rochester Formation remains relatively uniform in thickness throughout this distance, varying from 17.2 m (58 ft) at the north end of Niagara Gorge to 18.6 m (61 ft) at the south end. But this apparent uniformity evidently results from the interaction of two factors: southward thickening of the lower or Lewiston Member, and erosional truncation of the upper or Burleigh Hill Member. As noted earlier, the Burleigh Hill unit thins markedly towards the south, and the contact relationship with the overlying DeCew Dolostone also changes from one of complete gradation at the north end of Niagara Gorge to a sharp, wavy contact at the southern end. Also, interbedding of DeCew and Rochester lithologies has been noted at the south but not at the north end of the gorge. Together these two factors may have resulted in the apparent thinning of the upper Rochester Shale towards the south.

These rapid lithologic changes contrast markedly with the consistent nature of the Rochester Shale along the east-west-trending escarpment. Corroborative evidence for rapid north-to-south change has been obtained from small stream outcrops of the Rochester Shale in the Fonthill reentrant, an 8 km (5 mi) long southward embayment in the Niagara Escarpment west of St. Catharines (Figure 12). Again the bryozoa beds of the Lewiston Member die out and rise upward in the section toward the south.

If the two sections are compared (Figure 12), one notes a consistent north-to-south change in both Niagara Gorge and the Fonthill reentrant, whereas the east-west cross section connecting these two areas shows only minor thinning of the Rochester Shale.

An additional area where north-south variation can be observed in the Rochester is in the Burlington Bay reentrant near Hamilton, part of the preglacial Dundas River Valley, and the end of Lake Ontario. At Route 403 roadcut (Loc. 5) on the south side of this area, the Rochester Shale is 4.3 m (14 ft) thick and can still be differentiated into lower and upper units, apparently corresponding to the Lewiston and Stoney Creek Members (Figure 13A). About 8 km (5 mi) north of this cut on the north side of Burlington Bay reentrant at Clappisons Corners, Ontario (Loc. 1), the Rochester Shale is represented by a highly condensed section of sandy, intraclastic limestones and calcareous shale only 0.6 m (2 ft) in thickness (Figure 13B). These observations, together with well log data, strongly suggest that the facies belts of the Rochester Shale run roughly east-west and coincide closely with the modern outcrop belt, which runs roughly parallel to the northern paleoshoreline.

Fortuitously, the Rochester outcrop belt provides enough north-south exposures to show conclusively that the regular array of stratigraphic units so continuous along the main east-to-west outcrop belt is restricted to a rather narrow belt. The entire picture changes within a few miles to the

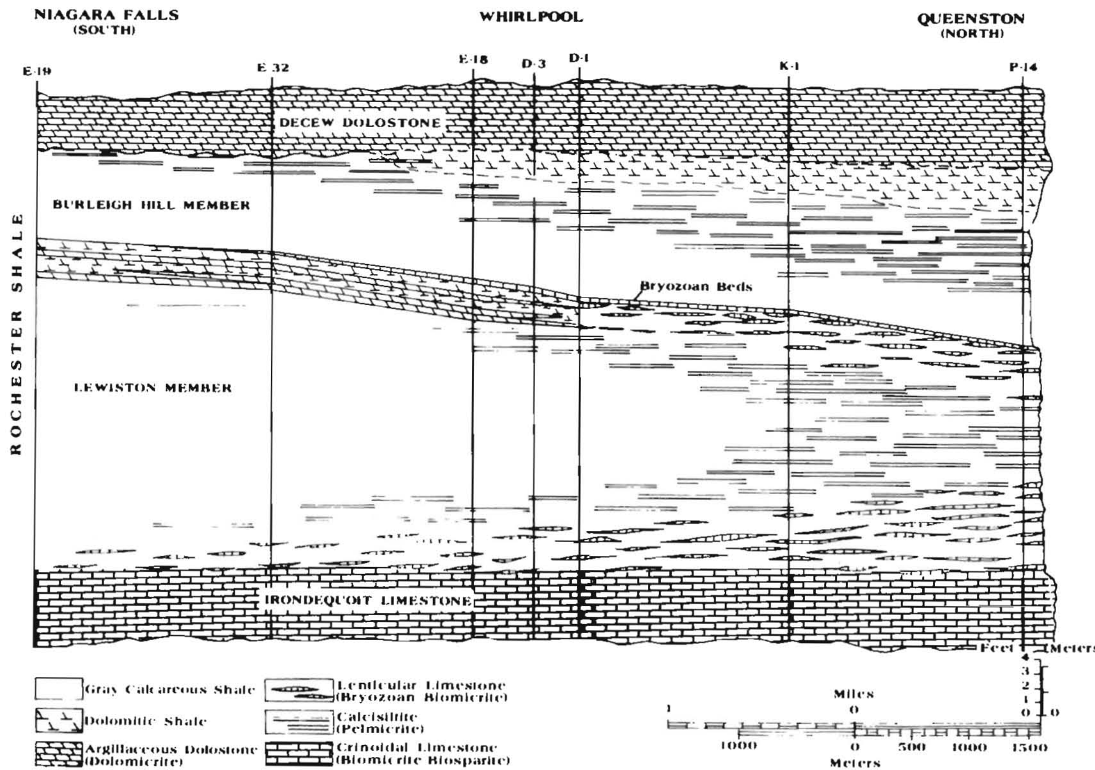

FIGURE 11: North-south stratigraphic relationships of the Rochester Shale and synjacent units in Niagara Gorge, vertical lines indicate positions of measured drill core sections, logged by Bolton (1957; appendix B., p. 107-141); numbers are those used by Bolton to designate cores.

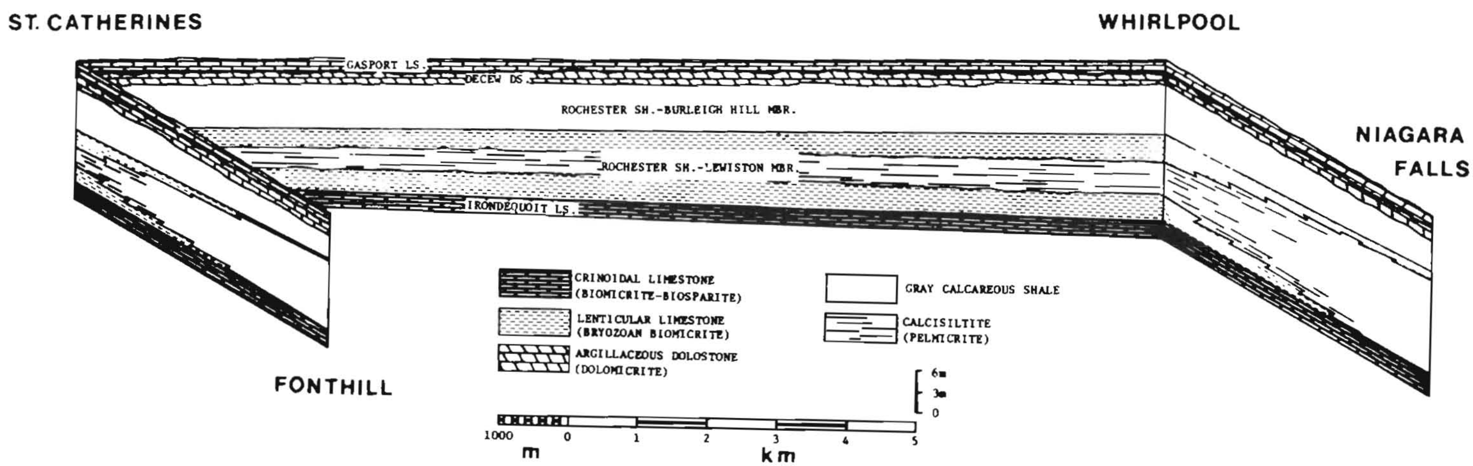

FIGURE 12: Stratigraphic relationships of the upper Clinton - Lower Lockport Groups from Niagara Gorge (right) to Fonthill Reentrant.

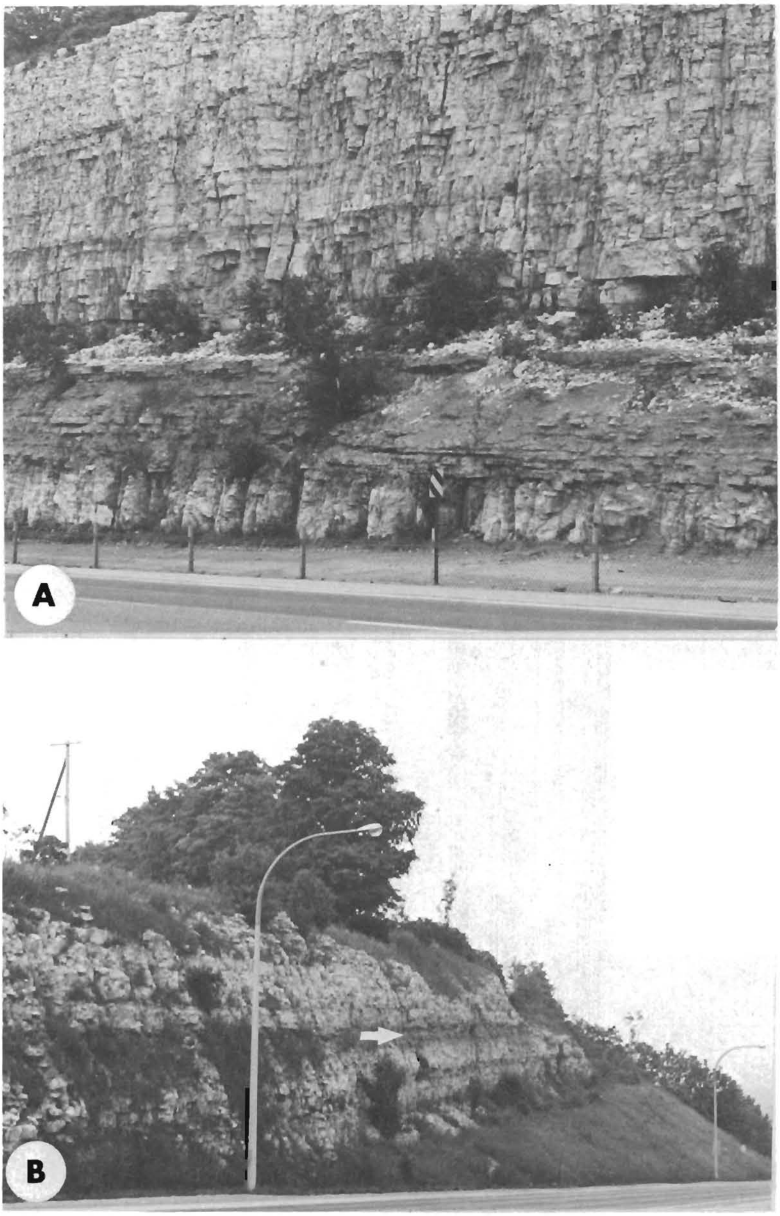

FIGURE 13: Rochester Shale sections in the Burlington Bay area. A) outcrop at Highway 403 roadcut, Ancaster, Ontario, (Loc. 5), on the south side of Burlington Bay reentrant; note approximately 4.2 m (14 ft) of Rochester Shale separating Irondequoit Limestone, at base of view, from massive section of Gasport and Goat Island formations (above trees). B) section along Highway 6 roadcut at Clappisons Corners (Loc. 1); Rochester Shale is represented only by 0.6 m (2 ft) gray band (arrow).

south. At least in the case of the Rochester Shale, "layer cake" stratigraphy is nothing more than an artifact; the erosional outcrop belt very nearly parallels the facies belts of the Silurian shallow sea and by implication the strike of the northern paleoshoreline. Thus the Rochester Shale, which was among the first stratigraphic units to be formally described, has also provided important new insights for Silurian depositional environments.

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APPENDIX A

REGISTER OF LOCALITIES

1. Roadcut exposures on both sides of Highway 6, Niagara Escarpment, 0.2-0.6 km southeast of Clappisons Corners, Ontario (NTS 1:25,000 Series, 30M/5d; Dundas Sheet).
2. Roadcut exposure along escarpment on north side of Seydenham Road, 0.5 km north of Dundas, Ontario (NTS 1:25,000 Series, 30M/5d; Dundas Sheet).
3. Stream gorge at Websters Falls, Websters Falls Recreation Area, 0.3 km east of Bullocks Corners, Ontario (NTS 1:25,000 Series, 30M/5d; Dundas Sheet).
4. Roadcut exposure on south side of Highway 2, extending west for about 0.4 km from gully of north-flowing tributary of Ancaster Creek, Ancaster, Ontario (NTS 1:25,000 Series, 30M/4e; Mount Hope Sheet).
5. Long roadcut exposure of Highway 403 (Chedoke Expressway) along north-facing Niagara Escarpment, about 1.5 km northeast of intersection with Mohawk Road, Ancaster, Ontario (NTS 1:25,000 Series, 30M/4e; Mount Hope Sheet).
6. Roadcut on both sides of Highway 6, and adjacent Jolly Road (Jolly Cut section of Bolton, 1957), Hamilton, Ontario (NTS 1:25,000 Series, 30M/4f; Mount Albion Sheet).
7. Roadcut on both sides of Lower Sherman Avenue at and just south of escarpment road, Hamilton, Ontario (NTS 1:25,000 Series 30M/4f; Mount Albion Sheet).
8. Stream gorge of Redhill Creek at Albion Falls, adjacent to Mount Albion Road, Mount Albion, Ontario (NTS 1:25,000 Series, 30M/4f; Mount Albion Quadrangle).
9. Roadcut exposures on both sides of Highway 20, Niagara Escarpment about 1 km south of Stoney Creek, Ontario (NTS 1:25,000 Series, 30M/4f; Mount Albion Sheet).
10. Gorge of Stoney Creek at Devil's Punchbowl recreation area immediately north of Ridge Road, East Stoney Creek, Ontario (NTS 1:25,000 Series, 30M/4f; Mount Albion Sheet).
11. Roadcut along west side of Ridge Road, East Stoney Creek, Ontario (NTS 1:25,000 Series, 30M/4g; Winona Sheet).
12. Long railroad cut along north-facing Niagara Escarpment, extending about 2 km eastward from Fruitland Road, Fruitland, Ontario (NTS 1:25,000 Series, 30M/4g; Winona Sheet).
13. Exposures of Rochester Shale in cliffs on west side of gorge of Forty Mile Creek, about 0.2 to 0.8 km south of Beamers Falls, Grimsby, Ontario (NTS 1:25,000 Series, 30M/4h; Grimsby Sheet).
14. Small cut bank exposures in gully of Thirty Mile Creek, 0.2 km north of intersection of Ridge and Thirty Roads near Beamsville, Ontario (NTS 1:25,000 Series, 30M/4h; Grimsby Sheet).
15. Discontinuous outcrops of Rochester Shale along Twenty Mile Creek, in Balls Falls Recreation Area, between main falls (Balls Falls) and second, smaller falls over the Gasport Limestone, Jordan, Ontario (NTS 1:25,000 Series, 30M/3e; Lincoln Sheet).

16a. Cut bank exposure along southeast side of Sixteen Mile Creek, 1.5 km north of 8th Avenue, near Jordan, Ontario (NTS 1:25,000 Series, 30M/3c; Fonthill Sheet).

16b. Exposures in gully of second northeast-flowing creek over Niagara Escarpment east of Sixteen Mile Creek and 0.6 km north of 8th Avenue access via Bruce Trail (NTS 1:25,000 Series, 30M/3c; Fonthill Sheet).

17. Gorge of Fifteen Mile Creek; accessible exposures are in base of Rochester Shale above lower bench on Irondequoit Limestone, 0.2 km north of 8th Avenue, Rockway, Lincoln Township, (NTS 1:25,000 Series, 30M/3c; Fonthill Sheet).
18. Exposures in gully of second east-flowing tributary of Twelve Mile Creek, north of Roland Road and about 0.8 km north of triple power lines, Pelham Township, Ontario (NTS 1:25,000 Series, 30M/3c; Fonthill Sheet).
19. Exposure and weathered material from lower 1 to 2 m of Rochester Shale along ledge at base of cliff in artificially cut, north face of Niagara Escarpment at DeCew Falls Hydroelectric Generating Plant, St. Catharines, Ontario (NTS 1:25,000 Series, 30M/3c; Fonthill Sheet).

20a. Roadcut in Niagara Escarpment on both sides of Burleigh Hill Drive 0.4 km south of Glendale Avenue and 0.5 km north of St. Davids Road; St. Catharines, Ontario (NTS 1:25,000 Series, 30M/3g; St. Catharines Sheet).

20b. Exposures in small west-flowing creek gully about 0.4 km east of Highway 406, and 0.5 km south of St. Davids Road, St. Catharines, Ontario (NTS 1:25,000 Series, 30M/3g; St. Catharines Sheet).

20c. Roadcut (now covered) along Highway 406 south of Glendale Avenue, 1.0-1.2 km southwest of St. Catharines, Ontario (NTS 1:25,000 Series, 30M/3g; St. Catharines Sheet).

21a. Exposures of Rochester Shale in the bottom of lock no. 3, Welland Canal, Thorold, Ontario (NTS 1:25,000 Series, 30M/3g; St. Catharines Sheet).

21b. Weathered dumps of shale excavated during construction of underpass tunnel for Highway 406 beneath Welland Canal; dumps are located along east side of present canal locks, west of old Welland Canal immediately south of Canadian National Railroad tracks, Thorold, Ontario (NTS 1:25,000 Series, 30M/3g; St. Catharines Sheet).

22. Exposures of Rochester Shale between Adam Beck A and B plants, temporarily accessible during construction in 1976, west side of Niagara Gorge, Queenston, Ontario (NTS 1:25,000 Series, 30M/3g; Queenston Sheet).

23a. Exposure of weathered Rochester Shale (lowest 0.5 m), ledge at intersection of Niagara Gorge and Niagara Escarpment, just below (west of) Lewiston Heights and 0.6 km south of Artpark, Lewiston, Niagara County, N.Y. (Lewiston 7.5′ Quadrangle).

23b. Exposures and talus from the middle Rochester Shale (6 to 9 m above base of formation), east wall Niagara Gorge directly below power lines crossing gorge from U.S. to Canadian side, 0.6 km north of Robert Moses Hydroelectric Generating Plant and 2.3 km south of Lewiston, Niagara County, N.Y. (Lewiston 7.5′ Quadrangle).

23c. Outcrop and weathered debris from lower 1.5 m of Rochester Shale and uppermost Irondequoit Limestone, east wall of Niagara Gorge immediately north of cut for Robert Moses Hydroelectric Plant and 2.9 km south of Lewiston, Niagara County, N.Y. (Lewiston 7.5′ Quadrangle).

23d. Weathered talus from basal Rochester Shale exposed along ledges on east wall Niagara Gorge above the south haul (access) road for Robert Moses Hydroelectric Plant beginning at cut for power plant and running 0.8 km south, 0.2 km west of Niagara University and 0.4 km north of Devils Hole State Park, Niagara County, N.Y. (Lewiston 7.5′ Quadrangle).

24. Exposures of Rochester Shale in cliff below Whirlpool Point, Whirlpool State Park, Niagara Gorge, about 4.5 km north of Niagara Falls, Niagara County, N.Y. (Niagara Falls 7.5′ Quadrangle).

25a. Exposures in cut on east wall of Niagara Gorge immediately behind new Niagara Sewage Treatment facility, 1.2 km south of Whirlpool Rapids bridge, Niagara Falls, Niagara County, N.Y. (Niagara Falls 7.5′ Quadrangle).

25b. Cliff exposure in east wall of Niagara Gorge at site of old Shoellkopf Power Plant (destroyed in 1954), 0.8 km north of Niagara Falls; Niagara County, N.Y. (Niagara Falls 7.5′ Quadrangle).

26. Weathered surfaces of Irondequoit Limestone around perimeter of Meyers Lake (abandoned limestone quarry), Bond Lake County Park, 0.2-0.3 km east of Black Nose Spring Road and 0.3 km south of N.Y. Rt. 31, Pekin, Niagara County, N.Y. (Ransomville 7.5′ Quadrangle).

27. High roadcut along Niagara Escarpment of south side of Thrall Road, Cambria, Niagara County, N.Y. (Cambria 7.5′ Quadrangle).

28a. Material obtained in place from exposures (now destroyed) of lower Rochester Shale along the west branch of Eighteen Mile Creek at Lockport Gulf, 0.8 km north of N.Y. Rt. 31 and 0.3 km west of N.Y. Central railroad tracks, Lockport, Niagara County, N.Y. (Lockport 7.5′ Quadrangle).

28b. Weathered exposures of Gasport Limestone at top of Eighteen Mile Creek gorge and along N.Y. Central railroad cut, Lockport Gulf, 0.2-0.5 km north of N.Y. Rt. 31, Lockport, Niagara County, N.Y. (Lockport 7.5′ Quadrangle).

29. Washings and loose material from lower Rochester Shale (about 2 to 3 m above base) in a highly weathered, and largely overgrown hillslope just west of Scovell Street, and 0.2 km north of intersection of Scovell and Gooding streets, Lockport, Niagara County, N.Y. (Lockport 7.5′ Quadrangle).

30. Field exposure of Gasport Limestone (glacial pavement) in small abandoned quarry at edge of Niagara Escarpment and immediately north of Crain Steet, Lockport, Niagara County, N.Y. (Lockport 7.5′ Quadrangle).

31. Discontinuous outcrops of middle and upper Rochester Shale along an unnamed, north-flowing creek 0.1 km west of Cottage Road north to N.Y. Rt. 31, 3.2 km northwest of Gasport, Niagara County, (Gasport 7.5′ Quadrangle).

32. Weathered debris from the middle Rochester Shale along north bank of Eighteen Mile Creek reservoir and 0.2 km west of Gasport Road, Gasport, Niagara County, N.Y. (Gasport 7.5′ Quadrangle).

33. Washings and loose specimens from the lower Rochester Shale (about 3 m above base of the formation) exposed in a highly weathered cutbank exposure along a north-flowing tributary of Jeddo Creek, about 0.5 km south of N.Y. Rt. 31, and 1.4 km east of Freeman Road, Middleport, Niagara County, N.Y. (Medina 7.5′ Quadrangle).
34. Gorge of Oak Orchard Creek, near falls at Shelby, Orleans County, N.Y. (Medina 7.5′ Quadrangle).
35. Discontinuous exposures along Fish Creek 0.4 - 1.5 km north of N.Y. Route 31, Millville, Orleans County, N.Y. (Albion 7.5′ Quadrangle).
36. Quarry exposure in Clarendon Stone Co., along east-facing segment of Niagara Escarpment along Clarendon-Linden monocline, Clarendon, Orleans County, N.Y. (Holley 7.5′ Quadrangle).
37. Discontinuous exposures along Salmon Creek between N.Y. Route 31 and Northhampton Park, Sweden, Monroe County, N.Y. (Brockport 7.5′ Quadrangle).
38. Exposures in small unnamed creek in the town of Spencerport, Monroe County, N.Y. (Spencerport 7.5′ Quadrangle).
39. Stream cut and tailings from excavation about 0.3 km south of Ridgeway Avenue near junction of Erie Canal and (dry) branch canal, South Greece, Monroe County, N.Y. (Rochester West 7.5′ Quadrangle).
40. Exposures in cliffs along east side of Genesee River Gorge, 2 km northwest of third falls (over Lockport Dolostone) and immediately below Brewer Street, Rochester, Monroe County, N.Y. (Rochester West 7.5′ Quadrangle). (Type locality Rochester Shale.)
41. Exposure of basal Rochester Shale along Densmore Creek, 0.2 km south of Norton Road and about 0.2 km west of Densmore Road, Irondequoit, Monroe County, N.Y. (Rochester East 7.5′ Quadrangle).

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