DEPARTMENT OF THE INTERIOR
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190

GEOLOGIC ATLAS
OF THE
UNITED STATES

NIAGARA FOLIO
NEW YORK

BY
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WASHINGTON D. C.
ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY
ASSISTED IN WORK DEPARTMENT OF GEODESY MAPS
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The Geological Survey is making a geologic atlas of the United States, which is being issued in parts, called folios. Each folio includes topographic and geologic maps of a certain area, together with descriptive text.

**The Topographic Map.**

The features represented on the topographic map are of three distinct kinds—(1) irregularities of surface, called relief, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called drainage, as streams, lakes, and swamps; (3) the works of man, called culture, as roads, railroads, boundaries, villages, and cities.

**Relief.**—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those of the most important ones are given on the map in figures. It is desirable, however, to give the observer a general idea of the relief and to define the contour interval or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above sea level. Thus, on the map each foot of altitude above sea level is represented by a certain number of inches of elevation on the map, and by a certain inclination of the contour line. The inclination of the line is always parallel to a horizontal line.

**Coastlines.**—A coast is a line along the shore of the ocean. A coastline is the characteristic edge of the ocean, and a third is in ice or motion. The most characteristic of the wind-borne or solar deposits is loam, a fine-grained earth, the most characteristic of glacial deposits is till, a heterogeneous mixture of laharps and pebbles with clay or sand.

**Solitary sediments** are usually made up of layers or beds which can be easily separated. These layers are called strata, and rocks deposited in these layers are said to be stratified.

**The Surface of the Earth is not Immovable;** every region it very slowly rises or sinks, with reference to the sea, and above lines are thereby changed. As a result of upward movement marine sedimentary rocks may become a part of the land, and most of the continental deposits overlaid by rocks originally deposited in sediments in the sea.

**Rocks exposed at the surface of the land are acted on by air, water, ice, minerals, and light; and these agencies have removed or unchanged the original deposits.**

**Metamorphic Rocks.**—In the course of time, and by various processes, rocks may become greatly changed in composition and texture, and by the action of water, fire, and ice, and by the change in temperature and pressure. Many of the new minerals are more peninsules. A burial deposit, glacial deposits (collectively known as drift), and other deposits belong to the secondary class. These rocks are usually distinguished by their small quantity of organic matter.

**Rocks of Many Kinds.** On the geologic map they are distinguished as igneous, sedimentary, metamorphic onto the map, the distribution of rock masses on the surface of the land, and, by means of structural and stratigraphic relations, as igneous, sedimentary, and metamorphic. The maps represent features of things.

**Types of Rocks.** Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

**Igneous rocks** are rocks formed from a mass of magma. Igneous rocks are made up of mineral matter, but not of water. This mineral matter is the result of the cooling of molten rock. Igneous rocks are divided into two classes: (1) intrusive rocks, which are formed underground, and (2) extrusive rocks, which are formed on the surface of the earth. Igneous rocks are the most abundant type of rocks on the earth. Igneous rocks are divided into two classes: (1) intrusive rocks, which are formed underground, and (2) extrusive rocks, which are formed on the surface of the earth. Igneous rocks are the most abundant type of rocks on the earth.

**Sedimentary rocks** are rocks formed from the remains of plants and animals that lived in the sea. Sedimentary rocks are divided into two classes: (1) clastic, which are formed by the wearing down of older rocks, and (2) chemical, which are formed by the precipitation of mineral matter from water. Sedimentary rocks are the most abundant type of rocks on the earth.

**Metamorphic rocks** are rocks that have been changed by the action of heat, pressure, and water. Metamorphic rocks are divided into two classes: (1) foliated, which are changed by the action of heat and pressure, and (2) non-foliated, which are changed by the action of water and pressure. Metamorphic rocks are the most abundant type of rocks on the earth.

**Formations.** For purposes of geologic mapping, rocks of all the kinds above described are divided into formations. A formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, so, for example, the deposit of sand and limestone is called a formation. Where the passage from one kind of rock to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, or by some other line of demarcation which is drawn in accordance with the character of the deposit.

**Geologic Time.**—The time during which rocks were made is divided into periods. Smaller time divisions are called epochs, periods, and systems.
DESCRIPTION OF THE NIAGARA QUADRANGLE.

By E. M. Kindle and F. R. Taylor.

INTRODUCTION.

The Niagara quadrangle lies between parallels 42° and 43° 30' and meridians 79° 30' and 79° 70', and includes the Wilson, Olewitz, Tonawanda, and Lackport 15-minute quadrangles. It thus covers one-fourth of a square degree of the earth's surface, an area, in that latitude, of 800 square miles, of which approximately the northern third, or about 280 square miles, lies in Lake Ontario. The map of the Niagara quadrangle shows also along the north side a strip from 1 to 3 miles wide comprising the Niagara River, and a small area in Canada. The district thus mapped, which has a land area—including the bed of Niagara River—of about 500 square miles, will hereafter be referred to as the Niagara quadrangle. It is situated in the northwest corner of New York and includes nearly the whole of Niagara County and a little of Erie County. (See fig. 1.)

In its general geographic and geologic relations the quadrangle forms a part of the border zone in which the Appalachian province merges into the Gneissed Plains. Although the two provinces are distinguished by their broad general characters they are not separated by a definite boundary, and all parts of the region in which the quadrangle is situated have had a common geologic history, recorded in the rocks, the structure, and the topography.

GENERAL GEOGRAPHY AND GEOLoGY OF THE REGIONS.

Geographic divisions.—The Appalachian province is bounded by the Central Plain on the southeast and southwest, and by the Gneissed Plains on the northwest and extends northeastward into Canada. Its northwestern boundary is indefinite but may be regarded as coinciding approximately with the southern limits of Pleistocene glaciation from southern Illinois to northeastern Ohio and thence with a line separating the lowland of the lower Great Lakes and St. Lawrence from the upland of western, central, and northern New York. The Gneissed Plains extend southwest from their southeastern limit thus defined to the Great Plains and from the Ouezak province on the south northwestward into Canada.

The Appalachian Plains is the only one of the several divisions of the Appalachian province that extends into the general region in which the Niagara quadrangle is situated. It is a broad dissected upland lying between the Appalachian Valley on the east and the lower ground of the Mississippi basin on the west and extending from the Caney Knob Mountains of New York southwestward into northern Alabama. The upland surface includes several minor plateaus of somewhat different altitudes, but as a whole it is distinctly higher than the surrounding areas and is in general bounded by well-marked escarpments.

In the region of the lower Great Lakes the Gneissed Plains province is divided into the Erie, Huron, and Ontario plains and the Laurentian Plateau. (See fig. 2.) The Erie plains includes the shallow basin of Lake Erie with a narrow strip along the southeastern border of the Province of Ontario between Lakes Erie and Huron, and a narrow belt in New York extending from Buffalo southward to the vicinity of the Town of Clarence. The Huron plains includes a strip of western New York, the northwestern part of the triangle of peninsulas of Ontario, and a part of the bed of Lake Huron. The Ontario plains includes the shallow basin of Georgian Bay, that part of the Province of Ontario between the bay and Lake Huron, a part of the bed of the lake, and a strip of New York about the south and east sides of the lake. The Laurentian Plateau occupies a great area in Canada extending from the St. Lawrence and Georgian Bay northeastward, northward, and northwestward for hundreds of miles.

Belief.—The general region in which the quadrangle is situated may be regarded as comprising central and western New York, southern Ontario, northern Pennsylvania, and northeastern Ohio. Viewed broadly it consists of a series of terraces or platforms descending northeastward from the Allegheny Plateau to Lake Ontario and separated by northward-facing escarpments. (See fig. 3.) North of Lake Ontario the surface rises again to the divide between the drainage basins of the lake and that of Ottawa River. The slope is gradual at first but steeper along the border of the Laurentian Plateau.

The northern part of the Appalachian Plains is known as the Allegheny Plateau. Its surface lies from 1500 to 2000 feet above sea level along its northerly margins and gradually rises northward to nearly 5000 feet in southern New York and to more than 2000 feet in northern Pennsylvania. Toward the east it is rather lower, but rises to 4200 feet in the Catskill Mountain, the highest part of the plateau. Its surface is deeply broken by valleys, the bottoms of the deepest lying more than 1000 feet lower than the general level, and in some parts of the region extensive nearly level areas occupy the interstream divides.

The Portage escarpment, so named because in western New York it is formed chiefly by resistant beds of the Portage formation, bounds the Allegheny Plateau on the northwest and is marked by a gently slope descent of 600 to 1200 feet from the upland. In Ohio it is low and broken by broad valleys opening northward. Across northeastern Pennsylvania and southwestern New York it is abrupt and nearly straight and its crest is about 3000 feet higher than and 4 or 5 miles back from the narrow plain bordering Lake Erie. New York escarpments are more irregular, the rise being less abrupt, though higher, and is broken by deep, narrow valleys extending westward from the plateau, so that it appears as a line of northward-facing steep-sided plateaus forcing out into the Erie plain. East of Auburn it merges into the Onondaga escarpment.

The Erie plain extends along the base of the Portage escarpment from Auburn to Buffalo, west of which it broadens so as to include the southern part of the triangular peninsula between Lake Erie and Huron and a narrow strip along the south shore of Lake Erie. Lake Erie is nearly everywhere shallow and its bed may be regarded as a broad depression in the surface of the plain rather than as a distinct lowland. In New York the Erie plain lies along the south shore of Lake Erie and extends outward to Genesee River, beyond which it is less distinct. Its surface is commonly 600 to 900 feet above sea level and is somewhat diversified by broad, shallow valleys.

The Onondaga escarpment, so named because it is formed by the rocks of the longondaga formation, bounds the Erie plain on the north and separates it from the Huron plain. It is poorly defined at Buffalo but is more prominent east of that city. At Rochester, it is about 500 feet high and extends southward to Genesee River where it is still higher. From Auburn outward to Schoharie Creek it is the escarpment bounding the Allegheny Plateau, and the Portage escarpment having merged with the northwestern shore of Schoharie Creek the Onondaga in turn merges into the Helderberg escarpment, the great slope bounding the Catskill Plateau on the northeastern part of the plateau. It is nowhere more than 300 feet high. At Buffalo the escarpment is about 600 feet high, and in the neighborhood of Niagara River its surface is nearly level, except for irregularities due to glacial deposits, and lies about 400 feet above sea level. Near Rochester it is lower, and out of Genesee River it merges gradually into the Ontario plain, giving way to the rising land of the Niagara escarpment. In Ontario it occupies the northern part of the triangular peninsula between Lakes Erie and Huron. Toward the northwest its surface gradually rises, so that in places south of Georgian Bay it is more than 1500 feet above sea level.

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The survey of the Niagara quadrangle for this publication was begun in 1892 by G. S. Gilbert, who partly prepared the maps and illustrations. The geologic mapping was completed by E. M. Kindle and the surficial geology map by F. R. Taylor. The descriptive text, except the "Introduction," was prepared originally by Lawrence E. Page, has been extensively revised by E. M. Kindle and F. R. Taylor jointly. In the preparation of the folio text and map has been used by Mr. Kindle's maps, notes, and preliminary descriptions, which have been modified and revised by the writers, and some parts of the region east of the Allegheny Front, and its results have been reviewed and in places revised by the present authors. The present maps and text are a more complete development of the former sheets. The authors and graphic artists have had the advantage afforded by the detailed map of the geysite just published.
Dreisong.—The streams of much the greater part of the region belong to the St. Lawrence drainage system, and the larger ones flow directly into the Lake Erie or into Lake Ontario. Nearly all of the Ontario plain is drained into Lake Ontario, but a few streams in its northwestern part flow to Georgian Bay, and a few streamlets empty into the Huron River through the Mohawk. All of the Erie and Huron plains is drained into Lake Erie except the area of Buffalo, which is drained into Lake Ontario by the Niagara River and into Lake Huron by the southwestern margin, which is drained into Lake Huron.

The northern and northeastern margins of the Allegheny Plateau are drained into Lakes Erie and Ontario, chiefly by short streams heading at the crest of the plateau and flowing down the slope to the Erie plain. Otherwise rises some distance back from the rim of the plateau and flow out across the overcountry in deep, narrow valleys. The most notable of these is Genesee River, which rises in northern Pennsylvania on one of the highest parts of the plateau and cuts through the overcountry in Portage Gorge, descending over several falls. Cayuga and Seneca lakes and most of the other Finger Lakes also occupy valleys extending some distance back from the plateau, and deep gorges in the Allegheny and Allegheny-slope are almost near their heads. In southeastern Ohio, where the plateau is lower and the overcountry is less pronounced, several small rivers rise on the uplands and flow into Lake Erie through rather open valleys in the uplands.

Nearly the whole of the Allegheny Plateau, however, is drained southwesternly into the Susquehanna and Delaware, and except in the Finger Lake region, in the Genesee Valley, and in Ohio the divide between the streams flowing to the Great Lakes and those flowing southwestwardly is practically at the crest of the Portage overcountry.

So close is the coincidence in places that Bear Lake, in Chautauqua County, New York, although it lies on the Allegheny Plateau and its water flows to the Gulf of Mexico, is but 5 miles from Lake Erie, and the ultimate sources of the Susquehanna and the Delaware, which flow to Chesapeake Bay, are but 6 or 8 miles from the Mohawk.

Stratigraphy and structure.—The consolidated rocks of the Allegheny, Huron, and Erie plains and the Allegheny Plateau, except a few small igneous dikes, are wholly sedimentary and of Paleozoic age, ranging from Ordovician to early Carboniferous. The Lannonite Plains, with its extensive southeastwardly into the Adirondacks, is occupied by a complex of both igneous and sedimentary rocks, chiefly of pre-Cambrian age and some or less metamorphosed. Undoubtedly they or similar ancient rocks extend everywhere beneath the region and form a floor upon which the younger strata lie. The stratified rocks form a floor, to which a general westward and southwestward dip of the Allegheny Plateau is added, and which is occupied by residual land.

Owing to migrations of the shores and to alterations between marine and terrestrial conditions in much of the region no section is known in which there was continuous deposition and which displays a complete sequence of strata. Everywhere deposition was interrupted at one time or another, and much of the area was probably removed by erosion. When deposition was resumed the beds then laid down were spread unconformably over those beneath, lying both horizontally and at various angles above the latter.

The most striking of the ice cover upon the surface of the region, which was formed during the later part of the Pleistocene epoch, was removed by the action of the streams. Owing to the high relief of the land the streams traveled over the surface with great velocity and with comparatively little denudation. The streams removed the Pleistocene deposits of leached material and plucked out masses of solid rock, carrying within it and dragging along at its base quantities of bowlder, sand, and gravel, which it removed by the process of wearing down and lifting up hilly masses. When it moved away it left the surface nearly everywhere covered with accumulations of transported material.

Some of the streams which were forced to seek new courses cut deep gorges, with waterfalls at the heads and thus were formed the numerous gorges and outcrops of western and central New York, Niagra among the number. Some of the gorges and falls were later abandoned, the streams being diverted elsewhere.

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Near the close of the Pleistocene epoch, when the ice had melted out of the region, the land was so much depressed that part of it was below sea level and Lake Ontario was a sea, connected with the ocean by the Gulf of St. Lawrence, which then extended that far west. At that time quantities of sand and gravel were carried into the main valleys by the streams and the bedrock surface was in places buried several hundred feet. More recent uplift has driven the sea out of the region. Lake Ontario again becoming fresh in consequence, and has set the streams at work clearing out their valleys again, but the task is still only partly accomplished.

The drainage system of the region under discussion, a northwestern slope from the Allegheny Plateau to the Great Lakes, with its numerous tributaries, is dominated by the Allegheny River, which enters the Great Lakes through Lake Erie. The Allegheny River is formed by the confluence of the Allegheny and the Sinnemahoning rivers in Pennsylvania and flows through the Allegheny Mountains to the Ohio River.

The Allegheny River is about 350 miles long and has a drainage area of about 15,000 square miles. It flows northward through western Pennsylvania and eastern Ohio, draining parts of those states and the western part of West Virginia. The Allegheny River has a number of tributaries, including the West Branch Allegheny River, the East Branch Allegheny River, and the Sinnemahoning River.

The Allegheny River is known for its scenic beauty and is a popular destination for fishing and boating. It is designated as a Wild and Scenic River by the federal government.
which traverses the Erie and Huron plains and the Mohawk and Hudson valleys and the location of which is therefore determined wholly by physiographic conditions.

The Great Lakes, as well as the St. Lawrence, furnish a deep waterway penetrating the very heart of the continent, which would appear to be the natural eastern outlet for the products of the great interior waters. Three factors, however, make necessary the construction of canals to connect Lake Erie and Lake Ontario. In the first place, the St. Lawrence reaches the Atlantic at a point so far north that it is not available as an outlet during the year, being closed by ice throughout the winter. In the third place, the most densely settled part of the Atlantic coast, the market for a large part of the products of the interior, extends from the Merrimack to the Potomac and lies so far south that the St. Lawrence route is too roundabout a way of reaching it from the interior. Hence traffic between the interior and the markets of the coast necessarily seeks a more southern, more direct, and more economical route from the Great Lakes to the sea.

The highlands of the Appalachian province extend from northern New England to northern Georgia and Alabama and interpose a serious barrier to traffic between the lakes and the Ohio river basin, makes necessary the construction of canals to connect Lake Erie and Lake Ontario. In the second place, the St. Lawrence reaches the Atlantic at a point so far north that it is not available as an outlet during the year, being closed by ice throughout the winter. In the third place, the most densely settled part of the Atlantic coast, the market for a large part of the products of the interior, extends from the Merrimack to the Potomac and lies so far south that the St. Lawrence route is too roundabout a way of reaching it from the interior. Hence traffic between the interior and the markets of the coast necessarily seeks a more southern, more direct, and more economical route from the Great Lakes to the sea.

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TOPOGRAPHY.

The land area of the province is 1,500,000 square miles, or about one-fifth of the total area of the continent, and the population is 7,000,000. The province is divided into two main sections: the eastern section, which is the more densely populated, and the western section, which is the more thinly settled.

The eastern section is the most fertile and productive part of the province, and is characterized by a series of parallel ranges of hills, which trend from north to south and are interrupted by a series of valleys.

The western section is less fertile and productive, and is characterized by a series of parallel ranges of hills, which trend from west to east and are interrupted by a series of valleys.

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near the lower end of the section and everywhere have a vertical cliff in their upper part and a steep slope below. At the west end of Great Island, at the head of the gorge, the slope is very steep and practically the entire surface of the lower 200 feet is a vertical rock wall, which is capped with 50 feet of surficial material. The river is 192 feet deep in one place just west of Great Island, hence the height of the narrow gorge is 800 feet lower than the eastern rim. No stream enters this upper section of the gorge from the sides except the east branch of the river itself, forming a sheet 200 feet wide, 800 feet deep, and 200 feet lower than the eastern rim.

The next section, a little more than a mile long, curves northward from the railroad bridge to The Whirlpool. It is on the west side of the gorge, with the width being only 800 feet for half a mile below the bridge. Throughout that distance the eastern wall is a vertical cliff of rock over 300 feet high wide, with a very narrow slope above the water in some places. Midway of the section, at Eddy Basin, the gorge widens, and at The Whirlpool it reaches its maximum width at 1900 feet and is 280 feet deep to the water and over 400 feet to the bed of the stream. The small hanging valleys of a few short streams enter this section of the gorge from the southwest, making notable about the middle of the river itself, forming a sheet 200 feet wide, 800 feet deep, and 200 feet lower than the eastern rim.

The third section of the gorge extends northeastward about 2 miles from The Whirlpool to the bend opposite Niagara University. Its top width increases from 500 feet at the outlet of The Whirlpool to 1900 feet at the bend opposite the Niagara Gorge and then decreases to 1600 feet at the bend. The water increases with the slope of the stream, ranging from 200 feet at the outlet of The Whirlpool to 290 feet at the bend. Along the top of The Whirlpool the water is 100 feet deep, but further downstream it is shallower, and the whole depth of the gorge is nearly uniform throughout its entire length from 290 to 400 feet. Near the lower end of the section the valley of Iliony River joins the gorge from the south in a small cave called Devils Hole.

The most striking feature of the third section is at Niagara Glen, where a predominating of the western wall reduces the width of the bottom of the gorge to about half that above it. Although the top width is greater than elsewhere except at The Whirlpool. The top of the promontory is a shelf called Wintzerflats, which ranges in width from 200 to 600 feet and is 15 to 25 feet below the western rim of the gorge. Its southward slope to the river is steep and fairly uniform. Its northwestern slope is abrupt near the top, the flat being bounded on that side by a cliff 50 feet high, below which the slope is less than a degree—500 feet across 500 feet deep—which opens northeastward upon Foster Flat, a broad, gently sloping shelf about 50 feet above the water. The cave is separated from the main gorge by a rough, rocky spur descending northward from the corner of the Wintzerflats. The slope of the spur, the cove, and a part of the flats are strewn with huge angular blocks of limestone of the kind forming the 12 of 7 of the river. Through the features displayed at Niagara Glen is an important part of the history of the development of the gorge and is treated under the heading "Geologic history."

The fourth section, 13 miles long, extends a little west of north from the head of the section opposite Niagara University to Lewiston, where it has a fairly uniform width from rim to rim of about 1200 feet. Near the lower end the walls rise 240 feet above the river, which is 150 feet deep in one place, and the gorge is practically a canyon 1300 feet across and almost 500 feet deep. Several small canyons in the eastern rim are formed by tributary streams, especially Fish Creek, which enters the gorge just within its mouth in a shallow hanging valley above a small above that descends the slope. About midway of the western wall Susan River enters in a notch called Susan River, which is 80 feet deep and is cut back 500 feet from the rim. Its origin and that of Devil's Hole, in the third section, are discussed under the heading "Geologic history."

Although not ordinarily regarded as a part of the Niagara gorge the valley of the river across the river opposite the Niagara Falls from the mouth of the river in rock cut is the section of the gorge to be regarded as a fifth section. It is a little more than 7 miles long and has an average width of 2000 feet. The height of the banks above the water ranges from 30 feet at the mouth of the river at 125 feet at Lewiston, and the river is from 40 to 150 feet deep, being deepest at Lewiston, near the mouth of the main gorge.

2. Geologic History.

General characteristics.—The width of the quadrangle is drained into Lake Ontario, either directly or through Niagara River, which flows from north to south along the west side of the quadrangle and sears the important features of the region. Two general characteristics of the streams of the region should be mentioned. One is the general tendency, especially of the smaller streams, to northeast or southeast courses. It is particularly noticeable in the small streams on Grand Island, north of Tonawanda, and in the northeastern part of the quadrangle. As an example of the development of the streams is due chiefly to the trend of the minor irregularities of relief, resulting from the glaciation of the region.

The other important characteristic, at least of the main streams, is the occurrence of rather deep slack-water reaches in their lower positions. This is displayed by streams entering the southern and northeastern part of Summit and Tonawanda Creek, utilizing the channel of the creek from Tonawanda to Pendleton.

The larger streams entering Lake Ontario, particularly the upper course of the Cattaraugus River, also have deep slack-water stretches near their mouths. Eighteen-mile Creek is 13 to 15 feet deep a mile south above its mouth and TWO-MILE Creek is 13 to 18 feet deep for 2 miles from its mouth. The cause of this condition, technically known as drawing, is explained under the heading "Geologic history."

The most important in the drainage system of the Great Lakes, to its value as a source of power, to the scenic attractiveness of its falls, rapids, and gorge, or to its complicated and fascinating geologic history, Niagara River is one of the most important and interesting streams in America. Its scenic beauty is illustrated in Plate 1 to 3, a view of Lake Erie from the east, the discharge of the upper four Great Lakes—except the parts artifically diverted through the Erie, Welland, and Chicago Dams—flows into Lake Erie and Lake Ontario. Where it flows out of Lake Erie its surface is 3533 feet above sea level and it is in places 50 to 50 feet deep and 75 feet wide a few miles in from the mouth of the river. Its depth is reduced to 20 or 20 feet or less and its fall is somewhat neutralized. A little more than 4 miles from the lake the river divides into a current of the river. The river is divided about five miles southeast of Niagara where it is again a temporary reach in two streams.

The western branch, about half a mile broad, flows almost directly north to North Island, about which it divides and is then joined by the eastern branch. The latter stream flows first northwesterly with a breadth of about one-thousandth of a mile. At Towanda it is joined by the eastern branch of Lake Erie and Lake Ontario. Where it flows out of Lake Erie its surface is 3532 feet above sea level and it is in places 50 to 50 feet deep and 75 feet wide a few miles in from the mouth of the river. Its depth is reduced to 20 or 20 feet or less and its fall is somewhat neutralized. A little more than 4 miles from the lake the river divides into a current of the river. The river is divided about five miles southeast of Niagara where it is again a temporary reach in two streams.
which enters the river from the southwest a little above the head of the rapids. Several short streams flow into the gorge, particularly at The Whipple, where the deep pool is especially prominent. Stony Creek is a prominent feature. On the plain a little south of Queenston Suton Creek flows down the western wall of the gorge in an area of rocky landscape. Suton, Phenomenon Creek, and Eighteenmile Creek rise on the slopes or near the base of the Niagara escarpment, but the sources of Johnson Creek and of the East Branch of Twelvemile Creek are on the Huttin plain just back from its crest. The East Branch of Eighteenmile Creek drains several square miles of the Huttin plain west of Lockport and descends the escarpment through the small gulf at Gasport. It continues northward to the beach ridge east of Hartland, but instead of breaching the ridge, as Johnson Creek does, it turns abruptly, flows westward and northward over the number of miles, and joins the main stream north of Lockport. Another tributary of Eighteenmile Creek rises on the plain southwest of Lockport and flows down the escarpment in a rocky gorge called The Gorge, which lies just west of the city.

OUTLINE

The Niagara quadrangle is situated in one of the most densely settled regions of North America and probably in few parts of the country is there greater agricultural uniformity distributed. The population of the New York portion of the quadrangle in 1910, as estimated by the census of that year, was 100,000, of which the chief town was Lockport and 50 per cent rural. The land area of the quadrangle in New York is approximately 600 square miles, and the total density of its population is 1,500 to 175 per square mile, a high rate for an area containing only one city.

There are four cities and five incorporated villages in the quadrangle, the total urban population being about 72,000, leaving 32,000 for the rural population. Much of this is in small villages, but, as may be seen by inspecting the topographic map, differentiation is possible inasmuch as between small villages and strictly rural districts. The area of the quadrangle exclusive of the city is about 550 square miles, and the density of the rural population is 54 per square mile, which is greater than that of most of the States of the Union, even if their urban population is included. This figure is exceeded in some parts of the quadrangle. The town of Newfane contains about 64 persons to the square mile, practically altogether a rural population and pretty evenly distributed throughout the town.

The largest city in the quadrangle is Niagara Falls, N. Y., which in 1910 had a population of 30,445. The other cities are Lockport (17,395), North Tonawanda (13,255), Niagara Falls, Ontario (9,248), and Tonawanda (8,290). These cities, which lie only partly in the quadrangle, Lewiston, La Salle, Wilson, and Youngstown, New York, and several villages, and many smaller villages are scattered about the area.

The chief occupation of the residents in the quadrangle is agriculture. The land is nearly uniformly cultivated, the principal crops being grain and hay, with considerable garden produce. The Ontario plain is a fruit-bearing belt, as the fertile soil and the mildizing influence of the lake upon the climate are especially favorable for the cultivation of orchard fruits, and nearly the whole of the land is used for that purpose. There is comparatively little timber in the quadrangle and no lumbering as a local industry.

The cities are important manufacturing centers. At Niagara Falls the development of power from the falls has led to the establishment of a number of industries employing especial electrical processes and to considerable general manufacturing. Lockport also is a manufacturing center large on account of the power developed there. North Tonawanda and Tonawanda are great centers of lumber manufacture, the lumber being brought by water from points on the upper lakes. As these towns are practically at the beginning of the Erie Canal they are centers of commerce, and Lockport, the market town for most of the area, even much of its growth, is on the canal at the point where it descends the escarpment through a series of locks. Oconto is a well-known summer resort and Akron carries on a small iron and steel industry. Fishing is a notable local industry in some of the towns along the lake shore.

The quadrangle is traversed by a number of railroads. Three lines of the New York Central system cross it from east to west, and other branches connect Tonawanda with Niagara Falls, Lockport, and Batavia. The West Shore line, which crosses the southeast corner of the quadrangle, a branch of the Erie Railroad extends down the river to the falls, and branches of the Michigan Central and Grand Trunk systems extend westward into Canada. Electric railroads connect the towns along the river and extend south and thence, and extend from North Tonawanda to Lockport and from Lockport outward and northward. An electric rail follows the Canadian side of the gorge from Lewiston to Queenston, running along the west brink of the gorge from one end to the other and another line descends the east side of the upper gorge from Lockport to Niagara Falls. The views of the falls, the gorge, and the rapids afforded by these two routes give them high rank among the impressive scenic railway lines of the world.

All parts of the quadrangle are reached by public highways, a number of which are excellent, though others are only fair. Mountaineous roads are also common with some of the large towns, and a brick-paved highway is being constructed between Lewiston and Youngstown. The Ridge Road, the highway that follows the crest of the beach ridge from Lewiston to Rochester, is one of the best-known roads of the country and so thickly settled as to have the appearance of a village street throughout a great part of its length.

The Erie Canal enters the south side of the quadrangle, following the outlet of Niagara River from Buffalo to points in the quadrangle as far as Chippawa. Considerable freight traffic is carried on as far as Tonawanda, and a few freight boats go down to Chippawa and to Port Dory, just above the bend of the rapids on the American side. Steamer lines cross the lake between Lewiston and Toronto and between Oconto and Toronto. Probably no other boat trip in the world is like that of the Mist of the Mist on Niagara River in the保持 of the views and the stirring experience of the rapids and falls. This excursion is made from landings just below the American Falls on the east side and directly opposite on the west side the river is a point as near the site of the great cataract as it is possible to navigate. The number of tourists who avail themselves of this opportunity of seeing what is probably the most impressive view of the great cataract is so great that two boats of the same name are now employed in making the trips.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

General outline.

The exposed rocks of the Niagara quadrangle are chiefly of silicified origin and range in age from Ordovician (?) to Recent. The primary sediments are the stratiﬁed rocks of Ordovician (?) age and unconsolidated surface deposits of Quaternary age. The same general sequence of relatively slight thinness over the surface of nearly the whole of the quadrangle. The hard rocks underlie the surface deposits everywhere and many igneous or metamorphic formations are exposed in the outcrops, and in a few other places, and have been exposed in many quarries and other excavations.

The total thickness of Palaeozoic strata exposed in the quadrangle is about 11,000 feet. The beds consist of sandstone, shale, limestone, dolomite, and gypsum, and comprise portions of the Silurian and Devonian systems and possibly of the Ordovician. Their sequence, thickness, and general character are shown graphically in the columnar section (fig. 5), and the several formations are described in detail in the following pages.

Only the upper part, if any, of the Ordovician system is exposed at the surface in the Niagara quadrangle. It is represented by a series of beds representable by some geologists as of Silurian age and is therefore not definitely assigned to either system in this paper. The Silurian system is represented by formations belonging to the Medina, Niagara, and Cuygna groups, but some other Silurian formations that are found elsewhere, especially the upper part of the Cayuga group, do not appear to be related. The Devonian rocks are represented by the Kalamazoo Formation of Upper Devonian age and the Woncong limestone, Middle Devonian age—the youngest Paleozoic formation in the quadrangle—at the northern end of the escarpment, and is the base of the Shubee beds. Here and there in hollows of the irregular surface of the Ordovician lie thin deposits of sand that are thought to be Ordovician sedimentary strata. The rocks exposed at the surface in the quadrangle are underlain by a considerable thickness of Ordovician and presumably also of Silurian rocks, and are overlain by a thick sequence of crystaline rocks. The general character of these beds is known from examinations made in areas further north, where they outcrop. In the Niagara quadrangle the underlying beds have been identified in a general way by means of borings sunk to depths of many feet, and the outcrop of strata thus penetrated are believed to be of Ordovician age. Their general character, sequence, and approximate thickness are shown graphically in the columnar section of rocks not exposed at the surface (fig. 4).

Ordovician or Silurian rocks.

MiddleOrdovician (?) Sandstone. 1000

Shale and sandstone. 500

Limestone. 70

Carboniferous (?) Sandstone. 100

Granite. 10

Quarzite. 10

The surface material consists of Pleistocene glacial and lake deposits and Recent alluvium. They were formed under widely different conditions and occur in different parts of the area, although their general order of deposition has been unrecorded they do not form a continuous sequence of superposed beds and can not well be represented in a columnar section. They are described in detail farther on in this text.

OREDOXY OR SILURIAN ROCKS.

Middle Ordovician (?) Sandstone. 1000

Shale and sandstone. 500

Limestone. 70

Granite. 10

Ordovician (?) Sandstone. 100

Quarzite. 10

The surface material consists of Pleistocene glacial and lake deposits and Recent alluvium. They were formed under widely different conditions and occur in different parts of the area, although their general order of deposition has been unrecorded they do not form a continuous sequence of superposed beds and can not well be represented in a columnar section. They are described in detail farther on in this text.
Fossils.—The formation appears to be entirely barren of fossils in the Nigen quadrangle, as careful search at a number of exposures has failed to reveal any. The absence of all is characteristic of red sediments in several other formations of Paleocene age and appears to bear some relation to the color. It is said that in the same northwest of the Nigen quadrangle the formation contains interbedded beds, the seams in number but those farther northwest more abundant, which bear fossils of Richmond age.

Age and correlation.—It has been reported, beds containing Richmond fossils are interstratified in the Queentown shales in Ontario as far back as Richmond age may be regarded as established. On stratigraphic grounds, also, the Queentown shale appears to be the equivalent of at least a part of the Richmond formation, although no specimens of the Richmond formation have been found in New York. The systematic position of the Richmond is, however, a matter of doubt, hence in this folio the Queenston shale is not definitely assigned to either the Ordovician or the Silurian system.

MEDIAN GROUP—UPPER PART.

AUBON SEDIMENTARY SYSTEM.

Description.—The Aubon formation is named from its occurrence at Aubon, in Orleans County, N. Y., where it is quarried. It consists of white, gray, and red sandstones, with some red shales, in which the Aubon formation in the Nigen quadrangle is 153 feet, as recorded in a well deep in Akron. At its outcrop in Lewiston it thickness is about 100 feet.

The formation is the upper part of the Medina sandstone as first defined and formerly mapped. The Aubon sandstone and the Queenston shale together constitute the Medina group as mapped in this folio. The white sandstone at the base and the thin gray sandstone at the top of the formation are called the Whirlpool sandstone member and the Thourub sandstone member respectively.

Distribution and occurrence.—The formation outcrops in a narrow belt at or near the base of the Nigen escarpment and forms an irregularly warped terrane extending across the quadrangle. East of Letchworth the terrain is broader than it is west of that city and is more or less broken by drift. The rock is quarried at several places near Lewiston, Lockport, and Gasport, but the formation is best exposed in the walls of the lower section of the Nigen gorge, where its full thickness is displayed. The base of the formation passes below the water level at the Whirlpool and the top disappears at about the foot of the falls. The best exposure is along the cut of the Lewiston branch of the New York Central & Hudson River Railroad near the mouth of the gorge.

Character.—The formation consists of white, gray, and reddish sandstones interbedded with more or less gray and red shale. The following typical section exposed along the New York Central Railroad cut in the Nigen gorge illustrates the character and diversity of the beds.

Section of Aubon sandstones and adjacent formations near base of Nigen gorge.

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<tr>
<th><strong>Clinon formation</strong></th>
<th><strong>Lithology</strong></th>
<th><strong>Thickness</strong></th>
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The sand bed of the formation, the Whirlpool sandstone member, marks an abrupt change from the clay shale to the coarse white sandstones. It is well exposed in the old quarry east of the bridge at Lewiston. Though white in the main, it is here and there spotted by minute black or greenish grains of an iron-bearing mineral that on oxidation forms small brown spots. As compared with most sandstones the rock contains very little mica. It is friable everywhere except bouldered, and when it forms the surface, as in a small area east of the bridge at Lewiston, the oblique planes of cross-bedding have been opened by frost.

In the quarries north of Lockport a bed at or near the same horizon as the Aubon sandstone member displays in marvelous perfection irregularly warped wave and ripple marks of the sort for which the Medina group has long been famous. These and other structural features of the rock have been studied by G. K. Gilbert, and theabhility of the rock appears to be the result of deposition while a rippled surface was being maintained on the ocean bottom.

The cross-bedding is in some places so delicate as to be seen clearly only where the sandstone has been subjected to long weathering, as, for example, just below the Thourub member in the section in the Nigen gorge given above, in which the oblique lamination is well shown on weathered faces of the rock but is scarcely noticeable on a freshly fractured surface.

Numbers of single valves of Lingula common that occur on the surfaces of flints from certain layers of the sandstones are e remnant, as parallel lines, all the bedding planes is precisely the same direction and a little ridge of strong matter sloping away from each. This alignment of the shells and the detached groupings of shoes of massive sand in layers no thicker than paper afford conclusive evidence of its present action.

The direction of the current may be determined, because the ripples of sand were accumulated in the current layer of the shells and the current must have flowed in the direction in which the beds of the shells are pointing. In the Lockport quarry, this direction of the current would be southeastward.

Here and there the bedding of the sandstones shows irregularities that are much larger than the ripple marks and cross-bedding which are so abundant. They consist of broad ridges and troughs in the bedding planes, from 10 to 20 feet wide and from 4 inches to 4 feet deep or high. They are seen in the old quarries near Lewiston and on the north side of Eighteenmile Creek at Lockport. One exposure on the New York Central Railroad south of Lewiston is illustrated in Plate XXI, and

Associated with these species are the remnants of a tabulate form was composed of small fragments of Lingula, which was evidently occupied by a species of marine worm.

Still higher in the formation at 100 feet below the top, the peculiar tabulate form Arthrophylla bekiwaki, which is probably related to the pteropod, appears in abundance. It is common at this horizon throughout a wide area in New York but has not been found in the lower part of the formation. A few fossils are present in the Thourub sandstone member, the uppermost bed of the formation. Among them are species of Plagiozoon and some undeterminable brachiopods.

Although the Aubon limestone contains a sparse fauna from the greater part of the formation appears to be entirely barren of fossils. The Whirlpool sandstone member, from which no fossils have been obtained, was made of nearly pure white sand. This and several other beds of the formation afford plain evidence of deposition under the influence of wave and current action, and it seems nearly certain that the surface layers of the fine sand, activated by waves and currents, must have been constantly shifting during their deposition. If, as is believed, the beds were deposited in comparatively shallow water at a great distance from shore, they constituted a good example of what zoologists call a "drift and sand" zone, in which conditions are regarded as unfavourable to the existence of marine molluscan life. The drifting sands that seem to have characterized considerable areas of the sea bottom near the coast during the greater part of Albion time appear to afford an excellent example of the seaward drift of fossils in parts of the formation and of their total absence from other beds.

IMMERS GROUP.

CLINTON FORMATION.

Description.—The Clinton formation is named from Clinton, Onondaga County, N. Y. where it is typically developed. In western New York it comprises shale members at the base and the top, with limestone between. Its thickness in the Nigen quadrangle is 90 feet. Together with the overlying Lockport dolomite it constitutes the Niagara group.

Distribution and occurrence.—The formation outcrops in a narrow band extending across the quadrangle along the slope of the Nigen escarpment. The limestones in the middle of the formation determine the intermediate terrace along the escarpment where the outcrop is double, the lower shale member occupying the slope of the lower minor scarp and the upper shale member forming the slope of the upper minor scarp. The rocks are exposed at a number of places, especially in the "gulfs" or notches in the escarpment and in the ravines of streams descending the slope. East of Lockport the outcrop is more or less concealed by drift. The formation is well exposed through the entire thickness of the Nigen gorge, where it forms a considerable part of the wall. The gorge has to a great extent been eroded in the upper part, and the limestone members in the middle of the formation make a narrow minor terrace near the bottom at several places.

Clinothecia.—The Clinton formation, as herein defined, comprises four members, represented in the columnar section (fig. 5) and well illustrated in Plate XVI. At the base is the
Sulcus, a sandy shell with a maximum thickness of 6 feet. It is overlain by the Walton limestone member, a dolomite limestone 6 to 10 feet thick, which in turn overlies by a 13-foot thick Limestone member, a coarsely crystalline limestone 10 to 15 feet thick. At the top is the Rochester shale member, an argillaceous shale having a thickness of 30 feet. The three lower members constitute the Clinton formation as originally defined and mapped in western New York, the Rochester shale having been called the Niagara shale by the Geologic Survey of Canada and with the present Lockport dolomite as the Niagara shale and limestone. Of these members the Rochester is the only one mapped, the others being too thin to be shown on the scale used in this folio.

Character.—The Sulcus shale member consists of greenish to bluish-green clay 30 to 50 feet thick. In the section in The Gulf, west of Lockport, it is made up of green sandstone and silt and shale and sandstone and is 10 inches thick, and at Niagara River it is an argillaceous shale 60 inches thick. In the Genesee River section at Rochester the member is 24 feet thick and is overlain by a 14-inch bed of iron ore, which is not found in the Niagara quadrangle.

The Walton limestone member consists of dolomite 10 feet thick, containing very few fossils. In physical, chemical, and fossil characters it differs widely from the overlying Clinton limestone member, but there is no trace in the Niagara quadrangle of the Mississippian forerunner of either member in the Genesee River section. The Walton member is well exposed along the New York Central Railroad in the Niagara gorge section and here where the wagen road descends the Niagara escarpment 2 miles west of Lockport.

The Irondale limestone member consists of light-gray, coarsely crystalline limestone 10 to 15 feet thick, containing numerous pink crinoidal stems. Its highly fissile character distinguishes it at a sight from the underlying Walton member. Other characteristics are slender vertical columns and zigzag fracture lines, many of which cross the surface of the strata, marking the position of the stylobitic structures. The columns range in length from a fraction of an inch to several inches. Some of the limestone stumps are ripple marked, as in the bed of Johnson Creek, where two limestone beds about 1 foot thick ripple marks 18 to 30 inches wide with crests to 4 inches high. Similar ripple marks are displayed in the quarry in the Clinton formation at Gasport. They indicate that the limestone was deposited in a sea of moderate depth.

The Irondale member is characterised by the occurrence of reef structures. These are formed by irregularly bedded dolostone-cored nodule-like masses of limestone, which are sharply differentiated from the enclosing limestone, being wholly different in composition and texture and generally much harder. They range in width from 7 to 35 feet and reach a maximum height of 10 feet. Some are confined to the limestone and others extend into the upper part of the Rochester; but the latter are not ordinary concretions is indicated by the marked contrast between the fauna found in them and that of the adjacent limestone. As a rule, the pods and trilobites are abundant in the nodule-like masses, and rare in the surrounding rock. Trilobites and some other large creatures appear to have frequented these parts of the reef. Ringsdale noted the local abundance of fragments of trilobites, and Stiel has pointed out that weathered surfaces show that the nodule were composed largely of bryozoans, which appear to have flourished in widely separated columns. The resulting blocks grew more rapidly than the adjacent sediments were accumulated and furnished a feeding ground for various free-swimming and detached species which were aggregated in large numbers and which remain added to the growth of the nodule. More than 100 species have been recorded from the reefs, among the most abundant being the small beads phosphaticollaria and the trilobite iridescens. Nearly a dozen reefs, one of which is shown in Plate XXI, are exposed along the Niagara gulf and below Lewiston Heights. A typical example is 1 mile 2 miles south of Lewiston, at the third watchman’s hut on the New York Central Railroad. A few have been noted between Lewiston and Lockport and there are others in the bed of the creek at Gasport.

The Rochester shale member consists of soft bluish-grey argillaceous shale. Its lower part is almost free from limestone beds, but its upper part characterised by the occurrence of 20 feet of limestone 1 to 3 inches thick. In the Genesee River section the member is about 30 feet thick. Like most of the other formations of the quadrangle it thickens toward the east, and at the type locality in Rochester it is 85 feet thick. The lithologic changes from the Irondale member to the Rochester member is abrupt. The close relation of the two is indicated, however, by the fact that the fauna of the

Together with the underlying Rochester shale member it was formerly mapped as the Niagara shale and limestone. With the underlying Clinton formation it makes up the Niagara group of this region.

Distribution and occurrence.—The formation occupies an east-west belt, 5 to 7 miles wide, extending across the quadrangle south of the Niagara escarpment, of which nearly every where forms the crease. In the upper bed of its area, its control of land forms, and its economic value, this is the most important limestone in the quadrangle.

It is exposed almost continuously along the base of the Niagarg escarpment from Niagara River to Lockport and is particularly well shown in the two "pools" at Lockport, East of Gasport only about half the length of the slope in the quadrangle is capped by limestone; in other places the top of the slope is shale and the northern edge of the limestone is from a quarter to a half mile back from the slope. This remarkable fact is probably due to the removal of the limestone from most of the crest by glacial erosion.

South of the escarpment the limestone is nearly everywhere covered by glacial drift except in the Niagara gorge, where all but the uppermost beds are exceptionally well exposed. It forms the rocky bed of the gorge throughout much of its length and is the rock over which the water falls. The highest beds of the formation appear to be covered in the quadrangle, and its total thickness is therefore estimated from the best data obtainable. Well records are inadequate for determining the exact line of separation between the Lockport and the overlying Clinton formation, but so far as can be judged the thickness of the beds above the highest layers exposed near the falls is 25 or 90 feet, making the total thickness of the formation 150 feet, as estimated.

Character.—The lowest beds of the formation consist of 6 to 8 feet of drift to bluish-grey fine-grained limestone, containing a large percentage of burnt wood and animal and mineral material and probably for making a natural cement of fine grout.

Although here and close-grained it weathered rapidly on exposed surfaces and is now black or dull, irregularly shaped fragments and, like the shale beneath it, tends to retreat more rapidly than the overlying limestone, which in consequence overhangs it slightly in right of way. In many places the transition from the shale below is gradual; in others large calcareous concretions at the base of the limestone extend downward into the shale, making the contact irregular.

The basal beds are overlain by light-gray to bluish-grey coarse-grained limestone, containing large fragments of burnt wood and animal material and probably for making a natural cement of fine grout. The overlying coarse-grained limestone, named from Gasport, where it is well exposed. The abundant crinoidal plates and stems and the other fossils give it a distinctly different appearance from the beds above and below, which are only sparingly fossiliferous. In the literature of the region this bed has been variously called the Lower Niagarg limestone, the Lockport Erratic marble, and the Cudulins limestone. Its average thickness is 9 feet, but in places it is more than 20 feet thick. It outcrops in a narrow belt along the brow of the escarpment and is capped by the geologic map by a special color. About the head of The Gulf, northwest of Lockport, it is only thinly covered with glacial drift over an area of about 200 acres, thus offering favorable conditions for quarrying.

The contact between the Gasport limestone and the beds beneath is sharp, without intercalation. It is exposed at Fish Creek on the east side of the Niagara gorge a little south of Lewiston, and on the west side of The Gulf near its head at Lockport. It is also well shown in the canal above the locks at Lockport, where about 4 feet of the underlying beds appear above water level and at a little distance look like fine-grained ambonite. The contact is displayed for several hundred yards continuously along the canal. It is slightly irregular, but there appears to be no stratigraphic break between the two limestones.

At Lockport the Gasport member is nearly pure magnesium limestone, whereas the beds both below and above it are highly fossiliferous. At the gulf 2 miles east of Lockport the member is slightly magnesian, but its physical features are the same as in the quarries in the Gulf. Grains of crinoidal stems are common in the top down near the lock which is only 15 feet thick; the base is lenticular dolomite and the base is flat or slightly convex.

The section on the Canadian side at Niagara Falls shows 7 feet of hard grey calcicoalystratified limestone, sharply defined from the soft beds above and below the same and from the phosphate beds below, and clay.

Definition.—The Lockport dolomite is named from Lockport, where the formation is well exposed along the Erie Canal. It consists chiefly of dark-gray to chocolate-colored dolomite having a total thickness in the quadrangle of about 130 feet.
from the incising rock, although both are magnesium limestone. The lenses are amorphous and contain neither crystalline nor any trace of bedding. They are lighter in color than the incising rock, the overhanging crumple to the buff-colored powder. They are of irregular outline and differ considerably in size, the larger ones having a diameter of 18 to 20 feet and a height of 4 to 5 feet. It is believed that they represent reefs of byssanites.

The part of the Lockport dolomite overlying the Gaspé limestones consists of two distinct members in physical texture and chemical composition. Where typically developed it is dark-gray to chocolate-colored, cemented dolomite containing small crinoidal, some coarse-grained, and others filled with masses of white gypsum or are lined with crystals of gypsum and dolomite both. On the Canadian side at Niagara Falls, where 20 feet or more of the bed are exposed for study along the roadway to the foot of the falls, the rock is hard-textured, chocolate-colored dolomitic limestone containing numerous veins of great beauty. Along the Erie Canal just southeast of Lockport is an extensive lateral exposure of the same beds, where the gray to buff dolomite, 25 feet thick, grades in places into argillaceous or sandy beds. The beds are bleached gray and have broken surfaces when fresh but weather on exposure to a mass of shaly fragments. A total thickness of about 120 feet of the formation is exposed at Niagara Falls and in the islands and cliffs above the falls. The middle and upper beds exposed consist of hard brownish-gray or chocolate-colored, argillaceous dolomite described with numerous paper-like pinnacles of brown carbonaceous matter. On fresh fracture the rock has a field of petroleum-like odor. Numerous nodules were specified by the excavator as „pikes‟ or„cane heads „by the Ontario Power Co. The crinoids generally contain amorphous, gypsey, calcite, dolomite, or more rarely cinnabar crystals. Some of the various cinnabar crystals include pinkish, ayslety silvers, and amber crystals of calcite, making specimens of great beauty. Among the less common minerals are amorphophyrite, ephelinite, calcitites, fluorite, pyrite, chlorite, manganite, malachite, and selenite.

Some of the highest beds of the formation have been made accessible for descriptions in the Erie Canal through the beds are normally covered by glacial drift their character may be studied in the extensive rock dump at the canal exposures a mile north of Pendleton. The rock is massive dolomite with numerous gypsey-filled cavities and scattered stylobites. Small specimens of gypsey are also found. Beds that appear to be the highest strata of the formation yet observed in the quadrangle were observed by the canal exposures three-fourths of a mile north of Pendleton. The rock is thin-bedded black or steel-gray dolomite that gives off a strong odor of petroleum on fresh fracture. Some beds include numerous thin partnering of black shale, and many contain large concentrations, which, on long exposure to the air, weaken in central sheets like the coats of an onion. Some of them have a mucous adhering in texture and structure from the surrounding limestones, and they show slantly curving beds of dark limestone covered by closely placed depressions or dimples a quarter to half an inch deep. A thin film of black carbonaceous matter covers every rock surface to separate these impressions of those present stylobites cannot be definitely stated. The upper part of the formation exhibits some other unique features at an old quarry 1/2 miles east of Niagara Falls, N. Y., where the rock is thin beded and several strata, 2 to 3 inches thick, curve sharply downward at intervals of 3 or 4 feet. The resulting series of lens-shaped cross beds gives the effect in cross section of a row of mossy inverted vases. (See PL. XXIV.) The downward curve in successive strata is in the same vertical line, as that adjacent plates fit into each other.

Fossils.—Fossils are in general extremely scarce in the Lockport dolomite. Those that have been found are of much interest, however, as they show the presence of three distinct fossil elements. The indigenous or normal Lockport fossils, derived from the Rochester formation, which preceded it in the region, appear to have its maximum development in the beds overlying the Gaspé limestones, which are exposed along the canal near Lockport. Another is the crinoidal fossils of the Gaspé limestones. A third fossils, prominent in some sections higher in the formation, is the Gaspé fossils, the assemblage which is of very different type from either of the other two and which has its maximum development in a more southerly portion of the Sherburne state in which both the Gaspé and the indigenous Lockport fossils appear to have lived contemporaneously.

The normal fossils of the Lockport dolomite is much more common in the argillaceous facies than in the more nearly pure dolomites. In the higher rock facies are comparatively scarce with the exception of corals. In the lower beds of the formation the fauna in its essential textures is the same as that of the Rochester shale, from which it is derived. In the section exposed near the head of The Gulf, west of Lockport, the lowest beds are filled with working corals, but have yielded no other organic remains. Associated with the crinoidal fossils that form so large a part of the Gaspé limestones are particularly the fish of the Devonian period, and it is believed that they represent reefs of byssanites.

The part of the Lockport dolomite overlying the Gaspé limestones is exceedingly rich in corals, some of which are not well known from any other place in the world. The crinoidal corals of the Lockport dolomite, as well as the Gaspé limestones, are believed to be of the same age as the Fossils of the Lockport dolomite at Gatling Island the following species, which represent essentially the western or Gaspé fossils:

- **Stromatopora sp.**
- **Helminthodesmus sp.**
- **Stromatopora sp.** (different branch form)**
- **Pteroides crassa**

In an old quarry 1 1/2 miles northeast of Stony Island, above Niagara Falls, N. Y., the Gaspé fossils represented in a highly fossiliferous layer, 3 to 4 feet thick, near the top of the quarry led. The following species were observed at this locality:

- **Pavilionella longissima**
- **Coccolithus sp.**
- **Orthoceras cf. cruciatum**
- **Cyclothalamus furcatus**

In the highest beds of the Lockport dolomite exposed by the canal exposures north of Pendleton a species of Lepidopetra and one of Bathysthima occur in great abundance in certain strata. One of the two or three species of Lepidopetra and one of the species of Bathysthima have been observed in the following beds:

- **Cyclothalamus furcatus**
- **Stromatopora sp.**

**Salina Formation.**

**Definition.**—The Salina formation is named from the town of Salina, Onondaga County, N. Y., in which it is typically developed. It consists of grey magnesium shale, beds of dolomite and gypsum, and, at the top, limestone containing beds of crinoids and other corals. The underlying Cobblekill dolomite constitute the Cayuga Group as developed in western New York. The thickness of the formation in the Niagara quadrangle is 400 feet.

The Salina formation was originally called the Oneonta salt group, but the name Onondaga has been changed in point of application of Middle Devonian age and for use in the alpine area rocks was discontinued in favor of the similar name Salina. In the region extending from Genesee River eastward the Salina comprises four members—the Pittsford shale member at the base, the Vernon and Camillus shale members, and the Bitter limestone member at the top. In the Niagara quadrangle the salina member is certainly identified and mapped, the lower part of the formation consisting of a mass of shale, dolomite, and gypsum not definitely distinguished but characterized by its curvature. The upper part of the formation exposed on the Salina quadrangle, is essentially the same as that of the Bitter limestone member of the Salina formation in the section near Lockport is 2 feet thick. It was at first regarded as part of the Oneonta limestone and is later referred to the Main limestone, but Harrington has since shown that it is the probable equivalent of the Cobblekill of eastern New York, which is named from its typical occurrence at Cobblekill, in Schoharie County.

**Cobblekill Dolomites.**

**Character and distribution.**—A bed of highly magnesium limestone known locally as the “Cobblekill” rock occurs on the Bitter limestone member in the Niagara quadrangle. In the section near Lockport it is 5 feet thick. It was at first regarded as part of the Oneonta limestone and was later referred to the Main limestone, but Harrington has since shown that it is the probable equivalent of the Cobblekill of eastern New York, which is named from its typical occurrence at Cobblekill, in Schoharie County.

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Character.—The rock is fine from magnesite and the greater part of the formation consists of nearly pure calcite carbonate. Its color ranges from light gray to bluish gray. Where the formation rests in depressions in the surface of the Cole’s dolomite there is in places a few inches of dark shale at its base. In the section in the quarry of the Newcomen Cement Co. at Fieldcreek, the basal shale is 6 inches thick and colored medium gray with fossils. Thin partings of greenish slate, as a rule thinly or calcarious, a quarter of an inch to an inch thick, here and there occur in the overlying beds of limestone. Most of the contact is one or more zones of thin chert layers and concretions. Most of the chert is black, though some of it is gray, red, and green. It does not appear to occur at any definite horizon in the formation. In the section near Fieldcreek a 6-foot bed of limestone containing chert septum 5 feet square here at the base of the formation.

Beliefs.—The formation lies unconformably on the eroded and irregular surface of the Cole's dolomite. At several places in and near Buffalo the unconformity is well developed. Small caverns were formed here and there in the surface of the Cole’s dolomite during the time of erosion in the early part of the Devonian period. These are filled with sand considered by J. M. Clarke to represent the Oriskany. At other places, as near Akron, the contact of the Oriskany with the underlying rock is marked by a few inches of blue clay or dark shale. The section just following north of the works of the Newcomen Cement Co. at Akron shows the character of the contact.

Section of Oriskany limestone and underlying shales near Akron.

<table>
<thead>
<tr>
<th>Oriskany Formation</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone and shale</td>
<td>6</td>
</tr>
<tr>
<td>Limestone, grayish-slate</td>
<td>5</td>
</tr>
<tr>
<td>Shale, dark, carbonaceous, carbonaceous</td>
<td>5</td>
</tr>
<tr>
<td>Sand, shale, with coal</td>
<td>5</td>
</tr>
<tr>
<td>Slate, bluish gray, marly like clay, containing lime-</td>
<td>5</td>
</tr>
<tr>
<td>stone and fossil</td>
<td>5</td>
</tr>
</tbody>
</table>

Cole's dolomite: Limestone. D. (magnesian) 4-6

Fossils.—The formation contains a rich marine fauna, consisting for the most part of invertebrates. In places the combined form reefs, which are especially numerous in the basal beds. Some of the more common species found in the formation in the Niagara quadrangle are the following:

<table>
<thead>
<tr>
<th>Fossil Species</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyritonectes</td>
<td>Spiral ammonite</td>
</tr>
<tr>
<td>Fissurella nammata</td>
<td>Spiral ammonite</td>
</tr>
<tr>
<td>Chesapecten</td>
<td>Cephalopod</td>
</tr>
<tr>
<td>Ataxia meladactyla</td>
<td>Cephalopod</td>
</tr>
<tr>
<td>Menopsida</td>
<td>Cephalopod</td>
</tr>
<tr>
<td>Mammillaria</td>
<td>Cephalopod</td>
</tr>
<tr>
<td>Lyricolus</td>
<td>Cephalopod</td>
</tr>
<tr>
<td>Helicoceras simplex</td>
<td>Cephalopod</td>
</tr>
<tr>
<td>Echinites simplex</td>
<td>Cephalopod</td>
</tr>
</tbody>
</table>

The deposits of Ordovician age belong almost wholly to the Pleistocene series and include glacial drift and associated lacustri- ne deposits. They cover nearly the whole surface of the quadrangle, the bedrock being exposed in only a comparatively small area. The beds are generally not more than a few feet thick and are composed of coarse gravel and sand which are well sorted and well rounded. The ice at many places during the retreat of the ice front across the quadrangle. With these deposits are associated glacial outwash and eskers laid down in the channels of streams running into the lakes.

The deposits of Recent age consist of alluvial sand and gravel along the courses of a few streams and of alluvial soil and meadow in a few swamp areas. They are of minor importance and only a few large ones are shown on the surficial-geology map.

PLACED IN SERIES.

PRE-WISCONSIN DEPT.

Drift underlying and apparently older than the Wisconsin drift has been found in a few places in the quadrangle. Nearly all the exposures, including the lake shores, were in quarry stripping and excavations north and south of the line, and stratified drift in the form of kames, eskers, and streams of outsized sand and gravel. The lacustrine deposits were laid down in lakes such as Lake Ontario, Lake Erie, Lake Michigan, and the Great Lakes. A few areas of glacial till and drift of Pleistocene age have been found in the area. In general, the advantage was to reduce the relief and make the surface smoother, but its partial adaptation to the rock surface upon which it was deposited led to the formation of masses of rock showing no particular form or arrangement except where it had been fashioned into drumlins or into elongated till ridges.

The greatest part of the surface of the quadrangle is occupied by till or bowlder clay of Wisconsin age. The till sheet also underlies the lake sediments nearly everywhere, and practically the whole surface of the quadrangle next west of Wilson is covered by a thick blanket of till, the lowest part of which is the most nearly the same as that which is found in the quadrangle east of Wilson. This forma- tion is one of the most continuous and has undergone least modification. It is well displayed east and west of Portage in the area between the escarpment and the Iroquois beach, on the southern part of Grand Island, and in smaller areas south of Lockport, south and east of Gaines, and west of Akron. In other parts of the quadrangle, especially in the large area north of the Iroquois beach, it has been extensively modified by subsequent, the clay, sand, and gravel having been washed out and the larger stones and boulders having been concentrated upon the surface. The ground moraine in the quadrangle is rather thin, its maximum thickness being 50 feet and its average thickness 10 to 15 feet.

Drumlin and drumhills forms.—Under certain conditions the till sheet, instead of being a form of layer, either flat or slightly upright, as it can be readily seen. It seems to have a similar shape, but without the development of a distinct form or arrangement except where it had been fashioned into drumlins or into elongated till ridges. The drumlins are elongated mounds that project from the escarpment and extend to the Iroquois beach, on the southern part of Grand Island, and in smaller areas south of Lockport, south and east of Gaines, and west of Akron. In other parts of the quadrangle, especially in the large area north of the Iroquois beach, it has been extensively modified by subsequent erosion, the clay, sand, and gravel having been washed out and the larger stones and boulders having been concentrated upon the surface. The ground moraine in the quadrangle is rather thin, its maximum thickness being 50 feet and its average thickness 10 to 15 feet.

The Wisconsin glacial deposits, excluding the till sheet, are most continuous and have undergone least modification. They are well displayed east and west of Portage in the area between the escarpment and the Iroquois beach, on the southern part of Grand Island, and in smaller areas south of Lockport, south and east of Gaines, and west of Akron. In other parts of the quadrangle, especially in the large area north of the Iroquois beach, it has been extensively modified by subsequent erosion, the clay, sand, and gravel having been washed out and the larger stones and boulders having been concentrated upon the surface. The ground moraine in the quadrangle is rather thin, its maximum thickness being 50 feet and its average thickness 10 to 15 feet.

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Moraine-like knobs and fences associated with the moraines.—Along the base of the Oomulac moraine southwest of Akrot are knobs of till which show almost as great relief as some of the moraines facing the moraine now extending more than 2 miles northeast from Wrights Corners. It is about one-third of a mile wide and at its southwest end is a small morainic ridge which extends beyond its present limits and that it has been removed by the powerful shore erosion of Lake Iroquois.

A long moraine runs southwest from Wrights Corners, in front of and a little below the Iroquois beach, so it is necessary to suggest a moraine origin. Another very stony fragment 2 miles further west may belong to the same formation. At Warren Corner and extending further than 4 miles further west probably belongs to this moraine.

Nothing further is known of this moraine either to the east or west. It lies so close to the Iroquois beach that it places has probably been destroyed by the lake.

Carron moraine.—No moraines other than those previously described have been identified with certainty in this quadrangle, but there is one in the Ridgeway and Oak Orchard quadrangle, the exact location of which has been determined in this area. A well-defined moraine was found a mile southwest of Torntown, within a mile or two of the shore of Lake Ontario, and was traced southwest along the shore of Lake Ontario.
Besides a small patch of fine sandy outlet in the southern edge of Lockport, the only notable outlet deposited associated with the Barre moraine is at the Lockport station on the Grand Trunk Railway. The deposit is at the head of the embayment formed in the encroachment by the mouth of the White Rapids. The gravel is mainly west of the railroad and the outlet east of it is all fine sand. The deposit is associated with the large kame that stands west of the mouth of White Rapids. It is not a continuous sand which in some places is fully divided from the east and south sides of the hill and in the outlet deposit east of it show fine examples of bouldered and cross-beded gravel layers, dipping mainly to the east and northeast. The gravel in both deposits are very coarse. The name appears to be related to the stratum that produced the outwash, and as such deposit the train of gravel that extends southwest to the kame at Landsby.

The largest kame area in the quadrangle and the only extensive deposit of the set begins about 1.5 miles east of Lockport and extends east-northeastward more than 3 miles. It is set in the west end of the ridge of the Allison moraine and was probably deposited at the time of the formation of the ridge. Most of the kame gravel is backed against the slope of the Niagara escarpment and lies lower than the crest, but some is in lee on top of the scarp. The western part is composed of gravel to a depth of at least 100 feet, as shown by the excavation, and is characterized by cross-bedded pebbly boulder clays. The eastern part extends northward into the Erie Canal and ends about half a mile northwest of Oneida. The canal is composed largely of fine sand, but includes some limned silty and clayey layers. On the southwest the flatter material merges gradually into the plain and isolated kames of coarse gravel resting on the brow of the escarpment west of the city. This area covers about 3 square miles. It has the typical knoll and basin topography of large kame areas, and is probably the remnant piece of an ancient quadrangle except the accumulations and gully washouts. The Erie Canal is excavated through the lower part of it for a distance of nearly 2 miles, and along much of its length one can distinguish gravel deposits. South of the canal its hummocky surface rises rather steeply 140 feet or more to the top of the escarpment and extends a short distance south from the canal. The deposits at the cemeteries in the northern part of Lockport appear to belong to the same time of deposition and are associated with moraine knolls which are probably also associated with the Allison moraine.

A few small gravelly knolls are scattered over the northern part of the quadrangle. Some appear to be located and not connected with any moraine, but most of them are on or near the line of the Carleton moraine and are probably more or less closely related to the position of the ice front at the time that moraine was deposited. They include the small hills east of Appleton, 1 mile southeast of Huron, and at Huron. The larger kame north of Hartland is not directly associated with any moraine, although the gravel deposit 2 miles north of Hartland appears to be a washed-down kame related probably to the same stream that made the kame east of Lockport.

None of the small eskers 2 miles southeast of Bayport (incorrectly represented on the topographic maps as a kame) stands slightly forward from the front of the moraine. It is more than half a mile long and about 15 feet high and begins from a southerly to a southeasterly course. Its position suggests that it was formed when the ice margin stood at or near the position of the Niagara Falls moraine, but it was probably formed in the early part of the halt during which the Barre moraine was deposited.

Three gravelly ridges 2 miles east of Youngstown are distinctly of the eskar type, but there are not deposited so generally and have been eroded by streams flowing along the side of the hill, for their sides are more gentle than those of typified eskers. They are lettered A, B and C and are conspicuous objects on the east front. The southernmost one is about a mile long and has a short spur projecting southwestward from its north end. Beyond a short break another ridge continues in the same line for about half a mile to the north and is joined by another short spur extending southwestward. Just out of end and parallel to it is another gravel ridge, or esker, and east of that is a lower, wider knob of fine sand between the eskers. Little remains of either type of form in its present form. The evidence for the eskers were formed at the time of the deposition of the Carleton moraine, such a relation seems probable.

**Notes**

An outwash deposit of fine, somewhat clayey sand, associated with the Niagara Falls moraine, occurs about a square mile south of the kame at Landsby. It was laid down in lake water by the same stream that deposited several of the gravel formations farther north. Part of it is shown on the map of the Niagara gorge.

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**Deposits of Glacial Lake Landy.**

**Bowen.—During the existence of glacial Lake Landy the level of the lake fell 85 or 90 feet, as shown by disintegrated shore lines. The first or highest show line of the lake (known as the Glensmore beach in southeastern Michigan) is very weak and has been recognized only at a few places in the region and nowhere within the Niagara quadrangle. To judge from the elevation changes which might be expected to occur near Akron at an altitude of 785 to 790 feet, but it was not found in the small area which rises above this altitude. At the time of the glacial Lake Landy the lake was in the maturity phase of its existence and a bedrock lake is likely at any place 100 feet or more above the present lake surface.**
of fairly coarse gravel and covers about a square mile. In a number of excavations it is shown to have a maximum depth of 6 to 8 feet, but it generally thins toward its edge in the northerly and eastern parts of the city.

Along the south side of Lake Tomawanda were formed deposits of fine sand and of considerable proportion of fine-grained silt, on the east shore of Getzville, around East Amherst and Swinburne, around Sand Hill, and north of Swiffla Mills. They contain gravel or pebbles and were derived from the north shore of the shallow lake, but they are largely of the nature of detritus. The deposit south of Getzville is related to Elliott Creek, that near East Amherst and Swinburne appears to belong to Getz and Ramrose creeks, and those near Sand Hill and Swiffla Mills are related to Murrell Creek. Perhaps some also may be gain by the construction of sand from the south side of the lake bottom, compared with that contributed by the streams, by noting the large quantity of delta sand forming the ridges east and southeast of Getzville and the small amount northeast of Hunts Corners, nearly all of which was probably derived from the lake bottom.

Clyp and sill—In the Tomawanda basin an extensive bed of silt and clay overlies the city previously deposited in Lake Lundy. The silt predominates, but thin sheets of clay are interbedded with it. The deposit covers all the lower part of the basin and extends from a point half a mile west of the mouth of Gill Creek in the city of Niagara Falls, N. Y., about to the old embankment on Tomawanda Creek west of the city of Rapids. The beds of the silt are fairly well defined in most of the area but are low and clear toward the east, where it thins gradually. On a line running north from Murrell Village the silt bed is about 5 mile wide, and elsewhere it averages 2 to 3 miles. Sections showing the silt to some depth were seen in pieces along Tomawanda Creek below the Erie Canal, in the Erie Canal, and in excavations in Maretta, Lona, and Newfield Falls. In Martinville a ditch showed 4 or 5 feet of stratified yellow fine sand and many reddish layers of clay at the bottom. In La Salle a ditch showed alternating layers of yellow silt and gray clay to a depth of at least 5 feet. The clay occurs listric or fusiform at this place and in some parts with fine yellow sand. The limit is said by one to 20 feet of the clay of Lake Lundy. Only on the flanks of drumlins and within and on the center of the basin of Niagara Falls was the silt found thin or as ill rock.

Deposits of Glacial Lake Iroquois—

After the waters of Lake Lundy fell the glacial waters of the Lake Erie basin became separated from those of the Ontario basin, and the new lake thus formed in the latter basin is known by the name of Lake Iroquois. It was held back by an ice barrier which spanned the St. Lawrence Falls and its valley, and its outlet was at Rome, N. Y., through the Old Ontario Canal to a pool on the Mohawk River called the Iroquois. The history of the waters of the Lake Ontario basin has not been fully worked out, but it is certain that the surface of Lake Iroquois stood considerably higher than that of the Iroquois basin. (See fig. 10.) At some time during its early history there was a differential uplift of the land at the north- east and south-west corner of the basin, the waters were backed up on its western shores and the first beach was submerged.

Iroquois beach—Fragmentary remains of a beach lower than the Iroquois beach were found in the eastern two-thirds of the quadrangle. Beginning a mile southwest of South Wilson this shore line extends in broken form outward and northeasterly toward the east side of the quadrangle, but no certain evidence of it was seen toward the west. It attains its best development in the eastern part of the town of Newfane and may be called the Newfane or early Iroquois beach. Its washed-down and broken appearance and the surfacing of its surface is indicated by the rapid erosion of the beach in front of the town. (See fig. 10.) At some time during its early history there was a differential uplift of the land at the north-east and south-west corner of the basin, the waters were backed up on its western shores and the first beach was submerged.

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Harland, are four or five small fragmentary gravel ridges and a few sandy patches. One of the gravelly fragments is a mile north of North Harland. The others are near the east boundary about 3 miles southwest of Berkner. The fragments are irregularly arranged and appear to have no connection with one another.

One of the best-preserved fragments runs northeastward from the corner 1 mile south of East Wilson. It is a well-formed low ridge composed of coarse gravel. Another ridge, which is much more rounded than the one just described, runs northeastward from 2 miles east of East Wilson and runs westward about 2 miles. Another, standing at a slightly lower level, begins half a mile east of South Wilson, runs westward for nearly 2 miles, and then turns sharply to the south. It may be noted that the most conspicuous fragments of the beach, both at South Wilson and east of Newfarm, are on low alluvia of the land facing northwestward, and that the strongest parts of the Irquon beach at a higher level stand in similar positions.

Nothing certainly representing the beach was found west of the hooked spit 1 mile west of South Wilson. It seems rather strange that the beach should be so completely destroyed over wide areas, except for a few small fragments that are well defined and records one of the important stages of the cliff and lake history. Because of its prominent topographic relief its position and course across the quadrangle are described under the heading "Topography.""

From the eastern boundary of the quadrangle to a point a mile southwest of Dickensonville the shore line is a conspicuous gravelly and sandy ridge through the whole distance except for 2 or 3 miles north of Lockport. From the point west of Dickensonville the beach gives place to a low cliff that continues to the east edge of the village of Lewiston. Thence a well-defined spit runs westward through the village to the bank of Niagara River, with a hook turning southwest toward the river and a longer one turning southeast through the village, as is well shown on the map of the Niagara gorge. On the Canadian side the shore is marked by a cliff extending from the south edge of Queenston westward past St. Davids. Most of all this cliff the wave cutting was done close to the base of the escarpment. Elsewhere in the quadrangle the beach touches the shore line only at the points where the coast is about half a mile at a place about 3 miles east of Lewiston, but from Lewiston to the mouth of Dickensonville the shore line is everywhere more than half a mile's width. For nearly 2 miles eastward from a point west of Lewiston the beach ridge gives place to a low shelf cliff cut in the north side of a moraine ridge near the mouth of the southeast of North River is also wave cut on its north side.

From the east edge of the quadrangle the ridge extends nearly due east to the village of Newfarm, without a break, except where Johnstown Creek passes through it. In this part it is well developed, but it attains its greatest height in the stretch extending southeastward from Red River past Redcorns, Southworth, of which it culminates in a short, high spit. Farther southwest a low conspicuous portion of the beach is carried upon a heathery moraine ridge, but around the head of the old bay the beach is still steeper and more broken. On the west side of the old bay a low but well-formed gravel ridge extends along the west end of Eighteenmile Creek. North of this is a great spit built southward from the east end of the moraine ridge west of Lewiston. From Dawson to the beach ridge extends nearly due east along the southeast of North River is also wave cut on its north side. At the end of the spit on the west and west side of the old bay at Lockport its top is nearly 40 feet above the adjacent shore line. It is built at an angle of 45° and extends in 28 miles in a direction N. 80° W. The variations of altitude and deformation of this beach are discussed under the heading "Geologic History." Spits of gravelly material built of coarse gravel and boulders with no filling between them. Fine and course layers alternate in sharply defined beds. Some of the spits are 8 to 12 inches in diameter, but some of the larger stones are not, their edges and angles retaining some prominence. The gravel is bouldered, the beds dipping steeply southeastward, in some places nearly south, in others northerly east, and there is almost no evidence of ordinary cross-bedding. On one or two spits a few inches of coarse gravel has been built on the back of some of the spits. At the same time the exposure has shown individual beds running to a depth of 40 feet and the bottom was not then exposed. A channel has been cut into the beach spar by wave action following the higher stage of Lake Iroquois and by wind.

*Gravel deposits in Lake Erie.*

*Graceful beds of interdunal.*—The first spits that flowed from the beach into the lake after the moment when the waters of Lake Lundy fell and early Lake Iroquois was formed sound...
the drift from their beds vigorously and began to build deltas where they entered the lake. But the lake waters below the outcrop were then falling at a competently rapid rate, so that the streams did not succeed in moving the true delta that built the limited gravel bars. The most notable results of this process may be seen along the course of the Capitol spillway. Mr. Gilbert mapped the gravel bars and found the highest one in the east end of Capitol at an altitude of about 520 feet above sea level and four miles to the southwest. The lowest one being about 100 feet below. North of Lockport two such bars were found, one on each side of the exit from The Gulf. The bars, so far as observed, are in some part largely of coarse, partly subangular material eroded from the drift-foreset beds parallel to the streams.

In 1863 excavations on the Iroquois spit in Lewiston showed several feet of rather fine beach gravels and sand, and at the bottom a bed of some coarse rubblestones with gravel and coarse sand filling that forms the torrential bars and the bars in the old channel near Niagara Falls. But the deposit was not exposed on the surface and so is not mapped. The deposit is quite unlike beach gravels and is probably laid down by the initial torrent and afterward covered over by the gravel of the Iroquois beach.

Gravel bars in old channels of Niagara River.—While the falls were below The Whirlpool the river above that point was flowing in a shallow channel, like that in which it now flows from Buffalo to Chippewa. This channel is now in drift, and in the cutting process the fine material was washed out and carried away while the gravel was formed into bars. There are not many such deposits in the old bed of the river, but some small ones are well known because of the fossil shells that have been found in them. These gravel deposits are shown on the map of the river. It was caused to occur on both sides of the old channel just south of The Whirlpool, another on the Canadian side south of Eddy Island, and two on the Middle River. The bars 1500 to 2000 feet south of Hubbell Point, on the Canadian side, is larger and well defined. It is about 700 feet long and 300 feet wide and is composed largely of coarse material including subangular stones a foot or more in diameter. An excavation indicates a depth of at least 6 or 7 feet. The filling between the larger boulders, is gravel and course sand, and it is in this filling that the fossil shells are found.

Much the largest of the gravel deposits connected with Niagara River occur on Great Island, in Prospect Park, and in the city of Niagara Falls, N. Y. Gravel bed covers about two-thirds of Great Island—the whole of its west end and its south side eastward to the Three Sisters Islands. The common portion of the deposit is at the upstream or eastern part of the island. The coarse rubblestones, with filling of gravel and coarse sand, characterise this part and are well displayed in a pit newly opened east of the park commission's barge. Toward the west, the surface of the deposit is slightly lower and the gravel is finer and more even in grain. Near the west end it is 10 to 12 feet deep. The gravel shows in the top of the bluff in the south and west sides of the island. Gravel has been taken from a huge pit a little back from the south bluff, but the pit is now used as a ground for rubbish. The gravel was well displayed there in its full depth and may still be seen in the north, east, and west ends of the pit. This pit was the richest of the Niagara localities for fossils. Gemberg, who has a list of Quaternary fossils of the Niagara region compiled by Mr. F. J. Battelle, including a total of 31 species from seven localities. A greater number of species (28) were found on Great Island than at any other place. The localities given are Great Island, Prospect Park, Queen Victoria Park, Mudly Island, The Whirlpool on both sides of the river, and Foster Flats. The list is as follows:

<table>
<thead>
<tr>
<th>Localities</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospect Park, Queen Victoria Park, Mudly Island, The Whirlpool on both sides of the river, and Foster Flats</td>
<td>31 species</td>
</tr>
</tbody>
</table>

In general relations, composition, and structure the Recent gravel in Queen Victoria Park is very similar to that on Great Island, except that the west of the upper rapids is now almost obliterated by the park and power improvements and shows no good exposure for fossils, but it was formerly mapped by C. O. Coleman 4 who collected the following species at this locality some years ago:

<table>
<thead>
<tr>
<th>Localities</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospect Park, Great Island, The Whirlpool</td>
<td>31 species</td>
</tr>
</tbody>
</table>

By comparing this list with that of Mrs. Leteon, given above, it will be seen that Coleman reports five species not found in any of the other localities. All the other fossiliferous gravel beds at Niagara are older than this one, a fact which may account for the fact that the entire fauna is different.

**Fossil in Niagara gorge.**—The accumulations of talus at the base of the cliffs in the Niagara gorge belong to the Recent series in that part of the gorge which has been made in the Recent epoch, and in a less degree the older talus accumulations have grown larger in the same time. The talus is composed of great numbers of huge blocks of ice, all filled with finer talus material, partly limestone and partly sand. In many places the large blocks are covered almost entirely by the finer material. Under the American Falls and the northern part of the Horseshoe Falls the fine material has been removed and only the large blocks remain.

**Sea sand in Prospect Park.**—The largest deposit in Prospect Park and the city of Niagara Falls, N. Y. is the sea sand that covers the entire area, including Prospect Park and an area extending two blocks eastward. Here, as on Great Island, the gravel is covered by the eolian or upland part of the sea sand. The entire area is covered by this eolian or upland part of sea sand. The entire area is covered by this eolian or upland part of sea sand. The entire area is covered by this eolian or upland part of sea sand. The entire area is covered by this eolian or upland part of sea sand. The entire area is covered by this eolian or upland part of sea sand. The entire area is covered by this eolian or upland part of sea sand. The entire area is covered by this eolian or upland part of sea sand. The entire area is covered by this eolian or upland part of sea sand.
Two small antlions occur in the Rochester shale member of the Clinton formation in the bed of the "gulf" at Gasport.

Local fossils appear to be much more common in the comparatively soft and friable strata of the Quehecorn shale than in the harder limestones. Local buckling of the beds affecting a small area has been observed at several localities. In the bed of Six Mile Creek east of New Sharon occurs a Yonkamone one of the largest of these. The strata has given the shell the second floor a dip of 8°-10°. A broad, low antlions of small extent is exposed near the northwest corner of town at Somert.

A few small metal marks in the Quehecorn shale occur in the outcrop near Wilson. Two of the antlions are of special interest because they afford definite evidence as to their relative ages. The more recent one is situated above the crossing of the east-west road at the head of the Hopkins Creek cemetery. Here the stratum bed for a few yards dips into a second bottom, where it is continued as a ridge with about 2 feet of uplift. The over of alluvion is about 2 feet thick and has been lifted into a ridge corresponding to the course of the antlion. Where this ridge enters the flood plain of a later stage of the stratum it has been partially obliterated. Thus the date of the uplift is definitely marked in terms of creek-terrace history, having been developed since the terrace was formed but before the highest stage of stream erosion. As the stratum and the terraces are of postglacial age, the uplift is very recent. This antlions trend X. 25° W. and lies parallel to the canyon of the creek. It is probably a secondary rift of erosion, the removal of overlying beds permitting relief from compression to develop local archae.

The other antlion whose relative age is known has a very different character. It is located at Thirty Mile Point on Niagra gorge. This remarkable metal trends northwest and southeast. The waves have captured it with a cross section of the bed dipping at an opening at one end. The shales here are broken and form an abrupt v-shaped arch which is overturned landward. The overlying shale has been thrust toward the southern edge as a way to overlie and include in the resulting horizontal trough a packet of shelly field, as shown in Plate XIX. This arch can be traced for a distance of 30 and more miles along the lake bluff. All the features connected with this fold indicate that it is the result of pressure exerted by gneissic ice from the northerly direction during the glacial epoch.

Although the fold at Thirty Mile Point appears to be clearly the result of ice pressure, it is probable that most of the other features that have been observed are the result of local stresses in the strata. They have doubled or developed at different times, but all are probably of comparatively recent date.

Nets.—Folds occur in the softer rocks of this region, chiefly in the same beds that are affected by most of the local antlions. None of the folds show more than a few inches of throw. Like the antlions, they are not uniform of trend and are no doubt the product of special local stresses. Although very discontinuous, the fossils exhibit an interesting variety of occurrence in the different sections and in some of these there will be no antlions.

On the Lake Ontario shore north of Somersett a vertical trend N. 60° W. and has a throw of 5 inches to the northeast. Near Gay Creek on the Ontario shore a thrust fault is exposed in the shale. Its dip is about 25°, and the vertical displacement is about 30 inches. Near by another thrust fault dips in the opposite direction.

In the bed of Twelve Mile half mile or more above Wilson there is a small thrust fault which dips in the opposite trend N. 75° W. The vertical displacement is only 2 inches. Three thrust faults in the same vicinity are separated by intervals of 3 and 15 feet. Two of these trend N. 85° E. and the third cast and west. They dip 10°-50° N. and have throws of 3, 8, and 4 inches, respectively.

A group of four thrust faults with a total displacement of 13 inches occurs on the Lake Steel north of Somersett in close association with a normal fault. The thrust faults dip 76° N. 10° W. and the normal fault dips in the opposite direction and has a displacement of 2 inches. It appears evi dent from these faults that at some point the stresses have been effective in different directions at different times within the period of faulting.

Joints.—In common with nearly all indurated rocks the shale is covered with cracks which slope at irregular angles and are deepened by joints. In places in the Queeneen shale three extremely narrow vertical fissures are rendered conspicuous by greenish or light-colored bands, an inch or two wide, which mark their course across the dark-red shales. Such bands are well developed at the east end of the Leodin bridge. The cleavage of the red shale along these joint seams which traverse it at intervals commonly of a few feet is evidently due to chemical changes in the iron oxide enter of the water concentrically through joints in the rock. In other words the rocks are widely spaced in these shales; in others they are very near together. In the channel of Six Mile Creek east of Nassaugon 50 joints were observed in a space of 62 feet, the interstices having an average width of about 2 feet.

The Queeneen shales contain a system of joints with a general east-west trend which shows considerable uniformity in direction. A large number of observations made by Gilbert on the direction of the joints in the Ordovician rocks of the world shows that in most of them it falls within 10° east and west. They are therefore parallel with the general direction of the strike of the Paleozoic rocks of the region. In the limestones the joints are a potent factor in the dissection and erosion of the stratum. They are effective in this way by permitting the removal of their walls and by affording a chance for frost action. In quarry faces and cliffs exposure the widening of joint openings is as a rule beneficent, but the work done by them may be very effectively widened by solution. In the Lekport dolomites, which forms the Rapids above the falls, the joints, some of the veins of the fissures in the rock, which have resulted from the corrosion of the joint faces. The formation of these crevices along intersecting joints has to some place left cord-like masses of limestone, which stand above the limestone floor in the shallower parts of the rapids.

A few small coves have been produced in the Lekport dolomite to the enlargement of joints. One of these, a cove of a mile northeast of Lekport Junction, near the roadbed, is of cylindrical shape and has diameters of about 28 and 30 inches at the mouth, narrowing to 12 inches a few feet inside. A small spring issues from the cave.

Another small cave, known as Devil's Hole, occurs in the bed of the Niagara gorge at the outlet of Four Mile Creek. It is not sure the formation should be referred to the Ordovician or Silurian. Whatever of these possible conditions may have dominated, it is clear that these small caves are very unfavorable to animal life. It is highly probable that the Queeneen deposits were laid down at no great distance from the shore of a land which was slowly rising which, while no trace of in the sea the fine grained muds due to long delay of the land surface. Although the sea was shallow it did not fill with sediment and this indicates that the region apparently accounted for the sedimentation. Thus deposition and shallowing of the sea did not reach a stage which would permit the development of crosst bedding.

SILURIAN PERIOD.

The rocks formed from the white and red sandstone and muds which were laid down at the beginning of the new cycle of deposition exhibit a striking development of wave marks and horizontal strata, indicating deposition near the shore in comparative deep water. This course of events resulted in the maximum activity of erosion and sedimentation in this region. During the deposition of the sand which later hardened into the Albian sandstone the northern shore line of the Appalachian Gulf probably retreated to a more southerly position than it reached again before the class of the Silurian. If the Albian sandstone is in part the equivalent of the much scarcer Osmund conglomerates toward the east, as now seems probable, its material was probably derived from the west or northeast. The extreme decrease in the amount of sedimental materials from sand to coarse conglomerate toward an old land area of that time, which is represented by the Archean beds, points toward the land being a barrier.

The extreme scarcity of organic remains in the Albian sandstone compared with their great abundance in parts of the Silurian region, in which they were deposited, has led some geologists to deny its marine origin and to assume that it is a continental formation. The insufficiency of this kind of evidence is manifest, however, and it is considered that off some parts of the present coast line of Great Britain scarcely a single mollusk can be found, while in other more favored areas of the British was “part of a mass bed may have a population of 16,000 mollusks to every square foot.” It seems to have been true of the Albian age, as it is of the present sea, that “traces of sand when of great extent are unnoticeable in the spread and variety of aquatic forms of life, even as they are obnoxious to terrestrial creatures.” The Albian sandstone has a considerable extent in a general east-west direction, reaching westward across Ontario to Lake Huron, beyond which it is unknown and probably merges into shale, while toward the west it is apparently still present 60 miles and there to become a coarse conglomerate. It appears rather clear that in this region it represents non-marine deposits supplied by sediments derived in the Canadian and Adirondack highlands to the north and northeast.

The Albian sedimentation was followed by the deposition of soft mud and mud which then formed the lower part of the Clinton formation. This complete change in the character of the sediments may have been brought about by the derivative action of these desperately slow in the sea and the northeaidering of the shore line. At least deposition of land-derived sediments practically ceased for the time being in the part of the region where the sands and clay beds continued to be deposited, and the sands and clay beds then became the prevailing beds in the region. The new conditions also

* Forbush, Edward. Natural History of American Fossils, p. 44.
served to introduce a fauna much richer and more varied than that which characterized the Medina sea, and the deposit of limestone was produced largely by the accumulation of marine shells accompanied by the precipitation of lime. Farther east in New York, however, the sea was not so clear, and in some areas, as at Clinton, N. Y., made somewhat similar to those that grew in the assumed Pleistocene sea of the Alban group.

After the deposition of lime mud which consolidated into about 24 feet of limestone, blue argillaceous mud was spread over the surface of the sea. The previous epoch of deposition, the Ararat, had taken 8,000 feet. The accumulation of lime mud, which was not only affected by the sinking of the adjacent land areas to low relief, for the sea again became free from silt and sandy sediments, while calcite and magnesium silts appear to have been equally abundant, and about 200 feet of dolomite represents the settlement of the following Lepanto epoch. Life was abundant where the conditions favored it, and a thin bed of nonmagnesian limestone accumulated at the base of the Lepanto is crowded with organic remains, whereas the relics of animal life, except comites, are very scarce in the overlying dolomite formation. The appearance in Lepanto time of the Gulpian fauna, which, in the extraordinary thickness of the shell of its mollusks, has no parallel in Paelolocene or Tertiary seas, is significant of the automobile and evolution of the shellfishes of at least the northern portion of the Appalachian gulf, for marine zoogeographers have shown that thick series of contemporaneous shells exist primarily as a protection against predaceous enemies but not against the action of the waves. If the physical history of late Lepanto time is interpreted in the light of this biological fact the conclusion is reached that the Sinian sea in western New York was so shallow that its bottom was subject to an intensity of wave action which made it impossible for the formation of but few marly shells, and only heavily armored creatures as the mollusks of Gulpian time. These animals came into this area only sparingly, although they were abundant in an adjacent area of the sea to the west.

The close of Lepanto settlement was marked by the return of calcite sedimentation and the appearance in the sea of a coraliferous fauna (the Silurian) which bears little or no resemblance to any fauna that preceded it. At about the time of the appearance of this fauna the sea water acquired a high degree of salinity and the nearly complete disappearance of life from the sea during much of the middle portion of the Silurian epoch was probably the result of the increase of the salinity beyond the point that would permit marine life. This condition was brought about by elevation of the outlet of the Appalachian gulf whereby it became nearly landlocked.

The Silurian was characterized by the deposition of vast quantities of calcareous and dolomitic rocks, which now form a large part of the present area of outcrop of the formation. Several theories have been proposed to account for this localization of the area of deposition of rock salt, but the cause appears to be that the water near the shore of the nearly landlocked Silurian sea was diluted to such an extent by fresh water coming in from streams that salt was precipitated. In the general region of the Niagara quadrangle the nearest land was not far away on the north and the quadrangle probably lay in the brackish-water zone. The deeper and more saline part of the sea, where the water was not much diluted by incoming fresh water, lay to the south and southeast, and in that part of the sea the salt beds were formed and the great deposits of rock salt occur to-day. In the later part of the Silurian epoch, however, the salinity seems to have decreased, because the sea bed again became more fossiliferous. After a short interval, in which the magnesium linestones of the Cobeck Formation were being deposited, sedimentation was terminated by an elevation of the sea level, by which it was covered, and the emergence terminated the Silurian period in this region and the land seems to have persisted through Helicen and most of Ordovician time.

DEVONIAN PERIOD.

During the early part of Devonian time this immediate region was a land area, subjected to disintegration and subsidence or erosion. After the reemergence of the land and the return of marine conditions, the sea was shallow and the great sill formed by the Onondaga sediment was spread over most of the entire land area. Next followed a long period during which silts and sandchie were not deposited in this part of the marine fauna, in part forming extensive coral reefs, occupied the sea floor, and the calcareous sediments which are now included in the Onondaga limestones were deposited. This sedimentation terminated the fourth and last great cycle of Paleozoic time. In the Onondaga epoch was followed by a long period of deposition of carbonaceous and argillaceous silts with minor layers of sand which showed a strong surface wave action, and the surface wave action, forming a large proportion of the Champlain and indicating increasing erosion on near-by lands. The uplift to which this increased activity of the streams was due, may have occurred in actual emergence of the sea bottom at the end of the Devonian, but it is nearly certain that the sea in which the lower formations were laid down extended over this immediate region, for they outcrop a few miles south of the quadrangle.

CARBONIFEROUS PERIOD.

It is not known precisely when this region emerged from the sea for the last time. The rocks of southern New York were no doubt laid here during the early part of the Mississippian epoch and again after that epoch, that from the unconformity now seen in the rocks of that time in the southern part of New York may be as old as the Pennsylvanian epoch, however, no means of determining whether the Niagara quadrangle was submerged between these periods of erosion. It is also a matter of great interest that the lower formations of the Pennsylvanian epoch now covered the quadrangle, although not far to the south the land was submerged and coarse deposits of land waste were formed. The clay and silt deposits of the coal seas, however, are composed of clays, siltstones, indicating strong erosion of near-by lands, rapid currents, wave action, and irregular distribution of currents. During this epoch the region was covered by the vast swamp in which coal plants grew luxuriantly and which now constitute the great coal fields of the northern Appalachians. In any event, this entire region was uplifted at the end of the Paleozoic era in consequence of the general period of Appalachian uplift at that time and did not again receive deposits of near-by lands that took place earlier in the Niagara region than in southern New York.

MESOZOIC ERA.

Throughout the whole of the Mesozoic era the region appears to have been a land surface undergoing erosion. The record of that time is therefore wholly physiographic and is necessarily fragmentary. So far as it has been deciphered it is briefly as follows: At first the land must have stood well above sea level, as to its probability it was considerably elevated during the great uplift that affected the whole of the Appalachian province near the close of the Pennsylvanian era. Although in certain parts of the region certain evidences of greater elevation are shown by the uplift, the strata in this area were not greatly deformed and the same is true of the surface. Practically nothing is known of the structural history or of certain general considerations lead to the inference that the land surface had a general slope northward from the axis of uplift, except that it would be highly irregular, with some depressions flowing northward and northwestern, although their ultimate point of discharge is not known. As a result of long and continuous erosion the region was reduced to a nearly featureless plain lying but little above sea level. There is good evidence that the entire region was so reduced at least once during the Mesozoic era, if not several times. The time of formation of the peneplain is not certainly known, but the best evidence available indicates that it was completed near the close of the Jurassic or the beginning of the Cretaceous period. No portion of that peneplain remains in the immediate neighborhood of the Niagara quadrangle, but it is recognizable in the nearly level surfaces on the interior in a large part of the Allegheny Plateau.

By a subsequent uplift of the region, possibly accompanied by a further slight normal movement, the surface erosion was greatly accelerated and the rejuvenated streams again began to cut down their valleys and reduce the general altitude of the surface. In this cycle of erosion all the regions north of the Portage escarpment was reduced to a new peneplain, represented by the nearly level surfaces of the present Erie plain and the Canadian Shield. A study of the physiographic development of the Niagara region has not progressed far enough to make it certain whether the Erie and Huron areas were formed in a single cycle of erosion, or whether they represent two peneplains. It is certain, however, that the present surface of that region may have culminated or nearly reached the crest of the Niagara escarpment from then on, it was a long time before the region was covered with a deep mantle of glacial drift. Such were the conditions at the time of the first Pleistocene epoch.

Quaternary Period.

PLEISTOCENE EPOCH.

klamath glaciomer.

At the beginning of the Pleistocene epoch the general region of the Niagara quadrangle must have presented much the same bradial physical features as at present—that is, it consisted of several somewhat dissected but nearly level plains, arranged in a series of terraces or steps descending northward and separated by low undulating, occasionally elevated or dissected areas. The surface differed from that of the present time, however, in a number of important details. It probably stood several hundred feet higher above sea level, the relief was notably more pronounced and the dissection of the surface more general, the drainage pattern was a long-established one inherited from previous erosion cycles, there were no glaciers and areas of snow, and the region, and the surface was generally covered with a deep mantle of denuded rocks. Such were the conditions at the time of the first Pleistocene epoch.
one of the earlier ice sheets invaded the Niagara region, though it is not possible to determine which one and there is some indication that the early ice sheet may have been somewhat more than one. The early ice sheet left a deposit of till, remnants of which are preserved in the region and have been described in this folio under the heading "Stratigraphy." In a few places evidence of the effect of this ice mass have been preserved on glacially scored rock surfaces beneath the older till. These strie together with the glacial polish on rock fragments in the old till, suggest the general source and direction of movement of ice as those of the Wisconsin glaciation. The existence of old drift, regarded by Leavitt as possibly Kenyon in age, on the west rim of the Niagara escarpment almost directly south of the Niagara quadrangle would seem to indicate that ice advanced at least that far. If so, its general effects, especially the partial obliteration of relief, the rejuvenation of drainage, and the formation of glacial lakes, must have been nearly if not quite as great as those of the later Wisconsin ice sheet. Evidence of such changes, however, has been mostly obliterated.

INTERGLACIAL STAGE

The earlier ice sheet eventually disappeared from the entire region and an interval of considerable length elapsed before the beginning of the invasion by the Wisconsin ice sheet. How much of Pleistocene time is represented by this interglacial interval is not known, but it must have included at least the equivalent of the Pleistocene interglacial stage. No indications of it have been found in the quadrangle other than the existence of the two drifts of different ages. At Searboro, near Commerce, is an extensive series of interglacial sand and gravel, presumably formed during this time and containing remains of plants which indicate that the climate was somewhat milder than at present. Vegetable remains found in a deep drift of the Whirlpool-St. David buried gravel have been regarded by some geologists as of the same age as those at Searboro, but there are reasons for believing that they are of later date. There is some difference of opinion regarding the origin and date of the cutting of this buried gravel, but the interpretation that seems most in accord with all the facts makes it of interglacial age and assigns it to the interglacial stage preceding the Wisconsin ice invasion. According to this interpretation, when the gravel had been cut back from the Niagara escarpment at St. David to the south side of the Whirlpool by a pre-Wisconsin Niagara river, its volume was greatly reduced until the advance of the Wisconsin ice sheet closed the outlet of Lake Ontario and raised the waters so that they flooded the Niagara region.

Origins of the Whirlpool basin and the Whirlpool-St. David buried gravel—It has long been recognized that the rock basin of the Whirlpool is older than the rest of the Niagara gneiss and has had a different history. It is a drift-filled gneiss of pre-Wisconsin (probably interglacial) age, and its course is shown on the geologic maps. The walls on its east and west sides are rock cliffs, like those in the gorge immediately above and below, but those on the north and northwest sides, from the top down to an undetermined depth below the water, are composed of drift. Fragments of the rock cliffs on the two sides run a smooth curve from the Whirlpool, showing the direction in which the buried gravel extends. Bowman Creek descends from the upland about a mile to the northwest and has cut a deep ravine in the drift. It lies mainly along the western side of the buried gneiss, for the western rock wall is exposed in the ravine for some distance.

South of the village of St. David there is a strongly marked escarpment in the front of the Niagara escarpment, the head of which shows no rock for about a mile but in a steep and much gullied slope of drift. This place is an almost direct line with the prolongation of the old cliff lines at the Whirlpool, and the rock gneiss undoubtedly extends through to the break in the escarpment south of St. David. A point terminal moraine crosses its northern part and forms the highest part of the filling. At the Whirlpool the old gneiss is 1875 feet wide at the top of the rock cliffs, 1950 feet at the top of the drift bluffs, and 1200 feet at the water line, and it extends 2 miles northwest from the Whirlpool.

The greatest depth found in the Whirlpool by Spencer was 126 feet, near the middle of the pool. A boring in the drift filling of the old gneiss was made by Spencer at a point about half a mile northwest of the Whirlpool. At a depth of 2039 feet difficulties were encountered that stopped the work before rock was struck, but the old channel is probably deep as the Whirlpool and the deep drift is probably a true glacial channel that was probably formed on the pre-glacial scar appeared. Above the point Bahrain sandstone is shown on the geology map. North of the electric railroad embankment, glacial strie and polished rock were found on the west wall of the gorge below the top, showing clearly that the gneiss was occupied by a portion of the ice sheet before it was filled with drift.

Those geologists who regard the buried gneiss as pre-glacial age attribute the widening toward its mouth south of St. David to embayment weathering and erosion during a long period in pre-glacial time. But the widening is now as it has been estimated and at least a part of it on the west side is due to glacial erosion. There are other reasons why the Reversion of Regions to Ice.

The direction, strength, and loudness of the movement are simply attested by the glacial markings. The axes of the elongated gneiss are almost 8° W. by 28° S. of the northeast corner of the quadrangle. Near the meridian of North Wilson the ridge makes a southeasterly head of about 13°, which gives an angle of 19° between the axes of the gliess and the direction of ice movement. On this course the ice met the Niagara escarpment obliquely. The trend of the large fillings that begin at the tip of the escarpment and run 300 yards or so to southwestward is nearly the same as that of the axes of the till ridges below the escarpment. The axes of the drumlins and the mounds south of the Niagara escarpment trend generally 8° S. W. by 28° S. and also record the deep ice current. They do not appear to have been affected noticeably by the direction of the northward movement of the thin border of ice during the later building of the slender mounds of the immediate region. The direction of the ice movement and its effect on the relief of the surface are also recorded in the trend of the great fillings in the surface of the Queenston shale now covered by drift, and in the northeast or southwest courses of many of the smaller streams. The other wide distribution of fillings shows the breach of the central body of the current, for on the Ongunqua escarpment 2 miles southwest of Akron fillings nearly as fine as those in the Pekin quartzite trend 8° S. of W. The locality is 20 to 25 miles southeast of the central axis of the current, and 200 feet above the general level of the plain where the central axis crosses. The whole area of this quadrangle lies in the path of the main current.

Not until the ice front had retreated a long way from its forth position and the Lake Erie ice lobe had sloughed back into the northeastern part of the lake basin did the direction of ice movement in the Niagara region show any notable change. Only then did the local elements of the land relief begin to be controlling factors in the ice movement. Two features—the basin of Lake Ontario and the Niagara escarpment—controlled, more than any other, the movements of the thinned ice sheet in the region and shaped the outline of its front. By the time the ice front had retreated nearly to Buffalo it had taken on its pointed outline, as shown by the position of the moraines in the accompanying map of the region (fig. 8), and had become a broad, gently rounded lobe. As the ice front retreated further and approached the Niagara escarpment the lobe grew still less rounded and its front became roughly parallel with the escarpment. When the ice front had retreated nearly to the present shore of Lake Ontario, its edge was moving in a direction nearly due south, as shown by the moraines. The ice edge was thin south of the escarpment during the building of the slender mounds and its sorting was continued till the trend of about 8° S. W. then narrowed to direction normal to the moraines. In the Pekin and Akron quarters light strie of late date trending more nearly south than a trend of about 8° S. N. and N. E. direction, however, is more westerly in places near the Niagara escarpment than might be expected from the late date of the moraines; probably because of the close proximity of the deep basin of Lake Ontario, for when the ice front was still south of the Niagara escarpment the deep basin of Lake Erie was behind it, and the ice front was not parallel to the escarpment on the Lake Ontario basin. This dominant motion gave the narrow border strip of thin ice a rather strong component of westward motion, its building being the axis of Lake Ontario basin. This dominant movement gave the narrow border strip of thin ice a rather strong component of westward motion, its building being the axis of Lake Ontario basin.
of recession the Lake Ontario ice lobe had become sharply defined and was spreading in all directions from its central axis toward the sea, the direction from which it came. At that time the ice was moving northwestward over Toronto and its north few miles farther out. (See fig. 8.)

The Lake Erie ice lobe was nearly all submerged, especially on the eastern portion of the Huron plain, ice coating generally light or lacking. Both the limestones and the sandstones were well adapted to receive ice coverings, being both strong and resistant to pressure. The recent displacess of ice sculpture are to be seen in the quarries on the occurrences where the limestones have been freshly stripped, especially in the Pekin quarries in the limestone of the Clinton formation. Of almost equal interest are those in the quarry quarries, on the Lockport dolomite, and at the quarries 2 miles southeast of Akron on the sandstone limestones. Besides the markings on the three limestones mentioned, striae and grooves are well preserved on some of the ledges of the Albian sandstones, where its former course is indicated. There have also been found on hard argonaceous lenses in the quartzite shale.

In the three large quarries mentioned the display of glacial markings is at times most confused, but it varies from time to time with the progress of quarrying operations. Besides polishings, fine-line strie and other markings of the lighter sort, all three of the quarries have shown good examples of large flutings. In the Pekin quarry several of the larger flutings 4 to 6 feet wide and 5 to 10 inches deep were visible in 1911. One showed a well-marked curvature, converging, bending from 82° W. to 84° W. The trend of the flutings ranges from 33° W. to 87° W., and that of the strait and grooves from 47° W. to 84° W., with an average of about 56° W. The latest strait, which are rather light ones, tend more northly and cross the hollows of the flutings without descending into them. The flutings and deepening grooves and many of the strie evidenced belong to the time of thick ice, and the lighter markings, which have a more southerly trend, appear to have been made beneath the thin ice of the closing stages of the recession.

In the Pekin quarry the ice scarring was heavy on the base of the escarpment but diminished rapidly back from the edge. Near the edge and for 30 to 100 yards back the scarring was mostly heavy, smooth, and free from weathering. Farther back deep weathering along joints which were much widened and filled with dark-red residual clay and sand increased, until at the southern edge of the strait and grooves there was nearly any ice-worn surface, but instead a deeply weathered and stained surface, homogeneous with weathered joints to depths of 2 feet. That part of the surface was mostly free from striations and interestingly accomplished before the Wisconsin glaciation and in all probability long before, for at the west end of the quarry 4 to 5 feet of strait and grooves, partly of pre-Wisconsin age, uncovered glacial surface.

The phenomena in the Quarry quarries are much the same as those at Pekin. The rock surface, however, was more uneven and there were troughs 5 to 10 feet deep, one of them relatively narrow and winding, like those formerly seen on Kelly Island, in Lake Erie. In a part of one of these there was a considerable mass of old, hard till, clearly of pre-Wisconsin age, overlies a small body of fine sand. The direction of strie in this quarry is 42° W. to 51° W.

In the quarry southwest of Akron several flutings nearly as large as those in the Pekin quarry trend 60° W. to 88° W., and the trend of the strait and grooves 82° W. to 85° W. The stripping showed weathered joints much as those at Pekin but not so deep. The drift covering was only a foot or less, the rock possessing a variable hardness. The general or average direction of strie and also of drumlin axes in the quadrigale is about 88° W. Wide departures from that direction are rare and are generally accounted for by some local peculiarities of relief. Along the base of the escarpments the strie generally trend more nearly west, but even slight depression in the general surface causes them to turn more nearly south. In Bowmann's, north of the electric mill, strie on the west wall of the gorge below the top follow the course of the wall southward. Because the flutings described above, certain parts of the Niagara escarpment are characterized by furrows which are much wider, deeper and larger.

The part of the Ouachita escarpment within the quadrigale shows the same sort and nearly the same degree of modification by glacial erosion as that in the Ouachita M. from the fact that the analyses of the soil are generally accounted for by some local peculiarities of relief. Along the base of the escarpments the strait generally trend more nearly west, but even slight depression in the general surface causes them to turn more nearly south. In Bowmann's, north of the electric mill, strait on the west wall of the gorge below the top follow the course of the wall southward. Because the flutings described above, certain parts of the Niagara escarpment are characterized by furrows which are much wider, deeper and larger.

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The lake was in reality only an expanded portion of Niagara River, the volume of which was relatively so large that fine city in suspension was entirely carried further on and only silt was deposited on the lake bed. The lake stood at its highest level and made its principal shoreline line early in its history, and probably most of the deposit on its floor was laid down at that time. The material was derived largely from the drift through which the river had been cutting a channel between Buffalo and Detroit. Temporaneous spillways to Lake Erie.—At first Lake Tonawanda discharged through five outlets, three of which were in the Niagara quadrangle. (See fig. 11.) That the volume of the river was large at that time is shown by the fact that large streams flowed through five of the outlets, one only—that at Cooperstown—being small. The Cooperstown spillway was largest, that at Holland was next in size, that at Lockport third, and that at Medina fourth. Although the streams were probably rather deep at first, after equilibrium had been established they were not more than 2 to 4 feet deep. Hence a slight fall in the level of the lake stopped the flow through all but the Lewiston spillway.

The short gorge made in the escarpment throw light on the volume and duration of the streams. Those at Lockport and Cooperstown are described under the heading "Topography." At first, when its volume was greatest, the stream that flowed through the gorge now occupied by the Erie Canal went both northeast and northwest from Lockport, but it finally settled in a northwestly course. At Holland and Medina the occurrence is low and consists of two cliffs, indicating that at each place there was a low fall or a rapids rather than a cataract. Each of these gorges is about 15 miles long and 90 or 90 feet deep and is cut in shale with Albion sandstone as the coping layer. At Shelby, 2 miles south of Medina, a gorge about half a mile long and 50 feet deep is cut in limestone. In the first course of this distributary a considerable stream flowed westward from Shelby across the flat divide and thence northward past Shelby Basin. In all the spillways of Lewiston the mouth of the stream is the mouth of the the Clinton formation or the Queenston shale, with either the limestone of the Clinton formation or the Albion sandstone as the cutoff layer. At Medina the stream was about half a mile into the Lockport dolomite, which at each place was relatively thin. It is almost certain that in some of the spillways, especially in the escarpment at Lockport and in the Cooperstown channel, there was an earlier small rivulet. The short gorges of the spillways east of Lewiston indicate a relatively brief existence for the streams that made them. Their general basin- ness in magnitude seems to show that all were made in about the same period and ceased at the same time.

Lewiston spillway.—The fact that the Lewiston spillway finally became the only outlet makes it probable that it was from the beginning the principal one. Its remnants (Qnc) are shown on the Niagara gorge map. It had two headward branches which united near Devil's Hole. The eastern branch headed in Tonawanda Lake in the eastern part of Suspension Bridge and flowed northwest and then northeast following the present course of Bloody Run. The western branch headed also in the lake in the vicinity of Goat Island and Niagara Falls and flowed northeast and then southeast, following Niagara River. The bend of the Bloody Run branch is about 1000 feet wide and 7 or 8 feet deep. The faint shore cliffs of Lake Tonawanda ending here are well marked. From its head it runs northward across the New York Central rail- road yards, where it turns northward and widens to nearly 3000 feet by its mouth, which is about 1000 feet a short distance south of Devil's Hole. The shore cliffs of Lake Tonawanda lead into the city of Niagara Falls, N. Y., and near the mouth of the western branch of this spillway was a point at a little south of Hubbard Point. Part of the original channel shows on the west side of the gorge from a point north of the Clifton House to Hubbard Point and on the point opposite, but from this locality nearly to the channel at the mouth of the river. The Whirlpool bed of the early spillway is well defined on the west side but is not developed on the east side. Beyond the Whirlpool the river of that time expanded to a width of about 4000 feet at Wintertree Flats but narrowed somewhat 1000 to 1500 feet beyond the Bloody Run spillway. From that point to the place this line had a helical expansion more than a mile wide and 11 miles long. This part of the river was shallow, its current being a flat band of deposit dolomite. At the mouth of the north side of this expansion the river made a narrow passage through the Barrie moraine before it leaped over the escarpment.

Hornblower represents the first change of the Lewiston distri- butary, uncoupled a shallow, fan-shaped basin about 1 1/2 miles wide. It is shown on the sketch map (fig. 14) as the Gut- arnet Basin. It is encountered wholly in drift and includes the site of Queenston and the greater part of Lewiston. The old drift bluffs forming its east and west banks are 30 to 50 feet high. The distributary first plunged toward the north-northeast, but in its later flow the river bitted the basin unmysteriously, passing out north-northwestward.

Old channel of Niagara River.—Clarity distinguished from the original Lewiston spillway are the remnants of the old channel of the main river made after the abandonment of the other spillways. This old channel is the bed that the river occupied at each locality until the falls reached that point. It lies mainly within the Lewiston spillway and at a lower level, but its course is higher and more meandering and nowhere easily succeeded to be followed. North of Foster Flats this old channel of the main river is not clearly distinguished from the new flume channel, but at the mouth of the interstream Flats and fortun- ately the river is known to be in two branches close together south the distinction is clear. The old channel is well developed just north of The Whirlpool and south of it, and also on the west side of the gorge from The Whirlpool to the railroad yards. South of Hubbard Point the remnants of the channel are confined mainly to the city of Niagara Falls, N. Y., and Goat Island. The great beds and scoured rock and stony till surface of the New York Central railroad station and the gravel and stony till surface on Goat Island are parts of the old river bed. A narrow strip on the west side of the gorge south of Hubbard Point and probably including the gravel bar north of the International Bridge is another part, but the bottom of the abandoned river bed on the west side is of later date. These old remnants are labeled Qnc on the map of the gorge.

At Lewiston a fragment of old river bed extending from the sandstone terrace north of the bridge to the north end of the gravel pit beyond the railroad station is certainly more recent than the escarpment basin and in all probability corresponds to some part of the old river channel above.

During its stages of reduced volume the river tended to erode in a narrower bed and the work done then may have had some influence on the later flow where the volume was large. In some places it may have made a narrow, deeper channel which at a later time come to be a deep place on the crest line of the falls, determining the place of the gorge and accelerating the rate of recession of the falls. There is some reason to believe that this occurred at the narrow at Swift Deft Point, about 1000 feet north of Hubbard Point, where, as Spencer has pointed out, the original channel crossed a col with a short but rapid descent to the north.

Glacial Lake Iroquois.—The history of the earlier stages of Lake Iroquois has not yet been satisfactorily worked out. That the lake waters fell from the lower level of Lake Lanoie to the edge of Lake Iroquois seems certain, but whether that first level was at the Newfane shore line or at some lower level is uncertain. Some features noted in Ontario have suggested to several authors the middle period of its existence. There is, however, a possibility that the observations have been mis- interpreted, and furthermore the interpretation suggested introduces difficulties that seem to be insuperable.

The Newfane bench records the lowest level of the lake of which there is evidence in the Niagara quadrangle. At that time the shelf was on the level of lake Iroquois probably early in its history. Some of the observations, if accepted, seem to indicate that the lake was completely drained for a time to the north or middle part of its existence. There is, however, a possibility that the observations have been mis- interpreted, and furthermore the interpretation suggested introduces difficulties that seem to be insuperable.

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and tilted the lake basin southwestward. As a consequence the water level was raised on the south side of the lake to the line along which the mouth of Lake Inajo was formed and the choir wall which spanned the St. Lawrence Valley somewhere below Kingston and held Lake Iroquois up to the level of the Rome outlet disappeared and the lake was drained off. This lake in the Lake Ontario basin fell to a level somewhat lower than the present level of Lake Ontario. The land then stood so low that an area of the counties known as the Champlain was extended up the St. Lawrence Valley to the lake, but the marine stage was comparatively short. An uplift of the land near Kingston caused the outlet of the lake above sea level and the present Lake Ontario was formed.

RECENT SPOIL.

The exact time of the beginning of the Recent epoch has not been established, but for convenience it may be regarded as having begun with the final disappearance of the ice from the Great Lakes region. As explained earlier, this event is recorded in the Niagara region by the diminution in the volume of Niagara River on account of the opening of the Niagara outlet and the diversion of the discharge of the upper three lakes to the St. Lawrence by way of Ontario River. This was after the draining of Lake Iroquois and probably during the marine stage of Lake Ontario.

Since that time additional southward-tilting of the land surface has taken place, which has affected the Niagara quadrangle. The outlet of Lake Ontario was raised, causing the lake level to rise, and because of the tilting the rise was not uniform throughout the lake. This rise of the water accounts for the lowering of the lower courses of the streams entering the lake. The tilting also closed the Nipissing outlet and restored the drainage of the upper three lakes to St. Clair River, thus greatly increasing the volume of Niagara River, which since that time has gone on cutting vigorously and forming the wide open valleys of the gorge. Still another effect of the tilting is the lowering of the lower courses of streams entering Niagara River above the falls, owing to the rising of the rock all along the maximum length of the falls, which decreases the height of the water in that part of the river. In addition, the modified volume of the tributaries flowing around Grand Island, diminishing the out branch and increasing the west branch. The southward-till of the land is also recorded in the present position of the old lake basins, which are not now level but rise northward. This is true not only of the basins of which portions are found in the Niagara quadrangle, but also of earlier glacial lake basins in the region south and east of Buffalo, the tilting of which has been ascertained by Fairchild to be in a direction a little west of south and to amount to 2.5 feet per mile. The beaches of Lake Landy and of Lake Tonwanda are so poorly developed and so fragmentary that the amount of tilting is not easily ascertained, but a number of observations give fairly harmonious results agreeing closely with those obtained by Fairchild. The Iroquois beach has a general east-till throughout the Niagara quadrangle and the amount of southward tilting can not be measured. It is not known, however, but it is probable that it is less than 1 foot per mile. The Iroquois beach, however, is much less than 15 feet beneath this limnose. This follows rather slowly and slowly sandstone of the Alliion formation for 50 to 90 feet below the surface of the pool, beneath which is another sandstone layer (Whitpool sandstone) 25 feet thick. This in turn is 300 feet or more of soft sand and shale (Queenston) extending below the bottom of the pool. Thus a massive layer of hard, compact limonite overlies several hundred feet of relatively soft sandstones containing a few thin layers of hard rock.

At first the blocks are angular, but even after they become rounded and although they are themselves worn away in the process, they may not entirely lose the fact that the depth of the water is greater than the height of the falls.\n
This is the brink of the gorge is an overhanging ledge projecting far out over the rolling rock wall. Whenver a block falls from the brink it contributes to the lengthening of the gorge at the top and at the same time supplies a new ledge for the process to continue. With each block of rock from the brink the supporting wall behind the falls is fractured with new vigor and the lengthening of the gorge proceeds with greater rapidity. This process has resulted in the making of the whole gorge from Lewiston to the Horshoe Falls, except the basin of The Whirlpool, which is older and is really an eroding basin.

From the foot of the falls the surface of the river descends 100 feet to Lake Ontario, but the strata rise about 140 feet from the falls to the Niagara outcrop. Thus it happens that the relations of the strata to the contours were different at the outcrop from those now seen at the falls. A stratum which is only a few feet above the water at the foot of the falls is nearly 200 feet above the water at the mouth of the gorge. Owing to the southward dip of the Lockport dolomites and in the beveling it has been reduced to a level fair to the level of the river. From the point Lake Tonwanda was drained, although the broken part of the river above Goat Island might be regarded as the last surviving remnant of the lake.

Significance of gorge character.—In considering the changes of the gorge and in its significance in the history, the most important elements are the top width and the depth. By noting these dimensions in the different parts of the gorge and determining the length of those sections which are characterized throughout by particular values of these elements, the principal periods of action of the chief forces involved in the making of the gorge can be determined. The dimensions of the gorge are well shown on the large-scale map and it is evident at a glance that there are at least four divisions (not counting The Whirlpool) characterized by important differences of width and depth and both and ranging in length from less than half a mile to 2.5 miles. A fifth division is recognized with difficulty and is not so well marked. In all of them there are other slightly less prominent characters which also suggest a possible subdivision, but these are not so clearly defined and their value and significance can be determined only when the bearing of the lake history is taken into account. These sections of the gorge are illustrated in Plates VI to XVII.

The top width of the gorge is the result of several different factors. Some of these are affected by weathering, which causes cliff recession and the formation of tunnels. Some of these factors are affected by the weight of the water and the pressure of the waves. In the narrower parts the bearing of the gorge is of the highest value, but in the older parts their significance is modified by a complicated history. Differences of geologic structure or lines of weakness in the rocks may have affected the dimensions of the gorge but certainly not to any great extent. The geologic structure is remarkably uniform throughout the face of the gorge and the thickness of the clays and sandstones is about the same for a few feet, but their effect is slight. All other factors, however, are negligible compared with the one which has been the great cause of the differences in the dimensions of the gorge—that is, variations in the volume of the river.

The Great Lakes, the rivers connecting them, and the St. Lawrence River in reality one great stream from northern Minnesota to the Atlantic. The lakes are in effect river.
voirs along the course of the streams, storing the water and equalizing the flow, and the overflow from the upper four lakes supplies Niagara Falls with nearly all the water that passes over them. Hence anything that affects the flow or level of any of these higher lakes, and therefore affects the discharge through Niagara River affects the falls accordingly.

Since the falls first began the upper Great Lakes have passed through five stages, each of which had a different effect on the discharge through Niagara River. These stages are:

1. Stage I: Initial stage of Lake Algonquin.
2. Stage II: Nipissing Lake stage.
4. Stage IV: Lower Great Lakes stage.
5. Stage V: Present Great Lakes stage.

During each of these stages, the water level and flow through the watershed changed, affecting the discharge through Niagara River. The period during which the upper three lakes discharged by another outlet and Niagara River carried only the discharge of Lake Erie, amounting to only about 15 per cent of the whole discharge of the four lakes. Knowledge of the late Pleistocene and Recent history of the upper Great Lakes is therefore necessary to an understanding of thesignificantly that the falls have undergone and to an interpretation of the characters of the several parts of the gorge.

Changes of drainage of upper Great Lakes—The first stage was that of early Lake Algonquin, which occupied the south half of the Lake Huron basin. The ice barrier spanned Lake Huron from side to side, as Lake Algonquin received no drainage from the Lake Superior and Lake Michigan basins. The volume of discharge was relatively large, however, for the lake received considerable water directly from the ice sheet. Its outlet was at Port Huron, whence it discharged southward through St. Clair and Detroit rivers to Lake Erie, and the volume of water passing through Niagara River was correspondingly augmented over that of Lake Erie alone. The volume of Lake Algonquin at that time was as large as, if not larger than, at present, but the flow over the Niagara escarpment divided into five streams, only one part following the channel immediately after the diminishing of Lake Algonquin.

During the second or Kirkfield stage of Lake Algonquin, although the lake was very much larger than before, the ice margin had retreated so that the water found an outlet past Kirkfield, Ontario, and down the valley of Trent River to Lake Iroquois, and the discharge at Port Huron ceased. During this stage, therefore, Niagara River carried only the discharge of Lake Erie, which was itself somewhat diminished in size.

During the third or Port Huron-Chippewa stage of Lake Algonquin, which occupied the basins of Lakes Superior, Michigan, and Huron, an outlet of the region on the north having changed the outlet from Kirkfield back to Port Huron and Chippewa, most of the discharge of the upper four lakes again passed through Niagara River. At first a considerable portion found an outlet at Chippewa into Illinois River, but the amount giving this way decreased later to a small fraction of the whole discharge. During the early part of this stage the discharge of the upper four lakes was probably at its maximum, for the effluents received directly from the ice sheet were greater than any other time. In the later part of the Port Huron stage the contribution from the ice had almost ceased and as there was still a small outlet past Chippewa the volume of discharges at Port Huron was probably slightly less than now.

At the beginning of the fourth or Nipissing Great Lakes stage the ice sheet finally disappeared from the north of Lake Huron, and all the waters of this lake with the exception of Georgian Bay flowed into Lake Erie. The Nipissing Lakes occupied the upper three basins, covering an area only a little larger than that of the present three lakes. The ice sheet having disappeared, no additional water was received from it and the volume of discharge of the upper three lakes was the same as that of the present St. Clair River.

The outlet, however, was continued from the northern part of Georgian Bay, past North Bay, Ontario, and down the valleys of Minto and Ottawa rivers. During this stage, therefore, Niagara River was again left with only the discharge of Lake Erie.

Continued upland of the land on the north mixed the outlet at North Bay, Ontario, and sent the discharge of the upper three lakes back to Port Huron and thence to Lake Erie and Niagara. This stage lasted until the outlet from the present lake was well above the surface of Lake Erie, and the flow from the remaining lake was divided between the two outlets, Port Huron and Georgian Bay. This change occurred at about the present level of Lake Ontario, and the deep lake opposite Queenston, too far north to have been scoured at the foot of the falls, was first formed at about the present level of Lake Ontario. This deep lake of Lake Ontario at least 150 feet lower than now. Great difficulties were involved in the explanation, and it seems more plausible that the hole was formed by the scour of the rapids when Lake Ontario stood only slightly lower than at present.

There is considerable uncertainty as to the character of this first falls. Some geologists believe that it descended in two or three, the upper from the edge of the Lockport dolomite, and the lower from the edge of the Hornblende limestone. It is also uncertain whether the depth of the river in this section is due to scouring at the foot of the falls or whether it indicates that the level of the escarpment was lower at the foot of the falls. There is also uncertainty as to the height of the water in the basin of Lake Ontario at least 150 feet lower than now. Great difficulties are involved in the explanation, and it seems more plausible that the hole was formed by the scour of the rapids when Lake Ontario stood only slightly lower than at present.

The problem of the correlation of the gorge sections and the lake stages is relatively simple. Five sections of the gorge, corresponding in character and sequence in the five lake stages, may be recognized. (See fig. 13.) The results of the investigations of G. K. Gilbert and the writer indicate that the correlation of the gorge characters with the lake stages mentioned above is complete. The Great Lakes have been studied and their history interpreted by J. W. Spencer, but his history of the lakes is somewhat different from that given here, his conception of the history of Niagara, which is dependent on the history of the lakes, is also somewhat different.

Influence of height of water in Lake Ontario basin—The height of the water in the basin of Lake Ontario also had an important influence on the early history of the falls and gorge. The height of Lake Iroquois and the succeeding waters in the basin of Niagara River has not yet been worked out. The extension of the scoured channel of Algonquin River (Spencer) from the level of the Iroquois to the point level of Lake Ontario has not yet been worked out. The volume of Lake Iroquois was so large that it may well have been a very low stage of Lake Iroquois early in its history, but no other evidence of such a stage is known. The water was entered in the basin immediately after the diminishing of Lake Iroquois, as the ice barrier on St. Lawrence River had melted away. The level of the marine stage is supposed to be marked by the Oswego Waterline. The Oswego dates under the present lake level at Oswego, but its depth below the present lake level in the western part has not been determined. The marine connection, however, was relatively shallow and was of short duration. Upshift of the land on St. Lawrence River east of Kingston soon shut out the sea and backed the water in the west end of the lake up to or nearly to its present level.

The United States Lake Survey charts show at the mouth of Niagara River a submerged channel known as Niagara Narrows, which has been supposed to be a deluge of the river formed when the lake stood at a somewhat lower level. As many years ago it was supposed to have been the mouth of the river under the present lake level at Oswego, but its depth below the present lake level has not been determined. There is nothing in the charts indicating a lower delta or a lower shore line.

Development of Niagara Gorge.

First section, or Lewiston Branch gorge.—The first section of the gorge extends about 3000 feet southward from its mouth at the suspension bridge at Queenston. (See fig. 14.) It is 1200 feet wide and nearly 500 feet deep to the bottom of the river, which is 120 to 150 feet deep. The floor of this section was formed during the existence of Lake Tonwanda, when the flow from that lake was divided, and during the first or early stage of Lake Algonquin. The entire one of the five distributaries of Lake Tonwanda, carrying about 25 per cent of the present volume of the river, then plunged down the escarpment in a great cataract which issued from a crevasse or a geysering of a deep pool beneath the falls.
The vertical height of the talus slope is almost universally 400 feet on the west side and 350 feet on the east side. The rapids have almost worn away the shale on the bottom and on the sides where it is exposed, and in nearly all of this section the upper part of the river is close to the east side. It seems probable that the depth of the section has been increased somewhat by wearing away of the rapids and the river bed may also have become somewhat narrower where it was cut down by the later small-volume river. When the recent tilting and raised the level of Lake Ontario a little, the water was backed up into this section, soaking the rapids somewhat and increasing the apparent depth and width of the river.

The ridge extending northward from the east edge of Wintergreen Flats was left as a narrow island or projecting point between the small gorge cut by this fickle side fall and the main bed of the river. It was entirely roofed of its water, leaving the old bed at Wintergreen Flats dry. The thickness of the water sheet and the high level of the water in the gorge are apparently sufficient to cut out the main cut from seeping deeply on the east and south sides of Wintergreen Flats, and it seems almost certain that the falls did not occur through the missing link in this section. The narrow channel of Foster Rapids has been more recently made by a second low cut plunging over the sandstone ledge.

While the falls were cut, the river at the university a side stream flowed northward over the wide, flat bed of the Lewiston spillway (shown as Que' on the map) and from that point to Foster Creek and fall into the river. In the recession which has taken away the older part of the revine which this stream made, but the part which remains has a floor of Ironquoniot limonite. The revine is about 75 feet deep and 150 to 200 foot wide and extends more than 400 feet back from the present gorge cliff. These dimensions indicate a rather small stream. It does not seem possible that the revine was made during the cutting of the Old Narrow gorge, when the volume of the river was small. The rock at Devil's Hole shows that Lake Tomaw-Mala was then high enough to discharge a small stream down the Budy Run distributary for some time after the main cut had passed the site of Devil's Hole.

Until the falls were cut, the level of Lake Iroquois continued to stand at its high level and the seeping power of the falls was slight, but Lake Iroquois was then drained and the water that had stood at the falls was higher than Lake Ontario fell probably at least 100 feet, increasing the height of the falls that much. At the same time the channel above the falls became more contracted, and the height of the deeper, narrower gorge, made probably at a slightly more rapid rate.

The reef which produces the sharp rapids at the outlet of The Whirlpool over its origin to the breaking away of the east wall of the old gorge of the buried Whitiment-St. David channel (described under the heading "Interchange stage") before the falls had time to wear out fully the rock in that section. When the break in the wall once, the lowering of the water in The Whirlpool must have been sudden, for the drift was easily cleared out of the old buried gorge. (See fig. 7.) Thus, waiving its cutting at the south side of The Whirlpool, the falls made the Eddy Basin before the volume of the river was reduced. The width and apparent depth of the Eddy Basin now stand and the depth of the deep part below The Whirlpool and also of the gorge above the railroad bridges; therefore the Eddy Basin is included in the Lower Great gorge.

This section of the gorge was made just before the final disappearance of the ice from the Great Lakes region. The recession of the falls in the making of the gorge went on without interception past the ill-defined line of separation between the Pleistocene and Recent epochs. The opening of the outlet at North Bay, Ontario, and the discharge of the Nipissing Great Lakes estuary marked the end of the life of the ice sheet as an ice dam in the Great Lakes region and the end of the Pleistocene epoch. For convenience the Pleistocene epoch may be said to have ended at that time, which is also practically the time when the ice sheet disappeared.

Fourth section, or Whirlpool Rapids gorge.—The fourth section extends from the sharp contraction at the south side of the Eddy Basin to the point of the railroad bridges along the railroad bridges. Its length is three-fourths of a mile. At the railroad bridges the east wall recedes at the top, producing a wide talus slope in place of the narrow slope to the north. Exclusive of this expanded part, the average top width of the narrow gorge is about 740 feet and the least width 725 feet. At the water the width is about 390 feet. Knowing these dimensions, the volume of the river, and the rate of flow in the rapids, Gibb calculated the depth of water to be about 35 feet. Spencer's soundings from the lower railroad bridge show a mid-stream depth of 96 feet and a shallowing toward the sides, but the water is there only beginning its descent and has not acquired its maximum current in the lower part of the rapids, where the velocity of the water is about 22 miles per hour. The narrowest point in the whole river is just below the Front Tennis Rail Road bridge, where the width is about 200 feet.

Great blocks choke the rapids on both sides and probably in the center of the river. Over the west side from 200 to 250 feet wide and, being on the inner side of the curve, uppers not to have been narrowed by the rapids. On the east side the blocks are more numerous and on the Niagara Gorge Railroad tracks through much of the distance. Before the railroad was built the blocks, except some large blocks at the edge of the river below the rapids and the shore was being eroded. An artificial embankment had to be constructed for the railroad at some points. In its narrower parts the slope is scarred and, and through most of the distance it is less than 150 feet. This fall is on the outer side of the curve and has been heavily scoured at its base. In spite of the narrowness of this section, it seems certain that since it was made it has been widened a little, both at the top and near the bottom at the rapids. The Whirlpool sandstone probably forms the floor of this section, except at its north end.

The Great gorge.—The fifth section extends from the place of widening just above the railroad bridges up to the Horns Hose Falls, a distance of 23 miles. It is both wide and deep and in these respects presents a strong contrast with the section just described. It shows a pronounced widening beginning about 200 feet north of the American Falls and extending to the south side of Goat Island, a distance of nearly 3000 feet. Details of the width and depth of the gorge are given in the table at the end of the text.

This section has been cut during the present lake stage, with the fall discharge of the four lakes passing over Niagara Falls. The falls have been cut through all of the rock in the section beginning just above the railroad bridges, where the water had the power of the gorge begins. The inequalities of width and depth that characterize the falls are due to changes of volume but arise from local condition, chiefly as affected the length of the crest line of the falls and the depth of water upon it. Geologic structure does not appear to have had a perceptible influence in this section, except perhaps in the last 1000 feet near the Horns Hose Falls, and there its influence is not clearly manifest in the section is also more nearly in the condition in which it was made than any other part of the gorge. It has undergone less weathering and has been affected less by other changes such as have occurred in the sections below it.

Old channel of Niagara River in Upper Great gorge stage.—Until the falls had worn down to the vicinity of Swift Point, about 1000 feet north of Hubbard Point, the bed of the river south of that place remained at the level of the gravel on Goat Island. Hubbard and Swift Drift points are on a limestone promontory, which apparently formerly crossed this place in the gorge as a ridge, called by Spencer Johnson Hills. (See fig. 7.) South of it is a deeply descending valley in the rock surface—the Falls-Chippewa preglacial valley of Spencer. When the crest of the falls was at the col of the Gorge, it must have been 200 feet higher than it is now, but from that time to the present the falls have been slowly backing down the slope to their present lower level.

This decrease in its ultimate height has lowered the river above the falls, causing it to cut the channels now occupied by the rapids above the falls on both sides of Goat Island. This process uncovered the preglacial valley of the Falls-Chippewa preglacial valley at the head of the rapids and gave the river a westward-sloping floor of rock. Descending 60 to 70 feet over this, the river acquired great momentum and struck strongly into the deep filling of the old valley on the west side. But the drift had a moderate power of resistance and turned the stream gradually toward the north. In this way the great embayments with rock floors and drift banks on the west side of the river opposite the falls and the upper rapids were made. Most of the first curve extending northward from near the Table Rock House (marked Que' on the map) was made while the falls were working southward 2000 to 3000 feet from Hubbard Point, and the south part of it was cut later; the cutting continuing to the time of the beginning of the American falls. The next curve, reaching from the west side of the Dufferin Islands to Table Rock House (Que' and Que') is fairly double, the curve changing slightly at a point about 1500 feet south of Falls View. This curve is of recent date and had not been long abandoned at the beginning of the historic period. This is shown by the side fall in Hennipin's sketch made in 1768. Its early part was made while the falls were pushing out west and the last part was made while the falls were about at the south side of Goat Island. The south half was probably of a still later date. The drift bank at river mouth to the extent of 140 to 160 feet high which it cuts the crest of the Niagara Falls promotes reality.

The sharp embayment at the Dufferin Islands (Que') is probably of slightly later date. The broken edge of the talus at the head of the rapids, which virtually forms a submerged dam across the river, dips gently southward, and both the deepest water and the edge of the water is about 140 feet high.
Before the improvements for Queen Victoria Park were made, the total length of the crest line of the Horseshoe Falls was 2000 ft. The improvements cut off 415 feet on the west side, where the water sheet was shallow and broken. In 1842 and 1875 the crest line was a fairly open curve, remotely resembling a wider pointed and asymmetrical horseshoe. (See Fig. 16.)

There was no sharp angle in the central part, but there was a recumbent portion in the valley of the river, leaving the American Falls only 4.88 per cent. as steep as the most rapidly eroded point on the crest recorded, the difficulty of determining just where that point is at different times and of making proper allowances for its change of place on the crest is so great that Mr. Gilbert determined the average rate of recession by taking a certain length, say 400 or 500 feet, of the central part of the crest line as a datum line for his computations. The mean rate of recession on this line is regarded as the true mean rate for the entire crest line.

Mr. Gilbert made a careful study of the rate of recession under the direction of Mr. J. M. Howley, and in 1859 he made a careful study of the rate of recession of the crest line of the American Falls under the direction of Mr. J. H. Howley, and in 1859 he made a careful study of the rate of recession of the crest line of the American Falls under the direction of Mr. J. H. Howley, and in 1859 he made a careful study of the rate of recession of the crest line of the American Falls under the direction of Mr. J. H. Howley, and in 1859 he made a careful study of the rate of recession of the crest line of the American Falls under the direction of Mr. J. H. Howley, and in 1859 he made a careful study of the rate of recession of the crest line of the American Falls under the direction of Mr. J. H. Howley, and in 1859 he made a careful study of the rate of recession of the crest line of the American Falls under the direction of Mr. J. H. Howley.
made the wide part of the gorge opposite the American Falls and Goat Island at a considerably slower rate than the narrower part recently made or the narrower part further north. Of course, whether the changing outlines of the gorge are due to the receding of the falls or the advancing of the river is a matter of the same sort as at Hubbard Point, the strength of the crest ledge was greater and recession tended to be slower. But this was offset by the greater breadth of the falls at that time. The section on the west side of the gorge opposite the American Falls and Goat Island is relatively shallow. The crest line was wide when this part was being made, and the water sharp and clear and very thin. At Carter's Cove, nearly opposite Prospect Point, the sheet was too thin to cut through the upper bed of the Albion sandstone. Yet, although it must have worked back somewhat slowly, that part of the fall was not left behind, as the side fall was at Wintergreen Falls. The deeper water toward the east side of the crest of the fall was shallower than it has been north of the American Falls, where four soundings show the great depth of 198 feet. It was so shallow that the shallower western part at Carter Cove kept pace with the recession. Further analysis, with these facts in mind, makes the rate for the cutting of the wide part of the gorge at the falls and also above Niagara University considerably slower than the rate determined from the surveys.

By taking account of this factor and the changes of volume caused by the changes of outline of the upper three lakes, more accurate estimates of the time consumed in the making of the gorge may be made. These estimates show that the time required for cutting the Upper Great gorge was 1500 years and 3500 years for cutting the Lower Great gorge probably 2500 to 3000 years. The same considerations apply to the small-volume sections with regard to the influence of the depth of the water sheet on the crest, but the variations of this factor in the making of the two Lake Erie sections and the first section of the upper river cannot be determined. Speculative estimate of the rate of recession with the volume of Lake Erie alone 0.12 feet a year, or one-twelfth of the large-volume rate. This rate seems a fair approximation for the small-volume sections, which had about three times the volume of the American Falls and the water was probably more concentrated on the crest line.

If we take maximum rates of recession throughout, the making of the gorge may have taken 20,000 to 35,000 years. It is not believed that more precise estimate can have any practical value, for such estimates would seem to represent a degree of accuracy which is really impossible with the data that are now available. Estimates ranging from 7000 to 12,000 years are evidently too low, and those ranging from 20,000 to 100,000 years are too high.

ECONOMIC GEOLOGY.

The natural resources of economic value occurring within the quadrangle include limestone, sandstone, shale, natural gas, clay, gravel, sand, mineral waters, and water power. The most important of these are the limestones and the sandstone.

LIMESTONES.

Four distinct limestones in this quadrangle are quarried for commercial use—the Clinton, Genesee, Brighton, and Onondaga. The lower two of these limestones outcrop across the entire width of the area mapping extending from Niagara River to Lewiston through Lockport and Medina and outward beyond the quadrangle. The two higher limestones, the Genesee and Onondaga, are found only in the extreme southwestern corner of the quadrangle, near Akron.

Steel flux.—The most recent as well as the most extensive use to which the limestones of this region has been put is its employment as a flux in the manufacture of steel. Only non-magnesian limestone of a high degree of purity has been quarried in this region for this purpose. But two of the limestones found here—the Onondaga and the Clinton—are ore of proper chemical composition for use as a steel flux. A third limestone, the Genesee, is sufficiently free from magnesia over a small area in the vicinity of Lockport to comply with the present local requirements for flux. In other districts magnesian limestone and dolomite are successfully used for iron and steel flux.

The only limestone that has thus far been utilized for this purpose is the Onondaga limestone, which is known in the area known as the Medina or white Medina and now forms part of the Medina group. Quarries have been opened in this formation at many points along its line of outcrop in the Niagara escarpment, from the gorge to the eastward margin of the quadrangle. Some of these quarries were first operated nearly a century ago. Old buildings constructed of this rock are seen in all the towns along the escarpment. Flagstone was shipped from the Whiteriver quarry at Lockport to Rochester as early as 1831. It was used still earlier in the construction of the Erie Canal.

All the sandstone quarried in this region comes from the Albion sandstone, which is well known as the Medina or white Medina and now forms part of the Medina group. For a century, six of these quarries have been opened in this formation at many points along its line of outcrop in the Niagara escarpment, from the gorge to the eastward margin of the quadrangle. Some of these quarries were first operated nearly a century ago. Old buildings constructed of this rock are seen in all the towns along the escarpment. Flagstone was shipped from the White River quarry at Lockport to Rochester as early as 1831. It was used still earlier in the construction of the Erie Canal. Albion sandstone was used for building buildings, bridges, and other construction projects in the early 19th century.

The only quarry now in operation is one near Lockport. The Albion sandstone in the quarry at Lockport may be seen in Plate XVIII. The only quarry now in operation is one near Lockport. The Albion sandstone in the quarry at Lockport may be seen in Plate XVIII. The only quarry now in operation is one near Lockport. The Albion sandstone in the quarry at Lockport may be seen in Plate XVIII.

Cement.—The limestones of this region include beds suitable for making high-quality cement. The upper Clinton and the Onondaga limestones, owing to their chemical purity, are available for use in making Portland cement. The presence, however, of an excellent natural cement rock in the Bertie limestone member has encouraged the manufacture of natural cement instead of Portland cement. The first commercial Portland cement for use in the United States was made over a small area southeast of Akron. The manufacture of natural cement began at Falkirk in 1834, and has been carried on along the course of the Genesee River ever since. The Genesee River is consequently a great center in the quality of Portland or artificially mixed cement as compared with that of natural cement has been difficult to determine, and this has resulted in the closing of the factory at Falkirk.

The beds that have the proper composition for natural cement are also thin and are worked out from both mesa and drifts which have rock a roof rock. The cement rock after mining is burned and then finely ground, when it is ready for use as a hydraulic cement.

Lock.—The Onondaga limestone furnishes an excellent grade of quicklime and has long been utilized for making lime at a number of points along its line of outcrop between Falkirk and Williamson. The non-magnesian limestone near the base of the Lockport dolomite (Genesee limestone) has also been used for lime in the vicinity of Lockport and near the Niagara gorge.

Building stone.—The Genesee limestone member of the Lockport dolomite is being quarried for building stone nearly all of which has been used locally. Much of it has been used in buildings, but nearly all of it has been used locally in the construction of the Genesee River and the Niagara River, and the New York Central Railroad. The Genesee limestone has also been used for building stone in the vicinity of Lockport and near the Niagara gorge.

Building stone.—The Genesee limestone member of the Lockport dolomite is being quarried for building stone nearly all of which has been used locally. Much of it has been used in buildings, but nearly all of it has been used locally in the construction of the Genesee River and the Niagara River, and the New York Central Railroad. The Genesee limestone has also been used for building stone in the vicinity of Lockport and near the Niagara gorge.
At Akron five deep wells were bored for gas seven years ago. After being abandoned for a time, these wells were cleaned out and furnished a moderate flow of gas for six to seven years. Akron obtains its present supply from the new and richer fields 4 to 15 miles south of the town. In the northern and middle portions of the quadrangle some wells have been drilled for gas and oil without success, no oil and only small amounts of gas having been found. One of these bores near the shore of Lake Ontario, 4 to 5 miles north-west of Barker reached a depth of 5700 feet. A small amount of gas, estimated to be sufficient for three families, was encountered but was not utilized. At Barker a 320-foot well sunk for fresh water found an abundance of salt water and a small flow of gas which was not sufficient to be of value. The "burning spring" on the bluff south of the Buffalo Islands is said to be a leakage of natural gas from a crevice in the rock.

In 1865 or 1864 boring was sunk to a depth of 2007 feet in the village of Clapperton. It is reported to have furnished gas for three stove ovens and two or three street lamps. This gas was found in shale at about 800 feet below the Allston sandstone. As a rule wells drilled for gas in the southern part of the quadrangle have been much more productive than wells drilled further north, but not all of these have been successful. A well drilled in Tonawanda several years ago to a depth of 1100 feet found only a very small flow of gas at 550 feet. The 3120-foot boring at Soung Island, on Grand Island, drilled at about the same time as the Tonawanda well, found nothing but salt water.

In the area immediately south of the Niagara quadrangle numerous wells in and near Buffalo have yielded good amounts of gas. The Buffalo wells found gas in the Silurian, Limestone, Portport, Clinton, and Allston beds. Apparently the white Allston sandstone was the most productive formation. The few wells which have produced gas in the Ordovician have yielded small quantities of gas where the rock texture and the structure are favorable, but that the Allston sandstone is much the most important and productive of these formations. The texture or physical characters which locally determine the efficiency of the rock as a gas reservoir can be overestimated only by analogy of the drill. The general structural features are now well known, but additional data as to the position of the strata, afforded by carefully made well records, will add much detail of economic value in the future. All of this region lies on a southward-sloping monoclone of great extent. In accordance with the recently developed theories concerning the accumulation of gas in a region whose structure is of this kind, commercial supplies of gas should be expected in or near those belts where the rate of dip shows a marked increase. In the description the structure it was pointed out that the rate of dip increases near the southern margin of the quadrangle. It is a very significant fact that all the successful wells in this quadrangle are in or near the zone in which the change in the rate of dip becomes marked, whereas wells drilled to the north of this zone have failed to yield gas in commercial amounts. Prospecting has already been done in this zone in the higher formations near the southern border of the quadrangle, but the underlying Ordovician limestone formations have never been properly explored. If the development of the region where the most accessible Allston sandstone has been exhausted another and more productive gas bed may be found in the Ordovician limestone at a depth of 3000 to 3500 feet in the region between Akron and Tonawanda.

**Water supply.**

All of the larger cities of the Niagara quadrangle obtain their supply of water from Niagara River, pumping it into standpipes from which it is distributed under considerable pressure. The average of Buffalo is emptied into the river 8 miles above Tonawanda and the use of the water purification has until recently cured at a high premium rate in these cities. The city of Niagara Falls, N. Y., has recently installed a filtration system and, according to the State chemists, the filtered water now is superior to that used by any other city in the State. Filtration plants are also planned for Tonawanda and Lockport. The water for Lockport is taken 1900 feet out in the river at Tonawanda and the cities of Tonawanda, Niagara Falls, N. Y., Lackawanna, and Youngstown have local intakes. At Lockport an attempt was made to obtain a supply from wells, but without success. The town of Akron obtains its water from a flowing shallow well in the rock, the flow being collected in a catchment basin. One of the few other flowing wells in the quadrangle—is a well 11 miles north of Beachville—flows about 20 gallons a minute. When this well was completed an older flowing well a quarter of a mile to the north west dry. The water-bearing gravel in these two wells lies beneath the impervious sheet of clay deposited in Lake Landy. The many farm houses in the region obtain water from shallow wells, the greater part of which yield very fair supplies at moderate depths from gravel and sand in the drift. Many of them are sunk to the rock, on the surface of which the water accumulates. The residence of the Boulevard and Lewiston and numerous smaller places also obtain their water from common wells.

**Water power.**

Part of the great power of Niagara Falls has been utilized by several large electric plants at the falls. The electricity is used largely at Niagara Falls, N. Y., and in Canada, but it is also utilized at Buffalo, Tonawanda, and other places. The mean volume of flow of Niagara River measured at Buffalo from 1865 to 1888 was 224,428 second-feet. The flow varies considerably, ranging from 187,250 to 256,680 second-feet.* The fall of the river at the falls is 212 feet and the energy of the river averages nearly 5,000,000 horse power but diminishes to about 3,000,000 horse power at lower stages; the available amount, however, is considerably less. It is calculated that a change of 1 foot in height of Lake Erie will increase or diminish the discharge by 25,300 feet, which is equivalent to 59,000,000 horse power. The water is diverted and utilized for power by several companies on both sides of the river and the hydroelectric lines thus obtained range from 126 to 210 feet.*

The first plant built for the use of water power at Niagara was erected by the Niagara Hydraulic Co. in 1832. It was not a financial success. When electrical plants were sufficiently improved several were installed on the American side and later others were built by Canadian companies. When the United States Government assumed control of the use of the water at the falls the diversion on the American side was limited to 15,000 second-feet. Under treaty with Great Britain in 1904 the limit for the American side was fixed at 28,000 second-feet and on the Canadian side at 30,000 second-feet, but these amounts have not been fairly utilized. In 1911 the estimated average diversion of the water by the several power companies was 24,419 second-feet, not including 480 second-feet taken by the Lockport companies from the Erie Canal.

In the modern power plants the water is taken from the river above the city, conveyed to the western part of the city near the gorge, and let down in vertical steel tubes, or penstocks, 8 to 9 feet in diameter, propelling turbine wheels connected with electric generators of 5000 to 15,000 horse power capacity. The project now being proposed is to transmit 445,000 horse power. Much of the power from the Canadian side is bought into the United States for commercial use. The current is carried in high-tension lines, the smaller ones with 60,000 volts and the longer ones with 110,000 volts. This enormous supply of power has given great impetus to the growth of many industries in which electricity can be utilized, especially at Niagara Falls, N. Y. Notable among these are processes requiring great heat, such as the manufacture of nickel; iron; copper; and aluminum, and smelting. Besides its local use in these industries it supplies light and power to Buffalo and many other places, including Toronto, Hamilton, and London, and is transmitted as far as Syracuse, N. Y., and Windsor, Ontario. Besides the diminution of flow due to the diversion at the falls the utilization of Niagara River, a deep outflow passing into the gorge of the west branch of Eighteenmile Creek. In fact the large manufacturing interests of this city owe their existence and development to this source of power. Electricity is also brought to Lockport from Niagara Falls. It is estimated that 4,900 horsepower is utilized and the annual value of the resulting products from thirteen industries is about $2,000,000. The cost is low, for only a very small rent is paid to the State for the use of the water.


**Dimensions of Niagara gorge and correlation of sections with lake stages.**

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<td>Recent</td>
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- *Report of Board of Bridges on Deep Waterways, 1890.*
BIBLIOGRAPHY.

The following partial bibliography includes the principal books and articles treating of the geology of the Niagara region or of related subjects. In order to avoid the necessity of numerous footnote references in the body of the folio the titles of most of the papers made use of by the authors have been summarized in this list, together with those of a few not treating of the geology of the Niagara region but referred to in the discussion of the problems presented by the region.

CARMICHAEL, T. C., and SALSBERRY, E. D., geology, vol. 1, 296.
COLEMAN, A. W., Glacial and interglacial beds near Toronto: Jour. Geol., vol. 19, p. 284, 1901.
— The Falls of Niagara, their origin, etc.: Canada Geol. Survey, 1892.
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— The geology of Ontario, Frank and Taylor, F. B.
— The geology of southwestern Ontario: Canadian Inst. Tracts, Toronto, 1913.
— The geology of Ontario, Frank and Taylor, F. B.
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— The geology of Ontario, Frank and Taylor, F. B.
— The geology of southwestern Ontario: Canadian Inst. Tracts, Toronto, 1913.
— The geology of Ontario, Frank and Taylor, F. B.
PLATE 5.-AMERICAN FALLS FROM BRIM OF GORGE ON CANADIAN SIDE.

View of water blocks of Lava rock deposited along active base. Lava Falls at right, with "Rock of Ages" at its base. Sheet of water flows over entire crest.
ILLUSTRATIONS II

PLATE VI. UPPER GREAT GORGE OF NIAGARA RIVER, LOOKING SOUTH FROM WEST END OF CASTLE ROCK WADDER BRIDGE. FALLS IN INTERMEDIATE BRIDGE IN DISTANCE, NEARLY 2 MILES AWAY.

Note great depth of water and steepness of gorge walls at right. Slope is steepest on lower western side. Rock shelves and cliffs at right and left suggest older gorges below.

PLATE VII. LOWER END OF UPPER GREAT GORGE IN FOREGROUND AND HEAD OF NARROW WHIRLPOOL RAPIDS IN MIDDLE DISTANCE, LOOKING NORTH ACROSS RAILROAD BRIDGES.

Note contrast in width of gorge and behavior of water in the two sections.

PLATE VIII. WHIRLPOOL RAPIDS GORGE, LOOKING NORTH (DOWNSTREAM) FROM NEAR EAST END OF GRAND TRUNK RAILWAY BRIDGE.

Each side of Eddy Basin is deep. Water in left foreground has not attained full velocity, gained velocity just beyond the bend of gorge to the left. Nearly vertical cliff above trench in foreground to right of center.

PLATE IX. EDDY BASIN IN FOREGROUND AND LOWER END OF WHIRLPOOL RAPIDS GORGE IN CENTER, LOOKING SOUTHEAST, UPSTREAM.

Swirl of water about center of view. Main current crosses each side of Eddy Basin in left foreground. Lookout station opposite large lap of hard conglomerate at center of view.

PLATE X. THE WHIRLPOOL AND DEEP POOL SECTION OF LOWER GREAT GORGE LOOKING NORTHEAST.

Steep rapids cross Whirlpool on right to left in foreground. Steepness of Whirlpool continues on left side of basin. Edge of Flat Rock in Flats on opposite bank.

PLATE XI. SHALLOW SECTION OF LOWER GREAT GORGE, LOOKING SOUTHWEST UPSTREAM FROM NIAGARA UNIVERSITY. FLAT ROCK AND HEAD OF FLAT ROCK IN DISTANCE.

Flat Rock and head of Flat Rock in distance.
and still smaller ones. The age of a rock is expressed by the name of the time interval in which it was formed. The sedimentsary formations deposited during a period are grouped together into a system. The principal divisions of a system are called series. Any aggregate of formations less than a series is called a group.

Instead as sediments accumulate and come to rest on the floor, the age of each bed in the series, and their relative ages may be determined by observing their positions. In many regions, beds that have been subject to folding or faulting, it may be difficult to determine their relative ages from their present positions. So, the sedimentary sequences may not be easily identified. However, if the sediments were originally deposited parallel to the earth's surface, then the sequence of the beds can be determined. The youngest beds are usually deposited first, and the oldest beds are deposited last.

The sea cliffs are an illustration; it may be drawn from any rock. In this class being abandoned river channels, glacial furrows, and peninsulas.

The making of a stream terrace on a river bed is a natural process. These terraces are formed as a result of erosion by rivers. The terrace is a flat surface that is cut into the river bed and is usually formed by the deposition of sediment.

Most rivers have a series of terraces, which are formed as the river level changes. The terrace level is determined by the climate and the availability of sediment. The younger terraces are usually formed during times of high water, while the older terraces are formed during times of low water.

The map showing the areas occupied by the various formations is called an areal geology map. On the margin is a legend, which is the key to the map. To accurately position any region of interest, the reader should locate the part of the map that is covered by the area of interest. For example, if the reader wants to see the area covered by the Mississippi River, they should look for the area covered by the Mississippi River on the map.

The map represents the distribution of economic deposits and rocks and shows the relation to the topographic features and to the geologic formations. The contours that appear on the areal geology maps are usually shown on the map by fitter color patterns and the areas of productive formations are emphasized by different colors. The map shows the location of each mine or quarry and is accompanied by a map of the principal mineral mined and some quarrs.

The areal geology maps are used to study the economic deposits, the productive formations, and the location of the mines or quarries.

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* Order by number.
* Printed and sold by order only, at $1 each.
* There are 58 sets of this table.

Circles showing the location of the area covered by any of the above folios, as well as information concerning topographic maps and other publications of the Geological Survey, may be had on application to the Director, United States Geological Survey, Washington, D. C.